NEW MEXICO SCHOOL OF MINES

STATE BUREAU OF MINES AND
MINERAL RESOURCES

C. E. NEEDHAM
President and Director

BULLETIN NO. 15

The Geology and Ore Deposits of Northeastern New Mexico

(Exclusive of Colfax County)

by
GEORGE TOWNSEND HARLEY

SOCORRO, NEW MEXICO
1940

CONTENTS

	Page
The State Bureau of Mines and Mineral Resources	6
Board of Regents	6
INTRODUCTION	7
Purpose and Scope of Report	7
Acknowledgments	9
PART 1. GENERAL FEATURES	
Geography	10
Location	10
Topography	10
Culture	11
Climate and Vegetation	12
Mineralized Areas	14
Partial Bibliography	17
Geology	18
General features	18
Pre-Cambrian rocks	19
Sedimentary rocks	20
Pennsylvanian system	20
Permian system	20
Abo sandstone	20
Chupadera formation	21
Triassic system	21
Dockum group	21
Jurassic system	22
Wingate sandstone	22
Todilto formation	22
Morrison formation	22
Cretaceous system	23
Purgatoire formation (Comanche)	23
Dakota sandstone (Upper Cretaceous)	23
Colorado Group (Upper Cretaceous)	24
Montana Group (Upper Cretaceous)	25
Tertiary system	25
Ogallala formation (Pliocene)	25
Quaternary system	25
Igneous rocks	25
Intrusive rocks	25
Volcanic rocks	27
Structural Features	28
The Mountain Area	28
The Plateau Area	30
The Plains Area	32
PART 2. MINING DISTRICTS	
Union County	33
Location and Area	33
Geography	33
Geology	34
Structure	34
Mineralized districts	35
Folsom	35
Black Mesa	36

CONTENTS

Page

PART 2. MINING DISTRICTS—Continued
Mora County 39
Location and Area 39
Geography 39
Geology 40
Structure 40
Mineralized districts 42
Coyote Creek 42
Other districts 43
Harding County 44
Location and Area 44
Geography 44
Geology 44
Structure 45
Mineralized districts 45
San Miguel County 46
Location and Area 46
Geography 46
Geology 47
Structure 48
Mineralized districts 50
Willow Creek (Pecos, Cooper) district 50
Johnny Jones Group 51
Rociada district 52
Smith mine 53
Crites mine 53
Joe Matt mine 53
Azure-Rising Sun mine 54
El Porvenir district 56
Tecolote district 57
Other districts 62
Guadalupe County 64
Location and Area 64
Geography 64
Geology 64
Structure 65
Mineralized districts 66
Pintada Canyon district 66
Quay County 66
Location and Area 66
Geography 66
Geology 67
Structure 67
Mineralized districts 67

PART 3. PRODUCTIVE MINES
The Pecos Mine 69
General 69
Location and Area 69
History 70
Geography 71
Geology 72
Early Schist and Gneiss Complex 72
Diabase 73
Granite 74
Syntectic rocks 76
Schists 76
Biotite schists 77

Page

PART 3. PRODUCTIVE MINES—Continued
The Pecos Mine—Continued
Geology—Continued
Schists—Continued
Quartz-sericite schist 77
Quartz-chlorite schist 78
Structural relations 78
Shear zone 78
Formation of shear zone 81
The Ore Deposits 83
Character 83
Production of Ore 85
Mining operations 85
Future of the district 88
The Stauber Mine 91
The ore deposits 91
Source of ore minerals 94
Controlling structures 95
Mining operations 95

ILLUSTRATIONS

Plate I. Index map of northeastern New Mexico .... in pocket
Plate II. Composite stratigraphic section in northeastern New Mexico .... facing page 18
Plate III. Geologic and topographic map of northeastern New Mexico .... in pocket
Plate IV. Structure contour map on surface of pre-Cambrian bedrock .... in pocket
Plate V. Geologic cross sections in northeastern New Mexico .... in pocket

Figure 1. Claim map of Azure-Rising Sun Mine 55
2. Geologic section in the Tecolote district 59
3. Areal geology near Pecos mine 75
4. Simplified block diagram of Pecos mine 79
5. Map of the 700 level, Pecos mine .... facing page 82
6. Map of the 1100 level, Pecos mine .... facing page 82
7. Map of the 1200 level, Pecos mine .... facing page 82
8. Longitudinal projection along Katydid orebody facing page 86
9. Longitudinal projection along Evangeline orebody .... facing page 86
10. Mine map of the Stauber property 90
11. Sections through the Stauber property 93

THE STATE BUREAU OF MINES AND MINERAL RESOURCES

The New Mexico State Bureau of Mines and Mineral Resources, designated as "a department of the New Mexico School of Mines and under the direction of its Board of Regents," was established by the New Mexico Legislature of 1927. Its chief functions are to compile and distribute information regarding mineral industries in the State, through field studies and collections, laboratory and library research, and the publication of the results of such investigations. A full list of the publications of the New Mexico Bureau of Mines is given on the last pages of this Bulletin, following the index.

BOARD OF REGENTS

HIS EXCELLENCY, HONORABLE JOHN E. MILES, *Governor of New Mexico, ex-officio* ---------- Santa Fe

MRS. GRACE J. CORRIGAN, *State Superintendent of Public Instruction, ex-officio* ---------- Santa Fe

GARNETT R. BURKS, *President* ---------- Socorro

ARTHUR B. THOMAS, *Secretary and Treasurer* ---------- Magdalena

J. O. GALLEGOS ---------- Socorro

HUGH L. JOHNSTON ---------- Hobbs

L. C. WHITE ---------- Raton

NEW MEXICO BUREAU OF MINES STAFF, 1940

C. E. NEEDHAM ---------- Director
S. B. TALMAGE ---------- Geologist and Editor
T. P. WOOTTON ---------- Geologist and Statistician
G. T. HARLEY ---------- Geologist
M. L. THOMPSON ---------- Geologist
N. P. PETERSON ---------- Geologist
DAISY WEIR ---------- Secretary to the Director
BLANCHE HAGIE ---------- Stenographer
JAMES MCKAY ---------- Graduate Assistant
JAMES GARTNER ---------- Student Assistant

The Geology and Ore Deposits of Northeastern New Mexico

(Exclusive of Colfax County)

By

George Townsend Harley

INTRODUCTION

Northeastern New Mexico has in recent years been an important producer of mineral wealth, almost all of which has come from two properties, the Pecos mine of the American Metal Co., at Tererro in San Miguel County, and the I. J. Stauber mine near Pastura in Guadalupe County. Elsewhere in the region, which also includes Mora, Union, Harding, and Quay Counties, the production, recorded and unrecorded, has been negligible, hardly exceeding a total of $5000 (See Table 2, p. 15) ; the deposits here are merely interesting examples of geological processes of mineralization without value as possible future producers of wealth. These unproductive counties are included in this report, therefore, mainly for two reasons: first, their metallic mineral resources are not of sufficient importance to warrant separate descriptions; and second, they contain copper minerals in numerous deposits of the sedimentary type, the outstanding example of which, in the State of New Mexico, is the Stauber mine at Pastura.

The field work for this report was begun July 1, 1934, and during that summer the Pecos mine and vicinity were examined. A great deal of time was devoted, at the mine, to a study of the cores from the Company's diamond drilling operations. During the summer of 1935 a field trip was made covering the remainder of the region described in this bulletin, and a study was made of the literature having a bearing on the work. The summer of 1936 and part of the early fall were devoted to the microscopic study of thin sections of the rocks and of polished sections of the ore specimens from the region. Most of these specimens were from the Pecos mine and vicinity, but many were from the Red Beds copper deposits. A short field trip was made, and the first drafts of maps and manuscript were submitted late in 1938; revision of manuscript and final drafting of maps were completed in the summer of 1940.

PURPOSE AND SCOPE OF REPORT

This bulletin has been prepared particularly for the use and information of prospectors, owners, and operators of mining property, and as a guide to non-residents who may become interested in the development of the metallic resources of the region. Technical phraseology and the presentation of highly scientific aspects of the geology, and of debatable theories, have been minimized, while the evidence gathered in the field, as shown by surface outcrops and by veins exposed in mine workings, has been emphasized.

With the exception of the Pecos and Stauber mines, most of the mine workings have not been operated for many years and consequently are in a bad state of repair or are obstructed by water and debris. It was not always possible to locate the owners, or men who had worked in these properties when they were fully opened, and consequently only a partial and usually an unsatisfactory account of what had been done underground could be obtained.

It is not contemplated by the State Bureau of Mines that much actual sampling of the veins shall be done by the geologist investigating ore deposits in the State for Bureau publications, and he is constrained to gather the figures as to the value of the ore from whatever sources are available, and to use proper judgment in interpretation. This report has been prepared largely on the evidence found on the surface, secured without regard for property lines, and supplemented by the study of practically all the openings accessible to the writer during his visits to the region.

The first part of the report includes descriptions of the physiography and of the rocks and a review of the geological history of the region. It also contains a brief discussion of the various types of orebodies and their mineralogy, and a brief review of the practical points involved in the search for ore. The second part is given to a detailed description of the individual districts in each county. In part three the Pecos and Stauber mines are described in the detail that their importance warrants. Guadalupe County contains by far the most important sedimentary copper deposit within the State; also, the occurrence of sedimentary copper mineralization is probably more widespread in this region than in any other part of the State, with the possible exception of Otero and Torrance Counties. Much has been written about this type of deposit, and geologists are not yet agreed as to the source of the copper minerals; it is proper, therefore, that this bulletin should include a fairly complete list of the papers that have appeared from time to time relative to such deposits in New Mexico and the adjacent territory.

While the material in this bulletin may be regarded as a basis on which to locate and plan future work in the ore deposits of the region, such work should not be prosecuted over long periods of time except under sound technical advice and direction. In the long run it is always the most economical procedure to secure the services of an experienced and reputable mining engineer or mining geologist, at frequent and stated intervals, and to rely upon his judgment and advice regarding the future possibilities of the mine, the quantity and value of the ore blocked out, the best campaign for future development, and the advisability of expenditures for plant and equipment.

ACKNOWLEDGMENTS

The writer was aided in the field work by owners of the various mines, and residents interested in mining, who supplied much important information or acted as guides during visits to the various districts and properties.

Special acknowledgment is due to Mr. A. H. Andreas, petroleum geologist, and geologist for the State of New Mexico, who accompanied the writer on a reconnaissance trip covering the northeastern part of the State and surrounding areas, and explained many features of the stratigraphy and structure of the region.

At the Pecos mine of the American Metal Co., the writer was most cordially received and every effort was made to supply him with first-hand information through the medium of trips underground, inspection of diamond drill cores, maps and records, and through full discussion of the problems and ideas involved. Of particular help in this matter was Mr. J. T. Matson, General Manager of the Company, Mr. C. Hoag, Mine Superintendent, Mr. H. D. Bemis, Mill Superintendent, Mr. E. C. Anderson, Chief Engineer, and Mr. K. V. Harris, Mine Engineer.

Others who guided the writer and Mr. Andreas in the field include Mr. A. G. Zummach in the Rociada district, Mr. D. J. Cassidy, former sheriff of Mora County, who took time to visit the various outcrops within reach of Mora, and Col. J. M. Potter of Clayton who supplied some excellent history about early operations in the region, and who gave descriptions of the mines now no longer open for inspection and the routes over which to reach the several localities. Mr. Leon Guy and Mr. J. P. Martin of Las Vegas made it possible for the writer to meet the proper people from whom to secure valuable information.

To the following members of the staff of the State Bureau of Mines and Mineral Resources, acknowledgement is due as indicated: To T. P. Wootton, geologist and librarian, for statistical data, and for final checking of tabulations; to Leonard H. Rackmil, class of 1935, New Mexico School of Mines, and Charles M. Dolliver, class of 1936, for services as student assistants in assembling of material and preliminary drafting; to Martin D. Dykers, class of 1936, as student assistant in preparation and preliminary study of polished sections; and to Charles R. Brady, Jr., class of 1938, and James McKay, class of 1940, graduate assistants, for aid in compilation and final drafting.

PART I. GENERAL FEATURES

GEOGRAPHY

LOCATION

The northeast quarter of New Mexico, including Colfax County, provides a topographical and structural unit well suited to a description of the geological sequence and structure of the region. For several reasons, the ore deposits of Colfax County are not discussed in this bulletin, so no details of the geology of that county are given. To promote clearness, however, the general topographic, stratigraphic, and structural features of the region are described in such a manner as to include the most general features of Colfax County.

The region under discussion includes the high continental backbone of the Sangre de Cristo Mountains and the Truchas and Rincon Ranges, which lie along the western border of Mora and San Miguel Counties. The northern border includes the northern line of Mora County, the western border of Union County adjacent to Colfax County and the northern border of Union County where it adjoins the Colorado state line. The eastern border is at the junction of Union, Harding, and Quay Counties with the States of Oklahoma and Texas. The southern border includes the south boundary of Quay and Guadalupe Counties, a portion of the western boundary of Guadalupe County, and a small part of the southern boundary of San Miguel County.

TOPOGRAPHY

The region within the boundaries indicated includes areas of mountain, plateau, and plain; Plate 1 shows the division of the region into these three areas. Altitudes range from about 3800 feet in the southeastern part to nearly 13,000 feet at the crest of the Sangre de Cristo Range in western Colfax and western Mora Counties. A large part of the region is of broken, high altitude, mountain or plateau types, and only in the southeastern portion does the altitude drop below 5000 feet and the country take on the appearance of rolling plains. The main range at the west presents an immense barrier, which, however, slopes south and terminates in low mountains closed round by plateaus from the south. The cross ranges are insignificant, except the Raton Range along the northern border of the State, which continues as high plateaus, interrupted by mountain masses, far into Union County. Several spurs extend from the main range into Colfax, Mora, and San Miguel Counties; the most noteworthy of these are the Cimarron Mountains in western Colfax County and the Turkey Mountains in western Mora County. However, low mountains and high plateaus, with many deep steep-walled canyons, are found rather generally over the region, except in the southwest. Numerous small streams and two large important ones, the Canadian and the Pecos Rivers, rise in the northern and western parts of the mountain area.

In the plateau and plains areas are many square miles of comparatively level country and numerous upland valleys and mesas that afford thousands of acres of fertile land; many of these have been reclaimed by irrigation projects or by improved dry-farming methods. Considerable timber covers the mountain slopes, and most of the high plateau country bears a growth of dwarf pine, piñon, and cedar. The low plateaus and the plains support little vegetation except tree growth along the streams, and crops on the various farms.[1]

CULTURE

The territory is well supplied with railroad facilities as shown on the index map of the region (Plate 1). The main line of the Atchison, Topeka & Santa Fe Railway enters the State over Raton Pass and extends southerly through Raton and Las Vegas, leaving the region over the west border of San Miguel County just south of the little town of Pecos. The Colorado and Southern Railroad enters the area through Emery Gap in Union County and passes southeast through Clayton into Texas. The Southern Pacific Railway enters from Texas into Quay County at Nara Visa and extends southwesterly to Tucumcari, Santa Rosa, and Vaughn, where it leaves the region. From these main lines of travel, several branch lines have been built to important points within the region; one of their main functions is to deliver coal from the Colfax County mines to the railroad division points at Clayton and Tucumcari. One of the principal branch lines is that of the Southern Pacific Railway from Tucumcari northward through Mosquero and Roy, French, and Colfax, to the coal camp at Dawson.

The principal cities in the region are Clayton (pop. 2515) and Folsom (pop. 389) in Union County, Mora (pop. 606) and Wagon Mound (pop. 852) in Mora County, Mosquero (pop. 401) and Roy (pop. 705) in Harding County, Las Vegas (pop. 4708) and Tererro (pop. 1750) in San Miguel County, Santa Rosa (pop. 1127) and Vaughn (pop. 961) in Guadalupe County, Tucumcari (pop. 4134) and Logan (pop. 404) in Quay County.[2] These cities are the principal marketing and distribution centers for the farm and cattle industries of the region, and in addition, Tucumcari, Clayton, Des Moines, Santa Rosa, and Vaughn are either junction points or division points on the railroads.

Lumbering, mining, farming, and cattle raising are the major activities in the region. Lumbering and mining are the

[1] U. S. Dept. of Agriculture, Weather Bureau, Summary of the climatological data for the United States, by sections; Section 6, Northeastern New Mexico (to 1920 inclusive).

[2] Commercial Atlas of the World, 1930, Geographical Publishing Co.

important industries in the western mountainous area. Cattle raising, with some dry-farming and a small amount of irrigated farming within the river valleys, are the major occupations in the plateau area skirting the mountains. Farming, both dry and irrigated, and cattle raising are the main occupations in the plains area of the eastern and southeastern parts of the region.

The Conchas Dam, recently completed in San Miguel County on the large Bell Ranch, has greatly increased the facilities for irrigating farm lands in the valley of the Canadian River in San Miguel and Quay Counties; this adds materially to the potential wealth of these counties. There is now being developed for this region an irrigation project to reclaim about 40,000 acres of land, to be named after ex-Secretary of War Hurley.

CLIMATE AND VEGETATION

The index map, Plate 1, shows the broad division of the region into mountain, plateau, and plains areas, within each of which the climatic conditions and type of vegetation are distinctive. The localities of the several weather-recording stations within each of these areas are shown on the map (Plate 1), and the climatological data for the region are given in Table 1. The great range in altitude and the abrupt topographic changes contribute to the wide variety of climatic conditions and a great diversity in types of vegetation within the region.

In the mountainous portion of the region the climate is cold in winter and cool in summer, and the rainfall and snowfall are considerable, as shown in Table 1. The maximum temperatures for the stations included in the mountain area have ranged between 85° and 93° F., while the minimum temperatures have been between –16° and –32°.

In the plateau area, or that part of the region which lies between 5000 and 7000 feet in altitude, the temperature throughout the year is more nearly uniform, rainfall and snowfall are less, and there are fewer stormy days than in the mountain area. Maximum temperatures for the stations listed in this section of the table have ranged between 98° and 107° and minimum temperatures have been between –18° and –31°. In the plains area the country is still dryer and the climate more nearly equable; maximum temperatures have ranged up to 108° and the minimum temperatures between –15° and –26°.

Vegetation is controlled by conditions of altitude, temperature, amount of precipitation, drainage, and other factors. In the mountainous area the slopes bear fine stands of timber, principally western yellow pine, firs, and spruce; there are also some oak, aspen, and other less valuable woods. Open meadows and cienagas are found within these forested areas and afford fine summer grazing. Running streams, which abound with mountain trout, are found in many of the canyons, and the presence of trees and grasses on the slopes prevents soil erosion and con-

TABLE I

Climatological Data for Northeastern New Mexico[3]

STATION	Elevation feet	Mean annual precipitation inches	Period of maximum precipitation	Days per year with 0.01 or more inches precipitation	Average amount snowfall inches	Mean annual temperature degrees F.	Mean annual maximum temperature degrees F.	Highest temperature	Mean annual minimum temperature degrees F.	Lowest temperature
MOUNTAIN AREA + 7000 ft.										
Harvey's Upper Ranch	9400	33.43	Feb.-Oct.	105	156	41.1	52.6	85	29.6	–16
Chacon	8510	20.88	Apr.-Sept.	64	78	---	---	--	---	---
Winsor's Ranch	8000	24.55	Feb.-Oct.	88	86	42.0	57.9	90	26.2	–27
Gallinas Point	7500	25.39	Apr.-Oct.	87	77	46.1	61.4	93	30.8	–24
Rociada	7150	22.75	Apr.-Sept.	69	74	45.1	61.8	93	28.4	–32
Mineral Hill	7050	21.11	Apr.-Sept.	50	55	---	---	--	---	---
PLATEAU AREA + 6000 ft.										
Des Moines	6622	18.51	May-Sept.	54	43	49.6	64.2	102	34.9	–22
Las Vegas	6400	17.94	May-Sept.	70	32	49.9	65.2	99	34.6	–31
Folsom	6399	18.27	Apr.-Sept.	64	52	48.6	63.4	97	33.8	–21
Levy	6252	18.02	May-Sept.	57	39	48.6	65.8	98	31.3	–29
+ 5000 ft.										
Roy	5884	15.89	May-Oct.	44	26	52.0	65.4	104	38.6	–19
Abbott	5771	15.67	May-Sept.	55	29	---	---	---	---	---
Park Springs Ranch	5100	15.57	May-Sept.	49	18	54.8	70.0	107	39.7	–21
Clayton	5054	17.46	Apr.-Sept.	54	26	53.3	68.4	105	38.2	–18
PLAINS AREA – 5000 ft.										
Valley	5000	16.88	Apr.-Sept.	39	38	---	---	---	---	---
Santa Rosa	4624	14.38	May-Sept.	44	15	57.8	72.8	108	42.7	–18
Bell Ranch	4500	15.72	Apr.-Sept.	54	15	56.2	72.8	107	39.6	–26
Tucumcari	4200	17.24	Apr.-Sept.	53	22	57.9	72.4	108	43.4	–18
Nara Visa	4000	17.13	Apr.-Oct.	50	15	56.1	71.7	108	40.5	–15

[3] U. S. Department of Agriculture, Weather Bureau, Climatic Summary of the United States; Section 28, Northeastern New Mexico (to 1930, inclusive).

serves the water supply. Logging is a relatively important industry in these mountains.

In the plateau area there is more open country, although there is a growth of scrub oak, juniper, and cedar. The grasses here are abundant although not so luxuriant as in the mountain meadows. The smaller streams of the mountains disappear beneath the surface during the greater part of the year and are found running only in the early spring and late summer months in normal years. The amount of growth in this area is sufficient to prevent excessive soil erosion and to conserve the moisture to a large degree. Cattle raising and upland farming, with some irrigated farming along the river flood-plains in their wider parts, are the more important occupations in the plateau area.

Within the plains area only the larger streams continue to flow throughout the year, and except for short periods after heavy rains the smaller canyons are dry. Trees are almost entirely lacking except on outcrops of the Dakota sandstone, where there is a persistent and characteristic growth of low bush-like scrub cedar and piñon. Along the valleys where ground water reaches close to the surface, groves of trees such as cottonwood, sycamore, willow, and walnut are to be found here and there, and many of the farmers and ranchers have cultivated shade trees and fruit trees on their properties. Erosion has cut into the land in many places with the development of deep arroyos and gullies. In the northeastern part, near Clayton, the land is included as part of the great "Dust Bowl" area, and shifting sands have ruined many farms during years of protracted drought. In the major valleys farming is the principal occupation, and in some places on the upland plains, dry-farming is successfully practiced. Elsewhere the short grasses of the plains are utilized in maintaining an important cattle industry, but this, also, has suffered severely from the drought conditions of recent years.

MINERALIZED AREAS

Plate 1 portrays the location of the several mineralized areas in northeastern New Mexico which are mentioned and described in this bulletin. The names of these districts are given in the following table, together with a tabulation of the known metals, the total production to date in as much detail as could be secured from the records, the areas in square miles of the counties of the region, and the population of these counties at the date of the latest census taken in 1930.

The ores found in this region have been derived from two sources. Such metals as zinc, lead, copper, and molybdenum, occurring in the sulphide form, have been found in pre-Cambrian rocks. This is true also for the gold and silver recovered from veins and related types of deposits. The evidence indicates that all of these metalliferous deposits were formed in pre-Cambrian

TABLE 2

Mining Districts in Northeastern New Mexico and their Chief Metals [4]

COUNTY	DISTRICT	METALS	PRODUCTION	AREA SQUARE MILES	POPULATION
Union			none	3877	11,036
	Folsom	Copper, gold, silver	none		
	Clayton	Copper	none		
Mora			$ 1,757	1854	10,322
	Coyote Creek	Copper, silver	1,757		
Harding			none	2114	4,421
San Miguel			35,966,555*	4894	23,636
	Rociada	Gold, silver, copper lead, zinc			
	Willow Creek (Pecos, Cooper)	Zinc, lead, silver, gold	35,966,555		
	El Porvenir (Hermit Mt.)	Molybdenum, tungsten, bismuth, copper			
	Tecolote	Copper			
Guadalupe			801,496	3031	7,027
	Pastura (Pintada)	Copper	801,496		
Quay			none	2905	10,828
	Logan	Copper	none		

* This figure does not include production in 1939 to the end of May, at which time the Pecos Mine at Willow Creek shut down.

[4] Minerals Yearbook, of several years, U. S. Bureau of Mines.

time. The second class includes the copper deposits in sedimentary rocks of Triassic age. These deposits are thought by some to be syngenetic with the deposition of the sediments; others think that the minerals may have been deposited after the sediments were laid down, by circulating surface waters in some instances, and by waters of magmatic origin in others. A third, but minor, type of metallization is shown by the gold-bearing stringers in the basalts of Quaternary age. While the quantity of gold in these stringers is very small, and they are too widely scattered to be of commercial interest, yet they have been the cause of some prospecting work in the basalt; and in one or two localities, placer deposits supposed to have been derived from these stringers have been reported.

Of the three classes of deposits just described, those in pre-Cambrian rocks are by far the most interesting and deserving of the greatest consideration in future prospecting work. Wherever these rocks have been exposed in the region, mineralization has been found in them, or deposits have been found in the nearby sediments supposedly derived from them. Unfortunately, only small exposures of the pre-Cambrian rocks are found in northeastern New Mexico, and these are in the most inaccessible and most densely forested parts of the mountain area, where plant growth, rockslide material, and erosional debris make prospecting slow and tedious. Under the cover of sedimentary beds of the region, it might well be expected that other ore deposits remain hidden, to await further advances in the science of geophysical prospecting, or their accidental penetration by the drill bit. The region just east of the mountain area in San Miguel and Mora Counties, and the vicinity of the ancient granite ridges believed to be the roots of former mountain ranges, are, in the writer's opinion, the places to be most closely studied when drilling operations are in progress. The contour map of the surface of the pre-Cambrian bedrock (see Plate 4) and the geological cross-sections of Plate 5, will be of aid in this study.

Deposits of the second class, with one notable exception, have not been highly productive of copper in this region. There seems to be no reason, however, for finally condemning the region on this account. It appears certain that minor basins were the loci of deposition of these deposits, and that impervious layers formed at top and bottom of the ore bed, so that mineralizing solutions entering the basin have been impounded and stagnated. The writer believes that in copper-bearing sedimentary regions, where Pennsylvanian, Permian, and Triassic rocks include lenses of arkosic and loosely cemented sandstones similar to those in which copper has already been found, careful prospecting of the shallow basins and synclinal folds is justified. It is recognized that great risks are involved in prospecting for this type of orebody, and the prospector should be cautioned against spending large sums of money in blindly searching over large areas of favorable structure, without other positive clues to guide him.

In the third group, which includes gold-bearing stringers in the basaltic rocks and reported placer deposits derived from them, very little hope is held out for the discovery of commercially profitable deposits. The opinion is expressed that prospecting in these areas of basaltic flow-rocks is simply so much time wasted.

PARTIAL BIBLIOGRAPHY

GENERAL

Baker, C. L., Geology and underground water of the northern Llano Estacado: Texas Univ. Bull. 57, 1915.

