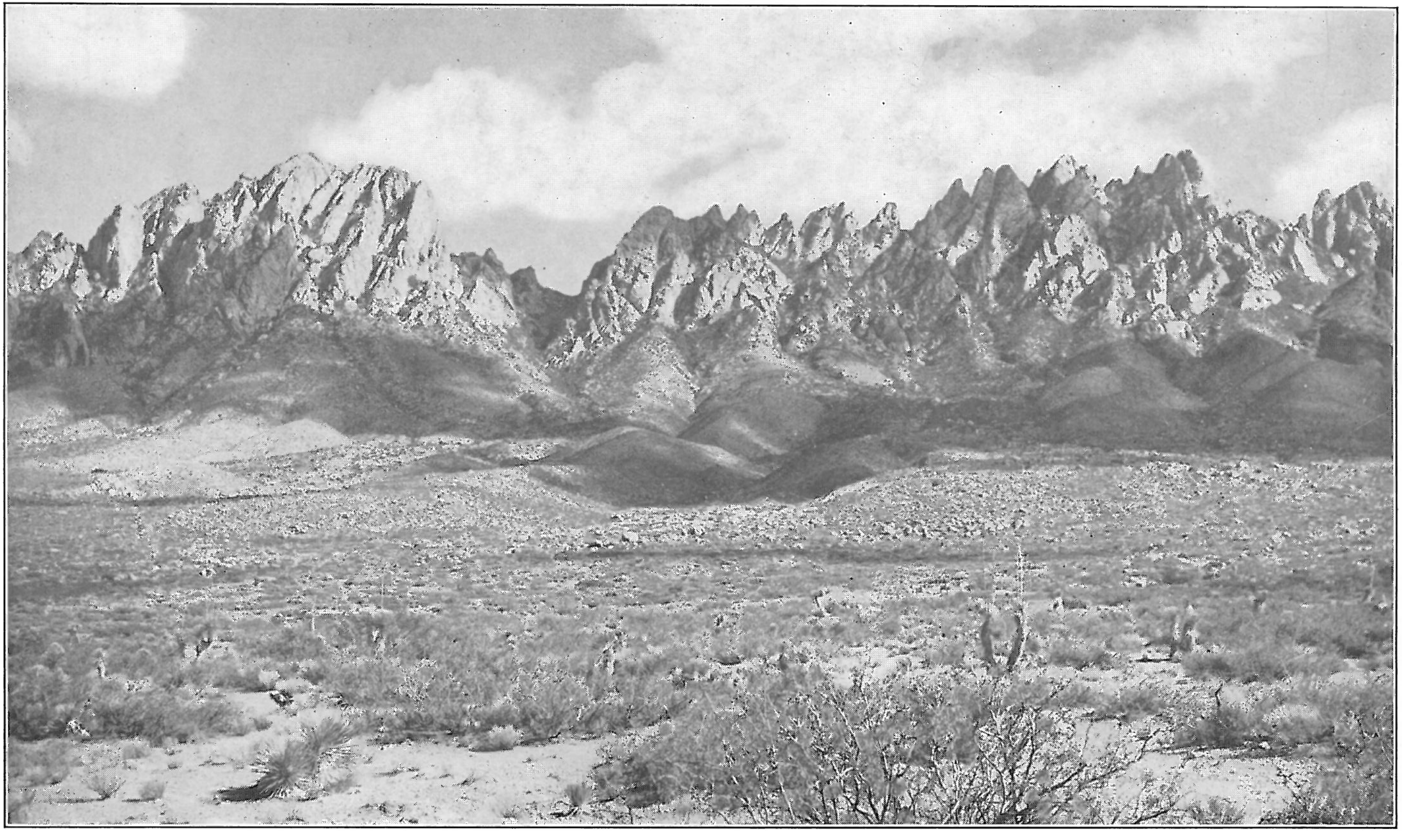

THE CENTRAL PART OF THE WEST FRONT OF THE ORGAN MOUNTAINS

The jagged aiguilles are quartz monzonite; the slopes leading up to them, Pennsylvanian sedimentary rocks and Tertiary lavas

NEW MEXICO SCHOOL OF MINES

STATE BUREAU OF MINES AND
MINERAL RESOURCES

E. H. WELLS
President and Director

BULLETIN NO 11

The Geology of the Organ Mountains

WITH AN ACCOUNT OF THE GEOLOGY AND MINERAL
RESOURCES OF DONA ANA COUNTY
NEW MEXICO

By
KINGSLEY CHARLES DUNHAM
Commonwealth Fund Fellow
Harvard University

SOCORRO, N. M.

1935

CONTENTS

PART I. THE GEOLOGY OF THE ORGAN MOUNTAINS—Continued

ILLUSTRATIONS

THE STATE BUREAU OF MINES AND MINERAL RESOURCES

The State Bureau of Mines and Mineral Resources of New Mexico was established by the New Mexico Legislature of 1927. It was made a department of the New Mexico School of Mines, and its activities are directed by the board of regents of the school. Its chief object is to assist and encourage the development of the mineral resources of the State.

BOARD OF REGENTS

PUBLICATIONS

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Bulletin No. 11. The Geology of the Organ Mountains, with an Account of the Geology and Mineral Resources of Dona Ana County, New Mexico—Kingsley C. Dunham. (Price $1.00.)

. Bulletin No. 12. The Non-Metallic Mineral Resources of New Mexico and their Economic Features (Exclusive of Fuels)—S. B. Talmage and T. P. Wootton. (In press; price 50 cents.)

Note—Bulletins 1, 2, and 3 were issued by the Mineral Resources Survey of the New Mexico School of Mines.

The Geology of the Organ Mountains
WITH AN ACCOUNT OF THE GEOLOGY AND MINERAL RESOURCES OF DONA ANA COUNTY, NEW MEXICO

By

KINGSLEY C. DUNHAM

INTRODUCTION

Dona Ana County embraces the southernmost part of the valley of the Rio Grande in New Mexico, together with a region of arid plains and abrupt mountain ranges. The most prominent topographic feature of this area is the north-south trending Organ range, lying to the east of the river. The county, including this mountain chain, exhibits a wide variety of geological phenomena, and has been the scene of mining operations for almost a century. It has nevertheless received very little attention from geologists, for while good reconnaissance studies of the geology and of the mineral deposits have been made, no part has previously been subjected to a detailed investigation. The principal object of the present report is to record the results of a detailed study of the geology of the Organ Mountains. In addition, a general account of the geology of the county, based upon reconnaissances made by the present author, and upon the writings of former workers, is included, together with a special section on the natural resources of the region.

The work was carried out during the writer's tenure of a Commonwealth Fund Fellowship, and this condition made it possible to take a broader view of the geological problems than is normal in studies sponsored directly by the State Bureau of Mines and Mineral Resources. Part I of the bulletin, entitled "The Geology of the Organ Mountains" is intended as a contribution to geological science, and in it the history of the range, as determined from field mapping and laboratory studies, is discussed. Part II is devoted to a general summary of the geological features of the rest of the county, and serves as a background for the detailed study, and for Part III, in which the mines and quarries of the county are described. In Part III the application of the geological results to the exploitation of the mineral resources of the region receives special consideration.

Two seasons were spent in the field, from September 1933 to January 1934, and from August 1934 to January 1935. The Organ Mountains were mapped topographically and geologically on a scale of one inch to one mile. A more detailed map, on a scale of four inches to one mile, was made for the Organ mining district. In addition, certain areas were mapped on larger scales. (Plates II and III, and figures in text) . The map of Dona Ana County (Plate I) is based partly on the general map of the State, by N. H. Darton, and partly on studies by the present author. The period intervening between the field seasons was spent in laboratory examination of material from the area at Harvard University, and some months were also devoted to this work during the winter of 1935.

ACKNOWLEDGMENTS

My attention was first directed to the possibilities of the Organ Mountains by Professor Waldemar Lindgren, to whom I wish to express my gratitude for having suggested such a profitable field of labor. For assistance during field work my best thanks are due to Mr. L. B. Bentley of Organ, whose wide knowledge of the mountains and collection of records, reports and assays were valuable aids. Mrs. Jane Boland also contributed materially to the success of the field seasons. I wish to thank Professors H. E. Quinn and L. E. Nelson of the College of Mines of the University of Texas for their willing co-operation and for assistance in the field, and with them the following gentlemen : Professors E. S. Larsen, Jr., and Russell Gibson of Harvard University ; Dr. M. Lewis of the Anaconda Company ; Mr. R. McI. Tyndale-Biscoe of the Geological Survey of Southern Rhodesia ; Mr. S. G. Lasky of the United States Geological Survey ; Mr. E. G. Hancox of the Royal School of Mines ; and the Director and technical staff of the Jornada Range Experiment Station. The owners and operators of mining properties generously allowed me to have free access to their mines and prospects. At Harvard University Professors L. C. Graton, E. S. Larsen, Jr., C. Palache, R. A. Daly, D. H. MacLaughlin and Kirk Bryan offered valuable advice and criticism. I desire to acknowledge with thanks the generous co-operation of President Wells and the New Mexico Bureau of Mines during the later stages of the work, and to express my appreciation of the care which Mr. Gordon Wells has taken in preparing the maps and diagrams for this bulletin. Finally my gratitude is due to the Trustees and Directors of the Commonwealth Fund Foundation, of New York.

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THE GEOGRAPHY OF DONA ANA COUNTY

SITUATION

Dona Ana County occupies an area of approximately 3,800 square miles in central southern New Mexico. West of the Rio Grande its southern border is the international boundary with the Republic of Mexico; east of the river it is the 32° line of latitude. The northern boundary extends north of latitude 33°; the range of longitude covered is from 106°24' to 107°17'. The index map on page 186 shows the contiguous states and counties.

RELIEF FEATURES

The Rio Grande enters the county near Garfield in the northwest corner, and from here follows a southeast course to a point on the international boundary near El Paso, Texas. Lying on either side of the river there are broad plains having an average elevation of 4000 feet, diversified by mountain ranges which rise abruptly like islands from a sea. Of these the most striking is the north-south linear chain lying east of the river, and including (from north to south) the San Andres Mountains, the Organ Mountains and the Franklin Mountains. The San Andres Mountains are partly in Socorro County; in Dona Ana County they extend from the north boundary to San Agustin Pass, a distance of 36 miles; the Organs continue from this point to Target Range Gap, 18 miles ; and the Franklins run from the Gap to El Paso, lying within Texas for the greater part of their length. The highest point in this threefold chain is Organ Peak, at the head of Fillmore Canyon in the Organ Mountains; for this peak the Wheeler survey gives an elevation of 9108 feet.[1] Much of the Organ range lies between 3000 and 4000 feet above the level of the plain. The San Andres and Franklin mountains are somewhat less lofty, the highest point in that part of the former range lying within the county being San Andres Peak, 7450 feet.

The Rio Grande in the northern part of its course through the county passes from the Palomas Valley into a gorge called by Lee [2] Selden Canyon, where it is flanked by hills and mountains. On the east side these include the southern part of the Sierra Caballos, Tonuco Mountain (sometimes called San Diego Mountain), the Dona Ana Mountains; on the west lie the Sierra de las Uvas, Robledo and Picacho mountains. The Sierra de las Uvas extend from the river to the western boundary of the county. Farther south the river flows through the Mesilla Valley, a broad depression whose elevation is consistently some hundreds of feet below that of the plains which flank it. In the south-

[1] Wheeler, G. M. Annual report upon the geographical surveys of the territory of the United States west of the 100th. meridian : Washington, 1879, Appendix 00, p. 125.

[2] Lee, W. T., Water resources of the Rio Grande valley: U. S. Geol. Surv. Water Supply paper 188, 1907, p. 15.

western part of the county there occurs a prominent peak, Mount Riley, and a group of hills known as the Potrillo and West Potrillo Mountains. The Cerro de Muleros, on the outskirts of El Paso, is partly in Dona Ana County and partly in Mexico.

DRAINAGE

The Rio Grande is the only stream flowing through the county, and at most seasons of the year loses rather than gains water during its passage from Garfield to El Paso. The flow of water in the river is controlled by the Elephant Butte dam, approximately 100 miles north of the northern border of the county, and in the Mesilla Valley the water is used for irrigation. The plains mentioned above are almost entirely without surface streams, even when they are adjacent to the river. Four plains may be distinguished: that in the Tularosa basin, lying east of the San Andres-Franklin chain; the Jornada del Muerto, between the San Andres and the Caballos and Dona Ana Mountains ; the Powell plain, southeast of the Sierra de las Uvas and west of the river; and La Mesa, the great area extending west of the river to the Potrillo Mountains. In aggregate these intermontane plains or basins make up at least 75 percent of the area of the county.

The mountains are dissected, sometimes deeply, by canyons, which may or may not be connected with the river. In some cases a channel runs across the plains from the mouth of a canyon, and conveys to the river the waters of the ephemeral stream which exists in the canyon for a few hours or days in the year. However, as most of the mountains are flanked by plains without surface drainage, such channels are few in number, and usually the waters spread out on the plains from the canyon mouths. Fillmore Canyon in the Organ Mountains possesses the only permanent stream in the region apart from the river, and this disappears beneath alluvium before reaching the mouth of the canyon.

CLIMATE

The climate of the region is hot and dry, typical of the continental arid belt to which it belongs. Owing to the high altitude, the diurnal range in temperature is considerable, and this fact coupled with the low humidity and high evaporation makes the weather pleasant the year round. Rainfall is generally confined to a few violent storms during July, August, and September. The fall and winter are the most agreeable seasons, for the days are warm and sunny and the nights are cool. Snowfall is very small, and except in the highest parts of the mountains, does not remain on the ground for more than a few hours. The spring season is usually windy, the prevailing wind being from the west. The accompanying table summarizes the climatic data

Climatological Data for Dona Ana County

Station	Elevation, Feet	Year's Record	Mean Annual ppt., Inches	Period of Maximum ppt.	Days per Year with 0.01 Inches or more ppt.	Average Amount Snowfall, Inches	Mean Annual Temp., Deg. F.	Mean Annual Minimum Temp., Deg. F.	Mean Annual Minimum Temp., Deg. F.
Agricultural College	3,868	73	8.57	July-Sept.	45	2.3	60.1	76.2	44.0
Chamberino	3,800	8	7.17	July-Aug.	29	1.2			
Garfield	4,100	33	10.08	July-Sept.	33	3.9	59.4	76.9	42.0
Jornada Range Reserve	4,150	17	8.95	July-Oct.	39	2.5	58.2	75.2	41.2
Lanark	4,156	25	8.20	July-Sept.	28	4.2			
Noria	4,114	12	9.01	July-Aug.	36	3.7			

obtained by the six U. S. Department of Agriculture Weather Bureau stations in the county. Three of these—the Jornada Range Reserve, Lanark and Noria—are situated on the plains, while the other three are in the Rio Grande valley. Climatic conditions in the mountains are therefore not represented by precise data. However, general experience and the observations of the local inhabitants indicate that these differ only in having a lower average temperature and a somewhat greater precipitation, which probably exceeds 10 inches per annum.

FLORA AND FAUNA

Climatic conditions have also determined the character of the vegetation in the county, and small variations in climate due to differences in altitude are reflected in a striking way in the zonal distribution of the flora, as discussed by Vernon Bailey for the region as a whole. Along the inner valley and on the flood plain of the river the indigenous plants include the cottonwood, the willow, saltgrass, fine-topped sacaton and others. The vegetation outside the valley is quite different. On the plains the Lower Sonoran flora, characterized by mesquite *(Prosopis glandulosa)* and creosote *(Covillea glutinosa)* is represented. The plant assemblage includes acacia, "Crona del Christo" *(Koeberlinia spinosa),* agave, sotol, the tree yucca *(Yucca radiosa),* ocotillo, sumac, several varieties of cactus and grasses. In this zone the response of the vegetation to soil conditions is very sensitive, and according to J. O. Veatch the highest, density of palatable (grama) grasses occurs on the oldest sandy soils of the plains, associated with yucca. Where the soil is loose or drifting,

Bailey, Vernon, Life zones and crop zones in New Mexico : U. S. Dept. Agric., North American fauna, No. 35, 1913.

[4] Veatch, J. O., The soils of the Jornada Range Reserve : unpublished report, Jornada Range Reserve, 1918.

bunch grasses replace the grama. On recently deposited sands mesquite is the dominant plant. Creosote, on the other hand, occurs on the porous gravels of the plain, but is absent where the soil is clayey. On clay soils burro-grass and tobosa-grass occur, with black brush, while on gypsum soils only muhlenbergia flourishes.

In the foothills of the mountains, the Lower Sonoran flora gives place to the Upper Sonoran, and there is some mingling of the characteristic members of both zones. In this region the ocotillo *(Fouquieria splendens)* apparently exists under critical conditions, for it is almost confined to limestone outcrops. The flora of the mountains belongs entirely to the Upper Sonoran except for a restricted area high up in the central part of the Organ Mountains. The characteristic plants are pinyon pine and juniper, and members of the assemblage include scrub oak, mountain mahogany, "apache plume," salt bush, erigonum, acacia, bear grass and mescal. The characteristic yucca is the so-called "Spanish bayonet" *(Yucca macrocarpa).* Cactuses include the prickly pear, cholla and petya. At the lower limit of the zone the influence of direction of slope is very conspicuous and in many places in the southern San Andres Mountains north-facing slopes, owing to their being less exposed to the sun, support a good stand of small pinyons while south-facing slopes are barren of trees.

In the high canyons of the Organ Mountains south of the Cox ranch, in Fillmore Canyon and in the canyon leading north from Soledad Canyon the Western yellow pine appears, representing the Transition zone.

Bailey has also demonstrated that a zonal dispersion of animals occurs, and for a complete account of the fauna the reader is referred to his work. Common animals in the region include the jack rabbit, cottontail, coyote, fox, badger, skunk, bat, kangaroo rat, pocket gopher, rat, mouse, squirrel, rattlesnake, king snake, garter snake, racer, turtle, lizard, and horned toad. Deer inhabit the higher mountains and antelope are observed on the Jornada del Muerto. Mountain lions are occasionally seen. Birds include the brown eagle, buzzard, hawk, quail, owl, woodpecker, humming bird, jay and roadrunner.

HUMAN RELATIONS

History[2]—*In* spite of the apparently inhospitable nature of the country, there is reason to believe that it has been inhabited

Prince L. B., Historical sketches of New Mexico from the earliest records to the American occupation : New York, 1883.
Bancroft, H. 11., History of the Pacific States of North America, Arizona and New Mexico: vol. 12, 1888.
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by man from early times. Recent discoveries by R. P. Conkling in a cavern at Bishop's Cap have revealed the bones of *homo sapiens* associated with those of a dire wolf, and of camels, sloths, early horses and other extinct animals in circumstances which suggest strongly the contemporaneity of the remains. E. L. Hewett regards the find as very significant and believes that this may represent the earliest record of man on the American continent.' Relics of former aboriginal tribes are found in many parts of the county. A considerable amount of pottery has been found at the Indian mound on the Jornada range, but no account of this locality has yet been published. The former existence of pre-Pueblo Indians at Mimbres, in Grant County, has been proved, and we may conjecture that tribes belonging to this period may have inhabited the present region ; as far as the author is aware, however, no evidence of permanent settlements belonging either to this or the succeeding early Pueblo period have been found in the county. The region is almost virgin ground from the archaeologist's point of view, and careful search may well reveal evidence of this sort. Pictographs, pictoglyphs, artifacts and grinding holes are found in many parts of the mountains. At the time of the first Spanish expeditions, there was a semi-sedentary tribe living in the southern part of the Mesilla Valley near the present site of El Paso. Otherwise, the region appears to have been inhabited only by roving bands of warlike Comanches and Apaches, who continued to be a menace to travelers until late in the 19th century. The Rio Grande route was one of several followed by early Spanish explorers coming from Mexico. The earliest of the expeditions known to have come this way was that led by Fray Agustin Rodriguez, a Franciscan missionary, in 1581. Two years later Antonio de Espejo and his followers traversed the same route. The first party of colonists, led by Juan de Onate, traveled to central New Mexico by way of Chihuahua, founded El Paso del Norte (now Cuidad Juarez), then followed the river up to Tonuco, whence they crossed the Jornada del Muerto. This desolate, waterless desert must have presented a serious obstacle to the travelers, and its name (meaning "Journey of the Dead") no doubt dates from the early Spanish occupation. Onate's route became, during Spanish colonial times, the regular means of communication for trade and other purposes with

western United States, part II, chapter VI: Papers of the Arch. Inst. Amer., Amer. series, No. 4, Cambridge, 1892.

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Hewett, E. L., op. cit. supra., p. 273.

Chihuahua and the City of Mexico, and it was by this same route that the colonists were forced to retreat after the revolt of the Pueblos in 1680. It seems likely that the travelers of the 16th, 17th, and early 18th centuries found the northern part of the Mesilla valley unattractive as compared with central New Mexico, for there is no satisfactory evidence of permanent settlements before 1770, when a presidio was established at Robledo, near the place where the road turned away from the river to the Jornada. There were, however, some settlements founded in the southern part of the valley, in what is now Texas, in 1680. Spanish grants, known as the Refugio grants, date from this time.

Probably the first American to follow the Chihuahua trail was Lieut. Z. M. Pike, sent as a prisoner to Chihuahua by the Governor of New Mexico in 1803. After the overthrow of Spanish power in 1822, several colonies were established along the river south of Robledo by immigrants from Mexico. A series of grants including the Dona Ana Bend grant, the Santo Tomas de Yturbide grant and the Brazito grant probably date from this time. In 1846 General Kearney's expedition took possession of New Mexico in the name of the United States, then proceeded to California over the Gila trail. Lieut. Col. Cook of Kearney's detachment was given orders to conduct his wagon train of supplies to California, and, instead of taking the northern route, he followed the old road across the Jornada, branching off at Rincon and thence crossing to Deming. This later became part of the first wagon road across the continent to California and the trail for thousands of emigrants on the Santa Fe trail from Missouri to "the coast." In 1849 an expedition from San Antonio to Santa Fe was led by Capt. R. B. Marcy.[8] From Santa Fe he proceeded south, crossed the Jornada to Dona Ana, and thence returned eastward by way of San Agustin Pass and the Tularosa basin. Marcy's report is accompanied by a map. The town of Dona Ana is described as a settlement with "300 inhabitants, principally Mexicans, who . . . depend for a subsistence almost entirely on the cultivation of the soil. They are obliged here . . . to irrigate." The town of Las Cruces was already in existence at this time. Dona Ana County came into existence in 1851 as a division of the Territory of New Mexico, with boundaries extending from the eastern border of the Territory as far west as the Colorado River. The international boundary survey of 1851 led to a dispute between the Mexican and United States surveyors, a large region west of the Rio Grande being involved. In this disputed area the town of Mesilla sprang up. The Gadsden Purchase, sometimes known as the Treaty of Mesilla, added the land to the county and made possible the railroad connection with California. The im-

[8] Marcy, R. B., Report on a route from Fort Smith to Santa Fe: 31st Congress of the U. S., Senate Ex. Doc. No. 64, 1850, p. 197.

portant role of Mesilla in southwestern affairs was, however, just beginning. Early in the Civil War it was taken by Col. J. R. Baylor, with a Confederate force from Texas. Quick to realize the importance of Mesilla as a strategic point on the southern route to California, and taking advantage of its isolation from Central New Mexico, he declared it the capital of the Territory of Arizona, and organized this territory under Confederate rule. It continued to be a capital city for a few months only; and after the defeat of the Confederate armies, Arizona was organized as a separate Territory, but one which did not include Mesilla, though land formerly included in Dona Ana County contributed largely to the new territory.

A period of peaceful settlement followed the Civil War, disturbed only by trouble with Apache Indians and American "bad men." The completion of the Santa Fe railroad in 1881 led to a large influx of settlers, and at the end of the century the towns of Las Cruces and Mesilla had about 1500 inhabitants each. The closing years of the century were marked by considerable mining activity. The last important event was the completion of the Elephant Butte Dam in 1916 and the irrigation of the Mesilla Valley as part of this project. This has contributed more than anything else to the recent development of the county.

Population, Towns.—The growth in population since 1860 when the first census was taken is shown by the table on this page. The decrease in 1870 may be ascribed to the loss of territory consequent upon the creation of Arizona; since then there has been a steady increase, in spite of loss of land to Sierra county in 1884, and to Otero county in 1889.

Total Population of Dona Ana County, 1860-1930

Year	Population	Year	Population
1860	6,239	1900	10,187
1870	5,864	1910	12,893
1880	7,612	1920	16,548
1890	9,191	1930	27,455

The city of Las Cruces, situated in the Mesilla valley, is the county seat and has a population of approximately 6000. Other towns include Hatch, Rincon (a junction on the A. T. and S. F. railroad), Dona Ana, Mesilla, Mesilla Park, State College, which is the site of the New Mexico College of Agriculture and Mechanic Arts, and Anthony, together with a number of smaller settlements. All these lie along the river valley. The only surviving mountain settlement is the mining camp of Organ, on the west side of San Agustin Pass, and this is at present well nigh deserted. On the Jornada the U. S. Forest Service maintains an experimental range, with headquarters 23 miles from Las Cruces. There are numerous cattle ranches scattered over the plains, and these together with a number of section houses on the Southern Pacific and Santa Fe railroads constitute the remaining habitations.

Industries.—Agriculture is the most important occupation in the county, and is confined for all practical purposes to the irrigated Mesilla Valley. Cotton, alfalfa, fruit crops and garden produce are raised successfully. There are numerous cotton gins. Second to agriculture in importance comes stockraising. In spite of their barren nature, the plains have been used for many years as cattle ranges, but overgrazing has to some extent impaired their usefulness. Mining is now of subordinate importance only, though at some periods it has approached the dimensions of a major industry.

Communications.—The Mesilla Valley is served by a branch line of the A. T. and S. F. railroad. From Rincon another branch runs to Deming. The main line of the Southern Pacific railroad crosses the southern part of the county. Paved roads link Las Cruces with El Paso to the south, Deming to the west, Hatch and Hot Springs to the north and Organ to the northeast. There are many secondary roads, and automobile travel is easy on the plains. The mountains are accessible from many such roads.

PART I

THE GEOLOGY OF THE ORGAN MOUNTAINS

INTRODUCTION

Name.—It is generally supposed that the Organ Mountains owe their name to a resemblance between the jagged spires which are their most striking feature and the pipes of an organ. Marcy[1], writing in 1849, says, "The Organ range of mountains takes its name from the supposed similarity of the high-pointed peaks to the pipes of an organ." There is, however, some local disagreement as to which part of the mountains actually resembles an organ. Some hold that the great aiguilles in the center of the west front of range were the inspiration for its name, while others point to the steep columnar-faced cliff south of San Agustin Pass on the east side. Professor G. A. Feather has suggested an alternative theory to me, namely that the mountains were formerly inhabited by a tribe of Indians whom the Spaniards called "los Orejones" (referring to their gnarled and wrinkled faces), and that their name was applied to the mountains, becoming corrupted to "los Organos" in the course of time.

Location of Mapped Areas.—The Organ Mountains cover Tps. 22, 23 and 24 S., R. 4 E. of the New Mexico Principal Meridian, together with parts of Tps. 22, 23 and 24 S., R. 3 E., and Tps. 22 and 23 S., R. 5 E. Geographically their northern limit is usually assumed to be at San Agustin Pass, but it has been necessary for the present geological study to extend the mapped area some three miles north into the San Andres Mountains in order to obtain a complete picture of the geological history of the range. This section of the report, therefore, includes a description of the southern end of the San Andres Mountains in addition to the Organ Mountains ; but the whole mapped area will be referred to as the Organ Mountains in Part I. The Organ mining district lies partly north of the Pass. A U. S. G. S. reconnaissance topographic map of the Las Cruces Quadrangle, on the scale of 1: 125,000, covers part of the Organ Mountains, but owing to the scale and inaccuracy of detail it did not prove to be of any use for detailed mapping. New topographic maps were, therefore, prepared for this work by the use of the plane table. One of these, on a scale of 1 inch to 1 mile, covers the entire range, an area of 225 square miles, while another, on a scale of 4 inches to 1 mile, covers the Organ Mining District at

[1] Marcy, R. B., op. cit., p. 198.

the northern end of the range, an area of 55 square miles. The geology has been mapped using these as base maps. (Plates II and III, in pocket.) In addition, there are topographic and geologic maps showing the details of certain smaller areas.

Physical Features.—The west front of the range resembles a scarp slope in its steep rise from the plains along an almost straight north-south line. Three units in this front may be distinguished ; immediately south of San Agustin Pass there is a flat-topped mountain reaching an altitude of 7600 feet. Baylor Pass lies between this unit and the next in which occur towering monoliths of bare rock with a remarkable jagged skyline reaching 9000 feet. (See frontispiece.) The region south of these aiguilles is less lofty and shows rounded outlines. Thirteen miles south of San Agustin Pass a deep valley, Soledad Canyon, has been cut through the range. The east front is less regular, though equally spectacular. At the northern end the range is little more than 3 miles wide but from the south end of the aiguilles a great spur projects to the east, and from here to the southern extremity the width is approximately 8 miles. The central part of the range is lofty, rugged and inaccessible. Extensive talus slopes have been developed on both sides of the range, forming a connecting link between the steep mountain slopes and the level plain. Some of these show perfect fan-shapes opposite the mouths of canyons. Except where obscured by talus, the rocks of the range are exceptionally well exposed, and are as a rule comparatively fresh. Contacts can be followed with an ease and certainty that is never rivaled in glaciated or humid regions.

Arrangement of Part 1.—The geologist is primarily a historian, and seeks to interpret the course of events long past from his study of the rocks. Therefore, in the pages following, the formations of the Organ Mountains are discussed as far as possible in the chronological order of their origin. Description of the rocks and minerals of the region is of subordinate importance in this part to the study of their genetic relations and evolution.

THE PRE-CAMBRIAN ERA

GENERAL FEATURES

The pre-Cambrian basement is well exposed on the east side of the Organ Mountains, and outcrops in the large area which includes Mineral Hill, the Antelope Hills and the rock pediment lying to the north and east on which Gold Camp is situated. Pre-Cambrian rocks appear again south of the Cox ranch and are found intermittently from here to the southern end of the range. On the west side two small fault blocks between Organ and the Stevenson-Bennett mine bring rocks of this age to the surface.

The predominant rock is granite, and it appears that the basement complex of the Organs forms part of a large composite batholith which was eroded to the hypobatholithic stage[1] in late pre-Cambrian time. A few roof-pendants or xenoliths, containing gneiss, schist, quartzite and diorite, remain to bear witness to cycles of sedimentation and igneous activity which preceded the intrusion of the batholith, but the size of the outcrops of these is insignificant compared with that of the batholith, and our knowledge of early pre-Cambrian history is, therefore, very sketchy. Granite of two ages occurs in the batholith, and small pegmatite sheets and dikes are very numerous. The outer contact of the batholith is not exposed in the present area, but may be seen to the north in San Andres Canyon. Epidiorite dikes of late pre-Cambrian age cut the granites.

ROCKS ENCLOSED BY THE GRANITE

GNEISS

Field Relations.—Rocks believed to be the oldest in the range are exposed in the gullies on the east side of the southeast ridge of the mountains, in sec. 11, T. 24 S, R. 4 E. These consist of gneisses, and their outcrop is completely surrounded by granite. The small size of the mass, less than 1000 feet in length, did not justify separate mapping on the 1 inch scale, and the area in which it occurs is not covered by larger scale mapping.

Petrography.—The rock is banded ; material containing both dark and light mica alternates with feldspathic bands. The bands are narrow, not exceeding 2 to 3 inches in width, and the boundaries between them are not sharp. The texture of the rock is unusually fine grained for a gneiss, and even the mica plates seldom exceed 5 mm. in diameter. In thin section the micaceous bands are found to consist of muscovite, biotite, orthoclase and quartz. The muscovite crystals are much larger than those of the other minerals, and enclose quartz grains in a poikiloblastic

[1] Emmons, W. H. On the mechanism of the deposition of certain metalliferous lode systems associated with granite batholiths : in Lindgren Volume, A. I. M. E., New York, 1933, pp. 345-349.

manner. Biotite occurs in small shreds, partly converted to chlorite. Orthoclase and quartz form a fine-grained mosaic ; the feldspar is strongly sericitized. The feldspathic bands contain orthoclase, minor amounts of oligoclase, and quartz.

Probably the rock has resulted from the injection of granite magma into pelitic sediments, but the process of assimilation has proceeded far and only the micaceous bands remain to indicate the former argillaceous rock. The bands terminate sharply against the granite of the batholith, and we are justified in assuming that the injection process was connected with some igneous cycle which preceded the intrusion of the cross-cutting batholith.

DIORITE

Field Relations.—The gneiss in the xenolith described above is cut by a black medium-grained igneous rock whose injection also preceded that of the batholith.

Petrography.—The rock is a hornblende diorite. In the hand specimen hornblende and feldspar can be recognized, the feldspars reaching a length of about 4 mm. No directional orientation of the crystals can be seen. In thin section the rock proves to have a porphyritic texture, with andesine phenocrysts in a granular groundmass composed of plagioclase and hornblende. The refractive index of the feldspar is greater than that of Canada balsam, and the maximum extinction in the symmetrical zone[2] is 20°. Albite and Carlsbad twinning are well developed, and pericline twins are frequently seen. The plagioclase is therefore an andesine, $Ab_{65}An_{35}$. It does not show zoning. The phenocrysts appear to have the same composition as the feldspar of the groundmass. The hornblende occurs in well-formed idiomorphic crystals, and has the following absorption scheme: Z (dark green) >Y (olive green) >X (yellowish green) . Small quantities of biotite and quartz occur, and accessory minerals are magnetite and apatite. Some idea of the mineral composition of the rock may be gained from the mode given in the table on page 34.

In view of the similarity in composition which exists between this rock and the epidiorites, it will be useful to summarize here the reasons for regarding it as an igneous and not as a metamorphic rock. The textural relations of hornblende and andesine form the most valuable guide to its origin. There is no evidence of the development of hornblende by replacement of feldspar ; the boundaries are smooth and are clearly due to the crystallization of feldspar round early-formed hornblende crystals. The hornblende does not exhibit the ragged edges which are

[2] Works consulted for data on the feldspars:
Goranson, R. W., The determination of plagioclase feldspars : Amer. Min., Vol. 11, 1926, pp. 139-154.

Chudoba, K., trans. Kennedy, W. Q., The determination of the feldspars in thin section : London, 1933.

characteristically developed by the secondary hornblende of the epidiorites. There is no reason to suppose that the plagioclase has been albitized. The only obviously secondary mineral is sericite, which is not characteristic of the epidiorites. Therefore, the diorite is regarded as an igneous rock formed from a magma of dioritic composition and injected shortly before the emplacement of the batholith.

CHLORITE SCHIST

Field Relations.—At the northern end of Mineral Hill another xenolith or roof-pendant, composed of chlorite schist, is exposed. The mass is 4000 feet long, and reaches a maximum width of about 300 feet. The general trend is N. 20° E., but the cleavage strikes north-south and dips at 80° to the west.

Petrography.—The rock is green and conspicuously schistose. Numerous "knots" are present, and the schistosity sweeps around these. Microscopically the rock is found to consist of chlorite, in plates having parallel orientations, interleaved with quartz. The chlorite is almost colorless in thin section and has a refractive index β=1.611; it is optically positive; it, therefore, belongs to the prochlorite group[3]. The knots repay careful study. Their maximum diameter is about 4mm., and they are composed of two minerals ; a strongly colored green chlorite occupies the center and this is surrounded by an aureole of sericite. The chlorite in this case has a distinctly lower refractive index than the prochlorite described above; β=1.590, and the mineral is optically negative. The birefringence is higher than in the prochlorite, and this mineral appears to fall within the jenkinsite group. Probably both chlorite and sericite have been derived from the alteration of an earlier mineral, possibly, in view of the high MgO-content of the chlorite, from cordierite. No residual material was, however, found, and the origin of the knots must remain in doubt. Other minerals of the schist include a few plates of hematite, sometimes oriented parallel to the schistosity, sometimes not so oriented, and a few apatite grains.

THE GRANITE BATHOLITH

COARSE-GRAINED GRANITE

Field Relations.—The earliest rock exposed in the batholith is a coarse-grained granite, with large phenocrysts of alkali feldspar. This is the predominant rock of the Organ Mountains pre-Cambrian. It is well jointed, and upon weathering tends to produce rounded hills, of very different appearance from the mountains made up of Tertiary intrusive rocks. In places, as on the ridge west of the Garrett ranch, the pre-Cambrian hills have small monoliths or tors near their summits, but these never resemble the aiguilles formed by the Tertiary quartz monzonite.

[3] Winchell, A. N., Elements of optical mineralogy ; Vol. 2, New York, 1933, p. 280.

A striking feature of the coarse granite is the parallel orientation of the large feldspars. This is seen in many exposures, and most frequently the strike of the "stretching"[4] is nearly north-south. Time did not permit a study of the "granite-tectonics" according to the methods developed by Hans Cloos, but the existence of primary structures is here mentioned to call attention to the fact that a study of this batholith from the tectonic point of view might yield some interesting results. Apart from occasional small xenoliths of mica-scist, the granite is quite free from dark inclusions. Locally there occur gneissoid patches which probably represent the result of the action of powerful stresses on the rock. As a whole, however, the granite is remarkably free from alteration due either to dynamic metamorphism or the action of heated fluids, and in most outcrops fresh rock can be obtained below the thin shell of weathering products.

Petrography.--The orthoclase crystals are tabular and frequently exceed 15 mm. in length; the other minerals visible to the unaided eye, including plagioclase, quartz, and biotite, generally have smaller grain sizes. Quartz is everywhere an abundant constituent and is plainly visible. The percentage of dark minerals is very small, so that the rock is light colored, generally gray, but locally near fractures which have permitted the access of iron-bearing solutions, it takes on a red color. This effect can be seen on the ridge east of the Smith Brothers' prospect near the northern end of the mapped area. The orthoclase is particularly susceptible to this form of alteration, and readily takes on a bright red color.

Microscopically the texture is found to be typically granitic. Biotite was probably the earliest mineral to crystallize, but it occurs in small quantities only. The plagioclase is an oligoclase, approximately $Ab_{80}An_{20}$. Some specimens contain orthoclase, while in others the alkali feldspar shows the combination of albite and pericline twinning characteristic of microcline; no reason for this variation could be discovered. In either case, a small quantity of albite is intergrown with the potash feldspar to form perthite. Quartz occurs as allotriomorphic masses filling the interstices between the feldspars, and also enters into a micropegmatitic intergrowth with orthoclase. The heavy minerals from two specimens were separated by immersing the powdered rock in bromoform, and among them the following minerals were identified: apatite, monazite, rutile, topaz, tourmaline, zircon, magnetite and ilmenite. The tourmaline is frequently seen in thin sections of the rock, and it appears that boron was a characteristic minor constituent of the granite magma. The mode of

[4] As defined by R. Balk, Primary structures in granite massives : Bull. Geol. Soc. Amer., vol. 36, 1925, pp. 679-696.

a typical specimen of granite, calculated from Rosiwal measurements, is given in the table on page 34, and will serve to show the approximate mineral composition of the rock.

Two examples of gneissoid granite were studied, one from the granite outcrop on the hill north of the Silver Coinage mine, the other from exposures northeast of the Stevenson-Bennett mine. In both a schistose appearance has been imparted by thin streaks of green chlorite which traverse the rock. Between the streaks there occurs a granular mosaic of quartz and orthoclase, the fresh glassy appearance of which indicates that they have been formed by recrystallization. The original minerals of the granite—quartz, orthoclase and biotite—remain in places and show clear evidence of distortion. The orthoclase is highly altered, probably to sericite, and contrasts strongly with the recrystallized orthoclase. The metamorphism is attributed to the effect of stress which probably led to the mechanical generation of heat.

Areas of strongly altered but not gneissoid granite were observed in the following places : at the summit of the ridge east of the Black Prince mine, at an elevation of 5400 feet at the northern end of the depression lying between this ridge and Mineral Hill, and on the ridge west of the Garrett ranch. In all these cases the alteration covers an irregular area; the rock is dark and evidently decomposed. In thin section the principal change appears to be very intense sericitization of the feldspars without development of schistosity. A small amount of clinozoisite and chlorite are associated. This type of metamorphism is not obviously related either to crustal stresses or to known passages followed by hydrothermal solutions, and no explanation of it is forthcoming.

Metasomatic alteration of the coarse granite near the Tertiary quartz monzonite and along the Tertiary mineral veins will be discussed in a later section (page 124).

MEDIUM-GRAINED GRANITE

Field Relations.—The coarse granite is intruded by a granite of medium grain. Time did not permit the separate mapping of the two types of granite, but contacts were examined and the relation between them is well established. On the hill east of the Stevenson-Bennett mine the relations can be studied particularly well; here the medium-grained rock encloses xenoliths of the coarse granite and also appears to include separate orthoclase phenocrysts from this rock. The later granite outcrops on the ridge east of Black Prince Canyon, on the Gold Camp pediment and also on the east side of the southeast ridge of the range.

Petrography.—The granite is usually reddish and even grained. Quartz is a conspicuous constituent, and orthoclase, biotite and plagioclase can be seen in hand specimens. In unweathered specimens the rock is fresh. The texture as seen in thin section is equigranular. Orthoclase is the predominant mineral ; quartz is abundant, and there is a small amount of oligoclase. Biotite is present, and among the accessory minerals magnetite, apatite, zircon and tourmaline have been observed. A micrometric analysis is recorded on page 34.

GRANITE PEGMATITE AND APLITE

Field Relations.—Innumerable small sheets and dikes of granite pegmatite occur throughout the area occupied by the granites. Their average width is not more than 6 inches, but occasionally they may reach as much as 2 feet across. They are lenticular bodies, which do not continue for more than 200 feet along their strike, and probably have an equally restricted vertical range. The average length is much less than 200 feet. They appear to have no consistent direction, and their attitude may vary from 0° to 90° with the vertical. The larger bodies frequently have borders of fine-grained micrograntie or aplite.

Petrography.—These rocks show all the features common to the normal pegmatites of granites. Microcline is the most abundant mineral and occurs in very large crystals, some of which are bounded by crystal faces. Its mean refractive index is 1.522, and its twinning is coarsely developed. It usually contains perthitic inclusions of albite whose albite law lamellae are in optical continuity with those of the microcline. Quartz occurs in two ways: it may form a graphic intergrowth with the microcline, or it may occur in cross-cutting veinlets whose margins suggest that some metasomatism has occurred. Magnetite and biotite are occasionally found in the pegmatites. The pegmatites appear to carry no rare minerals, and cavities are never found in them. They must be interpreted as closed-system pegmatites, probably crystallized at great depth below the surface. In view of the known presence of boron, fluorine and rare earths in the magma, it seems surprising that tourmaline, topaz, monazite and related minerals are absent from the pegmatites. Perhaps more careful search would reveal some of these minerals, but it was not the writer's good fortune to discover them.

Pre-Cambrian mineralization.—Although mineral deposits of proved pre-Cambrian age are known at several places in New Mexico, none are found in the Organ Mountains. This is not surprising when it is realized that the exposed granite must be in the central core of the batholith, a region in which ore deposits are hardly ever found. There are numerous metalliferous veins which cut the pre-Cambrian rocks; but it will be shown later that all of these are of Tertiary and not pre-Cambrian age.

Mineral Compositions (Modes) of pre-Cambrian Rocks

No.	Name and Locality	Weight-percent							
		Plagioclase	Orthoclase Microcline	Hornblende	Biotite	Tremolite, Calcite, Albite	Quartz	Micro-pegmatite	Magnetite, Accessories
1191	Diorite Southeast ridge	47		51	1		0.5		0.5
1012	Coarse-grained granite, NE. of Black Prince mine	6	57		4		30	1	2
1084	Medium-grained granite, NE. of Stevenson-Bennett mine	7	52		7		32		2
1013	Epidiorite Type I. NE. of Black Prince mine	53		19	17				11
1134	Epidiorite, Type II. Mormon mine			37	25	36			2

EPIDIORITE DIKES

Field Relations.—The youngest rocks of the pre-Cambrian system comprise a series of basic dikes, which are widely scattered throughout all the areas in which the basement complex outcrops. Dikes of this character are not found cutting the Paleozoic sedimentary rocks, nor do they occur in any later formations; it must therefore be concluded that they were injected before the peneplanation which brought to a close the pre-Cambrian era. Their metamorphosed condition supports this conclusion. It is nevertheless probable that the attitude of the pre-Cambrian rocks has undergone little change since their injection, for in all but a few cases they have dips varying between 70° and vertical. An analysis of their directions of strike does not indicate an adherence to one or two dominant trends such as many dike-swarms show, but it is found that in the Organ mining district, where all the epidiorite dikes were mapped, a great majority of them trend between north and east, and very few between north and west. The lack of regularity in direction may be explained in at least two ways; the stress conditions at the time of injection may have been particularly complicated ; or there may have been more than one period of injection. Single dikes frequently change their direction in a manner which is reminiscent of the change in strike of the fissure-veins at Butte, Montana, when they pass from tension to shear conditions. Intersections of epidiorite dikes are as a rule complicated by later earth-movements along one or other of the dikes, as at the crossing of the Pagoda and Steampump dikes; it is not, therefore, possible to determine the relative ages of injections, and the rocks of the dikes are too severely metamorphosed to make a classification into suites upon a petrographic basis feasible.

Petrography.—As originally defined by von Gumbel[5], the term epidiorite signified a rock composed of pale green fibrous hornblende with plagioclase, chlorite, ilmenite or magnetite and occasional augite. It has come to be used as a field term, covering metamorphosed basic igneous rocks containing hornblende, and a recent attempt by Read[6] to define it more precisely has not met with universal approval. The term is used in the ordinarily accepted sense here, and covers a group of rocks varying rather widely in mineral composition, but all arising by metamorphism of basic igneous rocks, and all containing hornblende. Two petrographic types have been distinguished in mapping; the first including rocks which exhibit the textural features of diabases, and which probably are metamorphosed diabases ; the second covering rocks in which these features are absent and whose origin is therefore less clear.

Type I.—This type embraces all the epidiorites of the Organ mining district except those lying between the Mormon and Sunol mines. Megascopically the rocks vary from gray to black according to their richness in ferromagnesian constituents. The grain-size varies considerably, from examples with feldspar laths not over 0.2 mm. long to those in which the lath may exceed 3 mm. Using a hand lens it is possible, however, to distinguish the diabasic texture even in the finest-grained members of the group. The rocks are non-porphyritic and individual dikes maintain approximately the same grain-size throughout their course ; occasionally, however, chilled margins represented by fine-grained rock can be seen against the granite. It is likely, then, that the dikes were injected long after the batholith had cooled down.

In thin section the haphazard arrangement of feldspar laths typical of diabases is exhibited, and there is good reason for the belief that the texture of the rocks was intersertal or ophitic before metamorphism. The mineralogy varies from that of slightly altered diabase to oligoclase-amphibolite, and a roughly continuous series can be recognized between these limits. The

[5] Wiseman, J. H. D., The central and south-west Highland epidiorites : Quart. Jour. Geol. Soc. Lond.. vol. 90, 1934. p. 355.

6 Read, H. H., Summary of progress for 1918: Mem. Geol. Surv. Gt. Britain, 1919, p. 27.

feldspar occurs in long laths and shows well-developed albite twinning even in the most severely altered rocks. Determined by means of refractive indices and maximum extinction in the symmetrical zone, it was found to vary from labradorite, Ab45 An_{55} in the dike at the Maggie G mine to oligoclase, Ab_{8}5An15 in a dike northeast of the Black Prince mine; the feldspar of most of the dikes investigated petrographically was, however, oligoclase. The feldspar is generally the most abundant constituent, the next in order of importance being green amphibole, which occurs in two forms : rudely idiomorphic hornblende with ragged edges, and green fibrous actinolite. Remants of augite were found in one specimen only, collected from the Pagoda-Gold Camp dike near the Sally mine. Biotite is usually present in small amount, and in two dikes examined, one northeast and the other southeast of the Black Prince mine it occurs in considerable quantity. Chlorite is rare, but in one example, an east-west dike near the main road 5.8 miles east of San Agustin Pass, it is present in quantity. The opaque minerals are abundant in all cases. Ilmenite or titaniferous magnetite seems to be the most widely distributed, and frequently shows alteration to leucoxene. Hematite and pyrite were also identified. Quartz in small clear patches is of frequent occurrence, while calcite was found in two rocks in which serpentine was also present. Apatite is universally present as an accessory constituent.

The textural relations of the minerals give some clue as to their origin. The feldspars, as stated above, are arranged in an intersertal or ophitic relation with the dark minerals. Their habit is that characteristically shown by the calcic plagioclases of diabases, not that in which sodic feldspars commonly occur. This fact, coupled with the calcic nature of the plagioclase in the less highly altered rocks, makes the conclusion that all the feldspars have suffered some degree of albitization a reasonable one. But, if this is true, it also follows that the replacement of CaO by Na_2O has been effected without destroying the outer form of the crystals. The feldspars show also another form of alteration : to amphibole by the development of tiny actinolite crystals inside their borders, and by marginal corrosion by hornblende. The presence of the remnants of augite mentioned above is important since it also lends weight to the view that these rocks were once diabases ; and it is probable that most of the hornblende has been derived from pyroxene. The hornblende is undoubtedly an alteration product; it has the frayed edges characteristic of uralitic amphibole, and can be observed to have replaced feldspar and augite, sometimes preserving the shape of the latter mineral. Olivine, if it were present in the original rock, would also contribute to the hornblende. Wiseman[7] concluded from a study of epidiorites in Scotland that hornblende and chlorite originated simultaneously from feldspar and augite. As far as hornblende is concerned, the results of the present investigation lend support to the view that both augite and plagioclase contributed to the reactions leading to its formation. In the rocks rich in biotite, this mineral occurs around the margins of the plagioclase laths in small crystals which have corroded the feldspar. Some of the opaque minerals appear to be primary, but some have been developed during the metamorphic process and occur as inclusions scattered through the amphibole ; this is especially well seen in a dike northeast of the Stevenson-Bennett mine, where the opaque mineral is magnetite. The quartz is believed to be of secondary origin. In the Maggie G dike cavities concentrically lined with serpentine (outermost), calcite and quartz occur, but there is no evidence to indicate whether these were originally in the rock, or were developed later; the filling is no doubt epigenetic.

Thus it is suggested that diabases consisting of calcic plagioclase, augite and perhaps olivine, with opaque minerals and apatite, have been converted into oligoclase-amphibolites containing oligoclase, hornblende, a new generation of magnetite, sometimes biotite, sometimes chlorite, and generally a small amount of free quartz. The rocks resemble closely the epidiorites found cutting the Moine and Dalradian series in Banffshire and Sutherlandshire, Scotland, described by Read[8].

Type II.—Epidiorites in which the diabasic texture is lacking are confined to the region lying between the Mormon and Sunol mines. The field relations suggest that some of these may be earlier than the Type I dikes. The dike along which the Mormon and Sunol veins run appears to be unique in this region in consisting largely of ferromagnesian minerals. Lindgren has already called attention to this rock.' When fresh the rock is dense and black and the hornblende grains can be distinguished clearly with the unaided eye. Microscopic study reveals the fact that the hornblende is present in idioblastic metacrysts, together with biotite and irregular remnants of albite in a fine-grained matte of actinolite and calcite. The amount of feldspar is variable; this mineral is absent from one specimen from the Mormon opencut, which may perhaps be taken to represent the climax of the metamorphism. It is notable that in those specimens containing feldspar in quantity, the large metacrysts of hornblende are absent, though there is much fine-grained actinolite. Possibly

[7] Wiseman, J. H. D., op. cit., p. 371.

[8] Read, H. H. The geology of the country round Banff, Huntley and Turriff : Mem. Geol. Surv. Scot. 1923, pp. 6, 93-95.
The geology of Central Sutherland: Mem. Geol. Surv. Scot., 1931, pp. 72-76.

[9] Lindgren, W., Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Surv. Prof. Paper 68, 1910, p. 207.

this rock type has also arisen from diabase, and represents the results of a more advanced grade of metamorphism. In its most advanced form it may be classified as a biotite-amphibolite. In the table on page 34 the mode of a specimen of this rock is compared with that of a characteristic Type I epidiorite.

Paralleling this dike and also transverse to it there are some narrow dikes of a somewhat different character. Megascopically their most arresting feature is the presence of quartz phenocrysts up to 25 mm. in diameter. The rock is generally green, with dark patches. Under the microscope it is found to consist of oligoclase, $Ab_{75}An_{25}$; hornblende showing idioblastic outlines ; calcite, and abundant chlorite, a light-colored variety replacing the feldspar and a dark variety replacing the hornblende. The quartz phenocrysts show corroded margins but are unaltered inside. Apatite is present. The texture does not suggest a diabase, but it is possible that the original rock may have been a quartz-diabase ; there is no evidence upon which to base a conclusive decision.

Petrology of epidiorites.—Some consideration has already been given to the details of the metamorphism; we may now enquire into the time and cause of the changes. We have already noted that the pre-Cambrian granites are in the main not metamorphosed. Why then should the dikes have suffered such severe alteration? Two reasons may be given. Firstly, it is a fact of general experience that granite is decidedly more stable under conditions of regional metamorphism than are basic rocks; and, secondly, the form of the dikes is such that they have provided loci for earth-movements and easy channels for the passage of solutions. Probably the metamorphism is due to stress and to the influence of fluids which have followed the dikes. Great importance cannot be ascribed to the stress factor, for the dikes are not at all schistose and it seems unlikely that the new minerals developed under great directed pressure. In ascribing the metamorphism to the influence of circulating fluids we need not necessarily assume that these have added any new material to the rock. It has frequently been observed that diabasic rocks change to epidiorites without alteration of the bulk composition of the rock, and all the materials necessary for the formation of epidiorites are present in diabases. A mineralogical re-arrangement, brought about by the conditions of chemical mobility induced by fluids is what probably occurred: We may note in passing that hornblende has up to the present defied all attempts to synthesize it from dry melts, and probably needs for its formation the presence of some volatile to act as catalyzer, in addition to water, which enters into its composition. In the absence of chemical analyses, the chemical aspects of the metamorphism cannot be pursued further.

Now it will be shown in a later section that the pre-Cambrian dikes formed channels for the flow of hydrothermal solutions emanating from the Tertiary batholith; and it is necessary to decide whether the metamorphism was induced by these solutions or by some earlier existing agents of alteration. Evidence giving a conclusive answer to this problem was forthcoming from a study of specimens taken adjacent to the Tertiary mineral veins which follow epidiorites at the Pagoda and Sunol mines. In both cases it was found that the hornblende had been converted into chlorite; that most of the biotite had gone to chlorite ; and in the Sunol case, that veinlets of albite, cutting across the rock, had appeared. A few much altered residuals of feldspar from the epidiorite stage remained. The changes are clearly retrograde ones[10] and as they are found in rocks nearer the veins than the rocks showing the higher grade of metamorphism, it follows that the Tertiary alteration was superimposed on rocks already in the epidiorite condition; and hence the amphibolitization must be regarded as a regional metamorphic effect of pre-Tertiary date. This conclusion is supported by the occurrence of epidiorites in regions far remote from the known areas of Tertiary mineralization, as in the Central San Andres Mountains.

SUMMARY OF PRE-CAMBRIAN EVENTS

1. Accumulation of elastic and pelitic sediments ; metamorphism and lit-par-lit injection of these by granite, producing quartzites, schists and gneisses. Intrusion of hornblende-diorite.
2. Intrusion of a very large composite batholith. In the present region the first rock emplaced was coarse-grained granite. This was followed by medium-grained granite, and later a great number of small normal pegmatites were intruded.
3. Intrusion of diabase dikes.
4. Uplift and prolonged erosion, stripping away the upper part of the batholith and revealing its central core. The cycle of erosion ended with the production of a smooth peneplained surface.

[10] Compare Wiseman, J.H.D., op. cit., pp. 397-405.

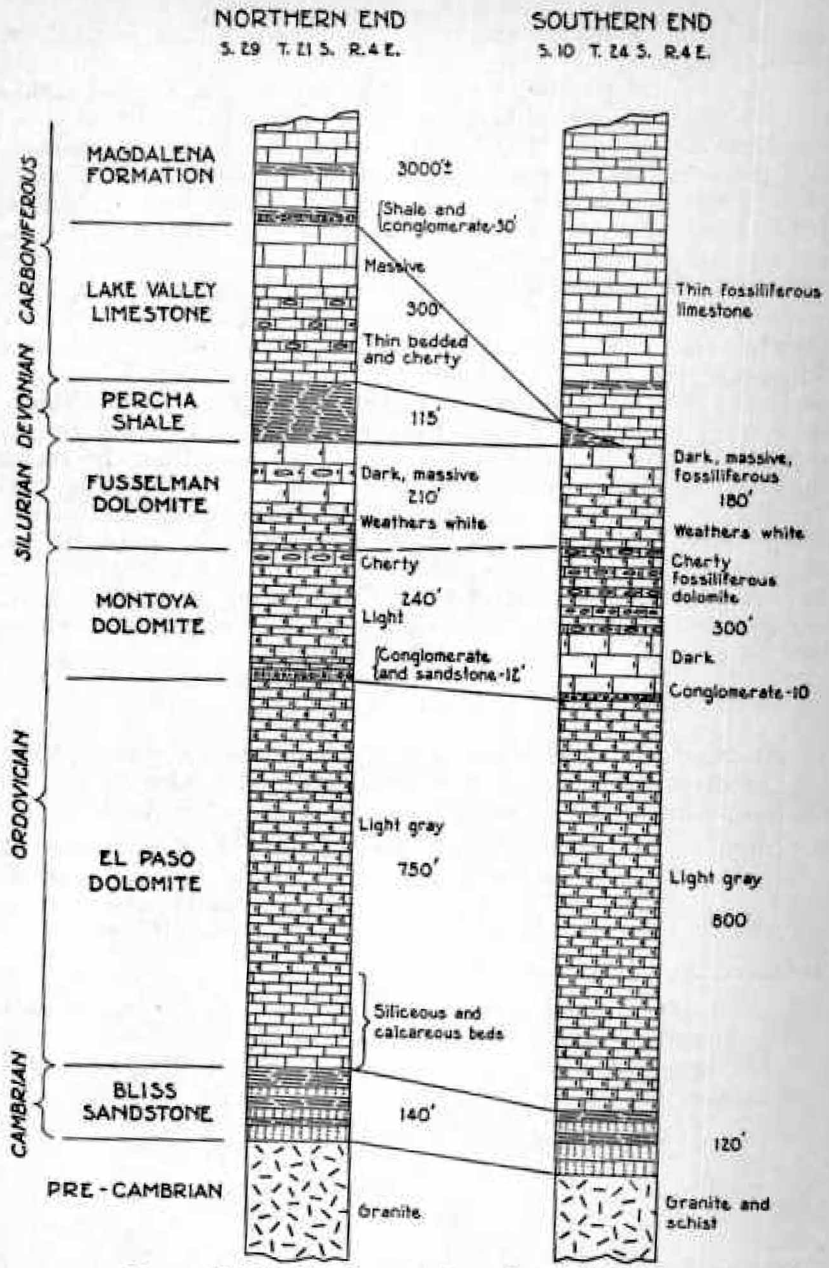


FIGURE 1.—Measured sections of Paleozoic rocks, in the Organ Mountains.

THE PALEOZOIC ERA

GENERAL FEATURES

A succession of limestones, sandstones and shales overlies the basement complex and is exposed at the northern and southern ends of the Organ Mountains, and also for some distance along the west side of the range. Although paleontological evidence indicates that there are large gaps in the sequence, it nevertheless appears to be a conformable succession, and angular unconformities between the formations appear to be lacking. Paleozoic time was, then, an era of quiet sedimentation unaccompanied by violent earth-movements. There were, as indicated by the non-sequences, periods of regression of the sea or of uplift of the land above sea-level, but even under these conditions the attitude of the beds suffered no change with respect to the horizontal. The general stratigraphic column for Dona Ana County on page 164 is designed to emphasize the periods of non-deposition as well as those of sedimentation. It seems unlikely that any considerable amount of erosion took place during the emergences, for there are no thick conglomerates and little evidence of dissection of inter-formational surfaces was found. Two sections across the lower Paleozoic beds were measured, one across the southeast ridge of the mountains, the other along a ridge near the Hilltop mine, in Black Prince canyon ; the mapping is based on these sections.

CAMBRIAN SYSTEM

Bliss Sandstone.—We have already noted that the last event of pre-Cambrian time was the uplift, erosion and ultimately the peneplanation of the ancient rocks. The basal sandstone of the Paleozoic series rests upon a smooth surface of pre-Cambrian crystalline rocks, indicating that the sea had transgressed over the peneplain. Clastic sediments, derived from some region still standing above sea-level, were laid down to form the Bliss sandstone. This formation has its type locality in the Franklin Mountains[1]. In the Organs, it outcrops along the east side of the southeast ridge, and crosses the ridge into Target Range Canyon near the Devil's Canyon mine. It is not seen again until it appears north of San Agustin Peak, whence it outcrops continuously as far as the Black Prince mine, where it is cut off by a fault. It consists of a series of quartzites and indurated shales, the whole formation weathering brown. Probably hematite is abundant as a coating of grains of other minerals. Glauconitic layers occur at several horizons, perhaps indicating minor disconformities. The thickness is 140 feet in the northern exposures, 120 feet in the southern. Annelid borings are common in the quartzites, but no

[1] Richardson, G. B., El Paso folio: U. S. Geol. Atlas. No. 166, 1909

other fossils were found ; correlation is therefore based on the fact that it is lithologically identical with the known Cambrian beds of the Franklin and San Andres ranges.

ORDOVICIAN SYSTEM

El Paso Dolomite.—Overlying the Bliss sandstone in the Franklin Mountains is a thick dolomitic series named by Richardson the El Paso limestone. This series is well exposed both at the southern and northern ends of the Organ Mountains, the thicknesses being 800 and 750 feet respectively. At their base the beds rest on the Cambrian quartzite; there is no evidence of erosion or of a stratigraphic break apart from the local occurence of glauconite in the beds below the contact. The bedding is thin and slabby, and the rock weathers a pale bluish-gray when unmetamorphosed; in the metamorphosed areas near the contacts of the Tertiary batholith the rock is converted into white marble and weathers white. A characteristic feature of the El Paso limestone is the presence of brown reticulating markings on the surface, believed by Darton[2] to be the remains of seaweed; these occur intermittently throughout the whole formation, and persist in the metamorphosed beds except when the highest grade of metamorphism is attained. Fossils are rare in the El Paso beds. In the northern exposure they have been destroyed by the intense metamorphism. At the southern end a few examples of *Ophileta* sp. and *Orthis* sp. were found. The dolomitic character of the Ordovician and Silurian beds of southern New Mexico and West Texas was first noted by Richardson in the Franklin Mountains. In the present area, tests with hydrochloric acid indicated that the whole thickness of the El Paso limestone at the southern end is dolomitic. At the northern end, calcitic beds occupy the lower part of the series, but are succeeded above by dolomites. These calcitic beds have been mapped separately on the Organ Mining District sheet (Plate III) since their role in the Tertiary metamorphism differs in some important respects from that of the overlying dolomites. An analysis of the El Paso limestone from the type locality is quoted in the table on page 45. Kirk regards the fauna of the El Paso limestone as representing late Beekmantown time.[3]

Montoya Dolomite.—A period of uplift followed the deposition of the El Paso series, and no beds of Middle Ordovician age were laid down. The Upper Ordovician is represented by the Montoya dolomite, also named by Richardson in the Franklin Mountains. This series is exposed in Target Range and Black Prince canyons and in both areas rests upon a basal conglomer-

[2] Darton, N. 11. "Red beds" and associated formations in New Mexico: U. S. Geol. Surv. Bull. 794, 1928, p. 184.

[3] Cited from Darton, N. H., op. cit., p. 185.

ate, which separates it from the El Paso dolomite. The conglomerate consists of rounded quartz grains of about 1 mm. diameter or larger in a calcareous matrix, and passes locally into a fine-grained sandstone along the Hilltop ridge. The two members of the Ordovician are readily separable by means of this conglomerate. A sandstone bed at the same horizon was observed by Dar-ton in the San Andres mountains.[4] As shown by the measured sections, there is a thickening of the Montoya formation towards the south. The lithology is closely similar to that described by Darton for this formation in the San Andres Mountains. The lower beds, about 100 feet thick, are massive and weather dark gray; they are succeeded by a thin-bedded series weathering light blue-gray. Tests again reveal the dolomitic character of the rock. The dark lower beds are distinctly crystalline even as seen with the naked eye. Chert in elongate rounded nodules is widely distributed throughout the formation but is especially abundant in the upper beds. It lies, in general, parallel to the bedding. In the southeast ridge a conglomerate of angular cherts in a dolomitic matrix was discovered in the lower part of the upper division. This may be interpreted in two ways; it may have originated by the selective replacement of a conglomerate of limestone pebbles, or it may indicate that chertification had already taken place before its deposition. The writer is inclined towards the latter view. The following fossils were obtained from the southern exposures :

Favosites sp.
Streptelasma sp.
Rhyncotrema argenturbica
Hebertella occidentalis
Plectorthis whitfieldi
Dalmanella sp.

(Identified by L. E. Nelson)

The *Hebertella* is especially abundant. The Montoya fauna is regarded as representing Richmond (Upper Ordovician) time. No fossils were found in the northern exposures, where they have been destroyed by metamorphism ; correlation by lithology therefore had to be relied upon.

SILURIAN SYSTEM

Fusselman Dolomite.—The Montoya dolomite passes up-

wards without apparent break into the beds of the Fusselman series ; these formations also bear a marked lithological resemblance. In the northern area, as in the San Andres Mountains, two members may be distinguished in the Fusselman ; a lower one of fine-grained character which weathers almost white, and an upper one consisting of hard dark dolomite, distinctly crystalline even when not influenced by Tertiary metamorphism. Fos-

[4] Darton, N. H., op. cit., p. 185.

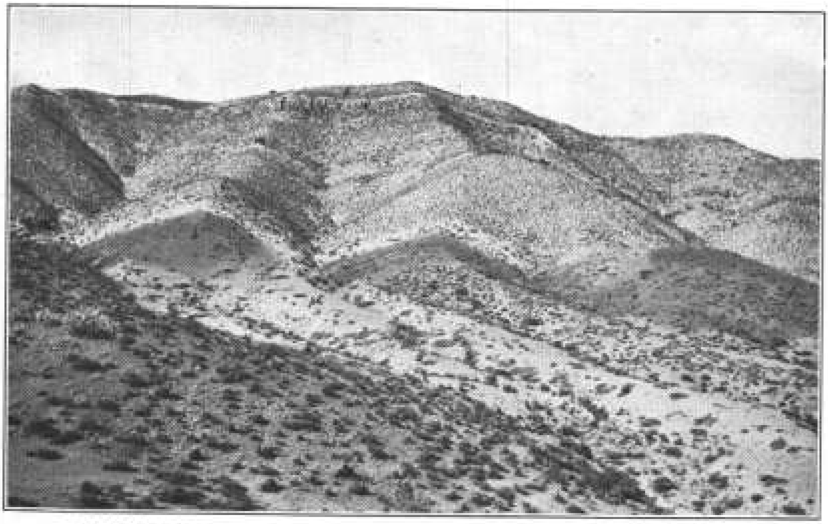
sill are rare; those found include some casts of *Pentamerus; Syringopora* sp. and *Favosites sp.* (from the hill above the Stevenson-Bennett mine) and *Halysites* sp. (from the southeast ridge) . These are sufficient to establish the age of the beds. The formation reaches a thickness of 1000 feet in its type locality, Fusselman Canyon near El Paso ; but in southern New Mexico its thickness is much less and does not exceed 210 feet in the Organ Mountains.

Dolomitization.—The Lower Paleozoic section in the San Andres-Organ-Franklin chain, 400 to 2400 feet thick, is composed largely of dolomite limestones. The magnesian character of these beds presents something of a problem, and as such deserves a brief discussion here. The field relations show that the dolomites of this region are "formational bodies" as defined in the Treatise on Sedimentation.'[5] During field work repeated tests failed to reveal calcitic beds in the Fusselman and Montoya formations, and the only ones found in the pre-Devonian succession were those at the base of the El Paso series. They are thus strictly comparable with such formational bodies as the Big Horn dolomite of Wyoming and the Niagara dolomites of the Great Lakes region. Now it has been shown that strata as rich in magnesium carbonate as these cannot have been deposited directly from the sea; no organisms whose shells would lead directly to the formation of dolomite limestones are known, and modern chemically precipitated limestones show only small quantities of $MgCO_3$. Evidently, then, dolomitization must be regarded as a change which has been imposed on beds originally more calcitic. A study of thin sections of the dolomites of this region served to support the view that they are not in their original condition, for they now possess a granular texture, and are composed of interlocking carbonate grains varying from 0.1 to 0.5 mm. in diameter. Such a granular mosaic is in marked contrast to the texture exhibited by the calcitic limestones of the Carboniferous series of this same region. Determinations of ω for the carbonate gave $1.680 \pm .002$ as a result, thereby definitely establishing the mineral as dolomite, $CaMg\ (CO^3)_2$. The alteration may account for the rarity of fossils in these beds as compared with the Carboniferous limestones.

Several theories have been advanced to account for dolomitization. The most recent may be discussed first. D. F. Hewett has advocated the hypothesis of alteration by juvenile waters originating in igneous magmas to account for the dolomites of the Goodsprings Quadrangle, Nevada.[6] While not denying that dolomite may be produced locally as a replacement of

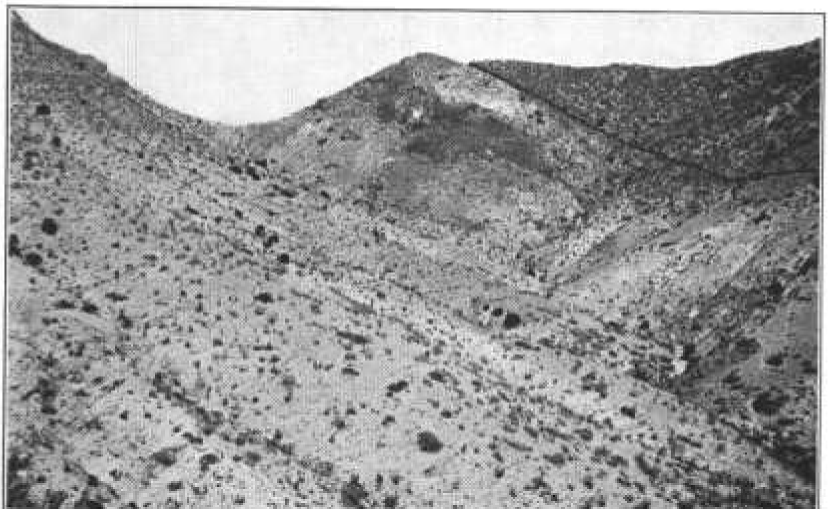
[5] Twenhofel, W. H., et al., A treatise on sedimentation : 2nd Ed. 1932, p. 332.

[6] Hewett, D. F. Geology and ore deposits of the Goodsprings Quadrangle, Nevada: U. S. Geol. Snrv. Prof. Paper 162, 1934, pp. 57-67.



A. PHOTOGRAPH OF THE WEST SIDE OF BLACK PRINCE CANYON

pC, pre-Cambrian granite; b, Bliss sandstone; e, El Paso formation; m, Montoya dolomite; f, Fusselman dolomite; p, Percha shale. The dumps of the hilltop mine appear below the crest of the ridge.



B. PHOTOGRAPH OF THE HEAD OF BLACK PRINCE CANYON, SHOWING PRE-CAMBRIAN ROCKS THRUST OVER CARBONIFEROUS LIMESTONES

The black line indicates the trace of the thrust plane.

limestone induced by hydrothermal solutions, for there are many examples of such an action associated with hydrothermal ore deposits,[7] the present author does not believe that this explanation can possibly be the right one in the region here under consideration. In the San Andres-Organ-Franklin chain dolomite limestone is exposed for 140 miles with an average thickness of over 1000 feet. The amount of material which would have to be removed in order to replace half the calcium of these rocks with magnesium is tremendous and probably exceeds altogether the capabilities of hydrothermal solutions. There is, moreover, no evidence of relation between the dolomites and igneous bodies or structural breaks along which solutions might have travelled.

A much more promising theory is that based upon the observations of Funafuti and Key West, in which it is held that the change is brought about by the action of sea water on the newly deposited limestone, leaching out the calcite.[8] The conditions under which dolomite is less soluble in sea water than calcite are not well understood, but in spite of this the leaching theory remains the most satisfactory for formational dolomites. It is suggested, then, that the dolomites were already in existence as such before the end of Silurian time. Dolomite does not appear again in the later formations. It is desirable to lay emphasis on the essential difference in character between the Lower and Upper Paleozoic limestones, and it is for this reason that so much attention has been accorded to the question of dolomitization.

Analyses of Lower Paleozoic Dolomites

	$CaCO_3$	$MgCO_3$	Insoluble
1. El Paso formation, 8 miles north of El Paso	57.37	30.54	12.09
2. Montoya formation 8 miles south of Hueco	54.31	37.17	8.52
3. Montoya formation 3 miles north of El Paso	55.75	31.59	12.66
4. Fusselman formation Franklin Mountains	51.67	35.20	13.13
5. Fusselman formation Hueco Mountains	51.12	35.61	13.37
6. Fusselman formation San Andres Canyon, San Andres Mountains	52.00	38.00	10.00
7. Theoretical composition of pure dolomite	54.34	45.65	00.00

Nos. 1 to 5 by W. T. Schaller, quoted from the El Paso folio, U. S. Geol. Survey. In these the CaO and MgO content only were given; $CaCO_3$, $MgCO_3$ and insolubles have been calculated.

No. 6 by Chase Palmer, quoted from Bull. 794, U. S. Geol. Survey, page 186.

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[7] Hewett, D. F., Dolomitization and ore deposition: Econ. Geol. vol. 23, 1928, pp. 821-863. Dunham, K. C., The genesis of the North Pennine ore deposits: Quart. Jour. Geol. Soc. London, vol. 90, 1934, p. 700.

[8] Twenhofel et al., op. cit., pp. 840-845.

DEVONIAN SYSTEM

Percha Shale.—An unfossiliferous black and gray shale series rests on a slightly irregular surface of the Fusselman dolomite in the northern area. An Upper Devonian fauna has been obtained from corresponding beds a few miles to the north by Darton[9]; this formation is, therefore, tentatively identified as the Percha shale of Devonian age. It outcrops from a point west of the Salazar Goat Ranch to the Black Prince mine, and is also found at the Stevenson-Bennett mine. In the southern area it occurs near the Devil's Canyon mine, but dies out before reaching the southeast ridge. It is not present in the Franklin Mountains. Two members may be distinguished; a lower one consisting of black fissile shales and an upper one comprising gray shales with limestone nodules. The limy upper beds have 'yielded fossils in the San Andres and elsewhere, but they are too much metamorphosed in the present region. The Percha shale marks a change in conditions in the sedimentary history of the region. For the first time since the Cambrian, fine-grained elastic sediment was being laid down.

CARBONIFEROUS SYSTEM

Lake Valley Limestone (Mississippian).—In the San Andres Mountains beds equivalent to the Lake Valley limestone of early Mississippian age occur. North of Organ a thick limestone overlies the Percha shale and this has been mapped as the Lake Valley limestone. The only fossils found were a few rugose corals, too much altered to be positively identified, and innumerable crinoid stems. The age of the bed is not, therefore, positively known. Lithologically, however, it is readily distinguishable from the thin-bedded limestones and shales of the overlying Magdalena series, and it resembles closely the Lake Valley limestone exposed in San Andres Canyon. Its thickness is approximately 300 feet near the Little Buck mine. Similar limestone occurs above the black shale at the Stevenson-Bennett mine. It is absent in the southeast ridge.

Magdalena Series (Pennsylvanian).—A thick series of beds of Pennsylvanian age forms the upper part of the stratigraphic column. These are exposed in a large area at the northern end of the range ; they continue along the foot of the western slope as far as the Modoc mine and reappear in the south at Bishop's Cap and in the southeast ridge. They rest on the supposed Lake Valley limestone between the Goat Ranch and the head of Black Prince Canyon, the basal member being a conspicuous brown shale which is locally conglomeratic. A similar shale separates these formations north of the Stevenson-Bennett mine. In the southern area a limestone bed of Pennsylvanian age rests directly

Darton, N. H., op. cit., p. 187.

on the top of the Fusselman dolomite. The lithology of the Magdalena beds reflects the oscillating conditions which prevailed throughout Pennsylvanian time, whether under the sea or in terrestrial swamps. The series consists of thin alternating limestone members of several varieties, interspersed with shales, and in the middle part of the succession, fine-grained gray and brown sandstones; limestones, however, greatly predominate. The series is a remarkable exemplification of the possible varieties of limestone. Fine-grained limestones occur, some weathering white, others brown. These alternate with coarse semi-crystalline beds, or with black carbonaceous limestones which produce characteristic buff-colored surfaces when weathered. Beds of chertified limestone are found as well as the usual rounded chert nodules. None of these beds exceed 100 feet in thickness, and most of them are decidedly thinner. Locally fossils occur abundantly in this series. Lack of time prevented the making of a thorough collection of the Pennsylvanian fossils of this region such as Professor Nelson has made for the Franklin Mountains; and attention was therefore concentrated on the lowest and uppermost beds. The fossils obtained are recorded in the table on page 48. According to Professor Nelson, who kindly identified them, they indicate that the series is of Magdalena age throughout. Due attention was give to the possibility that dolomite might occur in this series. The only limestones, however, which failed to react readily with 1 :1 hydrochloric acid were those which showed clear evidence of having been chertified. It seems probable then that the Pennsylvanian limestones have not suffered dolomitization. Determinations of the refractive index ω for carbonate grains from some of the coarse limestones of the region which were suspected of being dolomitic gave values under 1.660, thereby demonstrating that the grains were calcite and not dolomite. The coarse beds no doubt owe their texture to recrystallization, and from the point of view of grain size they are comparable with the dolomites ; but they are lacking in the regular, almost equigranular pattern exhibited by those rocks. Chert is widely scattered through the series, both as nodules and as beds. There seems no reason to doubt that much of this chert is of syngenetic origin, as Tarr[10] has claimed in a general review of the subject, and this may be taken to apply to the chert in the Lower Paleozoic rocks as well. A syngenetic origin explains particularly the nodular cherts ; in the case of the chert beds, there is more room for doubt. Microscopic observations on some of these show that they consist of fine-grained carbonate with tiny irregular and sometimes ramifying streaks of crystalline quartz which appear to be replacing the limestone. If this represents an epigenetic

[10] Tarr, W. A., and Twenhofel W. H., article in : A treatise on sedimentation : 2nd ed. 1932, pp. 519-545.