Baldwin, S. P., Descriptive geology of northeastern N. Mex.: Geol. Soc. America Bull. 39, pp. 161-162, 1928.

Bryan, Kirk, Geology of the State line dam site: N. Mex. State Engr. 8th Bienn. Rept., pp. 255-258, 1938.

Darton, N. H., "Red Beds" and associated formations in N. Mex.: U. S. Geol. Survey Bull. 794, 1928.

Garrett, D. L., Stratigraphy and structure of northeastern N. Mex.: Am. Assoc. Petroleum Geologists Bull., vol. 4, pp. 73-82, 1920.

Gould, C. N., Tentative correlation of the Permian formations of the southern Great Plains: Geol. Soc. America Bull. 38, pp. 431-442, map, bibliography, 1927.

Heaton, R. L., Ancestral Rockies and Mesozoic and late Paleozoic stratigraphy of Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 17, p. 109, 1933.

Heaton, R. L., Stratigraphy vs. structure in Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 21, p. 1241, 1927.

Lee, W. T., Extinct volcanoes of northeast N. Mex.: Amer. Forestry, vol. 18, pp. 357-365, 1912.

Lee, W. T., Building of the southern Rocky Mountains: Geol. Soc. America Bull. 34, pp. 285-300, 1923.

Prout, F. S., Schist east of Santa Rosa, N. Mex.: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 88, 1927.

Winchester, D. E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines, Bull. 9, 1933.

Yeo, H. W., Rept. on Canadian River investigation: N. Mex. State Engr. 8th Bienn. Rept., pp. 259-297, 1928.

ECONOMIC GEOLOGY

Bush, F. V., Romero molybdenum mine near Las Vegas: Min. Sci. Press, vol. 110, p. 374, 1912.

Butler, B. S., Relation of the ore deposits of the southern Rocky Mountain region to the Colorado Plateau: Colorado Sci. Soc. Proc., vol. 12, pp. 23-36, 1929.

Horton, F. W., Molybdenum, its ores and their concentration: U. S. Bur. Mines Bull. 111, 1916.

Hubbell, A. H., Pecos Mine, a new lead-zinc project: Eng. and Min. Jour., vol. 122, pp. 1004-1012, 1926.

Lindgren, W., Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910.

Stott, C. E., Geology of the Pecos mine: Eng. and Min. Jour., vol. 131, pp. 270-275, 1931.

SANDSTONE COPPER DEPOSITS

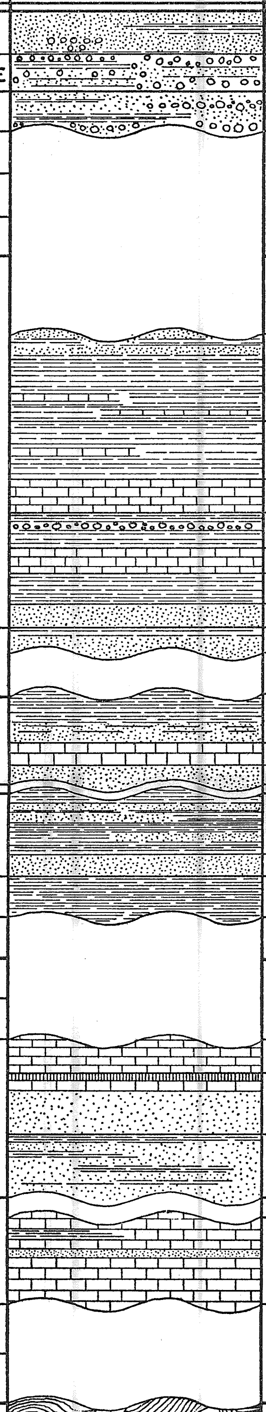
Austin, W. L., Copper deposits in Mora County, N. Mex.: Colorado Sci. Soc. Bull. 1897, no. 11, pp. 2-5, 1898.

Austin, W. L., Some New Mexico copper deposits: Colorado Sci. Soc. Proc., vol. 6, pp. 91-95, 1902.
Ball, S. H., Sandstone copper deposits at Bent, N. Mex.: Min. Sci. Press, vol. 107, pp. 132-136, 1913.
Bastin, E. S., The chalcocite and native copper types of ore deposits: Econ. Geology, vol. 28, pp. 407-446, 1933.
Butler, B. S., Loughlin, G. F., and Heikes, V. C., et al., Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 152-158, 1920.
Coffin, R. C., Radium, uranium, and vanadium deposits of southwestern Colorado: Colorado Geol. Survey Bull. 16, 1921.
Dorsey, G. E., Origin of the color of Red Beds: Jour. Geology, vol. 34, pp. 131-143, 1926.
Emmons, S. F., Copper in the Red Beds of the Colorado Plateau region: U. S. Geol. Survey Bull. 260, pp. 221-232, 1905.
Emmons, W. H., The Cashin mine, Montrose County, Colo.: U. S. Geol. Survey Bull. 285, pp. 125-128, 1906.
Finch, J. W., Sedimentary metalliferous deposits of the Red Beds: Am. Inst. Min. Met. Eng. Trans., vol. 77, pp. 378-392, 1928.
Fischer, R. P., Sedimentary deposits of copper, vanadium-uranium, and silver in southwestern United States: Econ. Geology, vol. 32, pp. 906-951, 1937.
Hager, D. S., Factors affecting color of sedimentary rocks: Am. Assoc. Petroleum Geologists Bull., vol. 12, pp. 901-938, 1928.
Hess, F. S., Hypothesis for the origin of the carnotites of Colorado and Utah: Econ. Geology, vol. 9, pp. 675-688, 1914.
Koberlin, F. R., Sedimentary deposits of copper, vanadium-uranium and silver in southwestern United States: Econ. Geology, vol. 33, pp. 458-461, 1938.
Lee, W. T., Note on the red beds of the Rio Grande region in central New Mex.: Jour. Geology, vol. 15, pp. 52-58, 1907.
Lindgren, W., Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910.
Lindgren, W., Mineral Deposits, 4th ed. pp. 403-409, 1933.
Rogers, A. F., Origin of copper ores of the "red beds" type: Econ. Geology, vol. 11, pp. 366-380, 1916.
Tarr, W. A., Copper in the Red Beds of Oklahoma: Econ. Geology, vol. 5, pp. 221-226, 1910.
Tomlinson, C. W., Origin of Red Beds: Jour. Geology, vol. 24, pp. 153-179 and 238-253, 1916.
Turner, H. W., Copper in the Red Beds of New Mexico: Econ. Geology, vol. 11, pp. 594-597, 1916.
Turner, H. W., Copper deposits of the Sierra Oscura, N. Mex.: Am. Inst. Min. Eng. Trans., vol. 33, pp. 678-681, 1903.

GEOLOGY

GENERAL FEATURES

The rocks of the northeastern section of New Mexico include metamorphic, igneous, and sedimentary varieties. The metamorphic rocks are of pre-Cambrian age. The igneous rocks are of pre-Cambrian, Tertiary, and Quaternary ages. The sedimentary rocks range in age from lower Pennsylvanian to Recent, with probably all intervening systems present in the stratigraphic sequence at one place or another. Plate 2 presents the generalized sequence of the formations in the region with the range in thickness of the various formations and the general characteristics of each. Plate 3 is a geological map of the region.



	SYSTEM	SERIES	GENERAL SECTION	MAXIMUM THICKNESS	GROUPS AND FORMATIONS			DESCRIPTION
CENOZOIC	QUATERNARY	RECENT						SAND, GRAVEL, AND CLAY
		PLEISTOCENE						GRAVEL, SAND, AND CLAY
	TERTIARY	PLIOCENE		0-150			OGALLALA FORMATION	CONGLOMERATE, GRAVEL, SAND, AND SILT
		MIOCENE						
		OLIGOCENE						
		EOCENE						
MESOZOIC	CRETACEOUS	UPPER			MONTANA GROUP			
				0-1800			PIERRE SHALE	SHALE, MOSTLY DARK GRAY, WITH THIN LIMESTONE BEDS ALTERNATING NEAR BOTTOM AND THIN SANDY BEDS ALTERNATING NEAR TOP
				300	COLORADO GROUP	NIOBRARA FORMATION	APISHAPA SHALE	LIMY GRAY SHALE
				50			TIMPAS LIMESTONE	IMPURE, SANDY TO SHALY LIMESTONE
				150-250		BENTON FORMATION	CARLILE SHALE	DARK GRAY SHALE WITH CONCRETIONS
				50-80			GREENHORN LIMESTONE	THIN BEDDED GRAY LIMESTONE WITH BLACK SHALE INTERLAYERED
				150-160			GRANEROS SHALE	DARK GRAY SHALE
				80-100			DAKOTA SANDSTONE	GRAY TO BUFF SANDSTONE, HARD, MASSIVE, LOCAL CONGLOMERATE
		LOWER (COMANCHE)		0-140			PURGATOIRE FORMATION	GRAY SANDSTONE, WITH DARK SANDY SHALE OVERLYING
	JURASSIC			150-300			MORRISON FORMATION	PALE GREENISH-GRAY CLAY OR SHALE, LIGHT COLORED SANDSTONE & THIN MAROON SHALE LAYERS ALTERNATELY
				0-10			TODILTO LIMESTONE	THIN BEDDED GRAY LIMESTONE LOCALLY SANDY
				0-100			WINGATE SANDSTONE	MASSIVE, LIGHT GRAY TO LIGHT RED SANDSTONE HARD & CROSS-BEDDED
	TRIASSIC	UPPER		500-700	DOCKUM GROUP			RED SHALE WITH RED, BROWN, & GRAY SANDSTONE, IN SUCCESSIVE LAYERS
				100			SANTA ROSA SANDSTONE	DARK GRAY SANDSTONE, PROMINENT CLIFF MAKER
		MIDDLE		50-200				RED SANDY SHALE
		LOWER						
PALEOZOIC	PERMIAN	UPPER						
		MIDDLE						
		LOWER		0-400	MANZANO GROUP	CHUPADERA FORMATION	SAN ANDRES LS.	GRAY THIN BEDDED LIMESTONE WITH SHALE & SUBORDINATE GYPSUM LAYERS
				600-800			YESO FORMATION (GLORIETA SANDSTONE)	BUFF COLORED CROSS BEDDED SANDSTONE WITH THIN LIMESTONE & GYPSUM AT TOP. SOME SOFT RED SANDSTONE.
				600-800			ABO SANDSTONE	SANDSTONE, BROWNISH RED, MOSTLY HARD AND SLABBY WITH RED SANDY SHALE LAYERS
	PENNSYLVANIAN	UPPER		600-2500			MAGDALENA LIMESTONE	LIMESTONE WITH BEDS OF SHALE, SANDSTONE, AND ARKOSE IN UPPER PART.
		MIDDLE						
		LOWER						
	PRE-CAMBRIAN							SCHIST, GNEISS, SLATE, QUARTZITE, GRANITE, DIABASE, ETC.

COMPOSITE STRATIGRAPHIC SECTION IN NORTHEASTERN NEW MEXICO

Descriptions of the various rocks have been worked up from the author's field observations and in large part from the more detailed descriptions by Graton,[5] Darton,[6] Winchester,[7] and Heaton.[8]

PRE-CAMBRIAN ROCKS

The prevailing pre-Cambrian rock of the region is schist, with which are associated in varying proportions gneiss, slate, quartzite, coarse red intrusive granite, and diabase or gabbro sills which have been folded and metamorphosed with the enclosing sediments.

The pre-Cambrian rocks are bared by erosion in two northerly-trending exposures in the southern prolongation of the Rocky Mountains. The westernmost of these exposures forms the core of the Truchas Range in the extreme western part of Mora and San Miguel Counties. The second exposure constitutes the core of the Rincon Range, east of the Truchas Range but still in western Mora and San Miguel Counties. A small window of pre-Cambrian rock is exposed in the valley of the Pecos River, between the Truchas and Rincon Ranges, at Tererro, the location of the Pecos mine of the American Metal Co. A fourth exposure is found in the east slope of the Rincon Range, northwest of Las Vegas where faulting and erosion have bared the pre-Cambrian rocks at Montezuma Hot Springs and in the face of the main fault scarp west of Las Vegas.

Very little detailed study has been made of the pre-Cambrian rocks anywhere in New Mexico, but the following relations appear wherever those rocks have been exposed in the State.[8a] Most of the granite cuts the schist and quartzite. Some of it, however, may be older than the metamorphosed sediments, and it is also known that there are granites of post-Cambrian age. The basic diabase and gabbro are younger than the metamorphosed sediments and intrude them as sills and dikes. Some of these sills are older than at least a part of the metamorphism, as they have been folded and altered along with the folding of the sediments.

Although the pre-Cambrian is exposed in the western mountainous part of the region, it is completely covered elsewhere. Through the logs of drill holes, however, Darton has constructed a generalized underground contour map [9] of the supposed surface of the pre-Cambrian in the northeastern part of the State, which

---

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

[6] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, 1928.

[7] Winchester, Dean E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines, Bull. 9, 1933.

[8] Heaton, Ross L., Ancestral Rockies and Mesozoic and Late Paleozoic stratigraphy of Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 17, no. 2, 1933.

[8a] Just, Evan, Geology and economic features of the pegmatites of Taos and Rio Arriba Counties, N. Mex.: N. Mex. Bur. Mines, Bull. 13.

[9] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, pl. 60, 1928.

indicates that this surface is nowhere very deep. There is some question, however, as to the accuracy of the interpretation of some of the well cuttings, and what has been called granite may in some instances be arkose or granite wash which was deposited in later Pennsylvanian or Permian time. Plate 4 is a revision of Darton's map of the pre-Cambrian surface with modifications and additions to date, obtained from the logs of 45 additional wells.

SEDIMENTARY ROCKS

The sedimentary rocks in northeastern New Mexico range in age from lower Pennsylvanian to Recent. (See Plates 2 and 3). Plate 5 presents several sections studied in the field and prepared by the writer from the areal map, numerous field sketches, and from the logs of drill holes.

PENNSYLVANIAN SYSTEM

Rocks of Pennsylvanian age (Magdalena group) constitute a prominent feature of the mountainous part of Mora and San Miguel counties. Darton states that, farther to the east, the Magdalena group is absent from most of the northeast part, where deep borings have passed through what are probably Chupadera or Abo beds (Permian), directly into granite. However, it is not certain that this is the case, and it is now suspected that many of the deep holes have stopped in granite wash of lower Abo or upper Magdalena age, and that there may be limestone of Magdalena age in place underneath.

Limestone is the principal rock of the Magdalena group, but sandstones and shales are interbedded. Gray and red sandstones predominate along the east side of the Sangre de Cristo Mountains in the northern part of the region. Elsewhere the sediments of this age, if present, are buried under more recent deposits. The thickness of the Magdalena group ranges from 600 to more than 1200 feet; near Pecos in San Miguel County a thickness of 1237 feet has been determined.

PERMIAN SYSTEM

Abo sandstone.—The red strata of the Abo sandstone, the basal formation of the Manzano group, appear at the surface around the south end and east side of the Sangre de Cristo Mountains (Rincon Range); the outcrop runs from Pecos in the western part of San Miguel County to Mora in Mora County. In places where the contact is visible the Abo appears to lie unconformably on the Magdalena group, but this contact is none too clear at any point within the northeastern region.

In general the Abo sandstone is a slabby red to brown sandstone with which considerable red sandy shale is included. The thickness of the formation ranges from 600 to 800 feet in this region.

Chupadera formation.—The Chupadera formation is the upper formation of the Manzano group, and in many places consists of the San Andres limestone above and the Yeso formation below. These divisions are not always separable, however, and even where differences exist, the change does not appear always at the same horizon. In northeastern New Mexico the Chupadera thins out and the most prominent member is a hard sandstone known as the Glorieta sandstone at the base of the formation, with thin shaly gray limestone and some gypsum above. The Glorieta sandstone is the prominent outcrop of the Glorieta mesa, where it forms the south wall of the canyon through which the Santa Fe railroad passes between Lamy and Chapelle. South of Ribera it makes both walls of the canyon of the Pecos River through Villanueva to Anton Chico. The Glorieta sandstone is further exposed by the erosion of several anticlines near Santa Rosa, as in the Pecos River canyon east of Dilia, at Puerto de Luna and at Guadalupe in Pecos River canyon south of Santa Rosa, and at San Ignacio in Pintada Canyon west of Santa Rosa.

Along the east slope of the Rincon Range, at about the Mora County line, the Glorieta sandstone seems to thin out; however, its disappearance may be due to overthrusting of the high granite block on the west along a high-angle reverse fault. This matter is discussed more fully under the heading of structure (see pp. 28-30). The overlying limestone member of the Chupadera thins out and is no longer visible in the steeply dipping beds west of Las Vegas.

TRIASSIC SYSTEM

Dockum group.—Most of northeastern New Mexico is underlain by a thick succession of redbeds that are continuous with the Dockum group of western Texas and Oklahoma.[10] Red shales and red sandstones predominate in this group, but some of the members are gray to brown in color. Near the base of the group is a prominent dark gray sandstone about 100 feet thick, the Santa Rosa sandstone, which has had considerable local influence in determining the topography.[11] At Santa Rosa this sandstone is underlain by 200 feet of red shale, but elsewhere this shale is thinner. In the vicinity of Santa Rosa and to the north, this formation is overlain by red shale, red, brown, and gray sandstone in successive layers having a total thickness of about 500 feet. They are exposed in the bluffs along the Canadian and Conchas Rivers. The Dockum beds reach a maximum thickness of about 1000 feet. Fossil bones found in the Dockum group at several localities, mostly in the Canadian and Conchas Valleys, are regarded as being of Upper Triassic age. Fresh water shells

[10] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 32, 1928.

[11] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 183, 1922.

have also been found, a few miles south of Santa Rosa and about 30 miles southeast of Las Vegas.[12]

JURASSIC SYSTEM

Wingate sandstone.—The Wingate sandstone crops out in the east front of the Rocky Mountain uplift in the vicinity of Las Vegas; from that point the outcrop swings southward, eastward, and northward in the front of the Canadian Escarpment, extending to a point near Bueyeros in Ute Creek Canyon. It is also visible in the outliers south of the Canadian Escarpment and south and west of Tucumcari, including Cerro Cuervo and a mesa south of Montoya. East of Bueyeros and south of the outliers near Tucumcari, the Wingate sandstone apparently thins and disappears. The Wingate appears to be absent also from the northeastern corner of New Mexico in the valley of the Cimarron River. In all the exposures it is a massive compact moderately hard cross-bedded sandstone. It is white, pink, salmon, and light red in color, and is generally exposed in the full thickness of the formation, as shown in the striking bluffs that form the canyon walls in the arroyos and river valleys of this region. The upper part of the Wingate sandstone over a large part of the area is white, buff, or yellowish in color.

The lower contact of the Wingate sandstone is an abrupt one owing to the sharp difference in character between the underlying Dockum beds and the Wingate sandstone, although there is little change in the attitude of the beds above and below the contact. Neither is there much accumulation of coarse deposits in the base of the Wingate nor evidence of erosional scour and fill at the top of the Dockum beds. The thickness of the Wingate sandstone in this region ranges from 100 feet near Las Vegas to 80 feet in the Canadian Escarpment; it thins and disappears near Tucumcari and east of Ute Creek.

Morrison formation.—The Morrison formation is present over much of northeastern New Mexico and shows extensive outcrops in the steep bluffs of the Canadian Escarpment, in the outliers west and south of Tucumcari, in the bluffs of the Cimarron River and Ute Creek in Union County, and in the neighborhood of Las Vegas.

At the base of the Morrison is a thin limestone that disconformably caps the Wingate sandstone through most of its extent in northeastern New Mexico. This is the Todilto member, which is visible above the Wingate in the Las Vegas region and along the south front of the Canadian Escarpment. It is visible in Cuervo Hill northeast of Santa Rosa, but it thins and disappears northwest of Tucumcari, and it does not extend quite as far to the east as does the Wingate sandstone. Its northern

[12] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 32, 1928.

limit is not definitely known but it does not appear in Mora County. Its maximum thickness in most places is not more than 10 feet. Locally this thin-bedded limestone member is sandy. The Todilto limestone, in northeastern New Mexico, does not show the gypsum capping that is common elsewhere in the State.[13]

The main body of the Morrison consists chiefly of pale greenish-gray clay or massive shale with thin maroon layers alternating. It includes also some light colored sandstone, part of which has a greenish-gray tint. It contains also a few thin beds of limestone of a concretionary type, and in the northeastern part, some reddish chalcedony concretions. The average thickness of this part of the Morrison is 150 feet, but it varies considerably from place to place.

Darton[14] included the Morrison formation as doubtfully Cretaceous, because of lack of precise evidence regarding the vertebrate remains that it contains. More recent work, however, tends to place it at the top of the Jurassic, a position which has been accepted in these pages.

CRETACEOUS SYSTEM

Rocks of Cretaceous age are widespread in northeastern New Mexico where they cover nearly three-fourths of the surface of the region. The oldest formation in the Cretaceous succession is the Purgatoire, which represents late Lower Cretaceous (Comanche) time. The Upper Cretaceous consists of Dakota sandstone at the base, with the shales and sandstones of the Colorado and Montana groups overlying in that order.

Purgatoire formation (Comanche).—The plateaus of northeastern New Mexico are underlain by Lower Cretaceous shale and sandstone, which are extensively exposed near Las Vegas in many canyons, in the southern face of the Canadian Escarpment, and in the several outliers south and west of Tucumcari. The Purgatoire is also well exposed in the bluffs that border the Cimarron River in the northeastern corner of the State.

This formation consists of a lower member of gray massive sandstone very similar in appearance to the Dakota sandstone of the region. The upper member of the formation consists of dark sandy shale. The average thickness of the formation is about 150 feet although local sections may differ both in lithology and in thickness. The Purgatoire rests on the clays of the Morrison formation or on the Todilto limestone, and is overlain by the Dakota sandstone.

Dakota sandstone.—Throughout northeastern New Mexico the basal formation of the Upper Cretaceous succession is a hard gray massive sandstone known as the Dakota sandstone. It is

[13] Darton, N. H., op. cit. p. 35.
[14] Darton, N. H., op. cit. pp. 37-38.

the surface rock of much of the Canadian Plateau area in Union and Mora Counties, and its exposures extend southward into San Miguel and Harding Counties to the Canadian Escarpment. It constitutes the surface rock of outliers to the south and west of Tucumcari, and it outcrops in the bluffs of the Llano Estacado in Quay and Guadalupe Counties. Its thickness ranges from 80 to 100 feet. In western Harding and Mora Counties the Dakota is concealed beneath the shales of the Colorado group, but the formation appears also along the east front of the Rocky Mountains near Las Vegas, where the beds are sharply upturned against the upthrown granite core of the Rincon Range. Locally the Dakota sandstone contains conglomerate, especially at its base.

Colorado group.—In northeastern New Mexico the divisions of the Colorado group are the same as those recognized in eastern Colorado. They continue southward into the Las Vegas region, and are also found as residual outliers on the Dakota sandstone at several places on the Canadian Plateau as far east as the Oklahoma State line, and southward almost to the Canadian Escarpment.

The basal formation is the Graneros shale, 150 to 160 feet in thickness and dark gray in color. Next above the Graneros is the Greenhorn limestone, 50 to 80 feet in thickness. The Greenhorn limestone is overlain by the Carlile shale, dark gray in color, which ranges in thickness from 150 to 250 feet. These three formations, the Graneros shale, the Greenhorn limestone, and the Carlile shale are the equivalent of the Benton shale formation of other regions.

Overlying the Benton formation is the Timpas limestone 50 feet thick, and the Apishapa shale 500 feet thick. These two members are known collectively as the Niobrara formation.

The Graneros shale is extensively exposed east of Wagon Mound, where its base lies on the Dakota sandstone in the slopes near the edge of the canyon of the Canadian River in Mora and Harding Counties.

The Greenhorn limestone consists of a succession of thin beds of limestone separated by thin layers of black shale. Many of the layers contain large numbers of *Inoceramus labiatus*, a highly characteristic fossil. The Greenhorn is exposed along the west side of the Canadian Valley east of the Atchison, Topeka & Santa Fe main line tracks from the Mora County line to Wagon Mound, and it is visible also in the railroad cut and along the highway leading north out of Las Vegas.

The overlying Carlile is a dark gray shale which contains many characteristic fossils and many biscuit-shaped concretions. Remnants of the Carlile generally overlie the Greenhorn limestone, wherever this member is present.

Outliers of the Colorado group, near the Canadian Escarpment and in the Clayton region, generally consist of small residual patches of Graneros shale capped by erosional remnants of the more resistant Greenhorn limestone. See map, Plate 3, for the locations of these outliers in San Miguel and Mora Counties.

The Timpas limestone crops out on Ocate Creek a short distance east of Colmor in northern Mora County. Next above this limestone is the Apishapa shale, which crops out along the Canadian Valley on the west side. The upper contact of the Apishapa is very indefinite as it appears to grade into Pierre shale of the Montana group in this region.

Montana group.—In northeastern New Mexico the Montana group, with its divisions, is the same as that recognized in southeastern Colorado, and the divisions are similarly named.

The basal formation is the Pierre shale, dark gray in color and of undetermined thickness in this region; it may be as much as 1800 feet thick where it crops out east of Las Vegas.[15] Although predominantly composed of dark gray shale, the Pierre is characterized by a small number of thin limy beds near its base, and by a few thin sandy beds in its upper part. The Pierre shale crops out east of Las Vegas, and it is probably present in scattered residual masses in northern Mora County and in western Harding County.

The upper Montana formations, the Trinidad sandstone and the Vermejo formation, are not present in the region described in this report.

TERTIARY SYSTEM

The Raton formation, of lower Eocene age, is absent from the region covered by this report. Ogallala beds, of Pliocene age, are extensively developed in the eastern and southern parts of the region, and are found in the plains section as the surface covering of the gently rolling hills in Union, Harding, Quay, and Guadalupe Counties. Small residual patches of the Ogallala formation are found also in the eastern part of Mora and San Miguel Counties.

Ogallala formation (Pliocene).—This formation consists of a mantle of gravel and sand covering the High Plains over a vast extent of western Nebraska and Kansas, eastern Colorado, and northwestern Texas, and extends approximately 125 miles into New Mexico. On the Llano Estacado it forms a thick covering in most places. Small areas of sand and gravel occur on the Canadian Plateau, near Roy and Mills in Harding County, and probably the high terrace remnant just north of Sapello, in San Miguel County, is an outlier of the Ogallala. In general the Ogallala formation is believed to be equivalent to part of the Santa Fe formation of the Rio Grande trough.

[15] Darton, N. H., op. cit., p. 43.

QUATERNARY SYSTEM

Deposits of Pleistocene and Recent ages include: valley fill material consisting of gravel, sand, and clay; alluvial deposits that occur along most of the streams in the region; and drifting sand dunes that have developed in the plateau and plains areas, particularly in the region surrounding Clayton on the edge of the "Dust Bowl" area. The thickness of the valley fill of Pleistocene age is variable and reaches several hundreds of feet, as shown in water wells. The local alluvial deposits of sand and gravel, and the sand dunes, do not attain a thickness of more than a few feet.