Fossils from the Magdalena Series

	1	2	11	12	4	6	896	891	890	888	B
Fistulipora rhombipora	X	--	--	X	--	--	---	---	---	---	--
Amplexus sp.	--	--	--	X	--	--	---	---	---	---	--
Campophyllum torquinum	--	--	--	X	--	--	---	---	---	---	--
Syringopora multattenuata	--	--	--	X	--	--	---	---	---	---	--
Zaphrentis ?gibsoni	X	--	--	--	--	--	---	---	---	---	--
Zaphrentis sp.	--	--	--	X	--	--	---	---	---	---	--
Cliothyridina orbicularis	--	--	--	X	--	--	---	---	---	---	--
Composita subtilita	X	X	X	--	--	--	---	X	---	X	--
Derbya cf. bennetti	--	--	--	--	--	--	---	---	X	---	--
Marginifera aff. lascellensis	--	X	--	--	--	--	---	---	---	---	--
Marginifera muricata	X	--	--	--	--	--	---	---	---	---	X
Productus cora	--	--	--	X	X	--	---	---	---	---	--
Productus ?burlingtonensis	--	--	X	--	--	--	---	---	---	---	--
Productus costatus	--	--	X	--	--	--	---	---	---	---	--
Productus semireticulatus	--	--	--	X	X	--	---	---	---	X	--
Productella sp.	--	--	X	--	--	--	---	---	---	---	--
Rhipidomella carbonaria	--	--	--	X	--	--	---	---	---	---	--
Spirifer cameratus	--	--	--	X	--	--	---	---	---	---	X
Spirifer opimus	--	--	--	X	--	--	---	---	---	---	X
Spirifer triplicatus	--	--	--	X	--	--	---	---	---	---	X
Spiriferina sp.	--	--	X	--	--	--	---	---	---	---	--
Wellerella osagensis	X	X	--	--	--	--	---	---	---	---	--
Bellerophon sp.	--	--	--	--	X	X	---	X	---	---	--
Murchisonia sp.	--	--	--	--	--	--	X	---	---	---	--
Pharkidonotus percarinatus	--	--	--	--	--	--	X	---	---	---	--
Schizostoma catilloides	X	--	--	--	--	--	---	---	---	---	--
Soleniscus sp.	--	X	--	--	--	X	---	X	---	---	--
Phillipsia major	--	X	--	--	--	--	---	---	---	---	--

Identified by L. E. Nelson

Localities

1. 25' above basal shale of series, Black Prince Canyon, ½ mi. north of mine, sec. 29, T. 21 S., R. 4 E.
2. 100' above No. 1.
11. 55' above base of series, Target Range canyon on ridge in sec. 16, T. 24 S., R. 4 E.
12. 350' above No. 11, same ridge.
4. East-west ridge from Hardscrabble Hill, east end, sec. 13, T. 21 S., R. 3 E.
6. Near fault on Hardscrabble Hill, sec. 13, T. 21 S., R. 3 E.
896. Highest beds of series below lavas, west slope of range, sec. 36, T. 22 S., R. 3 E.
891. 375' below No. 896.
890. Next bed below No. 891.
888. 80' below No. 891.
B. Collection from Bishop's Cap, made by Prof. L. E. Nelson.
(Figures given are stratigraphical distances.)

effect, it may be ascribed either to silicification which occurred shortly after deposition while the limestone was still within reach of sea or more probably river waters ; or may be due to the action of much more recent circulating waters. Tertiary hydrothermal solutions are known to have brought about silicification in the limestones, as will be shown later, but the chert beds are found in the San Andres Mountains far remote from the known centers of Tertiary activity, and cannot be explained in this way. The subject of the chertification must be left, therefore, in this unsatisfactory state.

THE PALEOZOIC SEAS

It is appropriate to devote some attention, in conclusion, to the relations which exist between the Paleozoic rocks of the present region and those of the surrounding areas. Recent studies in Oklahoma and Texas have shown that in early Paleozoic time a relatively narrow geosyncline extended from the Ouachita Mountains of Oklahoma to the Marathon basin in Texas.[11] To this region of sedimentation and subsequent intense folding the name Llanoria geosyncline has been applied. It was bounded on the southeast by an ancient landmass called Llanoria, which now lies buried under the Gulf coastal plain of Texas; this mass continued into what is now Mexico as Columbia. To the northwest there was another landmass which has been called Siouis by Schuchert.[12] In the geosyncline Paleozoic sediments with a maximum thickness of 25,000 feet were accumulated, and there exists between these and the corresponding sediments of southern New Mexico a striking contrast both in thickness and in state of deformation. The sediments of the present region may be interpreted best as foreland deposits, forming a relatively thin cover over the basement of crystalline rocks which formed the northwestern borderland of the Llanoria geosyncline. Their deposition may, therefore, be attributed to the flooding of the peneplained surface of Siouis by epicontinental seas.

The studies of N. H. Darton, Sidney Paige and others[13] have revealed the presence of sediments similar to those of the San Andres-Organ-Franklin chain in many of the mountain ranges of southern New Mexico. In all cases these are relatively thin and do not exceed 5000 feet in total thickness. Enough evidence has been accumulated to indicate approximately the limits of the Paleozoic seas, if one makes the assumption that the absence of a particular formation in the succession is due to its non-deposition and not to erosion before the next formation was laid down. As we have already noted, there is little evidence of interformational erosion in this region, so that this assumption is not altogether unjustified. In Upper Cambrian times the embayment covered southern New Mexico and extended as far north as the southern end of the Oscura Mountains. Its eastern extension is uncertain, but to the west it probably continued into Arizona. The El Paso sea occupied roughly the same area. There is a definite thickening of the Bliss and El Paso formations towards the south, as can be seen from figure 2 on page 50, showing the relations between the sediments of the San Andres-

[11]E. H., Adkins, W. S. and Plummer, F. B. The geology of Texas : vol. 1. The University of Texas Bull. 3232, 1932, pp. 21-23, 127-140.
King, P. B. An outline of the structural geology of the United States : XVI Int. Geol. Congress, Guidebook 28, 1932.
[12] Schuchert, C., Ancestral Rocky Mountains : Amer. Assoc. Pet. Geol. Bull. 14, 1930, PP. 1224-1227.
Li See Darton, N. H., op. cit.

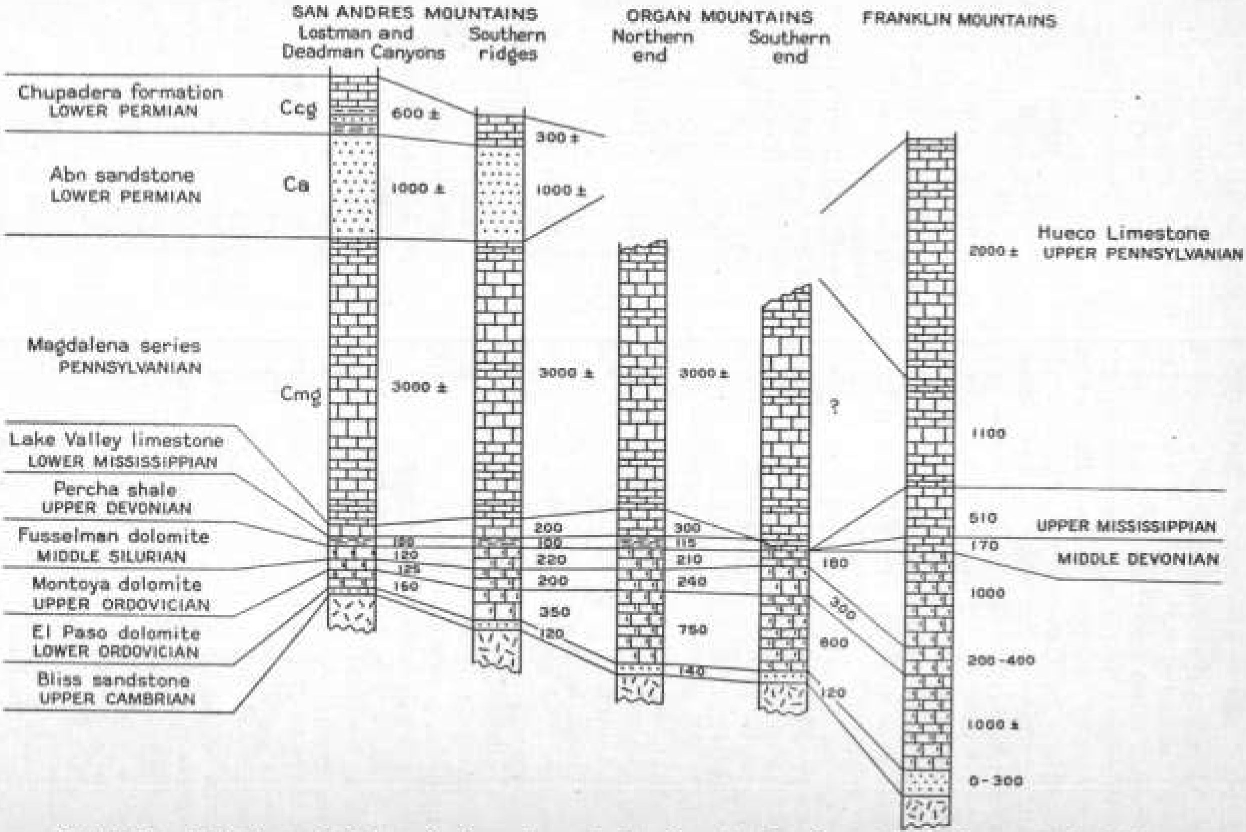


FIGURE 2.—Variations of Paleozoic formations in the San Andres-Organ-Franklin mountain-chain.

Organ-Franklin chain. A similar thickening is revealed when the sections in the Black Range, Cooks Peak region and the Florida Mountains are compared. There was a regression of the sea during Middle Ordovician times, but this was followed by another widespread flooding in the Upper Ordovician. The area covered seems to have been much the same as that occupied by the earlier seas, and again the northern shoreline was probably in the region of the Oscura Mountains. It seems likely that the Fusselman sea occupied a more restricted area. The Fusselman limestone dies out in the central part of the San Andres Mountains; and it seems certain that this transgression did not reach Arizona, for Silurian beds are lacking in that State.[14] Gentle warping may have occurred at the end of the Silurian, for in Upper Devonian times the southernmost part of New Mexico seems to have been elevated above sea level. This is indicated by the absence of this formation from the southern Organs, the Franklins, the Floridas and the Victorio Mountains. In the north the Percha beds die out before reaching the northern Oscura Mountains and are absent from the Socorro region. The Lake Valley limestone covers a similar area. The Pennsylvanian epoch was marked by a great extension of marine conditions, the old land which occupied the northern part of New Mexico being inundated at this time. The Magdalena series outcrops throughout the southern part of the State, except in the Florida and Victorio Mountains, where Permian rocks rest directly on Lower Paleozoics. There may be reason to suppose that the Magdalena series was eroded in this region. Summarizing, we may say that the Paleozoic era was a time of sedimentation in shallow seas. After Cambrian times, the adjacent lands can have had little relief, for elastic sediments are rare. The sediments of the Llanoria geosyndine came not from the northern land mass, but from the south.

THE VOLCANIC EPOCH

THE PRE-LAVA LAND SURFACE

Rocks of Permian age and of Mesozoic age are not exposed in the Organ Mountains. In view of their presence in the adjacent mountains, however, we may assume that they were deposited and eroded before the commencement of the great outpourings of lava which were the next important event in the history of the region. There is reason to suppose that the Organ Mountains lay near the southern margin of the basin in which the terrestrial Abo sandstone of Permian age was deposited, and beds referred to this formation outcrop a short distance to the north, near the Davis ranch in the San Andres Mountains, and also in

[14]in Darton, N. H. An outline of the geology of Arizona: Univ. Ariz. Bull. 119, 1925, p.54

Robledo Mountain to the west. Later rocks which may also have been deposited over the Organ Mountains area include the Chupadera formation of Permian age, and the Sarten sandstone and Mancos shale of Cretaceous age.

Near the end of the Cretaceous, uplift took place, and the beds of the region were gently tilted towards the west. This event marked the initiation of the long period of earth-movements and igneous activity which continued to post-Pleistocene times. Erosion followed the uplift, and it seems likely that a considerable thickness of sedimentary material was stripped off before volcanism began. Evidence of this process is to be found in the conglomerate which underlies the basal tuff of the lava series. This is well exposed along the west foot of the mountains, in sec. 36, T. 22 S., R. 3 E., and it appears again at the head of Target Range Canyon. Its thickness varies from a few feet to almost 100, and it is believed to represent a fan deposit. It consists of rounded pebbles and boulders of limestone up to 1 foot in diameter, with subordinate amounts of sandstone and shale. Careful search failed to reveal the presence of any igneous rocks in it, and there is every reason to suppose that all the material in it was derived from the Magdalena series, upon which it rests. It contains many derived fossils but none which would indicate the exact time of its deposition. There is a difference in attitude of 10-20° between the general dip of the conglomerate-lava series and the dip of the Magdalena series, and it is from this fact that the tilting of the Magdalena beds was deduced. When volcanic eruptions began, therefore, there was in existence a land surface composed of Magdalena limestones, dissected and locally surrounded by the products of their disintegration.

GENERAL FEATURES OF THE LAVAS

Distribution.—Extrusive rocks make up the southwestern quarter of the mountains, and are exposed along the west front from Fillmore Canyon to Pinto Blanco, a distance of eight miles. The maximum width of the areas which they occupy is five miles. North of Fillmore Canyon, a narrow strip of lava is faulted in, high up on the western slope below the aiguilles; and west of this outcrop, the basal members of the extrusive series may be seen overlying the Magdalena formation. Lavas appear again on Hardscrabble Hill, north of Organ. A number of isolated outcrops which occur on the bolson plain west of the mountains, suggest that this may be underlain for some distance by lavas.

Age.—Unfortunately it has proved impossible to determine the exact age of the volcanic rocks. As will be shown later, the lavas were extruded before the intrusion of the Tertiary batholith ; and they rest on Pennsylvanian rocks. By analogy with other districts in southern New Mexico, we may come somewhat closer to the age, for it appears that volcanism commenced in this region in late Cretaceous times and continued into the Miocene. Flows interbedded with late Cretaceous sediments are now known to occur in parts of southwestern New Mexico and Arizona [1] so that it is possible that volcanism began in late Cretaceous time in this region. The lavas of New Mexico are, however, mainly Tertiary in age, and in the absence of evidence it seems most satisfactory to assign a Tertiary age to the flows of the southern Organs.

Lithologic Units.—Four divisions were discriminated during mapping. These consist of a basal rhyolite-tuff series, which rests on the conglomerate described above; a series of relatively thin andesite flows, here called the Orejon andesite; a rhyolitetuff formation, called the Cueva rhyolite; and a great thickness of rhyolites grouped under the name Soledad rhyolite. Lindgren, Graton and Gordon[2] state that the following general succession holds for the Tertiary lavas of New Mexico. (1) Quartz-trachyte or rhyolite ; (2) Andesite, basaltic andesite, latite; (3) Rhyolite; (4) Basalt. The sequence of flows in the present area conforms with their findings, stages (1) to (3) being represented in the mountains, and stage (4) appearing on the adjacent bolson plains. It does not, of course, follow that the whole series expressed in the general succession given by these authors belongs to a single petrogenetic cycle.

BASAL TUFF

Field Relations.—Beds of tuff rest on the pre-lava conglomerate in Sec. 36, T. 22 S., R. 3 E.; their outcrop forms a broad arc swinging round from a point south of the Hayner mine boarding house to the vicinity of the Orejon mine, where the beds disappear under the alluvium at the mouth of Fillmore Canyon. In Fillmore Canyon blocks probably derived from this basal tuff are seen as inclusions in the quartz-monzonite. There are some exposures of the tuff at the head of Target Range Canyon. The rock varies greatly in color and composition, being white, dark green or brown; its pyroclastic nature is, however, always in evidence. Three-quarters of a mile south of the Hayner cabin, there is an excellent exposure in the walls of a narrow canyon. Here the pre-lava conglomerate is seen to its best advantage. Among the first-deposited beds of the tuff limestone pebbles can sometimes be identified, and there is a pebble-dike 12 inches wide, with abundant limestone and sandstone fragments, cutting

[1] Paige, S., Silver City folio: U. S. Geol. Atlas, No. 199, 1916.
Ross, C. P., Geology and ore deposits of the Aravaipa and Stanley mining districts, Graham County, Arizona: U. S. Geol. Surv. Bull. 763, 1925.
Lasky, S. G., and Wootton, T. P., The metal resources of New Mexico, N. Mex. Sch. of Mines, State Bur. of Mines and Min. Res., Bull. No. 7, 1933, p. 72.

[2] Lindgren, W., Graton, L. C., and Gordon, C. H., op. cit., p. 43.

through the lowest bed of the series here. The matrix of the dike is fine grained and probably consists of volcanic mud. The dike was "intruded" or perhaps filled from above before the second layer of tuff, a fine-grained type, was deposited. The prominent hill southwest of the Modoc mine is made up chiefly of basal tuff, while in the southwest part of Target Range Canyon similar beds outcrop along the east side of a prominent ridge west of the Devil's Canyon mine. The tuff indicates that the period of volcanism began with explosive violence, but the location of the vent was not discovered. At least part of the tuff was accumulated below water, for some of the beds show a regular stratification with layers of dark mud. The more massive beds may well have accumulated on the land.

Petrography.—The fragments are generally angular and are of several different types. White rhyolite, with subangular phenocrysts of glassy quartz and turbid feldspar in a cryptocrystalline groundmass, is common. Purplish quartz-latite, containing phenocrysts of oligoclase and orthoclase is also frequently observed. In the upper beds of the series andesite fragments with conspicuous plagioclase and hornblende laths appear, indicating the initiation of the andesite eruptions which followed the laying down of the basal tuff. The groundmass of the tuff is very fine grained, and not all its minerals are recognizable. Green chlorite and calcite were identified, and it is conjectured that the rest of the material in the massive beds is of a quartzo-feldspathic nature.

OREJON ANDESITE

Field Relations.—This division is named from the Orejon mine, in which the andesite occurs as the hanging wall of the main fault. It is exposed in a downfaulted segment along the foot of the high peaks of the range, east of the Hayner mine. It is observed to rest on the basal tuff south of the Hayner cabin, near the Modoc mine and in Target Range Canyon. Fillmore Canyon is cut through rocks of this series, and on Organ Peak there is a continuation of the Fillmore outcrops. The andesite appears in Soledad Canyon and continues south to Target Range Canyon. The weathered surfaces are generally brown and are readily distinguishable from those of the Soledad series, which have a purple tint. The series is approximately 600 feet thick and is made up of comparatively thin flows, probably not individually exceeding 75 feet in thickness. The texture and amount of dark minerals varies from flow to flow. The isolated outcrop of andesites on Hardscrabble Hill, north of Organ, has been tentatively correlated with the Orejon group.

Petrography.—Unweathered specimens of this rock may be brown or gray, or may have a greenish tint, due to the presence of epidote. They are, for lavas, coarsely crystalline, and feldspar and hornblende crystals may reach lengths of 3 mm. A marked fluxion texture is frequently exhibited, the long axes of the crystals being roughly parallel to the bedding of the lavas. The rocks exhibit a porphyritic texture, but the phenocrysts, of plagioclase and hornblende, generally exceed the groundmass in volume. All the specimens from this group examined microscopically showed evidence of considerable alteration, and the determination of the minerals was thereby rendered difficult. The feldspars, determined by the extinction method, proved to be low-lime andesine, approximately $Ab_{70}An_{30}$, where determination was possible. Zoning is shown in some of the larger phenocrysts. Hornblende was found in all specimens examined, generally in six-sided idiomorphic crystals. Frequently reaction rims of an opaque mineral surround the hornblendes. The groundmass is composed of a second generation of plagioclase, in small laths, and a variable amount of cryptocrystalline material. There was a suspicion that some of the cryptocrystalline material might contain orthoclase and quartz, in which case the rock would show a transition in the direction of latite. In one specimen from Hardscrabble, glomeroporphyritic aggregates of orthoclase were discovered, and this rock must, therefore, be classed as a latite. In the absence of satisfactory evidence, the rest of the series is regarded as andesitic. Accessory minerals are not abundant, but apatite and magnetite were noted in some sections.

Two types of alteration occur. In a specimen of gray andesite from the Modoc mill-site, it was found that the hornblende had been wholly converted to talc and calcite, the only thing remaining from the primary mineral being the outline, which had been preserved by the dark reaction rim. The feldspar in this rock is kaolinized, but enough remained to make a satisfactory determination possible. This represents one type of alteration, the cause of which is not understood. The other type, held to be due to the action of fluids from the Tertiary batholith, consists in the conversion of the feldspars to green epidote, the alteration of hornblende to chlorite and the introduction of abundant quartz in replacement veinlets. It is especially important near the contacts between the batholith and the andesite, and in the region traversed by the Torpedo-Bennett fault-zone.

CUEVA RHYOLITE

Field Relations.—The type locality for this formation is La Cueva, west of the mouth of Fillmore Canyon. Here an upturned bed of rhyolite tuff has weathered into a series of fantastic monoliths, at the foot of one of which there occurs a cave. The Cueva series overlies the Orejon andesite and outcrops in Fillmore, Soledad and Target Range canyons. Its thickness varies from

120 feet at La Cueva to over 250 feet in its conspicuous outcrop at Pinto Blanco. West of Devil's Canyon mine the shape of the outcrops closely resembles those at La Cueva. The section exposed at the type locality shows the lowest members of the series to consist of tuffs intercalated with mud flows. These are succeeded by a flow of pure white rhyolite approximately 50 feet thick which shows well marked banding and has been quarried in a small way for use as a building stone. The uppermost beds are rhyolite tuffs, containing fragments of rhyolite. At Pinto Blanco, the fragments are mostly andesite, closely resembling the Orejon andesite. At this outcrop the whole thickness is apparently made up of tuffs, and the bedding is well developed. A photograph of Pinto Blanco has been published by Keyes,[3] who wrongly regards the rock as Carboniferous limestone. The Cueva series represents a reversion to explosive conditions after the quiet outpouring of the Orejon lavas.

Petrography.—The massive white rhyolite from La Cueva consists of a cryptocrystalline aggregate, probably of quartz and orthoclase, with bands of pale brown glass. There are large patches of calcite, and white mica is abundantly present, sometimes among the cryptocrystalline material, sometimes concentrated in streaks. A few ghost-like crystals having the shape of orthoclase but consisting now of quartz may have been intratelluric phenocrysts. A few small spherulites occur. In the vicinity of Soledad Canyon the character of the rhyolite changes somewhat and here spherulites, often flattened, up to 10 mm. in diameter are conspicuous features. These are white and appear to consist of quartz and feldspar in radial growth; the refractive index of material from them lies between 1.520 and 1.550. The groundmass has a purple tint and shows marked flow banding; it is still partly vitreous.

SOLEDAD RHYOLITE

Field Relations.—A remarkable mass of rhyolite makes the thickest unit in the lava series. It is exposed in a spectacular way in the cliffs at Dripping Springs and in the mountains adjacent to Soledad Canyon, its type locality. It covers by far the greater part of the lava field and occupies a surface area of approximately 35 square miles. The unusual features of the series are its uniformity and its lack of flow partings. An examination of the great thickness exposed at Dripping Springs failed to reveal any breaks by which separate flows might be distinguished ; similarly, no partings were found in the Soledad Canyon region. On the other hand, at the southern and western margins of the mass the presence of a series of flows is suggested

[3] Keyes, C. R., Geology and underground water conditions of the Jornada del Muerto: U. S. Geol. Surv. Water Supply Paper No. 123, 1905, opposite p. 14.

by differential weathering, for some parts of the series here tend to form steep cliffs with sub-columnar jointing, while others produce slopes. This effect can be seen in the conical hill south of La Cueva. There does not appear to be a difference in mineral composition between the harder and softer beds. The total thickness of the Soledad formation must exceed 2500 feet. It occupies a structural basin of which only the eastern half remains; the rest appears to have been downfaulted and covered with alluvium. The underlying Cueva beds, in which the stratification is evident, dip towards a center which lies approximately under the northwest limb of Soledad canyon. The interpretation of the mode of extravasation of this great body of rock presents some difficulties. At first sight one is tempted to conclude from its uniformity that it is an intrusive body, but the texture of the rock and its field relations are very much against this simple interpretation. It seems almost inconceivable that this should represent a single lava flow, as it appears to do in its greatest outcrops. Such a flow would be without parallel in regions of active volcanism. There are, however, a number of cases in regions of former extrusive activity which present similar features. In the San Juan region of Colorado, Professor Larsen[4] has observed near Alboroto a quartz latite flow over 2000 feet thick, and several rhyolite flows which locally have comparable thicknesses. The Greenstone cliff flow, in the Michigan copper region, reaches 1300 feet in thickness.[5] The rhyolite exposed in the Grand Canyon of the Yellowstone is at least 2000 feet thick and shows no break.[6] Daly and Molengraaf[7] and Hall[8] consider that at least a part of the great series of igneous rocks in the Bushveld complex were accumulated subaerially, with basining of the foundation rocks taking place concurrently. As mentioned above, there is evidence of basining in the present region, and the conclusion that this occurred concomitantly with the extrusive process is perhaps warranted.

It is suggested that eruption was a continuous operation, and that it took place at a uniform rate, under uniform cooling conditions, and that the magma did not change in composition during the process. This argues an easy connection with the magma reservoir, and, while no evidence can be found to support the hypothesis of areal eruption due to deroofing of a subjacent body, it may be concluded that closely allied conditions obtained. It should be added that the Soledad lava cannot be

[4] Personal communication.

[5] Butler, B. S., Burbank, W. S. et al., The copper deposits of Michigan: U. S. Geol. Surv. Prof. Paper 144. 1929, p. 22.

[6] Daly, R. A., Igneous rocks and the depths of the earth: New York, 1934, p. 143.

[7] Daly, R. A., and Molengraaff, G. A. F. Structural features of the Bushvelt complex, Transvaal: Jour. Geol., Vol. 32, 1934, pp. 1-35.

[8] Hall, A. L., The Bushveld igneous complex: Geol. Surv. S. A., kern. 28, 1932, p. 459.

regarded as a surface manifestation of the Tertiary batholith exposed in the Organ Mountains, since it differs both in composition and in age from the rocks of the intrusive body. The vent from which the lava issued has not been discovered, and it is likely that it is buried beneath the lavas in the central part of the basin if the hypothesis outlined above is correct.

Petrography.—Fresh surfaces of the rock are gray or purplish-gray ; weathering imparts a purple tint. The structure is porphyritic, the phenocrysts being cream-colored feldspars up to 3 mm. in length. The phenocrysts do not exhibit parallel orientation. Two units can be recognized in the groundmass; the greater part is aphanitic but there are irregularly scattered patches of coarser texture, in which tiny grains may be visible to the unaided eye. In thin section the three components, phenocrysts, fine groundmass and coarse segregations are clearly revealed. The phenocrysts consist of an alkali feldspar which presents some interesting features. Its faces are sharp and have not been corroded. Careful examination shows that it is an antiperthite. The host shows twinning of two types, Carlsbad and microcline, and has a mean refractive index of 1.533.[9] The optic axial angle (presumably due to a mass polarization effect) is deduced from the shape of the isogyres to be about 45° ; the mineral is optically negative. In the present confused state of knowledge regarding the potash-soda feldspars, it is not easy to know how to interpret these data. The index is too high for anorthoclase or analbite, according to Winchell; [10] but would fall within the anorthoclase range according to Chudoba.[11] It is too low for albite, and the twinning is not that ordinarily found in plagioclase feldspars. It seems likely that the mineral is a potash-albite or anorthoclase, but it is impossible to deduce its composition with any degree of certainty. Occurring as irregular patches in this host there is another feldspar, also showing microcline twinning, though on a much finer scale. Becke tests on thin section show that this has a lower refractive index than the potash-albite, and determinations by the immersion method gave a mean index of 1.526, indicating a microcline or soda-microcline. The phenocrysts are believed to have crystallized as a homogeneous feldspar in which potash was subordinate to soda, and to have undergone unmixing when the temperature fell below the stability range of the solid solution.

The groundmass is rather coarser than is usual in rhyolites. Seen beneath high power, it has a spongy texture, and probably consists of quartz, alkali feldspars and occasional flakes of bio-

9 Refractive index measurements are subject to an error of $\pm$.002.

10 Winchell, A. N., Elements of optical mineralogy : vol. 2, New York, 1933, p. 357.

11 Chudoba, K., trans. Kennedy, W. Q., The determination of the feldspars in thin section : London, 1933, p. 10.

tite. The feldspar has a refractive index very close to that of the potash-albite, but microcline twinning is only rarely seen. In some examples exsolved patches, too small for determination, were noted. The feldspars were somewhat kaolinized in all specimens examined.

Chemical Composition.—A new analysis of the Soledad rhyolite by F. A. Gonyer is given below. The analyzed specimen was collected three-quarters of a mile east-north-east of the divide in Soledad Canyon; it is a representative sample and contains anti-perthite phenocrysts in a groundmass of cryptocrystalline quartz and alkali feldspar, with occasional coarse patches.

Analyses of Rhyolites

	I Soledad Rhyolite Soledad Canyon	II Average of 102 Rhyolites (Daly)
SiO_2	73.30	72.77
TiO_2	0.28	0.29
Al_2O_3	12.82	13.33
Fe_2O_3	1.42	1.40
FeO	1.94	1.02
MnO	0.00	0.07
MgO	0.22	0.38
CaO	0.16	1.38
Na_2O	4.24	3.34
K_2O	5.26	4.58
H_2O-	0.00	
H_2O+	0.24	1.50
CO_2	0.00	
P_2O_5	0.00	
S	0.09	
BaO	0.02	
	99.99	

Norm of Soledad Rhyolite

qu		27.36
or		31.14
ab		35.63
an		0.28
di	$CaO.SiO_2$	0.23
	$MgO.SiO_2$	0.07
	$FeO.SiO_2$	0.18
hy	$MgO.SiO_2$	0.43
	$FeO.SiO_2$	1.48
il		0.61
mag		2.09
		99.50

For comparison, the average composition of 102 rhyolites, calculated by Daly[12] is given in column II. The Soledad rock is richer than the normal rhyolite in both soda and potash; however, potash still predominates over soda. It appears from this that

[12] Daly, R. A., Igneous rocks and the depths of the earth: New York, 1933, p. 9.

the feldspar of the groundmass must be orthoclase ; if it were a mixture of orthoclase and albite, the soda would almost certainly predominate over the potash, since the soda molecule is more important than the potash in the phenocrysts and coarse segregations. The normative albite is slightly in excess of the normative orthoclase. Comparison also shows that the iron content is much higher than in the average rhyolite, while the lime content is lower.

THE TERTIARY INTRUSIVE CYCLE

INTRODUCTION

The central and most rugged part of the Organ Mountains is composed of crystalline plutonic rocks forming a complex which has excited the interest of geologists from the earliest days of investigation in the region. Antisell[1] believed that the mountains had a core of ancient syenite, but observed that this was cut by trap dikes and porphyritic feldspar rock. Shumard[2] noticed the metamorphism of the Carboniferous limestones against the granitic rock. Keyes[3] aexpressed the opinion that the crystalline rocks were of pre-Cambrian age, and considered that they had been "thrust upwards much more than any other part of the (Jornada) plain's periphery . . ." Lindgren[4] demonstrated definitely the post-Carboniferous age of the major part of the crystalline rocks of the range, and Darton[5] in his reconnaissance map of the San Andres Mountains was able to discriminate between pre-Cambrian and Tertiary intrusive rocks. The purpose of the present section of the work is to discuss the details and significance of the various igneous and metamorphic rocks and mineral deposits of Tertiary age. It will be shown that all of these can be explained as consequences of a single cycle of igneous activity, commencing with a three-fold rise of magma from some cauldron deep in the earth's interior, continuing with local differentiation by residual concentration and ending with the emplacement of the hypogene ore deposits of the region. The structural adjustments of the country rock and newly consolidated igneous rocks will be considered, as well as the metamorphic changes brought about in the rocks surrounding the batholith.

Tertiary intrusive rocks crop out over an area of 41 square miles, and an extrapolation of their eastern contact across

[1]Antisell, T., Geological Report: U. S. Pacific railroad exploration, vol. 7, Part 2, 1856, p. 162.

[2] Shumard, G. G., Structure of the Jornada del Muerto: Trans. St. Louis Acad. Sci., 1, 1858, p. 341.

[3]Keyes. C. R. Geology and underground water conditions of the Jornada del Muerto: U. S. Geol. Surv. Water supply paper 123, 1905, p. 18.

[4] Lindgren, W., and Graton, L. C., A Reconnaissance of the mineral deposits of New Mexico: U. S. Geol. Surv. Bull. 285, 1906, P. 83.

[5]Darton, N. IL, "Red Beds" and associated formations in New Mexico: U. S. Geol. Surv. Bull. 795, 1928.

the alluvium-covered rincon east of San Agustin Pass would bring the total area up to 55 square miles ; the body therefore belongs in size to the group of batholiths in the strict sense as defined by Daly,[6] and is a small example of the type. The northern contact is exposed two miles north of Organ. On the east the margin is exposed as far south as Fillmore Canyon, where it turns southeast and crosses the high eastern spur of the range east of Organ Peak. It appears in Soledad Canyon. The southern contact forms the precipitous head of Target Range Canyon.

AGE AND STRUCTURE OF THE BATHOLITH

Attention may first be turned to the relation between the major intrusives and the country rock, since it is upon this relation that the identification of the batholith as such depends. The eastern contact between sediments and intrusives yields no information of value in connection with the question of the form of the body, since it is a complex faulted boundary. At the northern end, between the Excelsior and Silver Coinage mines, there is no reason to suspect any faulting along the contact except for a short distance near the Goat Ranch ; and in this region the contact is beautifully exposed. It pursues a sinuous course, cutting across in turn all the formations from the Magdalena series to the pre-Cambrian basement. On a hill west of the Goat Ranch igneous rock is frozen to the Percha shale, and here the contact can be seen dipping steeply to the north. Shafts and excavations reveal a similar dip near the Big Three mine, and in the gulch which runs southeast from the Goat Ranch. High up on the hill above the Silver Coinage mine the contact cuts across the basal beds of the El Paso dolomite and the Bliss sandstone. Similarly at the south end of the mountains, the contact transgresses successively the pre-Cambrian, the dolomites, the Percha shale, the Magdalena series and the basal tuff of the lava series. It does not, however, cut across the Orejon andesite. Between Target Range Canyon and the Modoc mine the contact is uniformly near the base of the andesites. It was thought at first that these flows might be later than the intrusive rocks, and that they might have accumulated on or against an eroded surface of the batholith, but this proved not to be the case, for blocks of andesite were found as xenoliths in the quartz-monzonite in Fillmore Canyon (Figure 3, page 62), and minor apophyses penetrate the andesite. The Orejon series thus forms a roof for the intrusive body, comparable with the roof of a laccolith. We have then crosscutting relations, typical of a subjacent body, up to the andesite horizon ; and a laccolith roof above this. Lindgren has cautiously described the body as a "laccolithic stock." [7] But as

[6] Daly, R. A., Igneous rocks and the depths of the earth : New York, 1933, p. 113.
[7] Lindgren, W., op. cit., 1906, p. 82.

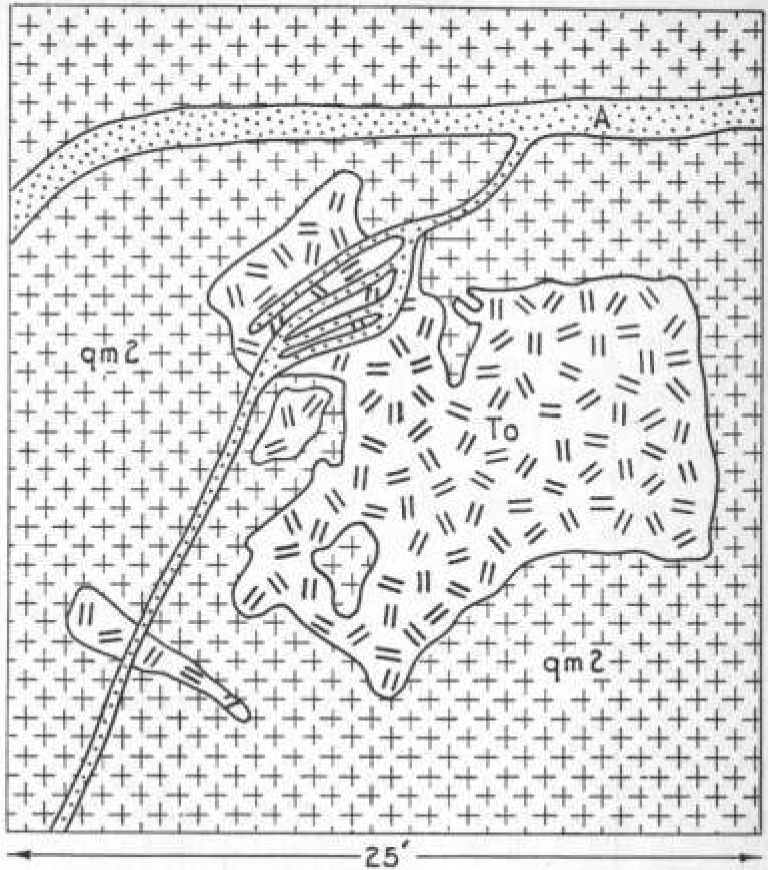


FIGURE 3.—Sketch of cliff face on north side of Fillmore Canyon, showing andesite block enclosed by quartz monzonite.
To, andesite; qm2, quartz monzonite; A, aplite.

there is no evidence whatever that this is a floored body it must be described as a batholith.

It is believed that "piecemeal stoping"e is the only hypothesis capable of explaining adequately the batholithic relations of the body. It is clear that a large volume of country rock has disappeared. There is no evidence of direct assimilation of this rock ; indeed all the evidence is against such an interpretation. Moreover, there is proof that stoping did occur, in the form of large xenoliths of pre-Cambrian granite and epidiorite, Paleozoic limestone, sandstone, dolomite and shale, and Tertiary lava and tuff. The finest examples are found in the vicinity of South Can-

cf. Daly, R. A., op. cit., 1933, p. 268 et seq.

yon (see map on page 66), and others occur in Fillmore Canyon (lava and tuff xenoliths), Soledad Canyon (granite and limestone), south of the Cox ranch (limestone), and both northeast and southeast of the Stevenson-Bennett mine (limestone). The xenoliths usually have a steep dip when bedding can be distinguished, and where several occur together the dips are usually widely divergent. The size of the included blocks varies from a few feet in length to over 2000 feet. The total volume of such xenoliths is, of course, small as compared with the total volume of country rock displaced, but this fact does not alter their significance.

More widely distributed than the accidental inclusions through the mass of the second and third major intrusive phases of the batholith are rounded igneous xenoliths. Evidence will be presented in the succeeding pages to show that these were derived from the rock of the first phase of the intrusive cycle when that rock was itself stoped by the magmas of the second and third phases; these inclusions are, therefore, cognate xenoliths since they are composed of material directly related to the same magma cycle as their host rock. They do not attain large dimensions. Their average diameter is between 6 inches and 1 foot; rarely do they exceed 2 feet in diameter. They appear to have undergone modification, in varying degree, by reaction with the later magmas. The widespread occurrence of the cognate as compared with the accidental xenoliths presents an interesting problem to which only a partial solution can be given. Frequently the cognate xenoliths are found at higher levels than accidental xenoliths of lower specific gravity, which must have sunk a considerable distance. For example, in the South Canyon area cognate xenoliths occur widely throughout the whole section of intrusive rocks exposed; whereas the sedimentary inclusions are found only low down in the section, near the level of the plain. To find some explanation we must appeal to the difference in size between the two types. Daly[9] has pointed out that the rate of sinking of solid blocks in the magma is dependent upon their size. According to the Stokes equation the velocity of a small sphere sinking through a liquid varies as the square of its radius; while for a large sphere Allen has shown that the rate of sinking is proportional to the square root of its radius. Whichever equation applies, it is evident that large xenoliths will sink more rapidly than small ones. Now field observations show that the accidental xenoliths, wherever they are seen, are many times larger than the largest of the cognate xenoliths. If we assume, then, that the country rock broke up into large blocks when it foundered into the batholith, we can account for the clearing of

[9] Daly, R. A., op. cit., 1933, p. 278.

the upper part of the batholith, now exposed to view, of most of the sedimentary xenoliths while leaving most of the cognate xenoliths in suspension. The most unsatisfactory part of this explanation lies in the difficulty of determining why the first phase of the intrusive cycle should have been shattered into such small fragments, while the country rock was removed in large blocks without the production of any small fragments. Perhaps the first phase was invaded before it completely consolidated. The rounding of the xenoliths believed to have been derived from this phase, in striking contrast with the angularity of the included country rock, and the evidence that they have been modified in composition suggest that reaction has tended to reduce their size.

Measurements of the specific gravities of representative specimens of the country rock were made with a view to comparing them among themselves, and also comparing them with specific gravities of the igneous rocks. The table on this page summarizes the results, which were obtained by the use of a hydrostatic balance. Attention may be directed to several interesting features of these results. According to Stokes' and Allen's equations, the rate of sinking is directly proportional to the difference in density between the sinking blocks and the liquid.

Specific Gravities of Invaded and Intrusive Rocks at Ordinary Temperature

NO.	NAME AND LOCALITY	SPECIFIC GRAVITY
1119	Orejon andesite, east of Hayner Mine (partly epidotized)	2.70
1269	Garnetized limestone, South Canyon	3.10
1289	Magdalena limestone, Hilltop trail	2.77
1267	Brucite marble, South Canyon	2.56
1272	Brucite marble, Target Range Canyon	2.55
1285	Fusselman dolomite, Black Prince Canyon	2.80
1030	Garnetized El Paso limestone, above Silver Coinage mine	3.42
1282	Metamorphosed quartzite with lazulite, Rucca Canyon	2.77
1259	Epidiorite, South Canyon	2.92
1281	Pre-Cambrian granite, near Eureka mine	2.63
1192	Mica schist, southeast ridge of Organ Mountains	2.72
	INTRUSIVE ROCKS	
1206	Phase I, monzonite, Texas Canyon	2.76
1002	Dark cognate xenolith, Quickstrike mine	2.75
1278	Phase II, quartz-monzonite, East of Hayner mine	2.59
1001	Phase III, coarse quartz-bearing monzonite, Quickstrike mine	2.67
	COMPARATIVE DATA [18]	
	Quartz diorte, syenite; crystalline rock at 20°	2.70
	Equivalent glass at 1100°	2.40
	Granite, crystalline rock at 20°	2.60
	Equivalent glass at 1100°	2.26
	Granite, crystalline rock at 1100°	2.48

[18] Daly, R. A., Igneous rocks and the depths of the earth: New York, 1934, p. 276; based on experimental data by Douglas, and Day, Sosman and Hostetter.

There is very little difference between the results for many of the country rocks and those for the intrusive rocks; it is not, however, with this relation that we are concerned, but with the density difference between the country rocks and the liquid magma at the temperature of intrusion of the magma. Some idea of the density difference between the solid intrusive rock and its liquid phase may be obtained by comparison with the data quoted from Daly. These show that rock in the glassy condition, corresponding to the liquid phase, has a considerably lower density than crystalline rock at the same temperature. There being no evidence of fusion of the xenoliths, it is clear that all of these would have an appreciably higher density than the magma, and would therefore tend to sink if the viscosity of the magma were such as to permit this. The field evidence indicates clearly that the viscosity was such that blocks could sink. The effect of metamorphism on the country rock seems to explain the relative quantities of the various rocks now seen as accidental xenoliths. Limestone is greatly increased in density when it is converted into lime-silicate rock, and metamorphosed limestone would sink more rapidly than any other inclusion. The density of dolomite, on the other hand, is lowered when it is converted into brucite marble, its usual metamorphic product. If periclase, the first product of metamorphism of the dolomite, had already been hydrated to brucite before the dolomite blocks began to sink, this would explain why metamorphosed dolomite predominates in amount over metamorphosed limestone among the xenoliths, while dolomite occupies only a subordinate place in the stratigraphic column. It is by no means certain, however, that hydration took place at such an early stage. The limestones, although occupying a higher position in the column, appear to have sunk more rapidly than the dolomites. The amount of pre-Cambrian granite also exceeds that of the limestones among the xenoliths ; this may also be explained by appeal to the difference in specific gravity between metamorphosed limestone and granite.

It seems quite clear that the accidental xenoliths have sunk a considerable distance. In the South Canyon area, the rock immediately in contact with the batholith is the pre-Cambrian granite. It follows that the limestone and shale xenoliths, which may be correlated with reasonable certainty with the Magdalena series, have sunk not less than 1400 feet, and probably much more. There is no reason to suppose that the xenoliths in this region are resting upon a floor, for the intrusive contact, exposed in the ridge south of the one in which the xenoliths are exposed, is almost vertical. What then caused the xenoliths to come to rest? A careful examination of the enclosing intrusive rock failed to show any fluxion texture such as would have been produced had the xenoliths moved appreciably after crystallization began. The facts appear to indicate that the magma became

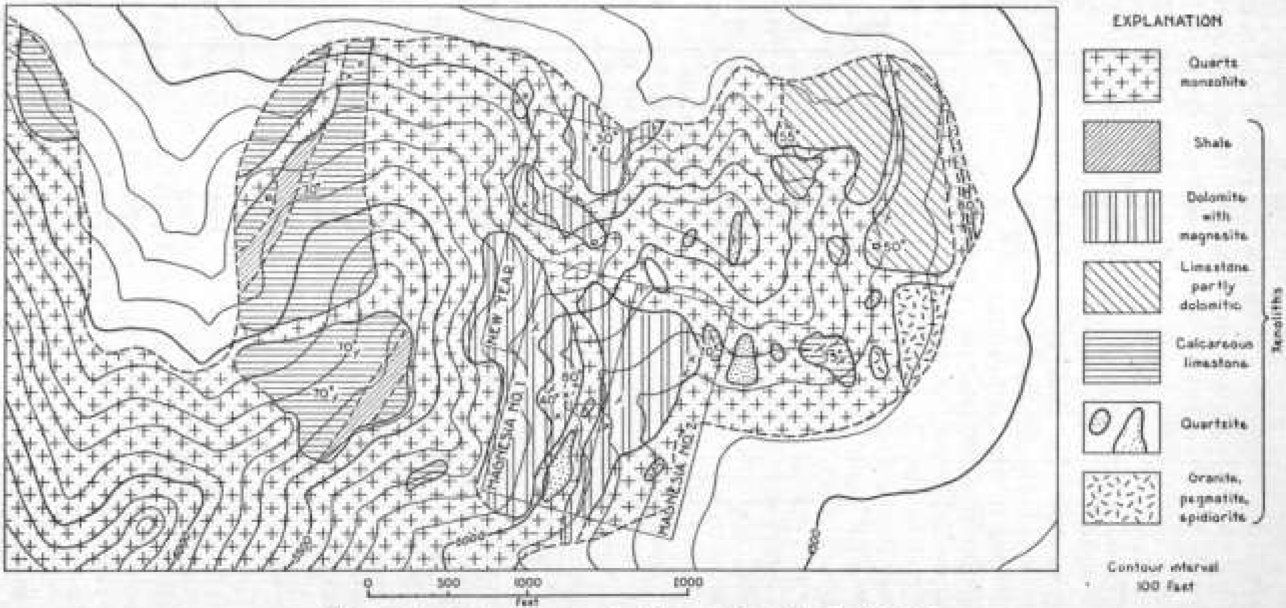


FIGURE 4.—Geologic map of ridge south of South Canyon.

extremely viscous before crystallization started, and may be taken to support the idea that the magma passed through a "durovitreous" stage before crystallizing.[11] This may have been due to undercooling; yet it would be remarkable if crystallization were deferred long after the magma became supersaturated when the melt was so abundantly inoculated with foreign material. The problem of the cessation of sinking of xenoliths in a magma is an interesting one, and one to which little or no attention has yet been given. There is a great need for experimental data upon the viscosity of silicate melts, especially those under conditions of supercooling.

In places a frozen record of the early stages of the stoping process can be seen. The best example is to be found on the hill above the Silver Coinage mine, and this is discussed below. Near the Devil's Canyon mine a block of dolomite is surrounded on three sides by the igneous rock, two sides being against dikes and the third against the main contact. On the ridge north of the Rakestraw camp the old granite is shattered and penetrated by stringers of quartz-monzonite. Careful examination of the xenoliths near South Canyon and elsewhere reveals the intimate manner in which they have been penetrated by the magma along fractures. It is suggested then that stoping took place up to the base of the Orejon andesite ; and the writer believes that this limit was set to the process by the state of jointing of the invaded rocks. The granite would undoubtedly be jointed during its own cooling process. All the sediments are well bedded and jointed rocks, and the fractures probably date from an early stage in the tectonic history of the area, as in other regions. The basal tuff is a soft, incompetent bed. The Orejon series forms a striking contrast. Even today it is a massive series with only a few unimportant joint-planes. While the basement rocks and the sediments would break off readily and sink into the advancing magma, the Orejon formation would tend to maintain its unity, and suffer distortion rather than disruption. That the process here outlined actually can take place is proved by some very instructive outcrops on the hill north of the Silver Coinage mine. Here the pre-Cambrian granite is overlain by the Bliss sandstone. The granite is cut by innumerable ramifying dikes and veins of quartz-monzonite, and the process of stoping has been caught in progress by the freezing of the magma. This state of affairs continues up to the base of the sandstone. The Bliss series, a relatively competent horizon as compared with the much-jointed granite, is cut by only three small dikes of monzonite ; it has preserved its unity. 11

Jeffreys, H., The earth: Cambridge, 1929, pp. 183, 184.

The abundance of large xenoliths shows that the country rock sank into the magma, and was not displaced by "upward punching." Nevertheless, the magma is believed to have been under great pressure, for it was able to distort greatly the surrounding rocks. The dip of the Orejon andesite is away from the batholith ; it exceeds 50° and swings round with the contact. At the northern end the dip of the sediments changes from the normal westward inclination found all through the San Andres Mountains, to a northerly direction, again away from the batholith, and increases from 25° to 45° or more near the intrusive contact. There are local complexities which indicate great magmatic pressure. The plunging anticline on the flanks of which lie the Little Buck and Rickardite mines may have been due to this pressure. North of the Goat Ranch the Percha shale has been intimately penetrated parallel to its bedding by offshoots from the major intrusive. The limestones and dolomites have been powerfully distorted in the same region. There is no reason to suppose that great magmatic pressure is inconsistent with the concept of stoping. A liquid may transfer the pressure on it to the walls of its container and solids of greater density than the liquid will still sink through it.

The age of the batholith is indicated by the evidence discussed above. It is definitely later than the Orejon andesite, and probably later than the rest of the lava series, since the Torpedo-Bennett fault zone, along which movement was initiated immediately after the consolidation of the last phase of the intrusive magma, cuts the Soledad rhyolite between Fillmore Canyon and Dripping Springs (see page 127) . The Silver Cliff prospect has explored the fault where both walls are rhyolite and has exposed a mineral deposit believed to have been derived from the quartz-monzonite during the last stages of crystallization of the batholith. If the lavas are regarded as Tertiary, the intrusive cycle must also be Tertiary. Proof of its exact age is wantting, but it should probably be classed with the late Cretaceous-early Tertiary period of intrusive activity. It was completed before the initiation of the Santa Fe cycle of erosion in Miocene time.

MAJOR INTRUSIVES

I. MONZONITE

Field Relations.—The batholith is of the composite class since it contains three distinct bodies of contrasted rock types, separated by intrusive contacts. Phase I, with which this section is concerned, is a monzonite rich in dark minerals. It covers a small elliptical area at the head of Texas Canyon in secs. 34 and 35, T. 22 S., R. 4 E. Its outcrop is surrounded on all sides by that of the quartz-monzonite of phase II, and the relations between the two phases are quite readily determined, for the contacts are well exposed. The quartz-monzonite intrudes the monzonite and sends small dikes with regular borders into it ; some of these can be seen on the north side of the ridge at the head of Texas Canyon. Phase III, a quartz-bearing monzonite, is not seen in juxtaposition with phase I.

Petrography.—The rock of phase I is dark in color due to the presence of abundant ferromagnesian minerals. The grain is medium and is fairly constant, the average size of feldspar grains being approximately 8 mm. Microscopic investigation shows that the rock is holocrystalline granular, with a monzonitic texture ; that is to say the plagioclase is idiomorphic and is surrounded by alkali feldspar which occupies the interstitial spaces.[1] The plagioclase has a mean refractive index of 1.540; 2E is near 90°, and maximum extinctions in the symmetrical zone are at 6° with the trace of the albite composition plane. The data indicate an oligoclase, $Ab_{85}An_{15}$. Twinning according to the albite and Carlsbad laws is universally shown in the oligoclase, and occasionally pericline twins are seen. Some crystals are conspicuously zoned, and in these the outer zones give higher extinction angles and are therefore considered to be more sodic than the inner core. The albite-law twin lamellae may or may not continue into the outer zones. The plagioclase crystals are frequently mantled with orthoclase-perthite, and when this is the case the break between the outermost zone of the plagioclase and the perthite is sharp and is readily distinguished on account of the difference in refractive index. The perthite consists of a host of orthoclase containing irregular patches of albite which tend to run diagonally across the crystals, without being in any definite crystallographic orientation, as shown in Plate V, E. Occasionally the twinning of the albite can be seen, but even without this it is easy to distinguish it from the orthoclase because of its higher birefringence and higher refractive index. The ferromagnesian minerals include enstatite, augite, hornblende, and biotite. The optical properties of the enstatite are as follows : β, 1.665 ; 2E, 75° ; optically positive ; extinction Z ∧ c, 0° ; colorless. According to Winchell's data,' this indicates a member of the enstatite-hypersthene series with 90 per cent $MgSiO_3$, and 10 per cent $FeSiO_3$. A variable amount of colorless monoclinic pyroxene is associated; in this Z A c is 43° and the mineral is an augite. The hornblende is green and strongly pleochroic, Z>Y> X. Chestnut-brown biotite occurs in large plates. The amount of quartz is insignificant, so that the rock is a saturated type. Accessory minerals are magnetite, titanite, apatite, and zircon.

[1] Holmes. A., Nomenclature of petrology : 2nd edition, London, 1928, p. 162.
[2] Winchell, A. N., op. cit., p. 218.

The textural relation of the minerals is such that their order of crystallization can be determined with reasonable certainty. Magnetite, apatite and zircon appear to have separated first, and may have acted as nuclei for the crystallization of the enstatite which followed, for the coincidence of the rhombic pyroxene with early accessory minerals is very striking. The relation between the monoclinic and rhombic pyroxenes is not clear, but both are certainly older than the hornblende which has arisen as a replacement of these minerals, no doubt due to reactions between the magma and the pyroxene crystals. The hornblende is enclosed by and partly converted to biotite. Probably separation of plagioclase commenced while the biotite was being formed, for rounded inclusions of oligoclase are found poikilitically arranged in the biotite. In general, however, the oligoclase grew independently of the ferromagnesian minerals, and seldom contains inclusions. The crystallization of the oligoclase having been completed, perthite began to be deposited, probably as a homogeneous alkali feldspar which later unmixed into its two components. In a few instances, the albite lamellae of the oligoclase seem to have been distorted by the growing alkali feldspar crystals. Quartz occupies interstitial spaces and is found also in myrmekitic intergrowths round the margins of some of the alkali feldspars. The observed order of crystallization corresponds closely with the general order deduced by Rosenbusch,[3] and may readily be explained in terms of a series of discontinuous and continuous reactions between magma and crystals, as suggested by Bowen.[4]

The rock is remarkably fresh, and in specimens taken below the thin crust of weathered rock the only alteration is a slight turbidity of the orthoclase, probably due to kaolinization. The plagioclase is much less susceptible to weathering, and is almost free from kaolin. The ferromagnesian minerals are all fresh.

Chemical Composition.—A new analysis of the dark monzonite is given on page 83 with the norm of the rock. The chemical composition accords well with the classification of the rock as a monzonite.

II QUARTZ-MONZONITE

Field Relations.—Phase II, consisting of medium-grained quartz-monzonite, occupies much the greater part of the batholith. It outcrops continuously from the first peak south of San Agustin Pass to the head of Target Range Canyon and forms the bedrock of most of the high central part of the mountains, including the aiguilles. There are, in addition, a number of small areas at the extreme northern end of the batholith. Its relations with

[3] Rosenbusch, H., Elemente der Gesteinslehre : revised by A. Osann, Stuttgart, 1923, p. 68.

[4] Bowen, N. L., The reaction principle in petrogenesis : Jour. Geol., vol. 30, 1922, pp. 177-198.

the monzonite of Texas Canyon have already been described. It is separated from phase III, which occurs at the northern end of the intrusive body, by a contact which is well exposed on a hill south of San Agustin Pass. Several xenoliths of phase II are enclosed in phase III near this contact, so that it may be interpreted reasonably as an intrusive boundary. When followed west from this hill it becomes less distinct, partly owing to the hydrothermal alteration of phase III in this region. North of the Rakestraw Camp a small area of phase II rock lies between the outcrop of the pre-Cambrian granite and that of the monzonite of phase III, and there is a similar area west of the mouth of Black Prince Canyon. East of the Goat Ranch a body of quartz-monzonite has been injected into the dolomite, and this is sharply terminated against phase III, the shape of the contact suggesting that phase III is the later intrusion.

In the field the quartz-monzonite is readily distinguished from the monzonite and the quartz-bearing monzonite. Its most striking characteristic is the conspicuous zoning of the feldspars, which usually have pink or purple centers and cream-colored margins. The general color of the rock is buff except in the region south of Soledad Canyon, where it is definitely red. The zoned feldspars are idiomorphic and this property can invariably be recognized in the hand specimen. Due to the paucity of dark minerals, the color is much lighter than that of phase I ; while distinction from phase III is effected in the field by the difference in grain, phase III being much coarser, and by the different appearance of the feldspars.

Petrography.—The quartz-monzonite is a buff or reddish granular rock composed largely of feldspars averaging about 7 mm. in length. The plagioclase can be recognized readily in the hand specimen by its conspicuous zoning, which is especially well revealed on weathered surfaces where the inner zones tend to decompose more readily than the outer zones. Quartz, although an important constituent, can be seen with the unaided eye only very seldom. Biotite is occasionally present, and rarely there is a little hornblende. Locally, as on the east slope of the range 1 mile south of San Agustin Pass, the rock has a porphyritic appearance, with feldspar phenocrysts of normal size in a fine-grained groundmass. This variety seems to pass without break into the equigranular rock. Tiny miarolitic cavities are a widespread feature of this rock, imparting to it a rather porous appearance.

In thin section the minerals found are perthite, oligoclase, quartz, biotite and accessory minerals, in order of decreasing abundance. Hornblende is occasionally found. The properties of the oligoclase appear to be identical with those of the oligoclase in phase I. The mean refractive index is 1.540, indicating $Ab_{85}An_{15}$, and this determination is confirmed by the measurement of extinction angles. Albite and Carlsbad twinning are well developed. The well-twinned oligoclase crystals are mantled with what appears to be a second generation of plagioclase, developed in a totally different crystallographic orientation, but having similar refractive indices. Albite twinning is rarely seen in the second generation, and there are good grounds for the suspicion that it is often not twinned according to the albite law, far too many sections without twinning having been seen to give any force to the simple explanation that the sections were cut parallel to the albite composition plane. The refractive index of this material shows that it is plagioclase and not orthoclase. Zoning is often well developed in it. Perthite surrounds this second plagioclase. Like the alkali feldspar in phase I, it consists of a host of orthoclase with streaks of albite; however, in one specimen, taken south of the Cox ranch, microcline twinning was observed in the host. The mean refractive index of the orthoclase is 1.523; it is thus readily distinguishable in thin section from the plagioclase. Biotite occurs sparingly in all fourteen specimens of this rock examined in thin section. Hornblende was found in only four. Quartz is everywhere an abundant constituent. Accessory minerals include magnetite, titanite, apatite, zircon and fluorite, the last-named mineral probably being of hydrothermal origin.

Only two aspects of the textural relations of the minerals call for special comment. Reference has already been made to the sequence of feldspars, which may be summarized here as (1) twinned oligoclase, (2) untwinned but zoned oligoclase-albite, (3) perthite. The separation of quartz began during the crystallization of the alkali feldspar, which is coarsely intergrown with the quartz in a mariner which approaches the granophyric texture.

The effect of superficial alteration has been mentioned above. In addition to noting the differential weathering of the plagioclase, it should be added that the perthite is much more susceptible to decomposition by atmospheric agencies than any of the other feldspars. In every thin section examined, the perthite had a cloudy appearance, presumably due to kaolin, and the effect was very intense in some examples.

Chemical Composition.—A new analysis and norm of the quartz-monzonite is given on page 83. The rock is definitely a member of the oversaturated class ; indeed it is chemically as near to granite as to quartz-monzonite. It differs from both average granite and average quartz-monzonite[5] by containing

[5] Daly, R. A., op. cit., 1933, pp. 9-15.

more soda and potash and less lime. It shows, then, rather definite "alkaline" tendencies.

III. QUARTZ-BEARING MONZONITE

Field Relations.—The third phase of the series of major intrusives lies at the northern end of the batholith, and makes the bedrock of San Agustin Peak and the area surrounding this mountain. Its relations with the rocks of phase II have been described above. The rock is coarse grained and has a granitic aspect. Fresh surfaces are gray, but the rock weathers brown and in the process the large crystals of alkali feldspar which the rock contains are rendered conspicuous. Particular attention was given to the orientation of the large feldspars, but, except in a small area near the Silver Coinage mine, where the feldspars were found to be elongated parallel to the direction of the nearby contact, their direction appeared to be random. The zoned plagioclases do not show up on weathered surfaces of this rock as they do in the case of phase II.

Petrography.—The rock is coarse-grained and contains alkali feldspar crystals exceeding 20 mm. in length. The average grain is, however, distinctly finer and seems to be about 10 mm. In the hand specimen, feldspars, hornblende, biotite, and titanite can be recognized ; quartz, though present, is not at all conspicuous and a lens is usually needed to see it. In thin section the plagioclase proved to have properties identical with the oligoclase in the two preceding phases. The mean refractive index was found to be 1.542, and the extinction methods confirmed the determination of the plagioclase as $Ab_{85}An_{15}$. The crystals are, however, less obviously idiomorphic than those of phase II. Usually they show zoning, with an outward change to a less calcic composition. The alkali feldspar, which is again perthitic, predominates over the oligoclase and has crystallized later; the texture of the rock may, therefore, be classified as monzonitic. The perthite has an orthoclase host with mean refractive index 1.524, and irregular patches of albite. A little colorless augite is locally present, but it is never an important constituent. Green pleochroic hornblende and brown biotite are universally present. Quartz occurs in small but varying amounts. Among the accessory minerals titanite is very conspicuous; others include titaniferous magnetite, apatite and zircon.

The order of crystallization of the minerals resembles that shown by phase I. Apatite, magnetite and augite were the earliest minerals to separate of which there is any record; these were followed by hornblende and then biotite, each of these being a product of reaction between the magma and earlier crystals. Oligoclase followed the biotite or accompanied it, and was succeeded by perthite. From its interstitial position, titanite is believed to have been a late mineral. Quartz was the last mineral to crystallize; here it occupies interstitial spaces and is not coarsely intergrown with the perthite as in phase II; there are, however, myrmekitic margins containing quartz around some of the feldspars.

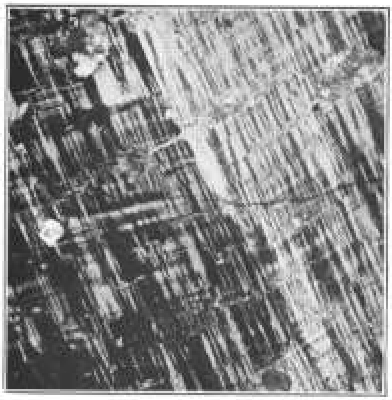
Chemical Composition.—On page 83, an analysis of the quartz-bearing monzonite is reproduced from Lindgren's account of the district.[6] The locality given by him, 500 feet south of the Merrimac mine, leaves no room for doubt that the material analyzed was from the third phase, and this is confirmed by the excellent petrographic description which accompanies the analysis. The analysis is described as representing a quartz syenite in Lindgren's account, but he classes the rock as quartz monzonite. A comparison with Daly's average monzonite, quartz monzonite and syenite[7] reveals that the rock occupies chemically a transitional position between syenite and monzonite. However, in view of the presence of a substantial amount of oligoclase and quartz, it cannot be classed with either of these; nor can it be termed a quartz monzonite, since there is much less Si00 than is normally found in quartz monzonites. It is, therefore, described as a quartz-bearing monzonite.

Distinction from the pre-Cambrian Granite.—The grain of

the Tertiary quartz-bearing monzonite closely resembles that of the pre-Cambrian granite, and on weathered surfaces these rocks look remarkably alike. One of the earliest problems of field mapping was the distinction of these rocks in the field. In view of the economic importance of distinguishing clearly between them, a tabular comparison of some of their megascopic characteristics is given below.

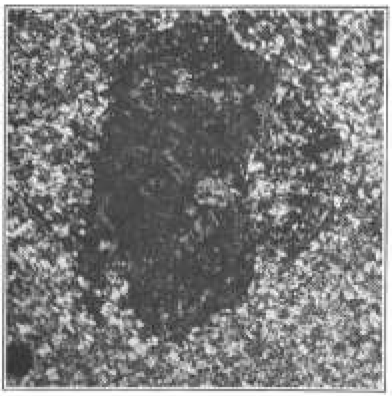
PRE-CAMBRIAN GRANITE COARSE TYPE	TERTIARY QUARTZ-BEARING MONZONITE
Abundant quartz, plainly visible to the unaided eye	Quartz not visible to the unaided eye
Very rare dark schistose xenoliths	Abundant dark rounded non-schistose xenoliths
Occasional gneissoid belts	No gneissoid belts
Numerous narrow pegmatites, containing quartz and feldspar in graphic intergrowth. No cavities or other evidence of metasomatism	Large irregular pegmatites, few in number. Contain a complex mineral assemblage showing evidence of important metasomatism
Cut by black epidiorite dikes	Not cut by epidiorite or any other type of basic dike.

[6] Lindgren, W., Graton, L. C., and Gordon, C. G., Ore deposits of New Mexico: U. S. Geol. Surv. Prof. Paper 68, 1910, p. 207.
[7] Daly, R. A., op. cit., 1933, pp. 11, 13, 15.

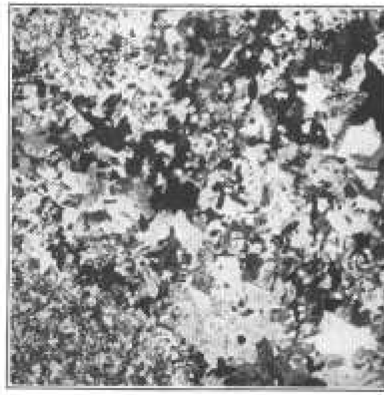


A

B

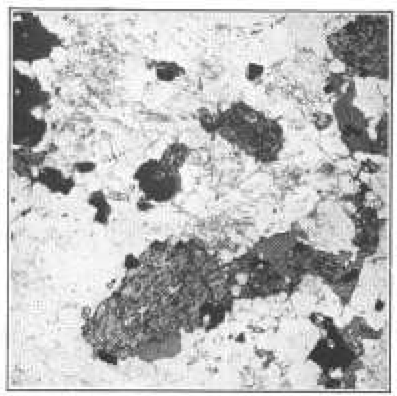


C



D

E



F

PHOTOMICROGRAPHS OF THIN SECTIONS
See opposite page for explanation.

EXPLANATION OF PHOTOMICROGRAPHS, PLATE V

A. Pre-Cambrian granite, coarse-grained type, near the Eureka prospect.
Microcline-perthite in which the albite segregations occur in streaks nearly at 90° to the Carlsbad composition plane.
Crossed nicols. X 20 (1287)

B. Pre-Cambrian epidiorite, dike southeast of the Black Prince mine.
Oligoclase crystals surrounded and corroded by actinolite and hornblende.
Ordinary light. X 25 (1093)

C. Soledad rhyolite, north of divide in Soledad Canyon.
Potash albite-antiperthite phenocryst in fine grained groundmass of quartz and alkali feldspar.
Crossed nicols. X 15 (1280)

D. Soledad rhyolite, north of divide in Soledad Canyon.
Coarse patch in the groundmass.
Crossed nicols. X 15 (1280)

E. Quartz monzonite, (phase II), lower part of Texas Canyon.
Oligoclase, possibly two generations, enveloped by orthoclase-perthite. Quartz, the last mineral to crystallize, appears on the left side of the field.
Crossed nicols. X 25 (1277)

F. Monzonite, (phase I), Texas Canyon.
Enstatite (showing cleavage) partly altered to hornblende and biotite, by reactions with magma. The light minerals are orthoclase and oligoclase-perthite.
Ordinary light. X 20 (1273)

HEAVY-MINERAL CONTENT OF IGNEOUS ROCKS

Attention may also be directed at this time to the heavy minerals, which furnish a comparison of another order between the two rocks. The table on page 77 sets forth the results of a study of the minerals having a specific gravity greater than 2.87 (that is, those capable of sinking in bromoform) in the pre-Cambrian and Tertiary intrusive rocks of the present area. Some light is thrown upon the minor constituents of the various magmas in this way. Zircon is a universal accessory constituent, and was found in every specimen studied; the zircons from the pre-Cambrian granite were, however, found to be larger and less regular in habit than those of the Tertiary monzonites, which occur in idiomorphic crystals in which the forms (110) and (111) are well developed. Apatite is also present in both Tertiary and pre-Cambrian rocks; in both a colorless variety is the only type found, and in both it occurs in needles and in short prismatic crystals. Brown tourmaline is found in the granites, but is absent from the monzonites, and yellow monazite, somewhat cloudy due to alteration, is also confined to the granites. A striking feature of the monzonite series is the presence of a notable amount of titanite, which occurs in brown idiomorphic and irregular crystals. This mineral was not found in the pre-Cambrian rocks. Other minor differences include the presence of topaz in the granite, while fluorite occurred in two specimens from the quartz-monzonite. Summarizing, it may be stated that the minor constituents represented among the accessory minerals of the granites include boron, rare-earths, zirconium, fluorine and titanium ; while the monzonites contained an unusually large amount of titanium, together with fluorine and zirconium. The absence of boron from the Tertiary magmas is confirmed by observations on the contact zone of the batholith. No tourmaline has been found either here or in any other Tertiary paragenesis in the region.

COGNATE XENOLITHS

Field Relations.–Mention has already been made of the dark inclusions found in the quartz-monzonite and quartz-bearing monzonite. The xenoliths are widely scattered through both rocks, but appear to be much more abundant in phase III than in phase II; they are also larger in phase III. They invariably show rounded outlines and often have a roughly elliptical shape but there is no evidence to show that they have been elongated in any definite direction. This fact is in keeping with the general lack of directional structures and textures in the monzonitic rocks of this area. The longest dimension of the xenoliths varies from a few inches to about two feet. They are generally more resistant to weathering than the host rock, and tend to

Heavy Minerals of the Intrusive Rocks

	PRE-CAMBRIAN		TERTIARY						
	Granites		Phase I	Phase II			Phase III	Pegmatites	
	1012	1280	1273	1277	1278	1279	1136	1146	1164
Index Figure[1]		0.50	20.87	0.87	0.38	0.41	8.37		
Magnetite, per cent		80.0	25.6	75.7	86.6	87.8	40.3		
Other heavy minerals, per cent		20.0	74.4	24.3	13.4	12.2	59.7		
Actinolite	----	----	----	----	----	----	----	----	X
Anatase	----	X	----	----	----	----	----	X	----
Apatite	X	X	X	----	----	X	X	----	----
Augite	----	----	X	----	----	----	----	----	----
Biotite	X	X	X	X	X	X	X	----	----
Brookite	----	----	----	----	----	----	----	X	----
Diopside	----	----	----	----	----	----	----	----	X
Enstatite	----	----	X	----	----	----	----	----	----
Epidote	----	----	----	----	----	----	----	----	X
Fluorite	----	----	----	X	----	X	----	----	----
Garnet	----	----	----	----	----	----	----	----	X
Hornblende	----	----	X	----	X	X	X	X	----
Monazite	----	X	----	----	----	----	----	----	----
Rutile	----	X	----	----	X	----	----	----	----
Titanite	----	----	X	X	X	X	X	----	----
Topaz	----	X	----	----	----	----	----	----	----
Tourmaline	X	----	----	----	----	----	----	----	----
Tremolite	----	----	----	----	----	----	----	----	X
Zircon	X	X	X	X	X	X	X	X	X
Ilmenite	----	X	----	X	X	X	X	----	----
Sulphides	----	----	----	----	----	----	----	----	X

[1] The Index Figure is the percentage-weight of heavy minerals in the rock.

project from weathered outcrops, often becoming completely detached. No systematic distribution of the xenoliths could be discovered ; in some outcrops they may compose as much as one-third of the exposed rocks, while in others they may be entirely lacking.

Such inclusions are not found in the monzonite of phase I. This observation leads to the suggestion that phase I was the source of the xenoliths, and further evidence in support of this contention is presented below.

In the region of the first prominent peak south of San Agustin Pass another type of igneous xenolith occurs enclosed in the quartz-monzonite. This type is fine grained and light colored, but in size and shape it resembles the dark xenoliths. It is not widely distributed like the dark type, but seems to be confined to the immediate neighborhood of the peak.

Petrography of the Dark Xenoliths.—The dark color of the xenoliths is due to the presence of abundant ferromagnesian minerals, chiefly hornblende. The grain is invariably finer than that of the host rocks, but occasionally large feldspar phenocrysts may be observed in the xenoliths. A comparison of specimens from different localities shows a considerable variation in grain size and in textural features. In some cases the xenoliths have a monzonitic texture, and are closely similar to the rock of phase I; but more commonly the plagioclase feldspar has crystallized in laths having irregular edges, and the haphazard arrangement of these laths recalls the ophitic texture. The minerals include hornblende, biotite, oligoclase, orthoclase-perthite, quartz and accessories. The hornblende has the following absorption scheme: Z (dark green) >Y (light green) >X (yellowish green) ; measurement of the refractive index β gave 1.645 and 1.648 in two cases, in both of which 2V was near 85° and the mineral optically negative. The biotite is chestnut brown and presents no unusual features. The plagioclase has a mean refractive index near 1.540, and gives maximum extinctions in the symmetrical zone of 4° to 5°. Its composition is thus identical with that of the plagioclase of the major intrusives ; it is an oligoclase, $Ab_{85}An_{15}$. Some crystals show zoning, the outer zones being less calcic than the inner zones. The orthoclase-perthite either occurs interstitially, in which case the rock has a poikilitic texture, or mantling the oligoclase, when the texture is monzonitic. Quartz when present is interstitial. Accessory minerals include apatite and titanite, which are unusually abundant in some of the xenoliths, magnetite and zircon.

The xenoliths vary considerably in composition, as may be seen from the modes recorded in the table on page 81. Sufficient evidence is not available to make possible an exact statement of the limits between which the xenoliths may vary, but certain features of the composition may be noted. The amount of oligoclase always exceeds the amount of perthite. Quartz may vary from less than 1 per cent to an amount comparable to that found in phase II. The quantity of hornblende present varies between wide limits, but the maximum amount is comparable to the total amount of dark minerals in the rock of phase I. Classified as separate rocks, xenoliths would range from hornblende-monzonite to quartz-monzonite.

Petrology of the Dark Xenoliths.—The origin of dark inclusions in granitic rocks has been discussed by many authors, who have described them variously as basic segregations, autoliths, altered sedimentary xenoliths and cognate xenoliths. That the xenoliths in the present case are not altered sediments is made quite clear by their composition; no sedimentary xenolith in the batholith has a composition even slightly resembling it. It is necessary, therefore, to decide whether the inclusions were formed by segregation from the magma which crystallized to form their host rock, and are autoliths or basic segregations, or whether they were derived from a pre-existing igneous rock (cognate xenoliths). In favor of the hypothesis of segregation, it is to be noted that they are composed of exactly the same minerals as the host rocks, and that they are rich in the minerals which crystallized early from those rocks. Pabst, in a recent study of the inclusions in the Sierra Nevada batholith; has demonstrated the identity of the minerals of host rock and autoliths. However, since the general abandonment of the theory of liquation, only the most vague and unsatisfactory explanations for the process of basic segregation exist, and in the present case it seems desirable to take advantage of the evidence of the existence of an earlier basic intrusion free from xenoliths in the batholith, and postulate that this or a closely allied rock was the source of the inclusions. This view is in accordance with the findings of Gilbert,[9] Nockolds,[10] Thomas and Smith[11] and Hurlbut,[12] all of whom studied xenoliths essentially similar, in their relation to their host rock, to those of the present area.

This mode of origin nevertheless implies much more than simple stoping of the early monzonite and incorporation of the xenoliths in the later rocks. It has been noted already that the inclusions are rounded, and the tentative suggestion has been made that the shape is to be attributed to reactions with the magma. Accepting the essential truth of the reaction mechanism as postulated by Bowen," it is possible to trace the history of the inclusions from the time of their incorporation in the magma to the end of the cooling process. It is unnecessary to distinguish here between the magmas of phases II and III, since the crystallization followed the same course in both. At the time when they first entered the magma, it may be supposed that hornblende was crystallizing from the magma. The pyroxenes were not, therefore, in equilibrium with the magma, and were converted into hornblende. At the same time perthite and oligoclase were also out of equilibrium, but not in the same way, for the crystallization of these minerals from the magma had not yet begun. It is suggested that they were dissolved by the magma, but that the process did not by any means reach completion. Probably most or all of the perthite was dissolved, and attack on the oligoclase had started, producing the cuspate margins now seen on this mineral, before orthoclase began to separate from the magma

[8] Pabst, A., Observations on inclusions in the granitic rocks of the Sierra Nevada: Univ. Cal. Pub. Geol., Vol. 17, 1928, pp. 325-386.

[9] Gilbert, G. K., Gravitational assemblage in granite Bull. Geol. Soc. Amer., Vol. 17. 1906, pp. 324-326.

[10] Nockolds, S. R., The contaminated granite of Bibett Head, Alderney : Geol. Mag., Vol. 69, 1932, pp. 433-452.

[11] Thomas, H. H., and Smith, W. C., Xenoliths of igneous origin in the Tregastel Plounanch granite, Cotes du Nord, France; Quart. Jour. Geol. Soc. Lond., Vol. 8, 1932, pp. 274295

[12] Hurlbut, C. S., Structure and inclusions of the Bonsai] tonalite : Ph.D. Thesis, Harvard University, 1933.

[13] Bowen, N. L., The evolution of the igneous rocks : Princeton, 1928, pp. 185-201.

bringing the dissolving of oligoclase to an end. At this stage the xenoliths consisted of a loose aggregate of hornblende and oligoclase. Possibly the lath-shaped form of the oligoclase may be explained as the result of greater solubility in the direction of the side-pinacoids, but this is advanced only as a tentative suggestion since there is no experimental evidence to support it. The embayed edges are confined to the side pinacoids and do not occur in the (001) direction. The rest of the history of the xenoliths is the same as that of the host rock. Perthite crystallized out around the oligoclase, and it was simply a question of how the oligoclase crystals were disposed with respect to one another whether a sub-ophitic or monzonitic texture was produced. Quartz followed, and filled up whatever spaces remained; the quantity of quartz present in the xenoliths must be viewed as a mechanical and not a chemical question ; it would obviously be subject to great variation.

We have considered here only the case in which the xenoliths were able to preserve their coherency. The original shape of the xenolith was completely lost, and no doubt material was contributed both mechanically and chemically to the magma. In some cases it is probable that the whole xenolith was completely destroyed. In either case, there must have been some contamination of the magma, and this subject will be considered on a later page.

Petrography of the Light Xenoliths.—The light-colored igneous inclusions have the same rounded form as the dark xenoliths. They are brown, non-porphyritic and fine grained. Due to their smaller quartz content, they lack the sparkling appearance of the aplites, which they resemble in texture.

The minerals present are orthoclase, quartz, subsidiary amounts of oligoclase and minor quantities of biotite and magnetite. The average grain size is about 1 mm., but some of the feldspars exceed this figure in length. The feldspars appear to have crystallized before the quartz. In the specimens examined microscopically, the feldspars were kaolinized.

A micrometric analysis appears on page 81. The rock may be classified as a leucogranite.

Petrology of the Light Xenoliths.—In spite of the granitic composition of these rocks, the texture is so different from that of the pre-Cambrian granites that they can hardly be supposed to represent accidental inclusions of pre-Cambrian material. It is suggested that they were derived from an early differentiate of the Tertiary magma. The possibility that the magma, probably approximating to quartz-monzonite in composition, differentiated into dark monzonite (phase I) and leucogranite at an early stage is one which may reasonably be entertained.

Mineral Compositions (Modes) of Intrusive Rocks of the Tertiary Cycle

NO.	NAME AND LOCALITY	WEIGHT PERCENTAGES						
		Oligoclase	Perthite	Pyroxenes	Hornblende	Biotite	Quartz	Titanite Apatite Magnetite
1206	Phase I, Texas Canyon	48	19		16	10		7
1273	Phase I, Texas Canyon	54	22		14	6		4
1002	Cognate xenolith, Quickstrike	44	22		27		1	6
1138	Cognate xenolith, La Cruz Canyon	42	31		12		12	3
1139	Cognate xenolith, La Cruz Canyon	42	33		3	4	15	3
1128	Cognate xenolith, Chappel claim	38	35		19	3		5
1036	Cognate xenolith, Peak east of Organ	10	59			1	28	2
1240	Phase II, Baylor Pass	36	45			2	17	1
1278	Phase II, East of Hayner mine	34	52				14	
1277	Phase II, Texas Canyon	30	46			4	19	1
1001	Phase III, Quickstrike	39	44			8	7	2
1019	Aplite, East of San Agustin Pass	1	51			3	45	

GEOCHEMISTRY AND PETROLOGY OF MAJOR INTRUSIVES

In the accompanying tables, analyses and norms of the three major intrusive phases are summarized. A comparison of these shows that, although the earliest phase is a saturated rock, while the two later phases are undersaturated, the variation is not a linear or serial change from "basic" to "acid" such as many intrusive complexes show." The same fact is evident from a comparison of the mineral compositions of the rocks (modes) summarized on this page. Phase II is much richer in silica, and poorer in alumina, iron, magnesia and lime than phase I; but phase III shows less silica, and more iron, magnesia and lime than phase II, though more silica and less of the other oxides mentioned than phase I. There is little variation in soda, but potash is higher in phase I than in the earlier and later rocks, corresponding to the greater amount of orthoclase in that phase. Sufficient evidence is not available to justify an extended discussion of the nature of the primary magma and the process

Compare Harker, A., Natural history of igneous rocks : London, 1909, p. 128.

of differentiation ; but some brief observations on the subject will not be out of place. First it may be noted that, in spite of the chemical differences between the rocks, there is a strong qualitative petrographic similarity. Microscopic study showed that the composition of the plagioclase is essentially the same in all three phases. There is a considerable amount of soda in the alkali feldspar, which is an orthoclase-perthite, in all the rocks. Thus it requires no stretch of the imagination to picture them as part of a single intrusive cycle, derived by differentiation from a single primary magma.

It has already been suggested that the first differentiation of the magma yielded monzonite, represented in phase I and the dark xenoliths, and leucogranite represented in the light xenoliths. Only one product of the second stage of differentiation is visible: phase II; but it may be conjectured that there exists, deeper down, a complementary "basic" phase. If it be supposed that the original magma had the composition of a rather silica-rich monzonite, then phase II represents not an increasing divergence from the initial magma but a decreasing divergence, as compared with the leucogranite xenoliths. In phase III there would on this hypothesis be even less divergence. It must be clearly understood, however, that, as no evidence of the nature of the primary magma exists, such a decreasing divergence is frankly speculative. We may carry the speculations one stage further and suggest that if there is a decreasing divergence it is due to incorporation of material from xenoliths of the first phase.

The intrusive process was accompanied by a progressive concentration of volatile fluxes. Little is known about the volatile content of the magma of phase I, but it may be remarked that there is a total lack of pegmatites, aplites and veins directly related to this phase. In phase II there occur aplites but no pegmatites ; while in phase III there are aplites, pegmatites with a long and complex history, and mineral veins directly related to the intrusive mass. Intense metasomatic changes in the country rock occur only in the aureole round the quartz-bearing monzonite. The quartz-monzonite, while it caused thermal metamorphism of a high grade, produced only very feeble metasomatic effects. The analyses show that the phosphorus pentoxide content of phase III is much higher than that of the preceding phases. There is a slight increase in barium oxide from phase I to phase III, and a definite increase in carbon dioxide. The water in combination increases in a similar way. From all these considerations, it is quite evident that as compared with the magma fractions which crystallized to form the earlier phases, that of the quartz-bearing monzonite was a wet magma. Its high volatile content is reflected in the extremely coarse grain of the rock as compared with that of the earlier rocks.

Analyses of Rocks of Major Intrusives, Organ Mountains

		Phase I (1273) Monzonite, Texas Canyon	Phase II (1278) Quartz-monzonite, East of Hayner Mine	Phase III Quartz-bearing monzonite 500 feet south of Merrimac Mine
SiO_2		55.80	68.92	61.12
TiO_2		1.52	0.47	1.30
Al_2O_3		18.08	15.50	15.78
Fe_2O_3		3.29	1.08	2.69
FeO		4.30	1.65	3.15
MnO		0.06	0.03	0.09
MgO		3.12	0.76	1.90
CaO		5.32	1.04	3.95
Na_2O		4.38	4.72	4.14
K_2O		3.51	5.17	4.48
H_2O-		0.00	0.00	0.32
H_2O+		0.29	0.36	0.56
CO_2		0.00	0.03	0.22
P_2O_5		0.06	0.03	0.45
ZrO_2		nd	nd	0.04
S		0.06	0.02	0.05
BaO		0.04	0.06	0.07
SrO		nd	nd	0.04
		99.83	99.82	100.35
			NORMS	
qu		1.68	17.52	10.14
or		20.57	30.58	26.69
ab		36.68	39.82	35.11
an		19.46	5.56	11.12
di	$CaO.SiO_2$	2.55		2.44
	$MgO.SiO_2$	1.60		1.70
	$FeO.SiO_2$	0.79		0.53
hy	$MgO.SiO_2$	6.20	1.90	3.00
	$FeO.SiO_2$	1.85	1.45	0.92
il		2.89	0.91	2.43
mag		4.87	1.62	3.94
ap		0.34	0.17	1.10
		99.28	99.63	98.12

Analyses of phases I and II by F. A. Gonyer, Department of Mineralogy and Petrography, Harvard University. Analysis of phase II by G. Steiger, quoted from U. S. Geol. Surv. Prof. Paper 68, page 207.

MINOR INTRUSIVES

APLITES

Field Relations.—*Veins,* dikes and small irregular bodies of aplite are found in phases II and III of the batholith. These were evidently injected very shortly after the consolidation of the rocks in which they are found. The veins and dikes vary in width from a few inches to about two feet, and they are never continuous for more than about 100 feet along the strike. They do not occur in consistent directions, either of strike or dip. Large, irregular aplite bodies were noticed on a ridge southeast of Organ ; one quarter mile west of San Agustin Pass ; and near the Alamogordo road $1^1/_2$ miles east of the Pass.

Petrography.—The aplites are buff-colored non-porphyritic rocks with a characteristic sheen on fresh surfaces. The texture is that usually described as "sugary," and the grain size about 0.5 mm. Minerals present include quartz and orthoclase, with subordinate oligoclase, albite, biotite and accessory iron oxides and titanite. Plagioclase does not exceed 10 per cent of the total mineral composition, while quartz is abundant. The composition is probably that of a granite. Quartz crystals have in some cases been the first to crystallize, and have grown inwards from the walls of the vein. Small cavities lined with tiny quartz and orthoclase crystals are frequently found.

The aplites may be interpreted as due to the crystallization of local magma residues from which part of the volatiles had already escaped. Their irregularity suggests that their emplacement was controlled by local rather than regional structural influences.

QUARTZ-FELDSPAR PORPHYRY SILLS AND DIKES

Field Relations.—A number of sills of porphyritic rock are found intruding the sediments surrounding the batholith at its northern end. These are exposed in the following places : on the isolated hill southwest of Hardscrabble Hill ; on the hill on which the Homestake mine is situated, this sill extending to the next hill north of this mine ; at the Memphis mine ; and near the Walton ranch, where a well has penetrated the sill. These intrusions appear to conform with the dip of the sediments. Crosscutting sheets are found in the Stevenson-Bennett and Philadelphia mines. A sill-like body caps the high ridge between San Agustin Pass and Baylor Pass.

Porphyry dikes were found in only four places. A dike which appears to feed the Homestake sill cuts through the quartz-bearing monzonite between the road to the Flying Bar-U ranch and the hill to the north of the mine. Other dikes occur on the ridge leading from San Agustin Pass to San Agustin Peak; on the hill south of the pass ; and in the canyon southeast of the Stevenson-Bennett mine at 6000 feet altitude. The three last-mentioned dikes trend north-south. The porphyry dikes are few in number and of slight importance.

Petrography.—The porphyries will be discussed in three groups : (1) The rocks of the sills and cross-cutting sheets which intrude the sediments, (2) the rock which caps the high ridge south of San Agustin Pass, and (3) the dike rocks.

Group (1).—The sills and sheets in the country rock have all undergone intense alteration, which has to a large extent obscured their original mineral composition. The rock of the sills is white, due to intense sericitization, or may locally be stained brown with limonite. The porphyries at the Stevenson-Bennett and Philadelphia mines have a brown color at their outcrops, but are white where they are seen near mineral deposits underground. The shapes of porphyritic feldspars are usually preserved, even in much altered rocks. The altered porphyry on Homestake Hill contains pyrite, and casts left after the removal of this mineral can be seen in the weathered outcrops.

The phenocrysts include quartz and feldspars. The quartz crystals are not invariably seen; when they occur, their rims show evidence of corrosion. It is seldom possible to identify the feldspar, which is preserved only as a ghostly outline. Both oligoclase and orthoclase were, however, identified in specimens from the outcrop of the sheet above the Stevenson-Bennett mine. The groundmass seems to have been a granular mosaic of quartz and feldspar, of micro-crystalline dimensions. In the case of the Walton Ranch sill, there appear to have been two stages in the formation of the groundmass. The first, enclosing the phenocrysts, is fine grained. After it had crystallized, the rock was brecciated, and the fragments are cemented by material somewhat coarser in grain than the original groundmass, but containing a high proportion of glass. Minor amounts of biotite, apatite and magnetite occur in the groundmass.

Sericitization is responsible for the highly altered condition of the rocks. In most examples, the feldspars have been completely replaced by tiny flakes of white mica, varying from 0.01 to 0.05 mm. in length. The mean refractive index lies between 1.580 and 1.590. Secondary quartz occurs in all the rocks, and its formation seems to have accompanied the sericitization. Epidote and rutile are also present among the secondary minerals, and pyrite has been introduced in most cases. A careful search was made for alunite, but none was found.

The Homestake sill was intruded after the consolidation of the outer shell of the last phase of the major intrusive series, since the dike which feeds it cuts through the outer part of that body. It was emplaced before the Torpedo-Bennett fault system came into existence ; the faults displace the dike. Exact evidence of the age of the other sills and sheets is wanting, but all are known to have been in place before the mineralization process reached its climax. The intense alteration of the rocks is due to the action of hydrothermal solutions from the quartz-bearing monzonite, and at the Homestake, Philadelphia and Stevenson-Bennett mines it can be related to the formation of ore deposits in the adjacent limestones. The Stevenson-Bennett sheet is further discussed on page 222.

Group (2).—The crest-line of the high ridge south of San Agustin Pass is made up of a sill-like body of porphyritic rock which dips to the west at about 15° in conformity with the jointing of the quartz-monzonite, into which it has been intruded. The roof of the body is not seen, but the floor is well exposed. The rock is sharply separated from the quartz-monzonite, and is readily distinguished owing to its textural peculiarities.

A characteristic appearance is imparted to this rock by the rounded phenocrysts of quartz and pink orthoclase which it contains. The orthoclase seems to have been unable to develop its normal interfacial angles. The phenocrysts average about 3 mm. in length, and are enclosed by a groundmass with an average grain of about 0.02 mm. Plagioclase does not occur in this rock, but the orthoclase is perthitic and evidently contains segregations of sodic composition. The quartz phenocrysts are much corroded around their margins. The groundmass is of the felsitic variety and appears to consist of quartz and orthoclase. Weathering has imparted a turbid appearance to the feldspars.

Group (3).—The dike rocks are variable in character. The feeder of the Homestake sill resembles the rock of that sill in all respects, and is highly altered, like the sill. The dike exposed southeast of the Stevenson-Bennett mine contains phenocrysts of quartz and perthitic orthoclase in a cryptocrystalline groundmass of quartz, orthoclase and finely divided iron oxides. Its mineralogy resembles that of the sill capping the ridge to the east, and it is possible that it may have been the feeder for that sill. The dikes near San Agustin Pass are quartz-monzonite porphyries, with phenocrysts of oligoclase and orthoclase-perthite in a cryptocrystalline groundmass of quartz and feldspar. Small crystals of hornblende and biotite occur, and the accessory minerals include apatite and magnetite.

RHYOLITE DIKES

Field Relations.—Late in the history of the intrusive cycle a series of felsitic dikes were injected. These have a very distinctive appearance in the field; they are fine grained, white or gray on fresh surfaces and dark greenish-gray when weathered. The wider dikes are jointed parallel to their walls and therefore tend to split off in thin, slate-like slabs at their outcrops. Such dikes are very numerous and have been found cutting all three major phases of the batholith, and extending out far into the country rock. A member of this series has cut through the feeder of the Homestake sill. There were at least three periods of rhyolite injection, as shown by the relations of the dikes immediately north of San Agustin Peak. The dikes of the first group trend between east-northeast and east-southeast, and form a series of linear echelons, the longest of which, extending from Black

Prince Canyon to Rattlesnake Hill, north of the Steampump ranch, is five miles long. The longest individual dike in this series is not over one-quarter of a mile in length. It is necessary to point out that the individual members of such an en echelon set cannot be supposed to have been part of a single continuous dike which was later broken up into many parts by faulting, for if this had been the case, the presence of the faults would now be revealed by the disturbance of other structures. The field evidence indicates clearly that no such fractures exist, except where the large through-going faults cut through the dike suites, and these faults disturb rather than enhance the symmetry of the echelons. The intrusion of dikes en echelon is a well-established process ; it depends on the opening of a series of parallel tension cracks in a staggered arrangement, and is generally attributed to torsional stresses. For comparison, the Tertiary tholeiite dikes of northern England, described by Holmes and Harwood[15] may be mentioned. The en echelon structure is not confined to dikes. The individual fractures of the 1906 San Andreas rift in California were arranged in this manner ; and mineral veins showing a similar disposition are known, among other places, at Butte, Montana, and at Guanacevi, near Durango, Mexico.[16] An opportunity of examining the end of one of the members of a linear echelon was afforded in the present area by a prospect hole sunk on an east-northeast dike, northeast of the Galloway mine. Here the dike could be seen tapering away to a point, while 50 feet to the southeast the next member of the echelon appeared ; the exposure was so good that it is possible to assert with confidence that the dike was not cut off by a fault plane. The shape of the dikes is thus lenticular. In the Organ mining district, where the rhyolite dikes were mapped, nine series embracing 70 individual dikes lying between east-northeast and east-southeast were found ; their distribution can be seen on Plate III. The dikes vary in width from 3 to 15 feet.

Later than the injection of the group above, there were two periods of injection of rhyolites in a general northwest direction. The Galloway dike runs from a point southeast of the Galloway mine to the contact between the quartz-bearing monzonite and the Lake Valley limestone, east of the Excelsior mine ; it is continuously exposed for over two miles and, while it is not divided up into an echelon, its sudden changes of direction suggest that torsional forces were still in operation when it was intruded. Its average width is 25 feet. It cuts through and displaces two members of the earlier series north of San Agustin Peak. Later than the Galloway dike but following a similar direction, is the Excel-

[15] Holmes, A., and Harwood, H. F., The tholeiite dykes of the north of England : Min. Mag., Vol. 22, 1929, pp. 1-52.
[16] According to Professor D. H. MacLaughlin, in personal conversation.

sior dike, which runs from San Agustin Peak to the Excelsior mine, where is is exposed underground. This dike at one of its bends cuts through the Galloway dike, and also cuts and displaces two of the east-west dikes. The Excelsior dike extends into the Lake Valley limestone north of the batholith, and here it acts as the feeder for a small laccolith of rhyolite, which forms the conical hill near the Excelsior mine. The roof of this body is plainly domed and the limestone dips away on all sides; the floor is not seen, however. The Excelsior dike is a continuous dike, but parallel to it there are a number of small en echelon series. Both the Galloway and Excelsior dikes enclose "horses" of the rock they are traversing, and three of these, at the Galloway mine, on San Agustin Peak, and at the mouth of La Cruz Canyon, attain large dimensions.

Rhyolite dikes are far more abundant in the neighborhood of phase III of the batholith than elsewhere in the region. They are, however, seen in a few places in the central part of the batholith ; two such dikes cut through phase I in Texas Canyon east of the Texas Main mine, and another one cutting phase II is seen adjacent to the Texas cross vein. South of the Cox ranch a rhyolite dike runs near the contact between phase II and the pre-Cambrian granite.

The rhyolites are distinguished from the aplites in the field by their color, jointing, greater width and consistent direction. They were injected at a much later period than were the aplites.

Petrography.—There is very little observable variation among the rhyolites, and they may be described as a group. They are very fine grained and sometimes carry large quartz phenocrysts. Their color varies from pure white to dark greenish gray. Many of them are banded parallel to their walls, and it is believed that the jointing so frequently seen in weathered outcrops is caused by the separation of the bands when exposed to atmospheric conditions. The banding and jointing are not seen in dikes less than about 5 feet wide, nor do they appear in the laccolith near the Excelsior mine, even though the feeder of this body is strongly banded and jointed. As seen underground, the banding persists but the jointing does not occur, so that it is evidently confined to the outcrops.

Under the microscope the texture is found to be felsitic ; quartz and an undetermined feldspar, probably orthoclase, make up a microcrystalline or cryptocrystalline groundmass in which rounded and sub-angular quartz phenocrysts, often corroded around their margins, are enclosed. The Excelsior dike and laccolith are unusual in containing phenocrysts of orthoclase-perthite, which reach about 0.75 mm. in length. A few shreds of biotite occur in some examples. The groundmass sometimes exhibits a rudely developed spherulitic texture. The banding mentioned above was found to be due to the alternation of cryptocrystalline with microcrystalline groundmass; the cause of this alternation is unknown.

Sericite was found to be an abundant constituent of every specimen of rhyolite studied. It occurs in tiny flakes and, as it seems to be associated with secondary quartz, it is regarded as an alteration product. In a specimen from the east-west dike exposed near the mouth of Black Prince Canyon, biotite was observed to have been replaced by rutile needles which had grown both parallel and in two directions at 45° to the (001) cleavage of the mica. Calcite was found in many specimens. As will be shown later, the rhyolites were intruded at a time when the hydrothermal mineralization of the region was actively in operation. The sericitization and silicification of the dikes is not, therefore, surprising; indeed it is very unusual to find a rhyolite dike without a small quartz vein along one of its walls.

There is no evidence that the rhyolite dikes ever reached the surface or became the feeders of lava flows. They are considered to represent the last residue of volatile-poor magma from deep down in the batholith.

METAMORPHISM OF THE INVADED ROCKS

GENERAL FEATURES

In this section the mineralogical changes in the country rock induced by the intrusion of the batholith will be considered. The structural deformation of the rocks surrounding the batholith has already been described ; there were, however, certain structural changes which occurred as the batholith consolidated, and in so far as these bear on the problem of metamorphism, they will be considered here. The main concern is, however, with the mineralogical rearrangements which have taken place in the invaded rocks in response to the new conditions of temperature resulting from, the intrusion and in response to the action of fluids emanating from the intrusive. It will be shown that in some of the metamorphosed rocks, mineralogical change without sensible change in bulk composition took place; this process is to be referred to as thermal metamorphism, in the strict sense of Harker.[1] Even in these rocks, the presence of water to act as a solvent is necessary, as Harker points out; and it is probable that the water was supplied by the magma. Another class of metamorphosed rocks includes those in which there has been loss of carbon dioxide and addition of water. These, too, fall in Harker's thermal metamorphic group ; probably the only vola-

Harker, A., Metamorphism : London, 1932, p. 2.

tile playing an important part was water. Much more common than these are the rocks in which the mineralogical changes indicate that many other substances which emanated from the magma contributed to the composition. These changes are to be referred to as metasomatic, and for purposes of description two types of metasomatic changes will be recognized. The first type, in part covered by Lindgren's term pyrometasomatic[2] was confined to an aureole not exceeding 500 feet wide around the batholith and to the inclusions in the batholith. In this type, part of the material for the new minerals was supplied by the rocks undergoing alteration, while part was introduced by fluids. The ratio between original and introduced substance varies between wide limits, reaching in the extreme case of andradite garnet 33 per cent original to 67 per cent introduced material. The outstanding characteristic of the first type is, however, that the new minerals depend upon the former composition of the rock which they replace ; thus each different rock in the metamorphic aureole has its own peculiar set of minerals. The minerals of the first type are mainly silicates.

The metasomatic changes of the second series, later in time than the first type, are characterized by unlimited introduction of new material. The minerals produced bear little or no relation to the former composition of the rock which they replace; they include quartz, sulphides, tellurides and native metals, fluorite and barite. Their distribution is much wider than that of the minerals of the first type, but it shows a much more definite structural control. This group of changes is referred to as hydrothermal.

The present section is concerned only with thermal metamorphic and pyrometasomatic changes; the hydrothermal changes will be discussed in the next section, on ore deposits. At the end of the present section the question of whether a real break exists between pyrometasomatic and hydrothermal types as here defined will be considered; for the moment, the classification is one of convenience.

The metamorphosed rocks include the pre-Cambrian granites and epidiorites ; the Bliss sandstone series ; the calcitic beds of the El Paso formation ; the dolomitic beds of the El Paso, Montoya and Fusselman formations ; the Percha shale ; the Carboniferous limestones and the Tertiary lavas. The exomorphic changes will be described under the stratigraphic unit concerned. In addition, the metamorphism of the accidental xenoliths in the batholith will be described; as the xenoliths possess characteristics which enable them to be identified with one of the stratigraphic groups, they will not be treated separately.

Lindgren, W., Mineral deposits : New York, 4th Ed., 1933, p. 696.

The only previous description of the metamorphism in the district is that by Lindgren,[3] who lists the minerals found in the limestones at the Excelsior, Memphis, Torpedo and Modoc mines. The time available during the present work has made possible a more detailed study of the subject.

PRE-CAMBRIAN ROCKS

Field Relations.—The pre-Cambrian granite is exposed in contact with the Tertiary batholith for long distances on the east side of the mountains ; metamorphism of the granite is, however, localized and not general. The best examples are to be found at the Lady Hopkins mine and on Little Antelope Hill, where the alteration seems to have been controlled by fissures oblique to the direction of the contact. At the Lady Hopkins mine a tabular mass of altered granite 10-20 feet wide and 800 feet long has been produced. The strike is northeast. On Mineral Hill the alteration extends for about 100 feet and the width of altered rock is 6 to 10 feet. Scattered alteration of a similar but less intense character occurs in the vicinity of the contact near the mouth of Black Prince Canyon, on the small hills rising from the valley between Rakestraw's camp and Mineral Hill, and along the contact south of the Cox ranch.

Xenoliths of epidiorite included in the quartz-monzonite were found in the South Canyon region.

Mineralogy of Altered Granite.—The altered rock from the Lady Hopkins mine will be described first, since it represents the most advanced type of metamorphism of granite. Here the granite is converted into a heavy rock rich in iron oxides. The large orthoclase phenocryts are very little altered, and remain as phenocrysts in the new rock; none of the other minerals can be distinguished in hand specimens. In thin sections it is found that the only minerals remaining from the original rock are the accessories and orthoclase. The new minerals are colorless augite, abundant biotite, hematite, magnetite and quartz. The opaque minerals were investigated by the polished surface method, and it was found that the magnetite occurs in idioblastic crystals, and has a distinct purple color, probably due to the presence of titanium. The hematite is somewhat more abundant than magnetite; it is allotrioblastic, and contains plates of magnetite arranged in two directions at 90 degrees. The iron oxides make up more than one-third of the new rock, and have apparently replaced quartz, orthoclase and plagioclase. Next in abundance to the iron oxides comes biotite, which is associated with these minerals. The crystals are very small and have a random orientation. The augite occurs in small crystals, and in

[3]Lindgren, W., Graton, L. C., and Gordon, C. **H.,** Ore deposits of New Mexico : U. S. Geol. Surv. Prof. Paper 68, 1910, pp. 54, 211, 212.

a few places is found in veinlets cutting across the orthoclase crystals. The veinlets were formed before the introduction of the iron oxides, since they do not extend beyond the boundaries of the orthoclase into the oxides.

The altered granite on Little Antelope Hill is similar, but here the specularite and biotite plates seeem to have a rudely parallel orientation, imparting a schistose appearance to the rock.

Alteration of an essentially similar but less intense character is found in many places near the granite-monzonite contact. It is marked by the appearance of black specks of biotite and iron oxides in the rock.

Mineralogy of Altered Epidiorite.—Specimens from two epidiorite xenoliths included in the quartz monzonite at South Canyon were studied petrographically. In hand specimen there is still a suggestion of the diabasic texture; but in thin section it was found that this was due not to an arrangement of the feldspars, but of the pyroxene and biotite. There is good evidence of the superimposition of thermal metamorphism upon the already metamorphosed rock. Hornblende was not found; apparently its place had been taken by a colorless pyroxene whose optical properties are given in the table on page 94. This occurs in small grains, associated with abundant brown biotite, In streaks which are perhaps a relic of a former ophitic texture. The feldspar has been recrystallized; the average maximum extinction in the symmetrical zone is 15° and all indices exceed 1.540; it is thus an andesine, $Ab_{68}An_{32}$. There has also been some later sericitization of the feldspar. Magnetite in tiny grains is very abundant. A remarkable development of pleochroic blue apatite, striated parallel to the base, was found in one specimen; the crystals have a length of 3 mm. and appear to be secondary rather than remnants from the original rock. Clinozoisite was fairly abundant in one specimen.

BLISS SANDSTONE

Field Relations.—The Bliss series is not metamorphosed at its contacts with the batholith at the northern and southern ends of the body ; but in Rucca Canyon, north of the east end of Sole-dad Canyon, there occur quartzite xenoliths believed to have been derived from the Bliss sandstone, and these have been highly altered.

Mineralogy.—The altered rock contains conspicuous masses of blue lazulite, associated with plates of white mica. Under the microscope the minerals present were found to be lazulite, in irregular masses, idioblastic andalusite, numerous small crystals of rutile, and colorless muscovite. The lazulite is strongly pleochroic, and apparently occurs in two varieties, in one of which the interference colors are uniform, while in the other a feathery extinction suggesting twinning or alteration is exhibited. The quartz of the xenolith has clearly been recrystallized, and the relations of the minerals suggest that they crystallized simultaneously.

CALCITIC BEDS OF THE EL PASO FORMATION

Field Relations.—*Calcitic* beds are found in the El Paso formation only in the northern part of the area. Lime-silicates are found in these beds on both sides of the plunging anticline east of the Merrimac mine, and they are well exposed in numerous prospect pits. The outcrop of the beds continues northeast from the anticline, and in Black Prince Canyon they can be seen overlying the Bliss sandstone. Silication of this stratigraphic unit continues to a point in Black Prince Canyon, southeast of the Hilltop mine, 2000 feet from the intrusive contact. The alteration is, however, very localized, and at many places nearer the contact, no lime-silicates occur in the beds. Marmorization extends far beyond the limits of silication, and the northernmost exposures of these beds, near the Black Prince mine, show almost complete recrystallization.

Mineralogy.—*Garnet* is the most abundant of the new minerals in these beds. As shown in the accompanying table a definite difference in refractive index between the isotropic and birefringent zones of the mineral was detected, the inner zones being andradite, and the outer a mixture of the andradite and grossularite molecules in the proportion 8:3.[4] Apatite in irregular masses and occasional idioblasts occur with the garnet, and a brown micaceous substance, tentatively identified as pyrophyllite, also replaces the recrystallized calcite. Quartz, specularite and ore minerals occur but are referred to the second stage of metasomatism.

LOWER PALEOZOIC DOLOMITES

Field Relations.—The dolomites of the El Paso, Montoya and Fusselman formations outcrop at both the northern and southern ends of the batholith, and are also found as xenoliths in the quartz-monzonite in the neighborhood of South Canyon. At the northern end they are seen in contact with the third phase of the batholith, and, as might be expected from the volatile-rich character of this rock, a considerable number of new minerals have been formed in the dolomites in this region. On the other hand, at South Canyon and at the southern contact the alteration is confined to recrystallization into magnesium oxide and calcium carbonate, and the production of silicates in the impure parts of

[4] According to data given by Winchell, op. cit., p. 181.

Determinative Criteria for Minerals in Metamorphosed Epidiorites, Bliss Sandstone and Calcitic Beds of El Paso Formation[1]

Metamorphosed rock and locality	Name of mineral	Optical Character	ω α	β	ϵ γ	Color, pleochroism, cleavage; extinction
Epidiorite xenolith, South Canyon	Augite	Biaxial +ive 2V 60°	1.680	1.689	1.708	Colorless; max. ext. 43° against (110) cleavage.
Quartzite xenolith, Rucca Canyon	Lazulite	Biaxial –ive 2V high	1.613	1.632	1.643	Z (bright azure blue) >Y (azure blue) >X (colorless)
	Andalusite	Biaxial 2V 90° length fast	1.631	1.638	1.644	Colorless; good (110) cleavage; symmetrical extinction on cross sections
	Muscovite	Biaxial –ive 2V 40° r>v	1.570	1.593	1.596	Colorless
Calcitic beds El Paso formation. North of Silver Coinage Mine	Garnet	Isotropic Birefringent	1.89 1.85			Andradite core Outer zones; some grossularite mol. present. Mineral is green.
	Apatite	Uniaxial –ive	1.638		1.635	Colorless
	?Pyrophyllite	?	1.56		1.61	Pale brown, micaceous

[1] In determining non-opaque minerals from their optical properties, the following works were consulted for reference: Larsen, E. S. and Berman, H., The microscopic determination of non-opaque minerals, 2nd Ed.: Bull. U. S. Geol. Survey 848, 1934. Winchell, A. N., Elements of optical mineralogy, Vol. 2: N. Y., 1933. Rogers, A. F. and Kerr, P., Thin section mineralogy: New York, 1933. All refractive index determinations are subject to an error of ± .002.

the beds. At the northern end the dolomites are well exposed in the gullies which run southeast from the Goat Ranch, and in Black Prince Canyon. Silicate rocks are again localized, and are found to a distance of only about 100 feet from the contact. Recrystallization continues as far as the rocks can be followed, to the reverse fault in Black Prince Canyon; it becomes less and less complete as the distance from the intrusive body increases. The xenoliths at South Canyon are completely recrystallized and altered, and in Target Range Canyon the silication of impure beds extends up to 400 feet from the contact, while recrystallization continues for over 2500 feet.

Mineralogy.—The metamorphism of the dolomite xenoliths in South Canyon and of the dolomites at the southern contact has given rise, where the beds were pure, to brucite marble. The first stage in the formation of this rock was the appearance of periclase and this was followed by hydration of the periclase, giving rise to brucite. In some specimens a considerable amount of periclase, in tiny crystals, remains unaltered so that we may assume that the available supply of water was not great at the time when conditions for hydration were good. The brucite is beautifully developed in rosette-like aggregates (see plate VI page 115) . In impure dolomites, that is those containing chert, forsterite has formed in addition to periclase. It occurs in rounded crystals in the carbonate matrix, and has been partly altered to serpentine; the hydration process is, however, far from complete. The concentration of magnesia into periclase and forsterite impoverished the carbonate matrix in this substance; it is found therefore, that the matrix of the brucite and forsterite marbles is not dolomite but calcite, with w 1.660.

At the northern contact the temperature probably never rose high enough to produce periclase for this mineral and its alteration product are lacking. Forsterite was probably formed, but all of it was subsequently converted into serpentine; pseudomorphs strongly suggesting the orthorhombic form of forsterite are frequently seen in the serpentine. Antigorite, the massive constituent, predominates over chrysotile in the serpentine, but chrysotile veinlets with the fibers perpendicular to the walls are nevertheless common. Magnetite is associated with serpentine in the gully southeast of the Goat Ranch and it must be regarded as a mineral of the early group. Other minerals associated with the serpentine include cordierite, in rounded crystals; diopside ; a bright green chlorite in crystals up to 5 mm. in diameter, identified as the magnesian chlorite penninite ; and a coarsely crystalline mica. The mica, which occurs in large plates with a bronze luster, was thought at first to be a vermiculite, but heating tests showed that it did not swell up in the manner characteristic of

Determinative Criteria for Minerals in Metamorphosed Lower Paleozoic Dolomites

Locality	Name of mineral	Optical Character	ω α	β	ϵ γ	Color; cleavage; extinction; twinning
Gully southeast of Merrimac mine	Cordierite	Biaxial –ive 2V 40°	1.550	1.556	1.559	Colorless, pseudo-hexagonal twins
	Spinel (Pleonaste)	Isotropic	1.739			Green; (111) cleavage
	Diopside	Biaxial +ive 2V 60°		1.685		Colorless; maximum extinction against (110) cleavage, less than 40°
	Penninite	Uniaxial –ive	1.682		1.678	Bright green flexible inelastic plates
Xenolith, South Canyon	Periclase	Isotropic	1.740			Small angular crystals
	Forsterite	Biaxial 2V 90°	1.637	1.665	1.672	Colorless, no cleavage but irregular fractures
Head of Target Range Canyon	Brucite	?	1.568		1.581	Colorless, in concentric aggregates

the Montana vermiculite, and, as it is sensibly uniaxial it is classified as a phlogopite.

Beautiful examples of the metamorphism of chert nodules in the dolomite were found in the northern region. The central part of the chert retains its normal character but it is surrounded by a reaction zone in which diopside and a green magnesian spinel occur. Beyond this zone the rock is converted into serpentine.

The absence of quartz is a striking feature of the metamorphosed dolomites in the silicate zone. The affinity of magnesia for silica is evidently great enough to prevent the crystallization of silica as quartz under high temperature conditions. Beyond the zone of silication, however, abundant quartz is found in the recrystallized dolomite.

DEVONIAN AND CARBONIFEROUS SHALES

Field Relations.—The Percha shale is in contact with the third phase of the batholith near the Goat Ranch at the northern end of the batholith ; the alteration of the rock does not appear to be very intense, for the normal appearance and cleavage are retained unchanged. Calcareous shales of the Magdalena series are in contact with the batholith west of the Excelsior mine, and at numerous points farther south they are brought against the batholith by faulting.

Mineralogy.—The alteration of the argillaceous facies of the Percha shale is feeble, and consists in the recrystallization of some of the clay material as fine-grained sericite and chlorite, and the recrystallization of the quartz present. Rutile was noted in one specimen.

The calcareous ,beds of the same formation are more susceptible to metamorphism. A specimen taken within one inch of the igneous contact showed a fine-grained mosaic of diopside, quartz, and andesine. The feldspar of the igneous rock across the contact is oligoclase, but there seems to be an abnormal amount of diopside in the monzonite, so that some contamination has probably taken place here.

Metamorphism of calcareous shales of the Magdalena series has given rise to a variety of minerals. Diopside is the commonest of these but associated with it there are varying amounts of a white mica, and in places fairly abundant anorthite, with mean refractive index 1.580. In one specimen a veinlet of anorthite cuts across the diopside rock. A white mineral from a vein parallel to the bedding of a shale west of the Excelsior mine proved to be scapolite, the only occurrence of this mineral found in the district ; andradite is associated with it.

Corundum is said to have been found in a shale near the igneous contact due west'of the Modoc mine, in the central part of the range. It did not prove possible to verify the occurrence of this mineral, but metamorphosed shales from this locality were found to contain sericite and green pleochroic biotite, with quartz.

Seams of green epidote are widely scattered through the shaly limestone in the vicinity of the contact between the Excelsior and Modoc mines but the amount of this mineral is never great. Its range, however, appears to be much greater than that of the other silicate minerals, for it persists far beyond the limits of the diopside-garnet rocks.

CARBONIFEROUS LIMESTONES

Field Relations.—The Lake Valley limestone is in contact with the third phase of the batholith between the Merrimac and Excelsior mines and locally has been strongly metamorphosed. At the Merrimac mine one of the lowest beds of the formation has been converted into a garnetite, and here the alteration extends 500 feet from the igneous contact. The bed has been explored by means of an incline, an underground map of which appears on page 235. Between the Goat Ranch and the east end of the hill made by the Excelsior rhyolite laccolith, beds of the Lake Valley series are in direct contact with the batholith, but are only recrystallized and not replaced by silicates. On the east, south and west sides of the laccolith, however, bodies of silicates appear in the limestones, and at the Excelsior mine the largest of these is exposed both on the surface and underground; it is approximately 900 feet from the contact. The whole outcrop of the Lake Valley limestone shows recrystallization from its western end to a region north of the Little Buck mine, beyond which its character is normal.

The limestone, cherty and shaly beds of the Magdalena series are in contact with the west side of the intrusive body between the Flying Bar-U ranch and the Modoc mine. The contact is, however, a faulted one throughout this whole distance, and there seems to be good reason for believing that the faulting took place after at least part of the metamorphism had been accomplished. The finest example of high temperature limestone metamorphism in the district is found at the Memphis mine, a surface map of which appears on page 231. Here bodies of massive garnetite have taken the place of some of certain thin impure limestones of the Magdalena formation, while other limestones interbedded with these have only been marmorized. There are three prominent silicate beds exposed at the surface, and others have been explored underground by means of shafts and stopes. The silicate zone extends up to 300 feet from the fault; west of it the beds are recrystallized and epidote continues to appear in the shaly members.

The limestones exposed west of the Torpedo mine are very little altered, and to the south the silicates are not found for three miles. East of Emmett Isaacks' ranch a narrow garnet zone not exceeding 10 feet wide extends along the fault, but intense alteration is not found again until the Modoc-Oreion-Trapezoid group of mines and prospects is reached. Here there are large bodies of garnet, with sulphides, against the fault; the east wall of the fault, however, is no longer the quartz-monzonite but is the Orejon andesite. The proximity of the silicate bodies to the lava led Lindgren[5] bto suggest that the metasomatism was brought about by the lavas, but the recognition that the lavas and limestones are in faulted contact makes this suggestion untenable. There are at least two explanations that are more satisfactory. Either the limestones in this region were at the time of metasomatism in contact with the quartz-monzonite and owe their present position to post-metasomatism faulting; or the metasomatism may be due to solutions which traveled along the fault from the batholith. An analogous case is presented by the occurrence of garnet, diopside and tremolite in limestone adjacent to the same fault on the hill south of Hardscrabble. Here again one wall of the fault is andesite, but the solutions can hardly have been supplied by the lava.

Limestone xenoliths in the batholith show some interesting features. Those northeast and southeast of the Stevenson-Bennett mine (not mapped) are recrystallized but not silicated ; but a large xenolith south of the Cox ranch has been intensely altered, and some modification of the quartz-monzonite has accompanied the process. At South Canyon various degrees of metamorphism are exhibited by the limestone xenoliths (see map, page 66).

Mineralogy.—The metamorphic minerals in the limestones have been summarized in the table below ; only a few of these need special comment. Three types of garnet are found. By far the most abundant is a brown or greenish-brown andradite. At the Trapezoid prospect some birefringent garnets were found to contain grossularite. The rare chrome garnet, uvarovite, occurs in a xenolith at South Canyon in association with beautifully crystallized green diopside, phlogopite and wollastonite.[6] This occurrence is an unusual one but is paralleled by one recently described by Eskola from the Outokumpu mine in Finland.[7] Attention may be directed to the complete absence of magnetite from the limestones ; a very careful search failed to reveal

[5]Lindgren, W., Graton, L. C., and Gordon, C. H., Ore deposits of New Mexico: U. S. Geol. Surv. Proof Paper 68, 1910, p. 221.

[6]Dunham, K. C., Xenoliths in the Organ batholith, New Mexico ; with a morphological study of diopside by M. A. Peacock : Amer. Min. (in preparation).

[7] Eskola, P., On the Chrome minerals of Outokumpu: Comptes Rendus de la Societe geologiques de Finlande, No. 7, 1933, pp. 26-43.

its presence. Specularite is abundant, but does not belong to the phase of mineralization here under discussion.

Metamorphic Minerals in Carboniferous Limestones

Minerals	Merrimac	Excelsior	Memphis	West of E. Isaacks' Ranch	Modoc Group	Hardscrabble	Xenolith south of Cox Ranch	Xenoliths at South Canyon
Andradite	X	X	X	X	X	X	--	X
Diopside	--	X	X	--	--	X	X	X
Wollastonite	--	X	X	--	--	--	--	X
Vesuvianite	--	X	--	--	--	--	--	--
Tremolite	--	X	--	--	X	X	--	--
Pargasite	--	--	--	--	--	--	X	--
Epidote	--	--	X	--	X	--	--	--
Apatite	X	--	--	--	--	--	--	--
Titanite	--	--	X	--	--	--	--	--
Uvarovite	--	--	--	--	--	--	--	X
Phlogopite	--	--	--	--	--	--	X	X
Grossularite	--	--	--	--	X	--	--	--
Specularite	--	X	X	X	X	--	--	--

TERTIARY LAVAS

The Orejon andesite and the basal tuff are the only members of the lava series which can be observed in contact with the batholith. The alteration of these is simple; it consists in the development of epidote from the feldspars, the conversion of the hornblende into chlorite, and the appearance of epigenetic quartz and calcite in irregular masses and tiny veins.

THEORETICAL CONSIDERATIONS

Thermal Metamorphism and Metasomatism.—Metamorphism by an intrusive magma of the rocks with which it comes into contact is accomplished through the agencies of heat and transfer of substances in solution. The relative importance of these two agencies has long been debated, and even today the subject commands no unanimous opinion. It is, however, generally admitted that both play their part. The views of the school of Rosenbusch and Zirkel, that the thermal factor is of paramount importance, have recently been restated with considerable emphasis by Harker,[8] but with the important admissions that water from the magma is needed in the process of metamorphism, and that pneumatolysis may be superimposed upon thermal metamorphism. On the other hand, the investigation of contact zones in the western United States, in Mexico and elsewhere has led, from the time of Lindgren's classic study at

[8] Harker, A., op. cit., 1932.

Determinative Criteria for Minerals from Metamorphosed Carboniferous Limestones

Locality	Name of mineral	Optical Character	ω α	β	ϵ γ	Color
Excelsior mine; Merrimac mine; pit near Big Three mine; Memphis mine	Garnet (Andradite)	Isotropic	>1.88			Green, greenish-brown
Trapezoid claim	Garnet	Isotropic Birefringent	>1.88 1.85			Andradite 3 Grossularite: 8 Andradite
East of Excelsior mine	Vesuvianite	Uniaxial –ive	1.717		1.712	Green. Zonal structure in thin section
Limestone xenolith, South Canyon	Wollastonite	Biaxial –ive 2V 40°	1.618	1.629	1.633	White
	Diopside	Biaxial +ive 2V 62°	1.672	1.679	1.704	Colorless in thin section; maximum extinction against (110) cleavage 39°
Limestone xenolith, south of Cox Ranch	Pargasite	Biaxial –ive 2V 85°	1.659	1.668	1.678	Two cleavages at approx. 120°
	White mica	Uniaxial –ive?	1.558		1.538	Extinction against basal cleavage, 4°
Orejon mine	Epidote	Biaxial –ive 2V high	1.738	1.756	1.776	Z (deep green) >Y (green) >X (pale green)
West of Excelsior mine	Scapolite Ma_{70} Me_{30}	Uniaxial –ive	1.578		1.552	White platy aggregates

Clifton-Morenci [9] to the firm establishment of the case for metasomatism. The literature of the subject has now reached very large proportions, and no attempt will be made to summarize it here. It may, hoVvever, be noted that in almost every case where analyses of metamorphosed and unaltered rocks have been compared, a substantial change in composition has been displayed. Umpleby's work in the Mackay region,[10] and Lindgren's Bingham investigation[11] are among the most convincing. Indeed, so excellent is the case for metasomatism, that there is a grave danger that its limitation will be lost sight of, and all new minerals found in rocks near igneous intrusions will be attributed to introduction of substances from the magma. Such an extreme position serves only to reduce to an absurdity an otherwise satisfactory theory.

It is a purpose of the present study to point out that while some of the new minerals formed as a result of metamorphism in the aureole surrounding the batholith owe part of their substance to emanations from the magma, yet the metamorphic minerals are dependent to a very important degree upon the former composition of the rock which they replace. It is possible, then, to set limits to the process of metasomatism.

Some authors, including Barrelb[12] V. M. Goldschmidt,[13] Harder,[14] Umpleby,[15] and Harker,[16] find evidence which enables them to distinguish between thermal, or to use Goldschmidt's term "normal" metamorphism and metasomatism. In view of the necessity for water even in the thermal process, the ultimate validity of this distinction may be open to question. In the present area, it is possible to recognize a continuous series of changes, beginning with metamorphism which would, on Harker's definition, be classified as thermal, and giving place to pyrometasomatic and ultimately to hydrothermal alterations.

The most striking feature of the minerals of the metamorphic aureole at Organ is their dependence in composition upon the bed in which they are found. We note that in the dolomites, the dominant minerals are magnesian: forsterite, periclase, pleonaste, cordierite, penninite, phlogopite ; whereas in the limestones the dominant minerals are calcic : lime-iron-gar-

[9] Lindgren, W., Copper deposits of Clifton-Morenci, Arizona : U. S. Geol. Surv. Prof. Paper 43, 1905.

[10] Umpleby, J. B., Geology and ore deposits of the Mackay region, Idaho : U. S. Geol. Surv. Prof. Paper 97, 1917, pp. 57-59.

[11] Lindgren, W., Contact metamorphism at Bingham, Utah : Bull. Geol. Soc. Amer. Vol. 35, 1924, pp. 507-534.

[12] Barren, J., Geology of the Marysville mining district, Montana : U. S. Geol. Surv. Prof. Paper 57, 1907, pp. 124-125.

[13] Goldschmidt, V. M., Die Kontaktemetamorphose im Kristianiagebiet: Kristiania, 1911, p. 119.

[14] Harder, E. C., Iron ore deposits of the Eagle Mountains, California : U. S. Geo:. Surv. Bull. 503, 1912, pp. 69-73.

[15] mpleby, J. B., Geology and ore deposits of the Mackay region, Idaho : U. S. Geol. Surv. Prof. Paper 97, 1917, pp. 65-66.

[16] Harker, A., op. cit., 1932, pp. 117-135.

net, wollastonite, vesuvianite ; while common to both groups there is diopside. The shales and quartzite contain minerals increasingly rich in alumina ; anorthite, andalusite, and lazulite, the lazulite probably having obtained its phosphorus from glauconite in the quartzite. The diagram below is designed to emphasize the dependence of the metamorphic minerals upon the original composition of the beds ; it shows the relations of the minerals to the four component system CaO-MgO-SiO_2-Al_2O_3. Evidently, then, much of the substance for the new minerals came from the bed in which they are now found.

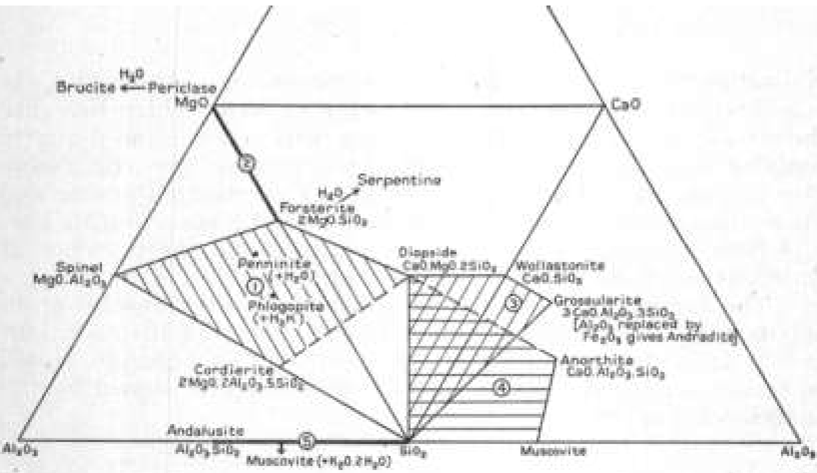


FIGURE 5.—Diagram to show the relations of the metamorphic minerals to the system CaO–MgO–SiO_2–Al_2O_3.
1, Metamorphosed dolomites, northern area; 2, metamorphosed dolomites, southern area; 3, metamorphosed limestones; 4, metamorphosed shales; 5, metamorphosed quartzite.

The metamorphism of pure dolomite to periclase-brucite-marble involves only loss of CO_2 and addition of water :

$$\underset{\text{Dolomite}}{MgCO_3.CaCO_3} = \underset{\text{Periclase}}{MgO} + CaCO_3 + CO_2$$

$$MgO + H_2O = \underset{\text{Brucite}}{Mg(OH)_2}$$

A micrometric measurement on a brucite marble from South Canyon was made to determine the completeness of the alteration; the results were as follows:

	I. Brucite marble	II. I. recalculated to 100 $CaCO_3$	III. Theoretical Proportions from pure dolomite
Calcite	62.3	100.0	100
Brucite	36.2	56.6	58
Serpentine	1.5		
	100.0 (by weight)		

In the complete metamorphism of a pure dolomite, brucite and calcite should be present in equal molecular proportions. It is found here that the ideal case is very closely approached; it may, therefore, be concluded that the process had been completed and equilibrium had been reached. The dedolomitization which accompanies the production of periclase was mentioned on page 195.

When silica is present, as in the case of the "seaweed streaks" in the El Paso dolomite, forsterite is the product of simple metamorphism :

$$SiO_2 + 2MgCO_3.CaCO_3 = \underset{\text{Forsterite}}{Mg_2SiO_4} + CaCO_3 + CO_2$$

Hydration of the forsterite produces serpentine. At South Canyon forsterite is found abundantly only in rocks which preserve the streaky appearance of the El Paso beds ; no unaltered quartz remains and we must assume that the process was completed. For the metamorphism of the dolomites of South Canyon and the southern contact we conclude that the only contributing factors were the heat of the quartz-monzonite and the presence of water, possibly supplied from the magma.

The further change of brucite marble into magnesite probably belongs to a much later stage in the history of the rock, but, as it is difficult to decide definitely the time of this change, it will be considered here. The nature of the change is shown by the analyses below :

	Target Range Canyon	Target Range Canyon
CaO	34.04	5.35
MgO	23.01	41.76
SiO_2	1.60	0.86
Fe_2O_3	0.73	0.49
Al_2O_3	0.35	0.27
Ignition loss	40.27	51.27
	100.00	100.00

Analyst, H. C. Lee, University of Ohio

There is a decrease in lime, and an increase in magnesia and carbon dioxide; the reaction also involves the removal of water:

$$\underset{\text{Brucite}}{Mg(OH)_2} + CO_2 = \underset{\text{Magnesite}}{MgCO_3} + H_2O$$

It is suggested that waters charged with carbon dioxide would be capable of effecting this reaction. The lime would be removed as calcium bicarbonate, and the magnesia precipitated as the carbonate magnesite, which, if this process is to work, must be supposed to be less soluble in carbonated water than calcium carbonate. Temperature may have been a controlling factor. A very porous rock was produced.

The metamorphism of the epidiorites probably brought about little further change in composition, though some fluorine and chlorine may have been added to form apatite. In the case of the quartzite xenoliths it appears that all the necessry constituents were present in the Bliss series: silica, alumina, potash and phosphorus.

So far changes have been discussed in which little or no new material apart from water was introduced. When attention is turned to the dolomites at the northern contact, it is found that the earliest minerals, forsterite and serpentine, were formed under conditions resembling those of the southern occurrences. The chert nodules in the dolomites here seem to have contained alumina, since the reaction rims surrounding them contain spinel. There is, however, in the northern region plain evidence of addition and subtraction of material. Iron was added in fairly large quantities, to form magnetite. There may have been some migration of alumina, either within the dolomite or from the magma, producing chondrodite, penninite and phlogopite. Experience shows that magnesia has a much greater affinity for silica than has lime.[17] The presence of diopside thus suggests that there was silica in excess of that needed by the magnesia, and at least part of the silica must have been introduced.

The new minerals in the limestones derived part of their material from the enclosed beds. West of the Torpedo mine it is notable that the beds containing silicates are not generally the pure limestones, which are merely marmorized ; they are the siliceous limestones. Wollastonite may well have developed without any accession of new material. Beds containing some magnesia would give diopside. Andradite, however, the most abundant of all the new minerals, could not have been developed without metasomatism, and when the enormous quantities of this mineral are considered, it becomes evident that a very substantial amount of iron has been added to the limestones. Accompanying the iron came fluorine (now fixed in apatite and micas), chlorine (now in scapolite) and silica, since there is far more silica present than can be explained by recrystallization. At South Canyon, chromium was also added, a process which confirms the views of Sampson,[18] who has pointed out that chromium is by no means invariably segregated at an early stage in the history of the magma, but may persist and appear as a constituent of the hydrothermal solutions which bring about serpentinization. As far as the author is aware, the case described by Eskola (above) and the present one are the only examples of chrome-garnet formed under pyrometasomatic conditions, in genetic connection with a granitic rock.

[17]Harker, A., op. cit., p. 84.
[18]Sampson, E., Varieties of chromite deposits : Econ. Geol. Vol. 26, 1931, p. 834.

The metasomatic introduction of iron is seen in an even more striking way in the metamorphosed pre-Cambrian granite, for here the whole rock, save only the phenocrysts, is replaced by a mixture of magnetite, specularite and biotite. The abundant development of epidote in the lavas may also indicate a migration of iron and silica.

Time Relations.—No evidence remains of any changes which may have been brought about in the country rock by the intrusion of the first phase of the batholith ; the metamorphic rocks which remain are the result of the second and third intrusions. Those produced by the second phase are found at the southern contact, and in the xenoliths of South Canyon and the Cox ranch ; those produced by the third phase are seen in the northern region. There is every reason to suppose that the metamorphism due to the second phase had been accomplished before the intrusion of the third phase. Comparing the effects of the two phases, we find that while the second was probably hotter, since it produced periclase in the dolomites, it was much less well supplied with volatiles than was the third.

The heating of the country rock commenced at the time of intrusion of the magma, and continued while stoping was in progress. Heat was transferred to the enclosing rocks in two ways, by conduction and by means of fluid emanations. Hess and Larsen[19] were among the earliest workers to call attention to the efficacy of moving solutions as carriers of heat in the process of metamorphism. It is possible to evaluate the relative importance of these two modes of transfer according to the distribution of thermal metamorphic minerals in the aureole. If the minerals are irregularly localized, the probability is that moving 'fluid supplied the heat for their formation, even though it may not have contributed to their composition. If, on the other hand, the minerals are uniformly distributed, conduction may well have been the dominant factor. In the case of the southern contact and the South Canyon dolomite xenoliths, the metamorphism is remarkably even. Periclase-brucite marble and forsterite-serpentine marble make up the whole substance of the xenoliths, and extend evenly from the southern contact for a distance of 400 feet. It is reasonable to conclude that conduction of heat effected the transfer here, and that fluids played only a subordinate role. On the other hand, the aureole of the third phase is irregular in the extreme, and even minerals like wollastonite, which may imply little or no transfer of substance, evidently derived their heat from hot solutions moving in localized courses.

[19]Hess, F. L. and Larsen, E. S., Contact-metamorphic tungsten deposits of the United States : U. S. Geol. Surv. Bull. 725-D, 1921, p. 255.

The only unequivocally thermal metamorphic minerals in the region are periclase and forsterite; andalusite, lazulite and diopside are tentatively added to the list, and wollastonite is regarded as a possibility. These minerals were, on clear evidence, the earliest to form in their respective habitats. While the igneous rock crystallized, conditions favorable for the formation of these minerals graded into those in which metasomatism played a more important part. Periclase was converted into brucite, forsterite into serpentine. The accession of iron-bearing fluids led to the formation of andradite, which is frequently found cutting across wollastonite and diopside in veinlets, indicating its later position in the sequence of minerals. Some of the water was at this period fixed in hydrous minerals such as vesuvianite and the micas. Magnetite was introduced into the dolomites at the northern contact. Fluorine-bearing fluids gave rise to apatite, chlorine-bearing fluids to scapolite.

It is believed that this process was a long-continued one, which lasted from an early stage in the consolidation of the magma until it had almost completely crystallized. Locally the fluids emanating from the magma were able to alter the newly consolidated igneous rock. The results of this endomorphic process are to be seen near the Memphis mine, where andradite has been formed in the quartz-bearing monzonite; near the contact of the Excelsior rhyolite laccolith and the same rock, where diopside, andradite and tremolite appear in the monzonite ; and in the South Canyon region, where garnet and actinolite have been formed in the quartz-monzonite. An apophysis of the third phase near the Goat Ranch has been strongly altered to garnet and diopside.

Structural evidence indicates the continuance of garnet-formation until after much of the batholith had crystallized. The Torpedo-Bennett fault cuts the second and third phases of the batholith ; related to its northern extension near Hardscrabble there is a small body of garnet-diopside-pyrite rock replacing limestone, while in the southern part of its course, the garnet zone in the region of the Modoc mine was formed. The evidence in both places suggests strongly that the fluids necessary for the production of the garnet and the sulphides traveled along the fault.

Much has already been said about the separation of the metasomatic process into two periods, the first, already described, involving only limited addition of new material, the second implying a much more complete change of substance. Since this must appear a somewhat arbitrary distinction, the evidence upon which it is founded will now be set forth.

Except in the case of the xenoliths, the complete metamorphism of which has already been described, the metamorphosed rocks show evidence of fracturing and shattering after the formation of the silicate minerals, and the introduction of a suite of minerals generally recognized as characteristic of lower temperature conditions. Among these quartz, hydrous silicates, sulphides, tellurides and native metals are to be found. Of these minerals all save quartz and the hydrous silicates are compositionally foreign to the rock in which .they occur. Not only do they cut across the silicates of the earlier phase in veins, but they replace them ; and from the standpoint of metamorphism we may class the changes brought about as retrogressive. Garnet, for example, is converted into chlorite. The field relations are particularly well shown in the excellent outcrops at the Memphis mine. Irregular veins with quartz and sulphides traverse the massive garnetite, and in the beds marmorized but not silicated by the first wave of metasomatism, replacement bodies of sulphides have been formed. The clear separation of sulphide and silicate bodies into different beds thus suggests a difference in age. The separation cannot be interpreted simply as a case of "ore on the limestone side of the contact zone";[20] in section at the Memphis we have, from east to west: first a thick bed of garnet rock ; then a series of sulphide bodies replacing limestone without garnet; then another silicate bed, followed again by marmorized limestone with sulphides near the top ; these are capped in turn by a final garnetite bed. Such an arrangement is much more readily effected by successive than by contemporaneous replacement, and when the evidence of cross-cutting veins of quartz and sulphides in the garnetite is considered, there can be little doubt that the most susceptible beds were first replaced by garnet, the less susceptible beds remaining to be replaced later by the quartz and sulphides.

The introduction of the sulphides and the minerals which accompanied them took place, then, after the silication process was complete. To what extent is the separation of the metasomatic process into two periods justified? At Clifton-Morenci, an area with which the Organ district has many features in common, Lindgren found good reason to separate contact metamorphism from hydrothermal metamorphism. Referring to the relation between the two, he says, "At first glance it might seem plausible to assign all the changes which have taken place in the metamorphic zone to the same hydrothermal alteration which has affected the porphyry along the fissure veins. The view, however tempting, is surely incorrect. Instead of one set of phenomena,

[20]Umpleby, J. B., The occurrence of ore on the limestone side of contact zones : Univ. Cal. Dept. Geol. Bull. 10, 1916, pp. 25-37.

we have two related and, in part, superimposed processes.[21] On the basis of difference of what Graton calls "intensity" of physical conditions,[22] this separation is quite justified.

It is quite likely, nevertheless, that the sulphides followed the silicates as part of a continuous mineralization process. The sulphides were formed at temperatures below those at which the "high intensity" silicates were capable of forming. In the great copper ore body at the Torpedo mine, representing the high-temperature zone of ore-deposition, both calcite and quartz occur as gangue minerals. Evidently this body was formed at a temperature below that at which silica and calcium carbonate can combine.

As mentioned earlier, there is also a significant difference in structural association between the mineral bodies formed during the first stage of metasomatism, and those formed during the second. The first group are highly irregular replacement bodies adjacent to the contact of the batholith, without any obvious control by fractures. The 'fluids may be supposed to have soaked through the rocks at this stage. Two transitional cases—the Modoc area and the hill south of Hardscrabble—connect the first group with the second. In these, garnet occurs adjacent to a fault. In the second group, in every case the existence of structural channelways along which the fluids moved can be proved. The fluids were able to travel much farther away from the parent igneous rock. Spatially, the products of mineralization due to the two periods of metasomatism are found to correspond closely with the two classes of *Metamorphose unter stoffzufuhr* of Niggli,[23] the first being equivalent to his perimagmatic contact metamorphism, the second to his apomagmatic metamorphism.

Summarizing the time-relations in the metamorphic process, it is found that the earliest products were minerals depending entirely or largely upon the composition of the rock which they replaced ; that these gave place to minerals whose development was metasomatic, part of their substance being derived from fluids expelled from the igneous rock (first metasomatic period) ; that these were succeeded by minerals almost wholly derived from fluids (second metasomatic period). As far as the evidence goes, it indicates that the whole process was a continuous one, but that the distribution of minerals was controlled, especially in the later stages, by channelways of structural origin.

Nature of the Fluid Emanations.—It remains finally to enquire into the nature of the medium which transported the substances during the metasomatic processes. Two observations

[21] Lindgren, W., op. cit., 1905, p. 176.
[22] Graton, L. C., Depth zones in ore deposition: Econ. Geol., Vol. 28, 1933, p. 522.
[23] Grubenmann, U., and Niggli, P., Die Gesteinsmetamorphose: Berlin, 1924, pp. 308-318.

are suggestive in connection with the first stage of metasomatism. Andradite is associated with apatite and scapolite, so that the iron may have traveled as the fluoride or chloride, both of which are known to be volatile substances.[24] However, the amounts of apatite and scapolite which remain are not sufficient to account for the great quantity of andradite found. Secondly, intense sericitization is not associated With the first wave of metasomatism. Since most authorities agree that the potash necessary for sericitization probably cannot be carried by gases, this second observation may be important.[25] These two observations are the only ones which can be cited in favor of a pneumatolytic rather than hydrothermal transfer of material during the early stage of metasomatism, and they cannot be regarded as conclusive.

The relative merits of the several possible means of transfer of substance under conditions such as have been described command no unanimous opinion. V. M. Goldschmidt[26] and Harker[27] among many others favor pneumatolysis, because they believe conditions to be such as to prevent water from existing as a liquid below its critical point. On the other hand, Morey[28] believes that the pressure would be adequate to prevent boiling, so that there would be a continuous passage from wet melt to hydro-thermal solution. Intermediate positions are adopted by Lindgren[29] and Niggli.[30] Recently Fenner[31] has advocated gaseous transfer of substances from the magma during the cooling process; while Bowen " has stated that boiling off of residual solutions may take place at a late stage in magmatic history. As has been shown above, it is possible that gases may have been responsible for the transfer of iron during the early metasomatic stage, but the evidence is not such that any definite conclusion can be reached.

The second metasomatic stage, during which the mineral deposits were formed, may be ascribed with reasonable certainty

to liquid hydrothermal solutions. Sericitization accompanies the mineralization, and the minerals formed are those which are recognized as characteristic of deposition at medium to low temperatures, probably below the critical point of water.

[24]Fenner, C. N., Pneumatolytic processes in the formation of minerals and ores : in Lindgren Volume A. I. M. E., 1933, p. 85.

[25] Compare Bowen, N. L., The broader story of magmatic differentiation: in Lindgren volume, A.I.M.E., 1933, p. 119.

[26]Goldschmidt, V. M., Kontaktmetamorphose ion Kristianiagebiet : Kristiania, 1911, pp. 211-213.

[27] Harker, A., Natural history of igneous rocks : London, 1909, p. 299.

[28]Morey, G. W.. Relation of crystallization to the water content and vapor pressure in a cooling magma : Jour. Geol. vol. 32, 1924, pp. 291-295.

[29] Lindgren, W., op. cit., 1933, p. 710.

[30]Niggli, P., trans Boydell, H. C.. Ore deposits of magmatic origin : London, 1929, pp. 4-12.

[31] Fenner, C. N., op. cit., pp. 74-76.

[22] Bowen, N. L., op. cit., pp. 118-126.

MINERAL DEPOSITS

GENERAL FEATURES

The closing stages of the intrusive cycle in the Organ region were marked by the deposition of ores from hydrothermal solutions, the last residues from the crystallization of the magma. The period of ore formation is classed as the second metasomatic period. An account of this period is presented in this section. Here the mineral deposits will be treated from the genetic rather than from the commercial point of view; for full descriptions of the mines and prospects, and an appraisal of their possibilities, the reader is referred to Part III of this work.

The ore deposits of the Organ District have been classified by Lindgren[1] as follows: (1) Fissure veins in intrusive rocks; (2) Replacement veins in limestone; (3) Contact metamorphic deposits. A similar but more extended genetic classification will be adopted here, as follows:

1. Pegmatites.
2. Veins cutting the Tertiary batholith.
3. Veins cutting pre-Cambrian rocks.
4. Deposits in the Torpedo-Bennett fault zone.
5. Replacement deposits in previously metamorphosed limestones and dolomites.
6. Other replacement deposits in limestones and dolomites.

Each of these groups, which will be considered in turn, possesses distinctive characteristics. Special attention will be paid to the structural conditions which have influenced the localization of the deposits. Finally, an attempt to present a unified scheme showing the relation of the types to one another will be made.

At and near their outcrops the ore deposits of the region have suffered oxidation due to reactions with meteoric waters and with the atmosphere. Very few of the mines are deep enough to have penetrated to the completely unaltered deposit, but in many cases enough hypogene material remains to make the determination of the character of the original minerals a matter of reasonable certainty. The present section is concerned only with the hypogene minerals; supergene changes in the deposits are dealt with in the section on late Tertiary and Quaternary events.

1. PEGMATITES

We return now to a consideration of the late stages of the cooling history of the third phase of the batholith. From several lines of evidence it has been deduced that there was a progres-

[1]Lindgren, W., Graton, L. C., and Gordon, C. H., Ore deposits of New Mexico: U. S. Geol. Surv. Prof. Paper 68, 1910, p. 209.

sive concentration of volatile fluxes during the intrusive cycle, so that phase III, the quartz-bearing monzonite, was much more abundantly supplied with these than either of the phases which preceded it. It is possible that the stock which is occupied by phase II is a cupola near the roof of a much larger body, and that the volatiles of the whole body tended to collect in it before crystallization commenced. The studies of Butler show the plausibility of such a process. As we have already noted, some of the volatiles, especially iron, the halides, and silica may have escaped during cooling; the greater part, however, remained in the magma and collected as crystallization proceeded, eventually forming an aqueous rest magma rich in hyperfusibles.[3] This seems to have collected in highly irregular pockets in the crystalline body.

At the same time there were locally in existence small segregations of a volatile-poor rest magma which produced the aplites. The reason for the separation of these two rest magmas is not understood; it is, of course, a problem common to all igneous bodies which contain both pegmatites and aplites. Derry has suggested that the separation is effected by squeezing after some crystallization had occurred, the aplite remaining as the mesh of crystals already formed, the pegmatite being later crystallized from the separated magma; but this explanation will not fit the facts in the present region, for the aplites are numerous and small, and occupy joint planes, while the pegmatites are large, irregular and few in number. Another theory worth considering is that the pegmatites were introduced from deeper sources while the aplites represent the local rest magma. The extreme irregularity of the pegmatites of the present region argues strongly against such an explanation. Some evidence of structural control would be expected had the pegmatite-magma ascended from a deeper source; whereas such evidence is quite lacking. The pegmatites are believed to occupy the irregular pockets where the volatile-rich rest magma accumulated. We can reach only the unsatisfactory conclusion that the normal course of crystallization of the body was able to give rise to two different rest magmas.

Field Relations.—Pegmatites occur cutting only the third phase of the batholith. The largest area occurs south of the Alamogordo road, approximately one mile east of San Agustin Pass. The exposure here is poor, but there is evidence of at least two kinds of material in this body ; very coarse-grained granite, and

[2] Butler, B. S., Summarized in: Ore deposits as related to stratigraphic, structural and igneous geology in the western United States : Lindgren Volume, A. I. M. E., 1933, pp. 234238.

[3] Bowen, N. L., op. cit., 1933, p. 111.

[4] Derry, D. R., The genetic relationships of pegmatites, aplites, and tin veins: Geol. *Mag.* Vol. 68, 1931, pp. 454-475.

orthoclase-albite-mica pegmatite. Lenses of quartz occur, but no metallic minerals have so far been found. At the Quickstrike mine, on the east side of San Agustin Peak, six bodies of pegmatite up to 100 feet in length are exposed. The mine workings show plainly that they are lenticular in the dip direction as well as in the strike direction. They show a rough parallel north-south elongation, and they grade into the surrounding monzonite. An extremely irregular body is exposed at the Ben Nevis mine, and another at the Gray Eagle mine, south of San Agustin Peak. There is an ill-defined mass east of the Quickstrike mine and a small body in the canyon west of San Agustin Peak. In no case do these bear any structural resemblance to vein deposits.

Mineralogy.—In striking contrast to the pre-Cambrian pegmatites, the mineralogy of the Tertiary pegmatites is complex, a large assortment of minerals being found. Transitional in position and in character between the monzonite of phase III and the pegmatite is the coarse granite from the area south of the Alamogordo road. This contains pink orthoclase crystals up to 40 mm. in length which are found in thin section to be perthitic, with conspicuous albite segregations. Other minerals present are quartz and chloritized biotite, and the rock has a granitic texture. In the pegmatite from the same locality, the predominant mineral is albite, which is traversed by replacing veins containing quartz, muscovite, hornblende, zircon, anatase and brookite. The titanium minerals were first observed in thin section but were concentrated by the heavy liquid method and identified crystallographically by Professor Palache. The refractive index of the zircon, determined by means of melts, was found to be near 1.991.

The pegmatites on the Quickstrike property are interesting because of the presence of a dark green pyroxene in bladed crystals up to 16 cm. in length. The optical properties of the mineral are as follows: α 1.690, β 1.695, γ 1.713 ; positive, 2V moderate ; maximum extinction 42°. According to Winchell's data,[5] the mineral belongs to the diopside-hedenbergite series and contains diopside 73 per cent, hedenbergite 27 per cent. The mineral bears a marked resemblance to the so-called hedenbergite found at Hanover, New Mexico. Associated with the pyroxene in the Quickstrike group orthoclase, actinolite, epidote, chlorite, pyrite, sphalerite, chalcopyrite, galena, argentite and very coarsely crystalline quartz occur. Some of the individual quartz crystals reach as much as one foot in length.

At the Ben Nevis mine, orthoclase, albite, a pyroxene having properties similar to that at the Quickstrike, actinolite, chlorite,

Winchell, N. H., op. cit., 1933, p. 226.

quartz, calcite, chalcopyrite, pyrite, sphalerite, galena, tetradymite, and argentite occur in a pegmatite. Some coarse yellow garnet was found, with refractive index 1.775, indicating the composition to be grossularite 80 per cent, andradite 20 per cent. Associated epidote has the following optical properties : a 1.733, β 1.751, *y* 1.772; positive, 2V 85°; these data indicate that the ratio Fe:Al is 2:5 according to Larsen's data ; or, according to Winchell, the mineral is a pistacite with 30 per cent $Ca_2Al_3Si_3O_{13}$. The quartz at the Ben Nevis is very coarse and in places has an amethyst color.

Orthoclase, coarse quartz and sulphides occur at the Gray Eagle mine. The green pyroxene is the principal constituent of the pegmatite in the canyon west of San Agustin Peak.

Genetic Features.—The pegmatites of the Organ District form an excellent illustration of the aqueo-igneous replacement theory of pegmatite formation which has come into prominence through the work of Larsen, Palache, Landes, Hess, and Schaller.[6] The sequence of mineral transformations can be studied very readily, with unambiguous results. Early minerals are traversed by veins containing later minerals, and also replaced by them.

- The following general sequence was obtained :

Group 1. Orthoclase, probably with some albite in solid solution.