IGNEOUS ROCKS

Igneous rocks, most of which are volcanic, are extensively exposed in northeastern New Mexico. A few intrusive rocks are present, the larger masses of which are related to some of the ore deposits of the region.

INTRUSIVE ROCKS

In the region discussed in this report, several exposures of intrusive rocks are known. Most of these are of pre-Cambrian age, although other occurrences are of Cretaceous, Tertiary, and Quaternary ages.

The pre-Cambrian granite masses are intrusive, and where exposed they are seen to cut gneiss, schist, quartzite, and the other pre-Cambrian rocks. In the pre-Cambrian rocks, there are also several occurrences of diabase dikes and sills which appear to be older than the granite intrusive masses. Darton [16] mentions syenite, amphibolite, porphyry, and other intrusions in the pre-Cambrian; these appear to be of pre-Cambrian age, but some are said to cut the granite intrusives. Examples of these pre-Cambrian intrusive rocks are the diabase sills and dikes found in the Willow Creek and Rociada mining districts, and the large masses of intrusive granite seen in the Willow Creek, Rociada, and Porvenir districts.

Sedimentary rocks, ranging in age from Pennsylvanian to Cretaceous, are cut by porphyry and other igneous rocks in the form of dikes, sills, and stocks. Examples of such intrusives are the dike cutting Cretaceous shales 4 miles east of Las Vegas, which Ogilvie [17] found to be an analcite-bearing camptonite; a dike of basic rock cutting Cretaceous beds 6 miles north of Las Vegas; and a third dike, striking north 10°–20° east for more than 15 miles, which cuts the Triassic beds on the west side of Cerro Cuervo, north of Los Tanos, in Guadalupe County.

---

[16] Darton, N. H., op. cit. (Bull. 794), p. 60.

[17] Ogilvie, I. H., An analcite-bearing camptonite from New Mexico: Jour. Geology, vol. 10, pp. 500-507, 1902.

VOLCANIC ROCKS

A large area in northeastern New Mexico is covered by products of volcanic eruptions that occurred mainly in late Tertiary and Quaternary time. No great degree of regularity appears to be established in the sequence of these flows, and outpourings of similar material appear to have erupted at various times. In general, older flows occupy higher positions, topographically, than do younger flows; flows that have been tilted are older than those that still remain in the original position of placement; and the younger flows, in addition to being in a lower topographic position and untilted, occur in places as long flows down canyons which had previously been eroded through the sedimentary strata. In general it has not been possible to separate late Tertiary outflows from those of early Quaternary time, especially the basalts that cap the high mesas. Tilted flows are regarded as being of pre-Quaternary age.[18]

The earliest volcanic outflow in northeastern New Mexico is probably that which now constitutes the Sierra Grande south of Des Moines. How far the flows from this center of extrusion originally extended is unknown, as the pile of volcanic material has been extensively eroded and was later surrounded and partly covered by basaltic lava from the Capulin volcanic cone to the north. The material of the Sierra Grande volcanic pile is andesite.

An example of intrusive rock is the feeder, or neck, of basic rock which is supposed to underlie the volcanic mass of similar rock which constitutes Sierra Grande, in Union County. This rock has been mapped by Darton as being of Tertiary age because it cuts the Dakota sandstone and apparently rests on it, while at the same time it is surrounded and partly covered with basic flow rocks of Quaternary age.

The next younger flows are of olivine basalt covering large plateau areas in Union, Mora, and Harding Counties. These flows are post-Cretaceous; in every locality noted they rest upon beds of Upper Cretaceous age. In the Raton coal basin of Colfax County, outside the region described in this work, flows similar in appearance and attitude occupy the tops of plateaus and rest on Tertiary beds. It is probable, therefore, that the large basalt flows described above are early Quaternary in age.

A third series of flows, represented by those from the Maxson cone north of Shoemaker and from the Capulin volcanic cone west of Des Moines, appear to be of late Quaternary age. Lavas from the Maxson cone have flowed down the canyon of the Mora River and thence into the canyon of the Canadian River for a distance of about 12 miles below Sabinoso, and are here seen to rest on Dockum beds of the Triassic system. Lava from the Capulin volcanic cone has spread widely over the surrounding

[18] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 62.

terrane in western and central Union County, and one arm of one of these flows has followed the canyon of the Cimarron River, which had previously been cut down through beds of lower Cretaceous, Jurassic, and Triassic ages to expose the Santa Rosa sandstone in the floor of the canyon. Later stream erosion by both Mora and Cimarron Rivers has cut through these lavas, to again expose the sediments over which the lavas flowed and upon which they came to rest. Several small volcanic cones are visible on the horizon in the region of the Capulin volcanic cone, to the north, east, and south.

STRUCTURAL FEATURES

The sediments over the greater part of northeastern New Mexico dip very gently to the southeast, and strike between 15° and 30° east of north. In western Mora and San Miguel Counties, the general strike of the beds is 15° east of north, but dips close to the granite core of the mountain ranges have been steepened by upheavals until the beds approach vertical and in some localities are even overturned. The map, Plate 3, and the geological cross-sections shown on Plate 5 bring out these general relationships quite clearly. The surface slope of the region is in the same general direction as the dip of the sediments but at a slightly higher gradient, 40 feet to the mile, so that, in general, erosion has exposed older beds in the southeastern portion of the region, with younger beds remaining in place in the northwestern part. Exceptions to this general statement are evident in two places. The Ogallala sands, of Pliocene age, and the more recent sands covering the plains area to the east, lap up over beds of Dakota sandstone, and Dockum beds of Triassic age, in the eastern, southeastern, and southern parts of the region. The second exception is in the western part, against the faulted massifs of the Rincon and Las Vegas Mountains, where the upturned beds are exposed through the entire thickness of the stratigraphic sequence down to the Pennsylvanian sediments, which in this region lie directly on the pre-Cambrian basement rocks.

THE MOUNTAIN AREA

The mountain area in this region lies above the 7000 foot contour as shown on the index map, Plate 1. This mountain area covers the extreme western parts of Mora and San Miguel Counties west of the cities of Mora and Las Vegas. Within this area the rocks to the west have been repeatedly faulted and lifted above the plateau area that lies to the east of the 7000 foot contour.

In this mountain region, the first event in the building of the present ranges was the arching and folding of the beds into a huge anticline which had a pitch to the south; the map (Plate 3) shows how the sediments curve about the southern nose of the structure. Continued elevation of this arched structure finally resulted in its rupture along three major planes, as shown on the map and sections, plates 3 and 5.

The easterly plane of rupture is just west of the city of Las Vegas. Here the sediments, from Cretaceous to Pennsylvanian, are upturned and locally overturned on the east wall of the fault, while on the west the beds have been domed in such a manner as to show a crescent-shaped exposure of pre-Cambrian rocks in the face of the fault scarp, as viewed from the highway north of Las Vegas. Another exposure of the pre-Cambrian along this same zone of faulting is at Montezuma Hot Springs in Gallinas Canyon. In this canyon the road passes first over flat-lying beds of Carlile shale, Greenhorn limestone, and Graneros shale until close to the zone of faulting. Then the road crosses vertically-upturned beds of Dakota sandstone, and the formations of Jurassic, Triassic, Permian, and Pennsylvanian ages, all greatly fractured and showing much evidence of squeezing and thinning. On the west side of the fault zone the canyon walls are of granite, much fractured, sheared, and weathered. Overlying the granite the faulted block is covered with limestone of Pennsylvanian age, all other sediments having been eroded. From this point, the Pennsylvanian limestone dips gently to the west for 3 or 4 miles; farther west near the next zone of faulting, the dip reverses and increases in steepness, until near the second fault zone the Pennsylvanian beds are again dipping steeply to the east, and locally stand vertically or even overturned.

This second line of faulting extends through Porvenir northward to Pendaries and Mora, where it apparently merges with the first line of faulting north of Mora in the canyon of Coyote Creek. To the south it can be clearly seen again in the canyon of Bernal Creek in the Tecolote mining district (see Fig. 2). Along this fault in the east wall are found the upturned beds of Pennsylvanian limestone, but the west wall is of pre-Cambrian rocks topped with flat-lying beds of Pennsylvanian limestone. In Coyote Creek northeast of Mora, the Permian formation becomes thinner and finally disappears; the Pennsylvanian limestone beds also thin out considerably. Whether this thinning and disappearing are due to non-deposition or to steep reverse faulting was not definitely determined, but the writer is inclined to the belief that these major faults are high-angle reverse faults, and that possibly both non-deposition and reverse faulting enter into the explanation of the disappearance of these beds.

At Gascon, northwest of Rociada, a subsidiary fault again brings granite on the west in contact with upturned Pennsylvanian beds on the east, but the displacement of this fault diminishes rapidly to the north, and while it can still be traced west of Cleveland and Holman, both walls are of Pennsylvanian age at this place. Several smaller faults occur in the pre-Cambrian area between Porvenir, Beulah, and Rociada, accompanied by small plates of limestone overlying the various faulted blocks.

The third major line of faulting extends along the western border of San Miguel County west of Tererro and Winsor's Ranch, and is believed by the writer to be part of the same zone of faulting which is visible along the highway at Glorieta about three miles west of the county line, in Santa Fe County. Here, again, the granite core of the Truchas Range apparently has been brought up on the west in contact with the Pennsylvanian limestone on the east, although a covering of surface wash and plant refuse hides this line of faulting. East of the fault zone, Pennsylvanian beds dip from 30° to 40° easterly, but the dip flattens rapidly to the east and in the valley of the Pecos River, in the vicinity of the Pecos mine, the limestone beds have been but little disturbed, and are flat-lying over the pre-Cambrian basement rocks, with dips ranging from a few degrees up to 12° toward the southwest.

THE PLATEAU AREA

The plateau area lies between 5000 and 7000 feet altitude and covers a broad belt east of the mountain area. (See index map, Plate 1.) It is a region of high expanses of rolling country, surmounted here and there by low mesas and buttes, consisting of residual masses of younger sediments of Benton age, and the remnants of once vast flows of basaltic lava, which appear to have covered, at one time, the greater part of this region. Several volcanic cones are prominent features of the landscape, especially east of Mora in Mora County and in the western part of Union County near Des Moines.

In general, the regional dip is to the southeast at an angle of less than one degree, but the structure of the plateau area is modified by three wide, shallow, synclinal basins, which are recognized on the surface by the residual masses of Upper Cretaceous beds of Benton age, which occupy the basins in the top of the Dakota sandstone. One of these basins lies east and north of Las Vegas in San Miguel County, the second is north of Wagon Mound on the west side of the Canadian River in Mora County, and the third is in Harding County east of the Canadian River and north of Roy. The axis of the Sierra Grande uplift, the largest arch in the region, separates the second from the third of these depressions along the line of the Canadian River.

At many places within this area folding of the surface strata into domes and anticlines is conspicuous. The most spectacular example of this is the great partly eroded dome of Turkey Mountain in Mora County, but at many other places the beds have been warped to a moderate degree, and subsequent erosion has produced rimrock topography surrounding low basinlike areas, at the structural high points of the folds. Most of these folds are included in a zone of flexure, which extends from the Sierra

Grande uplift in western Union County, in a southwesterly direction parallel to the mountain, to the western part of San Miguel County, where the trend of the zone swings to the west around the southern nose of the Rocky Mountains. Most axes of the several structures within this zone are parallel to the trend of the zone, and in the northeast, from Des Moines to Las Vegas, structural axes trend northeasterly, while around the southern nose of the Rocky Mountain uplift, arranged like ripples around the bow of an advancing boat, the axes of the folds lie curved toward the west. A second zone of folding in the surface sediments is found extending from Clayton in eastern Union County, through eastern Harding, eastern San Miguel, and western Quay Counties, but in this zone the trends of the axes of the individual structures do not correspond with the trend of the zone, nor do they correspond with each other. An examination of the structures shown on the Oil and Gas Map of New Mexico,[19] will be of interest in this connection.

It is apparent, from a study of the sections on Plate 5, that surface deformation in this northeastern part of the State is localized over old granite ridges in the pre-Cambrian bedrock. These ridges appear to lie roughly parallel to the trend of the granite cores of the present mountains and they are probably the roots of parallel mountain ranges of the ancient Rocky Mountain system, which were not sufficiently elevated, during the period of orogenesis which formed the present Rocky Mountains, to be exposed at the surface.

The amount of drilling in this region has not been large, and many of the logs on record are not too accurate, yet the data on hand clearly suggest that, during the elevation and formation of the present Rocky Mountains, these ancient buried ridges were involved in the movement to a moderate extent, and were folded, elevated, and in some places slightly faulted. This movement has been reflected in the warping of the sedimentary beds over these ridges, and where faulting in the granite ridges was more severe than usual, the faulting carried through the entire sequence of the sedimentary rocks and is now exposed at the surface, as shown on the map (Plate 3) northwest and southeast of Wagon Mound.

In connection with the ore deposits of the region, this structural picture is highly interesting. In most instances the sedimentary copper deposits lie in one or the other of these zones of folding of the surface beds over the ancient granite ridges, and in more than one of these deposits, faulting is strongly suspected in the granite beneath, and in the lower beds of the sedimentary series.

---

[19] Oil and gas map of New Mexico: N. Mex. Bur. Mines. D. E. Winchester, 1931; revised by A. Andreas, 1936.

THE PLAINS AREA

Where bedrock is visible in the plains area, it consists predominantly of the basal part of the Triassic Dockum group, and in many places the Santa Rosa sandstone is prominently exposed. In eastern San Miguel County and western Quay County, west of Tucumcari, an outlier of the plateau to the north, in the form of a large mesa, exposes in its bluffs the sediments younger than the Santa Rosa, up to Dakota sandstone which caps the mesa. In eastern Guadalupe and southern Quay Counties, the bluffs of the north rim of the Llano Estacado present similar exposures of the younger sediments, up to Dakota sandstone, and this in turn has been covered by sands and gravels of Ogallala age. In the extreme eastern part, in Union, Harding, and Quay Counties, Ogallala beds lap over the older sediments and hide them from view except where an occasional window has been eroded to expose small areas of Dakota sandstone and rocks of the Benton formation. The sections on Plate 5 show that the old granite ridges, described as underlying the plateau area, continue southward, although not so prominently, under the plains area. Folding of the surface sediments into local domes and anticlines is common over the extensions of these buried ridges, but the tendency of these local structures to line up into zones and to maintain parallel axial trends is much less pronounced than in the plateau region.

PART II. MINING DISTRICTS

UNION COUNTY

LOCATION AND AREA

Union County is in the extreme northeastern corner of New Mexico. It has an area of 3877 square miles and a population of 11,036 in 1930, of whom 2515 persons are listed as residing in the city of Clayton. The northern boundary of Union County is the Colorado State line; the county is bounded on the east by Oklahoma to the north and the Texas Panhandle to the south. The southern line is the northern boundary of Quay and Harding Counties, and the western boundary adjoins Colfax County.[1]

GEOGRAPHY

The lowest elevation in Union County is in its southeastern corner, at 4200 feet, while in the northwest portion the Capulin volcanic cone and the Sierra Grande reach elevations of 8200 feet. These, however, are both isolated peaks in the area that is essentially a high plateau or tableland about 6500 feet above sea level. In general the western and extreme northern parts of the county are characteristic of this high plateau type which merges into the rolling plains type of country to the east and southeast (see map, Plate 1). Along the northern boundary of the county, the Cimarron River has cut a deep picturesque canyon, within which are small but comfortable ranches that utilize the water in the canyon. North Canadian River and Carrizo Creek, both dry for most of the year, drain eastward through the central part of the county, but these have not cut deeply into the surface sediments. In the southwestern corner of the county, Ute Creek drains toward the south and in its many branches it has deeply eroded the surface rocks. In the northwestern part of the county the scenic effect is strikingly bare and rugged, with extensive barren wastes of black lava. Above these basaltic flows volcanic cones, both large and small, arise in many places. One of these, the Capulin volcanic cone, is such a perfect specimen of its kind that it has been set aside and improved as the Capulin Mountain National Monument. The greater part of the county, particularly in its central part, is floored with light-colored sandstone which is characterized by an extensive but scattered growth of low bush-like scrub cedar. In the eastern and southeastern parts of the county, a richer type of soil covers the surface and the country assumes the rolling and more cultivated appearance of the plains. During the recent drought, however, eastern Union County became part of the great "Dust Bowl" area and many of the once

[1] Preliminary reports on the 1940 census give population figures as follows: Union County, 9068; Clayton, 3171.

prosperous farms and ranches now lie deserted under a shifting cover of sand which all but buried the farm dwellings and other improvements. Where the Cimarron River and Ute Creek have cut their canyons through the rock strata, a succession of layers of variegated hues has been exposed in the canyon walls, red, greenish-gray, buff, and brown, which with the bright green of cultivated fields and the somber green of the scrub cedars high on the rimrock make these canyons extremely beautiful.

GEOLOGY

The greater part of Union County is floored with light gray to buff Dakota sandstone, which supports a characteristic growth of scrub cedar wherever this rock crops out. In several places younger sediments of the Benton formation (Upper Cretaceous) are found as residual patches overlying the Dakota sandstone, as at Emery Gap, Moses, Clayton, and Pasamonte. In the northwestern, central, and southwestern parts of the county, numerous flows of olivine basalt have covered the sediments; subsequent erosion has removed this basalt, except for patches which now cap the buttes and plateau areas. Numerous volcanic cones in the region suggest that there were many sources for this lava. The basalt is now exposed in detached and isolated residual masses as at Bueyeros; in other places, the lavas poured out and came to rest in deep canyons, as in the canyon of the Cimarron near Folsom. The erosional work of the Cimarron River to the north, and of Ute Creek to the south, has exposed sections of the older rocks in the walls of the canyons to depths of several hundreds of feet. At the base of the Canadian Escarpment, exposures of Santa Rosa sandstone are visible in the floor of the valley. In the face of the escarpment, in Ute Creek, and in the Cimarron canyon, are to be found in ascending order: red sandstone and shale of the Dockum group, white to red sandstones and a thin gray limestone of Jurassic age, greenish-gray shale and clay streaked with numerous thin maroon shale layers and thin beds of light colored sandstone which are typical of the Morrison formation, and on top, the sandstones of Purgatoire and Dakota age. In the eastern part of the county, Tertiary sands and gravels of the Ogallala formation lap over the older sediments to form the rolling hills of the plains area, and a few isolated patches of the Ogallala formation, and of more recent material, overlie the Dakota sandstone in the western and southwestern parts of the county.

STRUCTURE

No faulting is evident in Union County. The sediments lie nearly flat, with very slight dips to the southeast, but locally they have been warped into anticlinal or domed structures. These have since been subjected to erosion, so that at the present time, in the majority of instances, the younger beds are visible in the local bluffs or rimrock surrounding eroded or topographic low areas. Northwestern Union County appears to have been a zone of structural weakness and the sediments have been warped up in the prominent Sierra Grande uplift, the axis of which trends southwesterly between the Capulin volcanic cone and the Sierra Grande. On the flanks of this uplift are to be found many low volcanic cones, most of them of Quaternary age, but the Sierra Grande is probably of Tertiary age; beneath these cones channels must have connected with a deep seated reservoir of magma. It seems probable that the present Sierra Grande overlies a spur of the ancient Rockies, which once existed as an old land mass. At other localities in the county warping of the sediments has been noted, as at two places in the walls of the Cimarron canyon, and near Pasamonte, Tate, and Clapham[20] in the southern half of the county. Other structures of this sort are probably present in the county, evidences of which are visible from the highways. As yet these structures have not been mapped.

MINERALIZED DISTRICTS

FOLSOM

Reports of gold strikes in the valley of the Cimarron River, 20 miles northeast of Folsom, date back to 1897, according to Mr. E. J. Young, manager of the telephone system at Folsom. Copper deposits in the sediments, similar to those found in Cimarron canyon north of Clayton, have been found in the same canyon near the site of the gold discoveries. For the location of the mining districts, see map, Plate 1.

The Folsom district is in an area of basaltic lavas, which have welled out from the Capulin volcanic cone and other lesser vents to cover an extensive area. At scattered localities small stringers of quartz have been found cutting across these lava flows in irregular directions, and in some of these stringers small quantities of gold have been reported. At no place, however, so far as the writer has been able to determine, has a body of mineralized rock been found of sufficient size and metal content, so that shipments could be profitably made from it. Gold in the basalt has been reported from many places in this district, and old assessment holes in the malpais are a common sight. These workings follow the stringers and veinlets of quartz, and it is reported that assays as high as one ounce gold per ton have been returned. The writer was unable to verify these figures as to the metallic content of the quartz veinlets, and in his opinion, the chance that such high assays would be repeated is most unlikely. In a few places, sediments derived from the weathering of these lava beds and their mineralized stringers have contained small amounts of gold in the form of placer deposits, but in these also, the amount

[20] Winchester, Dean E., Oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, p. 138, 1933.

of gold is negligible, the individual grains of the metal are very small and much flattened, so that apparently there is only slight chance of such placer deposits proving valuable.

In the canyon of the Cimarron River, about 15 miles northeast of Folsom, this basaltic lava has flowed for several miles within the canyon, and it is in this arm of the flow that the original discovery of gold is said to have been made. The vein which caused the greatest excitement at the time of its discovery occupies a crevice that ranges from 6 to 18 inches in width, in which the gold values were reported to be high but very spotty. It was further reported that the ranchers in the region bought off the discoverers of the vein in order to prevent the land being classified as mineral land, but it seems more probable that the vein soon proved to be of no commercial value.

Farther east in the Cimarron canyon the river passes beyond the limits of the basalt flow, and has trenched deeply into the redbeds of the Dockum group. Here, at several places within a few miles, the rocks in the canyon are stained green and blue by malachite and azurite. Also, in places small nodules of chalcocite coated with malachite can be found in the beds of gray sandstone, which are here interbedded with the normal red and brown shales. Prospecting has been conducted in these beds in the past, but evidently no deposits of commercial size were found, for the workings are of small extent and have been idle for many years.

Several years ago, according to Mr. Young, preparations were made to develop the gold and copper deposits of this district, but after a small amount of preliminary work, the venture was abandoned. Only a few prospect holes, tunnels, and open cuts have been dug in this district, there is no history of any ore having been shipped, and all of the claims appear to have been long since abandoned. Silver and lead have been reported, but this report was not verified.

BLACK MESA

The Black Mesa district lies in the steep and narrow valley of the Cimarron River, in the northeastern part of Union County, and includes the old Bob Wagner ranch in Secs. 33 and 34, T. 32 N., R. 35 E., on which most of the active work of development in this district was performed.

The floor and lower walls of Cimarron Canyon consist of red to brown sandstones and shales of the Dockum group. Overlying the rocks of the Dockum group are those of the Jurassic system including typical exposures of the Morrison formation, and at the crest of the bluffs the Dakota sandstone forms the rimrock. The strata here are flat-lying or gently undulating without evidence of pronounced structural warping, although to the east of the district about 6 miles the Cimarron Valley anticline shows in the walls of the canyon, and to the west of the district about 8 miles the Cimarron dome is similarly visible. In the walls of the canyon, at the level of the valley floor, a gray shaly sandstone member is visible and in the open valley several small residual hills formed of this same material project above the valley floor. It was in one of these small hills, located on the south bank of the river channel on the Wagner ranch, that copper staining was first investigated, and most of the subsequent work in the district was performed. Copper staining was found also in the walls of the canyon nearby; at several places in the canyon between Black Mesa and the Folsom district, outcrops of this same bed of sandstone show irregular copper staining. It is also reported that many similar outcrops, generally copper stained, are to be found to the eastward for a considerable distance beyond the Oklahoma line.

At the surface, the ore consists of particles of malachite and azurite impregnating the rock and apparently replacing the cementing material between the grains. In places carbonaceous material, such as leaves, stems and tree fragments, has been replaced. Melaconite, the black earthy oxide of copper, is also present in these ores, particularly in association with replacements of the organic material. The writer saw no evidence of chalcocite or other sulphide minerals in the surface outcrops of these ores, and in general these outcrops had the appearance of being much more thoroughly oxidized than the outcrops of similar deposits elsewhere in the region.

Specimens of ore from underground show that the great bulk of the mineralization is malachite and azurite with some chrysocolla, and that many particles contain small relict cores of sooty chalcocite. No native copper, chalcopyrite or bornite was observed by the writer. Mr. J. H. Dean and Col. J. M. Potter, both of Clayton, stated that the ore from the upper levels contained native copper associated with the malachite and azurite, but no sulphides; later reports speak of deeper-level ores as containing malachite, azurite, melaconite, chalcocite, chalcopyrite, bornite, and pyrite.

The deposit was probably discovered about 1900, and the Old Hickory Mining Co. was formed. This company was later absorbed by the Copper Chief Mining Co., which in turn was absorbed by the Sater Copper Co., and finally all holdings were absorbed by the Fort Pitt Copper Co. The Copper Chief Mining Co. was organized in 1901 with a capital of $500,000 to take over the Old Hickory Mining Co. holdings of 10 claims. This company claimed to possess a ledge of ore 1800 by 6000 feet in area and with a depth of 100 feet, assaying 5 percent copper, $2 in gold and 50 ounces in silver per ton. A tunnel was driven to a distance of 250 ft. for the purpose of blocking out ore reserves, and a concentrating plant was built.

The Sater Copper Co. was organized in 1903 with a capital of 2,500,000 shares, par value $1 per share, and at this time the property consisted of 20 claims and a 5-acre smelter site. A shaft, sunk by this company in the most conspicuous outcrop in the canyon, is reported to be 380 feet deep and is said to have a moderate amount of drifting from it at level intervals of 50 feet. The tunnel mentioned above was extended to 300 feet and about 500 feet of development work was performed adjacent to it. Several other shallow shafts and short tunnels were driven to prospect for ore, but at present these are all caved and inaccessible. Veins were reported in the sandstone, of which four were said to average 25 feet in width and to assay 18 percent copper, $2 in gold, and 7 ounces in silver, and it was stated that the ore consisted of carbonates at surface and sulphides at depth, while two other veins, reported as being 6 feet wide, were said to be equally rich. At one time the company reported having 2,000,000 tons of ore blocked out, which, of course, was impossible with the amount of development listed and its location on the property. This company came to grief through internal bickering in about three years time and the property was shut down.

In 1907 the Fort Pitt Copper Co. was organized with a capital of $2,500,000 with shares of $5 par value. This company acquired 27 claims in the district including all property held previously by former companies. The property was reported to contain seven fissure veins in sandstone, of which two were said to be 6 feet wide and to contain 14 percent copper and 15 ounces of silver per ton. Development on the property at this time consisted of shafts 85 and 380 feet deep, and of tunnels 25, 50 and 300 feet long. Ore reserves were stated to be 60,000 tons but even this greatly reduced estimate appears to have been exaggerated. The improvements on the property consisted of five buildings, a 190-H.P. steam plant, and two hoists. Activity in the district continued sporadically until 1913, when work was finally discontinued, and at present the buildings are dismantled or in bad repair and all workings are caved and full of water.