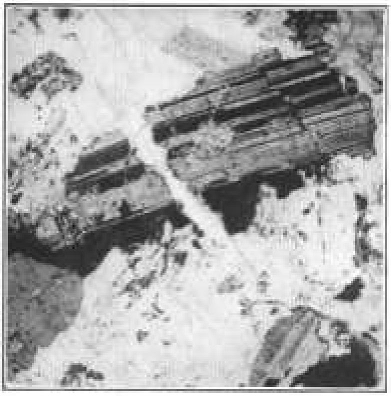
Group 2. Albite, quartz ; replacing orthoclase. *Fracturing*

Group 3. Quartz, very coarse. Muscovite.Diopside-hedenbergite. Grossularite.Anatase, brookite, apatite.

Group 4. Quartz, finer-grained.Epidote.Actinolite, replacing the pyroxene.Chlorite.Pyrite.Tetradymite. Chalcopyrite.Sphalerite. Galena.Argentite.

Comparing this succession with that generally found in complex acid pegmatites, as summarized by Schaller,[7] we find that it follows the usual course observed in such bodies. However, it appears that the pegmatites of the Organ District are unusually rich in sulphides, while the familiar boron and lithium minerals of granite pegmatites are entirely lacking.

[6]The history of this theory is fully described by Landes : Landes, K. K., Origin and classification of pegmatites : Amer. Min. Vol. 18, 1933, pp. 33-56, 95-103.
[7]Schaller, W. T., Pegmatites : Lindgren volume, A. I. M. E., New York, 1933, p. 150.



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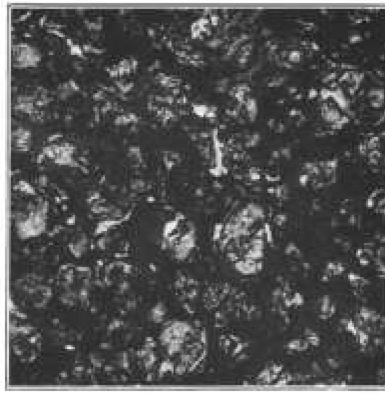

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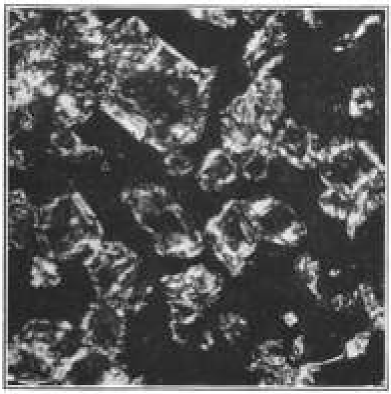

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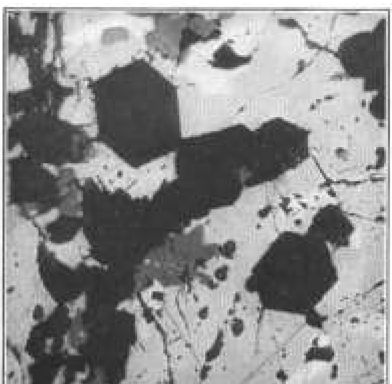

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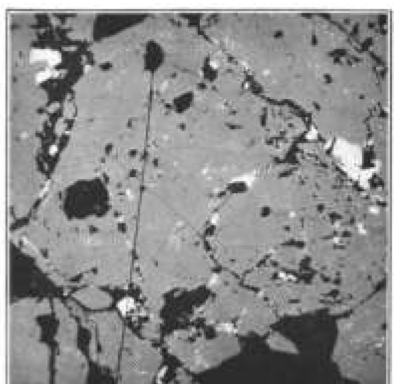


F

PHOTOMICROGRAPHS OF THIN AND POLISHED SECTIONS
See opposite page for explanation.

EXPLANATION OF PHOTOMICROGRAPHS, PLATE VI

A. Pegmatite, 1 mile east of San Agustin Pass.
Albite crystal distorted, and veined by quartz.
Crossed nicols X 20 (1146)

B. Garnet-rock, Merrimac mine.
Andradite (high relief), replaced by chlorite (gray), and quartz (white), and surrounded by sphalerite (black).
Ordinary light X 30 (1070)

C. Metamorphosed dolomite, gully southeast of Merrimac mine.
Serpentine, probably pseudomorphs after forsterite, enclosed by magnetite (black).
Crossed nicols X 23 (1050)

D. Brucite marble, South Canyon.
Brucite (concentric aggregates) in calcite matrix. A crystal of forsterite, partly replaced by serpentine, appears in the lower left-hand corner of the field.
Crossed nicols X 23 (1231)

E. Silver ore, Hawkeye mine.
Tetrahedrite (light gray), sphalerite (dark gray), chalcopyrite (white), and quartz (black). Typical leptothermal silver ore.
Ordinary light X 55 (1140)

F. Lead-zinc ore, 200-foot level, Stevenson-Bennett mine.
Sphalerite (dark gray) traversed by veinlets containing galena (white). The sphalerite contains spots of chalcopyrite.
Ordinary light X 28 (1295)

A to D, Thin sections; E and F, Polished sections.

In view of the occurrence of sulphides, we are adopting a reasonable course if we regard the pegmatites as transitional between the magmatic and hydrothermal stages, or between igneous rock and ore deposits; indeed this occurrence might have been used to good account at the time when the hydrothermal theory of ore deposition was in course of being established. Attention must, however, be paid to a recent statement by Loughlin and Behre:[8] ". . . the ore forming solutions in large quantity are derived from a deep source that was developed by further differentiation after the pegmatitic and contact metamorphic stages." It is quite unnecessary to postulate any such deep source of solutions in the present case. It is not, of course, suggested that the ore deposits of the Organ region were derived entirely from the pegmatite bodies now exposed; but it is asserted that the residual fluids of the magma collected into pockets of identical character with those now occupied by the pegmatites, scattered through the upper part of the batholith, and that the fluids were thence expelled after the crystallization of the early minerals, the feldspars and pyroxenes. The expulsion of fluids may have been due to boiling off, as Bowen has suggested,[9] or to earth pressures. An important implication of the occurrence of sulphides in the pegmatites is that the period of sulphide deposition was later than the period of formation of the normal pegmatite minerals, and not earlier as it would be on the theory recently advanced by Fenner.[10]

In the pegmatites, stages corresponding closely with the magmatic, early metasomatic and late metasomatic stages should appear; and an inspection of the general sequence of minerals will show that this is the case. Group 3 in the succession listed just above is the equivalent of the pyrometasomatic stage in the metamorphosed country rocks, and contains garnet and pyroxene; while group 4 contains almost the full assemblage of minerals characteristic of the later quartz-sulphide type of metasomatism.

2. VEINS CUTTING THE TERTIARY BATHOLITH

Distribution.–Mineral veins are found cutting the intrusive monzonites in only the northern part of the range. In Texas Canyon the Texas Main vein occupies a fault which traverses both the first and second phases of the batholith, and the Texas Cross vein follows the course of a felsite dike in the second phase. These are the only veins of importance known in the two earlier phases. Cutting phase III there are numerous veins,

[8]Loughlin, F. G., and Behre, C. H., Jr., Classification of ore deposits : Lindgren volume, A. I. M. E., New York, 1933, p. 52.

[9]Bowen, N. L., op. cit., 1933, p. 118.

[10] Fenner, C. N., op. cit., 1933, pp. 75, 76.

some of which have been worked on the Big Three, Crested Butte, Hawkeye, Poor Man's Friend, Silver Coinage and Silver Moon properties. Other examples occur near Rakestraw's camp; north of the main road east of San Agustin Pass ; and near the Cox ranch road south of the Galloway mine. With this group the veins which follow along the rhyolite dikes must be included; all of these, save that at the Galloway mine, contain only quartz and scattered pyrite.

Structure.—The strike of the veins is within a few degrees of east-west, except in the cases of the Poor Man's Friend, Davy King and Texas Canyon veins, and the veins which follow the walls of dikes. The east-west veins dip steeply and may be inclined to the north or south. The Poor Man's Friend vein has an arcuate outcrop due to its low dip, 40° southwest; its general direction of strike is northwest. The deposit at the Galloway mine occupies stringers in the north side of a loop in the northwest-trending Galloway dike. The Davy King vein strikes northeast, and dips steeply southeast. The Texas Main vein strikes N. 76° E. and dips 80° N., while the Cross vein strikes 50° E. and dips steeply to the north.

Of all the veins of this type, the Texas Main vein is the only one which is known to occupy a fault of considerable displacement. For part of its course it brings the first and second phases of the monzonite series together. All the other veins are in fissures along which the displacement has been small. The fissures were formed after the jointing of the intrusive rocks, for at the Hawkeye and Poor Man's Friend properties the veins make a small angle with the joints, showing that they are not mineralized joint planes. The veins are generally narrow, varying from a few inches to about two feet. Mineral-bearing portions occur as irregular shoots separated by barren stretches of the fissure; individual shoots seldom exceed 100 feet in any dimension and frequently are much smaller. The Texas Main vein is quite exceptional in this respect. Its maximum width is about 8 feet, and the mineralization appears to be continuous for about 1500 feet along the outcrop, though variable in width. Chloritic gouge may or may not be present; it is notable in the Silver Coinage and Texas Main veins.

Age Relations.—The Texas veins are known to be later than intrusive phases I and II of the batholith ; the rest are later than phase III. The Galloway and Excelsior rhyolite dikes cut through the veins at the Big Three and Hawkeye properties, and the relations, well exposed at the surface, admit of no other explanation than that the dikes are later than the veins. However, the deposit at the Galloway mine is equally definitely later than the

Galloway dike. It appears then that the rhyolites were intruded while the mineralization was actually in progress.

Mineralogy.—For mineralogical description the veins may be divided into two groups; those cutting the third phase, and those cutting the first and second. The first group belong to the quartz-tetrahedrite-galena type.[11] The following primary metallic minerals [12] are present: pyrite, chalcopyrite, sphalerite, tetrahedrite, galena, argentite ; locally subordinate amounts of enargite and tetradymite, the bismuth telluride, have been found. Gold is present in traces only, except in the Davy King vein. The tetrahedrite is the silver-bearing variety, freibergite. Quartz is the most abundant gangue mineral and is present in variable amount in all the veins. It is much less coarse in grain than the quartz which was formed during the early stage in the pegmatites and in the contact metamorphic zones. A difference in coarseness of quartz is frequently observed between higher and lower-temperature deposits, as Graton[13] pointed out. Frequently the quartz lines the walls of the vein and is associated with early pyrite; the later sulphides then occur in the center of the vein. In veins of this sort the quartz has not usually been able to develop crystal faces, but where the sulphides are not present a comb of quartz projecting into empty central cavities is often found. Other gangue minerals include green fluorite and brown siderite, found in the Silver Coinage vein, and barite, present in a vein near the mouth of Black Prince Canyon. Chlorite, deriving its constituents partly from the wall rock, is often found, and in cavities in the Silver Coinage vein it has crystallized with quartz. Calcite seldom occurs in veins of this type.

The silver for which the veins are chiefly valuable is associated with three primary minerals, galena, tetrahedrite and argentite. Veins without the last two minerals do not contain more than about 20 ounces silver per ton; but where tetrahedrite is present, the assays may reach 1200 ounces per ton. As tetrahedrite does not exceed one-third of the total sulphides, it must carry about 10 per cent silver. A specimen of sulphides from the Silver Moon vein assaying 3.6 per cent silver was examined by means of polished sections. Tetrahedrite and galena were the only silver bearing minerals present. The galena was examined under high power but no inclusions of argentite or other silver minerals could be found, and treatment with potassium cyanide

[11]Lindgren, W., Mineral deposits: 4th Ed., New York, 1933, p. 565. McKnight, E. T., Mesothermal silver-lead deposits: Lindgren volume, A. I. M. E., p. 589.

[12]dentified by optical and etch tests on polished surfaces and by microchemical tests. The following works were consulted for reference: Short, M. N., Microscopic determination of the ore minerals: U. S. Geol. Surv. Bull. 825, 1931. Schneiderhohn, H., and Ramdohr, P., Lehrbuch der Erzmikroskopie, Bd. II: Berlin, 1931.

[13]Graton, L. C., Depth zones in ore deposition: Econ. Geol., vol. 28, 1933, pp. 528, 535. 537, 541.

failed to bring out any black spots. It follows, according to Guild's observations, that the silver content of the galena cannot exceed 0.10 per cent[14] Thus tetrahedrite is evidently the carrier of most of the silver in this case. The other important silver mineral is argentite. In material from the Silver Coinage stope, it is clear that argentite and not tetrahedrite is the source of the silver. The relations show clearly that argentite is a late material, associated with galena in veinlets, some of which cut across the other sulphides. Some supergene alteration of chalcopyrite and galena to chalcocite and covellite was noted in this material, but argentite was not found to be associated with these minerals. Probably the argentite is a hypogene mineral in this case, but there is always the possibility that supergene argentite may occur in some of the veins; none has been definitely proved. At the Galloway mine, argentite and galena are the primary minerals. Tetrahedrite is the silver-bearing mineral in the veins on the Big Three and Hawkeye properties.

The minerals in the Silver Coinage and Silver Moon veins were studied in polished sections in order to determine their order of deposition. It was found that quartz and pyrite were the first minerals to form. Fracturing then occurred, and the other sulphides followed, occupying ramifying veins through the pyrite and partly replacing it. (See Plate VIII, page 156). The following general sequence of primary minerals was determined:

1. Quartz, pyrite.
2. Chalcopyrite, enargite, sphalerite, tetrahedrite, galena, quartz.
3. Argentite.

The minerals of the second group were deposited at approximately the same time ; each one may include any of the others. It was found that the succession held for the other veins of the type as far as the limited material available showed.

Adjacent to the veins the monzonite has been hydrothermally altered. Quartz and the accessory minerals remain unchanged. Orthoclase-perthite is more resistant to this type of alteration than oligoclase, and is little altered ; this is exactly the reverse of the relative response of these minerals to superficial alteration (See page 70) . Plagioclase and to a lesser extent orthoclase are converted into fine-grained chlorite (predominating) , sericite, quartz and carbonate. Biotite is bleached and converted into chlorite. This type of alteration corresponds with that found beyond the sericite alteration along the veins at Butte, Montana,[15] and is of a low-intensity type.

[14]Guild, F. N., The enrichment of silver ores : in Laboratory investigation of ores, New York, 1928, p. 213.

[15] Personal communication, M. Lewis II.

In two cases veins of this type show mineral variation. The Ruby vein on the Big Three property is said to have increased in sphalerite content when followed down to 200 feet depth, while in a horizontal direction the mineralization of the Poor Man's Friend vein changes from quartz-galena-tetrahedrite at the northwestern end to quartz-sphalerite-galena at the southeastern end. These changes may be regarded as expressions of mineral zoning.

In the second group, there are only the veins in Texas Canyon to consider. The Cross vein is too much oxidized to permit a reliable determination of its primary minerals. The Main vein, however, is not deeply oxidized and primary material is readily obtained. The minerals are pyrite and chalcopyrite in roughly equal amounts, in a gangue of vuggy white quartz. Minor amounts of galena and tetradymite are present. Gold averages 0.194 ounces per ton (30 assays), silver 13.87 ounces. A search for the gold in polished sections using a magnification of 1200 diameters was not rewarded with success, but the ore is known to be refractory, and the likelihood is that the gold is present either in the pyrite or chalcopyrite. A small amount of argentite was noted in one section, and the silver is thus thought to be present as the sulphide. Barite is locally an important constituent of the Texas Main vein. At the lower levels (5670 to 5900 feet altitude) only a small quantity is present, but near the crest of the ridge forming the west wall of the canyon (6200 feet) , barite is present in quantity, and continues down the slope to the west. There appears to be a diminution in quantity of sulphides with the upward increase in barite. This change is also referred to primary zoning.

The alteration along the Texas Main vein resembles closely that along the other veins in the batholith and is chloritic in character. In the monzonite of phase I, pyroxene, hornblende and biotite have all been converted into chlorite. The feldspars have given rise to sericite and chlorite. The alteration imparts a light color to the rock, so that the vein may be traced by the light rock which fringes it on either side to a distance of about 3 feet; the altered rock passes gradually into the dark, fresh monzonite.

3. VEINS CUTTING PRE-CAMBRIAN ROCKS

Distribution.-Veins are abundant in the northern area of pre-Cambrian rocks, their commonest mode of occurrence being along epidiorite dikes. As shown below, they are of Tertiary age. The Gold Camp sub-district, lying north and east of Mineral Hill, contains many veins of this type, among which the. Mormon, Sally, Sunol and Santa Cruz veins are the most important. On the west side of Mineral Hill the Emma group of prospects, ineluding the Black Hawk property, has explored similar veins, while at the northeast end of the hill the Eureka prospect exposes a good example of the type. Southeast of Mineral Hill veins occur at the Maggie G and adjacent prospects. In the region of the Black Prince mine several shafts have been sunk on veins following along epidiorite dikes, and to the northeast at the Buck Deer prospect another example may be seen. The vein at the Rock of Ages mine follows a rhyolite dike.

Less important is a second class of veins which occupy fissures cutting the granite, but which are not adjacent to dikes. The Dona Dora and Alligator tunnels have exposed such veins, and farther north other examples occur at the Pharmacist mine and south of the Eureka prospect.

Veins in the pre-Cambrian rocks are confined to the northern area, lying to the east at the outcrop of the third phase of the batholith. A little gold has been found in a vein along a north-south epidiorite dike near the mouth of Texas Canyon, but this is the only occurrence south of Antelope Hill.

Structure.—In structural features the veins cutting only the granite resemble closely the veins in the Tertiary monzonite. The general strike is east-west, the dip is steep ; the mineral filling does not exceed one foot in width. The fissure may continue for a fairly long distance, for example, the Dona Dora vein has been followed by a tunnel for 1700 feet ; but the mineralization is confined to a few sporadic shoots. (See map, page 207) .

The veins following along the epidiorite dikes are structurally more complex. The fissure may occur along the footwall or hangingwall of the dike or may cut across it. At the prospect on the ridge southeast of the Black Prince mine, veins occur both on the hangingwall and footwall, and also in the center of the dike. At the Eureka prospect the vein occurs on the footwall, but a branch vein has been found trending towards the hangingwall. There are veins along both walls of the Maggie G dike. The vein at the Dummy B and Pagoda prospects is on the hangingwall, while at the Black Hawk prospect the mineralization follows the footwall. The Mormon dike is mineralized on the hangingwall, but small veins cut across the dike ; at the Sunol mine both walls of the dike as well as fissures within it carry mineral material. The Santa Cruz vein follows the footwall. Evidently no rule can be made about the localization of the fissuring with respect to the dike; the true complexity of the fissuring was revealed by underground mapping at the Sally mine. The dike is split up by fissures into a number of segments which are displaced relative to one another (See map, page 212). Any of the fractures may be mineralized. The complexity of the pattern cannot be seen at the surface because of the poor exposures of the dikes.

By mineralization the dikes are thus converted into lodes containing many small fractures differing widely in direction and attitude. These conditions result in the localization of mineralized ground in highly irregular shoots, controlled by the local structure. The maximum width of vein matter developed in the shoots does not generally exceed 2 feet.

The most highly mineralized area in the pre-Cambrian terrane is found along the belt of type II epidiorites lying between the Mormon and Santa Cruz mines. Outside this area, both veins and dikes are much more widely spaced. The pre-Cambrian dikes have evidently played an important part in the Tertiary mineralization process by acting as planes of weakness along which structural adjustments could take place, providing in the process channels for the movement of mineralizing solutions. The amount of movement has been greater in fissures of this type than in those in the monzonite or granite; gouge is always present, and the vein matter originates at least in part by the replacement of the gouge.

Age relations.–The Pagoda shaft provides the clearest evidence of the Tertiary age of the veins in the pre-Cambrian. The northern area of pre-Cambrian rocks is traversed by a series of echelons of Tertiary rhyolite dikes, identical in character with those which cut the monzonites. Near the Pagoda shaft one of these rhyolite dikes seems to be displaced by the Pagoda epidiorite (Fig. 6, page 123). Underground, however, the true relations can be seen. The rhyolite actually cuts through the epidiorite, but faulting along the hangingwall of the epidiorite took place after the injection of the rhyolite and thus caused an offset of the rhyolite. The mineralization definitely took place after the last movement on the fault. Galena replaces the gouge, and in hand specimen has a schistose appearance, as if it had been sheared ; but examination of a polished surface of the galena showed that it has not been distorted. Evidently it inherited its texture from the gouge. The Pagoda deposit is typical of the veins cutting the pre-Cambrian, and is clearly of Tertiary age. Similarly, the Eureka vein-fissure displaces a rhyolite dike which has cut through the epidiorite dike. Further confirmatory evidence comes from the texture of the veins. Many vugs occur, lined with quartz or calcite crystals. The veins belong to a leptothermal type and are quite different from the hypothermal, compact deposits characteristically found in the pre-Cambrian rocks in New Mexico and Arizona.

Mineralogy.–The mineralogy of the veins is simple. Quartz and pyrite are universally present. Chalcopyrite is the next most abundant constituent, and was noted in the Black Hawk, Buck Deer, Eureka, Green Girl, Maggie G, Mormon, Pagoda,

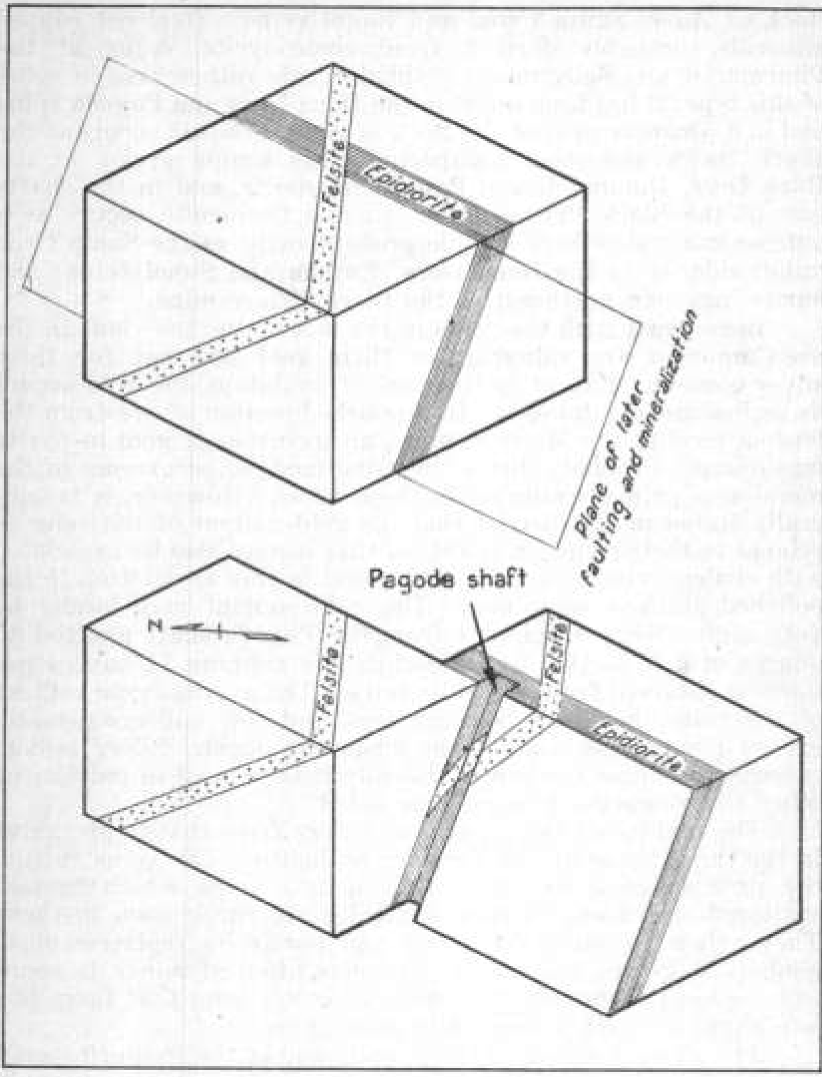


FIGURE 6.—Block diagrams to show structural relations at the Pagoda prospect.

The upper diagram represents the conditions after the injection of the Tertiary felsite dike, but before the faulting along the hanging-wall of the epidiorite. The lower diagram shows the present relations. The contacts between the epidiorite and felsite cannot be seen on the surface, but are visible underground.

Rock of Ages, Santa Cruz, and Sunol veins. Oxidized copper minerals, probably derived from chalcopyrite, occur at the Pharmacist and Sally mines. Sphalerite is rather rare in veins of this type ; it has been noted in the Dona Dora and Pagoda veins and in a prospect west of the Rock of Ages. Galena occurs at the Black Hawk and other prospects of the Emma group, at the Buck Deer, Dummy B and Pagoda prospects, and in the shafts east of the Black Prince mine. Calcite frequently occurs as a gangue mineral ; others include green fluorite, at the Santa Cruz mine; siderite in the Dona Dora, Eureka and Sunol veins; and barite in a vein northeast of the Black Prince mine.

In contrast with the veins in the monzonite, the veins in the pre-Cambrian are valuable for their gold and not for their silver content. Except in the zone of oxidation, the gold occurs as inclusions in sulphides. In a polished section of ore from the 90-foot level at the Mormon mine, an inclusion of gold in pyrite was found. Probably this is the usual mode of occurrence of the metal as a primary mineral in these veins. However, it is generally stated in the district that the gold-content of the veins is related to their copper-content, so that it may also be associated with chalcopyrite. No gold was found in this association in the polished sections examined. The gold content may locally be very high. Some specimens from the Pagoda shaft assayed 35 ounces of gold to the ton. Recently ore running 11 ounces per ton was obtained from the Sally mine. The average gold content of the veins, however, is much less, and few will consistently exceed 1 ounce per ton for the whole ore shoot. Silver seldom exceeds 10 ounces per ton. Probably it is present in galena; no other silver-bearing mineral was noted.

The texture of the veins also differs from that of the veins in the third phase of the Tertiary batholith. The veins cutting the pre-Cambrian are essentially quartz veins which contain scattered sulphides ; massive sulphides are rarely seen in them. They originate partly by filling and partly by replacement of gouge. Vugs are numerous. The deposition of minerals seems to have been essentially contemporaneous, except that there is a late phase of calcite stringers in some veins.

The alteration both of the granite and of the epidiorite adjacent to the veins is of the chloritic type. The changes brought about in the epidiorite have been described on page 39. Hornblende and biotite are converted into chlorite ; new albite and quartz are formed. In the granite, chlorite and sericite replace the feldspars ; the quartz remains unaltered.

4. DEPOSITS IN THE TORPEDO-BENNETT FAULT ZONE

Distribution.—The name "Torpedo-Bennett fault zone" is applied to the north-south trending fault system which extends along the west side of the Organ Mountains from Hardscrabble

Hill to Dripping Springs. It is composed of several parallel and sub-parallel faults which branch and re-unite, and form in places a zone 1400 feet wide. Mineral deposits in this zone, structurally related to it, occur on the hill south of Hardscrabble; at the Torpedo, Stevenson-Bennett, Hayner, Modoc and Orejon mines; and at the Trapezoid and Silver Cliff prospects.

Structure.—The fault zone is dominated by normal faults, but appears to contain some reverse faults in addition. The major fault-planes dip consistently to the east with few exceptions. On Hardscrabble Hill the zone is represented by a single fault which, if it truly dips to the east as it appears to do, must be a reverse fault since it brings Magdalena rocks on the east against Tertiary lavas on the west. Between the hill south of Hardscrabble and the Flying Bar-U ranch the fault is concealed by alluvium, but the supposed southern continuation appears south of the ranch, where it brings the Magdalena series on the west against the quartz-bearing monzonite. North of the Memphis mine it splits into two branches, one of which continues to separate the monzonite from the older rocks, while the other cuts through the Magdalena limestones' and appears on the quartz-capped hill immediately south of Organ City. Between Organ and the mouth of the canyon leading to Baylor Pass, the zone is very complex and contains four or five minor faults between the outer faults (See surface map of Stevenson-Bennett mine, Plate XII, pp. 220-221). All the rocks of the stratigraphic column are visibly involved in the fault zone. In places, notably at the Torpedo mine and to the west, the rocks between the faults are brecciated. Southeast of the Hayner mine the outer branches of the fault come together and a single normal fault, the plane dipping steeply to the east, continues south past the Modoc and Orejon mines to Dripping Springs.

The orebody at the Torpedo mine occurs in brecciated quartz-bearing monzonite, which lies between two heavy fault gouges, apparently representing the eastern branch of the main fault. The orebody reaches a maximum width of 150 feet and is 800 feet long. It has been explored to a depth of 500 feet. The gouge on the footwall side is 12 feet wide, and separates the orebody from the Magdalena limestones ; that on the hangingwall side is about 3 feet wide and separates the orebody from the barren monzonite. The deposit is not, therefore, a contact-metamorphic deposit in the usual sense, as stated by Lindgren;[16] the workings which have been opened up since Lindgren visited the district in 1905, especially those from No. 4 shaft, show very clearly that it is a tabular replacement deposit in the intrusive rock, struc-

[16]Lindgren, W., Graton, L. C., and Gordon, C. H., Ore deposits of New Mexico : U. S. Geol. Surv. Prof. Paper 68, 1910, pp. 211, 212.

turally controlled by the faulting in the Torpedo-Bennett zone, and having no direct connection with the feebly metamorphosed limestones adjacent to it. In structural detail, the primary ore as seen in the workings from No. 4 shaft resembles closely the type of ore found in the "porphyry copper" deposits. The monzonite is traversed by innumerable tiny fractures which have been filled with quartz and sulphides, and from which replacement of the rock has to some extent taken place. The cracking-up of the monzonite is ascribed to the intense stresses which produced the faulting. The orebody, like the bounding faults, dips to the east.

At the Stevenson-Bennett mine the conditions are somewhat different. The easternmost fault brings dolomite against pre-Cambrian granite, while the western fault brings the Percha shale into contact with the Magdalena series. The three ore bodies are replacement deposits in the dolomite and are related to north-south fractures lying within the zone between the major faults. The structure is further complicated by the presence of an intrusive sheet of quartz-monzonite porphyry which strikes northeast and dips northwest. This sheet was injected before the faulting. The western orebody, known as the Stevenson, lies along a fault at and near the surface, but in depth it follows the lower contact of the porphyry sheet. The eastern or Bennett orebody is a tabular mass averaging 10 feet wide, dipping 80° west. Its known vertical extent is 600 feet, its maximum length is 500 feet. The fractures to which it is related pass through the porphyry sheet, but the igneous rock seems to have been an unfavorable host. Above the porphyry sheet the orebody resumes its width, but dies out before reaching the surface. To the north and south it passes into barren silicified dolomite. The Page orebody is a small replacement deposit related to a fracture lying between the two other deposits. As in the case of the Torpedo mine, the essential structural control is the fault zone, but here the mineralization is related to fractures paralleling the major faults, not to brecciation between fault planes.

The Hayner mine, 3 miles south of the Stevenson-Bennett, has opened up four fissure veins cutting Magdalena limestones and shales, close to and no doubt related to the main western fault of the zone, which here brings the Magdalena series on the west against the Orejon andesite on the east. Johnston [17] has brought forward evidence for regarding the deposits as replacements related to fracture zones.

The Trapezoid and Modoc deposits are irregular replacements in Magdalena limestone adjacent to the fault, which is here a single plane, dipping to the east and bringing Orejon andesite

[17]Johnston. D. W., Jr., Fluorspar in New Mexico: N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 4, 1928, pp. 83, 84.

against the limestone. The relation to the fault is very plainly shown in the stope on the main level at the Modoc mine. A small amount of vein matter occurs in the fault, but the deposit is found mainly in the limestone adjacent to it ; it extends 25 feet from the fault. The Orejon deposit is a pipe-like body parallel to the fault and within a few feet of it. It varies from 5 to 8 feet in diameter and has been explored for 125 feet down the dip, which is 29° south.

Structurally resembling the Modoc deposit is a mass of pyrite with silicates adjacent to the fault on the hill south of Hardscrabble.

The Silver Cliff prospect has exposed the southward continuation of the fault. Both hangingwall and footwall are Soledad rhyolite ; the fault dips steeply to the east.

Age Relations.—The faulting took place after the consolidation of much of the third phase of the batholith, and after the intrusion of the Homestake and Memphis porphyry sills and the porphyry sheet at the Stevenson-Bennett mine. It is likely that the metamorphism of the sediments had been actively in progress for some time before the faulting, but iron-bearing solutions at high temperature gained access to the fault to produce andradite in the limestone on the hill south of Hardscrabble and in the Modoc area.

The fault zone occupies a critical position in the history of the hydrothermal mineralization, for it provided channels for the circulation of the solutions which gave rise to the largest sulphide bodies in the region, those at the Stevenson-Bennett and Torpedo mines. It is suggested, moreover, that the faulting made possible the escape of solutions which had collected in the pegmatite pockets of the third phase of the batholith.

Mineralogy.—The deposits of the Torpedo-Bennett fault zone exhibit a wide variety in mineral composition, and it will be necessary to describe the individual deposits in turn.

The primary minerals at the Torpedo mine are quartz, pyrite and chalcopyrite ; no other primary copper minerals have been found. Gold is present in traces only ; the silver content rarely exceeds 2 ounces per ton. Small amounts of galena and sphalerite occur locally, but they are not of importance. It is said that a mass of lead-zinc ore was discovered in the limestone adjacent to the fault on the 500-foot level, but the mine is important only for its copper. The hydrothermal alteration of the monzonite consisted in chloritization and sericitization of the feldspars and conversion of the ferromagnesian minerals into chlorite. Quartz and sulphides were introduced.

At the Stevenson-Bennett mine, pyrite, galena and sphalerite with subordinate chalcopyrite are the primary sulphides. The dolomite adjacent to the sulphide bodies is converted into a fine-grained white jasperoid, locally containing tremolite. Quartz, aragonite and dolomite crystals line cavities. Abundant green fluorite occurs in the Stevenson orebody near the surface, and a small amount of this mineral has been noted in the Page orebody at No. 1 level. Silver in the primary ore averages less than 20 ounces per ton, and seems to be contained in the galena; no other silver-carrying minerals were found. A polished section of sulphides from the 200-foot level showed that pyrite, in idiomorphic crystals, was the first mineral to crystallize. Sphalerite followed, perhaps with chalcopyrite in solid solution, for it contains the spots of chalcopyrite which have been interpreted by some authors as due to exsolution.[18] Galena is later than sphalerite and traverses it in many small veins (Plate VI, page 115) . Mr. Bentley informs me that he has definitely established the presence of thallium in the sulphides from the Page orebody. The waters from the mill were poisonous at the time when this orebody was being worked.

The deposits at the Hayner mine contain white, purple and green fluorite. The only other mineral present is calcite, which occurs in crosscutting veinlets. The veins are remarkably free from quartz.

The Modoc and Trapezoid deposits are galena deposits in an andradite-epidote gangue. The galena is almost non-argentiferous ; it contains ordinarily not more than 3.5 ounces of silver per ton. , The silver content is said to rise to 22 ounces in a 50-foot winze from the 90-foot level. The galena replaces marmorized limestone and calcite between the andradite crystals. Areas rich in andradite, as seen in the Trapezoid workings, are also poor in galena ; the garnet was not favorable for sulphide replacement. It was, however, partly converted to chlorite by the later phases of the hydrothermal solutions.

The Orejon deposit contains andradite, specularite, chalcopyrite, sphalerite, galena and coarse quartz, replacing limestone.

Barite, colorless fluorite and quartz are the minerals at the Silver Cliff prospect; they form the matrix of a breccia composed of bleached and silicified fragments of Soledad rhyolite.

Silicification.—Many of the faults in the zone have been silicified, and huge outcrops of barren quartz mark the course of the faults. The magnitude of the bodies of silica may be seen from the Torpedo and Stevenson-Bennett maps (pages 214, 220). The quartz is fine grained, and replaces brecciated limestone and dolomite in the fault and adjacent to it, preserving the shape of the breccia fragments even after replacement is quite complete.

[18]Van der Veen, R. W., Mineragraphy and ore-deposition : Vol. I, The Hague, 1925, p. 46.

In places quartz crystals are found in cavities, and here and there calcite crystals appear to have been replaced by quartz. The quartz is usually free from limonite; only very rarely can pyrite casts be found in it. Earth-movements have taken place after the silicification, producing joints, which are everywhere present, and slickensides on the quartz, which can be seen one-half mile north of the Stevenson-Bennett mine. This silicification, which is much more widespread than the ore deposits, and appears to represent much greater metasomatism, bears a relation to the mineral deposits that is difficult to determine. In the Stevenson orebody fluorite appeared at one place to have been brecciated and cut across by fine-grained quartz, but such an occurrence is unusual and it seems unwise to base any general conclusions on it. There are many possibilities. The silicification may have been due to hydrothermal solutions and may have taken place before, contemporaneous with, or after the ore deposits were formed ; or it may have been deposited from the groundwaters, as Locke[19] has suggested in the case of the superficial silicification at Tyrone and elsewhere. It seems unlikely that all of it was formed before the ore deposits, though quartz was undoubtedly an early mineral in them. Some of it may be contemporaneous ; there is little evidence for regarding the quartz as hydrothermal and post-mineralization, since it is so seldom possible to find quartz cutting primary minerals. But quartz was certainly deposited as a secondary mineral, and, in view of the evidence to be presented in a later section that much of the quartz in these faults occurs near the surface only, the author is inclined to regard much of it as supergene in origin. The problem will be further discussed in the section on supergene processes in the mineral deposits.Large areas of silicified limestone of similar character are found in the San Andres Mountains. One of particular interest extends from the northwest part of the Organ Mining District towards Quartzite ridge, where it has very prominent outcrops. A silver deposit now containing only supergene minerals is associated with it at the Smith mine.

5. REPLACEMENT DEPOSITS IN PREVIOUSLY METAMORPHOSED SEDIMENTARY ROCKS

Distribution.—The deposits at the Merrimac, Excelsior and Memphis mines are the best examples of this class. Others are found east and southeast of the Merrimac mine on the Ophelia, Iron Mask, Copper Bullion and Cobre Grande properties. All these deposits are adjacent to the quartz-bearing monzonite. At the southern contact of the quartz-monzonite (phase II), a single example is found at the Devil's Canyon mine.

[19] Locke, A., Leached outcrops as guides to copper ore : Baltimore, 1926, pp. 26-29.

Structure.—This group embraces the so-called contact-metamorphic deposits. As as has been stated in the section dealing with metamorphism, the sulphides and the minerals associated with them are regarded as having formed later than the silicates. By no means all the silicate areas have been attacked by later hydrothermal solutions. The garnet zone in the calcitic beds of the El Paso formation is very extensive; sulphides in it are restricted to a few minor occurrences. There are large areas of silicates virtually free from sulphides in the Lake Valley limestone near the Excelsior laccolith. The metamorphosed limestones exposed west of the Torpedo mine contain no sulphides. The metamorphosed xenoliths were not affected by hydrothermal solutions during the second wave of metasomatism.

The presence of silicates in the calcareous beds surrounding the batholith had the effect of providing a relatively unfavorable environment for the deposition of sulphides. It is found, therefore, that the sulphides tended to accumulate in beds which had not been replaced by silicates. As described on page 108, the Memphis mine shows these relations very clearly. The sulphides have replaced not the garnetized beds, but the marble between them. Since the limestones are thin here, the form of the sulphide bodies so produced is tabular, following the west dip and north-south strike of the beds. Four sulphide-bearing beds have been exposed at the Memphis (see map, pages 231-232). Immediately above the first garnetized bed, bodies of sulphides and oxidized ore have been explored from the Roos shaft and an opencut south of the engine house. Northwest of the engine house an open stope called the Zinc stope has exposed another body about 5 feet wide which was followed to a vertical depth of approximately 200 feet. At least two other sulphide horizons were worked in depth from the South shaft, but these could not be entered with safety at the time of the investigation. In addition, there is a zone from which oxidized silver ore was obtained, along a north-south fracture between the South shaft and the Zinc stope.

The Excelsior mine was not accessible, but it is said that the orebody is an irregular replacement deposit in marble adjacent to an area of silicates. Examination of material from the mine dump confirmed this information.

At the Merrimac mine is a tabular replacement deposit in a limestone 6 feet thick, lying immediately below a series of beds in which replacement by garnet has proceeded to a remarkable degree of completeness. It dips northwest at 36°; the maximum explored width of the shoot is 35 feet ; it has been followed down the dip about 200 feet. An interesting feature is the presence of west-northwest trending fissures containing sulphides which can be seen cutting through the roof and sides of the stope. (See map, page 235) . They are believed to have acted as feeders from below for the deposit.

In the calcitic beds of the El Paso formation sulphides occur in scattered masses associated with irregular veins which cut through the garnetized limestone.

Sulphides are rare in the dolomites at the northern contact. In the gully southeast of the Merrimac mine, sulphides cut the metamorphosed dolomite along a shear zone which probably formed after the period of silicate formation. Near the Goat Ranch small irregular sulphide bodies occur in dolomite which has been only marmorized.

At the Devil's Canyon mine, in Target Range Canyon, an irregular body of barite replaces serpentinized dolomite near the southern contact of the batholith. It appears to have spread out from north-south fissures which proceed for a short distance through the quartz-monzonite, and pass into the dolomite.

It may be concluded that as a general rule, the replacement deposits are highly irregular when in thick limestones, but are essentially tabular when in thin limestones.

Age Relations.—At the Excelsior mine the Excelsior rhyolite dike cuts through the orebody This dike is later than the veins at the Big Three and Hawkeye properties (page 117); and from the completely unaltered nature of the material from this dike found on the Excelsior dump, it is conjectured that the dike was injected later than the mineralization there also.

Studies of the textural relations of minerals both in hand specimens and under the microscope show clearly that the sulphides were formed after the silicates had developed in the limestones. It is upon this general fact that the division of the process of metasomatism into two periods is based. It should be clearly understood, however, that this division does not necessarily imply a time-break between the two periods. As explained on an earlier page, the evidence indicates that the mineralization process may have been continuous.

Mineralogy.—The primary minerals at the Memphis mine include specularite, pyrite, chalcopyrite, tetradymite, sphalerite, galena and quartz. Tetradymite, the bismuth telluride, has already been mentioned as a constituent of the Ben Nevis and Texas Main deposits; but it is more abundant at the Memphis mine than elsewhere in the district. The presence of bismuth in the Organ district has long been recognized, but the nature of the primary mineral in which it occurs has not previously been known. Native bismuth and bismuthinite have been mentioned as occurring,[20] but as the writer actually found neither of these

[20]Schrader, F. C., Stone, R. W., and Sanford, S., Useful minerals of the United States : U. S. Geol. Surv. Bull. 624, 1917, p. 209.

minerals, he believes that the only primary bismuth mineral is tetradymite. It occurs in silver-gray plates resembling specularite in habit; radiating thin tabular crystals occasionally occur in cavities. The presence of selenium in this mineral may be suspected since it gave a reddish precipitate with potassium iodide during microchemical examination.[21] A remarkable feature of the tetradymite is the graphic pattern which is brought out when it undergoes oxidation. The pattern is on a very fine scale (Plate VIII, page 156) , and in the oxidation process the intergrowth produced is between oxidation-product and primary mineral. However, etching of the unoxidized mineral by nitric or hydrochloric acid will bring out a similar pattern, so that the intergrowth evidently does not originate during the oxidation process; indeed oxidation may be regarded merely as a natural etching process which reveals the intergrowth. It seems then that the apparently homogeneous tetradymite is actually made up of two minerals in intimate intergrowth. Unfortunately the intergrowth is much too fine in scale to permit the separation of the two ; and their response to the various etching agents tried on them differs only in degree and not in kind. Doubly polarized light fails to reveal the intergrowth. The nature of the components can thus only be a matter of conjecture. Perhaps one is rich in sulphur, or even selenium, the other a pure telluride.

Tetradymite is associated with sphalerite, galena and specularite in the workings west of the 200-foot level of the South shaft. Polished sections show that the earliest minerals to form were specularite and quartz. Tetradymite and the sulphides seem to have crystallized together, with a second generation of quartz.

The deposits worked above the 200-foot level of the South shaft and in the upper workings of the Roos shaft were oxidized copper deposits. The nature of the primary minerals is in doubt; probably chalcopyrite was the most important. In the Zinc stope, below the oxidation zone, sphalerite is abundant, with subordinate pyrite, chalcopyrite and galena. The nature or primary source of the silver in the fracture zone between the South shaft and the Zinc stope is not known.

At the Excelsior mine the primary sulphides are pyrite, chalcopyrite, sphalerite and galena. Shipments of ore from this mine were penalized by the smelter for bismuth, so it is likely that some tetradymite occurs here ; however, none was found. Andradite and vesuvianite near the sulphide body are replaced by iron-rich chlorite, thuringite, with refractive index 1.640. The sphalerite contains blebs of chalcopyrite, and also inclusions of a pale yellow mineral which proved to be marcasite. This is the

[21] Compare Short, M. N., Microscopic determination of the ore minerals: U. S. Geol. Surv. Bull. 825, 1931, pp. 167-168.

only occurrence of marcasite in the district, and it is possibly a supergene mineral here.

The Merrimac deposit contains sphalerite as the predominating mineral. Much pyrite is present, and chalcopyrite and galena occur in subordinate quantity. Alteration of andradite to thuringite is again noted here, and in one polished section pyrite was observed to have replaced the central part of a garnet crystal. Veinlets of pyrite and sphalerite cut across the garnets. The order of deposition of the sulphides is the normal one; pyrite was the earliest and was followed by sphalerite, perhaps containing chalcopyrite in solid solution, since spots of this mineral are abundant in it. Some chalcopyrite was definitely deposited later than sphalerite, in veinlets which traverse both pyrite and sphalite. Galena was the latest mineral; it truncates the chalcopyrite veinlets.

The sulphides replacing the serpentinized dolomite on the Iron Mask claim include sphalerite, pyrrhotite, chalcopyrite and a small amount of galena. These cut across the serpentine in veins; and magnetite, also belonging to the first stage of metasomatism, is embayed by sphalerite. Among the sulphides, sphalerite and pyrrhotite were deposited, followed by chalcopyrite which traverses them in veinlets.

In the sulphide deposits in the calcitic beds of the El Paso formation, quartz, specularite and chalcopyrite occur. The quartz is coarse grained, and contains cavities in which specularite has grown. The amount of chalcopyrite is small.

The Devil's Canyon deposit is a large replacement body of barite, with subordinate colorless fluorite. The host rock is dolomite which has been converted into brucite-serpentine marble. Hydrothermal solutions followed fractures which cut also the quartz monzonite, and from these replacement of the marble proceeded. The quartz monzonite is feebly sericitized adjacent to the fractures. The association barite-brucite-serpentine is an anomalous one, and in this case may be taken as a clear indication of two distinct periods of mineralization, separated by a time interval. During the first, which occurred when the quartz-monzonite (phase II) was crystallizing, the brucite-serpentine marble was formed as a consequence of the normal process of thermal metamorphism. At a later time, probably after the crystallization of the quartz-bearing monzonite (phase III) the barite was emplaced.

6. OTHER REPLACEMENT DEPOSITS IN LIMESTONES AND DOLOMITES

Distribution.—Two classes of replacement deposits in calcareous rocks have already been considered, those structurally related to the Torpedo-Bennett fault zone, and those in previously metamorphosed sediments. There remains a small group of deposits which do not fall into either of these categories, occurring at the Little Buck, Rickardite, Hilltop, Black Prince, Philadelphia, Homestake, Jim Fisk and Smith mines, and at several prospects north and west of the batholith. The Bishop's Cap fluorite prospect may be included in the same group.

Structure.—,Two major types of structural association may be recognized. In the first, the controlling factor has been the contact of the Percha shale and the Fusselman dolomite; the sulphide bodies replace the upper part of the dolomite immediately under the shale. The Little Buck, Rickardite, Hilltop and Black Prince properties cover the entire exposed Percha-Fusselman contact at the northern end, where the deposits of this type occur. Some feeble mineralization has been noted along this contact in the Stevenson-Bennett mine. Solutions proceeding away from the intrusive followed small fissures through the dolomite; examples can be seen in the workings at the Rickardite and Hilltop mines, and in the opencut at the Black Prince mine. Their flow was deflected when they reached the impervious Percha shale, and instead of continuing along the fissure they followed the shale-dolomite contact. In this way a solution-breccia was produced along the contact, reaching as much as 6 feet in width; the introduced minerals cement and replace this breccia. Structurally similar deposits at the same stratigraphic horizon are known in many parts of Dona Ana County (page 195) ; they are also found in the Silver City district,[22] the Georgetown district, at Cooks Peak, and at Kingston. In the Organ district the ore bodies are small and highly irregular; their thickness seldom exceeds 3 feet and their extension both in strike and dip is always uncertain. At the Little Buck and Rickardite mines there is some evidence that the sulphides were deposited under minor arches in the shale.

A second type of replacement deposit is found at the Homestake and Philadelphia mines. Here the sulphides replace Magdalena limestones adjacent to porphyry intrusions. At the Homestake the mineralization is found at the bottom contact of the porphyry sill, which dips to the northwest. At the Philadelphia there appears to be a dike or crosscutting sheet; sulphides occur where shear zones through the limestone come into contact with the porphyry. In No. 1 shaft at the Philadelphia, for example, the porphyry strikes N. 30° W. and dips steeply to the east. A shear zone strikes N. 10° W.; the mineralization occurs at and near the junction of the shear zone and the porphyry.

There are, in addition, a number of minor occurrences. The Jim Fisk deposit is related to a vein striking northeast through

[22] Lindgren, W., Graton, L. C. and Gordon, C. H., Ore deposits of New Mexico : U. S. Geol. Surv. Prof. Paper 68, 1910, pp. 304, 319.

the Magdalena series. The Smith deposit is a highly irregular replacement associated with a huge mass of epigenetic quartz in the Magdalena series. West of the Modoc mine a small body of fluorite replaces a thin Magdalena limestone. The Bishop's Cap deposits are replacements related to fracture zones in the Magdalena series.

Mineralogy.—There is a progressive variation in mineral content in the deposits along the Percha-Fusselman contact as it is followed away from the contact with the intrusive. At the Little Buck mine, sphalerite is the most abundant primary mineral, with pyrite and some galena associated. A polished section shows that pyrite crystallized before sphalerite. Rich gold and silver ore was formerly obtained from the workings here; a specimen in Mr. Bentley's collection shows native gold in quartz. Mr. Bentley informs me that the silver ore gave a strong tellurium test. It is no longer possible to obtain any of this material, so that the nature of the telluride must remain in doubt. Medium-grained quartz is the gangue mineral in this deposit. On the Rickardite claim, sphalerite is abundant, but at the northeast end it decreases greatly, and galena shows a corresponding increase. Pyrite is again widespread. Galena predominates at the Hilltop mine, forming a "manto" up to about 2 feet thick under the shale. Below this a mass of fine-grained quartz occurs, which is stated to contain gold up to several ounces per ton. The lead telluride, altaite, is found replacing carbonates at the Hilltop in association with pyrite and galena. It has the remarkable property of causing galena adjacent to it on polished surfaces to appear purple in color. It was thought at first that the purple mineral was some unfamiliar species, but repeated etch and microchemical tests failed to reveal anything but lead sulphide; and it was found that when altaite and standard galena specimens were examined together in a comparison microscope, the galena appeared to have a purple tint. Schneiderhohn and Ramdohr,[23] working with altaite from Las Cruces, New Mexico—presumably from the Hilltop mine—noted the same effect. The copper telluride rickardite has been found by Mr. Bentley in the Hilltop workings and also in a pit near the northeast end of the Rickardite claim. This mineral is evidently very rare, and none was found during the present work. Some green fluorite occurs at the Hilltop. Oxidation has destroyed the primary minerals at the Black Prince mine; from the nature of the altered material it may be conjectured that they were argentiferous galena, pyrite and subordinate sphalerite.

Small amounts of hydrous silicates are found in the dolomite between the Little Buck and Hilltop mines, associated with the

[23]Schneiderhohn, H., and Ramdohr, P., op. cit., 1931, pp. 264, 265.

sulphides. Chrysotile is the commonest of these and is found in irregular veinlets with fibers oriented either perpendicular or parallel to the walls. In the west tunnel at the Hilltop mine, a small mass of white asbestos was found, in which the fibers parallel the walls ; the optical properties are as follows : ci 1.503, y' 1.519 ; mass polarisation figure, biaxial negative with low 2V ; parallel extinction, length slow. This is tentatively identified as a chrysotile. White tremolite also occurs in the dolomite.

Pyrite and argentiferous galena are the minerals in the Homestake and Philadelphia deposits; the silver content of the Homestake sulphides averages about 20 ounces per ton, and this is probably contained in the galena.

Nothing is known about the primary minerals at the Jim Fisk and Smith mines; only highly oxidized material can now be seen. A small deposit of sphalerite occurs in limestone south of the Hayner cabin. Fluorite, barite and quartz are found west of the Modoc mine, while at Bishop's Cap white fluorite, quartz, and pink manganocalcite are associated.

PYRITIZATION OF THE QUARTZ-BEARING MONZONITE

As indicated on the map of the Organ Mining District, several large areas occur in which the phase III monzonite has been subjected to hydrothermal alteration by solutions which have deposited pyrite. Such areas occur along the Torpedo-Bennett fault zone both north and south of Organ, and may extend over 1200 feet from the fault zone. A large independent area occurs one mile east of Organ, and covers approximately one quarter of a square mile.

Repeated assays have been made upon altered monzonite from these areas, but no copper, lead, zinc, or gold, and only doubtful traces of silver have been detected. The only introduced metallic mineral is pyrite; the feldspars of the igneous rock are slightly sericitized. Some quartz has accompanied the pyrite.

Alteration of a similar type follows the contact between phases II and III south of the Poor Man's Friend mine.

It is estimated that the amount of pyrite introduced does not exceed 3 per cent of the rock, and is usually much less. Even so, the alteration of areas of igneous rock as large as these implies the transport and removal of large quantities of material. The relation of the process to the mineralization in other parts of the district is not understood.

GENETIC RELATIONS

Zoning.—In the Organ district there is evidence of a rational distribution of minerals in a crude zonal arrangement with respect to the quartz-bearing monzonite. At the Memphis mine, the orebodies nearest the intrusive are copper bodies ; sphalerite becomes abundant in the bodies farther away from the contact, at the Zinc stope. (See plate VII) . Considerably farther away from the contact, at the Philadelphia and Homestake mines, argentiferous galena is the dominant sulphide. A copper zone, a zinc zone and a lead zone may thus be recognized. The occurrence of fluorite and barite in the outer parts of the district, and in the hills and mountains surrounding the Organ Mountains suggests that the outermost zone is characterized by these minerals. The transition from the zinc zone to the lead zone is particularly well displayed in the deposits along the Percha-Fusselman contact north of the batholith. The Little Buck and the southwest part of the Rickardite claims cover zinc deposits; the rest of the Rickardite, and the Hilltop and Black Prince claims are on lead deposits. Fluorite first appears at the Hilltop mine; barite is abundant in the shafts in the pre-Cambrian northeast of the Black Prince mine, where the galena is non-argentiferous. There is a great falling-off in silver content towards the outer limit of the lead zone. The copper-zinc deposit at the Excelsior mine is near the main contact; farther away, argentiferous galena is found at the Old Tough Nut prospect. The deposits of the Torpedo-Bennett fault zone further exemplify the zonal arrangement. The Torpedo orebody, in the quartz-bearing monzonite, is a copper deposit. One and one-half miles farther south, at the Stevenson-Bennett mine, the Bennett orebody below the 200-foot level belongs to the zinc zone, while above this level it passes into the lead zone. The Stevenson orebody, near the surface, suggests the transition to the fluorite zone. The fluorite zone is well exemplified three miles farther south at the Hayner mine. From these observations the conventionalized diagram on page 138 has been constructed. Attention may be called to the distribution of silver minerals. The copper and zinc zones are generally poor in silver; the inner part of the lead zone is rich in silver, as shown at the Homestake and Stevenson-Bennett mines.

The deposits in the pre-Cambrian rocks and the Texas Canyon veins must be regarded as belonging to the copper zone; apart from the upward increase in barite in the Texas Main vein they show little variation.

The veins scattered through the quartz-bearing monzonite show no consistent zonal arragement. Two examples have been mentioned above which show a transition from the lead zone to the zinc zone, with corresponding decrease in silver-content, the Ruby and Poor Man's Friend veins. The veins of this type cannot be correlated spatially with the deposits in the sediments surrounding the batholith. If the hypothesis that the residual liquids of the monzonite magma collected into a large number of scattered pockets is correct, the lack of a consistent zonal

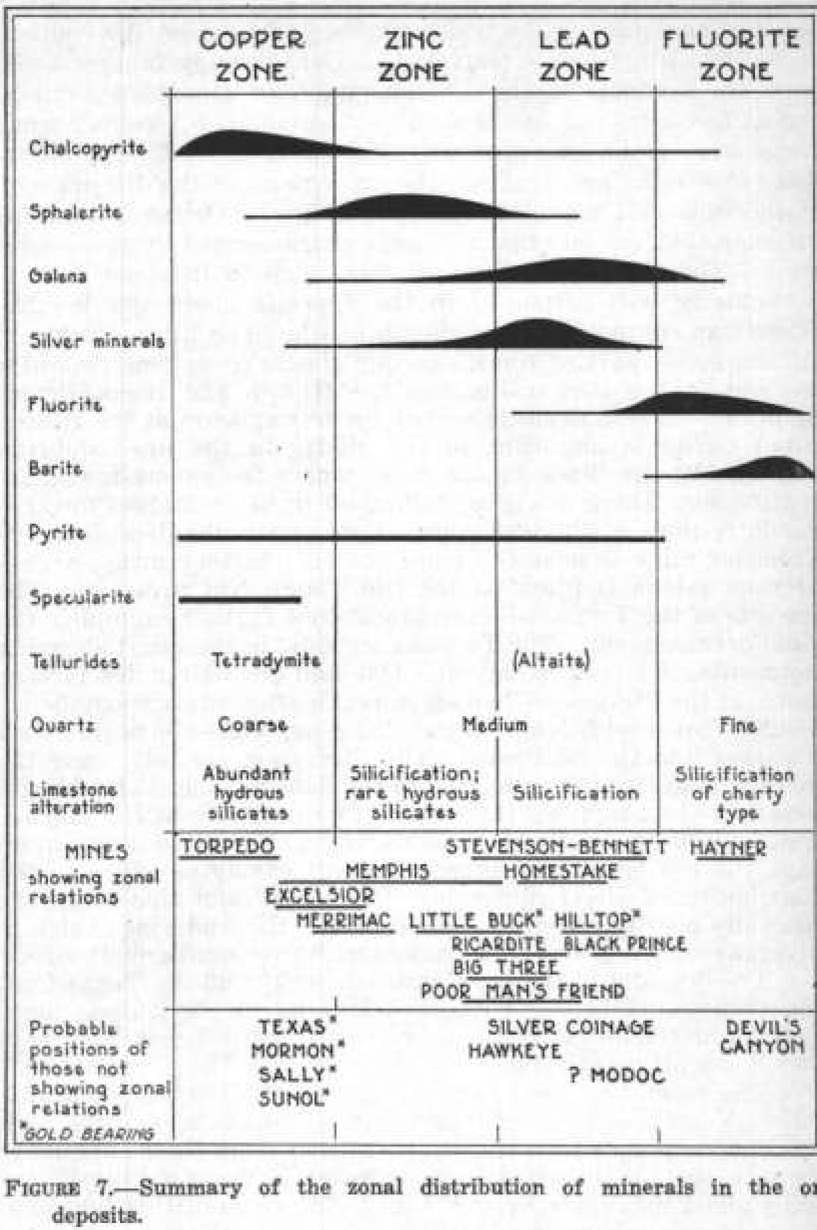


FIGURE 7.—Summary of the zonal distribution of minerals in the ore deposits.

PHOTOGRAPH OF THE MEMPHIS MINE FROM THE NORTHWEST

The limestone-monzonite contact runs immediately east (left) of the headframe, which is on the Roos shaft. Copper ores were mined from the Roos workings, zinc ores from the open stope in the right foreground.

arrangement in these veins is explicable, since they would be derived from different local sources. On the other hand, before the hydrothermal solutions left the batholith, they are thought to have collected along a few well-defined channels, of which the Torpedo-Bennett fault-zone is one example. In this way, zones consistently arranged with respect to the third phase of the batholith were produced outside the batholith.

The sulphides in the pegmatites are interpreted as having been deposited from solutions which remained in the pegmatite after the squeezing-out or boiling-off process. They would not be expected to be related to the zoning.

The deposits in the Modoc area provide a glaring anomaly in the zonal arrangement. Galena, low in silver, is the predominating sulphide, but the gangue is andradite; coarse quartz, specularite, chalcopyrite and sphalerite occur nearby in the Orejon pipe. This area of mineralization has some of the characteristics of the inner zones, some of those of the outer zones; it lies in the Torpedo-Bennett fault zone, but $1\frac{1}{2}$ miles farther from phase III of the batholith than the Rayner mine, which is taken to represent the outer zone of mineralization related to this phase. We can only conclude that in the Modoc region the fault tapped some nearer source of hydrothermal solutions, possibly another cupola of coarse-grained monzonite, not yet exposed.

The Silver Cliff and Bishop's Cap deposits are typical outer zone deposits. The barite body at the Devil's Canyon mine, in spite of the fact that it replaces brucite-serpentine marble near the contact of the batholith, is also an outer zone deposit. The barite is believed to have been related not to the adjacent second phase of the batholith as was the brucite-serpentine marble, but to a distant source in the later volatile-rich phase.

In spite of crudities and some anomalies in the zonal arrangement, two conclusions appear to be warranted; first, that the minerals were deposited from the hydrothermal solutions in order of solubility, the controlling factor being the falling temperature of the solutions as they proceeded farther and farther from their source. Secondly, the third phase of the major intrusive series was the source of the mineral deposits, apart possibly from those in the Modoc area.

Influence of the host rock.—Distance from the source was not, however, the only factor controlling the zonal disposition of the ore deposits. The nature of the host rock determined to a striking degree the extent of any individual zone. Carbonate-rocks are chemically reactive. Solutions traveling through these lose heat which is contributed to endothermic reactions. On the other hand, solutions traveling through relatively inert rocks like granite, lose heat only by conduction. What is more important, in carbonate rocks metasomatism takes place with ease, and the solutions are not confined to their narrow initial channels of movement; whereas in inert rocks the solutions are unable to spread far from the channelways. Thus, on comparing the extent of the zones in granite with the extent of those in limestone, a great difference is apparent. The copper zone in the limestones is confined to the immediate neighborhood of the contact with the intrusive; whereas the copper zone in the veins in the pre-Cambrian granite and in the quartz-monzonite is much more extensive and the deposits in it are correspondingly feebler. The silicate phase of metamorphism tends to be concentrated along definite channel-ways in the pre-Cambrian granite, as at the Lady Hopkins mine, but extends much farther from the contact of the Tertiary batholith than does the same phase in limestones.

Classification.—According to Lindgren's[24] scheme of classification, the pegmatites belong to the deposits formed in magmas by processes of differentiation; the deposits which occur within the silicate aureole to the contact metamorphic or pyrometasomatic group; the veins cutting pre-Cambrian and Tertiary intrusive rocks, and the replacement deposits in limestone, apart from the silicate-oxide deposits belong to the mesothermal class. A recent modification of the Lindgren classification proposed by Graton[25] would place the pegmatites in the pneumotectic group; the veins and replacement deposits other than the silicate-oxide bodies in the leptothermal group. The question of classification will be taken up again in connection with a general review of the ore deposits of the county in Part III. It will suffice here to state that the fluorite-barite-non-argentiferous galena deposits which represent the outer zone are classed as telethermal-leptothermal.

It should be noted that the Modoc and Orejon deposits, although not situated near the contact of the batholith, are classed as pyrometasomatic members of the hypothermal group. Their mineralogy is that typical of "contact metamorphic" deposits, but they have the form of replacement deposits related to a fault zone. The occurrence shows that, given suitable structural conditions, "high intensity" mineralization is by no means confined to the immediate neighborhood of the intrusive body.

SUMMARY

The following is a summary of the process of concentration of volatiles and hyperfusibles in the magmas, and of the metasomatic effects produced by them in the intrusive and intruded rocks :

[24] Lindgren, W., Mineral deposits, 4th Ed., New York, 1933, pp. 207-212.
[25] Graton, L. C., The depth zones in ore deposition : Econ. Geol. vol. 28, 1933, pp. 514-551.

1. Nothing is known of the volatile content of phase I, the dark monzonite.

2. During the intrusion of the magma of the quartz-monzonite (phase II), and during its crystallization, water, with small amounts of silica, iron and chromium, was communicated to the rocks in contact with and enclosed in the batholith. The importance of volatiles other than water was slight, and it is believed that the magma of phase II was not rich in volatiles.

3. Gases or liquids containing iron, silicon, halides and water may have been evolved from the magma of phase III during the early stages of its crystallization; such fluids were undoubtedly evolved during the later stages. The chief metasomatic products in the enclosing rocks were silicates and oxides. The period of formation of these is called the first metasomatic period.

4. A volatile-rich rest magma collected into pockets during the crystallization of phase III. The ordinary magmatic constituents of the rest magma crystallized to produce the early minerals of pegmatites. Some boiling off of volatiles may have occurred, so that fluids from the pegmatite pockets may have been able to contribute to the process of silicate and oxide formation in the rocks adjacent to the batholith.

5. In the main, however, the fluids did not escape from the pegmatites until the process of silicate formation in the rocks near the batholith was almost complete. The escape of the fluids was made possible by fissuring in the intrusive rock and in the pre-Cambrian rocks, and by tension faulting between the intrusive rock and the country rock on the west side. The expulsion of the fluids may have been due to boiling-off, or to the pressure of the superincumbent rocks, or to local compressive stresses.

6. The fluids followed structurally determined channels. These included tension cracks in the monzonites and pre-Cambrian granites; planes of movement along epidiorite dikes in the pre-Cambrian basement; the Torpedo-Bennett fault zone ; irregular cracks or fissures through the metamorphosed limestones ; the contact of the Percha shale and the Fusselman dolomite; and the contact between certain porphyry intrusions and limestone.

7. Minerals were deposited from the solutions as they moved through these channels, the nature of the material at any place depending on the temperature of the solution and the chemical nature of the wall rock. This period is called the second metasomatic period.

8. Carbonate rocks were readily replaced, fault gouges much less readily ; igneous rocks proved fairly resistant to metasomatism. The solutions traveled much farther through igneous

rocks than through carbonate rocks before becoming exhausted. The accompanying table summarizes the paragenesis of the minerals associated with the Tertiary intrusive cycle.

TECTONIC ADJUSTMENTS

PRE-INTRUSION FOLDING

Prior to the intrusion of the batholith, a series of folds was developed in the rocks of the region. As shown on page 52, there is evidence that uplift and gentle folding took place before the extravasation of the Tertiary lavas. It has also been suggested that basining of the sediments below the great pile of Soledad rhyolite took place during its extrusion. The folding of the broad anticline which forms the southern part of the San Andres Mountains[1] probably occurred at this time. The batholith was intruded into a region of low anticlines and synclines, of which only parts of the limbs of anticlines remain today, in the Sierra Caballos, in the San Andres Mountains and the Sacramento Mountains.

THRUST AND REVERSE FAULTING

More localized compressive stresses than those responsible for the folding caused thrust faults to be developed, also before the intrusion of the batholith, but probably after the lavas had been poured out at the surface. At the head of Black Prince Canyon a thrust fault dipping 35 degrees east has carried the pre-Cambrian granite over the lower part of the Magdalena series. (Plate IV, page 44). The minimum dip slip is approximately 2500 feet, and the minimum vertical separation approaches 1000 feet. To the south it is ill exposed, but the belt of brecciation associated with it may be followed to a point south of the Black Prince mine. North of Black Prince Canyon the dip of the fault plane becomes steeper and the associated brecciation less pronounced. The fault does not apparently affect the intrusive monzonite to the south and is therefore considered to have been in existence before the batholith.

On Hardscrabble Hill the apparent northern continuation of the Torpedo-Bennett fault zone seems to be a reverse fault, along which movements perhaps occurred simultaneously with those on the Black Prince fault. The footwall of the fault on Hardscrabble is Tertiary lava.

In the east foothills of the San Andres Mountains there are low-angle faults which may correspond in age with those described above ; and on the west side of these mountains a sharp fold, with which thrust faulting is associated, extends from Little Well on the Jornada Range to San Andrecito Canyon, a distance of 12 miles.

[1] See section, Darton, N. H., "Red beds" and associated formations in New Mexico : U. S. Geol. Surv. Bull. 794, 1928, p. 192.

STRUCTURE	Folding Thrust Faulting	Distortion and Stoping of Invaded Rocks			Torsion Fissuring	N.-S. Normal Faulting	Torsion		E.-W. Faulting
BATHOLITH		*FIRST PHASE* Magnetite Apatite Zircon ENSTATITE AUGITE HORNBLENDE BIOTITE OLIGOCLASE ORTHOCLASE Titanite Quartz	*SECOND PHASE* Magnetite Apatite Zircon HORNBLENDE BIOTITE OLIGOCLASE ORTHOCLASE QUARTZ Titanite	*THIRD PHASE* Magnetite Apatite Zircon Augite HORNBLENDE BIOTITE OLIGOCLASE ORTHOCLASE QUARTZ Titanite	*PEGMATITES* Orthoclase Albite Quartz Quartz Muscovite Diopside-Hedenbergite Grossularite Anatase, Brookite Apatite Quartz,	*VEINS* Quartz, Pyrite, Chlorite Chalcopyrite, (Enargite) Tetrahedrite Sphalerite, Galena (Tetradymite) (Fluorite, Barite, Siderite) Argentite - Pyrite Chlorite, Epidote, Actinolite Chalcopyrite, Sphalerite Tetradymite, Galena Argentite		Quartz Galena Argentite	
MINOR INTRUSIVES				Apophysal Dikes Aplites	Dikes Sills qmp East-West Rhyolite Dikes		North-West Rhyolite Dikes		
IN LIMESTONE		*Xenoliths* Wollastonite Diopside Uvarovite Pargasite White mica		*Northern Area* Wollastonite, Diopside Andradite ——> Vesuvianite Apatite		Chlorite Tremolite Quartz, Pyrite Specularite Chalcopyrite Sphalerite, Galena Tetradymite Fluorite			
IN SHALE				Diopside, Rutile Anorthite Scapolite Muscovite					
IN DOLOMITE		*Xenoliths and Southern Area* Periclase ——> Brucite Forsterite ——> Serpentine		*Northern Area* Forsterite ——> Serpentine Diopside Spinel Cordierite Phlogopite Magnetite Penninite		Tremolite Pyrrhotite Quartz, Pyrite Chalcopyrite Sphalerite Galena Altaite, ?Rickardite Gold, Fluorite, Barite			
IN QUARTZITE		*Xenoliths* Lazulite Andalusite Muscovite Rutile							
IN EPIDIORITE		*Xenoliths* Augite Biotite Andesine Apatite				Chlorite, Albite Quartz Pyrite Chalcopyrite Galena, Sphalerite Gold, Fluorite			
IN GRANITE					Augite Biotite Magnetite, Specularite	Chlorite, Sericite Quartz Pyrite Chalcopyrite Sphalerite, Siderite, Gold			
GEO-CHEMISTRY		*MAGMATIC PERIOD:* Crystallisation from melts containing the following elements: Fe'', Fe''', Mg, Ca, Al, Na, K, Ti, P, F, Si, O, H, S.	*THERMAL METAMORPHISM* with limited metasomatism H_2O, Cr, SiO_2 added CO_2 lost	*THERMAL METAMORPHISM*	*FIRST METASOMATIC PERIOD* Addition of Fe''', SiO_2, F, Cl Loss of CO_2 Perimagmatic space relations	*SECOND METASOMATIC PERIOD* Addition of SiO_2, Fe'', Cu, Bi, Zn, Pb, Ag, Au, S, Te, F, Ba, K, H_2O. Apomagmatic space relations			

Summary of Mineral Paragenesis, Organ Mountains Intrusive Center

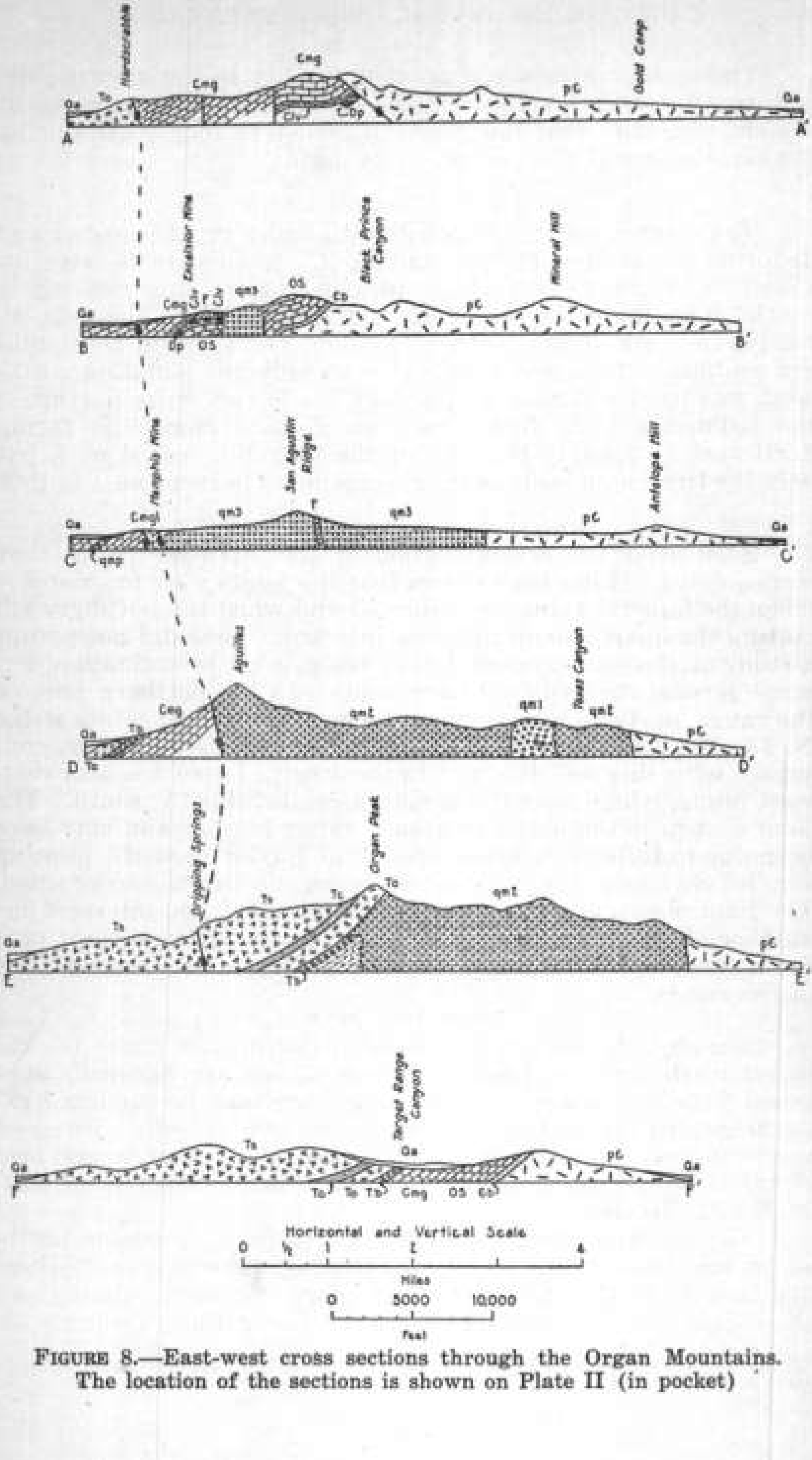


FIGURE 8.—East-west cross sections through the Organ Mountains. The location of the sections is shown on Plate II (in pocket)

These observations add another locality to the growing list of thrust faults in Western North America. Butler,[2] in a recent review, considers that much of the thrusting took place during the early stages of the Laramide revolution.

INTRUSION OF THE BATHOLITH

The magma rose into the batholith under great pressure and distorted the sediments surrounding it. It appears to have invaded the western limb of an anticline whose axis ran north-south. The dip of the sediments was changed from the west direction to north at the northern contact, and south at the southern contact. In the northern region an anticline plunging northwest was produced near the contact, while two miles northwest the sediments were folded into an arcuate monocline facing northwest. Probably the roof of the batholith was domed, but only the Orejon andesite outcrop remains to bear witness to this.

JOINTING OF THE INTRUSIVE ROCKS

Soon after the crystallization of the intrusive rocks, they were jointed. It has been shown that the joints were in existence when the mineral veins were formed and when the porphyry sill cutting the quartz-monzonite was injected. Time did not permit a study of the joint system during the present investigation, but some general observations were made. In the northern part of the range, north of Baylor Pass, the most prominent joints strike N. 15° W. One set dips at about 70° to the east ; another, conjugate with this set, dips 20° to the west. There are also east-west joints, which near the northern contact dip 45° south. The joint system in the northern area is fairly regular and may have been due to tectonic stresses. South of Baylor Pass the jointing is more obviously complex, and no dominant direction was noted. The joint planes are very large and continuous, and intersect one another at oblique angles. They have played an important part in the development of the jagged aiguilles in the central part of the range.

DIKES AND VEINS

The rhyolite dikes, which were intruded after phase III had crystallized, occur as linear echelons. They are generally supposed to be due to torsional stresses ; they may be produced experimentally, for example, by depressing two opposite corners of a rectangular plaster block, while the other corners are held rigid. The first set of dikes trend in a general east-west or east-northeast direction.

The injection of these dikes was followed by simple north-south tension, which opened up east-west fissure veins. These are later than the east-west dikes, since one such vein follows the course of an east-west dike on the Crested Butte property.

[2] Butler, B. S., Stratigraphic, structural and igneous factors: Lindgren volume, A.I.M.E., 1933, p. 225.

Northwest-trending rhyolite dikes, later than both east-west dikes and veins, were then injected. There were at least two periods of injection of dikes in this direction. Again the openings for the dikes were produced by torsional stresses.

In the pre-Cambrian rocks, shearing took place along epidiorite dikes, those most affected being the ones trending east-west; some of the northeast dikes, notably the Pagoda dike, were, however, affected.

NORTH-SOUTH NORMAL FAULTS

The Torpedo-Bennett fault zone has already been described. Except in its supposed northern continuation on Hardscrabble it is dominated by normal faults, most of which dip steeply to the east. Between the Memphis mine and a point southeast of the Hayner mine the belt is complex, and in the region of the Stevenson-Bennett mine it encloses an inlier of pre-Cambrian and lower Paleozoic rock. West of the Hayner mine there is an inlier of Magdalena limestone between the Orejon andesite and the batholith. The fact that the contact between the Magdalena limestones and the batholith is a faulted one along the west side is shown by many exposures. The fault gouges are exposed at the surface near No. 1 shaft on the Torpedo property, and also underground. On the east side of the Memphis claim, a pit has exposed the gouge. Excavations west of the Emmett Isaacks ranch exposed the fault plane. It can be seen near the head of gullies southwest of the Hayner mine. Fault-planes cutting sediments and lavas in this zone are visible at the Memphis, Stevenson-Bennett, Modoc, Orejon and Silver Cliff mines. The faulting is known to exist quite apart from the stratigraphic evidence. In many places the faults contain bodies of silica and form prominent, wall-like outcrops ; this is a common feature of faults in the region.

The stratigraphic evidence by which the continuity of the faults is traced is presented on the maps accompanying this report and need not be described here. Some idea of the magnitude of the faulting may be gained from the displacement of the Cueva rhyolite near the mouth of Fillmore Canyon. The stratigraphic separation, measured perpendicular to the bed, is 3200 feet ; the horizontal separation 3800 feet and the vertical separation 5000 feet. Farther north the movement is distributed among a number of faults.

Possibly belonging to the same period of faulting are some of the faults which traverse the pre-Cambrian rocks in the Gold Camp area, and continue north into the San Andres Mountains. The course of these faults through the pre-Cambrian is not known with great certainty, since the only means of tracing them is by observing the displacement of dikes; on the maps, therefore, they are shown in dotted lines. One of these faults is exposed by the Dona Dora tunnel. The accompanying diagram shows that there is evidence that this fault moved twice; it has displaced an epidiorite dike 600 feet, while it has shifted the Dona Dora vein, which has a similar strike and dip, only 225 feet horizontally. The correctness of this conclusion hinges upon the identification of the two parts of the vein with one another. They are entirely similar mineralogically; they have exactly the same width and attitude. In view of the rarity of veins of this type, the conclusion that they are parts of the same vein seems warranted. In this case, there was both pre-mineralization and post-mineralization movement on the fault. The main gouge of the fault is 6 feet wide. A parallel post-mineralization fault cuts the Sally dike (map, page 212).

LATE EAST-WEST FAULTS

Post-mineralization faults striking between east-west and N. 35° W. are a feature of the region. They traverse and displace both the Black Prince thrust fault and the faults of the Torpedo-Bennett fault zone. The Excelsior laccolith is cut by a member of the series which runs roughly parallel to the northern contact of the batholith. Faults of this age are not mineralized, apart from bodies of quartz whose origin is not necessarily hydrothermal. All the evidence combines to indicate a post-mineralization age for them.

The largest example is the fault which has formed a line of weakness for the erosion of Soledad Canyon. It cuts quartz-monzonite and lavas; the horizontal slip is nearly 8000 feet, the stratigraphic separation approximately 4000 feet. The fault plane is not seen, but its presence is inferred from the great displacement of the andesite and the quartz-monzonite. Several large faults occur at the southern end of the mountains; one of these brings in the Cueva rhyolite at Pinto Blanca. Where they traverse the Soledad rhyolite the faults are easy to follow because of the bleaching of the rhyolite which occurs adjacent to them. The mass of limestone at Bishop's Cap is probably faulted against the lavas beneath the wide alluvial gap lying to the north of the Cap.

The inliers of pre-Cambrian and Lower Paleozoic rocks in the region of the Stevenson-Bennett mine owe their exposure to the uplift of two blocks along east-west and west-northwest faults. A complex pattern of faults cuts the sediments north of the batholith. The largest of these is the Hilltop fault, immediately north of the Hilltop mine. It has a stratigraphic separation of 900 feet; the fault plane is seen in an excavation below the west adit of the mine. The gouge is strong and contains Percha shale as drag; it dips to the north at 70°. The other faults in the northern region are of much smaller magnitude. The monocline east of Hardscrabble is displaced by the probable westward continuation of these faults. Across the bare limestone hills the fault planes may be followed with remarkable ease, but they are frequently covered with talus, or they may disappear beneath stream washes. The faults in the northern area which are shown traversing the Magdalena series were mapped by following the fault planes, and not by stratigraphic evidence, since the detailed stratigraphy of the Magdalena has not yet been worked out in this region.

The effect of the late faults was to split the range up into a number of fault-blocks. These are not generally apparent in the present topography.

SUMMARY OF THE TERTIARY INTRUSIVE CYCLE

1. Folding of the country rock into broad anticlines and synclines. Thrust faulting.
2. Intrusion of phase I of the batholith, dark monzonite.
3. Intrusion of phase II, medium-grained quartz-monzonite. Stoping and distortion of phase I and the enclosing rock. Thermal metamorphism of included blocks and the intruded rock at the southern contact, and feeble metasomatism.
4. Intrusion of phase III, rich in volatiles and hyper-fusibles. Stoping and distortion of the country rock. Metamorphism and metasomatism of granite and sediments. Injection of apophysal dikes. Crystallization as coarse-grained quartz-bearing monzonite. Jointing.
5. Intrusion of quartz-feldspar porphyry sills, sheets and dikes.
6. Volatile-poor rest-magma of phase III produces aplites. Volatile-rich rest-magma collects into pockets and begins to crystallize as pegmatites. Some liberation of volatiles occurs, contributing to the first wave of metasomatism.
7. Torsional stresses produce fissures arranged in linear echelons ; into these, rhyolite dikes are injected. Fluids escape from the pegmatites along these dikes and along east-west fissures, initiating the second wave of metasomatism.
8. A great belt of normal faults down the west side of the range is produced. Residual fluids escape through these faults, through fissures in the granite and monzonite, through fracture zones and along shale-dolomite contacts in the country rock. Ore deposits are emplaced.
9. Injection of northwest-trending rhyolite dikes. Feeble mineralization continues after their injection.
10. Post-mineralization east-west faulting.

LATE TERTIARY AND QUATERNARY EVENTS

STRUCTURAL CHANGES AND PHYSIOGRAPHIC EVOLUTION

Miocene and Pliocene Erosion.—Supposedly at the end of the Oligocene period, the intrusive cycle had completed its course. Due to the cumulative effect of earth movements which began at the end of Cretaceous time and continued through the early periods of the Tertiary, the region of the Organ Mountains was highly elevated above sea level. Tectonic processes which contributed to this state of affairs were: broad folding; crustal shortening accomplished by thrusting; the doming of the roof of the batholith; and normal faulting. The work of Bryan and his associates[1] in the Rio Grande region to the north, and in the Canutillo Quadrangle to the south of the present region, has revealed the presence of a great thickness of partly consolidated sediments of supposed and proved Santa Fe (Miocene-Pliocene) *age.* Observations made during reconnaissance work in Dona Ana County (page 175) have confirmed the presence of Tertiary sediments in the region immediately west of the Organ Mountains, covered by thin Quaternary alluvium. Thus erosion of the primitive Organ Mountains may be supposed to have been actively in progress in mid-Tertiary times. A thickness of some thousands of feet of fanglomerate and gravel were accumulated west of the mountains during this period. However, final proof that the Organ mass was the source of this material is lacking; a study of the supposed Santa Fe beds is needed. East of the range, there is a thickness of over 1000 feet of sediment in the Tularosa basin, the age of which is not known. If this is proved to be of Tertiary age, it will follow that the Organ-San Andres chain was uplifted relative to that basin during late Tertiary times. Meinzer and Hare[2] have shown from the distribution of rock types in the gravels that the composition of the fill depends on the adjacent mountains.

Bryan's studies have shown that by the end of Santa Fe time erosion of the mountains in the Rio Grande region had reduced them to small residuals, or had obliterated them. It may be conjectured that the unroofing of the Organ Mountains batholith took place before the end of the Tertiary.

Post-Santa Fe Uplift.—The San Andres-Organ-Franklin chain is a typical basin range as defined by Gilbert.[3] It belongs

[1]Bryan, K., Pediments developed in basins with through drainage as illustrated by the Socorro area, N. Mex. (abstract) : Geol. Soc. Amer. Bull., Vol. 43, 1932, pp. 128, 129.
The formation of pediments : Comptes Rendus XVI Int. Geol. Cong. 1933 (in press). and personal communications respecting work in central New Mexico, and the work of Mr. Dangerfield in the Canutillo district.

[2] Meinzer. 0. E. and Hare, R. E., Geology and water resources of the Tularosa basin, N. Mex.: U. S. Geol. Surv. Water Supply paper 343, 1915, p. 66.

[3] Gilbert, G. K., in Progress report for 1872, U. S. Geog. and Geol. surveys west of the 100th meridian: 1874, p. 50.

to the Mexican Highland subdivision of the Basin and Range province.[4] None of the events in the geologic history of the Organ Mountains so far described seems competent to account for the form of the chain. The great east-facing scarp of the San Andres Mountains appears to the present author to constitute convincing evidence of the essential correctness of Gilbert's hypothesis of origin of the basin ranges; no hypothesis of erosion could hope to account for such a feature. It is tentatively suggested, therefore, that the mountain chain was elevated relative to the Tularosa basin by faulting. Some of the faults which traverse the region of pre-Cambrian rocks northeast of Mineral Hill and cut through the sediments in Black Mountain to the north may have moved sympathetically with the faulting at this time; we have noted already that two of them acted after mineralization was completed. On the west side of the San Andres Mountains, the rocks dip under the Jornada plain. In a broad sense, the rocks underneath this plain form a syncline[5]; but the southern part seems to have been modified by block faulting[6]. Near the west side of the Organ Mountains runs the Torpedo-Bennett fault zone, but since the downthrow side of this fault is to the east, it is clear that it has not contributed to the elevation of the mountain block. Any post-Santa Fe faulting along the west side of the Organ Mountains must have taken place west of the Torpedo-Bennett fault zone. Dangerfield's studies in the El Paso region have revealed little evidence of such faulting along the west side of the Franklin Mountains. The conclusion that the San Andres Mountains form a fault block, uplifted relative to the Tularosa basin on the east, and rotated so that the upper surface dips under the sediments to the west seems to be warranted ; and no good reasons can be found for failing to regard the Organ and Franklin ranges as part of the same block. Probably only minor faults occur along the west side.

On a later page evidence that Robledo and Tonuco Mountains were uplifted after the deposition of the late Tertiary sediments will be presented (page 176). It is suggested that the final elevation of the Organ Mountains took place at the same time, that is, at the end of Tertiary time. The uplift inaugurated the Quaternary cycle of erosion.

It will be realized that there are many gaps in the evidence bearing on Miocene, Pliocene and Quaternary structural changes. The events outlined above are not entirely proved by local evidence, but in the absence of such data it seemed advisable to

[4]Fenneman, N. M., Physiography of the western United States : New York, 1921, P. 393.
[5]Darton, N. H., "Red beds" and associated formations in New Mexico: U. S. Geol. Surv. Bull. 794, 1928, p. 196.
[6] Harley, G. T., Geology and ore deposits of Sierra County, N. Mex.: N. Mex. Sch. Mines, State Bur. Mines and MM. Res. Bull. 10, 1934, p. 22.

make the story consistent with the general history of the period in the Rio Grande region.

Quaternary Erosion.—The present configuration of the mountains dates from the Quaternary period. It owes it peculiarities to the arid conditions under which it was developed; the great cliffs rising abruptly from the almost level plain are typical of the mountains of the Southwest.

In spite of the aridity, the dominant factor in erosion is now and has been stream-action. The carving of the topography must be ascribed to the action of ephemeral streams, running for a few hours after rains as raging torrents. The drainage pattern is remarkably well adjusted to the bedrock structure of the range. Soledad Canyon, largest of the canyons, follows the course of a major fault of large displacement. The canyon running north from Soledad coincides with the outcrop of the soft Cueva rhyolite. Similarly, Fillmore Canyon is cut through Cueva rhyolite. Target Range Canyon parallels the structure, and seems to be cut through Magdalena beds; at the northern end it is terminated by a cliff over 1000 feet high formed of quartz monzonite near the contact of the batholith and the limestones. A branch canyon to the west and north follows the Cueva rhyolite. There are no long canyons where the bedrock is unfaulted Soledad rhyolite. Texas Canyon, one of the largest in the quartz monzonite, follows a fault line. Black Prince Canyon follows the outcrop of a thrust fault. In the region north of the batholith the relation between bedrock structure and drainage patterns is very intimate.

The line of the Torpedo-Bennett fault zone has been re-excavated by erosion, producing a remarkable series of reversed fault-line scarps. That they are not fault scarps is shown by the fact that the cliff is on the downthrow side of the fault in each case. Good examples may be seen at the Stevenson-Bennett mine and near the Silver Cliff prospect. The precipitous slopes above Dripping Springs, amounting virtually to cliffs over 2000 feet high, were probably produced by the wearing back of the fault-line scarp. The west face of the pinnacles in the central part of the range may be regarded as part of the fault-line scarp. The slope changes abruptly at the foot of the pinnacles from 28 to 50-85 degrees, and it is here that the fault runs.

The classification of mountain slopes developed by Bryan in the Papago country[7] applies excellently in the present area. Cliffy slopes on massive rocks ranging from 45° to 90° with the horizontal are very general on the monzonitic rocks of the batholith; they are rare, fault line scarps excepted, on the Soledad rhyolite; they are not developed on the other lavas or sediments.

[7] Bryan, K., Erosion and sedimentation in the Papago country, Arizona : U. S. Geol. Sure. Bull. 30-B, 1922, p. 42.

There are a few examples on pre-Cambrian granite. Debris-mantled slopes between 20° and 45° are seen on both sides of the central part of the range; they pass rather abruptly into pediments and fans with low slope angles. The transition zone between debris-mantled slopes and pediments varies from a few feet to approximately three hundred feet in width.

The particular form taken by the mountain slopes is intimately related to the jointing of the rocks. The spectacular aiguilles are due to erosion along widely spaced joints which intersect one another at oblique angles; single joint planes may be continuous for upwards of 1000 feet. More work is needed to establish the directions of the joint planes; but a general inspection of the pinnacles leaves no doubt that the joints were the controlling factors in their evolution. Between Baylor Pass and San Agustin Pass, where the quartz monzonite is capped by a fine-grained and little-jointed sill of quartz feldspar porphyry, the outline of the mountain is smooth and contrasts strikingly with the great spires to the south. The pre-Cambrian granite, containing many short joint planes, forms rounded hills without jagged outlines; here and there small monoliths may cap the hills, as on the hills west of the Garrett ranch. The Soledad rhyolite also forms rounded rather than jagged mountains; joints are very numerous and closely spaced in this rock, and it tends to break up into spalls only a few inches in diameter. Smooth slopes are produced on sediments except where fault and fault-line scarps occur. Metamorphosed sediments were in general more resistant to erosion than those which remained unaltered.

Between the mountain slopes and the basins, long pediments occur. The region northeast of Mineral Hill is an admirable example. The slope rises smoothly for three miles from the Tularosa Basin, at about 150 feet per mile. Pre-Cambrian granite is exposed all the way. The hills and mountains rise abruptly at slopes greater than 20°, often as much as 40°, from the pediment. West of San Agustin Peak a pediment one mile wide has been cut on the quartz-bearing monzonite. Its slope is in complete continuity with the slope leading to the Jornada Basin; but along the line of the Torpedo-Bennett fault zone a row of low hills formed of resistant metamorphosed rocks and porphyry sills occurs. Many of the fans at the mouths of canyons on both sides of the range are not alluvial fans as they appear to be, but are convex surfaces cut on solid rock. A good example may be seen one-half mile south of Organ.

After the post-Santa Fe disturbance, aggradation gave place to degradation in the basins, and erosion surfaces were cut cross the distorted sediments by lateral planation due to meandering ephermeral streams. The erosion surfaces were not confined to the soft Tertiary rocks but were extended into the mountains, forming pediments such as have been described above. Meanwhile the mountain slopes receded, but, in doing so, maintained their angle of slope as Lawson has shown[8]. The base level probably remained stationary for a long period during the Quaternary, or perhaps rose gradually as sediment was accumulated in the central parts of enclosed basins. In later Quaternary time, however, several important lowerings of base level occurred. This led to the dissection of the pediments and the highest erosion surface of the region, which is continuous with them. Streams now produced small canyons up to twenty feet deep in the pediments, and some of the rock fans were dissected by streams which ran between the fan and the mountain slope. An example in miniature may be seen on the Stevenson-Bennett surface map (pages 220-221), and a larger example is to be found one-half mile south of Organ. The lowering of base level on the west side was due to the lowering of the Rio Grande, as will be shown in a later discussion (page 178) ; on the east side there was also some erosion of the pediments, which is less readily explained since the streams drain to a closed basin. Bryan suggests that there may have been climatic changes leading to increased rainfall which affected the rate of erosion[9].

OXIDATION AND ENRICHMENT OF THE DEPOSITS

THE GROUND-WATER TABLE

As the unroofing of the batholith took place, the upper parts of the ore deposits of the region came into the vadose zone, where active circulation of groundwaters was in progress. The oxidizing action in this zone led to important mineralogical changes in the ore deposits.The position of the present water-table is known from shafts and wells. In the Gold Camp district, northeast of Mineral Hill, the depth below the surface is 90 feet, as shown by the Mormon,Sally and Sunol shafts, and wells at the Steampump ranch and at the Schneider camp. The flow of water is fairly considerable, and bailing proved to be entirely inadequate during the sinking of the Sally shaft below the 93-foot level. In the immediate district of Organ, the water-table varies in position with distance from the Torpedo-Bennett fault zone. In the Memphis and Tor-pedo mines, in and adjacent to the fault zone, the 200-foot level is now quite dry; this is due to the fact that the water drains along the fault zone to the deep drainage tunnel at the Stevenson-Bennett mine, which cuts the fault zone at an elevation of 4860 feet, 100 feet below the 200-foot level in the Torpedo. The water level in the fault zone stood much higher before this tunnel was

[8]Lawson, A. C., The epigene profiles of the desert : California Univ. Dept. Geology Bull., Vol. 9, 1915, p. 29.
[9] Bryan, K., op. cit., 1922, p. 65.

driven ; Lindgren[10] states that there was a flow of 700 gallons per minute at a depth of 150 feet in the Torpedo mine in 1905. At the Stevenson-Bennett mine much water was encountered below the main tunnel level before the driving of the drainage tunnel. Away from the fault zone, the water level appears to be between 100 and 150 feet deep. The Organ well, in limestone west of the Torpedo mine, contained water at 104 feet depth in 1934. The Homestake workings, approximately 100 feet deep, were dry. The well at the Walton ranch, in porphyry, tapped water at 90 feet, while in normal seasons water stands at 80 feet in the well at the Flying Bar-U ranch, in quartz-monzonite. Farther north, a well only a few feet deep at the Goat Ranch taps abundant water ; this well seems to be on the contact between the Percha shale, the Fusselman dolomite and the monzonite. In the Merrimac shaft, water stands at 80 feet below the surface.

The present water table is thus a shallow one as compared with that found in many districts in arid regions.

DEPTH OF OXIDATION AND ENRICHMENT

All the ore deposits of the region have suffered some degree of oxidation, and much the greater part of the metal production has come from oxidized deposits. The depth to which oxidation extends in variable. In the pegmatites, sulphides are found within a few feet of the surface. The silver veins in the monzonite generally have a heavily oxidized capping, but sulphides are encountered above the water level, usually at no great depth below the surface. At the Silver Coinage mine the unaltered sulphides were found at a depth of 20 feet. The shallow shafts at the Hawkeye mine show sulphides at about the same depth. In general it seems safe to conclude that the deposits in the mountainous parts of the region are oxidized only to very slight depths. This is true in the veins cutting the pre-Cambrian rocks on Mineral Hill and on the ridge east of Black Prince Canyon. At the Merrimac mine, oxidized ores extend to 35 feet below the surface, where they are succeeded by sulphides. The depth of oxidation in the replacement deposits on the Little Buck, Rickardite and Hilltop properties does not exceed 25 feet.

On the other hand, the depth of oxidation in deposits below pediments is usually considerable. In the veins at the Sally, Mormon and Sunol mines oxidized ore persists to groundwater level (90 feet) but may contain residual sulphides. At the Mormon mine sulphide ore was found below the water level. At the Excelsior mine, oxidation is said to persist to the water level. The deposits at the Memphis mine are deeply oxidized, and sulphides are rare above 200 feet depth. The limit of oxidation is

[10] Lindgren, W., Graton, L. C., and Gordon, C. H., Ore deposits of New Mexico : U. S. Geol. Surv. Prof. Paper IS, 1910, p. 211.

even greater in the Torpedo mine. Here great bodies of copper silicate extend to a depth of over 300 feet. Similarly at the Stevenson-Bennett mine, limonite and other products of oxidation not of post-mine origin are by no means lacking on the 200-foot level, and are said to be found even on the 450-foot level, which is no longer accessible. In these cases, oxidation has extended far below the modern water level. In general, the water level is taken to be the downward limit of oxidation, but, according to Lindgren[11], there may be exceptions to this rule, where there is "decided local movement of the oxygen-charged water downward along the fissures." Unless it be granted that such cases may occur as exceptions, it is necessary to postulate a rise in ground-water level after oxidation.

Sulphide enrichment of the Torpedo copper deposit has taken place at a depth of 365 feet, immediately below the zone of oxidation. Chalcocite is, however, found in residual masses in the oxidized ore. At the Excelsior mine, supergene sulphides are said to occur near the water level. A body of chalcocite was found only 30 feet below the surface in the Roos workings at the Memphis mine. On the other hand, oxidized ores persist to a depth of 200 feet in the South workings. It is not known whether an enrichment zone occurs in this part of the mine.

OXIDATION OF COPPER DEPOSITS

The only important primary source of copper is chalcopyrite, $CuFeS_2$. Tetrahedrite, Cu_8Sb2S_7, occurs in small amounts, and insignificant traces of enargite, Cu_3AsS_4, and rickardite, Cu_4Te_3, are recorded. Pyrite is the invariable associate of chalcopyrite. In the vadose zone where oxygen abounds, pyrite and chalcopyrite oxidize slowly and a solution containing the sulphates of iron and copper is produced. The nature of the supergene minerals deposited from such a solution is dependent upon the rock through which it is moving. In limestone the acid solution reacts speedily with the rock, depositing the carbonates azurite, $2CuCO_3.Cu\ (OH)_2$, and malachite, $CuCO_3.Cu\ (OH)_2$. Iron is deposited as limonite. Chrysocolla is of subordinate importance in deposits of this type, which are exemplified at the Excelsior and Memphis mines.

In the Torpedo orebody, which is in monzonite, the first effect of the acid sulphate solutions was to convert the feldspars and sericite into kaolin ; near what seem to have been rich sulphide shoots, the action has been very intense and the rock has been completely converted into a mass of soft kaolin. As noted by Lindgren in the Clifton-Morenci district[12], and experimentally

[11] Lindgren, W., Mineral deposits : 4th Ed., New York, 1933, p. 814.
[12] Lindgren, W., The copper deposits of the Clifton-Morenci district, Arizona : U. S. Geol. Surv., Prof. Paper 43, 1905, p. 191.

proved by Sullivan[13], kaolin acts as a precipitant for copper salts. In the Torpedo deposit, the principal copper mineral of the oxidized zone is the silicate chrysocolla; it appears to replace the kaolin. With it is associated a black substance which contains about 10 per cent copper, with manganese and silica. It has been tentatively identified by Mr. Bentley as stubelite, a hydrous copper-manganese silicate, but there is some doubt as to whether this is a valid species; more probably it is a mixture of several minerals. Owing to its softness it did not prove to be well adapted to microscopic study, and its nature remains uncertain. Locally a little turquoise has been found replacing the kaolin. Azurite and malachite occur in minor amounts. Limonite does not seem to be as abundant as the amount of pyrite in the primary sulphides would lead one to expect.

The oxidation process is still actively in operation in the Torpedo mine, and abundant brochantite, $CuSO_4.3Cu\ (OH)_2$, is being deposited in the mine workings. This mineral represents post-mine oxidation.

The copper carbonates and silicates have in certain cases been reduced to cuprite, Cu_2O and native copper. Cuprite surrounding chalcocite and covellite which have replaced chalcopyrite was noted on a polished surface of ore from the Excelsior mine. Native copper was abundant in the Torpedo mine and persisted to the 200-foot level.

ENRICHMENT OF COPPER DEPOSITS

Sulphate solutions which penetrate beneath the lower limits of oxidation are capable of reacting with the primary sulphides, depositing copper as secondary sulphides and removing iron. This leads to enrichment of the ore in copper ; the process is well known and has been the subject of many important studies[14]. In the present region the supergene copper sulphides include bornite, Cu_5FeS_4, covellite, CuS, and chalcocite, Cu_2S. It may be supposed that the enrichment began soon after oxidation of the deposits commenced; as the level of oxidation descended, supergene and hypogene sulphides alike were subject to oxidation. In some cases, residual masses of supergene sulphides were left high up in the oxidation zone; one such example is the chalcocite body which was mined between the 30- and 50-foot levels from the Roos shaft on the Memphis property. Generally, however, the supergene sulphides are encountered immediately below the oxidized ore. At the Torpedo mine, massive chalcocite

[13]Sullivan, E. C., The chemistry of ore-depositon—precipitation of copper by natural silicates: Econ. Geol. vol. 1, 1906, pp. 67-69. 14

[14]Graton, L. C., and Murdoch, J., The sulphide ores of copper: Trans. A.I.M.E., Vol. 45, 1913, pp. 26-93.

Emmons, W. IL, The enrichment of ore deposits: U. S. Geol. Surv. Bull. 625. 1917. Recent studies are summarized by Emmons, Recent progress in studies of supergene enrichment : Lindgren volume, A.I.M.E., 1933, pp. 405-411.

EXPLANATION OF PHOTOMICROGRAPHS, PLATE VIII

A. Sulphide ore, Silver Coinage mine.
Pyrite (white) replaced by chalcopyrite (light gray) and sphalerite (dark gray).
Ordinary light X 30 (1290A)

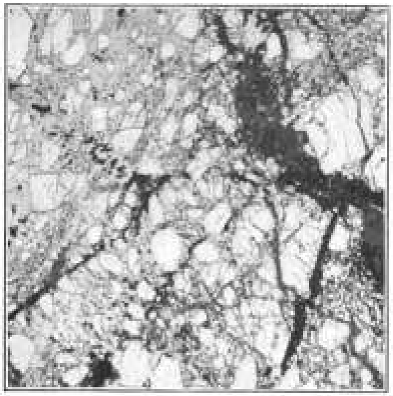
B. Sulphide ore, Silver Coinage mine.
Veinlets of argentite (gray) cutting through the gangue. Galena (white) is partly replaced by argentite.
Ordinary light X 80 (1290A)

C. Bismuth ore, South shaft, Memphis mine.
Graphic pattern developed in tetradymite by natural oxidation. An identical pattern can be produced by artificial etching with nitric acid.
Ordinary light X 200 (1216)

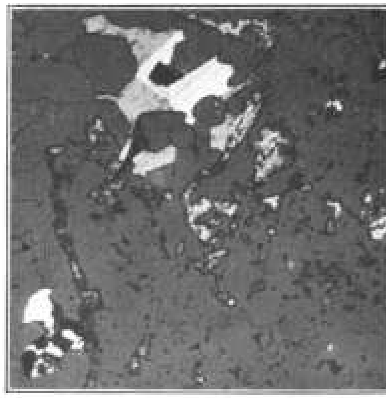
D. Gold ore, 90-foot level, Mormon mine.
Flakes of native gold (center of field) enclosed by limonite which has replaced pyrite.
Ordinary light X 70 (1293)

E. Sulphide ore, east workings of Hilltop mine.
Altaite and Galena (showing triangular pits) in carbonate gangue.
Ordinary light X 28 (1166)

F. Enriched sulphide ore, from winze below the 300-foot level, Torpedo mine. Pyrite traversed by veinlets containing chalcocite (gray). Small remnants of chalcopyrite occur in the chalcocite in the center of the field.
Ordinary light X 28 (1211)



A



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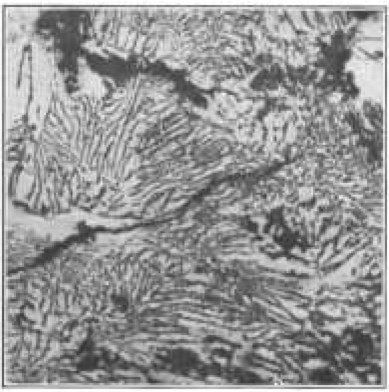

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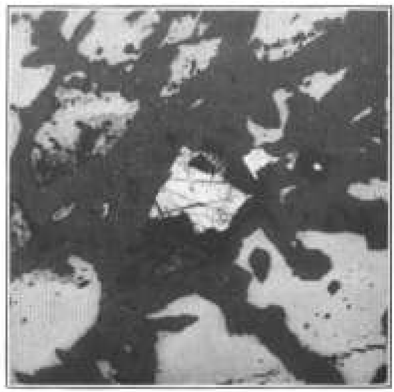

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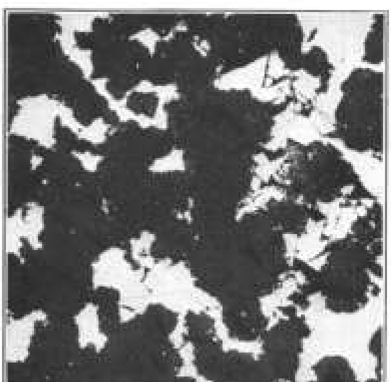
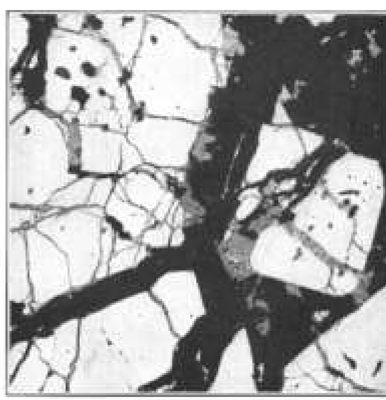


E



F

PHOTOMICROGRAPHS OF POLISHED SECTIONS
See opposite page for explanation.

ore was found below the 300-foot level. Polished sections show that the chalcocite replaces chalcopyrite and pyrite. Replacement of chalcopyrite is almost complete, while the pyrite is only fringed with chalcocite or traversed by veinlets of this mineral. (Plate VIII, page 156). This observation is in accordance with the conclusions of Graton and Murdoch[15] that pyrite is much less susceptible to replacement by supergene sulphides than is chalcopyrite. In the Excelsior mine the primary sulphides are chalcopyrite and sphalerite. The enrichment proved to be rather feeble in the specimens obtained; it showed, however, the difference in susceptibility between the two minerals. Sphalerite is not at all altered; whereas the chalcopyrite grains have been penetrated by subparallel tongues of bornite, and partly surrounded by this mineral, which is probably of supergene origin. The bornite is itself replaced by chalcocite. In the sulphide ore from the Silver Coinage, covellite, related to tiny fractures, replaces tetrahedrite, galena and chalcopyrite. It is present only in insignificant amount.

OXIDATION AND ENRICHMENT OF SILVER DEPOSITS

The process of oxidation of silver deposits in arid regions leads to their enrichment; by far the richest part of the silver deposits is near their outcrops. This is due to the formation of silver halides near the surface, the source of the halogens being the saline dusts of the desert[16]. In the Organ district, rich outcrops have been exploited on Big Three, Galloway, Gray Eagle and Crested Butte properties. Minerals identified include cerargyrite, AgCl; bromyrite, AgBr; and embolite, Ag(Br,Cl). These minerals do not persist below a depth of 6 feet from the surface in the veins in the monzonite, but at the Smith mine in an irregular deposit in limestone they appear to have been found down to about 15 feet below the surface. At the Galloway mine native silver is said to have been found near the outcrop.

In certain other deposits the silver has not been fixed as halides, but rather as argentojarosite in the oxidation zone. A specimen from the Homestake mine assayed 600 ounces of silver to the ton; the primary ore at the same mine averages less than 100 ounces, so that the production of argentojarosite represents a substantial enrichment. Probably argentojarosite occurs in the outcrops of many of the silver deposits associated with limonite; it is not easy to identify.

Sulphide enrichment of silver has not been proved with certainty in any of the deposits of the present region. As stated on page 119, argentite is invariably the last sulphide to form in the

[15]Graton, L. C. and Murdoch, J., op. cit., p. 39.
[16] Keyes, C. R., Origin of certain bonanza silver ores of the arid region : Trans. A.I.M.E. Vol. 54, 1911, pp. 500-517.

supposed hypogene deposits, and it cannot be said with certainty that it is not a supergene mineral in these cases. However, as it is not associated with the known supergene sulphides, chalcocite and covellite, even in specimens where argentiferous tetrahedrite is undergoing alteration to these minerals, it is classed as hypogene.

OXIDATION AND ENRICHMENT OF GOLD DEPOSITS

Gold is associated with pyrite and chalcopyrite. When oxidation of these minerals to limonite and copper carbonates takes place, the gold remains as unaltered particles included in the new minerals. In a polished section of ore from the oxidation zone at the Mormon mine, a particle of free gold was found in limonite which had replaced pyrite. There was no reason to suppose that any migration of the gold had occurred. However, in gold veins of this type, there may be a slight concentration of gold in the upper part of the oxidation zone, due to removal of other constituents in the veins. Blanchard and Boswel[17] have shown that limonite tends to be exported from the outcrops of pyrite veins when the gangue is an inert one and the amount of chalcopyrite is less than the amount of pyrite. Export of limonite reduces the iron content and by residual concentration increases the proportion of other constituents. This process may perhaps operate below the outcrop. In general, however, variations in gold content are much more probably inherited from primary variations in the veins.

Enrichment of gold involving migration and redeposition has not been proved in the present region, but there are two cases which suggest that it may have occurred. In the Dona Dora tunnel a rich shoot of gold ore was found at the place where primary sulphides gave place to limonite. None of the ore remains, so that the state of the gold could not be determined. The shoot was not more than a few inches wide. Manganese is abundant in this vein ; it occurs in primary manganiferous siderite. Chlorine, from saline dusts, may have penetrated into the deposits, assisting the enrichment process. The remarkably rich pocket recently found at the Pagoda prospect, assaying 35 ounces of gold per ton, was at the bottom of the oxidation zone. Again manganiferous siderite was found in the vein.

OXIDATION OF ZINC DEPOSITS

Sphalerite is the sole primary zinc mineral. It is readily oxidized and yields calamine, $ZnSiO_3.(OH)_2$, which occurs abundantly in pale blue crystalline aggregates at the Memphis mine, and in colorless crystals at the Stevenson-Bennett mine; hydrozincite, $3Zn(OH)_2.2ZnCO_3$, found at the Merrimac and Rickardite

[17] Blanchard, R., and Boswell, P. E., Notes on the oxidation products derived from chalcopyrite: Econ. Geol., vol. 20, 1925, pp. 613-638.

mines; and smithsonite, $ZnCO_3$, which appears to be widespread in rather small amounts in the oxidized zones of the zinc deposits. Apparently calamine is quantitatively the most important of the oxidation products of sphalerite in the present region, even in limestones.

OXIDATION OF LEAD DEPOSITS

The oxidation of galena results in the formation of anglesite, $PbSO_4$, cerussite, $PbCO_3$, and wulfenite, $PbMoO_4$. Rarely pyromorphite, $PbCl.Pb_4 (PO4)_3$, occurs near the surface. A few crystals of the rare phosgenite, $PbCl_2.PbCO_3$, were found at the Stevenson-Bennett mine some years ago. Cerussite is the most abundant of these minerals, and forms large bodies in the limestone at the Stevenson-Bennett mine, where it also occurs as a replacement of altered porphyry. Wulfenite occurs in considerable quantity in the oxidation zone of the Bennett orebody, and has been an important source of lead. The origin of wulfenite is very difficult to explain. No molybdenite or other primary molybdenum mineral has been found here in spite of a careful search; it appears that the molybdenum may have been introduced by the groundwaters from some distant source. This conclusion was reached by Harley[18] who studied the vanadium deposits in the Sierra Caballos, which also contain wulfenite. Galena, the only sulphide other than pyrite in these deposits, failed to give a positive reaction for vanadium or for molybdenum. On the other hand, Newhouse[19] concludes from a chemical and spectroscopic study that a partial source of the molybdenum in deposits such as these is the small amount contained isomorphously in the primary sulphides. At the Stevenson-Bennett mine, wulfenite was deposited at the same time as cerussite, fine-grained quartz and limonite.

Altaite, PbTe, yields in the oxidation zone a very soft mineral which is pale brown by reflected light ; it is distinctly isotropic and gives the following etch tests : HNO_3, vigorous reaction, instantly blackens ; HCl, instantly blackens ; $FeCl_3$, black stain ; HCN, blackens ; KOH, $HgCl_2$ negative. In places this substance appears to be fairly homogeneous, while in others it exhibits concentric banding into which minute bands of highly anistropic silvery white mineral enter. These bands, which are visible only under high power, are thought to be native tellurium. The oxidation product of altaite, while it has been mentioned by Schneiderhohn and Ramdohr,[20] has never been found in sufficient quantities for analysis, and has not been named. The material available in the present area was not such that separation of the

[18]Harley, G. T., The geology and ore deposits of Sierra County, N. Mex.: N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 10, 1934, p. 206.

[19]Newhouse, W. H., The source of vanadium, molybdenum, tungsten, and chromium in oxidized lead deposits: Amer. MM., Vol. 19, pp. 218, 219.

[20]Schneiderhohn, H., and Ramdohr, P., op. cit., pp. 264-265.

mineral for analysis was possible. It may be conjectured that the substance is a lead tellurite.

OXIDATION OF TETRADYMITE

At the Memphis mine a pit southwest of the Roos shaft exposes supergene bismuth ore which contains at least two minerals. The most abundant is a light yellow mineral which forms pseudomorphs after tetradymite. Using microchemical methods, a strong bismuth test was obtained, but the presence of tellurium was not proved. The mineral effervesced in acid. It was tentatively identified as bismutospharite, $Bi_2(CO_3)_2 2Bi_2O_3$ In addition, a yellow mineral giving a positive test for tellurium was found in some specimens. As no unaltered tetradymite was found admixed with this material to account for the tellurium, identification was tentatively made as montanite, $Bi_2(OH)_4TeO$ (?). The basic bismuth carbonate bismutite was not found.

Reference has already been made (page 132) to the graphic intergrowth pattern which is revealed in tetradymite when it undergoes oxidation. It is likely that one of the minerals above enters into this intergrowth.

SILICIFICATION

The massive siliceous outcrops associated with certain of the faults in the Torpedo-Bennett fault zone have already been mentioned in connection with the Tertiary mineralization process. While it is very likely that large bodies of silica were deposited in conjunction with this mineralization, there is also some evidence which indicates that silicification near the surface has taken place during the oxidation process. At the Torpedo mine, the low-grade orebody revealed by the workings from No. 4 shaft has a very prominent barren siliceous outcrop. The workings directly beneath this outcrop, on the 200-foot level, show only a small amount of silica, in irregular veinlets ; in this case it seems very probable that there has been some upward movement of silica during the oxidation process. Similarly, two tunnels to the west of the mine have been driven to cut the silicified breccia zones associated with the western faults in depth. In both cases brecciated limestone, almost free from silicification, has been found.

There are two possible explanations for these facts. On the one hand, there may be discontinuous shoots of hypogene quartz in the faults, so that the three tunnels passed beneath the shoots. This hypothesis is fairly well supported by the surface evidence the silicification is by no means continuous throughout the whole exposed length of the fault zone, nor is it continuous on any single fault for more than about 2000 feet. On the other hand, the silicification may be a supergene effect, confined to the immediate vicinity of the surface. Locke[21] reached the conclusion that this was the case in connection with silicified zones at Tyrone, New Mexico, and Graton[22] has noted similar occurrences in Shasta County, California. In many parts of New Mexico there are silicified fault zones, and in many cases these are far removed from centers of igneous activity. On the whole, the supergene hypothesis seems to be the most satisfactory, and it may be added that the climate of the region seems to be particularly favorable for the supergene transportation and deposition of silica.

[21] Locke, A., Leached outcrops as guides to copper ore : Baltimore, 1926, pp. 26-29.
[22] Graton, L. C., Personal communication.

PART II

AN OUTLINE OF THE GEOLOGY OF DONA ANA COUNTY

INTRODUCTION

Mountain ranges and hills cover approximately one-quarter of the area of Dona Ana County, and it is from these that our knowledge of the pre-Tertiary geology of the region comes; these, too, contain the deposits of economically valuable minerals. The rest of the county is occupied by basins underlain by loosely consolidated fanglomerates and gravels of later Tertiary age, under a thin alluvial cover, and by the valley of the Rio Grande. In the present section an outline of the geology of the region is presented. The older rocks are described from the ordinary viewpoints of stratigraphy, petrography and structure; the late Tertiary and Quaternary formations are approached by the methods of physiography.

In preparing this outline, the work of N. H. Darton,[1] who was responsible for the geologic map of the State of New Mexico, has been freely drawn upon for information regarding the sedimentary rocks. The geologic map of the county, which accompanies this report, is based upon Darton's map, which has been enlarged, and revised in accordance with the new maps of the Organ Mountains and with reconnaissance studies made by the present author in the Dona Ana Mountains, the San Andres Mountains, and at Robledo. Johnston's map of Tonuco Mountain[2] has been incorporated.

PRE-TERTIARY ROCKS

THE PRE-CAMBRIAN BASEMENT COMPLEX

The basement complex is exposed along the foot of the east-facing scarp of the San Andres Mountains and in the great canyons which penetrate this range from the east ; it outcrops in the Organ Mountains, and is seen on the east side of Tonuco Mountain.

The earliest rocks include gneisses and schists. Dark biotite-schist is exposed in Deadman, San Andres and Bear can-

[1]Darton, N. 11. Geologic structure of parts of New Mexico: U. S. Geol, Surv. Bull. 726-E, 1922.
Geologic map of New Mexico: U. S. Geol. Surv., 1927.
"Red beds" and associated formations in New Mexico: U. S. Geol. Surv. Bull. 794, 1928.

[2]Johnston. D. W., Jr., Fluorspar in New Mexico, N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 4, 1928, p. 66.

yons. Locally granite has been injected into it, forming biotite-gneiss. In Deadman Canyon it is cut by massive igneous rocks of dioritic or gabbroid character. Chlorite schist occurs on Mineral Hill in the Organ Mountains (Page 30) and at Tonuco. Gray and white quartzite occurs in Deadman and Bear canyons, and on Mineral Hill.

The schists, gneisses and diorites appear to be roof pendants or xenoliths in a granite batholith of huge size. Gray and pink granite predominates over all other basement rocks in the San Andres and Organ mountains. Pegmatites are abundant, but, with the possible exception of mica, they contain no valuable minerals.

Epidiorite dikes are widespread among the pre-Cambrian rocks. They were intruded, probably as diabases, after the consolidation of the granite batholith, and have suffered metamorphism since their emplacement.

PALEOZOIC SEDIMENTARY ROCKS

CAMBRIAN SYSTEM

Bliss Sandstone.—Resting unconformably on a smooth surface of the basement rocks there is a series of quartzites and shales of Cambrian age. These outcrop in the San Andres and Organ mountains, and for a short distance south of the northern border of the county in the Sierra Caballos. In the San Andres Mountains the thickness is 40 feet in Hembrillo Canyon, 110 feet in San Andres Canyon, and 120 feet in the southern ridges.[3] In the Organ Mountains the thickness varies from 120 to 140 feet. There is thus a gradual southward thickening of this formation (see Fig. 2 page 50). The quartzites are gray or brown, and the shales are brown; iron is abundant in the formation. Annelid borings occur in the quartzites.

ORDOVICIAN SYSTEM

El Paso Formation.—Dolomites and dolomitic limestones of late Beekmantown age outcrop in the San Andres, Organ, and Caballos Mountains and may be present at Robledo and in the northern part of the Franklin Mountains. The formation gradually thickens to the south, from 200 feet at Hembrillo Canyon to 800 feet in the southern Organ Mountains. Fossils are recorded from the San Andres Mountains near San Andres peak.

The beds consist of gray slabby dolomites with reticulating brown markings on weathered surfaces. These occur only in this formation. Chert nodules occur in some of the beds.

Montoya Formation.—In the localities mentioned above, the El Paso formation is overlain by dolomites belonging to the Mon-

[3] Darton, op. cit., 1928, p. 184.

toya formation, of Richmond age. Two lithologic divisions may be recognized: a lower member consisting of very massive, dark-colored dolomite, resting on a thin sandstone or conglomerate which separates the formation from the El Paso formation; and an upper member of thin-bedded dolomitic limestone with abundant chert nodules. The lower member varies from 70 feet thick in Hembrillo Canyon to 110 feet in the southern ridges of the San Andres Mountains, while the upper member varies from 50 feet to 85 feet in thickness between the same localities. The formation continues to thicken towards the south. The lower member forms a cliff in the San Andres Mountains, while the upper one makes a shelf.

SILURIAN SYSTEM

Fusselman Formation.—The Fusselman formation, consisting of dolomites of Niagara age, outcrops in the San Andres, Organ, and northern Franklin mountains, in the Sierra Caballos and in Robledo Mountain.[4] It consists of two characteristic members, a lower one of gray thin-bedded dolomites, with much chert, and an upper one of massive dark dolomite. The upper member frequently forms a cliff. The thickness of the formation varies from 120 feet in Hembrillo Canyon to 1000 feet in the Franklin Mountains, but it is doubtful whether the full thickness of the formation is present in the northern part of the Franklins, in Dona Ana County. The grain of the dark upper member is everywhere coarse, and on weathered surfaces it has a sugary appearance, which is very easy to recognize. An analysis of Fusselman dolomite from San Andres Canyon appears on page 45.

DEVONIAN SYSTEM

Percha Shale.—Throughout the San Andres Mountains, in the northern part of the Organ Mountains, in Robledo and in the Sierra Caballos, a series of shales with Upper Devonian fossils rests on a slightly irregular surface of the Fusselman formation. The thickness of the formation is between 100 and 120 feet. In the southern part of the Organ Mountains it thins out and disappears. It is not present in the northern ridges of the Franklin Mountains, where the Fusselman dolomite is overlain by Carboniferous limestones. Two divisions are, recognized, a lower member consisting of black fissile shales, and an upper member of gray shales with intercalated nodular limestones. Only the upper division is fossiliferous. The Percha shale forms a gently sloping shelf above the cliff made by the Upper Fusselman beds in many localities.

[4]Lee, W. T., Notes on the Lower Paleozoic rocks of New Mexico: Amer. Jour. Sci., 4th series, Vol. 26, 1908, p. 185.

CARBONIFEROUS SYSTEM

Lake Valley Limestone (Mississippian).—A massive limestone overlies the Percha shale in the San Andres Mountains; lower Mississippian fossils have been obtained from this bed in San Andres Canyon, in Lion Den Canyon, and west of San Nicholas Spring. The formation is believed to be present north of the Organ Mountains batholith, and it also occurs in the Sierra Caballos. It has not been identified as yet in Robledo Mountain. In the Franklin Mountains a bed of upper Mississippion age occurs,[5] but the Lake Valley series is absent. The formation may be locally discontinuous in the San Andres Mountains; it is 100 feet thick in San Andres Canyon. Chert nodules are abundant in some parts of the formation.

Magdalena Series (Pennsylvanian).—Pennsylvanian time is represented by a thick series of alternating limestones, shales and sandstones known as the Magdalena series. The thickness in the Franklin Mountains is 1100 feet, and there is a great thickening northwards. North of Organ the series is approximately 3000 feet thick; in the San Andres Mountains it probably reaches the same figure. Robledo Mountain is made up chiefly of Magdalena beds and they figure importantly in the southern Sierra Caballos. Bishop's Cap and Tortugas Mountains are composed of Magdalena beds. Comparatively thin limestones make up the greater part of the series. Individual beds seldom exceed 100 feet in thickness. The limestones vary greatly in character, some being fossiliferous, others barren of fossils; some are coarse grained, others fine grained. Black carbonaceous limestones appear in the upper part of the series. Thin brown shale beds occur here and there, and there are a few sandstones, chiefly in the middle part of the formation. Chert is abundant, and may occur in nodules orbeds. In the upper part of the series in the San Andres Mountains, red sandstones and shales alternate with limestones,indicating a transition to the terrestrial Abo sandstone of Permian age. The exact boundary of the formation has not yet been established; indeed it is doubtful whether sufficient evidence can be obtained to fix the boundary exactly. There is a similar transition to the Abo sandstone in the central part of the Robledo-Picacho range.

Hueco Limestone (Pennsylvanian [?]).—In the northern part of the Franklin Mountains the Hueco limestone is exposed in the foothills on the west side of the range. The beds consist of gray limestones, and contain gypsum. Richardson[6] eclassified the Hueco limestone as Pennsylvanian, but it has since been found that his Hueco formation contained a considerable thickness of

[5] Personal communication, L. E. Nelson.

Magdalena beds. Nelson regards the Hueco limestone, in the restricted sense, as of Pennsylvanian age, on account of the close similarity of the Hueco and Magdalena faunas.[7] The presence of the fusulinid genus *Schwagerina* has led other geologists to regard the Hueco beds as Permian in age. The dividing line between Pennsylvanian and Permian remains a matter of dispute, and no contribution can be made to the subject in these pages.

Abo Sandstone (Permian).—Red sandstones of the Abo group outcrop along the west side of the San Andres Mountains, at Tonuco, in the southern part of the Robledo-Picacho range, and on the east side of the Sierra Caballos. They are apparently absent south of Organ, and do not appear in the Franklin Mountains. In the central San Andres Mountains the thickness is 1000 feet, but this diminishes towards the southern outcrops near the Davis ranch.

The Abo beds were accumulated under terrestrial conditions, but there were occasional advances of the sea, as indicated by thin limestones interbedded with the sandstones. Red sandstones predominate, but in places white or yellow sandstones alternate with them. The grain of the beds is generally fine, and no conglomerates were observed; evidently the sand grains had been transported some distance. Individual beds are generally thin and appear to have been deposited under water; large masses of cross-bedded sandstone were not observed in this region.

North of the ruined Goldenburg ranch on the Jornada Range Reserve, fossil plants occur abundantly in a white sandstone member of this group. These have not yet been identified.

Chupadera Formation (Permian).—In the southern San Andres Mountains near Little Well and the Davis ranch the Abo sandstone is overlain directly by massive gray limestones which probably represent the upper member of the Chupadera formation, the San Andres limestone. Farther north shales, sandstones and gypsum beds are intercalated between the San Andres limestone and the Abo sandstone. The Chupadera formation appears in a series of discontinuous outcrops in the western foothills of the San Andres Mountains. Limestones belonging to this formation are seen immediately north of Picacho, underneath the Tertiary lavas. The formation does not appear south of this point.

CRETACEOUS SYSTEM

Beds of Comanche Age.—On Cerro de Muleros, a conical hill near El Paso which is traversed by the boundary between the Republic of Mexico and Dona Ana County, beds of Comanche (Lower Cretaceous) age outcrop. These include limestones, sandstones, shales and marls, containing, according to studies by

[7] Personal communication, L. E. Nelson.

Bose,[8] a Fredericksburg fauna in the lower part of the section, and a Washita fauna in the upper part. The total thickness of the beds is almost 1000 feet. The relation of these beds to corresponding beds in Texas is shown by a section given by Adkins.[9] The limestones are quarried for cement manufacture in the neighborhood of El Paso.

Limestones with beds of gypsum make up the Potrillo Mountains. According to Lee,[10] these contain a Fredericksburg fauna, and are correlated with the Sarten series of southern New Mexico. The beds exceed 500 feet in thickness.

Mancos Shale. Near the Davis Ranch in the southern San Andres Mountains sandstones and shales outcrop; these have yielded a Benton fauna, indicating a horizon equivalent to the lower part of the Mancos shale of northern New Mexico and Colorado. Their thickness is 200 feet. One mile south of the Davis ranch, a pit has been opened on a coal seam associated with carbonaceous shales. The underground workings at this place have collapsed, so that the nature of the seam can no longer be determined. The outcrops of the Mancos beds continue as far north as Middle Tank on the Jornada Range Reserve.

EARLY TERTIARY ROCKS

SEDIMENTS

GALISTEO (?) SANDSTONE

Near the Davis ranch in sec. 19, T. 20 S., R. 4 E., and secs. 24, 25, T. 20 S., R. 3 E., several hundred feet of conglomerate rest on the sandstones and shales of the Mancos group with marked unconformity. The conglomerate is composed entirely of pebbles of Magdalena, Abo and Chupadera limestones and sandstones, and has been thoroughly consolidated. A section by Darton[11] shows that it transgresses across the Cretaceous beds, and was therefore deposited after the uplift and warping of the beds had occurred. On this account it may be suggested that it is of approximately the same age as the conglomerate underlying the lava series in the Organ Mountains. It contains abundant petrified logs, and, as these are characteristic of the Galisteo sandstone of central New Mexico, it is tentatively correlated with that formation.

[8]Bose, E. Excursion au Cerro de Muleros : X Int. Geol. Cong., 1906, Guidebook 20. Monografia geológica y palaeontológica del Cerro de Muleros, cerca de cuidad Juarez, Estado de Chihuahua: Bbl. del Inst. Geol. de Mexico, num. 25, 1910.

[9]Sellards, E. H., Adkins, W. S., Plummer, F. B., The Geology of Texas: vol. 1, Univ. Texas Bull. 3232, 1932, p. 368.

[10] Lee, W. T., quoted by Darton, N. H., op. cit. 1928, p. 39.

[11]Darton, N. H., op. cit., 1928, p. 192.

IGNEOUS ROCKS

GENERAL FEATURES

The Tertiary igneous rocks of Dona Ana County include lavas of acid, intermediate and basic composition, and intrusive rocks of the syenite-monzonite family. Brief descriptions of the field occurrence and petrography of the rocks follow, arranged by localities. The reader is referred to Part I for a description of the igneous rocks of the Organ Mountains; they are not described again here.

DONA ANA MOUNTAINS

The Dona Ana Mountains lie northeast of the town of Dona Ana, between Organ and the Rio Grande. They appear to represent the dissected remains of a much larger group of mountains, now almost buried beneath late Tertiary and Quaternary gravels. Andesite, latite and rhyolite flows and syenite porphyry intrusions make up these mountains. The cliffs on the southwest side of the range, over 1000 feet high, are composed of rhyolite, rhyolite tuff and latite. On the west side of the range two thin obsidian flows were noted among the rhyolites. This series is overlain by alternating andesite and white rhyolite flows, which in the central part of the mountains pass upward into massive gray-green andesites. The mountains have been carved out of part of a structural basin, open to the east and closed to the west.

The rhyolites and latites may be correlated tentatively with the basal series in the Organ Mountains; the andesites with the Orejon andesite. The upper flows in the Organ section appear not to be represented in the Dona Ana Mountains.

The lavas are penetrated by large sills and dikes of syenite porphyry. The sills are conformable with the structure of the basin ; they swing round in a series of arcuate outcrops, and dip towards the center of the basin. Large dikes up to 300 feet wide join the sills and cut across the structure ; one such dike, running east-west on what appears to be the axial line of the basin, forms the prominent ridge on the east side of the mountains.

The rhyolites were not examined petrographically. An obsidian specimen from an excavation $2^1/_2$ miles north of Dona Ana proved to be a black vitreous rock with abundant phenocrysts of clear sanidine (mean refractive index 1.524, 2V low) up to 2 mm. in length. A few small oligoclase crystals are associated with the sanidine, and in one case the sanidine had grown around a core of oligoclase. Under the microscope the groundmass is seen to consist of perfectly isotropic glass of a pale brown color. The refractive index of the glass is 1.503; according to an unpublished diagram by M. A. Peacock, this indicates that the silica content of the glass is 68 per cent.

The latite is a purplish-gray rock with abundant feldspar phenocrysts. Oligoclase occurs in lath-shaped crystals and exceeds in amount the orthoclase, which occurs in irregular patches. A small amount of quartz is present. The specimen examined, from a quarter of a mile northeast of the highest peak of the mountains, showed alteration to pale green epidote and calcite.

Andesite specimens from the ridge south of the east end of the road which runs through the mountains show phenocrysts of oligoclase, $Ab_{70-75}An_{30-25}$. The groundmass consists of tiny oligoclase laths, with a very small amount of quartz but no alkali feldspar. Accessory minerals include apatite and opaque iron minerals. Variable amounts of green epidote, sericite and calcite occur.

The intrusive syenite porphyry superficially resembles the quartz-monzonite of the Organ Mountains batholith. The microscope, however, reveals some differences in composition between this rock and the quartz-monzonite. The phenocrysts, up to 5 mm. long. make over two-thirds of the rock. and consist of orthoclaseperthite, containing exceedingly abundant albite segregations. A few crystals have cores of oligoclase, but these are distinctly rare. Plates of brown biotite occur. The groundmass is made up of alkali feldspars averaging about 0.75 mm. in length and quartz which makes up about one-quarter of the total material in this part of the rock. The amount of oligoclase is insufficient to justify the classification of this rock as a monzonite, but the large amount of albite in the perthite suggests a monzonotic rather than a syenitic composition. Probably the rock is an alkalic differentiate of the magma from which the Organ Mountains rocks were derived.

The foregoing observations are the results of a very brief and sketchy study of the Dona Ana Mountains. Structurally and petrographically they offer many features of interest, and would repay a detailed investigation.

CERRO DE MULEROS

Cerro de Muleros is made up of a nearly circular body of intrusive rock, surrounded by Cretaceous sediments. On page 171 a map of this hill by Bose is reproduced. In general, the sediments dip away from the intrusive mass, but there are interesting local complexities in the structure. It seems reasonable to regard the mass as a laccolith in view of its shape and domed roof ; the floor has not yet been recognized. Minor faults are arranged both radially and concentrically with respect to the intrusion.

The igneous rock has been described by Rosenbusch as a syenite porphyry, with phenocrysts of orthoclase and plagioclase. The plagioclase is zoned, the cores being $Ab_{57}An_{43}$, the outer layer

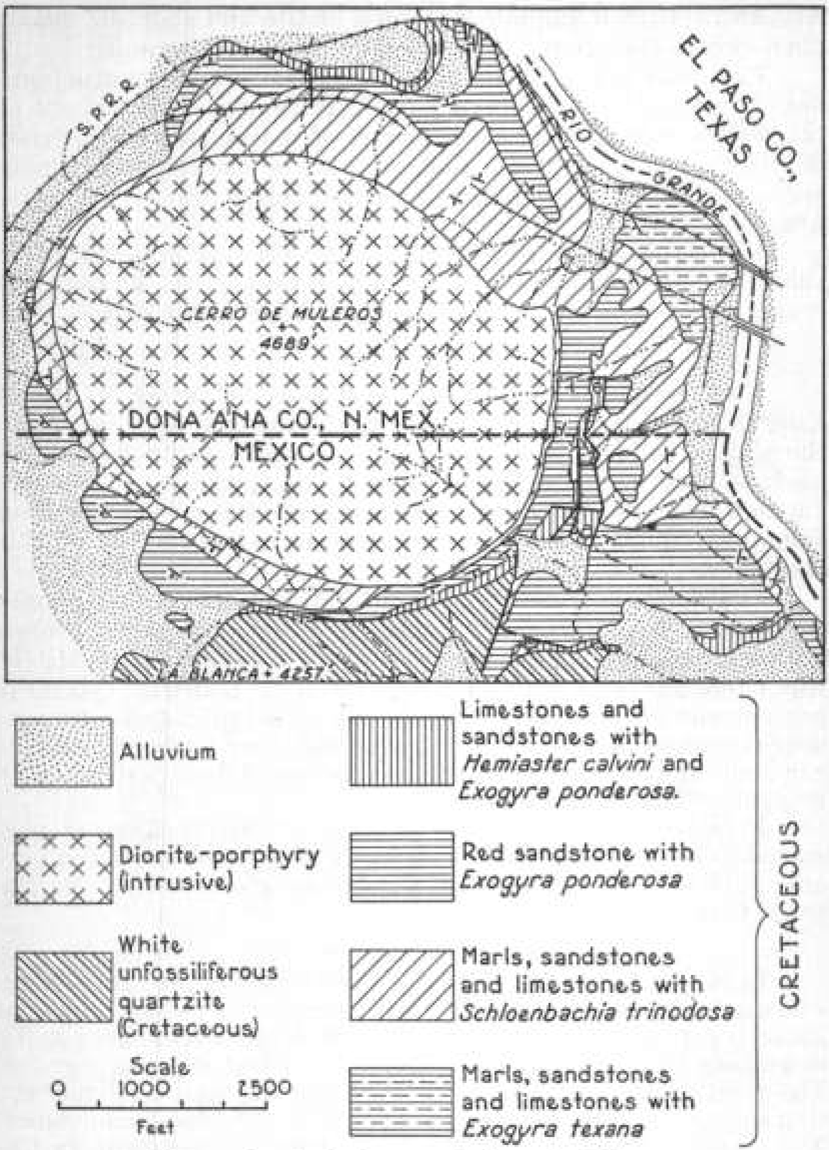


FIGURE 9.—Geologic map of Cerro de Muleros.
From a map by E. Bosë, X Int. Geol. Cong., Guidebook 22, 1906.

$Ab_{69}An_{31}$. Brown amphibole, brown biotite and sporadic quartz phenocrysts also occur. The groundmass is microgranitic.[12]

Professor Quinn kindly permitted the examination of a number of thin sections of this rock in his collection. The amount of plagioclase considerably exceeds that of orthoclase, and in view of this fact it is suggested that the rock be classified as a monzonite or even diorite porphyry, in accordance with modern petrographic usage.

The structure and petrography of Cerro de Muleros is the subject of a forthcoming study by Professor Quinn, so that this region was not examined during the present investigation.

MOUNT RILEY

Northwest of the Potrillo Mountains the mass of Mount Riley with its several peaks rises approximately 1500 feet from the plain. Only the southwest side of the mountain was examined; it was found to consist of a great thickness of massive e dacite. The smooth, even weathering of the whole mountain suggests strongly that it is composed entirely of rocks of this character.

The dacite is yellowish-brown and contains visible plagioclase laths of small size. It rings like phonolite when broken with a hammer. Under the microscope it is seen to consist of tiny oligoclase laths making a rude trachytic texture. Quartz is present and an unusual feature is that it is optically continuous over considerable areas. A few elongate hornblende crystals occur and there is much finely divided amphibole and chlorite present. Some calcite was noted.

From its physiography, the mass of Mount Riley is presumed to be of pre-Santa Fe origin. However, no lavas comparable with those of this region were found elsewhere among the early Tertiary lavas.

NORTHWESTERN REGION

Lavas make up the Sierra de las Uvas, and are exposed in the southern Sierra Caballos, at Tonuco, and in the RobledoPicacho range. The rocks of all these mountains appear to be essentially similar, and it is convenient to treat them as a group. The predominating rock type is rhyolite tuff and agglomerate, containing near the base of the section interbedded sandstones. The manganese deposits at Rincon [13] in the southern Sierra Caballos, are in these rocks. In the Sierra de las Uvas a great thickness of pyroclastics occurs, capped by a sheet of basalt. Darton [14] gives the following section:

[12]Quoted by Bose, E., op. cit., 1906, p. 2.

[13]Wells, E. IL, Manganese in New Mexico : Min. Res. Surv., N. Mex. Sch. Mines, Bull. 2, 1918, pp. 35, 36.

[14] Darton, N. H., op. cit., 1928, p. 324.

9. Basalt
8. Basalt-agglomerate
7. Rhyolite
6. Volcanic ash
5. Rhyolite
4. Ash
3. Hard tuff
2. Ash and tuff
1. Agglomerate

The total thickness is approximately 300 feet. At Radium Hot Springs rhyolites, with marked flow banding, are interbedded with tuffs. On Picacho a series of rhyolite tuffs and rhyolites is exposed. In the hills west of the Powell ranch pink rhyolite tuffs are capped by a dark andesitic flow.

The basalt of the Sierra de las Uvas appears to be conformable with the other lavas. It dips to the west, and disappears under the alluvium, reappearing in the range south of Nutt, in Luna County. The structure here is thus a broad syncline. It is clear that this basalt is of a distinctly earlier age than the flows which rest on the Quaternary erosion surfaces. One mile north of Picacho, two plugs of basalt break through the Permian sediments (indicated by "b" on the physiographic map, page 177) ; the physiographic relations suggest that these supplied not the Quaternary and Recent basalts, but the older Tertiary flows. Beautiful columnar jointing is developed parallel to the walls of the necks. The basalt contains phenocrysts of oligoclase, $Ab_{73}An_{37}$ in a groundmass of ordinary basaltic composition, with labradorite $Ab_{45}An_{55}$, colorless olivine, and very pale brown augite, in a brown glassy mesostasis. The phenocrysts are surrounded by a narrow reaction rim of more calcic feldspar. They serve to connect these basalts with the Tertiary magma cycle; oligoclase is the characteristic plagioclase of the early Tertiary intrusives and extrusives. The final product of differentiation of the magma was evidently of basic composition.

SUMMARY OF TERTIARY IGNEOUS ACTIVITY

Enough evidence has not yet been accumulated to make possible a complete statement of the igneous history of Dona Ana County. There are certain facts, however, which serve to link together the observations made in the various mountains of the region, and upon these it is possible to base a tentative outline of the history.

If it be assumed that the intrusions in the Dona Ana Mountains were contemporaneous with the intrusion of the Organ Mountains batholith, a lava series earlier than the intrusions can be recognized. This consists of rhyolite tuffs, latites, andesites and soda-rhyolites. A possible clue to the relations between this group and the lavas in the northwestern region is provided by observations at Tonuco. Johnston[15] has presented convincing evidence that the fluorite vein in pre-Cambrian granite and schist here was emplaced before the accumulation of the agglomerate which rests on the old rocks. The vein is truncated by the agglomerate, and fragments of fluorite appear among the detritus enclosed by the agglomerate. Observations during the present study confirmed his views. There is no reason to believe that the fluorite in the agglomerate was formed by replacement; and moreover the formation of a fissure vein 10 feet wide in granite and schist, without disturbing an overlying agglomerate bed, would hardly be possible. The fluorite vein has all the typical characteristics of the outer zone deposits of the Tertiary intrusive cycle in the Organ Mountains (page 138). If so great a burden may be laid on this evidence, we may conclude that the tuffs and agglomerates of the northwestern region were erupted after the intrusive cycle had run its course.

Their accumulation was preceded by profound erosion. In the Sierra Caballos they transgress across all horizons from the Bliss sandstone (Cambrian) to the Mancos shale (Cretaceous). At Tonuco they rest on the pre-Cambrian granite and schist. North of Picacho the rhyolites rest on the San Andres limestone of the Chupadera formation (Permian).

The igneous history of the region may be summarized as follows:

1. Post-Cretaceous warping and uplift. Accumulation of Galisteo beds.
2. First period of eruptions:
   Rhyolite tuff, rhyolite, latite, Andesite,
   Rhyolite-tuff, soda-rhyolite.
3. Intrusion of the Organ Mountains batholith, the sills and dikes of the Dona Ana Mountains, and possibly the laccolith at Cerro de Muleros. Formation of ore deposits.
   Possibly some extravasation of lava accompanied the intrusive process.
4. Uplift and erosion.
5. Second period of eruptions:

Rhyolite tuff, agglomerate, ash beds. Basalt-agglomerate.
Basalt.

6. Earth movements, initiating the Santa Fe erosion cycle.

No sort of certainty is claimed for this scheme; it is erected to provide a coherent picture, and to afford future workers something definite to criticize.

[15] Johnston, D. W., Jr., Fluorspar in New Mexico : N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 4, 1928, p. 68.

LATE TERTIARY AND QUATERNARY ROCKS

LATE TERTIARY AND QUATERNARY PHYSIOGRAPHIC HISTORY

MIOCENE-PLIOCENE EROSION AND SEDIMENTATION

Some erosion and deposition of elastic sediments accompanied the accumulation of the Tertiary volcanic rocks, especially during the supposed second period of volcanism, when sandstones were laid down among the tuffs and agglomerates. As the volcanic activity subsided, probably in early Miocene time, erosion of the mountains and sedimentation in intermontane basins became the dominant processes. Under these conditions a thickness of some thousands of feet of fanglomerates and gravels were deposited, partly in lakes, for many of these sediments are well bedded. The known basins of accumulation of bedded Tertiary sediments lie west of the San Andres-Organ-Franklin chain, and underlie the Jornada del Muerto and the plains west of the Rio Grande. Bedded, partly consolidated sediment is exposed where these plains have been dissected, as along the sides of the Rio Grande valley and in the craters of Kilburn and Stehling. As yet no search for fossils in these beds has been made in the present area ; but the finding of remains in similar beds both to the north and south by Bryan and his associates[1] leaves little doubt that these beds are the equivalents of the Santa Fe formation, of Miocene-Pliocene age.

The age of the sediments underlying the Tularosa basin is not known, but, according to Meinzer and Hare,[2] it is probable in view of the thickness of the fill that late Tertiary sediments are present, since a long time would be needed to fill the basin.

A well at Lanark on La Mesa 945 feet deep failed to find the base of these sediments.[3] Near El Paso the thickness is known to exceed 1561 feet.[4] Underneath the Jornada plain, solid rocks are found at depths varying from 200 to 1200 feet. In the Tularosa basin the thickness exceeds 1800 feet at Dog Canyon station; 1 1/2 miles west of Alamogordo a well over 1000 feet deep failed to reach bedrock. Allowing for post-Tertiary erosion of these beds, it is likely that their maximum thickness was between 2000 and 3000 feet.

On the general map of the county (in pocket) and on the physiographic map of the Las Cruces Quadrangle (page 177), Santa Fe beds have been mapped only where they could be seen in contact with solid rock, except in the case of the area west of Rodey, which was mapped by Darton. It is presumed that much

[1] Bryan, K., Personal communication.
[2] Meinzer, 0. E., and Hare, R. E,, Geology and water resources of the Tularosa basin, New Mexico : U. S. Geol. Survey Water supply paper 343, 1915, p. 64.
[3] Lee, W. T., Water resources of the Rio Grande Valley in New Mexico : U. S. Geol. Surv. Water supply paper 188, 1907, p.
[4]Meinzer, 0. E., and Hare, R. E., op. cit. supra, pp. 63-66.

of the area now thinly covered with Quaternary alluvium and indicated as such on the county map is underlain by Miocene-Pliocene bolson deposits.

By the end of the Tertiary it is likely that the topography of the mountains had been reduced to a mature stage so that only a few residual hills projected above the level of the plains. The plains were true bolsons in the sense of Hill[5] and Tight;[6] they were constructional features.

End of Tertiary time.—The dividing line between the Tertiary and Quaternary periods is best defined structurally in southern New Mexico: it is assumed that the Tertiary period was brought to a close by profound earth movements which elevated the mountains above the plains. The mountains as they are now seen are believed to date from the beginning of the Quaternary epoch.

On the east face of Robledo the Santa Fe gravels, dipping gently to the west, are brought against the Lower Paleozoic limestone by a fault trending N. 20° W. At Tonuco the Santa Fe beds are faulted against the volcanic agglomerate along a line running N. 15° W.; the Santa Fe beds dip between 60° and 80° to the west near the fault. In both cases the mountains are elevated relative to the gravels. These are the only proved cases of post-Santa Fe faulting. The great north-south fault which defines the east side of the San Andres-Organ-Franklin chain is believed to date from this period, and the uplift of the other basin ranges of the county is considered to have been contemporaneous.

That such an uplift did indeed take place in the San Andres-Organ range is suggested by the presence of an old mature topography high up in the southern part of the San Andres Mountains. The south, east and north faces of the lobe of these mountains which projects eastward just north of Bear Canyon are precipitous, consisting of cliffs and steep canyons. This youthful topography extends up to a discontinuity near the heads of the canyons, above which there are valleys having gentle grades, crossing the almost smooth summit region. The discontinuity in slope occurs at about 6500 feet elevation in all the canyons; below this level, the slopes are steep, above it they are gentle. These relations indicate that the mountains were reduced to hills with low relief—in this case about 700 feet—making part of a mature topography. Since the present difference in elevation between the discontinuity and the surface of the plain is about 2500 feet, it is thought that the post-Santa Fe uplift was of this order.

[5] Hill, R. T., U. S. Geol. Surv. topographic atlas, folio 3, 1900, p. 8.
[6] Tight, W. G., Bolson plains of the Southwest : Am. Geologist, Vol. 36, 1905, pp. 271-284.

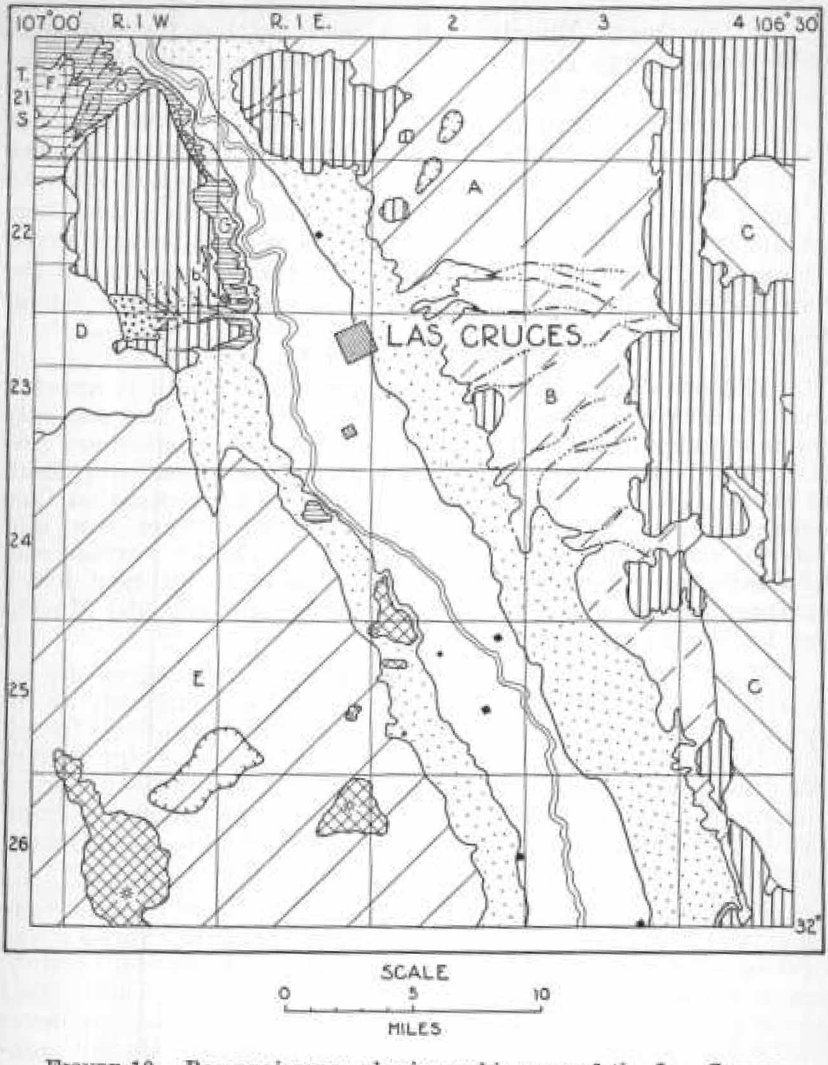


FIGURE 10.—Reconnaissance physiographic map of the Las Cruces Quadrangle.

Vertical ruling, pre-Tertiary and early Tertiary rocks
A, undissected Jornada surface
B, dissected Jornada surface
C, Tularosa basin
D, first erosion surface
E, La Mesa surface (continuation of A)
F, supposed remnant of Jornada surface
G, Picacho surface
b, b, volcanic necks (basalt)

Heavy stipple, Santa Fe formation in contact with earlier rocks
Light stipple, dissected remains of early surfaces fringing the Mesilla valley
Unshaded, Mesilla valley, on which flows the present Rio Grande
Cross shading, Quaternary basalt flows; stars indicate craters

In the Organ Mountains it is possible that the comparatively smooth high ridge running east for four miles from the head of Fillmore Canyon at an elevation between 8000 and 8500 feet is a similar remnant of a mature stage, but the evidence here is less satisfactory. If this ridge represents the surface of Santa Fe time, the great pinnacles of the range did not have a relief over 1000 feet with respect to that surface, and their erosion must be regarded as relative to the Quaternary cycle. The uplift of the Organ Mountains was greater than that of the San Andres if the ridge in question represents an older topography.