Attempts to develop this deposit have been attended by numerous machinations. In this connection, a statement by Stevens [21] concerning the Fort Pitt Copper Co. is worth quoting:

> The prospectus of the company, written by a cheerful liar, states that not one of the great mines of the United States has as great a percentage of copper as the Fort Pitt, and that there is a greater value back of this stock than any stock on the market, and that it is as safe as real estate, with ten times the earning power, all of which statements are unmitigated prevarications. By reason of its bad antecedents and wilful lies, the company is considered a swindle.

Such evidence as could be gathered on the surface indicates that this deposit is contained in a flat-lying, rather thin bed of shaly sandstone, and that the mineralization is weak and irregu-

[21] Stevens, Horace J., The Copper Handbook: pp. 818-819, 1911.

larly distributed throughout the bed. When the price of copper is high, a small group of individuals might profitably work the several outcrops by close sorting and use of low-cost methods, but for a company organization to attempt to operate this deposit at a profit is, in the writer's opinion, hopeless.

MORA COUNTY

LOCATION AND AREA

Mora County is in the extreme northwestern corner of the region treated in this report. It has an area of 1854 square miles and a population of 10,322 at the last official census (1930) of whom 606 persons are listed as living in the city of Mora and 852 as residents of Wagon Mound. The County is bounded on the north by Colfax County, on the east by Harding County, on the south by San Miguel County, and on the west by Santa Fe and Taos Counties.[1]

GEOGRAPHY

The lowest elevation in Mora County is in its southeastern corner in the valley where the Canadian River passes into San Miguel County at an elevation of 4920 feet. The highest part of the county is in its western part where the Truchas Range, the Sangre de Cristo Mountains, and the peaks of the Rincon Range rise to heights of 12,464 feet in the extreme southwestern corner, and range between 11,808 and 10,500 feet along the entire western border. The mountain area above the 7000 foot contour includes the western half of the county, while the plateau area, below 7000 feet and above 5000 feet includes the eastern half (see Plate 1). In the western part the mountain ranges trend slightly east of north, with parallel narrow valleys between the upthrust mountain blocks. The location of these ranges with their intervening valleys controls the drainage pattern of the region. Coyote Creek lies east of the Rincon Range and flows south and southeast to join the Mora River in the southern part of the county. Mora River heads on the western slope of the Rincon Range, flows south to Mora, and then eastward through a break in the range at La Cueva, and follows the south boundary of the county to join the Canadian River. In the southwest corner of the county the Pecos River has its origin near Truchas Peaks and flows southerly into San Miguel County. Many small creeks in the timbered mountains afford excellent fishing and recreational facilities. Lumbering and stock raising are the major industries in this area.

In the eastern half of the county the terrane is typical of the plateau area, consisting of high flat tablelands cut by deep canyons such as those of the Canadian River and the Mora River.

[1] Preliminary reports on the 1940 census give population figures as follows: Mora County, 10,898; Mora, 925; Wagon Mound, 976.

Scrub cedar and piñon pine abound in the plateau region, range grasses are abundant, and ranching is the major industry. In some places dry land farming on a moderate scale is profitable, and along the stream channels some irrigated farming is successfully practiced.

GEOLOGY

The western half of Mora County consists of mountainous masses of pre-Cambrian rocks upon each of which a capping of Magdalena limestone forms the western dip slope and appears at the top of the eastern fault scarp. These limestone beds dip gently to the west over the main part of the pre-Cambrian core, but near the fault scarp of the next mass to the west the beds are turned sharply upward and stand with steep dips to the east and locally are vertical or overturned. The map (Plate 3) shows the repetition of this condition from east to west, and the sections (Plate 5) bring out the relationships more clearly. The eastern half of the county is largely floored with Dakota sandstone, which has a very gentle dip slightly south of east. Locally the dip is modified by gentle undulations and folds. In the north central part of the county the Dakota sandstone is covered by beds of Benton age, north of Optimo and Wagon Mound. In the valleys of the Canadian and Mora Rivers deep erosion has exposed beds of Jurassic and Triassic age, and along the eastern base of the Rincon Range, east of Mora, beds of Permian age have been exposed along the base of the fault scarp that forms the eastern slope of the mountains.

In the central part of the county, rocks of Dakota and Benton age are covered with large flows of olivine basalt, and the volcanic cones from which these lavas emerged are still visible as prominent landmarks. Outstanding examples are the Maxson cone north of Shoemaker, and the Ocate cone south of Ocate. Flows from the Maxson cone are evidently of quite recent age inasmuch as they flooded the deep canyon of the Mora River, as shown on the map, Plate 3. Since the time of this flow, the Mora River has again cut its canyon down through the basaltic flow to bare once more the old valley floor of Dockum (Triassic) beds.

STRUCTURE

Faulting constitutes a prominent feature in the structure of Mora County. In the western half of the county, repeated upthrusting of the sediments along zones of fracture has been the cause of the formation of the Rincon, Sangre de Cristo and Truchas Ranges, these constituting the southern extension of the Rocky Mountains into northern New Mexico. It is apparent that arching of the sediments into a broad anticline was the first type of activity in this mountain making period; this was followed by the fracturing of the beds in the arch along nearly parallel planes trending slightly east of north, with elevation of the faulted blocks to successively higher positions from east to west (see Plates 3 and 5). Along the east flank of the Rincon Range, where the plateau area begins, beds from the Permian to the Dakota sandstone, and locally the Benton, are upturned along the fault zone so that one can see the entire stratigraphic succession along the highway from Las Vegas to Mora, where the road crosses the vertically dipping outcrops of these beds near La Cueva (see map, Plate 3).

In the eastern part of the county, faulting and folding have combined to develop the outstanding structural features. Although the sediments dip gently to the southeast, they have been warped to form a wide synclinal depression, which is probably a southward continuation of the Raton coal basin in Colfax County to the north. This synclinal depression underlies the area covered by beds of Benton age, from Colmor on the north county line, through Wagon Mound, to Optimo near the south border of the county. The east flank of the synclinal basin appears to have formed on the west flank of the old granite ridge that constitutes an extension of the Sierra Grande uplift in Union County, and which apparently can be traced by means of drill hole logs (see sections, Plate 5), continuously southwest to Vaughn in Guadalupe County. Local intensification of warping has resulted in the formation of Turkey Mountain dome, a conspicuous feature of the landscape 12 miles west of Wagon Mound. The flanks of this dome dip at an average angle of 26° in all directions. The high central peak of the dome consists of Glorieta sandstone of Permian age, surrounded by low encircling cuestas of red to brown shales and sandstones belonging to the Dockum group, and these in turn by cuestas of the Morrison formation, and of sandstone which, although in one thick body, probably represents both Purgatoire and Dakota. The base of the member, designated by Darton [22] as Morrison equivalent to that in Union County, consists of a conspicuous white sandstone, which may be the Wingate; if it is Morrison, then the Wingate sandstone is absent from this locality. Other local structures into which the rocks of Mora County have been arched are the Canadian anticline 12 miles east of Wagon Mound, and the Wagon Mound anticline about 9 miles south of Wagon Mound. Several other areas of folding occur in the county but they are smaller and have not been mapped. West of Watrous and Valmora, and extending in a northwesterly direction to disappear under the basalt flows north and west of the Turkey Mountain dome, is a fault which has elevated Dakota sandstone on the west against Benton beds on the east, the apparent displacement being about 200 feet.

[22] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 271.

MINERALIZED DISTRICTS

COYOTE CREEK

The Coyote Creek mining district is situated in the valley of Coyote Creek about 12 miles northeast of Mora near the small hamlet of Guadalupita. Beds of Dakota sandstone are underlain successively by beds of Purgatoire, Jurassic and Triassic ages along the east side of the valley, all having slight dip toward the east. In places these beds are capped with remnants of a flow of olivine basalt which probably originated at the Ocate crater to the east. The remnants, ranging between 50 and 150 feet in thickness, have protected the underlying soft sediments from rapid erosion and have preserved them in the form of buttes and mesas along the east side of Coyote Creek for several miles (see map, Plate 3). West of the creek, where Triassic and Pennsylvanian beds are in close proximity to the fault zone along the east side of the Rincon Range, the beds turn sharply upward and stand vertically or dip to the east. Beds of Permian age pinch out and disappear on this fault zone east of Mora, and are not present in the valley of Coyote Creek.

Copper deposits occur in Triassic beds on the west side of Coyote Creek, and exposures of the copper-bearing minerals have been found at various places for a distance of approximately 10 miles. Beds of Dockum age stand vertically in the valley throughout this distance, and are composed of red shale and red and gray sandstones in a thin-bedded sequence. Copper staining is found in a prominent greenish-gray shaly sandstone member of this sequence having an average thickness of 6 feet, which crops out in numerous places along the creek wherever small side arroyos cut across it. In detail this member consists of alternating thin beds of sandstone and sandy shale, and the individual layers vary from a fraction of an inch to several inches in thickness. Plant remains, thoroughly carbonized, and small flakes of mica are characteristic of many of the bedding planes. Cross bedding on a minute scale is also characteristic. The sandstone is arkosic and the individual grains are cemented with iron-stained calcite.

Chalcocite has replaced the sandstone in the form of nodules from ¼ to 1 inch in diameter, and in small veinlets, cutting across the bedding, which average about ¼ inch in width. Veinlets of gypsum cut across the individual beds and lie in the bedding planes, but appear to be later than the chalcocite. The chalcocite has replaced the cementing material between the individual grains of the rock, and to some extent it has replaced the grains themselves, particularly the feldspars. Subsequent oxidation has converted the outer surfaces of the nodules and veinlets of chalcocite into malachite, and in some instances this alteration has penetrated so deeply that only very small relict cores of the original chalcocite remain. Carbonaceous material apparently has not been replaced to such an extent in these deposits; the calcite cement between the grains has been much more readily replaced.

Mora County has produced only $1757 in mineral wealth which has been officially recorded, and most of this has come from the Coyote Creek district. Several small treatment plants, built in the canyon in years past, are now in ruins. Mining operations appear to have been confined to open cuts in the sides of the arroyos wherever evidence of mineralization was visible at the surface, and to a few shallow pits and short tunnels. All of these workings are now caved or largely filled with surface wash and debris. The ore is very spotty in character and scattered in occurrence and no opportunity apparently exists for the use of organized mining methods anywhere in the district. The writer is of the opinion that especially high prices for copper might enable individual operators to make fair wages by breaking into the mineralized bed close to the surface and carefully sorting the nodules and pieces of vein matter, to be sacked and shipped to a smelter. No place in the valley seen by the writer gave evidence of being able to bear the costs incident to organized mining and the construction of a treatment plant.

OTHER DISTRICTS

On the north fork of the Rio la Casa, about 9 miles west of Mora, small lenticular veins and bunches of quartz have been found in the pre-Cambrian rocks. Assays of the material have been reported to run from 27 cents to $2200 per ton in gold and silver, but no tonnage of gold-bearing material exists, as the veins are all small and the values exceedingly scattered and irregular.

In the northern part of the county, in the pre-Cambrian rocks north and east of Chacon, small prospects have been reported along the western slopes of the Rincon range. These are said to contain gold, silver, copper, lead, and zinc, but nothing that would warrant any attempt at development has been uncovered to date.

One mile southwest of the town of Mora, in one of the old terraces of the Mora River valley, some placer operations were conducted in years past. Several hundreds of cubic yards of gravel were moved in this venture, judging from the evidence that remains, with apparently but little return from the effort. The source of the gold in this deposit has always been a mystery to the residents of the region, but it appears most likely that it originated in the gold-bearing quartz lenses and veinlets, which have been found in considerable numbers near the headwaters of Rio la Casa and Lujan Creek northeast of Chacon. In many places in the State of New Mexico, where the pre-Cambrian rocks have been exposed, many of these lenses, veinlets, and other types of gold-bearing quartz concentrations are known to be present;

and, in most cases, in the valleys below the exposures, small quantities of gold have been found in the gravels. The gold near Mora evidently travelled a considerable distance prior to its deposition in the terrace gravels. This is shown by its fine state of division, the flaky nature of the grains, the absence of sharp corners and edges on the grains, and by its great fineness which is said to average 910.

HARDING COUNTY

LOCATION AND AREA

Harding County is situated in the east central part of the region described in this bulletin. It has an area of 2114 square miles and had a population of 4421 according to the census of 1930. The principal cities are Mosquero, the county seat, with a population of 401, and Roy with a population of 705. The north and east limits of Harding County adjoin Colfax and Union Counties, the southern boundary is the dividing line between it and Quay and San Miguel Counties, and on the west the Canadian River in its deep narrow canyon separates it from Mora County.[1]

GEOGRAPHY

The lowest elevation in Harding County is 3800 feet, in the broad valley of Ute Creek where it crosses over the southern boundary line into Quay County; the highest part lies north of Roy and extends northward through Mills and east of Abbott to the county line with elevations of about 6000 feet. The greater part of Harding County is within the plateau area. Only at the southeastern corner, where Ute Creek and its tributaries have cut deeply into the plateau rocks to carve a valley 10 to 12 miles in width, are elevations less than 5000 feet; here the country assumes the gently rolling appearance of the plains area. In the plateau area, high level stretches of tableland and mesa extend for miles in all directions, with abrupt canyons, several hundred feet deep, carved by the Canadian River on the western border, and by Ute Creek and its extensive tributaries through the central and eastern parts. Scrub cedar and piñon are widespread in the plateau area, and range grasses prevail throughout the county. Cattle raising is the important activity of Harding County, with dry land farming rapidly being developed in the vicinity of Roy, and with some irrigated farming in the valleys where running water or water at shallow depths is available.

GEOLOGY

The rocks in Harding County dip regionally to the southeast at a very low angle. In the plateau area the surface rock is pre-

[1] Preliminary reports on the 1940 census give population figures as follows: Harding County, 4,344; Mosquero, 739; Roy, 1104.

dominantly Dakota sandstone. In the western part of the county, from Roy northward to the county line, rocks of Benton age are in place over the Dakota sandstone as shown on the geological map (Plate 3), and these, in turn, are in part covered by the Ogallala formation of Tertiary age. West of Ute Creek, Dakota sandstone is covered with a long narrow flow of olivine basalt, and several outlying remnants of this flow form the caprock on buttes in the valley of Ute Creek. In the valleys of the Canadian River and Ute Creek, erosion has bared the stratigraphic succession from rocks of the Dockum group, including occasional exposures of the Santa Rosa sandstone in its lower part, to the rimrock of Dakota sandstone at the level of the plateau. In the eastern part of the county the Ogallala formation has covered the older rocks with a moderately thick cover of sand, gravel, and conglomerate which appears to rest directly on rocks of Dockum age in the south, and on Dakota sandstone in the northeast corner of the county.

STRUCTURE

No evidence of faulting is present in the surface rocks of Harding County. The regional dip of the county is locally changed in direction to form several domes and anticlines, a few of which have been mapped and described;[23] among these are the Jaritas dome and the Abbott dome in the northwest corner of the county, the Lost anticline and the Fowl Canyon anticline south of Mosquero, and in the valley of Ute Creek, near Bueyeros, the Baca anticline and the Sierra Negra anticline, which are productive of carbon dioxide gas in large quantities.

MINERALIZED DISTRICTS

Harding County has no mining districts although in times past mild excitement has been felt for brief intervals over alleged rich strikes of metals.

In the basalt area north and west of Bueyeros it is reported that stringers of quartz in the flow rocks have occasionally returned moderate to rich single assays for gold, but so far as the writer could ascertain, no tonnage of gold bearing material has ever been found, and only an occasional prospect pit has been dug in this part of the plateau.

In the valley of Ute Creek, near Gallegos, a discovery of placer gold was reported a few years ago. Apparently several prospectors moved into the valley and remained for a short time, but the results were highly disappointing and the excitement quickly subsided. It is probable that Ute Creek and its tributaries have concentrated small quantities of gold, derived from the basaltic flow rocks to the north, in several places along the river bed; such material would be very fine and flaky, and in the writer's opinion, there is no chance whatever of finding valuable

[23] Winchester, Dean E., op. cit. (N. Mex. Bur. Mines Bull. 9.)

placer deposits in this county. In the southern extremity of the county, south of Gallegos, the Triassic rocks at the base of the Canadian Escarpment contain deposits of copper minerals, which are found in a bed of bluish-gray shaly sandstone. Chalcocite has evidently replaced the cementing material between the grains of the sandstone; at times the mineralizing action was so intense as to include replacement of the grains themselves and the development of nugget-like masses of chalcocite lying across the structure of the sandstone. Very few plant remnants were visible in hand specimens, and those that were seen appeared not to be replaced by copper. Chalcocite has nearly everywhere been altered to malachite which forms a shell around a residual core of chalcocite.

Although the copper-bearing rocks are exposed over a distance of 5 or 6 miles along the base of the Canadian Escarpment in this locality, the impression was gathered that the mineralization is weak and irregular, and that the probability of developing ore in commercial quantities is negligible.

SAN MIGUEL COUNTY

LOCATION AND AREA

San Miguel County lies in the west central part of the region under discussion, and includes mountain, plateau, and plains areas. It covers 4894 square miles, and had a population of 23,636 according to the census of 1930. Of this population, 4708 were reported to live in Las Vegas, the county seat, and 1500 lived in Tererro, the largest mining camp in the region. San Miguel County has been the principal producer of metals in northeastern New Mexico, most of the production coming from one mine. San Miguel County is bordered on the north by Mora and Harding Counties, on the east by Harding and Quay Counties, on the south by Guadalupe and Torrance Counties, and on the west by Santa Fe County.[1]

GEOGRAPHY

The western quarter of San Miguel County is in a region of high and broken mountain ranges which reach elevations of 12,000 feet in the northwest corner of the county. The summits are progressively lower toward the south, until these southern prolongations of the Rocky Mountains disappear under a cover of sediments and merge into the plateau area in the southwestern corner of the county at elevations of 6800 to 7000 feet. The eastern three-quarters of the county is included in the plateau and plains areas. The central and northeastern part of the county, from Las Vegas to the county border and north of the Canadian Escarpment, is a high level plateau area, deeply dis-

[1]Preliminary reports on the 1940 census give population figures as follows: San Miguel County, 27,865; Las Vegas, 12,318; Tererro, 122.

sected by the Mora and Canadian Rivers and their tributaries. South of the Canadian Escarpment, elevations decrease rapidly and the terrane takes on the typical appearance of the plains area with elevations less than 5000 feet above sea level. The lowest point in the county is where the Canadian River leaves it, in the extreme southeast corner, at an elevation of about 3900 feet.

In the western part, the mountain ranges trend slightly east of north, with long narrow valleys lying between them. The Pecos River heads in the southwest corner of Mora County, and, flowing south through one of these narrow valleys, traverses the western part of San Miguel County. On the east flank of the main mountain mass, drainage is to the east into the Mora and Gallinas Rivers. The Gallinas River flows into the Pecos River just south of the southern border of the county, near Chaperito. In the mountain area lumbering and mining are the principal occupations, although ranching and upland farming have an important place. Guest ranches and summer camps are scattered through the hills in the Pecos Canyon and in the mountains west and north of Las Vegas. In both the plateau and plains areas, range grasses grow abundantly, and cattle raising is the most important occupation. In the valleys of the Pecos, Gallinas, Mora, and Canadian Rivers are numerous small farms and orchards, which utilize the waters of these rivers for regular and systematic irrigation. On the high plateaus some dry-farming is attempted with moderate success.

Dwarf cedar and piñon abound in the high plateau area but are of little commercial use except for firewood and fence posts. In the plains area cattle and sheep raising are the main activities and irrigated farming is important in the river bottom areas. Trees are scarce in this area except for occasional groves of cottonwood, willow, sycamore, and black walnut along the river bottoms, and for small groves of cultivated shade and fruit trees.

GEOLOGY

In the western mountainous part of the county, folding and faulting of the beds, and subsequent erosion, have brought the pre-Cambrian granite into view where it forms the cores of the ranges which constitute the southerly prolongation of the great Rocky Mountain range. Erosion has removed all of the sediments from over these cores in places; in other parts only a covering of Pennsylvanian limestone remains (see map, Plate 3). To the eastward younger formations are found in the high plateau areas, the formations including the entire stratigraphic sequence as known for this region. Pennsylvanian and Permian beds outcrop along the east flank of the mountains west of Las Vegas, and in the southwestern part of the county they overlap the steeply plunging southern noses of the ranges. Eastward from the eastern flank of the mountains lie successively younger formations of Triassic, Jurassic, and Cretaceous ages. They are upturned between the mountains and Las Vegas, and exposed in bluffs of the Canadian Escarpment and in the walls of the canyons of the Gallinas, Mora, and Canadian Rivers. In the southeastern part of the county, Triassic beds of the Dockum group are exposed in the base of the bluffs of the Canadian Escarpment and in the floor of the plains area; in many places the Santa Rosa sandstone, which lies at or near the base of the Dockum group, is exposed. At only one place in the county do beds of Ogallala (Tertiary) age appear to be present, and this is on an outlier of the plateau in the southeastern part of the county, south of the Canadian River.

No igneous intrusions later than the pre-Cambrian have been recognized in the county except small feeder dikes; no Tertiary extrusives have been found. Basaltic flow rocks of Quaternary age, erupted from the Maxson cone near Shoemaker in Mora County, have flowed down the canyon of the Mora River, and erosional remnants of this flow are now to be seen along the canyon, and in the canyon of the Canadian River for 12 miles southeast of Sabinoso. Dikes of basic rock cutting beds of Benton age, 6 miles north and 4 miles east of Las Vegas, are probably of Quaternary age, and are thought to have been feeders for the basaltic flows.

STRUCTURE

The regional dip of the rocks in San Miguel County is to the southeast at a very low angle. In the western part much faulting has followed an original anticlinal arching and folding of the beds, and has served to slice the mountain region into a series of wide fault blocks, each of which has been uplifted to form one of the southern spurs of the Rocky Mountains. These up-faulted strips have been named, from east to west, the Rincon (Las Vegas) Mountains, the Sangre de Cristo Range (this is the southern extension of the main range of the same name in Colorado), and the Truchas Range which cuts across the northwest corner of the county. On these blocks the local dip of the capping limestone is toward the west at a low angle, except near the western edge of each fault block. Here the beds are in many instances sharply upturned, often to such an extent that they are vertical or even locally overturned. Along the western dip slope of the Sangre de Cristo Range the Pecos River has cut a steep narrow canyon through the Pennsylvanian limestone. East of this canyon the beds dip to the southwest at about 12°, but on the east flank of the Sangre de Cristo range to the west, near the contact with the granite core of the range, the beds dip between 30° and 45° to the northeast. At the junction of Willow Creek with the Pecos River, at Tererro, the river has cut deeply enough to expose, through a window in the limestone, a small area of the pre-Cambrian basement rock, and it is in this exposure that the Pecos mine was developed.

In the eastern block, known as the Rincon Range to the north and as the Mora and Las Vegas Mountains to the south, the drainage is across the faulted block into the Gallinas and Mora Rivers. Along the east front of this range faulting has exposed the granite in at least two places northwest of Las Vegas. One of these exposures can be seen in the face of the fault scarp from the highway north of Las Vegas. The other exposure is visible in Gallinas Canyon west of Las Vegas, at Montezuma Hot Springs. In Gallinas Canyon about 4 miles northerly from Las Vegas, an excellent cross section of the entire block may be seen. At Las Vegas, beds of Benton age lie horizontally, but near the range the beds are turned up sharply, and the road passes in rapid succession over vertical beds of Dakota sandstone and Purgatoire sandstone of the Cretaceous system, the Morrison formation and Todilto and Wingate beds of the Jurassic system, Dockum beds of Triassic age, and Chupadera and Abo beds of the Permian system. Next along this road appears a wide area of crushed granite upon which lies a considerable thickness of Pennsylvanian limestone, which dips from 6° to 12° to the west, and which forms the dip slope of the faulted block. Near Porvenir, these limestone beds are reversed in dip and the dip increases until in places the beds dip eastward from 60° to 90°. After passing over these steeply dipping beds, one comes to the granite core of the Sangre de Cristo mountain mass.

Along the major faults, the greatest displacement appears to have been in the northern part of San Miguel County, about where the Gallinas Creek cuts through the front range fault block and thence westward from Porvenir (see sections 3 and 4 on Plate 5). North and south of this region of maximum movement, the throw of the faults appears to decrease; for example, Plate 3 shows where the fault near Gascon dies out rapidly to north and south. In the southern part of the county, the fault on the east of the front range block dies out about 6 miles southwest of Las Vegas, and the fault which passes through Porvenir and marks the east boundary of the Sangre de Cristo block dies out about 20 miles south of the settlement. In both instances beds of later sediments lap up around the steeply plunging noses of these faulted blocks, and, as shown on sections 5, 6 and 7 of Plate 5, the southerly extension of the fault blocks grades into gentle anticlinal folds which apparently continue to pitch toward the south. The general effect of this faulting has been to arch each of the blocks in a north-south direction as can be seen in the fault scarp of the front range as viewed from the highway north of Las Vegas.

In this region it seems probable that compression from the west has been the cause of the folding and faulting, and that the major faults are of the reverse type, and that for the greater part, blocks on the west have been elevated relative to the blocks on the east, and that the planes or zones of faulting are vertical or stand with steep dips to the west.

East of Las Vegas, although the beds regionally dip at a low angle to the southeast, there is a local synclinal depression or basin lying north and east of Las Vegas and extending as far as the county line. This basin is shown on the map, Plate 3, as being filled with beds of Benton age. Still farther east a fault, with strike S. 20° E., cuts through the beds of the plateau area and has elevated beds on the west as much as 200 feet relative to those on the east. At the point of maximum displacement, the Dakota sandstone on the west side of the fault has been raised into contact with beds of Benton age on the east.

Around the southern end of the Rocky Mountain uplift, where the sediments overlap the plunging noses of the ancient granite cores, several anticlines are conspicuous. Among these are the folds south of Pecos, the structure that crosses the Pecos River canyon at Ribera, and the Nuevo anticline south of Villanueva. These three anticlines have a trend slightly north of east, and appear to have been formed by the pressure exerted on the sediments from the northwest due to upthrusting of the southern spurs of the Rocky Mountains.

A few folds occur in the central and southern parts of the county although this section is relatively undisturbed. In the extreme northeastern part, between the Canadian River canyon and the east boundary of the county, are a number of anticlines with axes trending in various directions. Sections 4 and 5 of Plate 5 show that in this area, in a manner similar to that in other parts of the region, extensive folds in the surface sediments appear to be regularly associated with old granite ridges of the pre-Cambrian land surface.

MINERALIZED DISTRICTS

WILLOW CREEK (PECOS, COOPER) DISTRICT

The Willow Creek mining district is in the extreme northwestern part of San Miguel county, in the narrow valley of the Pecos River where Willow Creek joins it from the east. Erosion at this point, combined with a slight arching of the beds, has opened a window at the base of the Magdalena limestone, to expose in the valley floor a small area of pre-Cambrian basement rocks; within this exposure the Pecos mine of the American Metal Co. of New Mexico is located. Southwest of the Pecos mine about 4 miles, on the east flank of the Truchas Range where pre-Cambrian rocks are widely exposed, there is a small property known as the Johnny Jones group. Other groups of claims are to be found in this district, but none have been developed beyond the prospect stage.

The Pecos mine is described and discussed in considerable detail in Part 3 of this bulletin, pages 69 to 89.

Johnny Jones group.—The claims of the Johnny Jones group lie west of the limestone contact, on the east slope of the Truchas Range, about 4 miles southwest of the Pecos mine. At the contact with the pre-Cambrian schist, the Magdalena limestone strikes N. 5° W. and dips 30° to 40° to the east. Lumbering operations are carried on in this forested region by the American Metal Co., and the ground is largely covered with plant debris and surface detrital material, concealing the contact. However, field evidence along the edge of the schist indicates that this is a fault contact, and that differential movement, superimposed on regional arching and folding, has raised the pre-Cambrian core of the Truchas Range relative to the Magdalena limestone, which is dragged up east of the contact.

The Johnny Jones workings consist of short tunnels and shallow shafts in the pre-Cambrian schist, prospecting an east-trending shear zone 8 to 10 feet in width. Chalcopyrite is the most important mineral in this shear zone. The strike of the schistosity is N. 40° E., the same as at the Pecos mine, and it is significant that this ore deposit lies in a direct line with the trend of the main deposit at Tererro. The dip of the schistosity is steeply northwest. The shear zone consists of several small parallel fractures in the rock. The schist between fractures or planes of shearing is slightly altered, and retains all of its original texture and color. Along the planes of shearing, quartz and chalcopyrite have been deposited as thin stringers, with only occasionally a mineralized cross fracture, between parallel shearing planes. Oxidation and enrichment have converted the primary chalcopyrite to sulphate, malachite, azurite, and oxides, and a coating of chalcocite is usually visible around residual particles of chalcopyrite. Relict chalcopyrite and chalcocite are visible in the ore in place within a few feet of the surface outcrops. Schist between the shear planes appears not have been mineralized although places in the outcrops are now stained bright green with sulphates and carbonates of copper.

It appears evident to the writer that this deposit is not of commercial size or grade. In support of this conclusion the following reasons may be given:

(1) The shear zone is relatively narrow and shows no indication of movement.

(2) The action of the mineralizing solutions was weak, as shown by the small amount of quartz and chalcopyrite deposited in the shear planes, and by the lack of mineralization and hydrothermal alteration of the schist between planes of shearing.

(3) Leached outcrops are small and scarce, and no zone of secondary enrichment was recognized.

ROCIADA DISTRICT

The Rociada district lies in the northwest part of San Miguel County, near the hamlet of Rociada close to the Mora County line. In a direct line it lies 20 miles northwest of Las Vegas, or 32 miles by road up Sapello Creek. All properties were idle at the time of the writer's visit in 1935. The district is said to have been discovered in 1900, and several small prospects were opened up, but little or no production has been reported. The general elevation of the district is about 8000 feet, with some parts reaching 10,000 feet.

East of Rociada, beds of Magdalena limestone stand vertically against the pre-Cambrian mass which constitutes the country rock. Faulting has been extensive in this district. The beds of limestone and red sandstones and shales show repetitions in the exposures along Sapello creek, and the Magdalena formation is in contact with pre-Cambrian rocks west of Rociada. The Rociada district lies at the eastern base of the Sangre de Cristo Range, within a small basin enclosed by faulted masses of pre-Cambrian rocks and blocks of the Magdalena formation. Most of the exposures of the district consist of pre-Cambrian gneisses and micaceous schists, into which have been intruded sills of diabase and masses of granite. Some of the diabase sills appear to be earlier than others, and have been folded and metamorphosed with the sediments; others are less metamorphosed and may cut across the schistose structure of the beds. The granite masses show no signs of being metamorphosed and are clearly later than all other rocks, as they cut across gneisses, schists, and diabase alike. The schists appear to be of sedimentary origin, and they occur intercalated with beds of crystalline limestone and quartzite. The strike of the faults and folds is north or slightly east of north, but the schistosity in the pre-Cambrian beds strikes N. 48° W., and dips 60° southwest. East of Rociada exposures of Magdalena beds are predominantly the limestones of its upper part, but west of the town only the lower arkosic beds of the Magdalena are exposed, and these formations have been repeated three times by faulting, which has brought them into contact with the pre-Cambrian basement rocks.

Mineralization appears to be entirely of pre-Cambrian age, and the ore deposits consist of lenses and fissures in the gneisses and schists, which have been filled with quartz vein matter carrying pyrite, chalcopyrite, sphalerite and galena, with minor amounts of gold and molybdenite. No production other than a small amount of molybdenite (?) has been reported from the district; the grade of ore is probably too low, and the ore shoots too small, to be profitably exploited. Some of the veins are continuous over long distances, but the lenticular masses of quartz are short, and the mineralization in both veins and lenses is limited to small shoots.

Smith mine.—The Smith mine, owned by Dr. Smith of Tererro, lies about two miles north of Rociada. The schistosity here strikes east and dips 60° south. The ore occurs in lenses in quartz in a biotite schist, with foot and hanging walls of sericite schist. Farther from the vein the biotite schist reappears and it is thought that the sericite schist of the walls may be a hydrothermal wall-rock alteration product. The primary vein material is an aggregate of quartz, pyrite, and chalcopyrite which, near the surface, has been altered to a yellow, limonite-stained mass containing malachite and azurite in vugs and stringers. Only a minor amount of chalcopyrite is present in the primary ore, and pyrite and quartz are the principal constituents. A winze has been sunk on the vein from a small underground chamber at the end of a short tunnel. Water stands in the winze to a depth of 30 feet, and the workings are partly caved. Outcrops on the surface over the mine workings extend for a short distance in both directions.

Crites mine.—The Crites mine lies one mile west of the Smith mine. Here the schistosity strikes N. 70° W. and dips 61° south. The ore occurs at a bend in the schistosity, where apparently the pressure had been relieved, allowing a lens of quartz to form in the space. The wall rock is sericite schist, an alteration product of biotite schist into which it merges within a short distance. In one place the foot wall is altered, for a short distance, to low grade steatite. North of the mine workings a bed of quartzite outcrops, but the attitude and extent of this outcrop could not be determined because it is covered by detritus. Pyrite and chalcopyrite were the primary minerals noted, but small bunches of sphalerite were reported to have been found in the shaft. Azurite and malachite are found in a yellowish to brown vuggy quartz outcrop. An inclined shaft has been sunk down the dip of the quartz lens to a reported depth of 150 feet; there were no ladders in place, and water stood at a high level. It was said that a pump had been left in place in the bottom of the shaft. A tunnel 40 feet long was driven into the hillside below the level of the shaft collar, but this had caved in at the portal and was inaccessible. The mine dump is no larger than would account for the development work described, and no production is claimed for this property.

Joe Matt mine.—The Joe Matt property is about 2½ miles southwest of the Crites mine. The vein strikes N. 40° E. and dips 48° southeast. The footwall is a sericite schist and the hangingwall is an acid igneous rock of porphyritic texture. On the footwall side of the vein are a few exposures of felsite, which may be a wide dike paralleling the course of the vein, or the fine-grained border of a larger granitic mass. There are many small exposures of diabase in this vicinity, which show little evidence of metamorphism. The ore is quartz with pyrite and chalcopyrite, oxidized at the surface to an iron-stained vuggy mass containing malachite and azurite. The mine is reported to have been operated about 1895 through an incline which is now caved in.

Azure-Rising Sun mine.—The Azure-Rising Sun mine is the property of A. G. Zummach, of Las Vegas, who kindly guided the writer over the district and supplied much of the information which has been included in this section. This property was once owned by O. A. Hadley, ex-governor of Arkansas, who did most of the development work on it. The property is located 4 miles southwest of Rociada and consists of five claims, Azure 1, Azure 3, Azure 4, Rising Sun 2, and Black Bear. The elevation at the mine is 10,000 feet.

The country rock is a gray micaceous schist, consisting principally of quartz and biotite, which appears to have been originally a sedimentary rock. Some coarse diabase was noted on the dumps and may indicate a dike of this material paralleling the vein. South of the mine, about half a mile, Magdalena limestone outcrops and appears to be capping a faulted section of the pre-Cambrian schist. The schistosity of the formation has a local strike of N. 60° E., and a dip to the northwest of 80°.

A series of veins striking N. 20° W. cut the schist, which has been extensively altered along both walls of the veins. Quartz and calcite are the principal vein materials; epidote, garnet, amphibole, and specular hematite are abundant in the wall rock. Tourmaline was seen in specimens on the dump of the Rising Sun shaft, and is said to be abundant higher on the range. In places these typical contact metamorphic minerals have developed in the vein filling, as well as in the wall rock. The values consist of bornite, chalcopyrite, chalcocite, and molybdenite. Gold has been reported; at the time Mr. Hadley was working these claims, the gold values were stated to be low, but Mr. Zummach reports, from the workings opened by him, assays as high as $200 per ton in gold and silver, with the ore averaging $100 in these metals. It seems probable, however, that such assays were made on picked or sorted material. Good chalcocite ore is said to have been developed on the 100-foot level, and at 115 feet water was encountered in the shaft. Specimens from the dumps show cores of bornite surrounded by minor shells of chalcocite. Molybdenite associated with quartz was seen in several hand specimens taken from the dumps. It was reported that a small shipment of ore was profitably made from these workings. The outcrops of the veins are oxidized to a brown granular mass, and are stained with malachite and azurite.

Fig. 1 shows the location of the veins and the shafts on this property. The vein system outcrops for 3000 feet within these claims. The Rising Sun shaft is reported to be 172 feet deep and

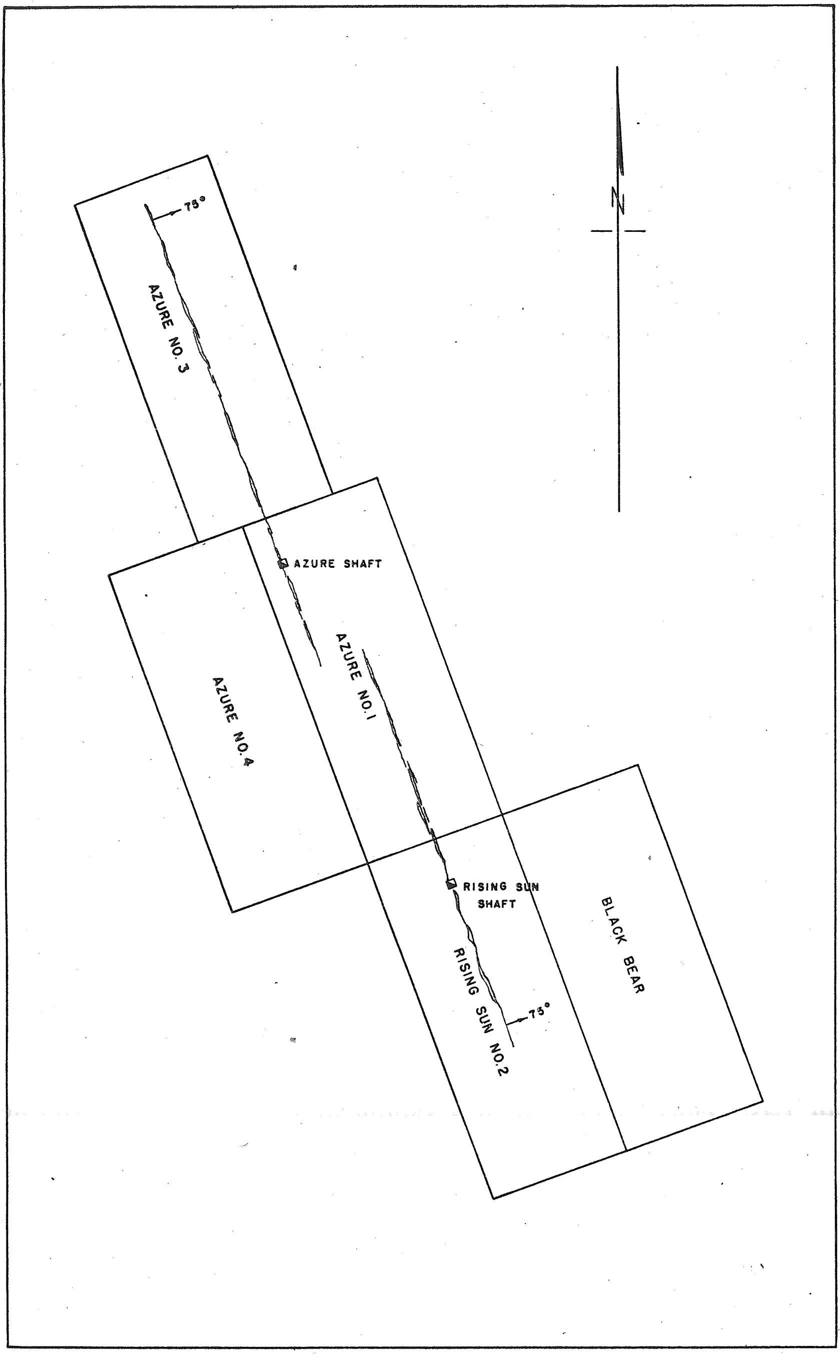


FIGURE 1.—Claim map of Azure-Rising Sun mine

it is said that a tunnel has been driven 400 feet south from the bottom of the shaft. The Azure shaft is reported to be 160 feet deep. A small amount of crosscutting is said to have been done from the 100 foot level of this shaft, but at the time these crosscuts were being advanced, water entered and drove the workmen out. On this level at the present time, there is a crosscut 20 feet to the east to cut the vein, and drifts run for 30 feet in each direction on the vein. Another crosscut has been driven 30 feet into the hanging wall on this level. The vein here is reported to be 5 feet in width, and the footwall is said to be mineralized for several feet. Mr. Zummach reports a second level at 150 feet, driven in later years, which reached the vein in 30 feet. Drifts on this level prospected the vein for 20 feet in each direction. On the 150 foot level the vein is said to be 5 feet in width, in a broken zone 12 feet between solid walls, the footwall side of this zone being impregnated with copper minerals.

There are several other small prospects in the district but the writer did not visit them. They are said to be similar to those already described.

EL PORVENIR DISTRICT

El Porvenir, or Hermit Mountain, mining district lies 15 miles northwest of Las Vegas and three miles north of Porvenir. Here is a coarse-grained pink granite intrusion in the pre-Cambrian complex, the intrusion making up the great mass of Hermit Mountain which rises to an altitude of 10,180 feet. Molybdenite has been found in pegmatite dikes and white quartz veins cutting the granite, and a small amount of prospecting has been done. Besides the typical minerals of the pegmatites, quartz, orthoclase, and muscovite, and the metallic mineral molybdenite, other associated minerals are chalcopyrite, scheelite, and bismuthinite. Surface oxidation has converted the dikes and veins near the surface into vuggy quartz masses which have been stained brown with limonite, and canary-yellow with molybdite derived from molybdenite. Occasional bright green and blue patches of malachite and azurite, derived from chalcopyrite, are seen, as are also whitish-yellow stains that may be oxidation products of the bismuthinite.

The Bert Hoover Mining Lode No. 1, owned by L. B. Hoover, of Las Vegas, is located in a saddle high on the south side of Hermit Mountain. The wall rocks are pink coarse-grained granite, and the vertical vein, which strikes N. 50° E., is composed largely of coarse milky-white quartz with a few scattered crystals of orthoclase and muscovite, indicating its close relationship to the pegmatite dikes of the region. A shaft 75 feet deep has been sunk on the vein and a tunnel, partly caved, driven from a small side canyon 1,000 feet below the shaft, is said to be on the same vein. The molybdenite has been found in small scattered pockets in the vein material.

TECOLOTE DISTRICT

The Tecolote district lies 10 miles north of the little station of Chapelle, on the Atchison, Topeka & Santa Fe Railway, its nearest shipping point. Tecolote Mountain, a prominent butte in the region, lies about 6 miles southwest of Las Vegas, on the north side of Tecolote Creek canyon. The various camps in the district, long since abandoned except for a few Mexican families who herd sheep in the region, are scattered around the western and southern sides of the mountain.

The mineralized district is about 4 miles wide and extends for nearly 10 miles in a northerly direction along the east flank of the southern continuation of the Las Vegas Mountains. L. C. Graton has described the Tecolote district,[24] and much of the material herein, including the cross section of the district (Fig. 2) has been taken from his work.

The district lies on the east limb of a much faulted sharp anticlinal fold. At Tecolote Butte, the beds are flat, but west of Bernal Creek they turn up sharply and in some places the beds stand vertically and are even overturned slightly to the east. West of the upturned beds and on the east flank of the main range the pre-Cambrian basement is exposed. Faulting in this area has been extensive so that in the region of steep dips the beds are repeated many times. The strike of the fault planes is northwest, parallel to the trend of the main range.

The pre-Cambrian rocks consist of granite, gneiss, and schist, which have been cut by pegmatite dikes and white quartz veins. Shearing has occurred in the gneiss along steeply dipping planes parallel to the trend of the range, but the rock is only slightly decomposed. The granite is intrusive into the gneiss and schist, and is believed to be the source of the pegmatites and quartz veins. These dikes and veins are known to contain small amounts of sulphide minerals, such as pyrite, chalcopyrite, molybdenite, and others; but these deposits are not believed by the writer to have furnished the copper in the sediments.

The younger sedimentary beds lie in sequence above the pre-Cambrian rocks. On the basement complex is the Magdalena limestone interlayered with several beds of grit, which is a typical arkose and contains grains of quartz, feldspar, some mica, several accessory minerals, and sericite as an alteration product of the feldspars. The grains have been loosely cemented with calcite and small amounts of iron oxide. Above the limestone there are 400 feet of red strata, mostly brown sandstones but with some red shale and thin beds of gray sandstone, which are believed to be of Abo (Permian) age, although Graton suggests that some Triassic beds are present. Above the red strata rests a thick bed of buff to white thick-bedded sandstone, arkosic,

---

[24] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 116-123, 1910.

cross-bedded, and much finer grained than are the arkoses of the Magdalena section. Graton[25] has called this bed doubtfully Dakota sandstone, but the writer is convinced that it is the basal part of the Glorieta sandstone, of Chupadera (Permian) age.

The ore occurs at two horizons, in the arkose grits of the Pennsylvanian beds, and in the coarser layers of arkose in the Glorieta sandstone. No ore is known to occur anywhere in the redbeds between the top of the Magdalena and the base of the Glorieta sandstone.

The arkosic grit of the Magdalena section is made up of grains of quartz, orthoclase, microcline, a little plagioclase, and a few grains of muscovite. Rarely a grain of one of the accessory minerals may be seen. The grains are loosely cemented with calcite and dolomite, and in places a small amount of iron oxide colors the cementing material to shades of yellow and light brown.

Since the formation of the rock and the introduction of the cementing material, the beds have been somewhat crushed and sheared during folding, and it is within the cracks and planes of weakness that the copper-bearing solutions gained access to the beds.

There is no evidence to show that the copper minerals were present in the grits when they were deposited. Neither is there any evidence that carbonaceous material, which might have served as a reducing agent, was present in the sediments. The feldspars are not greatly altered, although in places patches of sericite and kaolin have developed. The evidence seems to show, therefore, that disintegration of the granite, sorting of the fragmental grains, and deposition, were rapid processes, and that since deposition the material has been subjected to very little action by surface waters.

In order of decreasing importance the minerals of the ore deposits are chalcocite, bornite, chalcopyrite, and pyrite. The pyrite occurs in small cubes, but the other minerals are of irregular outline. The sulphides occur mainly in the interstitial carbonate cement, but in places stringers of metallic minerals cut across the altered feldspars, preferentially replacing kaolin; in only a few cases was it seen that the feldspar had been directly replaced. In some places the sulphides occupy the full width formerly occupied by carbonates, but in others the sulphides are completely surrounded by carbonates. Where the sulphides occur within feldspar grains, the means of entry has been along fractures by replacement of the carbonate filling, and finally by replacement of the adjacent sericite and kaolin.

Most of the ore has undergone extensive oxidation, and the most abundant oxidized minerals are malachite and azurite. In the replacement of chalcocite, azurite appears to have formed

[25] Graton, L. C., op. cit. p. 117.

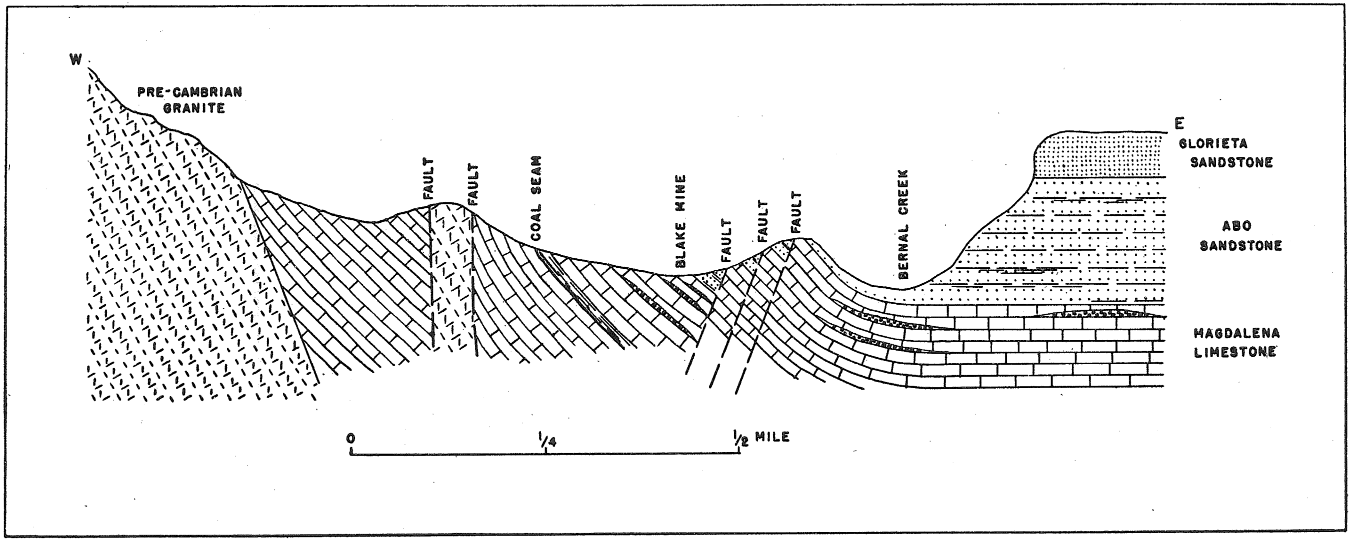


FIGURE 2.—Geologic section in the Tecolote district

first, and this, in turn, has been converted to malachite; a typical fractured specimen of the ore shows a central core of chalcocite surrounded by a thin band or shell of azurite and this, in turn, by a shell of malachite. In many grains the chalcocite has been completely converted to malachite. In a few grains a speck or two of pyrite is seen to be the only relict sulphide present. Bornite and chalcopyrite are found in small particles, usually of microscopic size, within the grains of chalcocite. In some places the carbonate surrounding a grain of the oxidized mineral has been stained malachite-green, but the carbonate remains transparent and retains the optical properties of calcite or dolomite. Some gypsum appears to have formed close to the malachite grains, probably through the action of copper sulphate solutions on the calcium carbonate cement.

The names of the abandoned mines in this district could not be ascertained from the present inhabitants of the region. One mine close to Bernal, probably the Blake mine described by Graton, consisted of a small open cut and an inclined shaft partly filled with debris, but which may originally have been 50 feet deep. The ruins of an old treatment plant were seen nearby. It is reported that these ores were treated by crushing through rolls, leaching in vats with sulphuric acid solution containing a little hydrochloric acid, filtering of the solutions and their treatment in a revolving trommel with scrap iron and old tin cans, which preciptated the copper in metallic form along with various impurities. It is said that the dried precipitate contained 70 percent copper. The mineralized horizon in this mine underlies the westernmost exposure of the red shale of the Permian beds, and is undoubtedly in one of the arkosic beds of the Magdalena formation.

Another mine, about 4 miles farther north and a mile or more southwest of Tecolote Creek, has had little underground work done, but a mill was built to treat the ore by leaching. The workings in this mine are in the Glorieta sandstone, the mineral occurring principally in the coarser arkosic layers, replacing the carbonate cement and to some extent the grains of altered feldspar and kaolin. This ore shows evenly distributed bands of these arkosic layers separated by purer sandstone.

Northeast of this second mine and about a mile and a half distant, two other wrecked leaching plants were found, and some scattered mine workings were seen in the base of the Glorieta sandstone. The ore appeared to be distinctly richer than that found at the two properties described above, and it contained more sulphides. More bornite is present in this ore. The pyrite and chalcopyrite appear to be earlier than the chalcocite and are enclosed by it. Bornite may be enclosed by chalcocite, but the two minerals appear to be intergrown in places and are probably of the same age. Oxidation has not progressed far, and the sulphide grains are coated by only thin films of azurite and malachite.

Several other small properties, which were not examined, are reported in this district. (See index map, Plate 1.) It is also reported that patches of the Magdalena formation, containing beds of arkose, occur at several places along the crest of the Las Vegas Mountains, and that in these arkosic beds, traces of copper have been found.

The ores of this district are spotty and of low grade. It was stated by the local residents that ore from the mine in Bernal Creek averaged 2.75 percent copper as it was shipped to the leaching plant, and that it was so spotty that much deadwork and hand sorting were necessary in the mine in order to keep the grade up to this figure. From the workings in Glorieta sandstone, ore of 8 per cent copper content had been mined, but this was even scarcer than the low grade material. It is obvious that ore of such grade cannot be considered commercial in such small quantities, except under the stimulus of very high prices for the metal, and even under such abnormal conditions it is probable that these properties can be successfully operated only as very small units, and that they do not warrant consideration by the larger mining companies.

The mineralized belt of the Tecolote district lies along the eastern base of the Las Vegas Mountains, in a zone where faulting is very evident. The faults trend parallel to the range and were probably a direct result of the pressure developed by the arching and intense folding of the region. It is repeatedly noticeable that close to the fault zone, throughout its entire length, the ore is relatively high in pyrite, chalcopyrite, and bornite, while farther east, and away from the fault zone, chalcocite is the only sulphide mineral present. At no place has any ore been found in these beds farther than 3 miles east of the fault zone. No ore was found anywhere in the granite or gneiss, and under the microscope no ore particles were found which appeared to have been laid down with the sediments. If the ore was brought in by surface waters, therefore, it must have been carried for a long distance, and as no primary deposits of any size are known in this region, the copper must have been derived from an enormous area containing minute quantities of the metal. It seems hardly probable in a country containing so much calcium carbonate, that such a source could have been adequate, and that the minerals in solution could have been carried so far without being precipitated. The more logical conclusion is that the ores are of magmatic origin in this district and that they came up in solution along the zone of faulting, to be deposited in the arkosic beds on the east side of the fault, principally by replacement of the carbonate cement of the beds, and in less degree by replacement of the sericite and kaolin. The pyrite and chalcopyrite were deposited early and near the fault, bornite had a wider distribution, and chalcocite spread the farthest and is found in a purer condition and at greater distances from the fault than the other minerals.