QUATERNARY EROSION SURFACES

The post-Santa Fe uplift renewed erosion, and it appears that the base level effective in the region was such that not only the mountains but also the plains were eroded. Quaternary history records a succession of changes in the local base level. Each of these positions of base level gave rise to an erosion surface which corresponded to equilibrium between stream flow and detrital load at that level. Each successive erosion surface was to some extent dissected by streams graded to the next lower surface, but large areas, especially on the Jornada del Muerto and La Mesa, escaped such dissection.

First Erosion Surface (D).[7]—South of the Sierra de las Uvas and west of Robledo the highest erosion surface of the region, 700 feet above the level of the present Rio Grande, is found. This is considered to represent the first attainment of equilibrium after the uplift. Only a small area about 8 by 4 miles remains. Under present conditions it forms an undrained region, sloping gently towards a center north of the Powell Ranch, which has at times been occupied by a shallow pond or playa.

Jornada-La Mesa Surface (A, E, F).—A lowering of base level led to renewed erosion, and much of the earlier surface was destroyed. The great plain of the Jornada del Muerto, continuing south as La Mesa, was produced at this time. The surface slopes gently to the south at 4.5 feet per mile, and Lee[8] believes that it was produced by the ancestral Rio Grande. Harley[9] supports Lee's conclusion and observed that old river terraces occur on the Jornada del Muerto between Rincon and Engle. Veatch,[10] on the other hand, regards such terraces as the outer limits of the transporting power of torrential floods from the mountains which spread detritus over the plains. Whether or not the river

[7] Letters refer to symbols on the physiographic map, page 177.

[8] Lee, W. T., op. cit., 1907, pp. 21, 23.

[9] Harley, G. T., Geology and ore deposits of Sierra County, N. Mex.: N. Mex. Sch. Mines State Bur. Mines and Min. Res. Bull. 10, 1934, p. 22.

[10] Veatch, J. 0., The soils of the Jornada Range Reserve : unpublished report, Jornada Range Reserve, 1918.

terraces actually remain, the essential truth of Lee's conception of this plain as due to lateral planation by a river remains unchallenged ; in no other way could the smooth southward grade be produced.

The Jornada and La Mesa plains are thus erosion surfaces, not gradation plains ; they have been modified from their original bolson character. They are cut not only on disturbed Santa Fe beds, but also across solid rock in the mountains, forming rock pediments which can be seen in the Organ, Franklin, San Andres, Dona Ana and Caballos mountains.

Picacho Surface (G).—According to Lee's theory,[11] the eruption of basalt at San Marcial in Socorro County dammed up the ancestral Rio Grande, and caused its course to be changed so that it no longer traversed the Jornada-La Mesa plain. Probably there was an accompanying change in base level. From San Marcial the river now found its way into the region through a series of narrow canyons, the last being the graben floored with Santa Fe gravels, between Robledo and the volcanic masses of Tonuco and the Dona Ana Mountains.

The lowering of base level caused the Jornada-La Mesa surface to be deeply dissected, and a lower surface, for which the name Picacho surface is proposed, was cut. This surface is well developed round the base of a conical hill called Picacho and extends northwards past Robledo. Its average height above the river is 100 feet. Basaltic eruptions occurred while the Picacho surface was in equilibrium. Near the village of San Miguel a lava flow erupted from a cone near the eroded edge of the La Mesa surface and flowed down towards the river. The flow blankets an erosion surface tentatively correlated with the Picacho surface. In many places the surface of La Mesa is covered by basalt flows, some of which may be contemporaneous with this flow on the Picacho surface.

Present Cycle of the Rio Grande.—A further lowering of base level initiated the present cycle of the Rio Grande. There were probably some minor pauses in the lowering of base level between the Picacho surface and the present level. Locally a 6-foot terrace occurs, sometimes extending into the mouths of tributary canyons, as for example 1 mile north of Picacho. The present river flows across a flood plain up to 5 miles wide, upon which agriculture is practiced in the Mesilla Valley. There can be little doubt that this surface was cut by lateral planation, but it cannot be said with certainty that some alluvial filling has not covered the eroded surface of the Santa Fe beds. The Mesilla Valley is flanked on either side by the dissected remains of earlier

[11] Lee, W. T., op. cit., 1907, pp. 21, 23.

surfaces (indicated by stippling on the physiographic map) . These no doubt include many small remnants of the Picacho surface, and possibly some others. Detailed mapping will reveal much that could not be shown on this reconnaisance map. In historical times the river has changed its course several times; the town of Mesilla, for example, was formerly on the west side of the river.[12]

South of a line between Las Cruces and Organ, the old Jornada surface (B) has been severely dissected by streams from the Organ Mountains. North of this line, however, this surface has changed little except where the Rio Grande Valley cuts through it. The Jornada del Muerto and La Mesa are both plains without surface drainage. Locally depressions (indicated by depression contours on the map) occur in the surface; these may be due to warping or local subsidence. Veatch's studies[13] showed that a narrow belt of gypsiferous lake beds trends northwest from the Jornada Reserve Headquarters, presumably following the last course of the ancestral Rio Grande. The change from an old age river plain to a series of very shallow undrained basins was due to the removal of the river, and to modifications arising from the accumulation of a thin layer of clastic material from the mountains over the surface, and to warping or subsidence.

On the Jornada and La Mesa, sand dunes drift about under the influence of the wind. A great area of dunes lies north of the Goldenburg ranch on the Jornada Reserve. The sand is probably derived from the neighborhood of the lake beds, and from regions of scanty vegetation, and under the influence of prevailing westerly winds it drifts to the east. In Lead Camp and San Andrecito canyons in the San Andres Mountains, there occur large areas of sand which has evidently been blown into the mountains from the plain to the east..

A large playa exists in the Tularosa basin,[14] six miles east of the San Andres Mountain. In normal seasons this contains a salt lake known as Lake Lucero at its southern end. Selenite crystals up to 1 foot long may be collected in the dry bed of the playa; and deposits of sodium sulphate have been found. In the banks west of Lake Lucero, wind-scour is even now disinterring giant crystals of selenite, with maximum dimensions as much as four feet, which lie embedded by the millions in the silt. Talmage[15] has shown that these large selenite crystals, by processes of fragmentation, recrystallization, and winnowing under the influence of prevailing westerly winds, have furnished the

[12] Griggs, G., History of Mesilla: Mesilla, 1930, p. 42.

[13] Veatch, J. 0., op. cit., 1918.

[14] Meinzer, 0. E., and Hare, R. E., op. cit., 1915, pp. 44, 45.

[15] Talmage, S. B., The origin of the gypsum sands of Tularosa valley ; Bull. Geol. Soc. America, 43:1, 1932, p. 185 (abstract) ; and The non-metallic mineral resources of New Mexico, N. Mex. Sch. of Mines, State Bur. of Mines and Min. Res., Bull. 12 (in press).

source material for the remarkable belt of gypsum dunes extending eastward from the playa for several miles. A portion of this "White Sands" area has recently been designated as a National Monument.

REVIEW OF THE PHYSIOGRAPHIC HISTORY

The general picture of the physiographic evolution of the

region presented above is based upon a reconnaissance study o the Las Cruces Quadrangle, and upon observations made by Lee in the Rio Grande Valley, and by Bryan and his associates north and south of the present area. There are many gaps in the evidence in this region. A detailed study of the supposed Santa Fe beds is needed, before it can be stated with complete confidence that they are Tertiary and not Quaternary. Probably there are more erosion surfaces than have been listed above. The area immediately north of the Las Cruces Quadrangle contains many interesting features and would repay careful study. The essential results of the reconnaissance are in harmony with the results of Bryan's detailed studies in the Albuquerque and Socorro areas. They indicate that the great period of erosion followed the early Tertiary uplift; that in late Tertiary time (and not Quaternary time) great thicknesses of elastic sediments were accumulated in basins without outlets ; that in Quaternary times erosion of the re-uplifted mountains and the plains took place, the material being removed from the region by the Rio Grande, except from the undrained basins, where a small thickness of alluvium was able to accumulate.

QUATERNARY BASALTS

There were minor outbursts of volcanic activity throughout the State during Santa Fe time, for basalt and rhyolite flows are found interbedded with the Santa Fe gravels. In Dona Ana County, no such flows have been found, but there are many thin basalt flows which were poured out in post-Santa Fe (Quaternary) time. Lee[16] believes that there were two distinct periods of volcanism in the Quaternary in the southwestern part of the county, since weathered lava flows, covered by soil, occur as well as fresh unweathered flows. It is likely that the last outburst was in comparatively recent times, for there are many cones which show little evidence of having been modified by erosion.

The lava flows, which appear to be without exception basalts, are thin but extensive, often not exceeding 25 feet in thickness, but continuing as much as 5 miles from the crater from which they were erupted. Cones, many of which have well-pre-

[16] Lee, W. T., Afton craters of southern New Mexico: Bull. Geol. Soc. Amer., Vol. 18. 1907, pp. 211-220.

served craters, occur in the West Potrillo Mountains, at Aden, near Afton, and southwest of San Miguel. The cones reach as much as 600 feet in height above the plain in the West Potrillos, but those to the east are much smaller.

West of Afton there are two huge, steep-sided depressions in the plain, known as the Kilburn and Stehling holes respectively. These were first described by Lee.[17] The Kilburn hole is 2 miles long (north-south) and $1^1/_4$ miles wide ; its depth below the plain is 250 feet. The Stehling hole is roughly circular, 1 mile in diameter and 150 feet deep. Both are surrounded by a rim reaching as much as 200 feet above the level of the plain. In section, there are stratified sands, presumably of Santa Fe age, from the floor of the depressions almost up to the level of the plain. There is then a thin flow of basalt, which was obviously poured out before the hole was formed. Above this there is unstratified sand, or bedded sand dipping towards the plain, containing large basalt rocks, cinders and pumice, forming the rim. Lee reviews the possible modes of origin of the holes under the following headings: (1) Impact of a meteorite, (2) Explosion of steam or other gases, (3) Sinking of the surface, caused by removal of underlying material, either by volcanic action, or by solution. He favors the second hypothesis, maintaining that the holes are explosion craters formed in the early stages of volcanic activity. This hypothesis is supported by Darton[18] Is in an article in which he describes similar craters which occur in flat country in Germany, in India, in Mexico and at Zuni, New Mexico. Dar-ton compares the craters with those formed by explosion without extravasation of lava at Bandai-San in 1888 and at Krakatoa in 1883.

In section, the lava flow exposed round the edge of the Kilburn hole is instructive. It is 15 feet thick. At the bottom there is a narrow chill zone ; and in the lower foot of the flow there are "pipe holes," the tops of which are bent towards the east, showing that the flow was moving in that direction. The central part of the flow is massive, though there are scattered patches of vesicular rock; the upper $3^1/_2$ feet contain many vesicles. The surface is scoriaceous. A microscopic comparison of specimens from the top, middle and bottom of the flow failed to reveal any significant difference in mineral composition.

Only a few thin sections of the basalts were examined. In the Kilburn flow, the feldspar, which is labradorite, $Ab_{40}An_{6o}$, occurs in lath-shaped crystals up to 1 mm. long. Olivine, beautifully fresh, occurs in idiomorphic or hypidiomorphic crystals. Pale brown augite occurs between the feldspars in small rounded

[17] Lee, W. T., op. cit., supra.

[is] Darton, N. H., Explosion craters : Science Monthly, Vol. 3, 1916, pp. 417-430

grains. The minerals are set in a brown glassy mesostasis which contains skeletal opaque minerals. Here and there, nodular masses of fairly coarse pale green olivine, which might prove to be of gem quality, and dark green augite occur in the rock. These may be as much as 2 inches in diameter. The composition of the San Miguel flow was found to be similar, but the grain was somewhat finer.

PART III

THE MINES AND MINERAL RESOURCES OF DONA ANA COUNTY

MINING DISTRICTS

The mines and prospects of Dona Ana County will be described according to the mountain range in which they are situated. A further subdivision into districts is convenient in certain ranges. The mining districts are listed below with their chief products. An index map of the county (Plate IX), shows the location of these districts and of the mapped areas in the county.

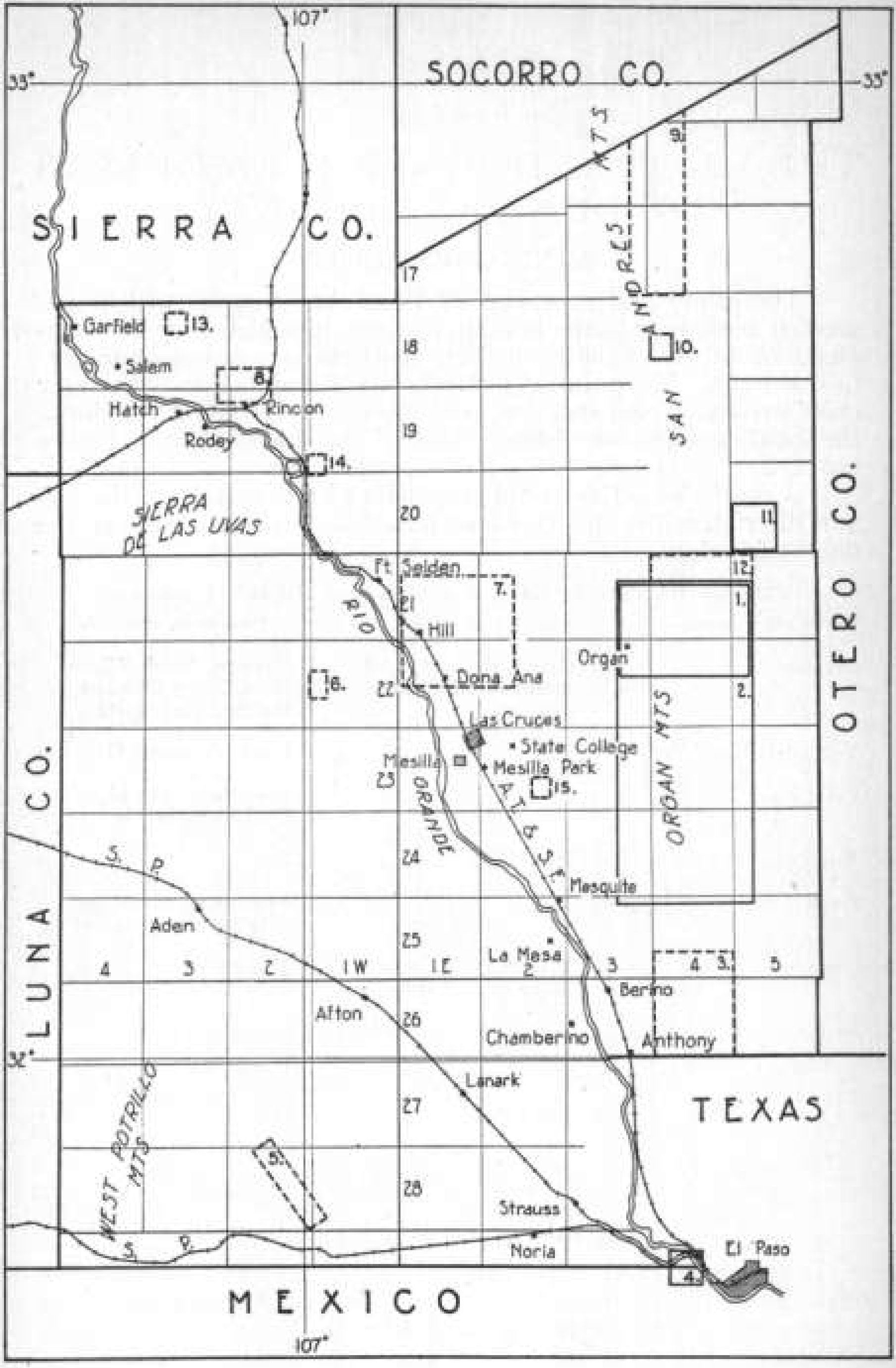
Almost the entire metal production has come from the Organ district, while the Tortugas mine has provided most of the fluorspar output.

Mining Districts in Dona Ana County and Their Products

MOUNTAINS	DISTRICT	MINERAL PRODUCTS
Organs	Organ district, and mines outside the district	*Copper, Lead, Silver* Gold, Zinc, Fluorite Barite, Magnesite
Northern Franklin		Lead, Jarosite, Gypsum
Potrillos		Prospects (Lead, Barite); Marble
Robledo	Iron Hill	Iron
Dona Ana		Prospects (Gold, Silver); Road metal
Caballos	Rincon Woolfer Canyon	Manganese Fluorite
San Andres	San Andrecito-Hembrillo San Andres Canyon Bear Canyon Black Mountain	Copper Lead Lead, Barite Gold, Lead, Barite
Tonuco		Fluorite
Tortugas		*Fluorite*

HISTORY OF MINING

Mining in Dona Ana County is known to have been carried on since 1849, when the Stevenson mine was discovered. There exists, however, a legend of a lost mine in the Organ Mountains



INDEX MAP OF DONA ANA COUNTY SHOWING LOCATION OF MINING DISTRICTS

Index to Mining Districts shown on Plate X

1. Organ mining district (Plate III)
2. Organ Mountains (Plate II)
3. Northern Franklin Mountains
4. Cerro de Muleros (Figure 9)
5. Potrillo Mountains
6. Iron Hill district
7. Dona Ana Mountains
8. Rincon district
9. San Andrecito-Hembrillo district
10. San Andres Canyon
11. Bear Canyon district
12. Black Mountain
13. Woolfer Canyon
14. Tonuco Mountain
15. Tortugas Mountain

which, if it has any truth in it, would indicate that mining began at a much earlier time. Since much effort has been devoted to a search for the lost mine by more than one generation of prospectors, a brief resume of the tale will not be out of place.

It is said that in the late years of the Spanish occupation of New Mexico, a priest named LaRue, stationed at a hacienda in Chihuahua, was told by a dying friend of placers and a fabulously rich gold-bearing lode in the mountains two days' journey north of Paso del Norte. When drought brought a famine to the community of peons in his charge at the hacienda, Father LaRue persuaded them to migrate northward with him, the Organ Mountains being his goal. Arrived here, the priest recognized landmarks which had been described to him, and, sending his men out to search, succeeded in finding the rich deposits. The colony settled at Spirit Springs (now the Cox ranch) and here the gold was concentrated in arrastres, and some of the ore was smelted in "vassos" (adobe furnaces). The mine is supposed to have been located in a deep canyon west or southwest of the springs. The long silence of the priest led the authorities of the Church in the City of Mexico to send an expedition to his former place of labor ; finding this deserted, they traced him to the Organ Mountains. Learning from his guards that the expedition was approaching, LaRue gave orders that the mine was to be covered up and the gold hidden. When the expedition arrived, he refused to divulge the secret of the whereabouts of the mine and gold, asserting that they belonged to his people and not to the Church. By night he was murdered by a soldier attached to the expedition, and afterwards some of the colonists were tortured, but the secret was never told. The mine is supposed to have been covered up by debris from the mountains. Several people have claimed to have found it. Colonel A. J. Fountain is said to have discovered it shortly before his mysterious disappearance. A goat herder named Tirso Aguire, well known in the mountains about twenty years ago, was supposed to be a descendant of one of the original miners. But none of the claims has been substantiated, and the search for the lost mine continues. It should be added that, although several of the supposed localities were investigated during mapping of the Organ range, neither mine nor rich gold mineralization was found.

The Stevenson orebody at the Stevenson-Bennett mine was discovered in 1849, and the property was acquired by Hugh Stevenson in the same year. The property was worked for ten years by Stevenson, the production up to 1857 being approximately $90,000.[1] The ore was smelted in an adobe furnace near Fort Fillmore, south of Las Cruces. Prior to 1854 a lead vein at

[1]Jones, F. A., New Mexico mines and minerals : Santa Fe, 1904, p. 74.

the mouth of Soledad (now Fillmore) Canyon had been worked by Barilla, the ore being smelted in an adobe furnace nearby.[2] The ore was very low in silver, and it seems clear that the vein referred to was the Modoc deposit. The remains of an adobe furnace may still be seen near the mouth of Fillmore Canyon. Antisell, writing in 1856, observes in a footnote, "I was not able to visit the old mine at Soledad Canyon, owing to several lodges of Apaches being encamped there at the time of my visit." Mining in these early days was carried on under great difficulties, for hostile Indians were a constant source of danger and the mechanical appliances available were crude in the extreme.

The Stevenson mine was purchased by officers at Fort Fillmore in 1858 for $12,500.[3] A company was organized and a mining engineer from Freiberg was engaged. In 1861, soon after the machinery arrived, Fort Fillmore fell to the Confederate forces under General Baylor, and the mine was confiscated. After the war some officers formed a syndicate to work the mine, but were stopped by an injunction. They resolved to sell the property to an English company, the figure named being $250,000, and an expert was sent out to examine it, only to discover that the claims had been "jumped." Litigation followed and an agreement was reached whereby the new locators were to secure patents on the claims, and give a half interest to the officers' syndicate. The first survey for the patents was made in 1871 and a second one, in accordance with the new mining laws, was made in 1883. Wheeler, writing in 1879, states: "The Stevenson mine, in the Organs, has been worked, but to little profit. The distance from the railroad and the consequent great cost of transportation has induced the owners to stop work for the present.[4]

The building of the railroad through the county in 1881 stimulated prospecting and mining, and by 1882 the Hawkeye, Memphis, Merrimac, and Black Hawk deposits in the Organ Mountains had been discovered.[5] There was now a steady production of silver and lead and a small quantity of gold. The years 1880-1900 were the time of greatest prospecting in the region and most of the important metal mines were discovered during this time. The Bennett orebody at the Stevenson-Bennett mine was discovered in 1887 by Carrera, who held a lease on the property. The greatest period of production of that mine followed, and it is said that $250,000 in lead and silver were taken out during his lease, which expired in 1888. About 1884 a small water-jacket

[2]Antisell, T., Geological report : U. S. Pacific R.R. exploration, Vol. 7, 1856, p. 162.

[8] Shine, Judith F., Taking on new life : Southwest review, Vol. 1, 192, pp. 15-19.

[4] Wheeler, G. M., Annual report upon the geographical surveys of the territory of the United States west of the 100th meridian : Washington, 1879, p. 224.

[5]Fountain, A. J., Mining industries of Dona Ana County : New Mexico directory and gazetteer, Santa Fe, 1882, pp. 49-52.

smelter was operated on the Memphis property.[6] The camp of Organ dates from this period.

The Mountain Chief mine in the Black Mountain district was discovered by Pat Breen in 1883. Activity in Gold Camp between Black Mountain and Mineral Hill began about this time. The Mormon mine was discovered by John Bonney about 1888 and for several years he operated a 3-stamp mill on the property, before selling it to a Chicago company. The Sunol mine was developed by a company consisting of Judges A. B. Fall, Young and Woods, and a mill was built. Several townsites were laid out in Gold Camp at this time and there was a regular stage-coach service along the east side of the mountains from El Paso. In 1893 there was a gold rush to Gold Camp, and about 1000 people were encamped in the district. At about this time Henry Foy discovered the Galloway mine, and a little later, in 1899, it fell to his lot to make the greatest strike of the period, the Torpedo deposit, which has contributed the greater part of the copper production of the county.

In the early years of the present century several of the mines in the Organ district were operating; these included the Torpedo mine, the Modoc mine, where a mill was built, the Memphis, and the Stevenson-Bennett, where there was a mill. Prospecting was carried on at the Hilltop (then called Eureka), the Big Three, Texas Canyon, Philadelphia and Homestake properties. Rich ore was taken out of the Little Buck mine. In 1904 the settlement of Kent sprang up round the Dona Dora mine and lasted for a few years. This was a prosperous time in the Organ district. Meanwhile, in the San Andres Mountains the San Andres lead mine, the copper deposits of the San Andrecito-Hembrillo district and the Bear Canyon properties were being developed. A decline in activity set in in 1909 and between this year and 1914 there was little activity and only a very small production, coming from the Big Three, Homestake and other small proper- ties. In 1914 there was a recovery and considerable shipments were made from the Excelsior and Stevenson-Bennett mines. In 1916 the Phelps Dodge Copper Company took a lease on the Tor- pedo, Memphis, Stevenson-Bennett and Excelsior properties and did a considerable amount of development work ; in 1917 the lease was relinquished. The American Smelting and Refining Company operated the Stevenson-Bennett mine under lease until 1920. The fluorite deposits at Tonuco and Tortugas were opened up in 1917 and 1920 respectively, and the Hayner property was developed in 1926. The Tortugas mine has continued production until recently, its product being concentrated in a mill near the

[6] Lindgren, W., Graton, L. C., and Gordon, C. H., Ore deposits of New Mexico : U. S. Geol. Surv. Prof. Paper 68, 1910, p. 212.

Production of Metals in Dona Ana County, 1869, 1871, 1882-1885, 1889-1933

Year	Tons Dry	Value Gold	Silver Ounces	Silver Value	Copper Pounds	Copper Value	Lead Pounds	Lead Value	Zinc Pounds	Zinc Value	Total Value	Number Mines
1869			15,152									
1871			7,576									
1882		20,000	697,674									
1883		85,000	949,613									
1884		5,000	34,884	38,721							43,721	
1885		8,000	9,303	9,954							17,954	
1889		4,956	64,031	60,189			1,863,158	72,663			137,808	
1890		500	22,092	23,196			107,232	4,825			28,521	
1891		700	20,294	20,091			201,637	8,670			29,461	
1892		650	91,118	79,272			1,100,000	45,100			125,022	
1893		10,000	24,806	19,348			1,250,000	46,250			75,598	
1894		21,000	3,000	1,890			166,667	5,500			28,390	
1895		15,000	91,738	59,629			853,664	27,317			101,946	
1896		18,000	104,479	71,045							89,045	
1897		5,340	16,717	10,030			234,325	8,435			23,805	
1898		4,350	11,135	6,569			123,368	4,688			15,607	
1899		4,350	10,859	6,515			108,614	4,887			15,752	
1900		2,873	6,532	4,050	712,385	118,256	179,976	7,918			133,097	
1901		3,655	15,275	9,165	515,162	86,032	165,116	7,099			105,951	
1902		3,400	192	102			9,950	408			3,910	
1903			9,671	5,125	611,796	83,816	147,610	6,199			95,140	
1904	5,580		24,101	13,979	40,000	5,120	1,581,488	68,003			87,102	5
1905	6,566	6,710	21,776	13,153	96,058	14,985	327,707	15,402	30,000	1,770	52,020	5
1906			34,051	22,814	434,000	83,762	1,207,193	68,810			175,386	4
1907	6,084	6	25,612	16,904	776,125	155,225	675,189	35,785			207,920	5
1908	3,090		9,283	4,920	21,150	2,792	379,697	15,948			23,660	5
1909	2,816	248	16,975	8,827	10,600	1,378	772,023	33,197			43,650	6
1910	2		15	8			705	31			39	1
1911	5		111	59	353	44	1,561	70			173	2
1912	78	17	1,790	1,101	6,685	1,103	26,129	1,176			3,397	4
1913	155	30	1,232	744	10,189	1,579	9,557	421			2,774	3
1914	451	927	3,564	1,971	78,180	10,398	29,879	1,166			14,462	3
1915	1,599	2,426	8,335	4,226	241,749	42,306	19,170	901			49,859	5
1916	2,615	503	7,948	5,230	206,187	50,722	34,696	2,394	106,679	14,295	73,144	9
1917	417	98	4,705	3,877	16,121	4,401	162,965	14,015			22,391	5
1918	6,076	109	45,661	45,661	110,676	27,337	1,616,479	114,770	114,000	10,374	198,251	4
1919	1,856		4,726	5,293	319,323	59,394	29,981	1,589			66,276	3
1920	1,407	44	4,779	5,209	168,853	31,069	120,100	9,608	12,652	1,041	46,971	9
1921	47		676	676			20.000	900			1,576	1
1922	43		413	413			12,576	691			1,104	4
1923	25								14,000	952	952	1
1924	55		300	201	8,893	1,165	2,064	165			1,531	1
1925	221		2,684	1,863	1,313	186	55,400	4,819			6,868	2
1926	2,462	104	5,131	3,202	12,377	1,733	235,200	18,816			23,855	4
1927	218	77	1,862	1,056	1,923	252	71,651	4,514			5,899	4
1928	872	14	3,959	2,316	39,000	5,616	105,897	6,142			14,088	4
1929	2,340		9,516	5,072	28,665	5,045	326,238	20,553			30,670	5
1930	897	3,113	1,587	611	17,000	2,210	11,000	560			6,484	2
1931	462	475	576	167	40,000	3,640	20,000	740			5,022	5
1932	35	6	227	64			2,000	60			130	3
1933	305	196	2,060	721	3,000	192	80,000	2,960			4,069	3
		122,877	779,781	595,229	4,527,763	799,758	14,437,862	694,155	277,531	28,432	2,240,451	

Totals are for the period 1884-1933.

State College. The manganese deposits at Rincon were developed in 1918. There has been little new mining activity since 1920. The Organ Ore Company held a lease on the Torpedo mine in 1921, and had plans for the erection of a custom mill, but these never materialized. The small metal production of the county has all come from the Organ district, where the dumps have been worked over. Prospecting was carried on in the Torpedo and Memphis mines in 1927-29 but with slight success. In 1927 the Portland-Southwestern Company opened up the Stevenson-Bennett mine, but the promoters of this concern were subsequently convicted of using the mails to defraud.

During 1933-34 a small mill was operated intermittently on the Stevenson-Bennett property by leasers. The enhanced price of gold following the lifting of the embargo in September, 1933, led to a search for gold deposits, and the Hilltop, Sally and Santa Cruz prospects have been developed. The Silver Coinage mine has made some shipments of silver ore.

The available statistics of production are summarized in the accompanying table. They do not call for special comment.

MINERAL DEPOSITS

GEOGRAPHIC DISTRIBUTION

The mineral deposits of Dona Ana County are found only in the mountainous areas in which igneous and sedimentary rocks of pre-Santa Fe age outcrop. The only important metal deposits are those in and near the Organ Mountains batholith. In the Organ district, copper, silver, lead, gold and zinc deposits occur. To the north of this district, gold, lead and barite are found in the Black Mountain district, while lead and barite with some fluorite occur at Bear Canyon. A lead and barite deposit occurs in San Andres Canyon. Fluorite with some barite has been mined at Tonuco and Tortugas, west of the Organ Mountains. In the southern part of the Organs and the northern part of the Franklins, barite and fluorite deposits with minor amounts of lead are found. Barite with a little lead occurs in the Potrillo Mountains. As shown on page 138, the outer zone of the Organ deposits contains fluorite, barite and some non-argentiferous galena. It is not, therefore, surprising to find that the deposits in the minor districts which surround the Organ Mountains should contain only outer-zone minerals, especially since the only subjacent igneous intrusion occurs in the Organs.

The distribution of ore deposits in Dona Ana County may be interpreted as an example of regional zoning. As applied to this region, the concept implies that fluorine and barium are able to travel much farther in solution than are most of the metallic sulphides. The general occurrence of fluorite and barite deposits, as in Illinois,[1] Kentucky, and the North of England,[2] in regions where the parent igneous rock has not yet been exposed, is best explained by reference to this concept. It appears that while the outer zone deposits—in this case leptothermal or even telethermal in type—have a more restricted vertical range than the deposits belonging to the highter intensity zones, as Graton[3] has shown, their lateral distribution may be much wider. Dines has recently shown that the lateral extent of the outer zones round the granites of Cornwall, England, is much greater than that of the inner zones.[4] Such arrangement is the result to be expected of the action of solutions which start from a few restricted centers, but which spread outwards as well as upwards from these centers.

Not all the deposits of the county can be explained as part of this scheme. In the San Andrecito-Hembrillo district, in the central San Andres Mountains, there occurs a group of small copper deposits which show affiliations not with the Organ center but with the deposits which Lasky has described from the northern part of the same mountains.[5] They are considered by him to "owe their origin to the post-Carboniferous intrusive rocks as represented by the laccolith at Salinas Peak and the dikes in the vicinity of Grandview Canyon.[6]

At Rincon manganese deposits of a very low-intensity type occur. A remarkable body of jarosite has been found in the Franklin Mountains. Many hematite bodies have been explored at Iron Mountain, west of Robledo. Magnesite, of metamorphic origin, occurs in the Organ Mountains in what may prove to be workable quantities. Gypsum is widespread among the sediments.

CLASSIFICATION

Ore deposits may be classified in many ways, according as emphasis is laid upon one or other of their properties. Their age may yield instructive information, for there are properties which seem to be peculiar to or characteristic of the several broad epochs of ore formation. This is especially true, for example, of the pre-Cambrian and Tertiary epochs of ore deposition in the western United States. The evidence in the present region indicates, however, that the deposits are all of Tertiary age, and,

[1] The bibliography of the Illinois-Kentucky region is summarized in the latest publication on the subject:
Bastin, E. S., The fluorspar deposits of Hardin and Pope counties, Illinois: Ill. State Geol. Surv. Bull., 58, 1931, pp. 11, 12.

[2] Dunham, K. C., The genesis of the North Pennine ore deposits: Quart. Jour. Geol. Soc. London, Vol. 90, 1934, pp. 689-720.

[3] Graton, L. C., The depth-zones in ore deposition: Econ. Geol., vol. 28, 1933, pp.514-551.

[4] Dines, H. G.. The lateral extent of ore-shoots in the primary depth-zones of Cornwall: Trans. Roy. Geol. Soc. Cornwall, vol. 16, 1934, pp. 279-296.

[5] Lasky, S. G., The ore deposits of Socorro county, N. Mex.; N. Mex. Sch. Mines State Bur. Mines Min. Res. Bull. 8, 1932, pp.74-86.

[6] Idem., p. 76.

if the relation of a majority of the deposits in the county to the Organ Mountains intrusive center as implied in the preceding section be correct, then most of the deposits were in process of formation at about the same time. Those related to the Organ Mountains intrusive cycle belong to the eastern margin of the great wave of intrusion and ore formation which affected western America during the Jurassic-Quaternary mountain-building period.[7]

No useful classification based upon age is therefore possible within the present area. A more profitable method of systematization is that based upon structure, and, in the scheme presented below, structural factors are given priority, since they controlled the localization of the deposits by providing permeable channelways for the access of the ore-forming solutions. In prospecting, structure forms a valuable guide, and in mining it is of paramount importance.

The other factors in the genesis of the deposits, the temperature, pressure and composition of the solutions, are taken into account by means of grouping into "intensity" zones. The concept of the "intensity factor" is due to Graton, who describes it thus : "The interaction of the three . . . . qualities of . . . . hydro-thermal solutions, *i.e.* temperature, pressure and composition, constitutes a composite quality that may be designated the physicochemical intensity of the solutions. The resultant effect of this degree of intensity on the local environment of rock character, structural detail and geothermal value at any given point along the solution pathway may be termed the 'intensity factor' of ore genesis at that point.[8] With some modifications, the depth-zones of Lindgren are restated by Graton in terms of "intensity." The "intensity factor" is determined in practice by a combination of observations on the structure, texture and mineralogy of the deposit in question; for a discussion of these the reader is referred to Lindgren's discussion of the fundamental concept of the depth-zones[9] and to Graton's paper. In the table below, the deposits of the county are classified according to "intensity zone," and in the mineralogical table which accompanies the next section, the composition of the deposits in the various zones is shown. The features of the ore deposits of the county will be sufficiently apparent from these two tables to make further general description unnecessary.

The regional zonal arrangement of deposits to which attention was directed in the preceding section is readily interpreted in terms of "intensity zones." The inner zones, in and near the

[7]Comp are Lindgren, W., Differentiation and ore deposition, cordilleran region of the United States : Lindgren volume, A.I.M.E., 1933, p. 172.

[8] Graton, L. C., The depth zones in ore deposition : Econ. Geol., vol. 28, 1933, pp. 522, 523.

[9] Lindgren, W. Mineral deposits : 4th Ed., New York, 1933, pp. 209-211.

Organ Mountains batholith, belong to the hypothermal, mesothermal and leptothermal groups. The outer zone deposits of Organ, and the non-argentiferous galena-fluorite-barite type found in many other parts of the county correspond to the telethermal-leptothermal group.

The use of the term telethermal-leptothermal requires some explanation. The deposits have the normal characters of the leptothermal type: a carbonate, barite or fluorite gangue with milky, fine-grained quartz, coarse banded texture, many vugs, and in some places abundant angular fragments of the wall rock. However, they are clearly of a distinctly lower "intensity" type than the leptothermal silver and gold deposits of the Organ district, and represent the products of solutions which have previously deposited most of their metal-content. They also represent products of solutions which have traveled far from their source. With only one exception (Tonuco) they are confined to limestones. The characters suggest a transition to the telethermal class as defined by Graton,[10] and the term telethermal-leptothermal is adopted.

The solutions were thus exhausted before they were able to come near enough to the surface to form the characteristic telescoped epithermal deposits. Deposits of the latter type may have been formed vertically above the batholith. but the roof was long ago removed by erosion. The deposits from the Organ center, now exposed to view, contain no epithermal types. The "epithermal" column in the accompanying classifications of deposits and mineralogy refers not to deposits from this center, but to an isolated epithermal deposit which occurs in the Dona Ana Mountains. This deposit differs in character from those associated with the Organ center; it may well differ in time of formation also.

The small copper deposits of the San Andrecito-Hembrillo district are tentatively classed as leptothermal. The principal hypogene minerals are chalcopyrite and fine-grained milky quartz.

MINERALOGY

The minerals of economic interest found in Dona Ana County are classified in the accompanying table (pp. 196-197), together with the common gangue minerals. The classification is a genetic one. The hypogene minerals, those formed directly from solutions which have originated in igneous magmas, are grouped according to zones of "intensity," as explained in the preceding section. The hypothermal deposits are found only near the immediate contacts of the Organ Mountains monzonite batholith, and related to the Torpedo-Bennett fault zone in the Modoc area

[10]Graton, L. C., op. cit. 1933, pp. 547-551.

Classification of Ore Deposits, Dona Ana County[1]

Structural Type	"Intensity" Zone	Mountains	Mines and Prospects
Irregular deposits in Tertiary intrusive	(Pegmatites)	Organs	Ben Nevis, Gray Eagle, Quickstrike
Veins in Tertiary intrusive	Leptothermal	Organs	Big Three, Davy King, Galloway, Hawkeye, Poor Man's Friend, Silver Coinage, Texas
Veins in pre-Cambrian basement	Leptothermal	Organs	Black Hawk, Buck Deer Dona Dora, Dummy B., Eureka, Green Girl, Maggie G., Mormon, Pagoda, Pharmacist, Rock of Ages, Sally, Santa Cruz, Sunol
	Telethermal-Leptothermal	Tonuco	Tonuco
Replacement deposits related to faults and shear zones	Hypothermal	Organs	Modoc, Orejon, Trapezoid
	Mesothermal	Organs	Torpedo, Stevenson-Bennett
	Leptothermal	Organs San Andres	Homestake, Philadelphia San Andrecito-Hembrillo district
	Telethermal-Leptothermal	Organs Potrillos Tortugas Caballos San Andres	Hayner, Devil's Canyon Prospects Tortugas Woolfer Canyon Group Bear Canyon "lower contact" San Andres Canyon
Replacement deposits in limestone within 500 feet of contact of Tertiary batholith	Hypothermal	Organs	Excelsior, Memphis, Merrimac, Cobre Grande, Iron Mask, Ophelia
Replacement deposits in the Fusselman dolomite beneath its contact with the Percha shale	Leptothermal	Organs	Little Buck, Rickardite, Hilltop, Black Prince
	Telethermal-Leptothermal	Northern Franklins San Andres	Copiapo, Lead prospects Black Mountain district Bear Canyon "upper contact"
Vein deposits in Tertiary extrusive rocks	Epithermal	Dona Anas	Gonzales
	Telethermal-Leptothermal	Organs	Silver Cliff
		Caballos	Rincon district

[1] According to the revised form of Lindgren's depth zone classification proposed by L. C. Graton, The depth zones in ore deposition: Econ. Geol., vol. 28, 1933, pp. 514-551.

and south of Hardscrabble Hill. They are valuable for their copper, zinc, and, locally, bismuth content. Mesothermal deposits are represented only at the Torpedo mine, chief copper producer of the county, and the Stevenson-Bennett mine, chief lead producer, both in the Organ district. Leptothermal deposits occur only in the Organ district; the valuable hypogene minerals are native gold, and the silver minerals, tetrahedrite, argentite, and argentiferous galena. All the high-grade silver deposits and all the gold deposits of this camp fall into this class. There is only one epithermal deposit, at the Gonzales mine in the Dona Ana mountains; small quantities of very high-grade precious metal ore were found. The telethermal-leptothermal class contains deposits valuable for their fluorite as at Tortugas, Tonuco and the Woolfer Canyon claims; and for barite, as at Devil's Canyon and Bear Canyon. One gold deposit, at the Mountain Chief mine, is included in the class. Non-argentiferous galena occurs non-commercially in many of the telethermal-leptothermal deposits. Small deposits in the San Andrecito-Hembrillo district, tentatively classed as leptothermal, have yielded some copper.

Among the supergene minerals, which are deposited from meteoric waters moving near the surface, deriving their solutes from decomposing hypogene minerals, two groups are recognized. The oxidation or "oxysupergene" zone[11]' those minerals formed at the surface and within the zone of circulating ground-waters, under oxidizing conditions. The minerals are numerous and varied, and have furnished the greater part of the metal production of the county. Almost all the copper, all the zinc, and the greater part of the lead came from oxidized ores. The mines of the county are shallow, and few have extensive workings below the oxidation zone. An important part of the silver production came from the outcrops of veins in the Organ district, where halides of silver and the native metal were present.

The enrichment or "sulphosupergene" zone occurs below the oxidation zone, and contains sulphides formed by reactions between the primary sulphides and descending meteoric waters carrying metallic salts derived from the higher portions of the deposit. While there is reason to suppose that considerable reserves of sulphosupergene copper ore still exist in the Organ district, ores of this class have contributed so far only a minor part of the copper production. Enriched ores are not of importance in the case of any of the metals apart from copper, with the possible exception of silver.

[11] The term is due to G. F. Loughlin, Geology and ore deposits of the Leadville mining district, Colorado : U. S. Geol. Surv. Prof. Paper 148, 1927, p. 146. The form of the table between pages 196 and 197 of the present work is based in part upon one given by Loughlin.

Minerals of the Ore Deposits of Dona Ana County

	"INTENSITY" ZONE	ORE MINERALS								GANGUE MINERALS			
		IRON	MANGANESE	ZINC	LEAD	COPPER	SILVER	GOLD	OTHERS	SILICA	ALUMINA	LIME MAGNESIA	OTHERS
SUPERGENE MINERALS	*OXIDATION ZONE (OXY-SUPERGENE)*	Hematite Limonite Jarosite	Manganite Psilomelane Pyrolusite Wad	Calamine Hydrozincite Smithsonite	Anglesite Caledonite Cerussite Phosgenite Plumbojarosite Pyromorphite Vanadinite Wulfenite	Azurite Brochantite Chrysocolla Cuprite Malachite Native Copper Stubelite (?)	Argentojarosite Bromyrite Cerargyrite Embolite Native silver		Bismutospharite Montanite Magnesite (?)	Chalcedony Opal Fine grained Quartz	Kaolin	Aragonite Calcite	
	SULPHIDE ENRICHMENT ZONE (SULPHO-SUPERGENE)	Marcasite (?)				Bornite Chalcocite Covellite	Argentite (?)	Native gold (?)			Kaolin		
HYPOGENE MINERALS	*EPI-THERMAL*	Pyrite					Hessite (?)	Petzite (?) Native gold (?)		Quartz: fine-grained and milky	Chlorite	Calcite	
	TELETHERMAL-LEPTO-THERMAL		Manganocalcite		Galena				Fluorite Barite	Chalcedony Quartz: fine-grained and milky		Calcite	Barite
	LEPTO-THERMAL	Pyrite		Sphalerite	Galena Altaite	Chalcopyrite Rickardite	Argentite Galena Tetrahedrite	Native gold	Fluorite	Quartz: fine to medium-grained, clear or milky	Chlorite Sericite	Calcite Chrysotile	Siderite Fluorite
	UPPER MESO-THERMAL	Pyrite		Sphalerite	Galena	Chalcopyrite	Galena			Quartz: clear, medium-grained	Sericite Chlorite Tremolite		
	HYPOTHERMAL (PYROMETA-SOMATIC CLASS)	Pyrite Pyrrhotite Specularite Magnetite		Sphalerite	Galena	Chalcopyrite	Galena		Magnesite Tetradymite	Quartz: clear, very coarse-grained	Sericite Muscovite Epidote Tremolite	Andradite Diopside	

ORGAN MOUNTAINS

INTRODUCTION

Most of the mines in the Organ Mountains are in the northern part of the range, in the area which has been mapped as the "Organ mining district" (Plate III, in pocket). As explained earlier, this area also includes the extreme southern end of the San Andres Mountains. Outside the area covered by the district map, there are a few mines, the most important of which are : the Texas Canyon group, in Texas Canyon ; the Modoc and Orejon mines and the Trapezoid prospect, near the mouth of Fillmore Canyon ; the Hayner fluorite mine, $1^1/_2$ miles north of the Modoc ; and the Devil's Canyon mine, at the head of Target Range Canyon. The position of these is shown on the geologic map of the Organ Mountains (Plate II, in pocket).

The mines and prospects of the Organ mining district are for the most part easily accessible by road. The main road from Las Cruces to Alamogordo, State highway 3, passes through the mining camp of Organ, 15 miles from Las Cruces. Ore from the mines is generally shipped to the American Smelting and Refining Company's smelter at El Paso, Texas, by rail from Las Cruces, or direct from Organ by motor truck, a distance of 60 miles.

The Hayner mine and the Modoc group of properties are reached by desert roads from Las Cruces. The road to the Texas mines is no longer passable.

The general geology of the Organ Mountains having been described in Part I, further discussion here is unnecessary. The purpose of the present section is to describe the history, production, ore deposits and developments of the mines and prospects of the region, with special reference to their future possibilities. The classification of deposits into six groups adopted in Part I (page 111) will again be followed, and the mines will be described according to the type of deposit which has been exploited in them. For "replacement deposits in previously metamorphosed rocks" the term "pyrometasomatic deposits" will be substituted, thus covering the whole mineral assemblage and not merely the sulphide-phase minerals in the case of the deposits containing high temperature silicates.

Mr. L. B. Bentley has been kind enough to allow the writer to have access to over 5000 assays made by him upon ores from the Organ Mountains during the period 1910-1933. Where it does not involve divulging private information, the results gained from a compilation of these assays will be presented as arithmetic averages, the number of assays used in arriving at the average being shown in brackets after the figures. It should be clearly understood that in most cases the assays considered were specimen assays, and may not therefore be taken to indicate the exact tenor of the ore at the mine in question. They will, however, serve to give a general idea of the characteristics of the ore.

PEGMATITES

BEN NEVIS MINE
(SW$^1/_4$ sec. 32, T.21 S., R.4 E.)

The Ben Nevis property, from which there has been a small production of high-grade silver ore, consists of three patented claims running up the southeast slope of San Agustin Peak. It was formerly owned by the late John Dodd of Organ. The property is at present held by the Shriner Estate, Temple, Texas.

The deposit is in an irregular body of pegmatite, 600 feet long and up to 100 feet wide. The minerals present are, in order of formation. (1) orthoclase, (2) albite, (3) diopside-hedenbergite, grossularite, apatite, very coarse quartz, (4) actinolite, epidote, chlorite, coarse quartz, with pyrite, chalcopyrite, galena, sphalerite, and tetradymite. The sulphide minerals are found in irregular shoots in the central part of the pegmatite, in which there are many cavities.

The developments include two short tunnels, one at 5850 feet elevation, the other at 5950 feet. The lower tunnel was not accessible, but in the upper tunnel an irregular pipe-like ore shoot about 10 feet in diameter, which extended up to the surface, and for an unknown distance below the tunnel, has been mined out. Assays[12] made in 1913 and 1914 gave the following results : gold, trace; silver 26 ounces ; bismuth and antimony detected (4). Probably some tetrahedrite was present.

Southeast of the lower tunnel an adit has been driven along the northeast wall of the Galloway dike, which crosses the Ben Nevis claims. No mineralization was found here.

GRAY EAGLE MINE
(NW$^1/_4$ sec. 5, T.22 S., R.4 E.)

The early history of the Gray Eagle mine, an unpatented claim southwest of the Ben Nevis, is not known. The last work done was by L. Molinar in 1924. The production is said to have been $30,000 in high-grade silver ores.

The deposits occur in irregular pegmatite lenses, in which the early minerals are massive white orthoclase, muscovite and quartz. These are replaced by sulphides, including chalcopyrite and galena. The sulphides have been oxidized, and it is believed that the ore shipped was from oxidized material, probably containing cerargyrite. The ore-shoots are highly irregular, generally only a few feet long. They appear to have been worked

[12] Assays are stated as follows : gold, silver, ounces per ton ; copper, lead, zinc, bismuth, Percentages.

out. The development includes three adits with about 400 feet of tunnels, and some small stopes.

Assays : silver, 102 ounces ; copper 6 per cent (5).

QUICKSTRIKE MINE

(N.1/2 sec.32, T.21 S., R.4, E.)

The Quickstrike deposits are said to have been discovered very early in the history of the district. The last work done was the driving of the low tunnel by A. Marshall about 1927. There has been a small production of hand-sorted silver ores. The property consists of three patented claims running up the eastern slope of San Agustin Peak, owned by the Shriner Estate, Temple, Texas.

Six pegmatite lenses in the quartz-bearing monzonite are exposed on the claims. These are highly irregular but have a general trend towards the north. The minerals present, in order of formation, are: (1) orthoclase, (2) albite, (3) diopside-hedenbergite, coarse quartz, (4) actinolite, epidote, chlorite, coarse quartz ; with pyrite, sphalerite, chalcopyrite and argentiferous galena. The sulphides occur in the central parts of three lenses exposed in a tunnel at 5450 feet elevation, in irregular shoots. A lens near the mouth of this tunnel has been followed to a depth of about 30 feet by a crooked winze ; the whole pegmatite pinched at this depth. The low tunnel, at 5350 feet, runs west and is 250 feet long. It was driven to cut the shoots exposed in the second tunnel, but it failed to do so, nothing but fresh quartz-bearing monzonite being found. The pegmatites exposed in open cuts above 5450 feet contain much quartz, but only scattered sulphide grains.

The highest assay recorded gave 1467 ounces silver ; an average of seven, not including this abnormally high one, gave : gold, trace ; silver, 54 ounces ; bismuth detected.

There seems to be little hope of developing further ore at this mine.

MICA PROSPECT

In the quartz-monzonite one mile south of the Cox ranch, some veins containing coarse mica have been exposed in pits adjacent to a limestone xenolith. These cannot be regarded strictly as pegmatites, but they are most conveniently classed here; probably they represent endomorphic effects in the intrusive rock. Some green amphibole accompanies the mica, which is shown by refractive index measurements to be a phlogopite. The mica plates are as much as 1 foot in diameter, but they have been contorted and appear to be of little commercial value. The prospect is owned by L. B. Bentley.

VEINS IN TERTIARY INTRUSIVE ROCKS

BIG THREE MINE

(SW $^{1}/_{4}$ sec.30, T.21 S., R.4 E.)

The Big Three group, comprising five patented claims, is situated $1^{1}/_{2}$ miles north of Organ. The property was originally located by Hufford, who mined silver chloride ore from shallow opencuts. In 1904 it was acquired by Johnson, Luchen and Gill, of Organ, who sank shafts and produced several carloads of silver ore averaging 100 ounces per ton.

The claims cover a group of three fissure veins in the quartz-bearing monzonite, and also the contact between the Lake Valley limestone, the Excelsior rhyolite laccolith and the monzonite. Lime-silicates but no sulphides occur in the prospects in the limestone ; attention may, therefore, be confined to the veins in the monzonite. The veins strike N. 85° W. The northernmost, which dips north at 85°, is exposed in a series of opencuts, and in the workings from the Ruby shaft, 200 feet deep (not accessible). The width of the vein varies from 1 foot to $2^{1}/_{2}$ feet. The minerals present are quartz, pyrite, galena, tetrahedrite and sphalerite. It is said that down to 175 feet, there was little sphalerite, but below this the zinc-content increased rapidly. Material from the bottom of the shaft exhibits coarse banding, with quartz and pyrite against the wall rock. then sulphides, and in the center quartz and calcite. Some stoping was done above the 175-foot level. The Excelsior dike cuts through this vein ; the contacts are well exposed in the shallow opencuts. The outcrop of the vein is said to have been very rich in silver; probably cerargyrite was present.

The middle vein, which dips 75° N., is a strong fracture zone containing little mineral material. The southern vein, which also dips north, is exposed in a shaft of unknown depth. Some tetrahedrite ore was obtained from it.

The inaccessibility of the underground workings at this mine makes it impossible to estimate its possibilities. Presumably work here was stopped because the mine was regarded as exhausted. No equipment remains.

CRESTED BUTTE PROSPECT

(NE$^{1}/_{4}$ sec.31, T.21 S., R.4 E.)

The Crested Butte property, consisting of three unpatented claims, was located during 1933 by W. Trueblood and J. Boyd, the present owners. The claims cover the outcrop of an east-west trending rhyolite dike, which is cut through by the Galloway and Excelsior dikes. The Excelsior dike splits into two parts where it crosses the east-west dike, and to the east of this intersection a narrow vein on the hangingwall side of the dike was found to contain silver halides, a specimen of which assayed: gold, 0.48 ounces ; silver, 300 ounces. To the southwest, a vein striking N. 76° W. cuts through the monzonite. It contains quartz and galena, but is only about 2 inches wide. The southern claim covers a vein striking N. 80° W., associated with a fissure zone 5 feet wide. The minerals present include quartz, limonite, barite, pyrite, galena and tetradymite. Very little work has been done on these claims, and further development, especially on the southern vein, appears to be justified.

DAVY KING MINE
(SW $^1/_4$ sec.30, T.21 S., R.4 E.)

The Davy King vein, which is covered by a claim belonging to the Big Three group, strikes N. 60° E. and dips steeply to the southeast ; the width is 3-4 inches. For so small a vein, a considerable amount of development has been done. An opencut follows the vein for 250 feet, and in the center of this a shaft, no longer accessible, has been sunk. The outcrop of the vein contained silver chloride ; the hypogene minerals include quartz, pyrite, galena and tetrahedrite. An appreciable amount of gold is said to have been present.

GALLOWAY MINE
(NE $^1/_4$ sec.5, T.22 S., R.4 E.)

The Galloway mine, 1 mile east of San Agustin Pass, was discovered in 1895 by Henry Foy of Organ. An interest in the mine was sold, and in 1896 about $35,000 in silver ore was taken from the outcrop of the deposit, which contained both cerargyrite and native silver. There has been no production since the rich outcrop was exhausted.

The deposit consists of tiny stringers in the north side of a loop in the Galloway rhyolite dike, cutting the hangingwall of the dike. The hypogene minerals appear to be galena and argentite. A shaft has been sunk to a depth of 180 feet, and good ore is said to have been found below water level, which is approximately 100 feet below the shaft collar. Assays of hypogene ore gave : gold, 0; silver, 97 ounces (8). Some further prospecting in this property might be justified if the present price of silver is maintained, or increased.

HAWKEYE GROUP
(NE $^1/_4$ sec.31, T.21 S., R.4 E.)

In La Cruz Canyon on the northwest side of San Agustin Peak three E.-W. fissure veins cut through the quartz-bearing monzonite. They are said to have been discovered by a priest during the middle part of the 19th century, and were formerly known as the Old Priest veins. The present owner is A. Marshall, who was prospecting the veins in 1933.

Most of the work has been done on the northern vein, which dips steeply to the north; it has been developed by a number of shallow pits and an inclined shaft about 80 feet deep. Mineralized ground occurs in small shoots or pockets only a few feet in strike or dip length, reaching a maximum width of about 1 foot. The minerals include quartz, pyrite, chalcopyrite, sphalerite, tetrahedrite and galena; tetrahedrite is locally an important constituent of the vein. Another vein to the south dips to the south; it contains a similar assemblage of minerals. The northern vein is cut through by the Galloway rhyolite dike. The contacts between the Galloway and Excelsior dikes and the monzonite have been explored by means of shallow pits and in places a showing of oxidized ore has been found.

Specimen assays of sulphide ore from this group range from 9 to 214 ounces silver, 3 to 68 per cent lead. Apart from the chloride-rich outcrops of the veins, which were exhausted many years ago, no payable ground has been found on this property.

POOR MAN'S FRIEND MINE
(SE1/4 sec.1, T.22 S., R.3 E.)

The workings on the Poor Man's Friend vein are on the lower slopes of the mountains, three-quarters of a mile southeast of Organ. The vein strikes N. 50° W. and dips 40° SW., the low dip causing the vein to have an arcuate outcrop, which can be traced for nearly half a mile. At the main workings, which consist of an opencut and inclined shaft situated near the middle of the exposed length of the vein, the minerals present are quartz, pyrite, galena and tetrahedrite, and their oxidation products. The workings at the eastern end of the vein, consisting of a short tunnel and several shafts, have exposed pyrite, quartz, black sphalerite and some malachite. Ore taken out of the main workings in 1926 and 1927 gave an average assay as follows: gold, 0 ; silver, 40.5 ounces (16) ; lead, 15.9 per cent (12) . The ore from the east end workings is said to be too low in silver to be payable.

SILVER COINAGE MINE
(SW.1/4 sec.29, T.21 S., 11.4 E.)

The Silver Coinage mine, the only active producer in the present class, was originally prospected by Henry Foy, who failed to find payable ore in the vein. Foy's tunnel was reopened in 1933 by the present owner, Rex Rakestraw, and partners, and a shoot of high-grade silver ore was discovered below the level of the tunnel, which is being mined at the present time (1935). The Silver Coinage claim runs west along the vein from the mouth of the tunnel. East of it another claim, the Silver Moon, belonging to the same property, has a narrow high-grade silver vein on it.

The Silver Coinage vein is a fissure zone cutting the quartz-bearing monzonite, striking N. 80° W. and dipping 80° S. The tunnel, which is at 6100 feet elevation, is 275 feet long. A fault striking N.-S. and dipping 60° E. cuts the vein 30 feet from the portal, and displaces it about a foot to the south. The productive ground is situated immediately west of this fault. The fissure zone maintains a width of 1 to 3 feet throughout the length of the tunnel, but the width of vein matter is variable. The developed length of the shoot when examined in November, 1934, was 23 feet, the depth about 20 feet. The vein was 1 to 2 feet wide, and consisted of massive sulphides, quartz, and thin tabular inclusions of the country rock. The minerals present include, in order of formation, (1) quartz, pyrite, (2) chalcopyrite, galena, and a small amount of sphalerite, (3) argentite. The wall rock is strongly chloritized. Green fluorite occurs in the fissure west of the ore shoot. Mr. Rakestraw informs me that a shipment made in the summer of 1934 was worth $55.00 per ton, the values being chiefly in silver. In the bottom of the stope the vein showed good promise of maintaining its width both in depth and towards the west.

On the Silver Moon claim a vein parallel to the Silver Coinage vein, but dipping 60°-70° N. has been discovered. The width as seen in a shallow opencut was 3 to 4 inches, but the assays are extraordinarily high, reaching as much as 1200 ounces silver. The minerals are quartz, pyrite, chalcopyrite, sphalerite, tetrahedrite and a small quantity of enargite ; the tetrahedrite makes up about one-third of the minerals present. This narrow vein is well worth prospecting, for if it should increase in width, the deposit would be a valuable one.

TEXAS CANYON GROUP
(Secs. 34,35, T.22 S., R.4 E.)

Texas Canyon is situated on the east side of the range, 10 miles from Organ. The veins here were discovered between 1890 and 1900, and there was some production of gold from the Cross vein during this period, the ore being treated in an arrastre until 1898, when a two-stamp mill was erected. The owners were John Dodd and his brother. In 1910 a company known as the Texas Canyon Mining and Milling Company was organized, and acquired the property. They purchased an aerial tramway which had previously been used at the Modoc mine, but were unable to raise the capital necessary to install it. In 1917 the road up to the mine and mill was built, but again the company was unable to raise funds to continue work. The last work done was in 1927, after which the claims fell open to relocation. They are held at present by F. C. Schneider, whose assessment work is up to date. Prospecting is now in progress in the Main vein.

Two veins are exposed in the canyon. The Main vein strikes N. 76° E. and dips 80° N., cutting in its course both the dark monzonite and the quartz-monzonite. It appears to shift a rhyolite dike which crosses the canyon, moving the sector of the dike south of the vein to the west of that north of the vein. Probably the displacement along the vein is considerable. At 5670 feet there is a tunnel about 50 feet long, at the mouth of which the vein shows a width of 6 feet of milky quartz containing pyrite and chalcopyrite ; at a rough estimate the ratio of sulphides to quartz is about 1 :8. Small amounts of tetradymite, argentite and barite occur in the vein-matter. The oxidation zone is shallow, and the quartz-limonite mixture which characterizes it is confined to within about 10 feet of the surface. A shaft is being sunk at the mouth of this tunnel. The vein has been followed up the slope above the tunnel by means of shallow excavations which reveal a width of from 3 to 6 feet of vein matter, enclosing horses of country rock. At 5925 feet an inclined shaft has been sunk on the vein, but this is at present inaccessible. The material on the dump shows that the shaft passed through the oxidation zone and reached primary sulphides. Pyrite (predominating) and chalcopyrite occur in the ratio of about 4:1. A little tetradymite is present. Above there are exposures up to and west of the saddle (6200 feet). In the upper part of the vein there is much more barite than is seen in the lower part; the other constituents are quartz and limonite. The distance between the low tunnel and the inclined shaft is approximately 1700 feet; the whole mineralized length of the vein is over 4000 feet. Ore from the shaft and lower workings gave assays, of which the following is an average: gold, 0.194 ounces (30) ; silver, 13.87 ounces (30) ; copper, 1.57 per cent (11) . The variation is not great, and this is believed to represent a fairly reliable average.

It was early discovered that while this vein is undoubtedly gold-bearing, the ore is not free-milling. Hence, treatment with the simple equipment possessed by the early workers yielded no results. In the light of the prevailing high price of gold, it is suggested that this deposit is worthy of serious prospecting, with a view to development, if the prospecting is successful, as a low-grade producer. The probable great length of mineralized ground, covering a vertical range of 530 feet, and the considerable width of the vein are favorable indications that there is at least a chance of developing large tonnages of ore. Drifts should be driven and careful sampling carried out to determine the possibilities of the deposit.

The Cross vein outcrops about a quarter of a mile east of the low tunnel on the Main vein, on the north side of the canyon. Its strike is N. 55° E., following the course of a narrow rhyolite dike. The veinstuff consists of quartz and limonite. No assays are available, but the ore is known to have been gold-bearing and free-milling, and the production of the group came from this vein. The workings consist of a tunnel 400 feet long, with a stope 50 feet long and 20 feet high near the portal, and two shallow surface cuts. The Cross vein appears to be worked out.

The road into Texas Canyon, from the Cox Ranch-Globe Springs road, is not passable at present, but could be improved sufficiently, without a great expenditure, to enable small motor trucks to go in.

OTHER PROSPECTS

North of the main road on the east side of San Agustin Pass an east-west fissure vein cutting through the quartz-bearing monzonite has been explored by means of shallow shafts. The minerals present are malachite and small plates of white mica.

Southwest of the Galloway mine, near the Cox Ranch road, a narrow fissure vein containing quartz and galena has been opened up in several pits.

On the slopes of the prominent peak southeast of Organ several small fissure veins containing quartz, limonite, pyrite and galena have been discovered in the quartz-monzonite, but none has proved to be worth mining. Small veins containing galena and sphalerite have been found in the neighborhood of Baylor Pass, also in the quartz-monzonite.

VEINS IN PRE-CAMBRIAN ROCKS

BLACK HAWK PROSPECT
(SE$^1/_4$ sec.22, T.21 S., R.4 E.)

The Black Hawk is the most important of a group of prospects on the west side of Mineral Hill known as the Emma group, located by the late John Dodd. There may have been a small production of lead ore. The claims are not patented, and the present owners are not known.

The Black Hawk vein follows along the footwall of an epidiorite dike trending N. 30° W. and dipping 44° NW. The vein is about 2 feet wide and contains quartz, pyrite, chalcopyrite and galena, and oxidation products derived from the sulphides. It has been opened up by means of a tunnel 150 feet long at 5600 feet elevation; some stoping has been done above the tunnel. A series of pits exposes the vein to the northwest and southeast of the tunnel. Assays gave the following results: gold, trace to 0.16 ounces; silver, 6.6 ounces (14) ; lead, 40.0 per cent (8) ; copper, 7.8 per cent (4). The grade of the ore does not appear to be high enough to justify the exploitation of the ore-shoot exposed by the workings.

A shaft on an E.-W. epidiorite dike to the south of the Black Hawk workings contains a showing of quartz, calcite, pyrite, chalcopyrite and galena, with limonite and malachite.

BUCK DEER PROSPECT
(NW¼ sec.21, T.21 S., R.4 E.)

The Buck Deer prospect, discovered during 1932 by F. Schneider, is situated 1 mile northeast of the Black Prince mine. A vein of white quartz runs within a wide epidiorite dike which crosses the region from Gold Camp to the Black Prince mine. The dike and vein strike N. 65° E., and dip 85° N. The vein is 2 to 3 feet wide, and contains milky quartz with scattered pyrite, chalcopyrite and galena. The workings consist of a shaft and opencut on the west side of the ridge traversed by the vein, and a cut on the east side. Very little development has been done, and no assays are available. If the gold-content of the vein justifies it, some more work should be done, for the vein is an unusually prominent one.

DONA DORA MINE
(NE.¼ sec.26, T.21 S., R.4 E.)

This property, formerly owned by the Dona Dora Mining and Milling Company, now defunct, was the scene of active prospecting between 1904 and 1910, or later. It is situated on the east side of Mineral Hill. The deposit is a fissure vein in pre-Cambrian granite, striking E.-W. and dipping 80° N. It has been explored by means of shafts and a tunnel 1850 feet long, as shown on the accompanying map. A N.-S. fault, one of the major faults of the region, was encountered 550 feet from the portal of the tunnel. On the surface, the horizontal displacement of the Steampump epidiorite dike due to the fault is 600 feet; the vein, although it has approximately the same attitude anddirection as the dike, is displaced only 210 feet. It is, therefore, concluded that the fault was in action at two periods, one prior to and one after the mineralization. It is not, however, mineralized where it is exposed in the crosscut which follows it. The vein has an average width of about 6 inches, but near the western end of the tunnel, it increases to 2 feet. From the portal to a point 25 feet west of the fault, it contains quartz and limonite. This oxidized material is said to have been gold-bearing in a shaft of unknown depth near the mouth of the tunnel, but seems to have been barren or of too low grade to mine in the tunnel, except in a small shoot 860 feet from the portal, where there may have been some supergene enrichment of gold. The oxidized vein filling gives place to quartz and pyrite with subordinate galena near the enriched shoot, and the

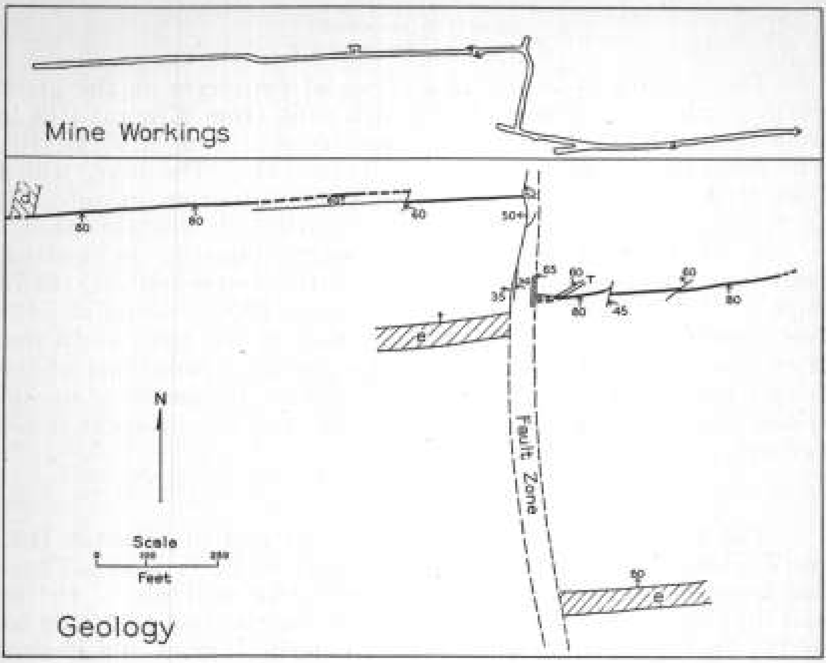


Figure 11.—Map of mine workings and geology, Dona Dora tunnel.

Heavy black line, Dona Dora vein; d, epidiorite dike, cut in breast of tunnel; e, e, Steampump epidiorite dike, projected from the surface, showing horizontal shift by fault; T, rhyolite dike. The country rock is pre-Cambrian granite.

within 250 feet of the west breast of the tunnel, where black siderite appears as an important constituent of the vein. An epidiorite dike, probably the Pagoda-Gold Camp dike, was cut near the breast. There is a shaft to the surface and a winze below the tunnel 100 feet west of the fault, where ore has been stoped out of the shoot mentioned above.

This long exploratory tunnel failed to find minable ore in quantity, and the operation was a failure.

In a gulch to the west of the portal of the main tunnel, a short adit known as the Alligator tunnel has exposed the same vein, at an elevation about 450 feet above the main workings. The vein is here $1^1/_2$ feet wide, and contains quartz, pyrite, galena and abundant sphalerite with black siderite. An inclined winze of unknown depth has been sunk in the vein and some stoping appears to have been done. The ore is said to carry very little silver and gold, and cannot, therefore, be mined with profit.

DUMMY B PROSPECT
(SW. 1/4 sec.26, T.21 S., R.4 E.)

The Dummy B is one of a series of prospects on the great north-northeast epidiorite dike which runs from Mineral Hill to Gold Camp ; it is situated at the southeast end of Mineral Hill. The present owners are Tiff and Rakestraw. The dike, which here strikes N. 43° E., cuts through pre-Cambrian granite. A fault follows along the hanging-wall and locally contains shoots of ore, the minerals present being quartz, limonite and galena. Only one assay is available: gold, 0.18 ounces; silver, 11.78 ounces. The workings consist of a tunnel 100 feet long at 5425 feet elevation, following the hanging-wall of the dike; at 55 feet from the portal a crosscut enters the granite. Northeast of the tunnel the hanging-wall has been explored by means of an inclined shaft. There is little ore in sight, and the prospect is not favorably regarded.

EUREKA PROSPECT
(SE. 1/4 sec.22, T.21 S., R.4 E.)

The Eureka claims, at the northeast end of Mineral Hill, were originally located by the present owner, W. S. Moore. There has been no production. An epidiorite dike striking N. 10° E. and dipping 75° W. has a mineral vein on the foot-wall side up to 1 1/2 feet wide containing quartz, siderite, pyrite and chalcopyrite. The vein is banded, with quartz combs on the walls, and coarse siderite in the center, containing sulphides. At 5375 feet elevation the vein has been opened up by means of an opencut 50 feet long and a tunnel 60 feet long. Near the breast of the tunnel a vein branches off from the main vein towards the hanging-wall side of the dike. The values have so far proved disappointing; the vein is apparently not gold-bearing and carries less than 1 ounce silver; the copper-content is about 4 per cent. Work is being continued in the hope of striking a shoot of high-grade gold ore.

To the south of the main tunnel, the vein has been prospected by a short tunnel at an altitude of 5650 feet. The character of the vein-filling appears not to have changed.

GREEN GIRL PROSPECT
(SE. 1/4 sec.13, T.21 S., R.4E.)

The Green Girl prospect consists of a shaft sunk on a vein cutting through pre-Cambrian granite in an E.-W. direction. The ore is about 1 1/2 feet wide, and contains quartz, specularite, pyrite, chalcopyrite, and malachite. It is said to have pinched out against an epidiorite dike in depth. Assays gave: gold, 0.21 ounces (4); silver, 0.41 ounces (4) ; copper, 2.27 per cent (3).

It was discovered by L. B. Bentley; the present locator is L. M. Richard. There has been no production.

MAGGIE G MINE

(Sec.35, T.21 S., R.4 E.)

This property consists of one patented claim running E.-W.; it was originally opened up by G. E. Fitzgerald. The present owner is L. B. Bentley. There has been a small production, and a shipment was made from the dump during 1932.

An E.-W. epidiorite dike, dipping steeply to the north, has veins along its hangingwall and footwall, containing quartz, pyrite, chalcopyrite, limonite and malachite. The veins reach a maximum width of about a foot. An inclined shaft, at present inaccessible, has been sunk on the dike; its depth is said to be 100 feet. There is a shallow opencut. Assays gave: gold, 0.66 ounces (17) ; silver, 16.28 ounces (16) ; copper, 8.98 per cent (9).

At the prevailing price of gold, further exploration on this property may be justified.

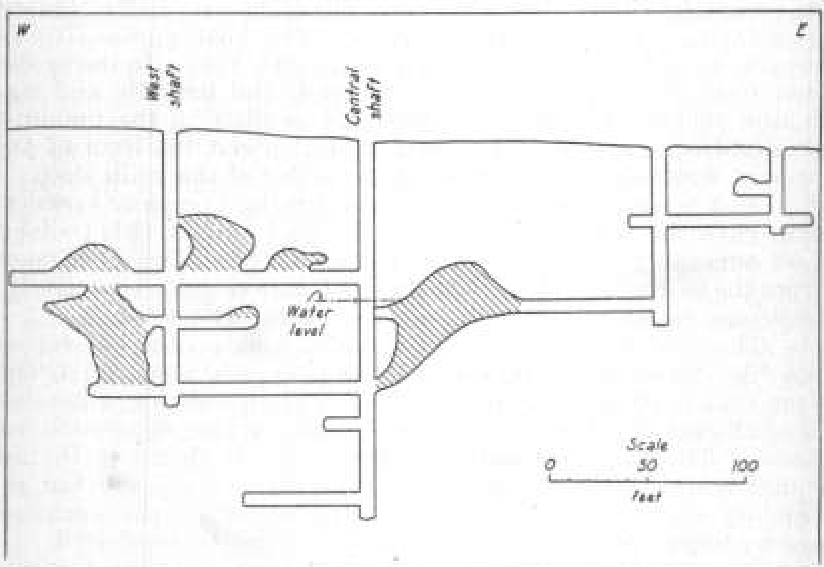


FIGURE 12.—Longitudinal section, Mormon mine. Shaded areas indicate stopes.

MORMON MINE

(NE.¼ sec.14, T.21 S., R.4 E.)

The Mormon mine, the only property in the present group with more than a slight production to its credit, is situated in the Gold Camp sub-district, 1½ miles northeast of Mineral Hill. It was discovered by John Bonney between 1880 and 1890, and prior to 1890 a three-stamp mill was operated by him on the property. In 1892 he sold the mine to the Tinsell Company, of Chicago, who did the greater part of the development of the mine between 1892 and 1900, when a mill was also operated. With the exhaustion of free-milling ore from the oxidation zone, operations ceased, but there was known to be refractory gold ore below water level. About 1910 the Mormon Mining and Milling Company was organized, and a cyanide mill was built. There seems to have been a small production of ore at this time, but the milling process was not a success, and the operation failed. The present locator is C. F. Schneider. The production is said to have been about $40,000 in gold up to 1910.

The deposit occurs in veins and stringers following the course of an epidiorite dike rich in hornblende, about 3 feet wide. The dike strikes N. 70° W. and dips steeply to the south. A vein varying in width from 4 to 15 inches occurs between the hangingwall of the dike and the pre-Cambrian granite, and stringers traverse the dike. The hypogene minerals are milky quartz, specularite, pyrite and chalcopyrite. The gold appears to be present as inclusions in pyrite (see pages 124, 156) . In the oxidation zone, quartz and specularite persist, and limonite and malachite replace the sulphides; the gold persists in the limonite. Oxidized ore gave place to unoxidized at about the level of the present water-table, 90 feet below the collar of the main shaft.

Assays made during the Mormon Mining Company's ownership gave the following results: gold, 0.84 ounces (24); silver, 1.08 ounces (24) ; copper, 3.50 per cent (6). Two specimens from the 60-foot level gave 4.55 and 9.39 ounces gold respectively; these are not calculated in the average given above.

The workings consist of two shafts sunk on the outcrop of the dike, respectively 100 and 137 feet deep, and a shaft 195 feet deep sunk south of the outcrop. There are, in addition, a number of shallower shafts and an opencut. No surface equipment remains. The size and location of the stopes is shown in the accompanying section. It is reported that there is payable but refractory ore below water-level in the mine; but, as the workings are no longer accessible, this report could not be confirmed.

PAGODA PROSPECT

(SW. 1/4 sec.26, T.21 S., R.4 E.)

Some local excitement was caused by the finding of gold ore assaying 35 ounces of gold per ton in the Pagoda shaft, northeast of the Dummy B prospect, during the summer of 1934. The owners are Tiff and Rakestraw.

The deposit occurs on the hangingwall of the Pagoda-Gold Camp epidiorite dike. A Tertiary rhyolite dike has cut through the epidiorite and has been displaced by the faulting along the hangingwall of the epidiorite (see page 123). In the fault gouge, lenticular bodies of mineral material occur, in part replacing the gouge. The minerals present are: quartz, pyrite, galena, amber-colored sphalerite, gold and oxidation products.