OTHER DISTRICTS

Mineral Hill lies slightly north of west from Las Vegas, a distance of about 10 miles in an air line, but about 30 miles over an unimproved road. While this district has heretofore always been considered to be a sub-district of the Tecolote district, the Mineral Hill area lies in part within the pre-Cambrian core of the Las Vegas Mountains, and to the west of the sedimentary belt containing the copper ore in sandstone which is so typical of the Tecolote workings.

There is no record of production from this district. A gold rush is said to have occurred in 1879-1880, but the excitement died in a short while when no commercial gold ores were found.

At Mineral Hill, a body of ore in a 3 foot bed of sandstone was said to assay 2 ounces silver and 16 percent lead, but in development it proved to be of small content. At Tres Hermanos Canyon, $25,000 is reported to have been spent on a showing of 3 to 5 percent copper ore in sandstone. This occurrence was prospected by tunnels and crosscuts, but without finding a commercial orebody. Between Kerney's Gap and Tecolote, several shafts were sunk to depths of 100 to 200 feet, on three veins containing gold, silver, and copper in mica schist, quartz, and hornblendite. Values in these veins disappear with depth.

Two carloads of muscovite have been shipped from this general region. The first carload was hand selected and proved to be profitable, but the second carload was shipped at a loss. The deposit is a pegmatite in the pre-Cambrian schist and is quite extensive. It may be productive of scrap and punch mica in which the 2 to 4 percent iron content in the green mica is not detrimental.

Ribera is a station on the main line of the Atchison, Topeka & Santa Fe Railway, in southwestern San Miguel County, located where the railroad crosses the Pecos River. The river at this point passes over beds of Abo age, consisting of brown and red slabby sandstone interlayered with red sandy shales. Just east of Ribera the Abo beds are covered by sediments of the Chupadera formation, the most prominent member of which is the thick cream- to buff-colored Glorieta sandstone. In the base of the cliff forming the northern exposure of the Chupadera beds, some copper ore has been found in the Glorieta sandstone and in the underlying Abo beds. This ore is similar to that of sedimentary copper deposits described elsewhere in this bulletin, in which chalcocite has replaced the cementing material between the grains of the sandstone, and to some extent the grains themselves in the more arkosic parts of the beds. Where the grains of the sandstone have been replaced, the copper has accumulated as nodules, a few of which are as large as walnuts. Where only the cement between grains has been replaced, copper is disseminated in fine specks throughout the rock. Subsequent oxidation has altered the grains and nodules to malachite and azurite, and soluble salts of copper have stained the surrounding rocks a bright green in many places. A small amount of prospecting has been done in these cliffs on both sides of the river as far south as Sena, but no production is recorded, and the writer saw nothing to warrant the belief that there is a large concentration of ore in the district. The amount of copper deposited in the beds appears to be insignificant and not in proportion to the amount of green stain locally present on the rock surfaces.

Ten miles south of Bernal (Chapelle) on the north bank of the Pecos River between the villages of Sena and Villanueva, the Rev. A. J. Miedanner has a small group of claims which he reports to contain gold. Here, along the north side of the river, the Glorieta sandstone outcrops in a bold cliff with a maximum height of 150 feet. Three tunnels have been driven into this cliff prospecting for ore. The lower tunnel, 30 feet above the base of the cliff, is 130 feet long. The second tunnel, about 50 feet higher than the first, is nearly 200 feet east of the lower tunnel and is less than 100 feet long. The third or upper tunnel, still farther east in the face of the cliff, is also less than 100 feet long. Each of these tunnels has been driven to prospect in a lens of cross-bedded sandstone which is underlain and overlain by thin beds of impervious shaly sandstone. In places these cross-bedded sandstones are stained with limonite, and the Rev. Mr. Miedanner reports assays, on hand specimens from these workings, varying from $22.00 and $12.50 in gold, down to $1.50 and traces of gold per ton, with no silver or copper. The ore appears to be very spotty; a sample taken by the writer, from the same place where the Rev. Mr. Miedanner took the sample assaying $22.00 gold per ton, returned only a trace of gold. The source of the gold in these cross-bedded layers of sandstone in the Glorieta sandstone is not apparent, but it seems more than a possibility that the gold is of placer origin. The gold seems to be confined to cross-bedded layers in the Glorieta sandstone, where it appears to have collected in very small pockets at places where there is an apparent change in the direction of trend of the lens. The ultimate source of the gold is believed to be in the granite core of the mountains to the north, where a large number of pegmatite dikes and quartz veins are known to be present; these, in common with similar occurrences elsewhere in the pre-Cambrian rocks of New Mexico, may contain a small amount of gold. Very little importance is attached to this deposit from an economic standpoint.

GUADALUPE COUNTY

LOCATION AND AREA

Guadalupe County is situated in the southern part of the region discussed in this bulletin. It has an area of 3031 square miles and a population of 7027 according to the census of 1930. The principal cities are Santa Rosa, the county seat, with a population of 1127, and Vaughn, a railroad town, with a population of 961. Guadalupe County is bounded on the north by San Miguel County, on the east by Quay County, on the south by De Baca County, and on the west by Torrance and San Miguel Counties.[1]

GEOGRAPHY

The lowest elevation in Guadalupe County is near the southeast corner where the Pecos River enters De Baca County at an elevation of 4265 feet. The highest elevations are along the west border and range around 6250 feet. The northern and western parts of the county lie within the plateau area. The central and southeastern parts are within the valley of the Pecos River and its tributaries and are at elevations below 5000 feet. Nowhere in this county is the terrane as rugged as it is north of the Canadian Escarpment; indeed, it is often difficult to decide whether parts of the county belong within the plateau or the plains area. Few trees are to be seen on the plateaus except in the eastern part, where outcrops of the Dakota sandstone on the bluffs are characterized by scrub pine and cedar. In the valley of the Pecos River groves of cottonwood and willow line the banks, with here and there in the settled areas, a few domestic shade trees or a small orchard. The entire county is covered with range grasses, and cattle and sheep raising are the important activities of the county. Along the Pecos River small irrigated farms are commonly seen.

GEOLOGY

The regional dip of the rocks in Guadalupe County is toward the southeast at a very low angle. The surface of almost the entire county consists of rocks of the Dockum group, with Santa Rosa sandstone, which occurs at or near the bottom of the group, prominently exposed in many places. In the extreme northwest corner of the county, in the southwest corner between Pastura and Vaughn, and in at least six places within the broad area occupied by the beds of Triassic age, the underlying Chupadera formation of Permian age is exposed. (See map, Plate 3.) At Cerro Cuervo, and near Isidore, mesas of rock younger than the Triassic are found, these exposures being in the outliers south of the Canadian Escarpment. In these exposures, rocks of Jurassic and Cretaceous ages are to be seen in the bluffs which are capped by Dakota sandstone. In the southeast portion of the

[1] Preliminary reports on the 1940 census give population figures as follows: Guadalupe County, 8600; Santa Rosa, 2302; Vaughn, 1329.

county, east of Santa Rosa, an extension of the Llano Estacado projects into the county for a distance of about 10 miles, terminated by the high bluffs south of the railroad and the highway between Montoya and Los Tanos. The bluffs of this high mesa consist of Jurassic and Triassic beds underlying the rimrock of Dakota sandstone, which, in turn, is capped by beds of the Ogallala formation. Beds of Ogallala age are found also east of Pastura, east of Santa Rosa, and in several isolated patches in the northwestern part of the county, apparently resting directly on beds of Triassic age.

West of Cerro Cuervo a porphyry dike, about 12 miles long, cuts Triassic beds in a northeasterly direction. This basic dike may have been a feeder for old lava flows similar to those farther north, which seem to have been eroded away in this part of the region.

STRUCTURE

At surface, no evidence of faulting on a large scale is seen in Guadalupe County, but in several places local folding is a feature of the region. On the cross sections (see Plate 5) the data obtained from drill holes seem to indicate that faulting may have extended into the county as an extension of the zone of faulting along the flank of the Rocky Mountain uplift west of Las Vegas. In the northwest part of the county the Esterito dome has been eroded, to show through a window an area of the Chupadera formation, entirely surrounded by bluffs of Santa Rosa sandstone; the higher slopes consist of red shales interlayered with brown sandstones and thin gray limestone of the Dockum group. South of the Esterito dome, the Guadalupe anticline has arched the beds for a distance of 12 miles in a northerly direction, and at the south end of the arch where Pintada Creek crosses the structure, the combined arching of the beds and the erosional work of the creek have exposed the Chupadera beds through a window in the floor of Pintada Canyon just east of San Ignacio. East of Santa Rosa, the Santa Rosa anticline trends southeasterly for 6 miles, where the axis apparently turns south to cross the Pecos River. In the Pecos River canyon, on the extension of this trend, a large area of Chupadera beds has been exposed from Puerto de Luna for a distance of 4 miles south. Other areas of folding, which have not as yet been mapped, are undoubtedly present in the county and at least two areas of the Chupadera show through the Triassic beds as a probable result of such folding. Further study of drill-hole logs on the sections covering Guadalupe County, and the addition of new data as fast as it is obtained, will undoubtedly do much to shed additional light on the structural trends and the configuration of the pre-Cambrian bedrock.

MINERALIZED DISTRICTS

PINTADA CANYON DISTRICT

This district lies in the west central part of Guadalupe County, about half way between Santa Rosa and Pastura, on the Southern Pacific Railway. The district has a radius of about 20 miles; near the center is the I. J. Stauber property, the only property in the district which has been productive. (See Part III, pp. 90-97.) Within this area there are many smaller outcrops, none of which look very promising, and none of which have been worked beyond the prospect stage. Throughout the district the ore consists of copper minerals scattered through sandstones and shales of the Dockum group. It is reported that copper-bearing outcrops have been found also in the underlying Chupadera formation, which is exposed in a large area to the southwest, and in a small window in the Triassic beds in Pintada Canyon, east of San Ignacio.

QUAY COUNTY

LOCATION AND AREA

Quay County is the extreme southeastern county of the region covered by this report. On the north it is bounded by San Miguel, Harding, and Union Counties, its east boundary is the Texas state line, to the south De Baca, Roosevelt, and Curry Counties adjoin it, and on the west Guadalupe County. Quay County has an area of 2905 square miles and a population of 10,828 as given by the census of 1930. The principal cities are Tucumcari, the county seat with a population of 4134, and Logan with a population of 404.[1]

GEOGRAPHY

The lowest elevation in Quay County is where the Canadian River crosses over the state line into Texas at an elevation of approximately 3800 feet. In its highest part the elevations just reach 5000 feet above sea level along the northern rim of the Llano Estacado. Thus the county lies wholly within the plains area. The cattle industry is the major interest of the county, although some dry land farming is being attempted northeast of Tucumcari and around Logan, where the New Mexico Agricultural College maintains an experimental farm to guide the local farmers in their efforts. Along the valley of the Canadian River, and in Ute Creek and Tucumcari Creek valleys, the bottom lands can be farmed under local irrigation systems. Except along the river bottoms, few trees are seen in the county, other than the scrub cedar and piñon, which characteristically mark the rimrock outcrops of Dakota sandstone.

[1] Preliminary reports on the 1940 census give population figures as follows: Quay County, 12,040; Tucumcari, 6163; Logan, 549.

GEOLOGY

Most of Quay County is underlain by Triassic beds of the Dockum group. In the rim of the Llano Estacado, and in the several mesas and buttes surrounding Tucumcari, which are outliers of the formations exposed in the Canadian Escarpment, rocks of Jurassic and Cretaceous age make up the stratigraphic sections in the bluffs, with Dakota sandstone as the prevailing rimrock. In the northern part of the county north of Logan, and in the southern part on the Llano Estacado, sands and gravels of Ogallala age are widespread as a relatively thick cover apparently resting directly on beds of Dakota sandstone.

STRUCTURE

As in the other counties of the northeastern part of the State, the regional dip of the strata is southeasterly at a very low angle. Locally the general dip has been disturbed by arching and folding of the surface strata into a series of anticlines having, in general, a northeasterly trend; in the northern part of the county a group of small structures known as the Dripping Springs anticlines, and the Logan anticline, trend to the northwest. In connection with these structures, it is interesting to note on sections numbered 5 and 6, of Plate 5, that a high area in the granite bedrock exists under them, and that possibly some faulting has occurred along the west flank of this old granite ridge.

MINERALIZED DISTRICTS

Copper deposits of the "Red Beds" type outcrop in the valley of the Canadian River about 8 miles west of Logan, near what is known as the Pierce Ranch. The beds in which these outcrops occur are of Dockum age and the mineralization is confined to a blue-gray shaly sandstone which lies considerably above the Santa Rosa sandstone. The Santa Rosa sandstone apparently does not outcrop anywhere nearby in the valley. Other outcrops of copper-bearing rocks were reported to the writer as occurring farther west in the Canadian River canyon, and in the canyon walls in tributary streams to the north, but these were not visited. The copper minerals occur as replacements between grains in the sandstone bed, and as small nodular masses cutting across bedding planes and replacing the grains themselves. Although a small amount of prospecting has been done on these outcrops, no shipments of ore have been officially reported from this county, and no extensive exposures of ore are to be seen anywhere in the workings. The mineralization appears to be weak and scattered, but a sufficient proportion of the copper appears to be in nodule form, so that, under the stimulus of high prices, close hand sorting of the material might be made to pay. The principal minerals present are malachite and azurite, with chalcocite as residual cores of nodules, indicating that the original deposits were sulphides which have later been altered to carbonates. In the writer's opinion, these deposits are not capable of being developed into anything that would warrant operations on a larger scale than one or two men, working together, could handle.

About 6 miles west of Logan, in a side canyon tributary to the Canadian River, a bed of greenish-gray shaly sandstone, which is impregnated with small pyrite crystals, is exposed in the base of the canyon walls. This bed was the cause of considerable excitement several years ago, when gold was reported as being present. A campsite was laid out in the canyon, several stone houses were built, and considerable machinery was moved in and set up, all at the expense of relatively large sums of money. It is not known how authentic the reports of the gold assays from this district are, but it appears certain from an inspection of the ground that no ore of commercial grade was ever shipped from these workings, and that within a short time the excitement died down and the camp was abandoned.

PART III. PRODUCTIVE MINES

THE PECOS MINE

GENERAL

The operations, geology and other details of the Pecos mine have been ably described in published articles by Lindgren and Graton,[26] Lindgren, Graton, and Gordon,[27] A. H. Hubbell,[28] Matson and Hoag,[29] Charles E. Stott,[30] H. D. Bemis,[31] Philip Krieger, [32] and E. C. Anderson,[33] and these papers should be consulted for a full understanding of local conditions. The writer spent three weeks at the mine in the summer of 1934, and visited it again in the fall of 1935 and in the summer of 1938. The summer of 1936 and part of the early fall of that year were devoted to the microscopic study of thin sections and polished specimens made from diamond drill cores and from surface and underground samples collected during the previous visits. During this period over 125 thin sections of rocks and polished sections of ores were studied. The writer originally had the idea, based on impressions gathered in the field, that it might be possible to determine, from the type of metamorphism, its intensity, and the presence of certain alteration products, where a diamond drill had passed through rock adjacent to an orebody, but he was disappointed in his quest for reliable and persistent criteria, and was finally forced to abandon the effort.

LOCATION AND AREA

The Pecos mine, owned by the American Metal Co. of New Mexico, is located at Tererro in the narrow valley of the upper Pecos River, at its confluence with Willow Creek in the extreme northwest part of San Miguel County. It is 14 miles due north of the village of Pecos on U. S. Highway 85, the old Santa Fe Trail; from Pecos the mine is accessible over an excellent gravelled automobile highway at a distance of 16 miles. From Glorieta, the nearest station on the Atchison, Topeka & Santa Fe Railway, the mine is 14 miles distant in a direct line. The mill, located at

[26] Lindgren, W. and Graton, L. C., A reconnaissance of the mineral deposits of New Mexico: U. S. Geol. Survey Bull. 285, pp. 74-86, 1906.

[27] Lindgren, W., Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 113-114, 1910.

[28] Hubbell, A. H., Pecos mine; a new zinc-lead project: Eng. & Min. Jour., vol. 122, no. 26, pp. 1004-1012, 1926.

[29] Matson, J. T., and Hoag, C., Mining practice at the Pecos mine of the American Metal Co. of New Mexico: U. S. Bur. Mines, Inf. Circ. 6368, 1930.

[30] Stott, Charles E., Geology of the Pecos mine: Eng. & Min. Jour., vol. 131, no. 6, pp. 270-275, 1931.

[31] Bemis, H. D., Milling methods and costs at the Pecos concentrator of the American Metal Co., Tererro, N. Mex.: U. S. Bur. Mines, Inf. Circ. 6605, 1932.

[32] Krieger, Philip, Geology of the zinc-lead deposit at Pecos, N. Mex.: Econ. Geol., vol. 27, nos. 4 & 5, pp. 344-364 & 450-470, 1932.

[33] Anderson, Eugene C., The aerial tramway: as used at the Pecos mine. Thesis, (unpublished) submitted to New Mexico School of Mines for professional degree Engineer of Mines, 1938.

Alamitos, is west of Pecos, and is served by a standard gage spur from the main line of the railway over a distance of 4½ miles. A 12-mile aerial tramway runs from the mine to the mill.

At Tererro the company owns 1540 acres of land and controls 540 acres of unpatented land upon which mine plant, power house, shops, offices, and townsite are built. At Alamitos it owns 912 acres in the form of millsites upon which the concentrator, shops, offices, dwellings, tailings dams, and tailings ponds are located. The tramway right-of-way is 200 feet in width. A pumping plant, on a 2-acre plot in the valley of the Pecos River at Valley Ranch, supplies water for the milling operations at Alamitos through 7000 feet of pipe line. Timber is purchased from the Federal Government from sections in the Santa Fe National Forest, within which the Pecos mine is located. The company cuts the timber and transfers it to the mine where it is framed for use. Payment is made to the Government on a stumpage basis, and it is estimated that mine timber costs the company less than $20 per thousand board feet, or about one-half the cost of mine-timbers that could be shipped in.

HISTORY

The Pecos orebody was discovered in 1881 by a prospector from Kansas named Case. In 1882 he organized the Pecos River Mining Co., and attempted to secure funds with which to develop the property. Soon after this the property was examined by members of the Cowles family and it was purchased by them. Mr. A. H. Cowles undertook to develop the property in 1886, but he soon abandoned the task because the ore could not, at that time, be easily treated in this country. The mine remained idle until 1903, when the Pecos Copper Co. was organized by Mr. Cowles and development was resumed, which continued until 1907 when work again ceased, and the property was idle from 1907 until 1916. During this period the mine was known as the Hamilton or Cowles mine. In 1916 the Goodrich-Lockhart Co. took an option on it and, except for the war period of 1917-1918, energetically pushed development work until 1921. During 1921-1925 experimental work on methods for treating the ores was carried on in England, Australia, Europe, and in the United States. Finally it was found that differential flotation would yield satisfactory results. In 1925 the American Metal Co. took the property on an option, and after a thorough examination, decided to develop and equip it.

By the end of 1910, 30 years after the location of the mine, the development workings included a tunnel driven into the orebody on a level with Willow Creek, and a shaft sunk to a depth of 400 feet, from which short levels were cut for the extraction of ore. At this time the property was considered to be a copper mine, as the ore near the surface at the north end of the orebody consisted of irregular masses of pyrite and chalcopyrite, with small amounts of sphalerite and practically no galena. Prior to 1910 a small amount of ore had been shipped, all of it from development headings, but no exact records are available. From 1916 to 1921, an intensive campaign of development was continued and an orebody sufficient to sustain operations for several years was blocked out. It was during this interval that development at greater depths showed that the orebody was principally a complex zinc-lead ore, with much pyrite and only small quantities of chalcopyrite. The period of greatest development began in 1925 when the American Metal Co. assumed charge of the property. A program of development and construction was begun, which was to cost around $2,000,000, which developed 1,000,000 tons of ore, and which saw a mine plant, mill, and a 12-mile aerial tramway with all accessory shops, equipment, and campsite construction completed by 1927, sufficient for handling 600 tons per day.

GEOGRAPHY

The Pecos mine lies on the western dip slope of the extreme southern extension of the Sangre de Cristo Range, where the Pecos River has cut a steep narrow canyon through the Magdalena (Pennsylvanian) limestone. West of the Pecos valley the lofty granite peaks of the Truchas Range have been faulted up against the limestone of the Sangre de Cristo mass. East of the mine the limestone gradually rises to form lower peaks which constitute the southern extremity of the Sangre de Cristo Range. Still farther east of this main mass, a southeastern spur, known locally from north to south as the Rincon Range, Mora Range, and Las Vegas Mountains, constitutes the eastern flank of the Rocky Mountains, west of Las Vegas. Both the Truchas Range and the Las Vegas Mountains plunge to the south and are finally surrounded and overlapped by sediments of a later age. Quoting from Krieger:[34]

Topographically, all of the region north of Glorieta forms a series of high ridges and mesas through which the Pecos River and its tributaries have cut deep, and in places, box-like canyons. West of the Pecos River, in the vicinity of the mine, the mountains rise abruptly from an elevation of 7,800 feet at the river level to 10,000 and 11,000 feet in the higher portions of the Santa Fe [Truchas] Range. They reach their greatest height in the vicinity of Baldy Peak, which has an elevation of 12,623 feet. On the eastern side, toward the Las Vegas Range, the rise is less abrupt, although to equally high elevations. This may be accounted for by the geologic structure of the region, with its gentle dip to the west. In places drainage channels have migrated down the dip of the sediments and the old pre-Cambrian surface, leaving broad flat areas along the east side of the river which now form excellent grazing and farm land.

The Pecos River, the principal stream of the district, heads about 15 miles north of the mine and flows south and southwest [southeast] through New Mexico and Texas until it finally empties into the Rio Grande near the Mexican Border.

---

[34] Krieger, Philip, op. cit., (Econ. Geol. 27: 4-5) pp. 350-351.

GEOLOGY

The general geological setting of the Pecos mine is of interest in connection with the study of the deposit. The basement rock is the pre-Cambrian complex, consisting of schist, derived in large measure from original sedimentary rocks, into which have been injected huge masses of diabase in the form of sills and dikes, and equally large stock-like masses and dikes of granite. The diabase has been metamorphosed almost wholly into a schistose material showing varying degrees of intensity of alteration.

From pre-Cambrian time until Pennsylvanian time, erosion planed off the surface of the pre-Cambrian rocks to a peneplane of remarkable uniformity which now lies, according to Krieger, with a regular dip of about 7° to the southwest. This even erosion surface cuts across the planes of schistosity in the rocks, and across zones of shearing and faulting, and it cuts off the tops of the orebodies. These relations indicate that the intrusions of diabase and granite occurred and that schistosity, shearing, and faulting of the basement complex developed in pre-Cambrian time, and that only minor movements have occurred since.

Overlying the pre-Cambrian rocks, and resting unconformably on the old erosion surface, are beds of Magdalena limestone and shale, 1000 to 1200 feet in thickness, which dip about 12° to the southwest and extend for several miles. The exposure of the pre-Cambrian rocks is through a window in the Magdalena limestone, at and near the confluence of Pecos River and Willow Creek. This limited exposure of the pre-Cambrian rocks makes the work of exploring for new orebodies extremely difficult and costly; there is no way of correlating the pre-Cambrian rocks, or of locating faults and offsets in the trends of the structure which may have influenced the position of ore lenses, except through the examination of diamond drill cores. No ore that can be associated with that of the Pecos mine deposit occurs in the Pennsylvanian limestone, and no local faulting of the beds is recognized. This indicates that, while faulting of a regional nature occurred, on both the east and west sides of the Pecos ore deposit during the formation of the present Rocky Mountains, the fault block in which the mine is situated must have had an almost vertical rise, being tilted only slightly to the west, with little or no internal pressure or distortion of the beds.

EARLY SCHIST AND GNEISS COMPLEX

The rocks of the pre-Cambrian complex consist of varieties of schist and gneiss, into which extensive intrusions of both basic and acid rocks have been forced. In the vicinity of the Pecos mine the writer noted places where it appeared that the earlier rocks had been originally present, but that they had been invaded by later diabase to such an extent that the boundaries of the mass and the identity of the host rock are almost completely obliterated by metamorphism and silicification.

DIABASE

The main rock at the Pecos mine is a dark-green medium- to fine-grained diabase. This diabase appears to have invaded an earlier schistose and gneissic complex, and it constitutes most of the country rock in the mine workings. It is fairly resistant to weathering and the various phases of the mass can be identified both on surface and in the mine. It grades from dark green very fine-grained dense rock to a coarser-grained type somewhat lighter in color, which to the unaided eye is obviously diabasic in texture. Both types have been subjected to strong dynamic stresses and have been metamorphosed and later silicified.

Although the schistose texture of the rock cannot always be seen in the hand specimen, microscopic examination shows that the diabase is for the most part a finely laminated compact schist, which has been recemented into a very dense and massive rock and sealed by the addition of later quartz. This is particularly true of the fine-grained type. A hand specimen of the coarser-grained type can be easily recognized as amphibole schist. Outcrops of this coarser-grained type are exposed in Willow Creek, east of the mine.

In the past it was thought that the diabase was made up of several different intrusives, this opinion being based on differences in texture and in degree of schistosity; but there are no definite contacts between these different phases of the mass, and the texture of one type changes gradually into that of the adjacent type. Stott[35] was apparently the first to recognize this condition, and he came to the conclusion that the entire body represented one intrusive period of diabase, which had been differentially altered by dynamic stresses and later igneous invasion.

The minerals of the diabase are andesine plagioclase (zoned and corroded), deep blue hornblende (constituting 50 to 60 percent of the rock mass), biotite, some pyroxene, and accessory magnetite, zircon, apatite, titanite, and rutile. The texture is diabasic throughout, even in the finest rocks, and the entire mass has been rendered schistose to different degrees. Actinolite and garnet are present as metamorphic minerals, and quartz and tourmaline appear as later introduced minerals. Alteration of hornblende to brown biotite and chlorite is frequently seen, and sericite is abundantly developed in the more schistose varieties of the rocks. Other alteration products are epidote, zoisite, uralite, saussurite, and leucoxene. The large variety of these secondary minerals, the corroded appearance of most of the primary minerals of the rock, the presence of interstitial quartz, and the alteration of the feldspars, strongly support the idea of profound alterations as a result of folding and attack by the aqueo-igneous emanations from some invading or underlying magma.[36]

---

[35] Stott, Charles E., Geology of the Pecos mine: Eng. & Min. Jour., vol. 131, no. 6, pp. 270-275, 1931.

[36] Krieger, Philip, op. cit. (Econ. Geol. 27: 4, 5) p. 356.

Several phases of the diabase are found in this district, along Willow Creek and in the mine; the variety is considered to be the result of differential attack by magmatic emanations; the many alterations are more variable and intense in the shear zone of the mine than elsewhere within the district. Kreiger,[37] as a result of his detailed petrographic studies reports:

> . . . . Some have been completely silicified; others have been so greatly altered that their original nature can only be inferred from the character of their alteration products. Uralite, judged to have been derived from original pyroxene, is one of the most prominent of the secondary products. Still others show such extreme chloritization that only remnants or faint outlines of the original minerals remain. Nearly all of them show addition of quartz and feldspar together with the development of zoisite, epidote, sericite and saussurite. Although initially the diabase had a considerable range in texture, and although it has been altered with variable intensity, the different facies form a reasonably constant petrographic unit distinguishable under the microscope.
>
> The diabase is judged to be the oldest recognizable rock unit in the district. It may have constituted a thick sill intruded into still older pre-Cambrian sediments which are now either entirely destroyed or hidden from view by overlying Pennsylvanian sediments. During pre-Cambrian time, the diabase was caught up in and intruded by a granite. The effect of the granite intrusion is undoubtedly responsible for the profound changes that have taken place in the diabase. It is thought that the diabase may now represent a roof pendant within the granite that has been exposed to permeation and flooding by aqueo-igneous solutions and gases from the granite mass. During the end-stage crystallization period of the granite intrusion, the mineralizers responsible for the metallization within the shear zone were produced.

GRANITE

Granite is found east of the mine in Willow Creek, and in several places in canyons east of the Pecos River, and in the Pecos River canyon south of the camp. In the narrow box canyon of Willow Creek, about a mile east of the mine, it may be seen as a great mass with nearly vertical walls, surrounded by large accumulations of slide rock.

The normal granite is a massive uniform pink medium-grained rock. The pink color of the fresh rock is due to the presence of salmon-colored orthoclase. On weathered surfaces the rock assumes a deeper shade which may be a deep salmon color or a light reddish-brown.

The minerals of the rock are orthoclase, microcline, perthite, albite, and quartz. Biotite is present in small amounts and other accessory minerals are muscovite, magnetite, and titanite. Biotite appears only along the margins of the quartz and feldspar crystals and is not intergrown with them. The minerals occur in crystalline particles of uniform and medium size throughout the mass, but crystalline outlines are not developed, except in the orthoclase, which may have partial to complete crystal outlines. Alteration products are muscovite, sericite, kaolinite, epidote, and a small amount of leucoxene. Attack

[37] Idem.

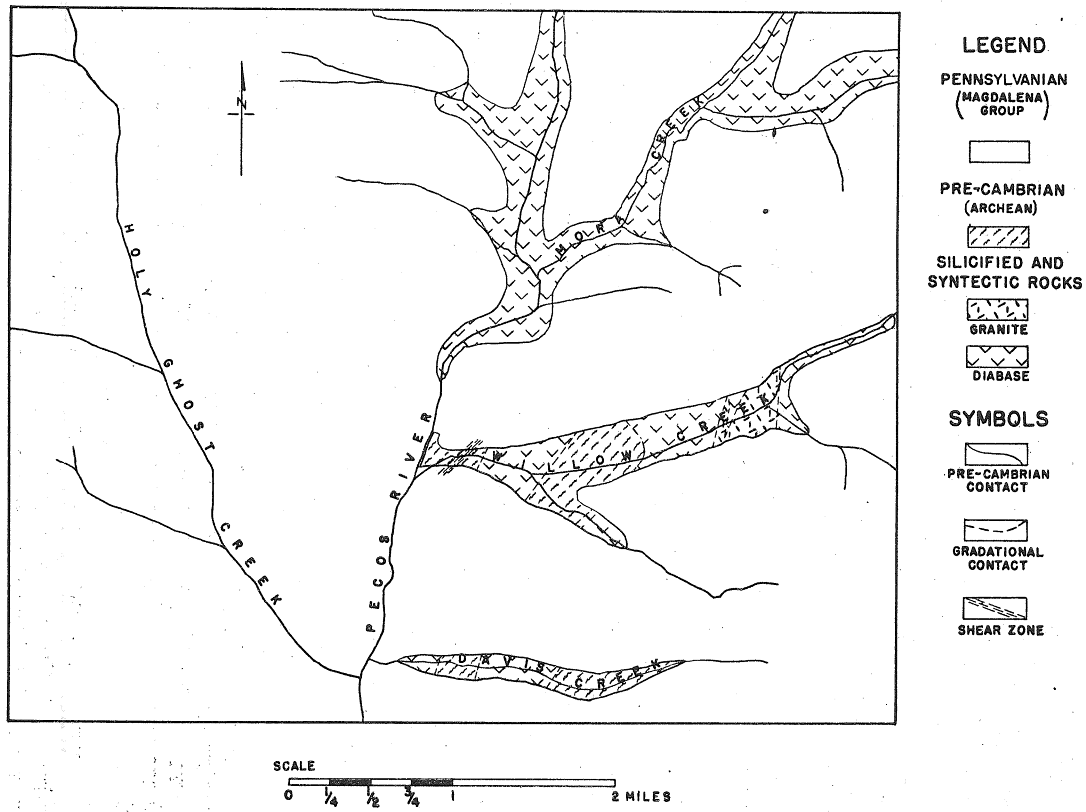


FIGURE 3.—Areal geology near Pecos mine

by magmatic solutions on the granite was not nearly so intense as on the diabase, probably because the attacking solutions were derived from the granite magma itself, and consequently were close to the granite in composition. In surface outcrops the granite is quite fresh in appearance, and, except for a deepening of its color, it has not been altered by weathering.

Granite has intruded the diabase as can be seen in Willow Creek canyon and elsewhere, where small dikes and stringers of fine-grained granite, or aplite, cut the diabase. Many of these dikes can be traced directly back into the granite mass; along its west border at least two of these dikes cross Willow Creek and merge with the main body of the rock on its south side. Further proof of the similarity of the dikes and the granite is found under the microscope, where the minerals of both rocks are the same, both being rich in soda-microcline, quartz, and albite.[38]

At several places on Willow Creek, irregular or dike-like masses of diabase are seen in the outcrops of the granite. Stott[39] has analyzed these occurrences by close mapping and study of diamond drill cores; although at first he believed that these diabase strips were later than the granite, he later concluded that they are simply remnants of diabase which were caught up in the granite magma. In some places are clearly seen isolated blocks of diabase entirely surrounded by granite or quartz-sericite schist. Usually these blocks are of the dense, fine-grained variety of diabase and they have been strongly silicified. In other places the blocks have been subjected to shearing and are now seen as bands of chlorite and biotite schist, alternating with bands of quartz-sericite schist of granitic origin.

SYNTECTIC ROCKS

Krieger[40] as a result of detailed microscopic investigation, has recognized several gradations between slightly altered diabase, and diabase that is almost completely granitized; these he designates as syntectic (melted together) products, using the term established by Sederholm in 1916. In the Pecos district, these syntectic phases do not appear to be related to ore deposition.

SCHISTS

Wherever the primary diabase and granite of the Pecos mine, and their syntectic products, have been exposed to movements and deformation, some variety of schist has been developed within the shear zone or in the adjacent wall rock. A wide range in the types of schists formed is found, due to the variation in the composition and texture of the original diabase and granite, and the variety of the syntectic products derived from them. In general, however, three major types may be recognized as fol-

[38] Krieger, Philip, op. cit., p. 358.
[39] Stott, Charles E., op. cit. (Eng. and Min. Jour. 131:6), p. 271.
[40] Krieger, Philip, op. cit., pp. 358-362.

lows: biotite schist that has developed from the dynamic metamorphism of unaltered or slightly altered diabase, quartz-sericite schist that has developed from the dynamic metamorphism of unaltered or slightly altered granite, and quartz-chlorite schist that is the result of the shearing and alteration of the syntectic rocks. Variations in the schistosity of the rocks depend on the amount of dynamo-metamorphism to which they have been subjected. Where definite planes of fracture and shearing can be seen in the rock, a talcy, schistose gouge is often developed; this condition extends over considerable widths in the zones of most intense movement in the ore deposits. On the other hand, where no planes of fracture or shearing are visible, and where the intensity of shearing has been moderate and has been equally intense throughout the entire rock mass, the rock still remains hard and dense and only a silky sheen has developed, particularly on faces parallel to the schistosity, to indicate that the rock has been metamorphosed.

Biotite schist.—This schist consists mainly of biotite, with subordinate amounts of quartz and sericite. Alteration of part of the biotite has resulted in the formation of chlorite. The biotite is a metamorphic product resulting from the movement due to shearing and pressure on the rock, and has been derived from the ferro-magnesian minerals of the original diabase. Biotite schist is found developed around the edges of isolated blocks of diabase and along planes of shearing in the wall rock at varying distances from the main zone of shearing and ore deposition.

Quartz-sericite schist.—Quartz-sericite schist has been developed in the mine by the shearing of granite, or a pegmatitic phase of granite. It is found at many places, generally in the wall rock at some distance from the main shear zone and mineralized areas. It has a fine granular texture, in which the schistose structure is often not distinguishable except under a hand lens, through which the orientation of the sericite may be seen. Under the microscope the schistose structure of the rock is very evident. Quartz is the most abundant mineral, constituting 60 to 70 percent of the rock. Sericite makes up 25 to 35 percent of the rock, and there are minor amounts of biotite, and its alteration product chlorite, with a few accessory minerals. The texture varies widely and the change in texture may be abrupt from one part of the rock mass to the next.

Krieger[41] writes:

> The rock is a good example of a schist developed through the shearing and granulation of a granite or granite pegmatite. The areas of coarser quartz are believed to be original quartz of the granite; the finer masses of mixed quartz and sericite, with a decided schistose structure, are derived from the shearing and granulation of the feldspars and the finer-grained quartz. In some of the unsheared granites and the more acid syntectic

41 Krieger, Philip, op. cit., p. 363.

rocks, poikilitic intergrowths are common. It is thought that the finest mixed patches of quartz and sericite occurring in the schists may represent areas of these intergrowths that have been much sheared and granulated. All three textures may be seen in the same field under the microscope.

Quartz-chlorite schist.—Quartz-chlorite schist occurs in great abundance within the shear zone in the Pecos mine, in close association with the metallic mineral deposits. It is found where the disturbance has been greatest, along the walls and in zones of pronounced movement within the ore bodies, and consequently much of it has been reduced to a soft talcy mass. It is a fine-grained mottled greenish rock. Since much of the metallization appears to be associated with this rock, Krieger[42] thinks that it may have been important in serving as a localizer for the deposition of the ore minerals.

This schist is supposed to have been derived from a mixed syntectic product, in which diabasic and granitic material alternately predominate. In thin section the rock is markedly schistose; it is composed of quartz, chlorite, and sericite, with accessory biotite and muscovite. The minerals of the rock are all oriented in the same direction, and the quartz grains show a slight parallel elongation. The sericite and quartz are usually intimately intermixed, but occasional patches of sericite alone are found; these are believed to represent feldspar crystals that have been completely altered. In other places large patches of chlorite are developed and Krieger[43] states that these contain parallel intergrowths of muscovite and biotite. He believes that these patches are derived from ferro-magnesian minerals, from the more basic portions of the syntectic product.

STRUCTURAL RELATIONS

The shear zone.—All the rocks of the Pecos district are schistose, and thus give evidence that dynamo-metamorphic deformation has been effective throughout the region. In the Pecos mine, more marked dynamo-metamorphic strains appear along what is called the shear zone. The total width of this shear zone is 600 feet, and the shearing planes strike north 40° to 45° east, which strike is parallel with the regional shear and schistosity in the district. The dip in the shear zone ranges from 75° to 85° northwest in the upper 500 feet of the mine. Between the 500 and 600 foot levels the dip is practically vertical, and below the 600 foot level it is to the southeast; the dip flattens with depth, and is only 38° to 40° in the lower levels. Within this wide shear zone, are axes of major movement along which the rocks are much more severely altered and crushed, with the development of talcy schists and wide streaks of gouge. On the east side of the zone is a major axis of distortion, and parallel to it and about 200 feet to the west is a secondary axis of distortion.

---

[42] Krieger, Philip, op. cit., p. 363.
[43] Krieger, Philip, op. cit., p. 364.

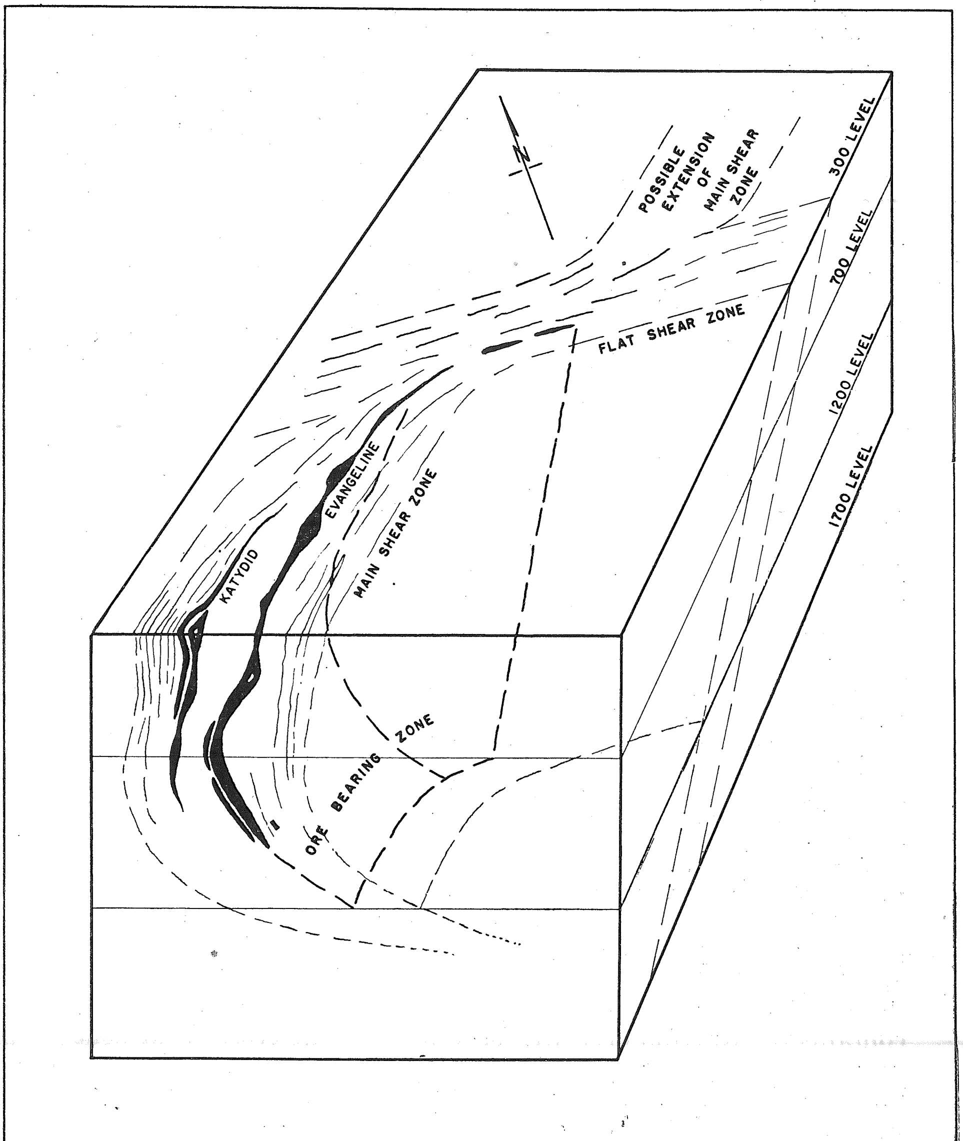


FIGURE 4.—Simplified block diagram of Pecos mine

Many minor axes of movement and shearing are found in the shear zone, parallel to the major and secondary axes of distortion, and in the wall rock on the east side of the shear zone. Several of these minor zones of disturbance have been located with diamond drill holes. The west wall of the shear zone is composed of dense, fine-grained, slightly schistose diabase, and is practically without any such axes of movement. All minor zones of movement appear to be of short dimensions, both vertically and lengthwise, and most of them are only a few inches in width, with the development of thin selvages of biotite schist and with little or no talcy schist or gouge.

The Evangeline orebody lies along the major axis of shearing, and the Katydid orebody is situated along the secondary axis. At many places in the mine, both in the main shear zone and in the east wall, small patches of ore have been located in the minor zones of shearing, but these have been of little importance.

Southwest of the main shaft, the zone of shearing has been traced for a mile, by underground and surface diamond drill holes. Northeast of the shaft, the zone is continuous and strong for 1500 feet, and then it swings to the east and becomes narrower and less productive of ore. This swing in the strike of the main shear zone has been caused by its being cut by a cross zone of shearing which strikes north 70° to 80° east, and has a dip of 55° to the south. This cross zone is about 400 feet in width, and in general shows much less severe shearing than the main zone. Parallel to the cross zone of shearing at several places in the mine, but more particularly in the northern part, zones of deformation have disturbed the continuity of the main northeasterly shear zone. There is no way of measuring the displacement along the cross shear zone, but after a considerable time spent in studying the region, the writer made an estimate that north of the cross shear zone, the main shear zone would be found offset between 700 and 1000 feet toward the east, as shown in the simplified block diagram, Fig. 4.

Movement continued along the major axis during a great part of the period of mineralization in the Evangeline orebody, and the ore is distributed more irregularly and replacement of the rock has not been so complete as in the secondary zone which contains the Katydid orebody. Movement in the cross shear zone apparently did not begin until the early stages of mineralization had passed, and only the later stages of mineralization appear to have affected this zone.

Within the shear zone are many masses, or horses, of only partly altered diabase. These are supposed to be masses of denser material that were detached from the walls during the shearing of the rocks and were dragged along during the later movements that occurred in this zone. These masses have rounded edges and their borders have been metamorphosed to biotite schist. Between the altered diabase masses, and in the main zones of shearing, the metamorphosed rock consists principally of quartz-sericite schist and quartz-chlorite schist. This is interpreted to mean that, at the time of the granite invasion, the present shear zone was a zone of weakness along which much granitic material was introduced into the diabase, converting it largely to syntectic products. On later shearing the granite was converted to quartz-sericite schist, and the syntectic rocks were converted to quartz-chlorite schist. Where masses of partly altered diabase are found in the shear zone, the planes of schistosity bend around them and cause irregularities in the trend of the ore and pinching or splitting of the deposits.

In the Katydid orebody, little or no movement took place during the deposition of the ore; as a result this orebody shows more continuity and more complete replacement than the Evangeline, and the ore is higher in grade and more uniform in mineral content throughout. The Katydid ground is the harder, has fewer soft and talcy streaks, and does not cave so readily; consequently, less timber is required in mining, and mining costs are somewhat lower.

There has been considerable post-mineral movement in the Evangeline deposit, and the rocks are broken and sheared, with patches of waste rock dragged into the ore. Along streaks of fault gouge, mineral has been dragged, and the indication is that the east wall of the shear zone has been dragged upward and to the north, relative to the west wall, as shown on the block diagram (Fig. 4). The Evangeline shear zone is much wider than the Katydid zone, as a result of the movement during mineralization and afterward, and for long distances along the east wall of the Evangeline orebody, post-mineral gouge can be seen on several levels of the mine.

Ore has replaced the highly schistose rocks, rather than the wall rocks on either side of the shear zone or the masses of dense diabase within it, and in general quartz-chlorite schist has been more completely replaced by ore than has the quartz-sericite or the biotite schist.

Formation of shear zone.—On each side of the main shear zone in the Pecos mine, the wall rock is a fairly dense fine-grained schistose diabase. In the west wall, drill holes showed that comparatively few zones of movement are present; consequently there has been little development of biotite schist in this wall. In the east wall, more movement has taken place within the block and the drill holes often cut narrow zones of shearing along which the diabase has been converted to biotite schist, and in some instances to quartz-chlorite schist. In a few of these zones ore has been found, but such occurrences are scattered and small, and are generally not worth further development.

The writer's concept of the structural relations of these blocks of dense diabase, and the manner in which the shear zone was formed, can be seen from the block diagram of Fig. 4. In this figure, block B represents the east wall of the shear zone, which is believed to have moved northward and upward relative to the block A, the west wall. This movement was brought about by compressive stresses supposed to have come from the west, and caused the intense shearing and schistosity in the shear zone between the two blocks. Within the shear zone, blocks of dense diabase were loosened from the walls along joint and fracture planes, and were supported in the more intimately sheared material.

Intrusion of the diabase by granite magma and granitic solutions followed this preliminary break, and movement between the blocks of unbroken diabase, and the assimilation of the fractured diabase by the granite materials, led to the formation of the syntectic products recognized and studied by Krieger (see page 76). Further movement along the zone converted the granitic material to quartz-sericite schist, while the syntectic products were converted to quartz-chlorite schist. Metallic minerals were then introduced, and in the early stages pyrite and sphalerite with minor amounts of quartz were deposited in the shear zone, and replaced the highly schistose material. After the deposition of these minerals further stresses developed, and a zone of cross fracturing was formed by the eastward movement of blocks A_1 and B_1 relative to blocks A and B. This zone of cross fracturing is 400 feet wide, strikes N. 70° to 80° E., and dips 55° to the south. It has been estimated that blocks A_1 and B_1 were moved 700 to 1000 feet east of their original positions.

Movement along the cross fracture has shifted the strike of the known ore bodies in the Pecos mine (see maps, Figs. 5, 6, 7) so that they swing into line with the cross faulting in the northern part of the mine and are pinched out in a short distance. The late stage of mineralization occurred after the cross faulting had disturbed the main shear zone and the mineralization at the north end of the mine, where new openings had been made, is typical of this late stage and consists of minor pyrite and sphalerite, with chalcopyrite and galena and abundant quartz.

The Evangeline orebody near the east wall of the main shear zone was subjected to movements throughout the mineralizing period, and consequently, in this deposit, the mineralization is variable. In the lower levels some of the ore is typical of the late stage of mineralization, and was deposited where new openings permitted the chalcopyrite-galena-quartz solutions to be injected into spaces opened between masses of the early stage pyrite-sphalerite ore.

The inference to be drawn from this concept of the structural history of the Pecos mine is that considerable prospecting north of the cross shear zone is warranted. Just how far north

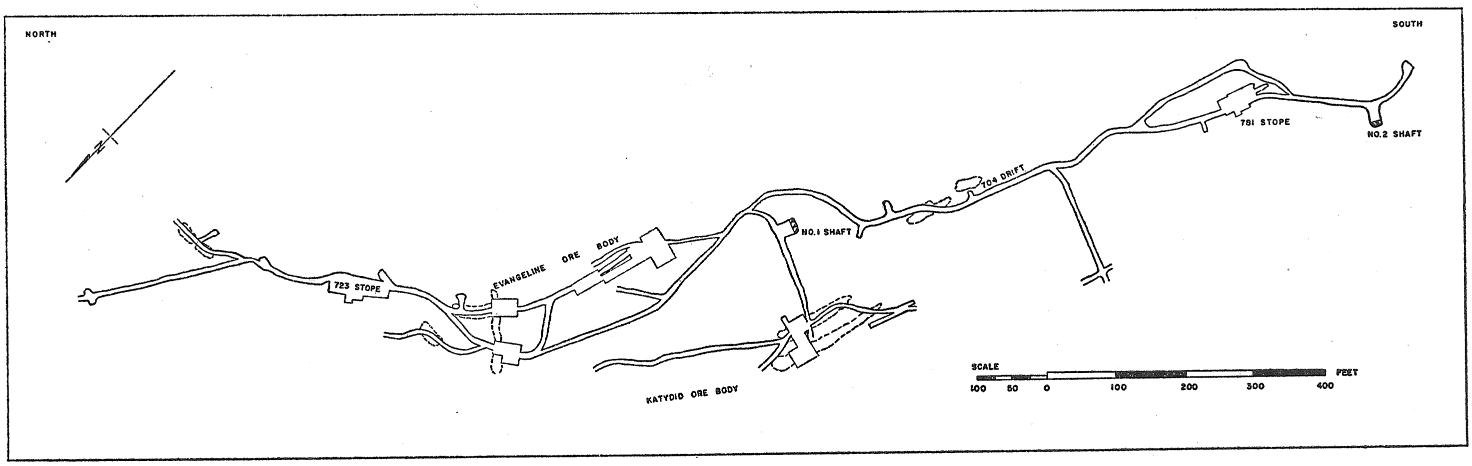


FIGURE 5.—Map of the 700 level, Pecos mine

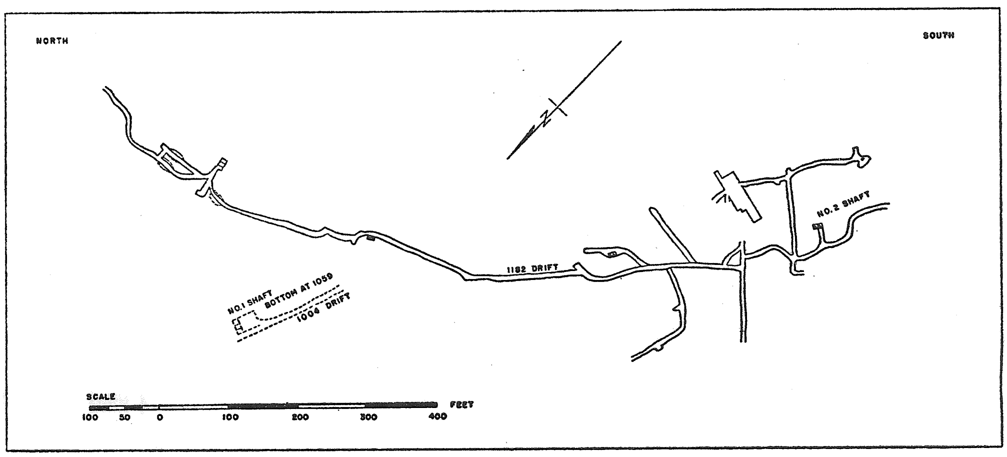


FIGURE 6.—Map of the 1100 level, Pecos mine

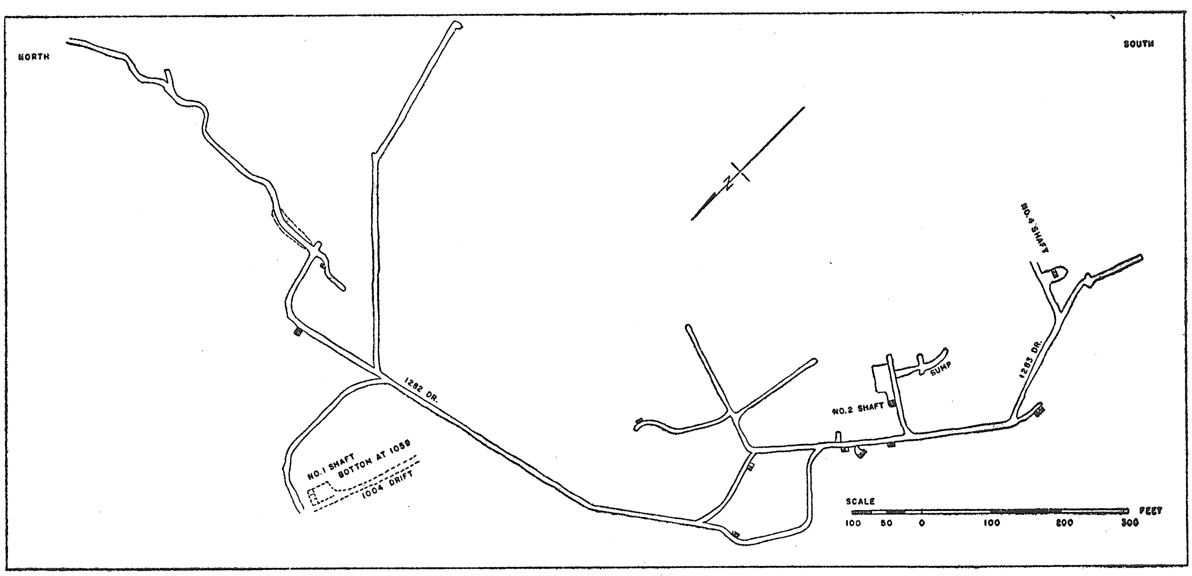


FIGURE 7.—Map of the 1200 level, Pecos mine

of the shear zone it will be advisable to go is still an open question. The cross shear zone is about 400 feet across, and present workings indicate that no continuous ore can be expected within it. If the northern extension of the main shear zone exists, and if it has been dragged out of its normal trend by the cross faulting, it has probably been squeezed and broken and pinched; an advance of workings for another 500 to 1000 feet may be necessary before drilling across to it. And finally, as stated before, just how far the zone has been moved to the east of the line of the main orebody in the mine is a question remaining to be answered.