The developments consist of an inclined shaft about 60 feet deep, with a short cross-cut to the north at 40 feet depth. The high-grade ore was found in the cross-cut, at the contact of rhyolite and the fault gouge. It appears to have been only a small pocket, and the ore taken out since its exhaustion has so far proved to be disappointing.

PHARMACIST PROSPECT
(NE. 1/4 sec.27, T.21 S., R.4 E.)

This property is situated on the east side of Mineral Hill, half a mile south of the Eureka prospect. The deposit, which was discovered and worked by John Bonney about 1900, is said to have produced a small amount of gold. It occurs in a fissure vein striking E.-W. through the pre-Cambrian granite. The minerals present are: quartz, pyrite, limonite and malachite. The developments consist of an inclined shaft 80 feet deep on the vein, from which some stoping has been done, and a tunnel 195 feet long, driven south of the vein, and communicating by means of a short cross-cut with the vein. A parallel vein which has not yet been prospected runs to the south of the Pharmacist vein.

ROCK OF AGES PROSPECT
(NE. 1/4 sec.35, T.21 S., R.4 E.)

The Rock of Ages property consists of one patented claim running N.-S., at the southeast end of Mineral Hill. The owner is L. B. Bentley. The deposit consists of narrow veins which follow the course of a rhyolite dike striking N.-S. and dipping 50° W. The dike has been shattered by faulting. Minerals present include: quartz, pyrite, chalcopyrite and malachite. Assays gave the following results : gold, 0.40 ounces (30) ; silver, 6.66 ounces (32) ; copper, 5.63 per cent (18). The developments include an inclined shaft 125 feet deep, with a drift to the south immediately above water level, at about 100 feet depth. To the south of the main shaft 150 feet, there is a shallow shaft. The vein as exposed in the main shaft is 6 inches to 1 foot wide, and seems to be consistently mineralized; the ore, however, is of too low a grade for profitable mining.

SALLY MINE
(Center sec.13, T.21 S., R.4 E.)

The Sally Mine is situated in the Gold Camp sub-district, midway between the Mormon and Sunol mines. It is a new venture; the sinking of the shaft was begun in 1933, on a 2-inch vein which assayed 3 ounces gold at the outcrop. The owners are the

Sally Mining Company ; W. L. Hammer, General Manager ; E. Shipe, Superintendent.

The vein follows an epidiorite dike striking N. 75° E. and dipping 50° N. As shown in the accompanying mine-plan, the mineralization occurs in a complex series of fractures which cut across the epidiorite. A post-mineralization fault shifts the dike and the veins associated with it. The highest assay so far recorded gave: gold, 11 ounces ; the average is much lower.

The developments include an inclined shaft which had reached a depth of 120 feet on the incline, or about 96 feet vertically when the mine was examined in November, 1934. Since

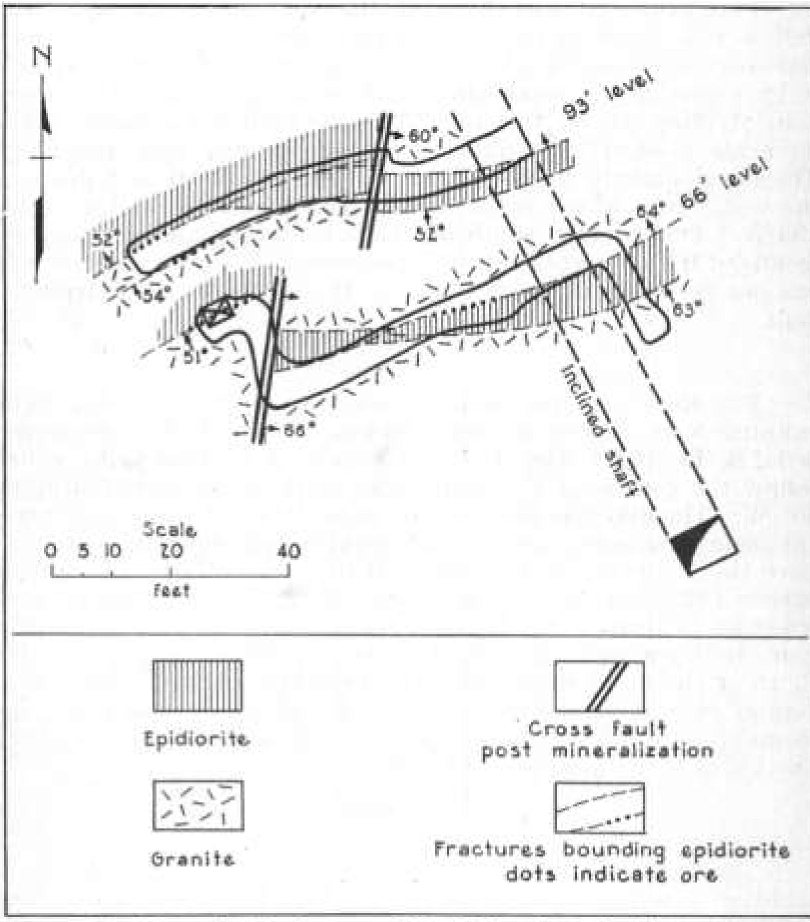


FIGURE 13.—Composite level map of the Sally mine, showing underground geology.

that time sinking has continued, reaching at the time of writing a depth of 160 feet on the incline. There are levels at 66 feet and 93 feet vertical depth, running west from the shaft, the 93-foot level being immediately above the groundwater table. Ore shoots up to 1 foot wide were discovered above the 66-foot level, 20 feet west of the shaft, and at the west end of this level, and also at the west end of the 93-foot level, where the high assays were obtained. Only a small amount of stoping had been done at the time of the writer's visit. The equipment includes a wooden head-frame, hoist, compressor and pumps. The management appears to be following a conservative and economical policy, and there appears to be a good chance that their efforts will be rewarded with success. The mapping of the mine during the present investitgation showed the necessity for testing not merely one wall of the dike, but the whole dike, and this should be borne in mind during prospecting. It is impossible to predict the position of ore-shoots or the continuity of those which have been discovered.

SANTA CRUZ PROSPECT
(NW.1/4 sec.19, T.21 S., R.5 E.)

This property, owned by F. C. Schneider and partners, was opened during 1933. There has been no production up to the present. The deposit occurs on the footwall of an epidiorite dike whose strike curves from N. 55° E. at the west end to N. 85° E. at the east end. The dip is 45° N. The vein, which is subject to abrupt swells and pinches, varies up to $1^1/_2$ feet wide. The minerals present are: quartz, pyrite, and chalcopyrite with much limonite. Fluorite occurs east of the main workings. The developments consist of an inclined shaft which had reached a depth of about 50 feet when examined in November, 1934, and shallow surface cuts. The prospect is equipped with headframe, hoist and compressor. Mr. Schneider has constructed a power-driven arrastre near the Mormon mine, in which he proposes to treat ore from the Santa. Cruz. The variability of the vein here makes the task of prospecting difficult and discouraging.

SUNOL MINE
(SE. $^1/_4$ sec.13, T.21 S., R.4 E.)

The Sunol mine was operated between 1890 and 1900 by a company consisting of Judges Fall, Woods and Young, who in 1892 erected a ten-stamp mill near the arroyo north of the mine. The production of the mine is not known, but it has not been worked during the present century. The present owners are the Sally Mining Company.

An epidiorite dike trends N. 80° W. and dips S. Mineralized fractures occur on both walls, and within the dike. In the oxidation zone, quartz, limonite and malachite occur; the unoxidized vein-matter contains pyrite, chalcopyrite and siderite. The unoxidized material is said to have been refractory.

The workings consist of three inclined shafts, one of which is said to be 200 feet deep, drifts and shallow surface cuts. These are not at present accessible, so no first-hand opinion of the mine's possibilities can be given.

OTHER PROSPECTS

Few of the epidiorite dikes of the region have escaped the attention of prospectors; there are, therefore, many prospects which have not been described. Southeast of Quartzite ridge, north of the Organ mining district, J. Yauger is driving a tunnel on an epidiorite dike striking N. 80° E. A vein follows along the dike, but contains only quartz, calcite and pyrite, and as yet has failed to show any values. At the Steampump ranch, a shaft was sunk on the E.-W. dike which crosses the pediment north of the ranch house ; the shaft is now used as a well, and lies on a patented claim. Between the Pharmacist and Eureka properties a fissure vein in the granite, said to carry gold values, has been exposed in a series of opencuts. In the region between the Mormon and Sunol mines there are many prospect pits, some of which expose feeble veins. Northeast of the Maggie G mine, a shaft on a claim known as the Tiberius exposes a narrow vein following the footwall of a dike striking N. 60° E. An assay of a specimen from the ore pile here gave: gold, 1.78 ounces; silver, 3.58 ounces ; but a general sample from this pile proved disappointing.

DEPOSITS RELATED TO THE TORPEDO-BENNETT FAULT ZONE

TORPEDO MINE

(NW. and SW. 1/4 sec.1, T.22 S., R.3 E.)

The Torpedo property consists of two patented claims, known as the Torpedo and Little Ben Scott, and one unpatented claim, the Papoose. These lie east of Organ and south of the main road.

History and Production.—The Torpedo deposit was discovered by Henry Foy in 1899. It was acquired in the same year by a company which developed the mine and had produced copper ore worth $100,000 before June, 1900. Between 1900 and 1904 the mine was worked by G. E. Fitzgerald. In 1903 it was valued at $250,000.[1] On Fitzgerald's bankruptcy in 1904, the mine passed into the hands of a company known as the Torpedo Mining Company, which was controlled by the late N. C. Forster. Operations continued until 1907, when the company became involved in litigation, and the mine was closed down. In the period between

[1] Jones, F. A., New Mexico mines and minerals, Santa Fe. 1904, p. 78.

1899 and 1907, three shafts were sunk, two to a depth of 300 feet, and large bodies of oxidized copper ore were taken out from stopes down to the 300-foot level. A small amount of work was done by R. McCart under lease between 1907 and 1914. In 1916 the Phelps Dodge Company took an option on the property, and sank No. 3 shaft to a depth of 500 feet. The option was relinquished in 1917. Various reasons are given. There were apparently labor troubles, there was difficulty with water, a new pump was dropped down the shaft, and there was a fall in the price of copper. There was no production from the mine during the period of the option, and apparently the prospecting done did not justify further work. In 1921 the Organ Ore Company held the property under lease, and cleaned out and re-timbered the 300-foot level and the winzes below. Some ore was produced at this time. The failure of the Organ Ore Company to raise capital adequate to complete the building of their custom mill led to the closing down of the mine. In 1928-29 Griffith and Phelps held a lease and sunk No. 4 shaft, south of the old workings.

Local estimates place the production as high as $800,000, but since this figure exceeds the total recorded copper production of the county (see table opposite page 191), it seems likely that it is too high. There is, nevertheless, no doubt that there has been a substantial production of copper from this mine.

The workings at the northern end of the property have caved, producing surface subsidence over a large area which extends from the No. 1 shaft to the old boilers. The only accessible underground workings are those connected with No. 4 shaft.

Geology.—The deposit is a replacement of shattered quartz-bearing monzonite, between two strong faults. The eastern fault separates the deposit from the barren intrusive rock, while the western one separates it from the limestones and shales of the Magdalena series. As the accompanying map and section show, the most productive ground extended from No. 1 shaft, near to which a shoot of high-grade oxidized copper ore came to the surface, southwards for 600 feet. The maximum width of the mineralized ground is about 200 feet. The workings on the 200-foot level from No. 4 shaft have exposed only low-grade ore ; they are, however, interesting because they reveal the nature of the hypogene ore-body, whereas farther north this has been largely obscured by heavy oxidation. The primary minerals are quartz, pyrite and chalcopyrite, and these fill ramifying cracks in the quartz-monzonite, producing a protore which resembles closely that seen in the "porphyry-copper" type of deposit. No doubt the hypogene material which gave rise to the high-grade shoots of oxidized ore farther north was richer in copper than that seen in the No. 4 workings, but there is no reason to suppose that it

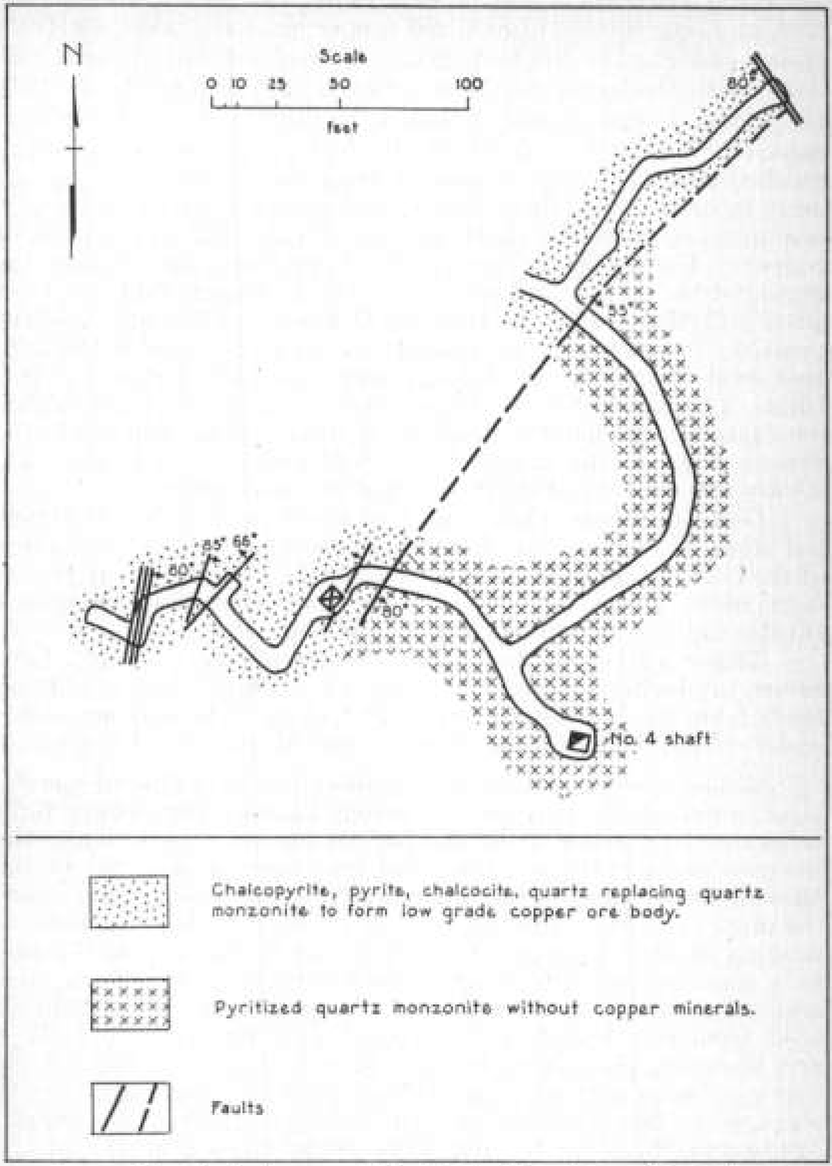


FIGURE 14.—Geologic map of the 200-foot level from No. 4 shaft, Torpedo mine.

differed in its other characteristics. Oxidation of this material gave rise to acid sulphate solutions which converted the monzonite into kaolin, almost completely destroying its former minerals and texture. The copper was deposited, apparently as a replacement of the kaolin, as chrysocolla and the doubtful copper-manganese silicate stubelite, and to a minor extent as malachite and azurite. Native copper was abundant locally. The high-grade oreshoots which are shown in section on page 218, and in plan on the 200-foot level on plate XI, were bodies of oxidized copper ore. It is stated on reliable authority that these continued with little change down to the 300-foot level, the limit of mining. It is also said that no ore below 5 per cent copper in grade was mined. Presumably the shoots were separated by low-grade ore, which is still in place. The accompanying table, which contains smelter returns, chosen at random, for typical shipments made during the mining of the oxidized ore-bodies, gives an adequate idea of the grade of this type of ore. An ex-

Grade of Ore from the Oxidized Zone, Torpedo Mine

Date	Ag	Cu	SiO_2	Fe	Mn	CaO	S
June 10, 1899	0.5	12.5	51.8	2.3		1.5	tr
August 14	0.5	14.3	47.6	1.4	tr	2.0	tr
September 5	0.5	10.0	51.0	1.0	1.6	1.0	tr
October 9	0.4	13.3	45.5	7.8	1.8	1.0	tr
November 2	0.3	11.4	50.0	2.7	1.7	1.5	tr
December 2	0.5	9.0	43.0	5.0	1.3	1.5	tr
January 4, 1900	0.6	13.0	52.2	0.8	0.2	1.5	tr
February 1	0.7	12.0	47.0	3.0	1.2	1.0	tr
March 7	0.6	15.5	46.0	1.8	1.3	1.0	tr
April 5	0.8	13.5	41.2	0.3	0.2	1.8	tr
May 2	0.4	11.2	51.0	2.1	0.7	1.0	tr
June 5	0.9	10.3	54.0	2.0	1.1	1.0	tr
July 3	0.8	11.1	58.0	2.4	1.4	0.5	tr
February 4, 1901	0.5	11.2	48.5	3.8	0.5	0.6	tr
March 22	4.8	17.8	51.4	3.2	0.5	0.7	4.1
April 16	10.4	19.2	54.0	5.0	0.3	0.8	8.4
May 17	2.2	17.8	47.0	5.6	0.4	0.6	0.5

amination of the smelter returns covering most of the life of the mine [2] shows that only very few shipments were made in which there was an appreciable sulphur-content. Three are quoted above in the table: they show in a significant way the increase in silver-content with rise in sulphur. What is even more important is the fact, supported by reliable evidence, that the sulphide zone below the great bodies of oxidized ore was not mined. It was reached by winzes below the 300-foot level. A polished surface (see plate VIII) shows that chalcocite is present, and that it replaces chalcopyrite and pyrite. The stoppage of mining at the 300-foot level was due to water trouble. There may, therefore,

[2] Preserved in Mr. Bentley's office at Organ.

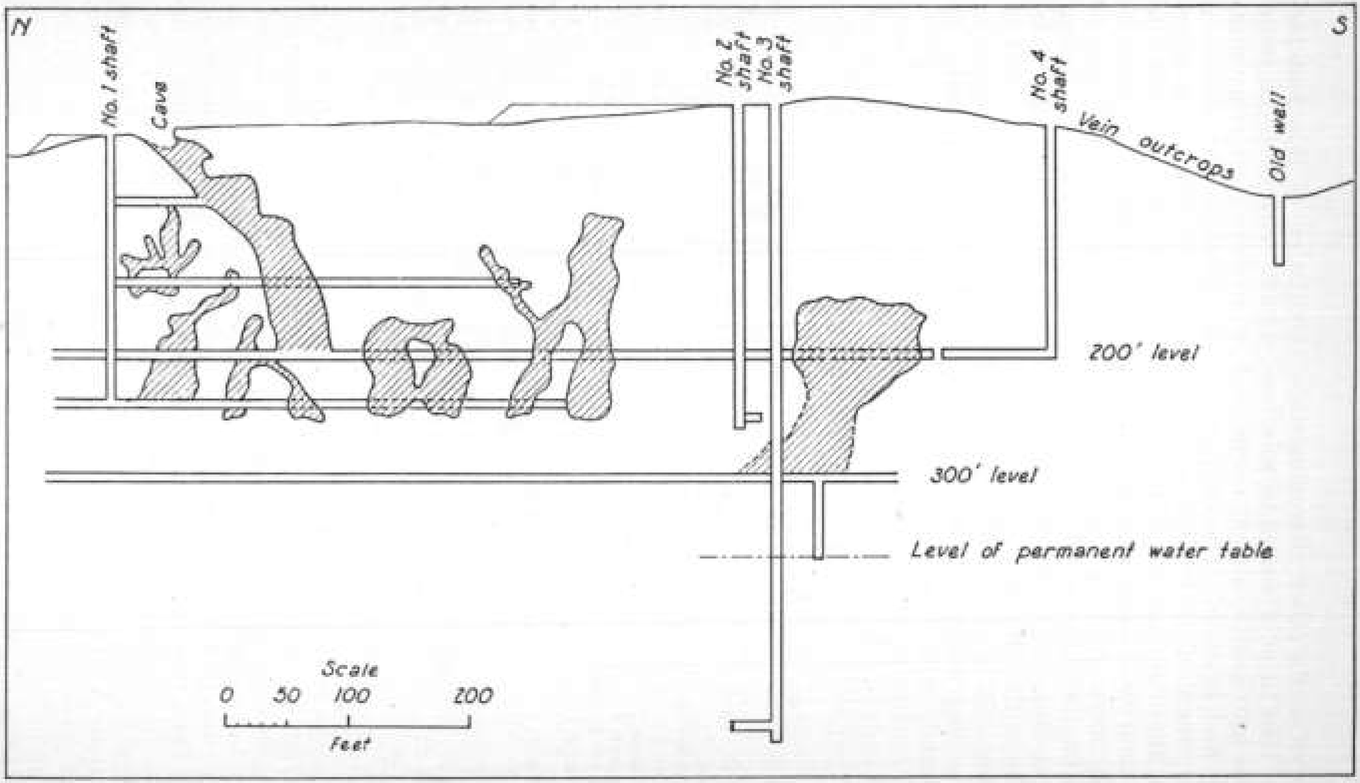


FIGURE 15.—Vertical projection parallel to the fault zone at the Torpedo mine. Shaded areas indicate stopes.

be a body of high-grade copper ore as yet not exploited in the mine ; and, if the increase in silver-content with sulphur is as significant as it appears to be, this ore may well be silver bearing.

The low-grade orebody exposed in the 200-foot level from No. 4 shaft has a proved length of 275 feet and a width of 75 feet. It is said to average 3 per cent copper. Griffith and Phelps, who developed this part of the mine, employed the services of the Radiore geophysical prospecting company, and on evidence furnished by their studies the orebody is believed to continue for some hundreds of feet to the south of the present workings. As the map of the claims shows, the fault zone can readily be traced to the south, for it has a bold outcrop containing barren quartz, just as does the outcrop over the known low-grade orebody. It has not been prospected south of the arroyo near which No. 4 shaft is situated.

Workings.—There are four shafts, No. 1, 200 feet deep, No. 2, 300 feet deep, No. 3, 500 feet deep, and No. 4, 200 feet deep. The main working shaft was No. 3, which is sunk in limestone, west of the orebody. The stopes and tunnels between Nos. 1 and 2 shafts, shown in the accompanying section, have caved, and the condition of No. 3 shaft may also be poor. The surface equipment of this part of the mine has been removed. The workings from No. 4 shaft, consisting of a tunnel on the 200-foot level (see map) , are in good condition. This shaft is equipped with a steel headframe and a gasoline hoist.

Future Possibilities.—The easily accessible oxidized ore from the richer part of the mine has been removed. There remains secondarily enriched ore, of unknown extent, and there is probably a large body of low-grade ore. A long stretch of untried ground remains to the south of the mine. The outcrop is quite or nearly barren, but it should be remembered that, with one exception, the outcrops over the known orebodies were also barren: it was for this reason that the deposit escaped discovery until mining activity in the district had been in full swing for over 20 years.

There are two mining difficulties. The flow of water, owing to the permeable nature of the fault-zone, is heavy. Previous operators have undoubtedly been hampered by their inability to deal with the water adequately. Further, the ground does not stand well. These difficulties are not at all necessarily fatal to successful mining.

This mine might well some day offer possibilities for an operation of moderate scale. It can be said without injustice that its development has been haphazard, and its management, during the producing periods, poor. Its future depends chiefly upon the state of the copper market.

COPPER BAR PROSPECT

The Copper Bar claim covers the northward continuation of the Torpedo ore zone. There are two shafts, one near the Torpedo No. 1 shaft, which is said to be over 200 feet deep. Kaolin containing nodular masses of chrysocolla and malachite was found, but no ore of high enough grade to ship. The north shaft, east of the Memphis mine, is said to be over 300 feet deep, and contains water. Apparently no ore was found.

FRANKLIN CLAIMS

The Franklin claims, patented, cover the southward continuation of the ore zone. Much of the ground is mantled with alluvium and has not been prospected. Near the south end of the property two shafts and a tunnel expose a fault which separates pre-Cambrian granite from shale, probably of Devonian age. The fault contains quartz with abundant pyrite, but no ore has been found.

STEVENSON-BENNETT MINE

(SE $^1/_4$ Sec.11, NE $^1/_4$ Sec.14, T.22 S., R.3 E.)

The Stevenson-Bennett property, consisting of three patented claims and one unpatented claim, is situated $1^1/_2$ miles south of Organ, in the western foothills of the mountains.

History and Production.—The Stevenson orebody on this property was discovered in 1847. The early history of the mine has already been described (page 188) . The operation of the mine may be divided into three periods. The first, lasting from the time of discovery until 1882, was occupied by the mining of the Stevenson orebody, which outcropped at the surface. The mining methods employed were very crude, and it is said that all the ore taken out during this period was carried out of the open stope on the backs of laborers. The ore was mined for its silver content, and most of the lead was wasted. It was smelted in an adobe furnace near the river. The production during this period was about $150,000.

The second period, from 1882 to 1890, began with the driving of No. 1 tunnel, the purpose of which was to cut the extension of the Stevenson orebody in depth. This tunnel, which was driven during Carrera's lease, cut the Bennett orebody, which has proved to be much larger than the Stevenson, though less rich in silver. The mine now became important as a producer of lead as well as silver. The ore above No. 1 level was taken out by Carrera, up to and beyond No. 3 level; in 1887-8 the production is said to have been $250,000. After the expiration of his lease, mining was continued by the Stevenson-Bennett Consolidated Mining Company, which operated a mill with a capacity of 50 tons per day up to 1908, when the capacity was increased to 300 tons.[1] Between 1890 and 1900 a shaft was sunk from the intersection of No. 1 level with the Bennett orebody, and from this shaft levels were developed at 100 feet and 200 feet.[2] Thus was begun the third period of mining, during which the exploitation of the mine below water level was undertaken. The main shaft was begun in 1905, to the northwest of the Bennett ore-body.[3] It was not completed, however, until 1908, when it was sunk to a depth of 450 feet. The American Smelting and Refining Company operated the mine under lease after the Phelps Dodge Company's option in 1916-17, and took out a considerable amount of ore. Apart from the reworking of the dumps, only a small amount of work has been done since this lease, which was given up about 1920. The equipment of the mine was dismantled at that time, but two small mills have worked on the property since then, the most recent, belonging to M. J. Drunzer and C. C. Dues being in operation at the time of the present investigation. The only underground mining since 1920 seems to have been done by F. Hayner; the rest of the work has consisted in concentrating material from the dumps. The production during the third period has been considerable. Jones[4] estimates the production between 1890 and 1900 to have been $200,000. Between 1900 and 1916 not less than $250,000 was produced, while the production by the American Smelting and Refining Co. is locally stated to have been $300,000. The total production of the mine is thus of the order of $1,200,000; this figure may well be a conservative estimate. It represents nearly half the total production of the county since 1884.

The property is now owned by the Torpedo Mining Company.

Geology.—The orebodies lie in a fault block, about 1 mile in north-south dimension, bounded to the north and south by post-mineralization faults trending N. 70° W. and E.-W. respectively. The block is traversed in a north-south direction by the faults of the Torpedo-Bennett fault zone ; these were formed before the post-mineralization faults. The N.-S. faults are associated, as near the Torpedo mine, with intense brecciation. Where this occurs in carbonate rocks, it has generally been followed by silicification, so that the course of the faults can be followed by prominent outcrops of silicified breccia, which may be as much as 100 feet wide. The geological relations show clearly that they coincide with lines of faulting. (See surface map, opposite this page).

The easternmost fault of the N.-S. series in the vicinity of the mine brings typical pre-Cambrian granite on the east against

[1] Mineral Resources of the United States, 1908, p. 512.
[2] Jones, F. A., op. cit., 1904, p. 75.
[3] Lindgren, W., Graton, L. C., and Gordon, C. H., Ore deposits of New Mexico: U. S. Geol. Surv. Prof. Paper 68, 1910, p. 210.
[4] Jones, F. A., op. cit., 1904, p. 75.

Bliss quartzite and lower Paleozoic dolomites on the west. It dips to the west. About 500 feet east of this fault, the pre-Cambrian granite is in contact with the Tertiary quartz-monzonite. A series of faults cuts through the dolomites, as indicated on the map, and there are many minor faults which could be seen only in the mine workings. The most prominent belt of brecciation is associated with the westernmost fault. The dolomites are overlain by black and gray shales referred to the Percha formation. There has been some differential movement along the shale-dolomite contact, but no ore has been found here at this horizon. Limestones of presumed Lake Valley and Magdalena age overlie the shale.

A sheet of quartz-monzonite porphyry striking northeast and dipping northwest cuts through the dolomites. It was injected before the north-south faulting, since it is displaced by the fault.

The orebodies are tabular and irregular replacements in the dolomite, related to faults and fissure zones and to contacts between porphyry and dolomite. The Stevenson orebody, which outcrops at the surface, is associated near its outcrop with a N.-S. fault which can be followed for a long distance to the north. About 50 feet below the surface, however, the ore follows the lower contact of the porphyry sheet, and the fault becomes barren. The fault, which dips steeply to the east, was cut in the eastward extension of No. 1 tunnel, where it is quite barren. The Stevenson orebody contains quartz, green fluorite, cerussite and smithsonite, with a few residual masses of argentiferous galena. The silver content of the ore was higher in this orebody than in the others. Antisell[5] gives the following analysis of galena taken from this orebody in 1856:

Pb 86.40 S 13.34
Ag 0.16: equivalent to 46.67 ounces per ton
Mn 0.20
100.00

The oxidized material contained considerably more silver, and is said to have averaged about 120 ounces. As will be shown later, the galena is not richer in silver than that found in the Bennett orebody, but the oxidized ore is much richer. It follows that surface oxidation caused enrichment of the ore in silver.

The Bennett orebody follows a fracture zone of small displacement through the dolomite, striking N.-S. and dipping 70° W. It is a tabular body, reaching a maximum length of nearly 500 feet. On the 200-foot level it averages about 10 feet in width,

[5] Antisell, T., Geological report, U. S. Pacific railroad exploration : 33rd congress of the U. S., Senate Ex. Doc., 77, vol. 7, part 2, 1856, p. 162.

but on No. 1 level and above it is much wider, exceeding 20 feet. Although the fractures to which this orebody is related passed through the porphyry sheet, little hypogene ore was deposited in the porphyry. There has been locally some replacement of porphyry by supergene minerals, but in general this rock is barren of payable ore. The orebody maintains its tabular form up to the lower contact of the porphyry. Above the porphyry the ore forms a much more irregular mass, which does not extend up to the present surface, though in places it continued for as much as 50 feet above the upper contact of the sheet. As the accompanying projection shows, the known vertical extent of the orebody is 600 feet. On the lower levels, the minerals present are pyrite, galena and sphalerite in a gangue of quartz and silicified dolomite. A little tremolite occurs locally. On the 450-foot level, the assays indicate that galena and sphalerite are present in approximately equal quantities. Above this level, the amount of sphalerite decreases relative to the amount of galena, while at No. 1 level, the zinc-content of the ore is low. As this level is in oxidized ore, this may be due in part to removal of zinc by the oxidizing waters, but the unaltered ore which can still be seen in places on this level shows little sphalerite. The oxidation zone, extending from the uppermost part of the orebody to below No. 1 level, contains limonite, cerussite and wulfenite, with minor quantities of anglesite and smithsonite. There has probably been some renewal of dolomite-replacement during the oxidation process, causing a spreading of the mineralized ground beyond the original limits of the hypogene material. Natural caves, partly filled with limonite containing much cerussite, were formed during oxidation; these provided an easily mined source of ore. They remain today as great cavities, into which boxworks of quartz project. Wulfenite, though subordinate in quantity to cerussite, was locally abundant, and was one of the important ore minerals. The problem of the source of the molybdenum has already been discussed (page 159). Some pale blue aragonite occurs in the oxidation zone. To the north and south the Bennett orebody passes into barren silicified dolomite. Underground the southern end is not safely accessible, but the northern end was examined on No. 1 level and on the 200-foot level. In neither case could any evidence of truncation of the body by faults be found, nor did surface mapping suggest the presence of any faults against which the orebody might have terminated.

Two sets of assays indicating the character of the hypogene ore are available ; the first represents assays made during the mining of the ore between the 200-foot and 300-foot levels in 1917, and the second represents sampling of the 450-foot level, every ten feet, before the closing of the mine:

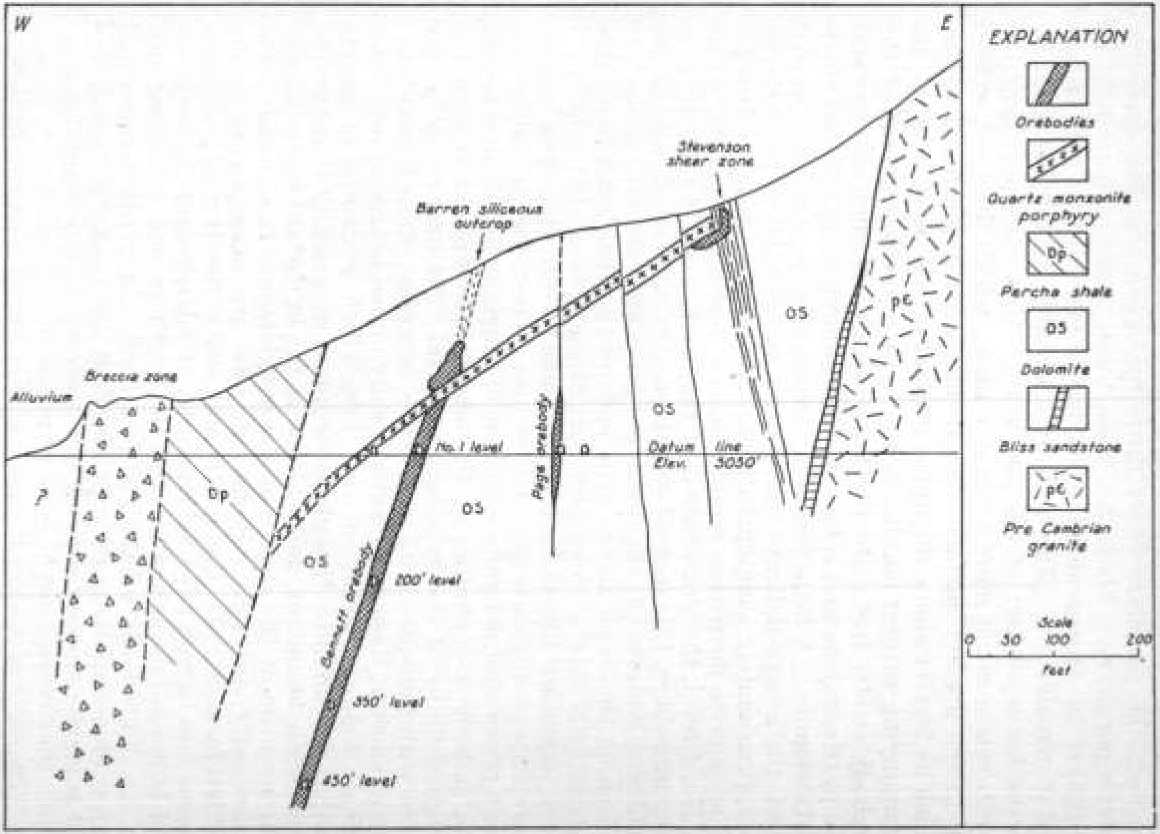


FIGURE 16.—Cross section of the Stevenson-Bennett mine. The position of the section is shown on Plate XII, line A-A.

	Ag (Ounces)	Pb (Per Cent)	Zn (Per Cent)
I.	11.45 (61)	15.6 (115)	15.2 (103)
II.	2.89 (19)	10.77 (19)	12.96 (4)

No assays for the oxidized ore are available, but reliable information states that the zinc content of this was low, the lead content up to about 25 per cent, the silver content about 20 ounces per ton. A single assay of oxidized ore with wulfenite gave the following result: silver, 1.42 ounces ; lead, 36.35 per cent ; molybdenum, 13.27 per cent. If average I is compared with the analysis of galena from the Stevenson orebody quoted on page 222, it will be clear that the silver-content of the galena is actually higher in this part of the Bennett orebody than in the Stevenson orebody, assuming that the galena is the only important silver-bearing mineral. However, near the surface silver halides were probably formed in the Stevenson orebody, enriching it in silver; whereas the Bennett orebody, since it does not outcrop, was not enriched in this way.

Between the Stevenson and Bennett orebodies, there is a small replacement deposit, known as the Page orebody, related to a N.-S. fissure. This outcrops in the southern part of the property, where it contains limonite with cerussite and smithsonite. It was mined underground by small stopes between Nos. 1 and 3 levels, where pyrite and galena were present in silicified dolomite. Thallium was detected in the ore from these stopes by Mr. Bentley.

Workings.—The developments include, on the Stevenson orebody, open stopes where the ore follows the fault, three tunnels (Nos. 5, 6, and 7) and two underground stopes in which the ore in the dolomite below the porphyry has been mined. These were the earliest workings.

The main entrance to the mine is No. 1 tunnel, which intersects the Bennett orebody 340 feet from its portal. There are large open stopes on this orebody, supported by pillars of low-grade ore and by a few stulls ; apart from the pillars, the ore has been stoped out down to the level of the drainage tunnel, 240 feet below the collar of the main shaft. A crosscut on No. 1 level runs to the east, connecting with the Page stopes, and continues east, where a branch drift has cut the Stevenson fault, and has been continued to cut the fault which brings dolomite against Bliss sandstone. No. 3 tunnel cuts the Bennett orebody near its intersection with the porphyry sheet. It also continues to the east, joining with the Page workings. Between Nos. 1 and 3 levels there are stopes both above and below the porphyry sheet. No. 4 tunnel has explored the lower contact of the porphyry sheet to the south. A continuation of the Page orebody was found, and

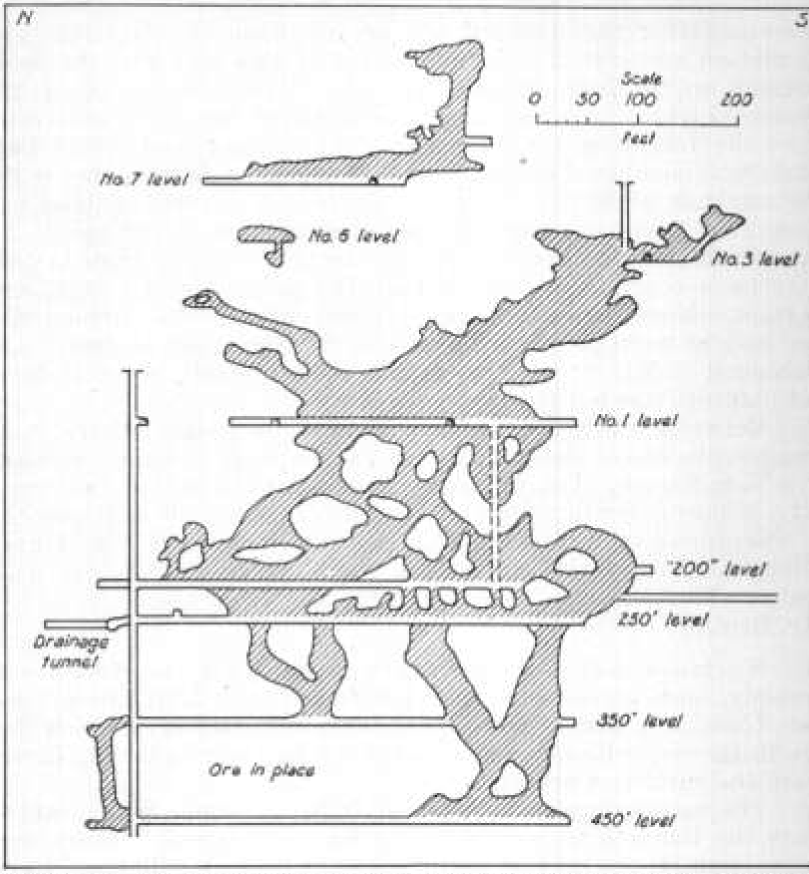


FIGURE 17.—Vertical projection parallel to the Bennett orebody, Stevenson-Bennett Mine.

Shaded areas indicate stopes. The workings on Nos. 6 and 7 levels are on the Stevenson orebody; the rest are on the Bennett orebody.

this has been stoped up to the surface. The deep levels are accessible from the main shaft, situated to the northwest of the Bennett orebody. This goes down through the shale into the dolomite, and reaches a depth of 450 feet, with levels at 200, 250, 350 and 450 feet. The water stands just below the 200-foot level at present. On the 200-foot level a long drive was carried north, without, however, finding any more ore. There are exploratory crosscuts to the east, but continuations of the Page and Stevenson orebodies in depth have not been found. Only a small amount of stoping has been done below the 250-foot level. The drainage tunnel, over 3000 feet long, cuts the shaft at the 250-foot level. There has been some caving in this tunnel, and it is not functioning efficiently at present.

The equipment of the mine in 1934 included a gasoline hoist, installed in a short tunnel (No. 2) at No. 1 level. A gasoline-operated pump was working on the 200-foot level, not to lower the water in the workings, but to supply water for the mill. A mill, consisting of a crusher, a grinder, trommels, a jig and three tables was operating, chiefly on material from the dumps.

Future Possibilities.—The ore reserves of this mine lie between the 250- and 450-foot levels. The width of ore is said to vary from 6 to 10 feet ; unfortunately exact measurements, made at the places where channel samples were taken, have been lost. It is not possible, therefore, to calculate with any degree of accuracy the reserves. However, it may be of interest to indicate conservatively what may be present. Calculating for a width of 6 feet of ore, and assuming that there are 12 cubic feet of ore per ton, the possible reserves between the 250-foot level and a depth 50 feet below the 450-foot level amount to 35,250 tons. The average assay for the 450-foot level may be taken to indicate very approximately the metal content of the ore. It is unlikely that this ore could be extracted profitably at the present price of lead and zinc, but there may be a time in the future when reopening would be justifiable. In the old workings, a small tonnage of ore remains in pillars, and in the walls of the stopes. Leasers may find this worth taking out.

The relations of the Stevenson orebody suggest that the mineralizing solutions traveled to it up the lower contact of the porphyry sheet, and not along the fault. This contact has not yet been adequately explored. It seems possible that the solutions actually came from the Bennett fissure zone; therefore some further testing of the porphyry-limestone contact is recommended, between the Bennett and Stevenson orebodies, and preferably to the south of No. 6 tunnel where the contact could easily be reached by a tunnel or a shaft through the porphyry.

It seems quite clear that the limits of the Bennett orebody have been adequately proved, and most of the argentiferous ore taken out. The uneconomic nature of the proved ore makes the future for this mine an unpromising one.

HAYNER MINE
(SW$^1/_4$ Sec.25, T.22 S., R.3 E.)

This property, owned by F. Hayner and G. Manasse of Las Cruces, is situated about 4$^1/_2$ miles south of Organ. Fluorite has been produced since 1928, and has been concentrated at the Tortugas mill. The geology and workings have been fully described by Johnston,[6] so that only a brief review is necessary here. The fluorite occurs in replacement deposits related to fissures in limestones of the Magdalena series. The fissures strike between N. 10° E. and N. 50° E., and dip to the east ; four deposits have so far been opened up, and there are several outcrops as yet unexplored. The spar is of good grade, containing very little silica, as the following analysis shows: CaF_2, 98.24 per cent ; $CaCO_3$, 1.08 per cent ; SiO_2, 0.64 per cent. There is a considerable reserve of fluorite. The mine is idle at present, owing to the low price obtainable for the product, and the long haul.

MODOC MINE
(SW. $^1/_4$ Sec.31, T.22 S., R.4 E.)

The Modoc property, consisting of one patented claim, is situated north of the mouth of Fillmore Canyon. It is believed to have been discovered by Barilla, prior to 1854 (see page 189), but its period of activity was from 1879 to 1905. Some estimates place the production as high as $200,000, but the writer feels doubtful about the correctness of this figure.

The deposit is an irregular replacement in Magdalena limestone adjacent to the fault representing the southward continuation of the Torpedo-Bennett fault zone. The fault strikes N.-S. and dips steeply to the east ; the hangingwall is Orejon andesite, the footwall, the Magdalena limestone. The minerals in the deposit include andradite, partly altered to chlorite ; epidote, quartz and galena. The galena is almost non-argentiferous, carrying only about 2 ounces of silver per ton. The deposit is classified as a member of the pyrometasomatic class of the hypothermal group ; it belongs to the special division of pyrometasomatic deposits which do not occur at or near the contacts between igneous intrusions and limestones.

The developments include a tunnel along the limestoneandesite contact, which intercepts the orebody about 45 feet from the portal. The mineralized ground is extensive, but ore of good grade in lead was confined to a mass about 50 feet long

[6] Johnston, W. D., Jr., Fluorspar in New Mexico: N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 4, 1928, pp. 83-85.

and 7 feet wide in the limestone. This continued to a depth of 90 feet below the tunnel, then pinched. The 90-foot level is reached by a vertical shaft in the limestone, no longer accessible, and a crosscut. The ore has been stoped out to this level. A winze 50 feet deep below the 90-foot level is said to have exposed ore which carried higher silver values.

Three milling processes were tried on this property. The Hooper pneumatic process, and another method of dry concentration were used, without success. About 1903 a conventional wet process with jigs was installed, and proved effective, but at this time the orebody became exhausted, and the company went into bankruptcy.

There may well be reserves of lead ore below the Modoc deposit. However, in view of the low silver content of the galena, it is doubtful whether such ore could be mined profitably. On the other hand, should the silver content increase, the property might well be a valuable one. The mineralization is strong, and there is every prospect of finding more ore in other favorable beds in depth.

OREJON MINE
(NE. 1/4 Sec. 1, T.23 S., R.3 E.)

The Orejon mine, formerly the property of the Aztec Copper Company, is situated near the fault, south of the Modoc mine. A pipe-like body of ore, following the dip (46° SW.) of a bed in the Magdalena series, has been exploited. The minerals present are andradite, epidote, chlorite, specularite, chalcopyrite, sphalerite and galena. The mineralogy is more typical of the pyrometasomatic class than is that of the Modoc deposit. Assays made in 1910 gave the following results : gold, trace to 0.06 ounces ; silver, 28.5 ounces (19) ; copper, 10.4 per cent (13) ; zinc, 9.0 per cent (2) ; lead, 21.2 per cent (11) . As these were no doubt made on picked specimens, they should not be taken too seriously, but they serve to indicate qualitatively the character of the ore.

The workings include a tunnel about 100 feet long, which communicates with an incline 125 feet long on the deposit, in a direction S. 55° W. The deposit, which was small, seems to have been worked out.

OTHER PROSPECTS

The Trapezoid prospect, north of the Modoc mine, has exposed a large mass of andradite with minor quantities of galena, some distance away from the fault. The developments are slight.

The Silver Cliff prospect, between Dripping Springs and the mouth of Fillmore Canyon, exposes the southward continuation of the fault seen at the Modoc. Here both the walls are Soledad rhyolite. The lava has been brecciated adjacent to the fault, and colorless fluorite and barite have been introduced. The deposit is of no economic importance.

PYROMETASOMATIC DEPOSITS

COPPER BULLION AND COBRE GRANDE CLAIMS
(SW. 1/4 Sec.29, SE. 1/4 Sec.30, T.21 S., R.4 E.)

The Copper Bullion and Cobre Grande group, comprising four unpatented claims, covers the outcrop of the calcitic beds of the El Paso formation, southeast of the Merrimac mine. No production is recorded. The deposits consist of irregular bodies of quartz with specularite and chalcopyrite, replacing garnetized limestone. The size of the ore-shoots is invariably small, and they appear to have no commercial possibilities. Assays on ore from the Copper Bullion claim gave the following results: gold, none; silver, 1.5 ounces (5) ; copper, 4.4 per cent (12). The developments include shallow inclined shafts and short tunnels.

EXCELSIOR MINE
(Center Sec.25, T.21 S., R.3 E.)

The Excelsior mine is situated $1^1/_2$ miles north of Organ. The property consists of five patented claims, covering the Carboniferous limestones near their contact with the quartz-bearing monzonite, and with a rhyolite laccolith. It was formerly owned by the George E. Wood estate, but it is said that it has recently been taken over by J. I. Pearce, of 201 North Wells Street, Chicago. The production is said to have been $60,000, chiefly in copper.

The limestones, which at the Excelsior mine belong to the supposed Lake Valley formation, have been recrystallized, and in places replaced by andradite, wollastonite and vesuvianite. The primary minerals of the sulphide group, including pyrite, chalcopyrite, sphalerite and a little galena were deposited, with quartz, later than the silicates. The sulphides have been oxidized, and large quantities of malachite were found in the upper part of the workings. Several tabular orebodies are said to have been found, dipping to the northwest. No doubt the form of these was due to replacement in favorable beds.

Assays gave the following results : gold, none ; silver, about 1 ounce; copper, 1.5 to 35.10 per cent; zinc, up to 37 per cent ; lead, up to 28 per cent. A representative sample of the dump taken in 1930 gave: gold, none ; silver, 0.78 ounces ; copper, 2.32 per cent. Shipments from the Excelsior mine are said to have been penalized for bismuth by the smelter. Probably some tetradymite occurs here.

The mine was developed from a shaft inclined at 60° to the northwest, 175 feet deep. It is said to lead directly into large stopes, but is no longer accessible. Judging from the size of the dumps, a considerable amount of work has been done at this mine. It is said that reserves of sulphide ore remain in the mine, consisting partly of enriched copper ore, partly of hypogene ore high in zinc.

South of the mine a prominent vein is exposed in the limestone, paralleling the monzonite contact. This has a heavy, barren gossan, and has not been explored in depth.

LADY HOPKINS PROSPECT

(S W. 1/4 Sec.26, T.21, S.R.4 E.)

This property was prospected prior to 1882; there has been little work since then. A pyrometasomatic deposit in pre-Cambrian granite has been explored here. Structurally, the deposit has many features in common with the leptothermal veins cutting the pre-Cambrian complex. It appears to be a replacement deposit related to fracturing along the footwall of an epidiorite dike. The minerals, which replace everything but the orthoclase phenocrysts in the granite, include augite, biotite, magnetite, and specularite. Apparently later than these, there are pods of quartz with pyrite and pyrrhotite. The developments include a tunnel 248 feet long at 4975 feet elevation, a tunnel 255 feet long at 5105 feet, and a shaft about 50 feet deep at 5225 feet. The deposit contains no valuable metals in quantities greater than traces. Mr. Bentley informs me that he has detected nickel in the sulphide material.

MEMPHIS MINE

(NW1/4 Sec.36, T.21 S., R.3 E.)

History and Production.—The Memphis mine was discovered prior to 1882. During 1884 a small water-jacket smelter was operated on the property.[7] There has been intermittent activity up to the present time, and a considerable amount of work has been done; indeed there has been more activity on this property than on any other in the district, the Stevenson-Bennett excepted. It was one of the group held under option by the Phelps Dodge Copper Company, but their activities were confined mainly to the Torpedo mine. The last work done was the sinking of the Roos shaft in 1927-1929 by the Memphis Corporation. The property is owned at present by the Torpedo Mining Company, which has recently offered the property, consisting of one patented claim, for sale.

Local estimates of the production vary between $200,000 and $400,000, the values being in copper, zinc and silver. Bismuth ore has been mined but not sold.

Geology.—The country rock is the Magdalena series of alternating thin limestones and calcareous shales. A fault which crosses the claim separates this series from the quartz-bearing monzonite to the east. At the northern end of the claim, the sedi-

[7] Lindgren, W., Graton, L. C., and Gordon, C. H., Ore deposits of New Mexico: U. S. Geol. Surv. Prof. Paper 68, 1910, p. 212.

mentary rocks are overlain by a sill of quartz-monzonite porphyry, and in this region the beds lie almost flat ; south of this sill, however, their dip increases, until near the South shaft they dip to the west at 45°.

Certain beds in the series have been almost wholly replaced by andradite, with subordinate diopside and wollastonite. Beds which escaped total replacement by silicates have in certain cases been replaced by quartz, specularite, and sulphides, including chalcopyrite, pyrite, sphalerite and small quantities of galena. Tetradymite is locally fairly abundant. Among the supergene minerals, chalcocite, malachite and azurite, chrysocolla, and calamine have been important. The distribution of silicate beds and ore bodies at the surface is shown on the accompanying map (Plate XIV). There are four principal ore-horizons. The first lies immediately west of the massive garnetite adjacent to the fault, and has been mined from the Roos shaft, where a large body of chalcocite was struck between the 30- and 50-foot levels, and from opencuts to the south, from which malachite, chrysocolla and stubelite (?) were obtained. This body has been followed only about 80 feet down the dip ; it appears to pinch on the west side of the stopes opened by the Roos shaft. A second body lies to the west, in the zinc stope. This has been mined for a length of 200 feet, and to a depth on the dip of about 200 feet. The body was four feet thick, and contained down to water level malachite, azurite and calamine. Massive sphalerite ore is said to be exposed in the bottom of the stope. A third zone lies southwest of the Roos shaft, and appears to follow a system of fissures. This has been mined to a depth of only about 20 feet, and consists entirely of limonitic material said to carry high silver values. The fourth, and most important ore zone is that developed from the South shaft. The bulk of the production of the mine has come from stopes on this zone; the minerals are said to have been malachite, azurite and chrysocolla. In addition to the principal orebodies, there are small shoots of oxidized ore in other shafts and excavations. A pit south of the Roos shaft exposes oxidized bismuth ore.

The workings at this mine have shown conclusively that the garnetite beds are poor ore-carriers. The Roos workings expose such beds underground on the 100- and 200-foot levels; scattered sulphides occur, but no payable ore was found on either level. The same is true on the surface.

Although many assays of Memphis ores are available, it is impossible to present figures which would adequately represent the typical ores which have been mined. Two averages may, however, be quoted. The first represents complex sulphide ore taken out during operations on the 180-foot level from the South shaft, during the years 1911 to 1915: gold, none or trace; silver, 10.8 ounces (39) ; copper, 6.6 per cent (61) ; zinc, 15.4 per cent (26) ; lead, 7.1 per cent (37) . For comparison, average figures for the oxidized bismuth ore from an opencut southwest of the Roos shaft may be given : gold, none or traces ; silver, 82.9 ounces (8) ; copper, 6.8 per cent (5) ; bismuth, 13.65 per cent (6) ; lead, zinc, not determined. Evidently the bismuth-bearing ores are rich in silver. As the El Paso smelter will not take bismuth ores, there has been no production of this metal, but reserves of it undoubtedly exist in the mine. Shipments from the orebodies which do not contain obvious tetradymite have been penalized by the smelter for bismuth.

Workings.—The South shaft, the original shaft of the property, is said to be 180 feet deep. It communicates with large stopes lying to the south and west, under the alluvium. These workings were considered too dangerous to be examined. There are many shallow shafts, inclines, and opencuts between the South and Roos shafts. The Roos shaft is 200 feet deep, and communicates with levels at 30, 50, 100 and 200 feet. It was sunk below the 50-foot level by the Memphis Corporation, which did some prospecting with a "long-rod" drill, from the north end of the 100-foot level, without, however, any success. The shaft appears to expose only massive garnetites. The 100-foot level extends 70 feet northeast and 50 feet southwest of the shaft; the 200-foot level extends 80 feet southeast and 40 feet northwest. These workings are in good condition. The zinc stope is open at the surface, and accessible almost to water level. A vertical shaft from the surface communicates with the deeper part of the stope.

North of the Memphis property, on the King claim, there is a vertical shaft 200 feet deep, with a drift to the west from the foot. Much pyrite was found, but no payable ore.

Future Possibilities.—At the present time, there is very little ore in sight on this property, zinc-rich ores excepted. It is clear, however, that much unproved ground remains. The eastern member of the Torpedo-Bennett fault zone, although it encloses rich orebodies at the Torpedo mine, has received little attention on the Memphis claim. It is exposed in only one shallow shaft, in which there is a feeble showing of malachite. It could readily be tested by means of a cross-cut from the 200-foot level of the Roos shaft. In view of the known tendency of orebodies in the fault zone to occur below quite barren outcrops, as at the Torpedo and the Stevenson-Bennett, this trial would appear to be worth making in the event of a recovery in the copper market. Apart from the rather remotely possible oxidized ore in the fault, it appears that all payable ore of this character has been worked out. There remains, however, the possibility that enriched sulphide ores could be found in depth below the 200-foot level, in view of the deep enrichment zone at the Torpedo. The most favorable place to search for such bodies would be near the fault, so that both favorable beds and the fault could be tested.

Under present conditions, it is impossible to recommend further work, since the ores so far produced have been valuable mainly for their copper and zinc.

MERRIMAC MINE
(NE. 1/4 Sec.30, T.21 S., R.4 E.)

The Merrimac mine, situated 2 miles northeast of Organ, was developed early in the present century. The property consists of one patented claim, owned by Mrs. W. C. Godfrey of El Paso, and the heirs of Mrs. Wilhoyt, Cameron, Mississippi. There is said to have been a small production of zinc ore.

The deposit is a replacement of a bed about 4 feet thick near the base of the Lake Valley limestone series ; it contains sphalerite and pyrite with subordinate chalcopyrite and galena, and their oxidation products, in a gangue containing andradite, partly replaced by chlorite, and quartz. The developments consist of a stope, inclined northwest at 36°, and a vertical shaft which communicates with the stope at water level, 80 feet below the surface. The incline continues below water level for an unknown distance. The accessible workings are shown on the accompanying map. Reserves of zinc-rich sulphide ore remain in the mine ; the oxidized ore, containing limonite, hydrozincite and smithsonite, has mostly been mined out. The size of the ore shoot does not, however, appear to justify the developments which would be necessary if the mine were to become a zinc producer. Zinc ores are not regarded with favor in the Organ district, since they cannot be sold to the El Paso smelter. Only a large operation, able to ship ore in quantity to Amarillo or elsewhere, could be made to pay.

IRON MASK AND OPHELIA CLAIMS
(SE. 1/4 Sec.30, 'T.21 S., 11.4 E.)

The contact between the lower Paleozoic dolomites and the quartz-bearing monzonite is covered by two claims southeast of the Merrimac mine, known respectively as the Iron Mask and Ophelia. The minerals present include: serpentine, phlogopite, penninite, cordierite, spinel, and diopside, replacing the dolomite up to about 25 feet from the contact. Small lenticular bodies of magnetite have been discovered associated with these minerals in the gulch running towards the summit of the ridge below which the Silver Coinage mine is situated. They are not of large enough dimensions to be of commercial value. Apparently later in age than the minerals listed above, there are veinlets with

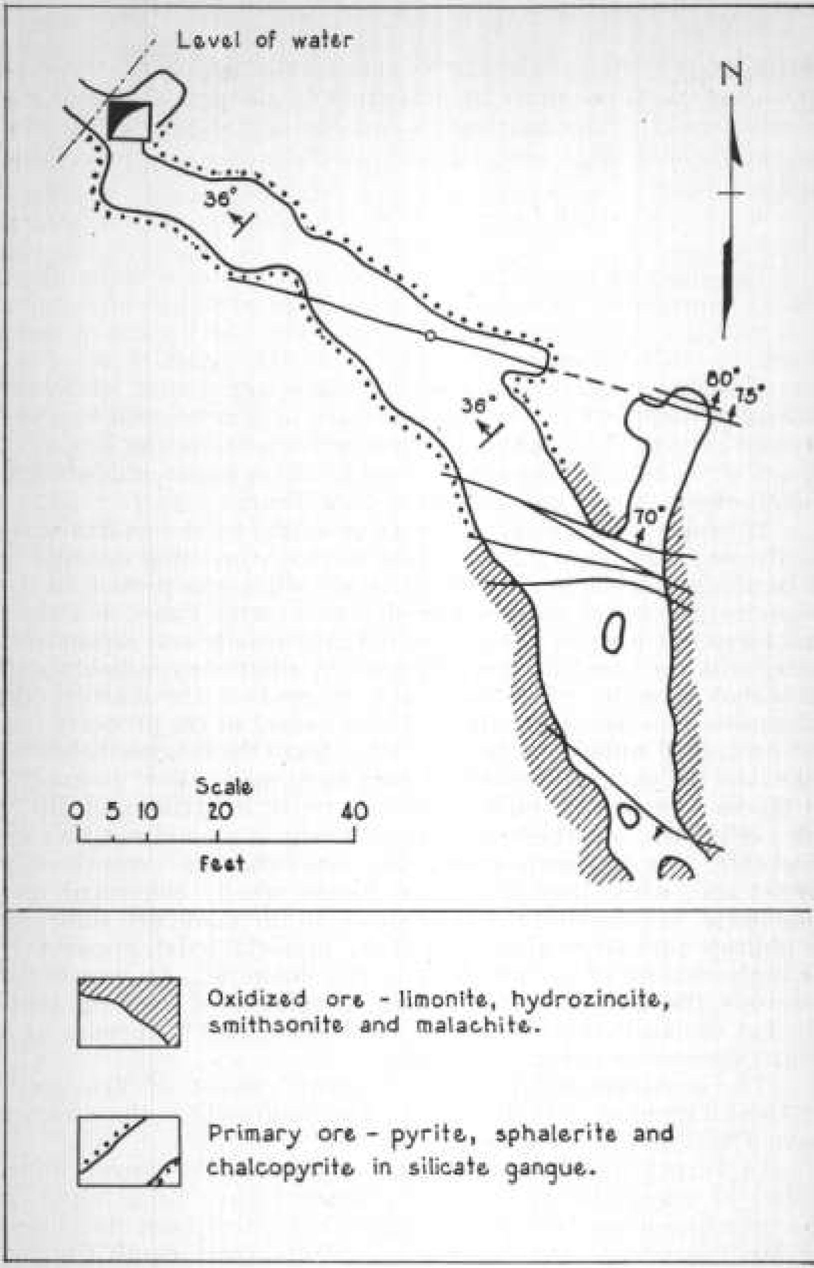


FIGURE 18.—Map of the inclined stope at the Merrimac mine. In the plane of the stope.

pyrite, pyrrhotite, chalcopyrite and sphalerite. The developments include three short tunnels and two inclined shafts of unknown depth. There has been no production, and the properties appear to hold little promise for profitable exploitation in the future.

SOUTH CANYON MAGNESITE DEPOSITS
(Sec. 35, T.23 S., R.4 E.)

The ridge on the south side of South Canyon is made up of quartz-monzonite containing numerous large xenoliths of granite, quartzite, dolomite, limestone and shale. The distribution of these is shown on the map on page 66. Only the dolomite xenoliths are of commercial interest, for in these are found lenticular masses of magnesite. The deposits have been developed by their present owner, F. C. Schneider, and active prospecting is still in progress. The xenoliths are covered by three unpatented claims, the Magnesia Nos. 1 and 2, and the New Year.

Metamorphism of the dolomite xenoliths by the quartz-monzonite converted them into periclase marble, consisting essentially of periclase and calcite. In places where silica was present in the dolomite, forsterite was produced. At a later stage, periclase and forsterite were in part converted into brucite and serpentine. Later still, the xenoliths were invaded by solutions, probably rich in carbon dioxide, which were able to convert the marble into magnesite (see pages 104-105). Development of the property has not proceeded sufficiently to show what form the magnesite bodies take, but the excavations which have been made show magnesite in places over 4 feet thick. The continuity in strike and dip is not yet known, but there is no reason why it should not be considerable. As the map shows, the xenoliths are exceptionally large; and, while they are by no means wholly converted into magnesite, yet the slight developments so far made are sufficient to indicate that large quantities of the material exist, apparently as replacements of certain beds in the dolomite. In weathered outcrops, the magnesite is not easily distinguished from the marble, but in excavations below the weathered shell it appears as a white massive or porous substance.

The developments in South Canyon consist of five open-cuts and a number of shallow pits. The magnesite in these varies from 1 to 5 feet in thickness.

In Target Range Canyon, east of the Devil's Canyon mine, bodies of magnesite of identical character have been found in the metamorphosed dolomite. These have also been developed by Mr. Schneider. Analyses of magnesite from South Canyon and Target Range Canyon are given below:

Analyses of Magnesite

	I	II	III	IV	V
SiO_2	1.74	2.51	0.13	0.86	1.01
R_2O_3	0.57	0.74	0.71	0.76	0.36
CaO	3.28	0.96	2.00	5.35	4.95
MgO	43.18	44.48	44.77	41.76	42.19
Loss on ignition (CO_2,H_2O)	51.23	51.31	52.39	51.27	51.49

Analyst, H. C. Lee, University of Ohio.

I-IV, Magnesite from prospect pits in Target Range Canyon;
V, Magnesite from South Canyon.

OTHER REPLACEMENT DEPOSITS IN CARBONATE ROCKS

LITTLE BUCK MINE
(NE¼ Sec.30, T.21 S., R.4 E.)

The Little Buck mine is situated 2 miles northeast of Organ, east of the Merrimac mine. It was originally developed by Mc-Cowen, of Organ, and up to 1905 had produced, according to Lindgren,[8] $42,000 in gold and silver. A considerable amount of prospecting has been done since that time by leasers, but only Professor Goss has succeeded in finding payable ore; he is said to have taken out ore worth $7,000. During 1933 L. M. Richard examined the property, without finding further ore. The mine was reopened during the summer of 1935 and a tunnel is being driven along the shale-dolomite contact by leasers. The present owners are the heirs of Mrs. McCowen ; and Mrs. Martin Lomond.

The deposits occur in the upper part of the Fusselman dolomite, underneath the Percha shale. Solutions moving along the shale-dolomite contact have produced a solution breccia in the dolomite, and in this the valuable minerals occur. The form of the ore shoots is highly irregular, and all of them seem to have been small, only a few feet in any dimension. The minerals present include quartz, pyrite, chalcopyrite, sphalerite and galena; sphalerite and pyrite predominate among the sulphides. The ore was valuable for its precious-metal content, both gold and silver being found. A specimen from this mine in Mr. Bentley's collection shows native gold in quartz. The ore, rich in silver, gave a strong test for tellurium, according to Mr. Bentley; while hessite may have been present, the tellurium content may have been due merely to the presence of altaite, which occurs on adjacent claims.

The developments consist of opencuts and shallow shafts, on the north side of a low ridge which is traversed by the shale-dolomite contact. Apparently the contact has not been tested below about 25 feet from the surface. Even though it would be necessary to pump water, because of the shallow water level in

[8]Lindgren, W.. Graton, L. C., and Gordon, C H., The ore deposits of New Mexico : U. S. Geol. Surv. Prof. Paper 68, 1910, p. 212.

this region, the sinking of an inclined shaft on the contact from the creek-bed north of the ridge appears to the writer to offer good chances for the discovery of payable ore. Only a small-scale operation would be justified.

The available assays represent mainly specimens obtained during prospecting, and should not, therefore, be taken to indicate the character of the ore mined : gold, 0.037 ounces (40) ; silver, 16.6 ounces (43) ; lead, 12.4 per cent (17) ; zinc, 24.7 per cent (2) ; copper, 1.82 per cent (2) .

The ore in sight at present consists chiefly of pyrite and sphalerite, and is of no value. Richard's work on this property showed that there is little hope of finding anything more in the present workings.

RICKARDITE MINE
(NW. 1/4 Sec.29, T.21 S., R.4 E.)

The Rickardite claim, formerly known as the Jim Fisk, is situated east of the Little Buck claim. The present owner is B. F. Horton. Oxidized zinc ore worth $2000 was produced in 1915. The contact between the Percha shale and the Fusselman dolomite crosses the claim ; the deposits are irregular replacement bodies of small size near the top of the dolomite. As at the Little Buck, the ore minerals cement what is essentially a solutionbreccia in the dolomite. Sphalerite and pyrite are the most abundant hypogene sulphides present, but at the east end of the claim galena becomes important, in accordance with the transition from the zinc zone to the lead zone (see page 138) . The content of precious metal is said to be low in the zinc-rich ores, but it probably increases as galena increases. The available assays show a range of 1.2 to 230.7 ounces in silver content.

The workings consist of an incline on the shale-dolomite contact, about 200 feet long, intercepted by a vertical shaft. This has exposed many small irregular masses of pyrite-sphalerite ore, the largest of which does not appear to exceed 10 feet in dip-length or 2 feet in thickness. The nature of the ore makes it uneconomic. There are many shallow pits, and several small open stopes where oxidized ore has been taken out. No further work on the zinc ores would be justified, but further exploration under the shale at the eastern end of the claim might be worth while in view of the silver content of the galena.

HILLTOP MINE
(NW.1/4 Sec.29, T.21 S., R.4 E.)

The Hilltop property was developed by John Thompson in 1904-5 as the Eureka mine. Some shipments of argentiferous galena were made, and specimens of altaite were sold to mineral collectors. The property was acquired by the present owners, the Hilltop Mining Company, of Oakland, California, A. 0. Meneray, Superintendent, in 1928.

The deposit is a replacement body in the uppermost beds of the Fusselman dolomite, underneath the Percha shale. The most abundant minerals are quartz, galena and pyrite. Some sphalerite occurs, and the rare telluride of lead, altaite, is present (see page 135) . The deposit is much more continuous and consistent in character than those on the Rickardite and Little Buck claims. There is a mass of partly oxidized galena, 1 to 2 feet thick, and beneath this a body of quartz said to carry values up to 5 ounces per ton in gold.

The deposit occurs near the outcrop of the shale-dolomite contact, high up on the west side of Black Prince Canyon. The old workings here have opened up the deposit by means of highly irregular tunnels and inclines. The present owners have cleaned out the old workings, discovering in the process the gold-bearing quartz body. They are now driving a tunnel in from the west side of the ridge, approximately 200 feet below the deposit, in an attempt to find its continuation on the dip. The tunnel has passed through the Lake Valley limestone and the Percha shale, and reached the dolomite. The contact has then been followed to the south. Several galena-bearing stringers have been cut, and preparations were being made in January, 1935, to run an inclined raise up the contact to connect with the old workings.

It is clear from the geological relations that the orebody will be tabular in form, and parallel to the shale-limestone contact. It may be confidently expected that the proposed raise will prove the continuation of the orebody on the dip, and the mine is likely to be a valuable small producer if the gold-bearing shoot continues for any distance down the dip. Argentiferous galena will also be a product of the operations.

The writer is not at liberty to place on record the results of assays made for the present company, but, in order to show the character of the lead ore, an analysis of a general sample of a shipment made in 1912 may be quoted :

Ag	12.40	ounces
Pb	50.37	per cent
Zn	13.51	
Fe	4.57	
CaO	2.15	
SiO_2	12.40	
S	10.12	
	92.92	

Analyst, L. B. Bentley.

It should be clearly understood that this analysis does not apply to the shoot of gold ore at present being prospected.

BLACK PRINCE MINE
(SE1/4 Sec.20, T.21 S., R.4 E.)

This property comprises a group of three unpatented claims covering the contact of the Percha shale and the Fusselman dolomite in the central part of Black Prince Canyon. The mine was developed early in the history of the district, but nothing is known about the production prior to 1917, when shipments were made by L. B. Bentley amounting to about $1000. There has been no mining since that time.

The deposits are irregular replacements, in dolomite, related to two structural controls : a NE. trending fissure, and the contact of the shale and dolomite. They occur on the west side of a ridge which is in effect a dip slope corresponding to the top of the dolomite. The main outcrop of the shale is at the foot of the slope, but there are numerous small outliers of shale resting on the dolomite. Some of the ore-shoots have been found beneath these outliers, and have been worked from tunnels and opencuts. The NE. striking fissure dips 55° SE. It has been exposed in an opencut near the summit of the ridge. The deposits contain oxidized lead-silver ore; only a small amount of unaltered galena remains. Assays gave the following results : gold, 0 to 0.04 ounces ; silver, 22.4 ounces (21) ; lead, 24.5 per cent (21). There is no ore in sight, and the small deposits seems to have been worked out.

HOMESTAKE MINE
(SE1/4 Sec.35, T.21 S., R.3 E.)

The Homestake property is situated three-quarters of a mile north of Organ, on the east side of a low hill. The production of lead-silver ore is estimated to have been $25,000; the present owners are E. Shipe and partners. The last work was done in 1927.

The deposits are replacements of Magdalena limestone underneath a sill of quartz-feldspar porphyry. The sill, which appears to conform with the bedding of the rocks, dips 35°-40° NW. The contact between the sill and the porphyry comes to the surface near the southern end of the property, and deposits containing limonite, cerussite and argentojarosite were mined here by means of an open stope and an incline which slopes to the north. A vertical shaft sunk at this outcrop failed to find further deposits in depth, but a newer shaft to the north has cut the contact at about 100 feet below the collar, and found a sulphide body containing chiefly pyrite and argentiferous galena. Owing to the altered nature of the sill, the workings are hard to support and are in bad condition at the present time. Little can be said about the possibility of the mine because the workings were too dangerous for more than a cursory inspection underground. There is, however, some good ore in sight, and further prospecting from the shaft appears to be justified. Assays made in 1912, 1913, 1914 and 1927 gave the following average : gold, 0 to 0.08 ounces ; silver, 27.8 ounces (32) ; lead, 11.5 per cent (33).

PHILADELPHIA GROUP

(SW. 1/4 Sec.36, T.21 S., R.3 E.)

This property consists of three patented claims northeast of the Memphis mine. There has been a small production of lead and silver from oxidized ores, and during 1934 material from the dumps was put through the Stevenson-Bennett mill. The present owner is E. Isaacks.

The deposits occur at the contact of dike-like bodies of quartz-feldspar porphyry with limestones of the Magdalena series. They contain limonite, cerussite and probably some argentojarosite, with residual masses of galena. The developments consist of three vertical shafts communicating with stopes underground. Only one of these was accessible, that nearest the road to the Flying Bar-U ranch. The workings here showed the igneous rock in contact with thin limestone beds. An ore shoot occurs where the fissure zone striking N. 15° W. comes into contact with the dike, here striking N. 40° W. The limestone strikes NE. and dips 55° NW. The deposit is very small.

On the northwestern part of the property there is an incline which has opened up a quartz-galena deposit replacing a thin limestone. The incline, which is parallel to the bedding, dips 30° in a direction N. 35° W.

The inaccessibility of the main workings makes it impossible to form any impression of the potentialities of this group. There is no evidence to indicate that valuable orebodies occur.

SMITH MINE

(NE. 1/4 Sec.18, T.,21 S., R.4 E.)

The Smith property, also known as the Kittie Doland, is situated northeast of Hardscrabble Hill. It is credited with the production of oxidized silver ore worth about 830,000. The deposits are irregular bodies associated with a great mass of silicified limestone. It seems likely that the valuable minerals were silver halides, but none of this material now remains. The workings are irregular inclines and shallow shafts. Evidently oxidation has been complete, for no hypogene sulphides can be seen in the workings. The only gangue minerals are very fine-grained quartz, which replaces limestone, and a small amount of green chlorite. There appears to be no ore in sight.

SILVER JIM MINE

(SW.1/4 Sec.18, T., 21.S., R.4 E.)

This mine was operated during the closing years of last century. The deposit is said to have occupied a fissure vein striking northeast, cutting Magdalena limestones and shales. Argentiferous galena is said to have been the ore mineral. The main workings have caved. A tunnel northeast of the main shaft shows no mineralization.

DEVIL'S CANYON MINE
(SW$^1/_4$ Sec.33, T.23 S., R.4 E.)

The Devil's Canyon mine, at the head of Target Range Canyon, has exposed a body of barite which replaces brucite-serpentine marble. As explained earlier (page 139), the formation of the serpentine and brucite, from forsterite and periclase, is referred to a much earlier period than the introduction of the barite. Thus, while the deposit would be classed as pyrometasomatic if all the minerals were thought to belong to a single continuous wave of mineralization, on the hypothesis that two waves have contributed, the barite body may be classed as an outer-zone deposit.

The mass of barite is about 100 feet long, measured north-south, and 20 feet wide. It has been explored to a depth of about 25 feet by means of an opencut. A small amount of colorless fluorite is associated with the barite. There seems to be a considerable reserve of barite, not only in this body but also in adjacent, as yet unexplored, replacements. The owners are A. and A. H. Beasley of Las Cruces. Shipments of barite were made during 1932, 1933 and 1934.

OTHER PROSPECTS

There are many sporadic occurrences of sulphide minerals in limestone, and many shallow shafts have been sunk to test these out. Only a few deserve mention. The Old Tough Nut prospect, north of the Excelsior mine, opened up a small body of argentiferous galena, from which some ore is said to have been shipped. Some showings of galena and sphalerite have been found between the Hayner and Modoc mines, but these have no proved value.

On the southeast side of Bishop's Cap some prospecting has been done on small replacement deposits containing good quality white fluorite in limestones of Magdalena age. These prospects have been described in detail by Johnston.[9]

The limestone and dolomite beds in the region are very well exposed, and it seems reasonable to conclude that all favorable mineralized outcrops in the region have been tested. No new outcrops of replacement bodies were found during mapping.

[9] Johnston, W. D., Jr., Fluorspar in New Mexico: N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 4, 1928, pp. 85-87.

NORTHERN FRANKLIN MOUNTAINS

GEOLOGY AND GEOGRAPHY

The Franklin Mountains of El Paso County, Texas, extend northwards for 8 miles into Dona Ana County. The northern part of the range is low as compared with the central and southern parts ; it is made up of elongated hills conforming with the north-south trend line of the San Andres-Franklin chain. Roads from Berino run through the hills northeast and east of the village.

The geology of the Franklin Mountains has been described by Richardson,[1] but his report does not cover the northern extension of the range. A brief reconnaisance during the present work showed that the hills represent the dissected remains of a west-dipping fault block, locally having a steep eastern face. The rocks exposed include lower Paleozoic dolomites and Carboniferous limestones. The dolomites appear only on the east side. Typical Silurian corals were found in the upper beds and it is possible that the whole thickness should be referred to the Fusselman formation ; not more than 500 feet of dolomite are exposed. A thin shale overlies the dolomite, and this is succeeded by thin limestones, which may be Mississippian[2] or Pennsylvanian in age. The greater part of the limestones consist of thin alternating beds typical of the Magdalena series. In the western foothills, east of Berino, the Hueco limestone is exposed[3]

MINES AND PROSPECTS

COPIAPO JAROSITE MINE

A remarkable deposit of jarosite occurs in the Magdalena series a short distance north of the northeast road from Berino. It is owned by the F. Schneider Company, El Paso, Texas. The limestones strike N.-S. and dip 30° west. They are cut by a shear zone striking N. 5° W. and dipping 35° to 40° east. The orebody is a replacement deposit 10 to 12 feet thick and having a maximum length of 350 feet in this shear zone. Slickensides indicating horizontal movements occur on the hangingwall of the orebody. The important mineral present is yellow jarosite,' $K_20.3Fe_20_3.4S0_3.6H_20$, which is silky to the touch. A persistent seam of limonite with goethite and gypsum about 2 feet wide runs through the jarosite. A soapy talcose material, white or pink in color, is associated with it. Occasionally there are malachite stains. Some banded aragonite has been found.

[1] Richardson, G. B., El Paso folio: U. S. Geol. Surv. Atlas. No. 166, 1909.

[2] King, P. B.. Notes on Upper Mississippian rocks in Trans-Pecos Texas: Amer. Assoc. Pet. Geol., Vol. 18, 1934, pp. 1537-1543.

[3] Nelson, L. E., Personal communication.

[4]Mr. Schneider informs me that this mineral was identified by Dr. W. F. Foshag of the Smithsonian Institute. I' is almost pure jarosite.

The deposit has been explored to a depth of about 200 feet on the dip by an inclined shaft. At a depth of about 100 feet, drifts run 20 feet to the north, 100 feet to the south. Stopes have been carried almost up to the surface from these drifts. The workings were not examined below the 100-foot level. It is said that at the bottom of the shaft a cave lined with banded green and white aragonite cut by jarosite was found. There has been some stoping below the 100-foot level.

The jarosite has been mined for use in the manufacture of paint.

LEAD-FLUORITE PROSPECTS

On the east side of the hills, about 1 mile northeast of the Copiapo mine, deposits containing fluorite and galena have been discovered in the upper part of the Fusselman dolomite. The dolomite dips to the west and is overlain by a thin shale at the base of the Carboniferous series. A north-south vein dipping 50° east cuts through the dolomite. This contains a few inches of mineral material, galena, limonite and quartz being the chief constituents. In the upper part of the Fusselman dolomite under the shale there are irregular bodies of quartz and fluorite, locally containing galena. The vein may be regarded as the feeder for these deposits. The galena carries about 4 ounces of silver per ton. The developments consist of a short tunnel on the vein, an opencut and five shallow shafts.

Small shipments of galena were made in 1914. The low silver content makes mining of the ore for its metal content uneconomic; and there is too much quartz associated with the fluorite to permit exploitation of the deposits for fluorite.

GYPSUM QUARRY

A bed of banded rock gypsum about 25 feet thick is exposed in a quarry 2 miles east of Berino in the foothills. The country rock is the Hueco limestone. This quarry supplies the El Paso Cement Company with gypsum; it is operated only when there is a demand for the product. The owner is F. Caever, Berino.

POTRILLO MOUNTAINS

GEOLOGY AND GEOGRAPHY

The Potrillo Mountains, in the southwestern part of the county, form a continuous ridge 7 miles long, with an average height above the surrounding plains of 1000 feet. Numerous short canyons have dissected the range. A road from Afton, 14 miles distant, runs through the gap between the northern end of the Potrillos and Mount Riley; from this a branch road runs at the foot of the west slope of the range.

The rocks exposed are gray limestones, stated by Lee[5] to be of Comanche (Lower Cretaceous) age. There is little resemblance between the limestones exposed at the northern end and those of Comanche age near El Paso, and it seems doubtful whether the whole range is made up of Cretaceous rocks. The limestones in question correspond lithologically with the San Andres limestone of the Permian, or the Hueco limestone of the Pennsylvanian. Sufficient time was not available during the present work to make a study of the beds, but the author wishes to call attention to the fact that this range deserves further attention from stratigraphers. The structure is anticlinal, the axis of the anticline lying near the crestline of the ridge.

PROSPECTS

At the northern end a shear zone striking N. 40° E. is exposed a quarter of a mile south of the road, cutting thin gray limestone which dips to the east at 20°. Adjacent to this there are replacement deposits in the limestone, containing white barite, calcite, galena and quartz, with supergene cerussite, pyromorphite and malachite. Six shallow shafts have been sunk, but these have revealed only small irregular mineral bodies. The mineralization is of a feeble character and it seems unlikely that there are workable deposits here. On the east side, 3 miles south of a road, a small amount of malachite with native copper is said to have been found in the limestone ; in a quartzite bed nearby a pocket of rich gold ore is said to have been mined 40 years ago by John Graham. The deposits on the east side were not visited, but the details here given are based on information from two independent sources. On the west side, a barite vein has been prospected on a detached hill 3 miles south of the pass between the Potrillos and Mount Riley. The limestones nearby are gypsiferous. A marble quarry has been operated at the southern end of the range.

DONA ANA MOUNTAINS

GEOLOGY AND GEOGRAPHY

The Dona Ana Mountains, north of Las Cruces and east of the Rio Grande, comprise a group of jagged remnants of a mountain mass which has been deeply dissected. They cover a roughly elliptical area, 7 miles by 4 miles. On the river side, many small canyons have cut into the range ; on the east and north the present canyons are few in number and wide. A broad canyon which divides the range into a northern and a southern part, is followed by a road running from the southern boundary gate of the Jor-

[5]Lee, W. T., quoted by Darton, N. H., "Red beds" and associated formations in New Mexico: U. S. Geol. Surv. Bull. 794, 1928, H. 39.

nada Reserve to Dona Ana. There is only one settlement within the mountains, a goat ranch on this road, 4 miles from the Jornada Reserve gate.

The mountains have been carved out of Tetriary igneous rocks. Both lavas and intrusive rocks are present, the lavas, described on pages 169-170, including rhyolites, rhyolite-tuffs, latites, and andesites, the intrusives being syenite porphyries. The total exposed thickness of the lavas is not less than 2000 feet. The syenite porphyry masses have the form of broad dikes and sills ; they appear to be discordant and concordant intrusions into a structural basin of lavas. A few dikes of rhyolitic composition occur.

PROSPECTS

GONZALES PROSPECT

Approximately one mile north-northwest of the Goat Ranch a vein deposit has been explored at the Gonzales prospect. The vein consists of interlacing narrow quartz stringers in a rhyolite dike 4 feet wide which strikes N. 80° W. and dips 85° north. The dike cuts purple andesite, which is altered to a greenish rock containing much chlorite and a little pyrite up to 2 feet from the dike. The dike was evidently subjected to stresses after it consolidated, forming fissures and locally brecciating the rhyolite. The mineral filling of the fissures consists of slender quartz crystals, forming combs in open cavities, and small amounts of pyrite. A small amount of very rich gold-silver ore was found in this vein. Two assays of this material, made in 1913, gave gold, 13.50 ounces, silver, 1835.30 ounces; and gold, 13.60 ounces, silver, 1526.05 ounces. Mr. Bentley informs me that a strong tellurium test was obtained. The minerals may have been hessite and petzite. This material is no longer obtainable. Near the outcrop the stringers contain limonite with the quartz; the oxidized material is said to contain some silver. The vein seems to be an example of the epithermal type of deposit, but a very feeble example.

The developments consists of a shaft 80 feet deep at the east end of the property. There is a shallow opencut 70 feet long west of the shaft, then a 25-foot hole. Twenty-five feet farther west there is another shaft 50 feet deep. The workings are on the east side of a low ridge; the course of the dike can be followed over the crest of the ridge.

A small amount of high-grade ore has been shipped. A considerable quantity of quartz with pyrite or limonite has been taken out and piled on the dumps, but this has evidently proved of too low grade for shipment. Further prospecting might reveal another shoot of high-grade ore, for the developments up to the present are slight as compared with the length of the dike in which the vein fissures occur.

OTHER PROSPECTS

South of the road through the mountains, 2 miles from the Jornada Reserve gate, a fissure striking N. 25° E. and dipping southeast cuts through epidotized andesite. Two shafts, one about 50 feet deep and the other about 25 feet deep, have been sunk on the fissure, and have revealed a small amount of malachite in it.

The contact between intrusive and extrusive rocks has been prospected at the head of the canyon which runs south from the road to the highest peak of the range, on which there is at present a geodetic survey monument. Veins of calcite and aragonite without metallic minerals have been found. Several pits have been dug on black obsidian flows in the southwestern part of the mountains, presumably under the impression that these were coal beds. The obsidian is quite worthless.

ROBLEDO-PICACHO MOUNTAINS

GEOLOGY AND GEOGRAPHY

Picacho is a prominent conical peak rising from the edge of the Mesilla Valley, 5 miles west of Las Cruces. Low ridges connect this peak with the mass of Robledo Mountain 7 miles to the north, and the whole mass is a structural unit which will here be called the Robledo-Picacho Mountains. The twin peaks of Robledo reach an altitude of 6000 feet, more than 2000 feet alcove the level of the Rio Grande, which runs along the east foot of the range. On the west side the mountains overlook the high Powell plain.

Structurally this unit is a fault block, bounded on the east by a post-Santa Fe fault trending N. 30° W. Near the northern end an E.-W. fault brings Carboniferous limestones on the north side against lower Paleozoic sedimentary rocks on the south side. Internally, the block appears to be a gentle syncline, plunging to the south. South of the northern fault, dolomitic limestones of lower Paleozoic age outcrop. These are overlain by a great thickness of limestones probably belonging to the Magdalena series, which makes up the main part of Robledo Mountain. Between Robledo and Picacho, "red beds" corresponding to the Abo sandstone series appear above the Magdalena limestones, passing upwards into the San Andres limestone. Immediately north of Picacho, the limestone is overlain by Tertiary rhyolite flows, which make up the conical peak of that mountain. Two plugs of basalt cut through the Permian rocks north of Picacho.

IRON HILL DISTRICT

LOCATION

The Iron Hill prospects are situated in the low hills on the west side of Robledo Mountain, 3 miles southwest of the western summit. The district is not accessible by road, and is most readily reached on horseback from the Powell ranch, 7 miles distant.

ORE DEPOSITS AND PROSPECTS

The deposits are bodies of hematite, replacing thin limestones of the Magdalena series, which dip southeast at 20°. The orebodies are lenticular, and appear to be related to fissure-zones which cut across the bedding of the limestone in various directions. Sixteen bodies of hematite have been opened up, and there are many other outcrops which have not been explored. The dimensions of the bodies vary greatly, from small lenses to masses 200 feet long, 120 feet wide and of unknown vertical extent. The minerals present are hematite, in coarse dark red botryoidal masses made up of radiating fibers, and subsidiary quartz and gypsum. They have evidently come into their present position by replacement of the limestone, for some unreplaced chert beds have been seen passing uninterrupted through the deposits, and in places the bedding of the limestone is preserved.

The origin of these deposits is not easily explained. They do not appear to represent the oxidized outcrops of sulphide deposits, for a careful search failed to reveal any trace of pyrite or any pseudomorphs suggesting its former presence. They contain none of the minerals characteristic of the ordinary metal deposits of the region. On the other hand, their crosscutting character indicates clearly that they are not sedimentary deposits. Either they were introduced from below by solutions ultimately deriving their iron from a magmatic source, or they were formed by cold waters descending from above. The only comparable deposits with which the writer is acquainted are the hematite deposits of West Cumberland, and the Forest of Dean, England.[1] These deposits are mineralogically similar, and have another feature in common with the Iron Hill deposits, namely that they occur in Carboniferous limestones which were formerly overlain by a great thickness of "red beds." One school of thought attributes the iron to leaching of hematite cement from the "red beds," and precipitation in underlying limestones.

Fourteen short tunnels have been driven, and in some a small amount of stoping has been done, the ore being piled on the dump. There are many shallow shafts. The work done has been

[1]Smith, Bernard, Haematites of West Cumberland, Lancashire and the Lake District, 2nd ed., Special Repts. Min. Res. Gt. Britain, vol viii, 1924.
Sibley, T. F., and Lloyd, W., Haematites of the Forest of Dean and South Wales, 2nd ed., Special Repts. Min. Res. Gt. Britain, vol. x, 1927.

sufficient to prove that moderate resources of iron ore of good grade are available. However, the remote situation of the district, and the great distance from the county to the nearest market for iron ores, at present prevent the exploitation of the deposits. They may be regarded as a possible source of iron in the distant future. The present owner is not known.

PICACHO DISTRICT

It is said that gold strikes have been made in Picacho, but authentic information about the exact location of the deposits could not be obtained. Mineral earth, from weathered lavas, was being obtained from shallow opencuts when the district was visited. An aragonite vein in the lavas north of the peak has been explored by a short tunnel. No other evidences of mineralization were found.

SIERRA CABALLOS

GEOLOGY AND GEOGRAPHY

The Sierra Caballos is an east-dipping fault block, with a steep scarp slope along the west side. Only the extreme southern end comes into Dona Ana County. The geology of the range, and the mineral deposits found in it in Sierra County have recently been described by Harley.[2] At the southern end, Tertiary rhyolite-tuffs, rhyolite flows and interbedded sandstones transgress across sedimentary rocks ranging in age from Cambrian to Cretaceous. Part of the eastward tilt of the range was probably accomplished before the extrusion of the lavas, but most of it took place after the lavas were in place, as indicated by the east dip of the flows.

The southern part of the range is accessible from Rincon, and by desert road from Garfield.

RINCON DISTRICT

The manganese deposits of the Rincon district, at the extreme southern end of the range, have been described in some detail by Wells,[3] from whose account the following information is taken.

The country rock consists of red sandstones and water-laid tuffs, probably of Tertiary age, striking E.N.E. and dipping to the south at the Morgan property, $1^1/_4$ miles northwest of Rincon, but changing farther north to strike N.-S. and dip east. On the Morgan group, a prominent ore-bearing fissure strikes N. 60° W. and dips 80° southwest, intersecting several other well-defined

[2] Harley, G. T., Geology and ore deposits of Sierra County, N. Mex.: N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 10, 1934, pp. 197-214.

[3] Wells, E. H., Manganese in New Mexico : N. Mex. Sch. Mines, Min. Res. Survey, Bull. 2, 1918, pp. 35-39.

fissures whose strikes vary from N. 10° W. to N. 40° W. In part, the ore bodies are pockets related to the intersection of fissures. Psilomelane is the most abundant mineral present, and more or less barite is associated. In depth, the psilomelane gives place to wad and manganiferous calcite. The mine workings consist of opencuts, tunnels, stopes and shafts distributed along the main vein for 600 feet. Very little ore has been mined at a depth of more than 30 feet.

The Rincon mine, three-quarters of a mile north of the town, has opened up several manganese-bearing fissures in a prominent breccia zone. A tunnel 85 feet long follows the most prominent of these, which contains shoots of high-grade ore 6 inches to 2 feet wide, separated by stretches of barren ground.

Placer ore, derived by weathering from the veins, has been worked on the Morgan group and on the Cook placer claims, three-quarters of a mile south of the Morgan property. The ore occurs in gravels of presumed Santa Fe age, and consists of fragmental psilomelane.

The district was active during 1918 when there was a demand for manganese ores, 471 tons being shipped from the Morgan group prior to July 1st of that year by R. E. Callow. The average grade of the ore was as follows : manganese, 38 per cent ; iron, 3.5 per cent ; silica, 5.5 per cent ; phosphorous pentoxide, .025 per cent. There has been no activity in the district since the post-war drop in the price of manganese took place.

WOOLFER CANYON DISTRICT

The fluorite deposits which occur in Woolfer Canyon, 7 miles east of Garfield, have been described in detail by Johnston,[4] from whose account the the following brief abstract is taken.

The Woolfer Canyon group of claims, owned by the New Mexico Fluorspar Corporation, lies in the neighborhood of a northwest-striking fault plane on the east side of a down-faulted block composed of Magdalena limestone and Abo sandstone between two uplifted blocks of Magdalena limestone. The country rock is cut by numerous fracture zones perpendicular to the main fault plane. These fracture zones are more pronounced in a prominent chert bed in the Magdalena series than in the limestones, but in both they have served as sites for the deposition of fluorite and the minerals associated with it, which include quartz, calcite and barite. Five replacement deposits related to fracture zones have been explored. The amount of quartz in the deposits may prove a serious handicap, but it is stated that this can be removed by cobbing.

[4] Johnston, W. D., Jr., Fluorspar in New Mexico : N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 4, 1928, pp. 61-64.

SAN ANDRES MOUNTAINS

GEOLOGY AND GEOGRAPHY

The San Andres Mountains extend from San Agustin Pass northwards for 60 miles. Their direction then changes to northnortheast, and they continue for another 15 miles to Mockingbird Gap. The southern half of the range is in Dona Ana County. The extreme southern end of the range has already been described as part of the Organ mining district (see page 26). The present section is concerned only with that part of the range lying between the Organ district and the county boundary, which crosses between Hembrillo and Goodfortune Canyons.

Between Little San Nicholas Canyon and the county boundary, the range is a west-dipping monocline. Along the east side the pre-Cambrian basement complex, consisting of schists, gniesses and granites, is exposed. Overlying the basement complex there is a series of sediments ranging in age from Cambrian at the base to Cretaceous at the top of the succession.[5] In this part of the mountains, the east side presents a steep scarp slope, surmounted by the Lake Valley limestone (Mississippian) or the Magdalena series (Pennsylvanian). The west side is a gentle dip slope, cut on Magdalena beds. Permian and Cretaceous rocks appear in the foothills west of the dip slope.

South of Little San Nicholas Canyon, the range is anticlinal. The beds dip to the east on the east side, to the west on the west side. The dip on the west side may be regarded as the southward continuation of the monocline ; the east side is structurally more complex. Large high-angle normal faults cut through the beds, and there are also some low-angle faults.

The first folding of the range into an anticline probably took place in early Tertiary time. Local compressive stresses produced a sharp fold which runs along the west slope of the range from Little Well to San Andrecito Canyon. This fold is essentially a steep monocline faced west and locally overturned. A reverse fault accompanies it south of Ropes Spring. Normal faulting occurred later in Tertiary time, and the final uplift of the range relative to the Tularosa basin to the east is believed to have taken place in post-Santa Fe time, at the beginning of the Quaternary period.

It is probable that the first streams developed on the newly uplifted block flowed east down the scarp slope and west down the dip slope. Later, north and south trending streams developed parallel to the beds on the dip slope. Owing to the steepness of the east slope, the streams there were able to work more rapidly than those on the west side. Some of them cut right through the range, capturing north and south streams on the west side.

[5]Darton, N. H., op. cit., 1928, pp. 183-193.

The great canyons which cut through the crest of the mountains include, from south to north, Bear, Lion Den, San Andres, San Andrecito, Deadman, Lostman and Hembrillo Canyons in Dona Ana County. Each of these, except Bear Canyon, though running westward through the crest of the range, heads in canyons trending north or south.

ORE DEPOSITS

Two structural types of mineral deposits have been found in the San Andres Mountains. In the San Andrecito-Hembrillo district, copper-bearing fissure veins occur. They are productive in the Bliss standstone and the El Paso limestone. They extend downwards into the pre-Cambrian granite, but do not contain workable ore bodies in the granite. They resemble closely the deposits farther north in the same range, described by Lasky,[6] who considers them to be related to the post-Carboniferous igneous activity which produced the Salinas Peak sill. No igneous rocks later than pre-Cambrian in age have been found in the San Andrecito-Hembrillo district.

Replacement deposits in limestone, containing galena, barite and locally fluorite occur in the Black Mountain, Bear Canyon and San Andres Canyon districts. Many of these are at the top of the Fusselman dolomite, underneath the Percha shale ; others are related to normal faults, as at the Bear Canyon "lower contact."

The mineralization is of a decidedly feeble type. The galena-barite deposits are more likely to be valuable for their barite content than for their lead content. The silver content of the galena is very low, seldom exceeding 4 ounces per ton. The copper deposits, while containing high-grade ore where secondary enrichment has taken place, are too small to be of much economic value, especially when the high cost of transport, due to the inaccessibility of the district, is considered.

SAN ANDRECITO-HEMBRILLO DISTRICT

LOCATION

The San Andrecito-Hembrillo district includes San Andrecito, Deadman, Lostman and Hembrillo Canyons and the east slope of the mountains between these canyons. None of the canyons are at present accessible by road beyond their mouths. The road which runs along the foot of the east face of the mountains from the Lucero Ranch to the Ritch Ranch is in fair condition, but the only branch road leading into the district which is at present passable is the one to the mouth of Deadman Canyon.

[6] Lasky, S. G., Ore deposits of Socorro County, N. Mex.: N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 8, 1932, pp. 74-86.

On foot or on horseback, the southern part of the district is more easily reached from the west side. A passable road leads across the Jornada Reserve to New Well. From here the distances are, to the Green Crawford mine in San Andrecito Canyon, 4 miles ; to the Kendrick prospect, 6 miles ; to the head of Deadman Canyon, 7 miles.

HISTORY AND PRODUCTION

No accurate data on the production of this district are available. The Green Crawford mine and the prospects in Hembrillo Canyon were developed during the closing years of last century and there may have been a small output of copper ore at that time. Some ore was shipped from the Green Crawford mine between 1920 and 1930. It is unlikely that the total production from the district exceeds $10,000.

GREEN CRAWFORD MINE

(SW1/4 Sec.31, T.17 S., R.4 E.)

The Green Crawford mine is in San Andrecito Canyon, approximately one-half mile west of the eastern boundary of the Jornada Reserve. The main workings lie on the north side of the canyon at an approximate elevation of 5200 feet. The deposit occurs in a vertical fissure vein striking N. 35° E. The vein cuts the Bliss sandstone and the El Paso limestone, which strike N.-S. and dip west at 20°. The vein does not exceed 3 inches in width in the Bliss series, but in the overlying limestone it reaches a maximum width of 15 inches. The primary minerals seem to have been chalcopyrite, quartz and calcite, possibly with some pyrite. Supergene enrichment has led to the production of covellite and chalcocite as replacements of the chalcopyrite. The replacement process at this stage was incomplete, and residual masses of chalcopyrite are abundant. Later oxidation produced hematite, cuprite and malachite. As seen in hand specimen, the ore consists of a matrix of red hematite and cuprite, containing small irregular sulphide masses. A polished section shows that a rude concentric arrangement exists around the chalcopyrite remnants, the succession of minerals outward from the chalcopyrite being as follows: (1) covellite, (2) chalcocite, (3) hematite, (4) cuprite. The succession is that normally found in oxidized secondarily-enriched copper ores. An assay of typical ore from this mine, by L. B. Bentley, gave the following results: gold, 0; silver, trace ; copper, 27.93 per cent.

The workings on the north side of the canyon include a tunnel 140 feet long on the vein in the Bliss sandstone. The vein is unproductive throughout the length of the tunnel. A raise at the northeastern end of the tunnel communicates with workings in the limestone; these are not at present accessible. One hundred and eighty feet northeast of the portal of the tunnel there is an open stope on the vein, 40 feet long, and approximately 40 feet deep. The vein is 1 foot wide in the northeast face of this stope, but pinches rapidly to 3 inches and apparently dies out 90 feet beyond the face. On the south side of the canyon, a tunnel 90 feet long has been driven on the vein, which is about 6 inches wide near the portal, but which pinched to the southwest. These workings are in the Bliss sandstone.

There may be a small reserve of high-grade copper ore at this mine in the limestone, but the high cost of transport would prevent even small-scale operations from being profitable at the prevailing low price of copper.

KENDRICK PROSPECT

Captain Kendrick of Las Cruces informs me that he has discovered a vein similar in character to the Green Crawford vein on the east face of the mountains between San Andrecito and Deadman Canyons. Cuprite is said to be the principal mineral present. This prospect was not visited during the present investigation, and no appraisal of its possibilities can be made.

LOSTMAN AND HEMBRILLO CANYONS

Veins of a similar type have been discovered in Lostman and Hembrillo Canyons. Mr. Bentley examined one such vein in Lostman Canyon, in 1910, on the Jeff Ake claim. He informs me that the vein trends north-south, and contains chalcopyrite, cuprite and hematite in the Bliss sandstone, while in the underlying granite, only quartz and a small amount of chalcopyrite are present. Two assays of ore from the sandstones gave respectively 11.82 and 38.17 per cent copper.

Hembrillo Canyon proved to be too difficult of access to be reached during the present work. Little is known of the deposits there. Lasky[1] makes the following statement: "Chalcocite is the principal ore mineral. The deposits are probably similar to those of the Goodfortune Creek district, Socorro County. Only a small amount of development work has been done."

SAN ANDRES CANYON DISTRICT

LOCATION

San Andres Canyon is in the central part of the range, 4 1/2 miles north of San Andres Peak. Formerly roads ran into the canyon both from the Goldenburg Ranch on the west and also from the east side of the mountains, but these roads are no longer passable. The road from the east could be cleared without a great amount of labor. On foot the canyon is best reached from

[1]Lasky, S. G., and Wootton, T. P., The metal resources of New Mexico and their eco. nomic features : N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 7, 1933, p. 44.

Ropes Spring on the Jornada Reserve, which is connected with the Reserve Headquarters by a good road. The distance from Ropes Spring to the San Andres lead mine is 4 miles.

HISTORY AND PRODUCTION

The San Andres lead mine was opened up about 1900. There may have been a small production of galena concentrates, but no data on the amount shipped were obtained.

SAN ANDRES LEAD MINE

(SW. 1/4 Sec.18, T.18 S., R.4 E.)

The present owner of the San Andres lead mine is W. J. Stevens of Las Cruces. The mine is situated on the north side of San Andres Canyon at an elevation of 5100 to 5200 feet, about a quarter of a mile west of the eastern boundary of the Jornada Reserve. The deposit is an irregular replacement in the Fusselman dolomite, adjacent to a prominent normal fault which strikes N. 15° W. and dips steeply to the west. As shown on the sketch map on page 256, the fault brings the Fusselman and Montoya dolomites on the east against the Lake Valley limestone on the west in the vicinity of the mine. The beds dip to the west at 30°. The deposit is a mixture, in order of decreasing abundance, of barite, quartz and galena. The galena is said to be almost non-argentiferous. The length of the deposit is about 200 feet, the maximum width 20 feet. It has been exploited by means of an opencut at 5200 feet elevation, which exposes a thickness of approximately 15 feet of barite and quartz with a small amount of galena. Large unreplaced residual masses of the country rock occur in the opencut. A shaft has been sunk in the center of the opencut, but this is no longer accessible. At 5100 feet, a tunnel has been driven on the fault; this reaches the bottom of the shaft from the opencut about 400 feet from the portal. Throughout the whole length of the tunnel, the fault is barren of mineralization; all that can be seen is a clay gouge varying from a few inches to 2 feet in width. Twenty feet south of the foot of the shaft a winze has been sunk to an unknown distance on the fault. A cross-cut to the east from the shaft foot has followed a minor fracture; this is also barren. The mine is equipped with a mill containing a crusher, screens, three sets of rolls, and 15 jigs. Power was supplied by a steam installation, and water was obtained from a well 60 feet deep near the mill. The capacity of the mill is said to be 100 tons per day. Near the mill there is a 100-ton smelter, which has never been fired. The small tailings dump near the mill indicates that it can have been run for only a short time.

This mine is an example of the bad practice of equipping a property with expensive machinery before adequate ore reserves

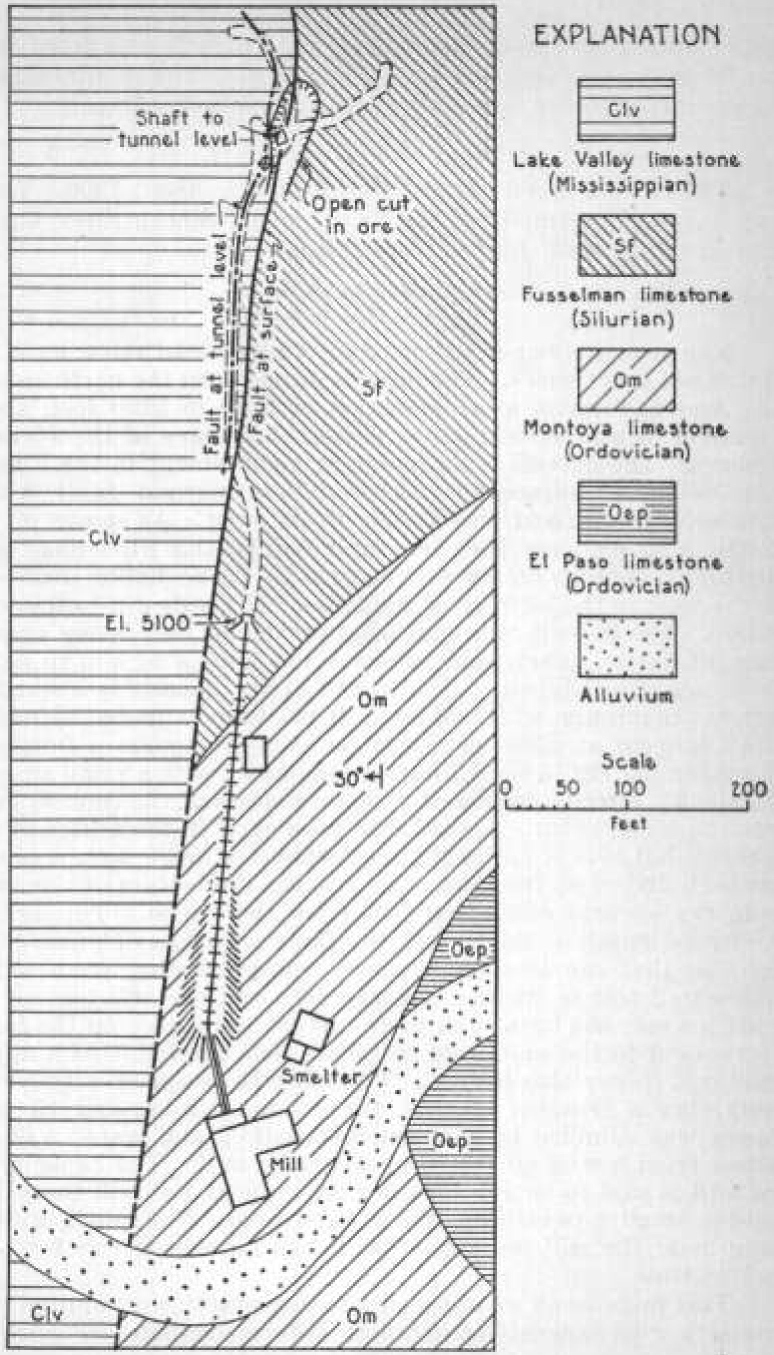


FIGURE 19.—Geologic sketch map of the San Andres lead mine.

have been proved. The expenditure on the mill and smelter was quite unjustified. The galena content of the deposit does not ex- ceed 3 per cent, and the deposit itself has evidently proved to be much less extensive than was expected. There is too much quartz in the orebody to make it worth consideration as a possible source of barite, and in the writer's opinion there is little hope of the property ever being of economic value.

The property was developed between 1900 and 1904. The original owners, who explored and equipped the mine, then sold out to Mr. Stevens, the present owner. No work has been done since 1904.

OTHER PROSPECTS

A group of four claims covers the contact between the Percha shale and the Fusselman dolomite northeast of the mine. There are a number of prospect pits, some of which have exposed feebly mineralized ground. None of these offer any inducement for further work.

BEAR CANYON DISTRICT

LOCATION

The Bear Canyon mining district extends from Bear Canyon in the south two miles north to Lee Gulch. There are two groups of mines and prospects, one in the foothills of the eastern lobe of the mountains, the other near the crest-line of the range. The lower group is accessible by a desert road 2 miles long connecting with the main Las Cruces-Alamogordo Highway at a point 37 miles from Las Cruces, 33 miles from Alamogordo. The upper group is inaccessible by road ; it can be reached on foot by steep trails running up Lee Gulch, and up the northern side of Bear Canyon.

HISTORY AND PRODUCTION

Most of the deposits in this district were developed by J. Bennett during the closing years of the last century and in the early years of the present century. In 1906 W. J. Stevens and J. G. Stewart of Las Cruces acquired the whole district, containing 26 unpatented claims, from Bennett. Litigation between Bennett and Stevens followed, but assessment work on the claims was kept up. The title has recently been perfected, the present owners being Stevens and Stewart. There has been a small production of galena concentrates, and two leasers have shipped barite from the lower workings.

GEOLOGY

In the foothills of the range the Bliss sandstone and El Paso limestone overlie schist and granite of pre-Cambrian age, and dip to the east at approximately 55°. The sediments are sepcrated from the granite by a low-angle fault, which is variable in attitude, but which in many places dips at 35° to the west. The presence of the fault is indicated by brecciation between the granite and the sediments, and by the cutting out of the lower part of the sedimentary series by the fault. The outcrop of the fault, owing to its low angle, pursues a highly irregular course across the low hills, as the map on page 259 shows. In spite of the fact that the older rocks are on the footwall side of the fault, it suggests strongly a thrust fault.

West of the foothills, pre-Cambrian rocks are exposed in the lower part of the main slope of the mountains. These are overlain by the normal sedimentary series, consisting of the Bliss sandstone, the El Paso formation, and the Montoya and Fusselman dolomites. To the head of Lee Gulch in Sec. 19, T. 20 S., R. 5 E., the beds dip to the east. They are traversed by a number of normal faults of moderate displacement (see Fig. 21, page 261). The summit plateau of the range is underlain by flat-lying Fusselman dolomite, on which small outliers of Percha shale rest. Farther west, a normal fault brings in limestones of Carboniferous age.

The ore deposits may be classified into two groups, the first including replacement deposits in the El Paso limestone in the foothills, related to the low-angle fault ; the second includes irregular replacement deposits in the Fusselman limestone near the summit of the range. The first group are known locally as the "lower-contact" deposits, the second as the "upper-contact" deposits. The mines and prospects will be described under these headings.

DEPOSITS AT THE "LOWER CONTACT"

(Secs.28,33, T.20 S., R.5 E.)

The outcrop of the low-angle fault in the eastern foothills is covered by six claims. Most of the exploration has been done on the three southern claims ; these were therefore mapped in detail (Fig. 20, page 259) . The general strike of the fault is north-south, but its outcrop is extremely irregular. The beds above the plane of the fault appear to belong to the El Paso formation ; they exhibit the characteristic "seaweed streaks," even though they have been recrystallized. Below the thrust plane, granite and mica-schist predominate, but the Bliss sandstone and the lower beds of the El Paso formation are also present locally. The mineral deposits occur as replacements of limestone fragments in the fault breccia, and as replacement of beds in the limestone series both above and below the plane of the fault. The mineralization is highly irregular.

The minerals present include barite, galena, green and colorless fluorite, and a little quartz, of hypogene origin. Supergene

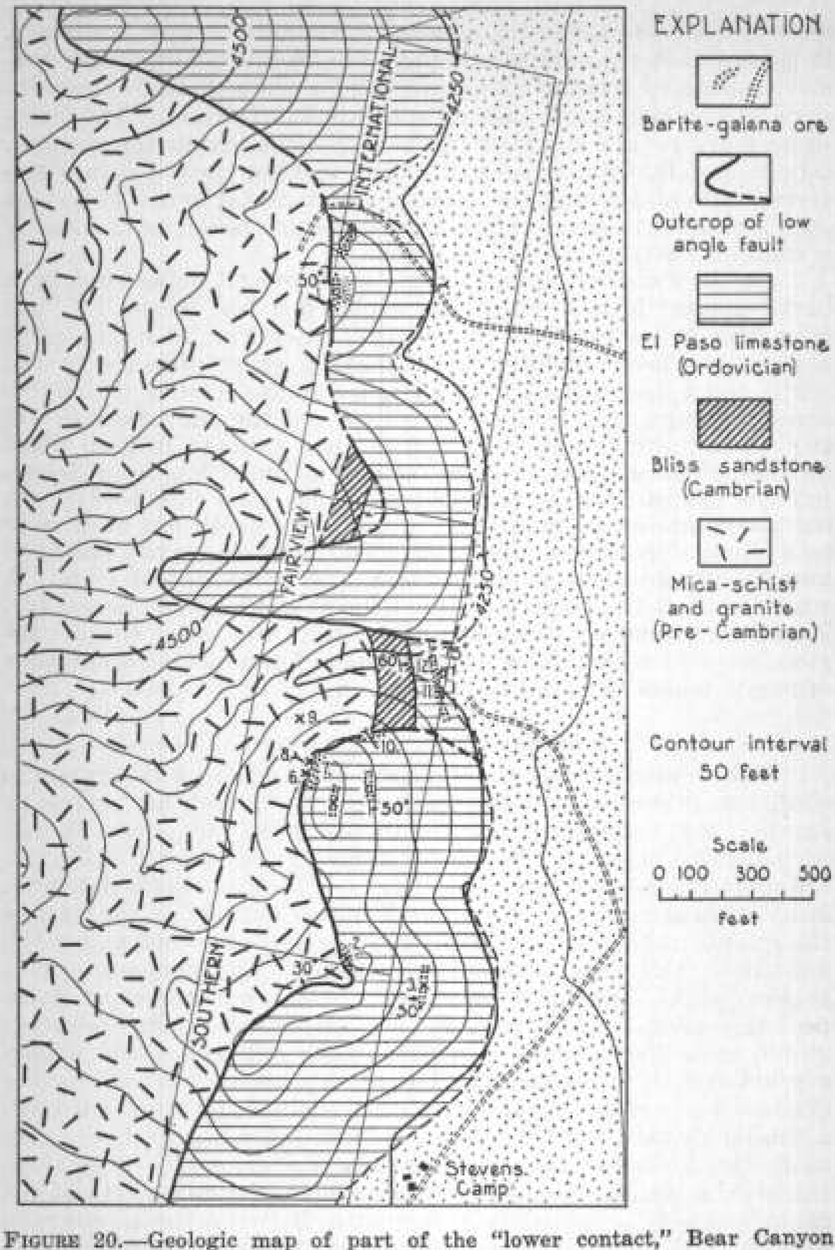


FIGURE 20.—Geologic map of part of the "lower contact," Bear Canyon district.

The numbered mines and prospects are described in the text.

minerals include cerussite, anglesite, vanadinite and wulfenite. It is said that vanadinite crystals of museum quality were formerly obtained from workings on the Fairview claim. The minerals are usually arranged in a consistent fashion. The limestone margins are silicified for 1 to 2 inches from the deposit. Galena and fluorite, if present, occur together next to the limestone walls and inclusions ; barite, which is far more abundant than any other mineral, makes up the rest of the deposit. Locally it contains coarsely crystalline galena.

On the Fairview claim, a shaft is at present being sunk on a barite-galena deposit which has replaced a bed in the El Paso formation below the fault plane (12). (See Fig. 20.) The same deposit has been explored by a shaft a short distance to the south, and a short tunnel (11) . Higher up the gulch in which this deposit occurs, two inclines have explored the fault breccia (6, 10) ; vanadinite crystals occur in cavities exposed in both these inclines. Beneath the western incline, a tunnel has been driven into the granite, but no mineralization has been found (8). On the International claim, a shaft of unknown depth has been sunk on a barite deposit near the fault. To the north, barite has been mined from an opencut 40 feet long and 10 to 15 feet wide. A winze sunk at the bottom of this deposit is no longer accessible. There are numerous other prospect pits in the lower contact region, most of which show some barite. There are also outcrops of barite which have not been explored.

DEPOSITS AT THE "UPPER CONTACT"

The mineralogy of the deposits on the top of the range is similar to that already described for the "lower contact" deposits, except that vanadinite and wulfenite have not been found. Structurally, however, the associations are somewhat different. The deposits replace the upper part of the Fusselman dolomite. Most of them have been found underneath outliers of the Percha shale, and in the cases where the shale is not found above the deposit, it has been removed by erosion. The deposits are in general highly irregular in shape. In the northernmost prospect (see, map, Fig. 21, page 261) one such deposit has been explored by a short tunnel. Barite, colorless fluorite, and galena are present ; it is estitmated that the galena content of the deposit is 5 per cent. To the southeast about a quarter of a mile, a similar deposit has been exposed in an opencut. In both these cases the shale can be seen overlying the dolomite. The shale can also be seen in two prospects a quarter of a mile north of the cabin formerly occupied by J. Bennett. Between these prospects and the edge of the plateau above Bear Canyon, there are outcrops of barite.

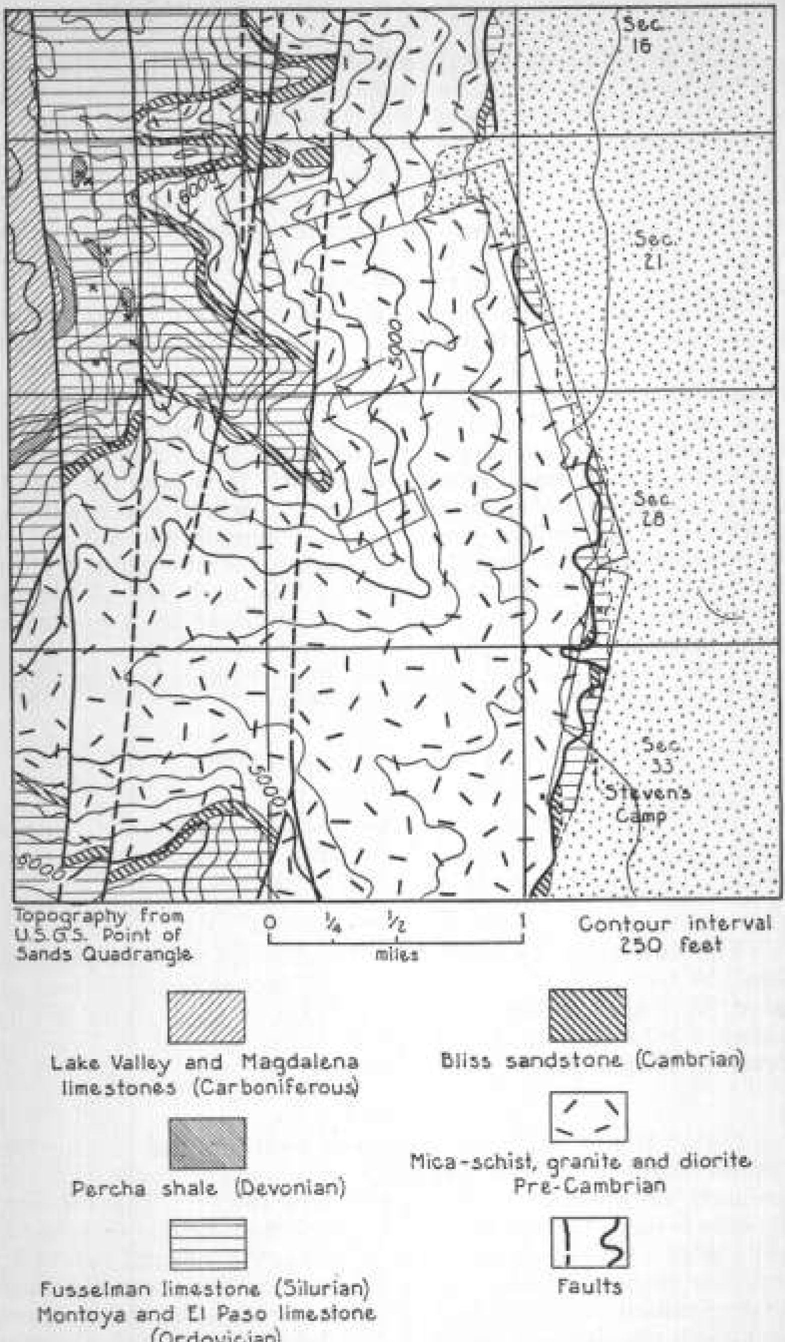


FIGURE 21.—Reconnaissance geologic map of the Bear Canyon district. In part based on a map by N. H. Darton, U. S. Geol. Surv. Bull. 794, 1928.

It is said that an attempt was made to smelt the galena from these deposits in an adobe furnace on the upper part of the range. It is not known whether any lead was produced, but the amount of work done in the prospects does not indicate that much ore was taken out. While many holes have been dug, few shafts have been carried beyond 25 feet depth, and only one tunnel, that on the northernmost deposit, has been extended more than 40 feet.

POSSIBILITIES

In summary, these deposits consist of highly irregular limestone replacements, with barite as the chief mineral, and galena in amounts not exceeding 5 per cent of the amount of barite. As the galena is not argentiferous, it is obvious that the deposits could not be worked for their metal content. However, a large reserve of barite has been proved, and much more could be opened up with a small amount of work. It is possible that the barite from the "lower contact" deposits, which are readily accessible by road, might prove to be of commercial value. For use in paint manufacture, it would have to be milled, but a simple plant with a coarse grinder, screens, rolls and jigs should give a good separation. Galena would be obtained as a by-product in the process.

The "upper contact" deposits, being relatively inaccessible, offer little hope of profitable exploitation.

BLACK MOUNTAIN DISTRICT

LOCATION

The Black Mountain district covers the mountains lying between Bear Canyon and the Gold Camp pediment, in the Organ district. It is accessible by road from the Sunol mine.

HISTORY AND PRODUCTION

The first mine discovered in this district was the Mountain Chief, located in 1883 by Pat Breen. This has been the sole producer; it is said to have yielded $12,000 in gold. The Bighorn tunnel, 1 mile east of the Mountain Chief, is said to have been driven in the early part of the century.

GEOLOGY

Black Mountain is the southern continuation of the Bear Canyon district. Lower Paleozoic sedimentary rocks rest on a basement of pre-Cambrian granite and schist. The mountain presents a steep face to the south, which may be due to east-west faulting of post-Santa Fe age. North-south normal faults traverse the region. Along the southern face the contact between the Fusselman dolomite and the Percha shale is well exposed; the known ore deposits occur in the dolomite below this contact.

MOUNTAIN CHIEF MINE

(NW. 1/4 Sec.11, T.21 S., R.4 E.)

The Mountain Chief mine, owned by W. E. Moore, Organ, New Mexico, is on the south side of Black Mountain. The deposit is an irregular replacement body in the upper beds of the Fusselman dolomite, which here dips to the north at 40°. The Percha shale appears on the north side of the deposit. Apparently the high-grade ore was entirely removed by the original owner. It occurred within a few feet of the surface, and is said to have been a mixture of limonite and coarse calcite with free, gold. Later owners sunk a 60-foot shaft into the dolomite beneath the ore body, cutting two other limonite bodies, neither of which carried gold values. Plates of green chlorite are associated with the limonite, which occurs in the bottom of the shaft. In a pit southeast of the shaft, quartz, and pyrite in cubes up to 2 inches on the side have been found. These are also non-auriferous.

The contact between the shale and the dolomite might be worth further exploration here; an incline could be sunk on this contact near the site of the orebody. There is no proved ore in the mine as it stands at present.

BIGHORN PROSPECT

(Sec.12, T.21 S., R.4 E.)

One mile northwest of the Sunol mine a tunnel 500 feet long, owned by J. Buergo and J. F. Shipe, Las Cruces, has been driven into the lower Paleozoic dolomite, with a general direction N. 50° W. The object of the tunnel is said to have been to cut a galena deposit exposed higher up on the mountain. Unaltered dolomite,. with a few joint walls and natural caves is all that can be seen in the tunnel.

OTHER PROSPECTS

Northeast of the Bighorn tunnel the Fusselman-Percha contact is well exposed. Locally, barite replacement deposits of small size occur near the contact. A barite-galena deposit is said to occur near the summit of Black Mountain. Mr. Schneider informs me that there are several small barite bodies at the dolomite-shale contact northwest of the Mountain Chief mine. A shaft 80 feet deep has been sunk on some showings of galena in the dolomite 300 feet south of the Mountain Chief mine. None of these prospects is of economic interest.

TONUCO MOUNTAIN

GEOLOGY AND GEOGRAPHY

Tonuco Mountain is on the east side of the Rio Grande, 7 miles southeast of Rincon. Towards the river it presents a steep face, probably a re-excavated fault scarp, 800 feet high. The geology has been described by Johnston,[1] from whose account the details which follow are taken. The mountain is composed of a series of Tertiary volcanic and elastic rocks about 800 feet thick, including agglomerates, mudflows and interbedded water-laid sandstones and conglomerates. This series rests directly upon pre-Cambrian mica-schist and granite. A sinuous fault which traverses the mountain from north to south brings Tertiary rocks and red beds of the Abo formation on the west against pre-Cambrian rocks on the east.

FLUORITE DEPOSITS

At the Tonuco mine a vein striking N. 70° W. and dipping 70° SE. cuts through the pre-Cambrian rocks. In the upper tunnel on the west side of the mountain the vein attains a width of 10 to 25 feet with granite on the hangingwall and schist on the footwall. Capping the pre-Cambrian rocks and truncating the vein is a bed of agglomerate which contains, in addition to fragments of granite, schist, latite and andesite, some pieces of fluorite and barite from the vein. The vein-filling consists of a mixture of fluorite and barite, in which quartz is locally abundant and some calcite occurs.

Between 1919 and 1921, 2500 tons of metallurgical lump were shipped from this vein; a few carloads have been produced since 1921. A mill, designed to separate the silica from the fluorite, proved unsuccessful, and the equipment of the mine has been dismantled.

On the eastern side of the mountain a series of narrow veins in the granite strike N. 20° to 30° W. In general, these are 2 to 4 feet wide, and contain a mixture of barite and fluorite. About 150 tons of spar have been shipped from these veins by Roy Beal.

A considerable reserve of fluorite remains in this region, but the elimination of the silica presents a metallurgical difficulty which has not yet been overcome.

TORTUGAS MOUNTAIN[2]

GEOLOGY AND GEOGRAPHY

Tortugas Mountain, 3$^1/_2$ miles east of Mesilla Park, is a fault block of limestone which rises about 500 feet above the surrounding plain. The beds, which are believed to belong to the Magdalena series, dip to the west and are bounded on the east by a north-striking fault and on the northeast by a fault striking N. 55° W. The east and northeast sides are steep facets whose strikes parallel the mineral veins of the mountain.

[1] Johnston, W. D., Jr., Fluorspar in New Mexico : N. Mex. Sch. Mines, State Bur. Mines and Min. Res. Bull. 4, 1928, pp. 65-72.

[2] The description of Tortugas Mountain is taken from an account by Johnston, W. D., Jr., op. cit., 1928, pp. 75-82.

FLUORITE DEPOSITS

Two veins in the mountain contain fluorite. The vein which has been exploited at the Tortugas mine strikes north and has been followed for a distance of 1200 feet along the outcrop. At the surface it dips 80° east, but at a depth of 250 feet in the mine the fissure is approximately vertical and at 286 feet it dips 60° west. The width of the vein varies between 1 and 8 feet. The filling is green fluorite, with a small amount of calcite, quartz and gypsum.

The workings extend for a distance of 1000 feet along the outcrop and to a depth of 286 feet below the collar of the main shaft. Most of the fluorite has been taken out down to the 150-foot level, but considerable reserves remain below this level. The mine product was conveyed from the shaft to the foot of the mountain on the east side by means of an aerial tramway ; then it was taken in motor trucks to a mill, situated near the State College.

Up to 1927 the mine had produced 15,328 tons, and there has been a substantial production since that time. The owners are Hayner and Manasse, Las Cruces. The mine is idle at present.

The Jones vein outcrops as a fracture zone near the first shoulder on the east side of the mountain, and strikes N. 50° to 55° W. It contains fluorite, calcite and a little gypsum. There has been a small production from this vein.

FUTURE POSSIBILITIES OF MINING IN DONA ANA COUNTY

GENERAL REVIEW

The geologic and economic features of the mineral deposits of the county, described in the preceding pages, provide a basis for an appraisal of the future possibilities of the mining industry in Dona Ana County. A brief summary of the salient facts may be presented here. The production of precious and base metals has been confined for all practical purposes to the mines in and near the Organ mining district, in the northern part of the Organ Mountains. Small metal deposits occur elsewhere in the county, but they are economically unpromising. In the Organ district, the greater part of the production has come from mines located on and near the Torpedo-Bennett fault zone. The Stevenson-Bennett and Torpedo mines have been operated on a moderate scale, able to support at their most successful periods some hundreds of employes. The Memphis mine, though smaller in scale, should also be classed with these, and possibly the Modoc mine might be included. All other mines have been small in scale, worked by individuals or small companies. With the exception of the Torpedo and Stevenson-Bennett mines, no mines have shafts over 200 feet deep, and by far the greater part of the production of the district has come from the oxidized parts of the deposits. These facts may indicate that the grade of the deposits is such that profitable mining cannot be carried on in depth, where there is a necessary increase in mining costs; or it may indicate that, owing to insufficient capital, operations have been unable to reach deposits below water level, so that considerable bodies of untouched ore remain. Unfortunately, it seems necessary to conclude in many cases that deep mining would not be justified.

In the small-scale mines, gold has been won from veins in the pre-Cambrian (Mormon, Sunol, Sally, Maggie G mines), from veins in the Tertiary intrusives (Texas Cross, Davy King) and from replacement deposits in carbonate rocks (Little Buck, Mountain Chief, Hilltop). Silver has been extracted from rich outcrops and complex sulphide ores in pegmatites and veins in the Tertiary intrusives (Silver Coinage mine and many other small deposits) and from replacement deposits (Homestake, Little Buck); copper, lead and zinc ores have come from pyrometasomatic and other replacement deposits.

ORE RESOURCES OF KNOWN MINES

Few of the mines in the Organ district have at the present time resources of proved economic value. There are proved ore-bodies of moderate size in the Stevenson-Bennett and Torpedo mines, but under present conditions they are of too low grade for profitable mining. The limits of the orebodies upon which prospecting and mining is actively in progress at the Sally, Hilltop and Silver Coinage mines are not yet exactly known, but the existence of payable ore has been proved. At the Texas mine it seems likely that prospecting will reveal the presence of a large tonnage of refractory low-grade gold ore. Some refractory ore probably remains in the lower levels of the Mormon mine. Several mines, notably the Memphis, Excelsior and Merrimac, contain reserves of zinc-rich sulphide ore, which under existing conditions cannot be mined profitably.

The development of further ore reserves in the known mines seems to be possible in several cases. At the Torpedo mine, there seems to be good reason to suppose that the chalcocite zone is still intact. If its richness is at all commensurate with that of the oxidized ore, it should contain high-grade copper ore, possibly having some silver values. The development of a moderate-sized body of low-grade ore at the Torpedo mine should also result from the exploration of the ground lying in the ore zone south of No. 4 shaft, and there is even a chance that other bodies of high-grade ore might be discovered ; however, an increased price for copper would be needed before further work here could be justified.

Apart from the Silver Coinage mine, where work is in progress, the only silver deposits which appear to offer much promise are those on the Homestake, Crested Butte and Galloway properties, where further small-scale prospecting might be worth while. In view of the enhanced price of gold, some further examination of the abandoned gold veins of the Gold Camp district might reveal payable ore. Such properties as the Maggie G, the Rock of Ages, and the Sunol may offer some promise for small-scale prospecting.

The reopening of the Modoc mine, and the sinking of a shaft below the present workings may some day be worth while.

NON-METALLIC MINERALS

The outer zone deposits contain reserves of fluorite and barite which may be of future value. The Tortugas mine, one of the largest producers of fluorite in the State, still has large proved resources and further exploration in depth is likely to develop more fluorite. The Hayner mine and the Bishop's Cap prospects both contain reserves of fluorite. At Tonuco some fluorite remains, but it is objectionably siliceous. In addition to the known deposits, there are probably others which careful prospecting will reveal; outcrops of fluorite were noted, for example, west of the Modoc mine.

Among the barite deposits, there have been two producers so far, the Bear Canyon district and the Devil's Canyon mine. Both contain large developed resources, and considerable potentialities; there are also many other deposits. The development of the barite resources of the county for paint manufacture should be considered as a serious possibility.

Magnesite may well become, in the near future, an important product of the county. More prospecting in the South Canyon and Target Range Canyon regions is needed to show exactly how much magnesite is available, but it is probable that a fair tonnage will be found.

Gypsum is abundantly present. Limestone for building purposes is readily obtained, but there is little demand for it. For road metal, crushed rhyolite is commonly used.

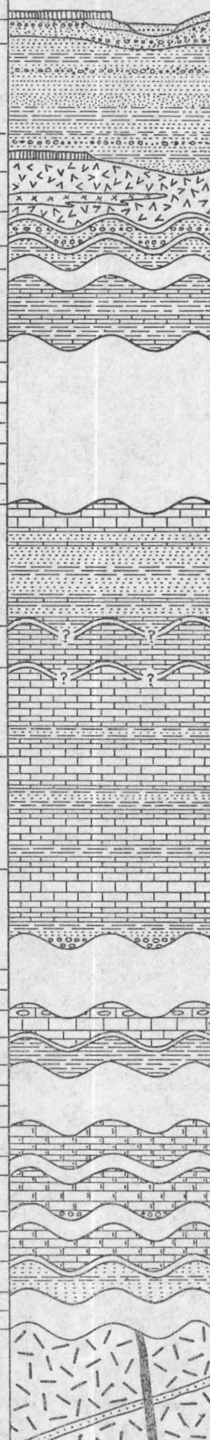
SUGGESTIONS FOR PROSPECTING

It seems reasonable to suppose that all the easily found deposits in this region have already been discovered. Future prospecting must, therefore, be directed towards the investigation of the less obvious places. The geological evidence shows clearly the importance of structural controls in the localization of the known ore deposits. In certain cases there remain favorable structures which have not yet been prospected, the most striking instance being the Torpedo-Bennett fault zone, between the Torpedo and Stevenson-Bennett mines. A long stretch of this fault zone, which has been so richly productive at the .mines after which it is named, is concealed beneath alluvium, partly under a broad arroyo, and partly under a wide fan. There may well be other orebodies concealed beneath the alluvium, especially since the lower Paleozoic dolomites, in which the ore was found at the Stevenson-Bennett mine, will be encountered at a slight depth below the surface. The few shallow pits sunk between the mines are entirely inadequate to reveal the possibilities of the zone; further prospecting is therefore strongly recommended.

Between the Memphis and Excelsior mines, the contact between the quartz-bearing monzonite and the Magdalena series is concealed, partly by thin alluvium, partly by a sill of porphyry. The probability that other sulphide bodies exist in this region is very strong, but prospecting might prove to be expensive and difficult.

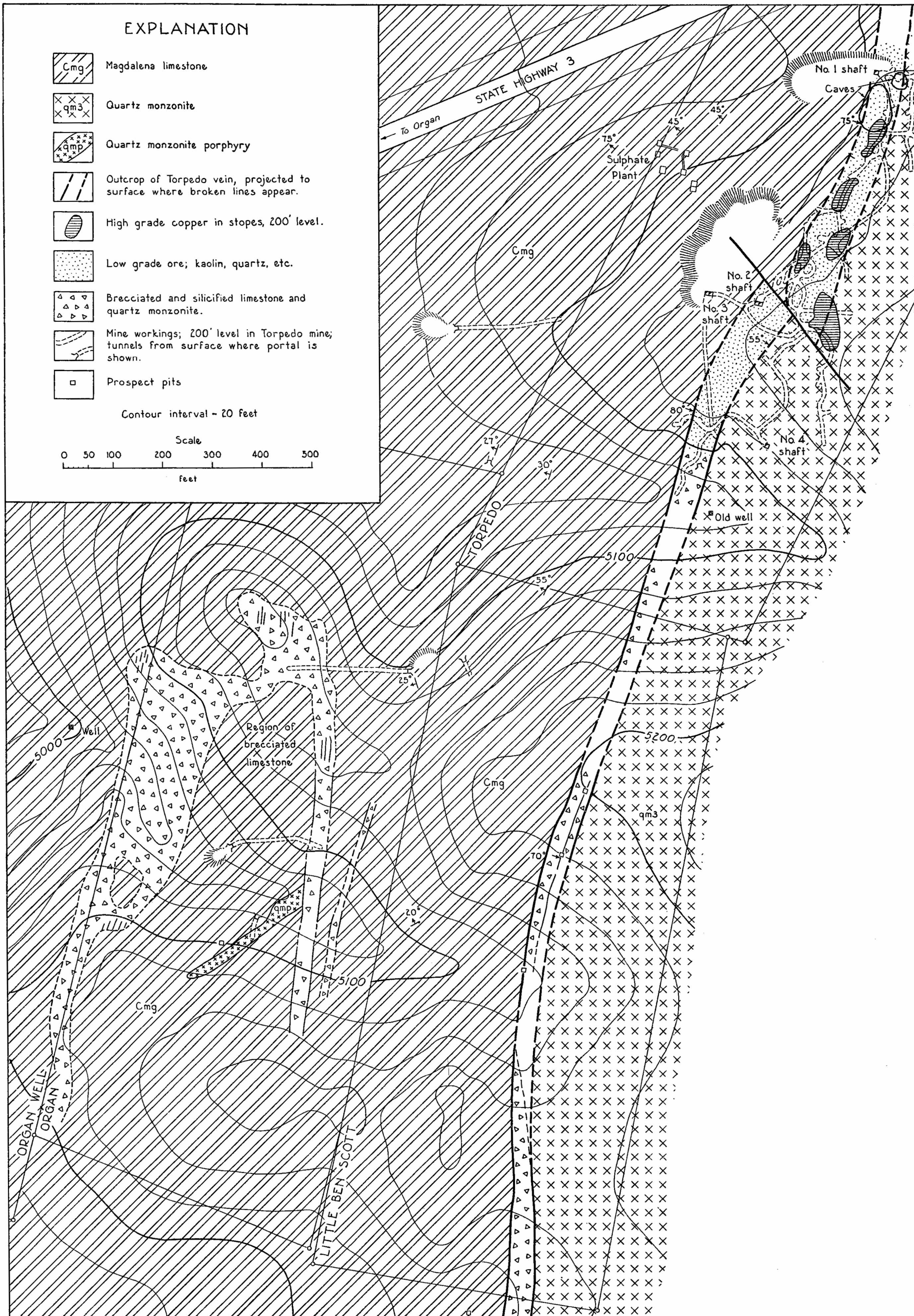
The contacts between dikes, especially those cutting the granite and the monzonites, are always worthy of careful investigation. There still remain good chances that prospecting of dikes in the less obvious places will lead to the discovery of further ore; the Sally mine is a recent example. In the sedimentary rocks, ore may be expected in replacement deposits adjacent to contacts between igneous and sedimentary rocks, near faults and fractures, and near the contacts between carbonate rocks and shales.

INDEX

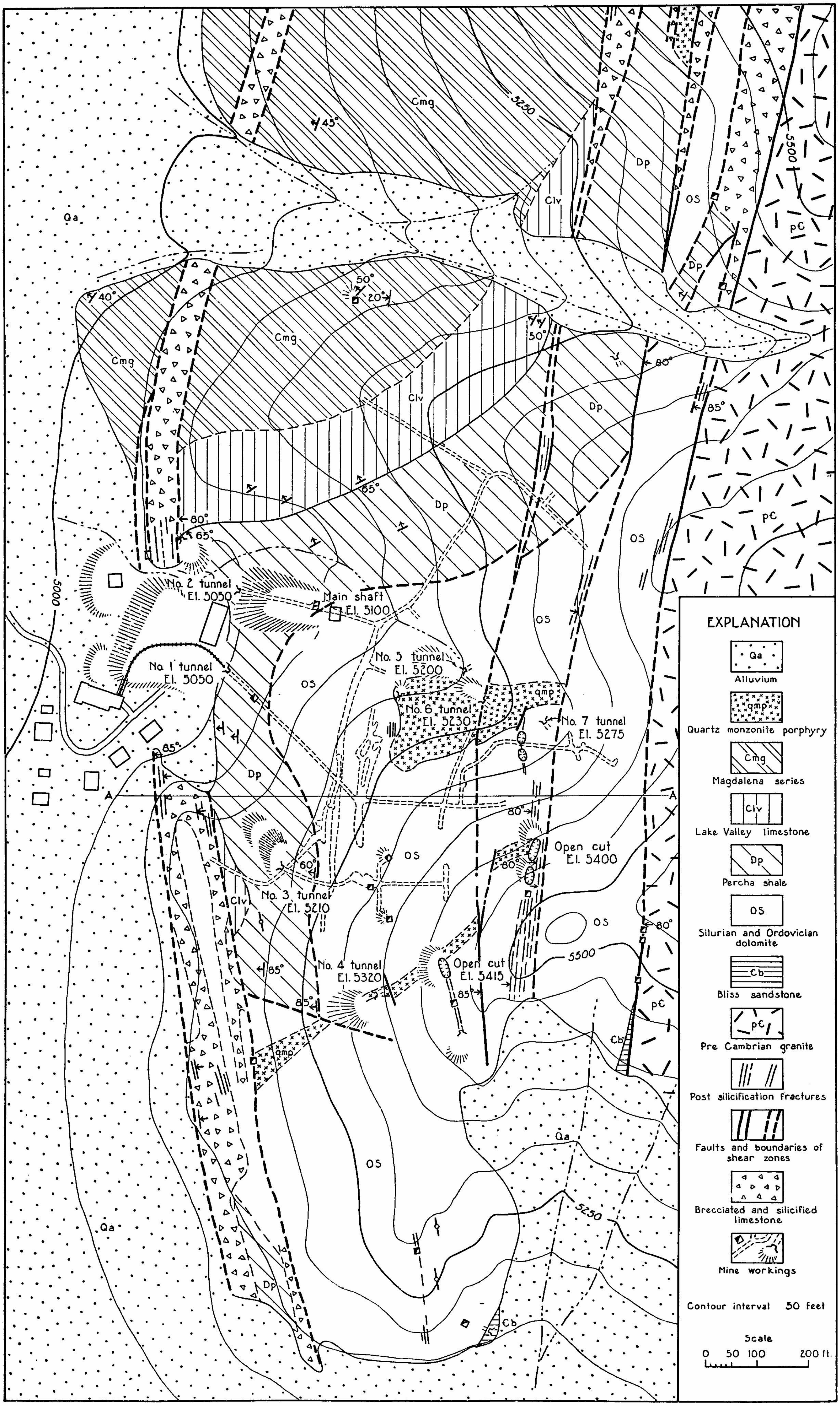


	SYSTEM	SERIES	THICKNESS IN FEET	GROUPS AND FORMATIONS	CHARACTER OF ROCKS
CENOZOIC	QUATERNARY	RECENT		FLOWS AND GRAVELS	Basalt flows and river gravels and sands.
		PLEISTOCENE	0-200	PALOMAS GRAVELS	Conglomerates and gravels.
	TERTIARY	PLIOCENE	Max. 4000±	SANTA FE FORMATION	Silt and sand; soft shales and sandstones; conglomerates.
		MIOCENE			
		OLIGOCENE	1000-4000	ERUPTIVES	Andesite rhyolite and latite flows, tuffs, agglomerates and breccias with quartz monzonite intrusions, ending with basalt flows.
		EOCENE		? GALISTEO SANDSTONE	Conglomerates and sandstones.
MESOZOIC	CRETACEOUS	UPPER	200	MANCOS SHALE	Sandstones and shales with coal.
		LOWER	1000±	SARTEN SERIES	Limestones and shales.
	JURASSIC	UPPER			
		MIDDLE			
		LOWER			
	TRIASSIC	UPPER			
		MIDDLE			
		LOWER			
PALEOZOIC	PERMIAN	UPPER			
		MIDDLE			
		LOWER	300-600	MANZANO GROUP: CHUPADERA FORMATION	Massive limestone underlain by red and gray sandstone with gypsum beds.
			1000	MANZANO GROUP: ABO SANDSTONE	Slabby sandstone, red and yellow, reddish brown shale with subordinate limestone.
				HUECO LIMESTONE	Thin limestones.
	PENNSYLVANIAN	UPPER			
		MIDDLE	600-3000	MAGDALENA FORMATION	Thin limestones with subordinate interbedded shales and sandstones.
		LOWER			
	MISSISSIPPIAN	UPPER			
		MIDDLE			
		LOWER	0-300	LAKE VALLEY LIMESTONE	Massive limestone, cherty in upper part.
	DEVONIAN	UPPER	0-140	PERCHA SHALE	Black and gray shales.
		MIDDLE			
		LOWER			
	SILURIAN	UPPER			
		MIDDLE	80-210	FUSSELMAN DOLOMITE	Upper - dark massive dolomite. Lower - gray dolomite weathering white.
		LOWER			
	ORDOVICIAN	UPPER	70-400	MONTOYA DOLOMITE	Upper - gray slabby beds with chert fossiliferous. Lower - dark massive dolomite resting on basal conglomerate.
		MIDDLE			
		LOWER	160-800	EL PASO DOLOMITE	Gray dolomite with siliceous limestone near base.
	CAMBRIAN	UPPER	40-120	BLISS SANDSTONE	Quartzite and indurated shales.
		MIDDLE			
		LOWER			
PRE-CAMBRIAN					Schist, gneiss, granite and diorite with pegmatite and epidiorite dikes.

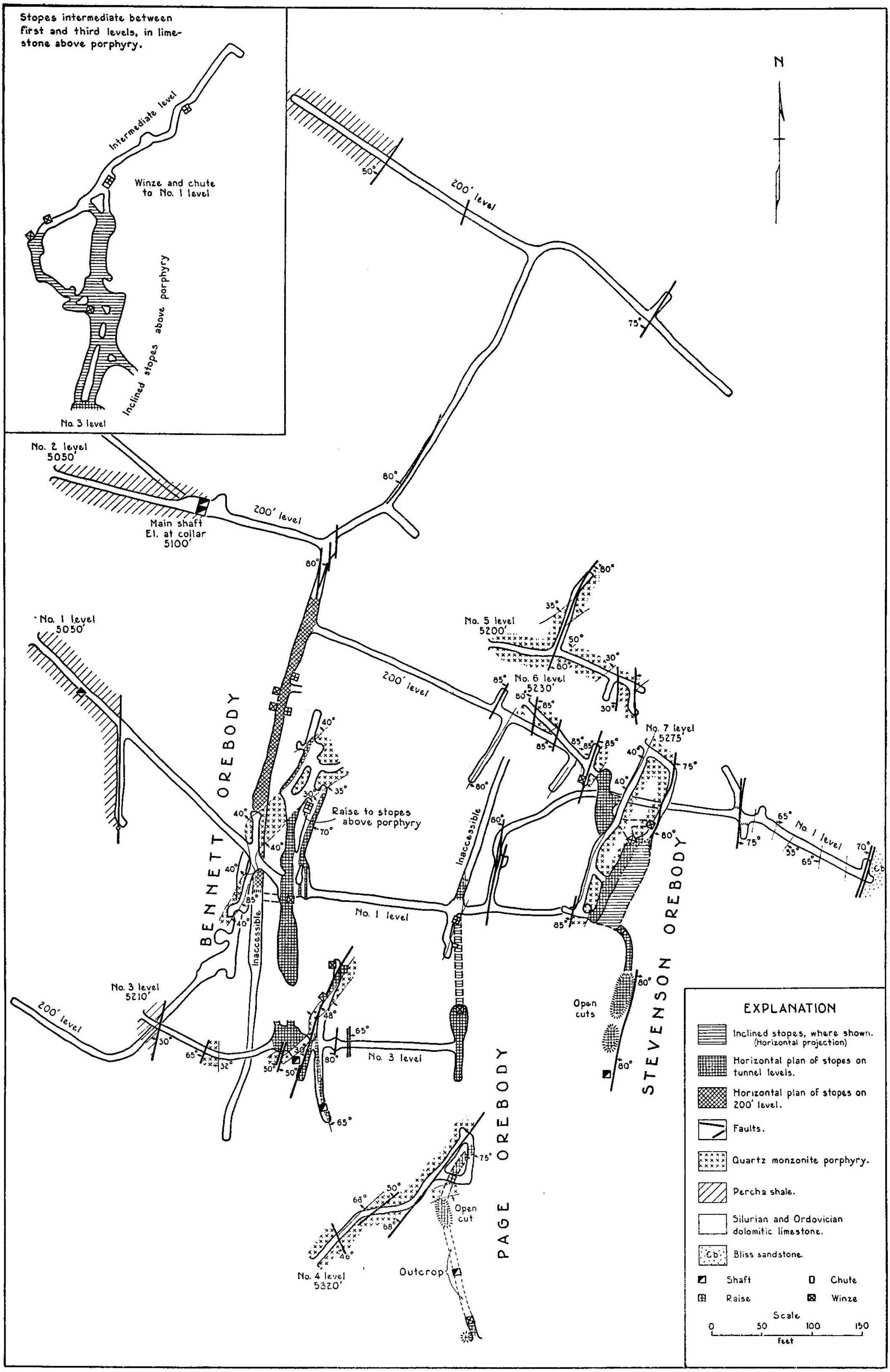
COMPOSITE STRATIGRAPHIC SECTION, DONA ANA COUNTY.



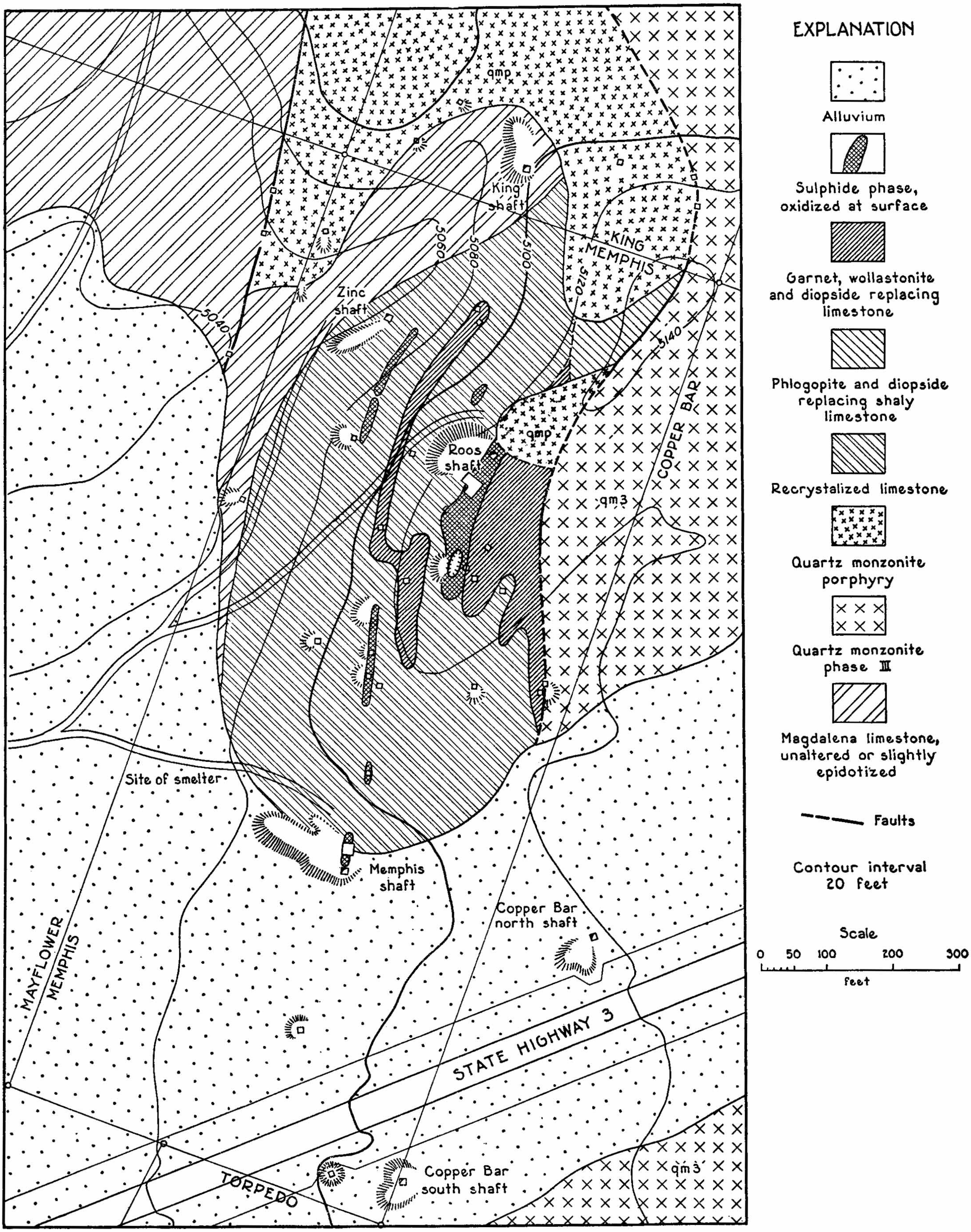
MAP SHOWING THE SURFACE GEOLOGY OF THE TORPEDO MINE



MAP SHOWING THE SURFACE GEOLOGY OF THE STEVENSON-BENNETT MINE



COMPOSITE LEVEL MAP OF THE STEVENSON-BENNETT MINE, SHOWING UNDERGROUND GEOLOGY



MAP SHOWING THE SURFACE GEOLOGY OF THE MEMPHIS MINE