The Evangeline orebody is much wider than the Katydid deposit as a result of the movement which took place during mineralization and afterward; fault gouge has been found on several different levels in the mine along the east side of the Evangeline orebody.

Ore has replaced the highly schistose rocks, rather than the wall rocks on either side of the shear zone or the masses of dense diabase within it, and in general the quartz-chlorite schist has been more completely replaced by ore than has the quartz-sericite schist. This is supposed to have a structural explanation rather than a chemical one, and it is believed that the more porous and shattered quartz-chlorite schist permitted free passage for the ore-bearing solutions in large quantities, and that there was no tendency for them to be soaked up by the wall rocks. It must be borne in mind, however, that the ore-bearing solutions were from the same source as the granite and hence would probably not be very active toward granite and quartz-sericite schist, but would tend to replace more readily the quartz-chlorite schist derived from the syntectic products of the crushed and sheared zone.

THE ORE DEPOSITS

CHARACTER

The ore deposits of the Pecos mine consist of zinc, lead, and copper sulphides, mixed with pyrite and quartz, and accompanied by gold and silver in moderate amounts. Pyrite is the most abundant mineral in the ore and must be eliminated in the concentration process in order to make a merchantable product. For the first three years of operation of the company, the average grade of the ore mined was 16.06 percent zinc, 3.73 percent lead, 1.02 percent copper, 3.39 ounces of silver, and 0.109 ounces of gold per ton. The average grade of all ore produced, in terms of the metals marketed, is shown in the tabulation of production (see Table 3). Silver accompanies galena in the ratio of 1.0 ounce of silver for each 1.0 percent of lead. Gold appears to be more erratic; recent development on the lower levels indicates that the gold was important in the last stages of mineralization and came in during the abundant quartz stage.

Gangue minerals are quartz, chlorite, actinolite, sericite, and tourmaline. Quartz, chlorite, actinolite, and sericite were formed during the recrystallization of the original rock by dynamometamorphic and hydrothermal alteration. Much quartz was also introduced with the ore minerals. Tourmaline, now appearing as crushed and broken crystals, was one of the last minerals to be introduced, after the deposition of the ore, but before dynamic disturbance had ceased. Roscoelite, the vanadium mica, has been found in very small quantities on the lower levels, associated with late-stage quartz in a part of the mine where the gold values were relatively high.

The order of deposition of the minerals was pyrite and sphalerite, in large quantities, followed by a small amount of pyrrhotite, which has replaced both pyrite and sphalerite. Later minerals are chalcopyrite and galena, with galena perhaps slightly later than the chalcopyrite, although in many specimens they appear to be contemporaneous. Bornite in very small amounts is a later mineral and appears to have replaced chalcopyrite. Vein quartz was a late mineral; it is much more abundant where pyrite and sphalerite are scarce and where chalcopyrite and galena are plentiful. Gold appears to have been deposited in the later stage, in places where quartz and chalcopyrite are most abundant. Silver is associated with galena. Sphalerite appears in two forms, a resinous mineral high in zinc and low in iron, which was the early form, and a later type called marmatite, which is lower in zinc and higher in iron.

Krieger[44] describes the variability of the ores as follows:

> The ore, like the rocks of the mine, is extremely variable. Some specimens contain practically all the major constituents, sphalerite, galena, chalcopyrite and pyrite closely associated with each other. In the majority, however, sphalerite and pyrite, the two most abundant constituents, are dominant. These were the earliest of the metallic minerals to form, the pyrite, in all cases, being the first. This was followed by the deposition of the sphalerite. Wherever these two minerals are observed together the sphalerite always replaces the pyrite, so there is no doubt as to the relations existing between them.
>
> The pyrite commonly occurs in the form of cubes that vary in size from very minute dimensions up to one-half inch or more. It is the most persistent of the metallic minerals and forms large aggregates of crystals in the schistose rocks. The crystallizing power of this mineral is well illustrated near the outer margins of the more massive diabase "horses," where it also occurs in numerous isolated crystals of remarkably well-developed cubical forms embedded in the massive rock. Fractured crystals of pyrite are numerous and indicate recurrent movement during mineralization with later replacement by sphalerite along the fractures.
>
> . . . . The sphalerite commonly occurs as massive bodies replacing the schistose rocks and the pyrite, and may be associated with galena and chalcopyrite. It may contain remnant crystals of pyrite, still showing a more or less cubical form, or the pyrite may be embayed and replaced by it. Sphalerite also contains numerous remnants of unreplaced chlorite, actinolite and sericite within it.

[44] Krieger, Philip, op. cit., pp. 461-462.

Both chalcopyrite and galena are later than the pyrite and sphalerite and replace the earlier formed minerals. The relation between the chalcopyrite and the galena, however, is less distinct; only one instance was observed where the galena occurs later than the chalcopyrite. The remainder of the specimens examined showed mutual boundaries between these minerals, and in view of the lack of definite evidence such as veinlets of the one mineral transecting the other, or residuals of one within the other, one is led to the conclusion that they were deposited contemporaneously, but definitely later than the pyrite and sphalerite. Slight overlapping may have occurred, with galena showing a tendency to be the later mineral.

Both chalcopyrite and galena occur in irregular masses disseminated through the sphalerite, pyrite and gangue minerals.

. . . . The chalcopyrite and galena also occur together in a number of stringers or veins, some of which cut the foliation of the schist. They probably represent the final stages of mineralization and penetrated the shear zone after most of the deformation had been accomplished.

Surface weathering processes have accomplished little or no oxidation, solution, and secondary enrichment of the minerals. The old pre-Cambrian surface beneath the Pennsylvanian sediments shows that oxidation has affected the ores for only a few feet of depth, and indicates that the erosion of the ancient rock surface proceeded at a rate equal to or in excess of the rate at which oxidation progressed downward from the surface.

PRODUCTION OF ORE

Table 3 shows the tonnage of crude ore and the tonnage of concentrates produced at the Pecos mine from the time it started operations in January, 1927, until the close of the year 1938, for which the last official figures are available. It also shows the quantity of metals recovered from the concentrates, and the grade of the ore in terms of recoverable metal. From the paper by Bemis[45] it appears that the Pecos mill has made an average recovery of 85 percent of the gold and silver content of the crude ore, and that the recovery of zinc, lead, and copper has averaged around 88 percent.

MINING OPERATIONS

Matson and Hoag[46] and Bemis[47] have published full accounts of the mining and milling operations of the Pecos mine. Figures 5, 6 and 7 are level maps of the mine, illustrating the lenticular form of the ore shoots longitudinally within the Evangeline and Katydid shear zones. The section, Fig. 9, and the block diagram of Fig. 4 show a similar tendency in a vertical direction. Longitudinal projections, Fig. 9 along the Evangeline vein, and Fig. 8 along the Katydid vein, indicate the distinct plunge of these orebodies to the southwest, which has been brought about by the zone of cross shearing that dips to the south at about 55° and cuts

[45] Bemis, H. D., Milling methods and costs at the Pecos concentrator of the American Metal Co., Tererro, N. Mex.: U. S. Bur. Mines, Inf. Circ. 6605, 1932.

[46] Matson, J. T., and Hoag, C., Mining practice at the Pecos mine of the American Metal Co. of New Mexico: U. S. Bur. Mines, Inf. Circ. 6368, 1930.

[47] Bemis, H. D., Milling methods and costs at the Pecos concentrator of the American Metal Co., Tererro, N. Mex.: U. S. Bur. Mines, Inf. Circ. 6605, 1932.

TABLE 3

Production of Metals from Pecos Mine, 1927-1938, in Terms of Recovered Metals

Year	Ore mined and treated at concentrator, short tons	CONCENTRATES AND RECOVERED METALS					
		Concentrates produced, tons	Gold fine ounces	Silver fine ounces	Copper pounds	Lead pounds	Zinc pounds
1927	164,874	66,971	11,406.19	509,446	1,989,000	8,706,000	42,445,000
1928	201,103	71,973	14,982.92	495,930	2,120,000	10,385,000	46,410,000
1929	216,809	69,800	16,597.19	471,619	2,641,000	11,439,000	45,730,000
1930	151,943	52,774	13,116.93	406,865	1,438,000	10,861,000	33,276,000
1931	184,502	63,691	14,941.02	420,386	1,096,000	15,125,000	41,633,000
1932	185,515	62,346	13,956.46	463,000	1,019,000	12,898,000	40,712,000
1933	191,905	60,576	19,424.69	621,977	1,753,000	14,149,000	39,329,000
1934	200,839	53,993	15,632.39	543,639	1,733,000	12,286,000	33,693,000
1935	185,380	44,308	14,816.66	432,622	1,227,000	10,323,000	26,744,000
1936	*150,932	32,650	11,541.00	300,514	909,000	7,491,000	19,334,000
1937	185,850	35,561	12,299.51	308,101	1,004,000	7,704,000	21,764,000
1938	203,900	37,104	13,847.20	322,400	1,184,000	8,554,500	22,581,000
Totals	2,223,552	651,747	172,562.16	5,296,499	18,113,000	129,921,500	413,651,000

* Miners' strike in February, March and April, total working days 263.

NOTE: The Pecos mine was shut down May 31, 1939; production figures for 1939 are not available.

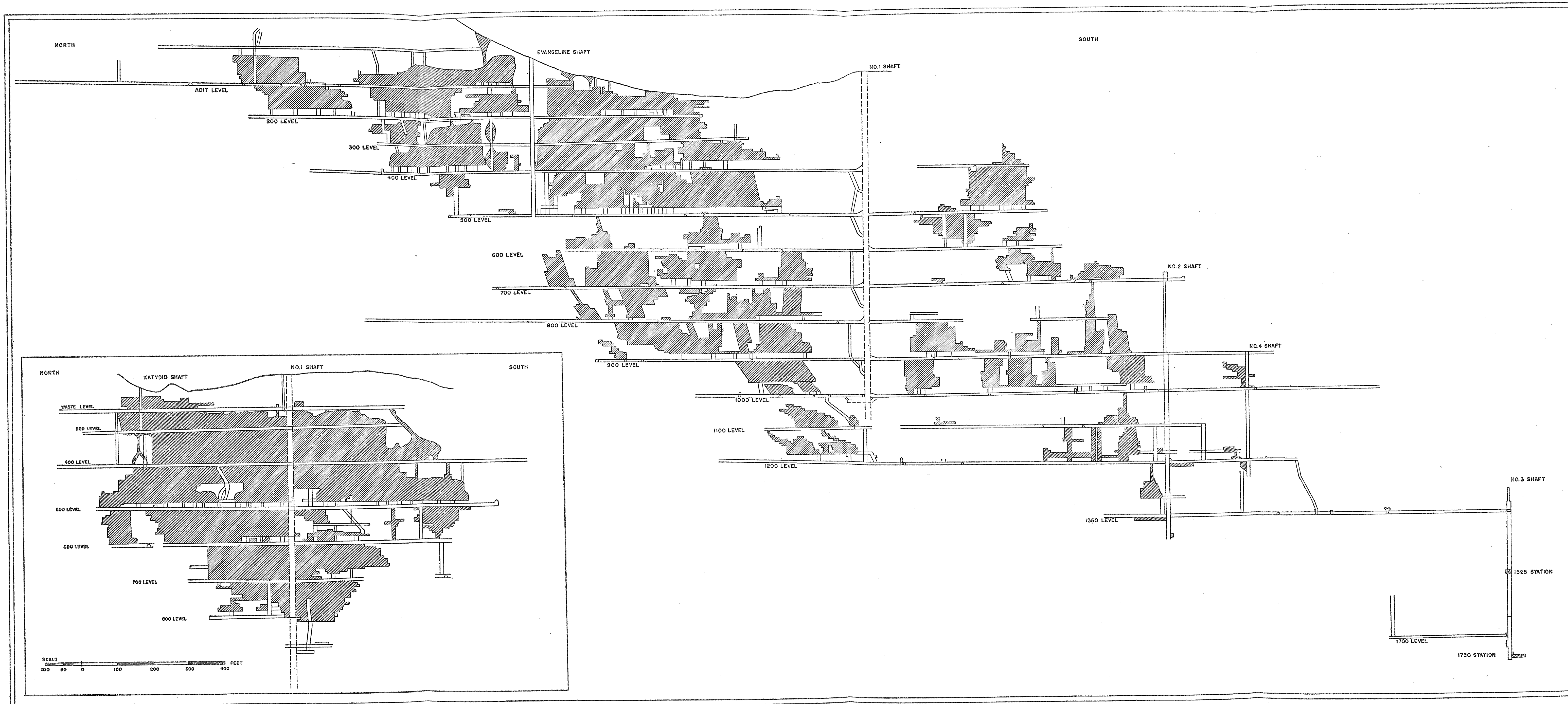


FIGURE 8.—Longitudinal projection along Katydid orebody

FIGURE 9.—Longitudinal projection along Evangeline orebody

the veins off along their lower margins. The tops of the veins plunge in the same direction, but much less steeply.

Prospecting and exploration is difficult and uncertain in the Pecos mine due to the lens-like form of the individual ore shoots, and to their erratic distribution within the ore zone. Matson and Hoag[48] have briefly described the method in use as follows:

> Prospecting by drifting consists of following the principal ore shoots along their strike. If the ore body pinches out, an attempt is made to follow the most promising of possibly several sheared zones. This is a matter of great difficulty, as the ore occurrences are erratic, and no sure guides to ore are known. For this reason orebodies when once found are sometimes explored by driving ahead the sub-level, which constitutes the sill floor of the stopes, considerably in advance of the main level drift. Following this work the main level drift can be placed to much better advantage with respect to turns, widenings, or pinching of the ore, or to parallel ore bodies.
>
> The shear zone is cross cut or drilled at frequent intervals. The walls and downward extensions are explored by diamond drilling from underground, and extensions along the strike are explored by diamond drilling from the surface. An E-S bit is used for this work. The walls are also tested for parallel ore shoots by deep-hole drilling with Leyner machines and sectional steel. These holes are usually between 50 and 100 feet in length. The steel used is 1¼ inch, hollow round, in 3, 6, and 9 foot lengths. Only two-bit gages are used, as this was found more satisfactory than the several that were used originally. The cost of this prospect drilling is shown at the bottom of Table 3 [in their paper].
>
> Some geophysical prospecting has been done, using the high frequency equipotential and electromagnetic methods. The results of this work were decidedly unfavorable. No orebodies were found where indicated by the surveys, whereas orebodies have since been found in areas indicated as barren.

During the life of this mine, 90,080 feet of diamond drilling has been done to explore the walls and lower levels. In addition, 20,610 feet of drilling has been done from surface in an attempt to find ore in the extension of the known shear zone, and to explore for possible parallel zones to the eastward, up Willow Creek. In all 110,690 feet of diamond drilling has been done, in the search for new ore.

The main shaft is a vertical four-compartment shaft, with levels at 100-foot intervals. It is located midway between the Evangeline and the Katydid shear zones on the surface, but in the lower part, due to the flattening of the zones in depth, the shaft is in the west wall of the Katydid vein, and deeper exploration has been through winzes from level to level. The main shaft has been sunk to 56 feet below the 1000 foot level. All ore and waste hoisting, and part of the handling of men and supplies are carried on through this shaft. In addition three two-compartment winzes have been sunk, one from the 900 to 1400 foot level, one from the 1350 foot level to the 1750 foot level, and one from the 900 foot level to the 1240 foot level.

The Evangeline shaft is 1000 feet northeast of the main shaft, and is used only for handling men and supplies.

Development work consists of crosscutting on each level

[48] Matson, J. T. and Hoag, C., op. cit., p. 3.

to the veins, and then drifting on the veins, usually in the footwall. Raises are divided into chutes and manways, cribbed with 6 to 8 inch round timber, from the level to the sill floor of the stope 20 feet above. Fill raises are driven from level to level as each new stope section is started. No effort is made to obtain speed in development work, as the rate depends on ease of waste and ore disposal. Development is carried on above stopes whenever waste is needed for stope filling, and on lower levels the rate of work depends on the amount of ore that can be handled through the main shaft.

Square-set-and-fill stoping and cut-and-fill methods have been used in this mine, but in later years square-set methods have predominated. Shrinkage stoping was tried in one place in the upper part of the mine, but in general the walls are not strong enough for this method to be successfully used.

Hoisting is by skips, from ore pockets at various levels to an ore bin at the collar of the shaft, from which the ore is fed into a jaw crusher, gyratory, and rolls, preparatory to being loaded on the aerial tramway.

For details of the aerial tramway, see the paper by Matson and Hoag,[49] and a thesis presented by E. C. Anderson[50] to the New Mexico School of Mines.

Mine timber is obtained from adjacent forests of native pine, fir, and spruce, and the supply is sufficient for a number of years. (See pp. 51, 70.)

Cut-and-fill stoping costs have been $2.11 per ton of ore, and square-set-and-fill methods have cost $2.66 per ton. Underground mining costs have been $4.38 per ton of ore. These figures are for the total tonnage produced in 1927-28-29, as reported by Matson and Hoag.[51]

The Pecos mill treated the ore by selective flotation methods at a maximum rate of 600 tons per day, and produced zinc concentrates and lead concentrates. The cost of milling for the four year period 1927-1930 inclusive was $1.33 per ton of ore treated. For further details of the milling operations and the problems that had to be solved in treating this complex ore, the reader is refererd to the paper by Bemis.[52]

FUTURE OF THE DISTRICT

When the Pecos mine was opened in 1927, the building of the plant was justified by the presence of 1,000,000 tons of ore, which was blocked out at that time. By the end of May, 1939, when the property was totally shut down, this mine had produced 2,000,000 tons of ore.

---

[49] Matson, J. T. and Hoag, C., op. cit., p. 11.
[50] Anderson, E. C., op. cit. (See page 69.)
[51] Matson, J. T. and Hoag, C., op. cit., pp. 17 and 19.
[52] Bemis, H. D., op. cit.

South of the present workings no ore has been discovered in the main shear zone, although much diamond drilling from the surface has been done in this direction.

Neither the east wall nor the west wall of the deposit has as yet shown an orebody, in spite of the many thousands of feet of diamond drill holes that have penetrated them at all levels and throughout the length of the mine. In this respect, however, the east wall is the more favorable prospect of the two, as some small stringers of ore have been cut.

With depth, the shear zone has flattened to the east and has become much narrower and less productive of ore with each lower level reached. This flattening and tightening appears to be characteristic of fracture zones formed under conditions of compression and reverse faulting, similar to those under which the Pecos shear zone was formed. The grade of ore has also decreased in this direction, and lead and copper values have increased relative to the zinc values in the veins. Further prospecting down the dip of the shear zone offers little hope.

There remains, however, the area to the north of the cross shear zone in the north end of the mine. Here it is believed that the main shear zone is continued but has been offset to the east between 700 and 1000 feet, a distance not so great but that the zone can be prospected by long drill holes from a drift extended northward from one of the main levels of the mine. In order to prospect this territory, a drift on the 700 or 800 foot level should be driven north 45° east for 400 feet through the cross shear zone, and possibly 500 to 700 feet farther to insure that drill holes will reach the main shear zone beyond where it has been warped and pinched, or otherwise affected by the cross shearing. In the writer's opinion, this is the best prospective area, and one that should be given a favorable rating at least equal to any areas so far prospected in the district beyond the main ore zone. The great thickness of limestone, covering the district to the north of the cross shear zone, unfortunately makes the use of surface prospecting prohibitive in this area.

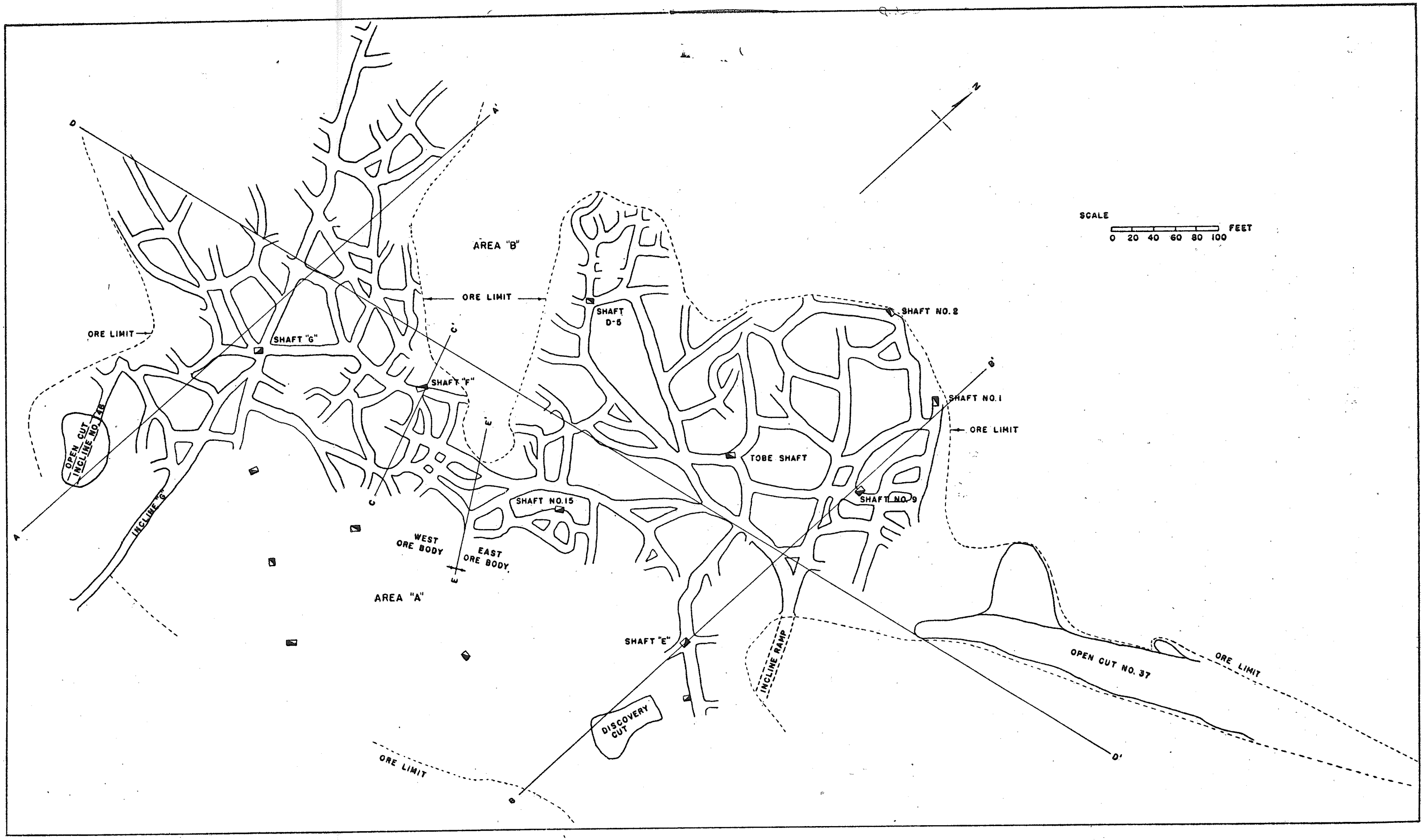


FIGURE 10.—Mine map of the Stauber property

THE STAUBER MINE

The I. J. Stauber property consists of a patented homestead of 320 acres, with the mineral rights, in Sections 6 and 7, T. 7 N., R. 20 E., New Mexico Principal Meridian. The mine is approximately 5200 feet above sea level. So far as is known, the ore deposit is not associated with any intrusives or faulting, but a study of section 6 on the plate of cross sections (Plate 5) indicates that the deposits occur over a high place in the granite bedrock, and that it is in a region of slight, but definite, warping of the beds. There are no known igneous rocks nearer than the Cerro Cuervo dike.

As shown in the structure sections (Fig. 11, A, B, and C) the Stauber orebody is a bedded deposit in sandstone. The ore bed is a medium gray sandstone which is generally cross-bedded. It is in the upper part of the Santa Rosa sandstone, and lies about 150 feet above the contact of the Dockum beds and the underlying beds of the Chupadera formation. The floor underlying the deposit is a clay bed 25 to 30 feet thick; above the East orebody (see Fig. 11) the overlying sedimentary bed is a clay. Over the West orebody the sediment is a cross-bedded sandstone (see Fig. 11). In places above the entire orebody, the overburden contains small bunches and bands of copper ore.

It was formerly believed that these beds of clay were altered igneous sills; a study of thin sections under the microscope reveals a microtexture resembling quartz-sericite schist; therefore, these clays are considered to be the end product of weak metamorphism of an arkosic sandstone.

THE ORE DEPOSITS

The ore occurs in a depression in the sandstone, as is clearly shown in the structure sections. The clay bed forming the floor of the deposit is rough in detail and contains many humps such as would be developed by minor faulting (see Fig. 11 A) but a detailed study of the floor at this point gives no evidence of past fracturing. One peculiar hump (see Fig. 11 C) is about 35 feet in diameter and about 6 feet high. One explanation for the presence of this hump, and of the ridges across the floor as shown in Fig. 11 A, is that they were formed by the flowing of the sandstone at the time it was metamorphosed. It is also possible that faulting may have occurred at the same time, and that the combined effects of flowing and metamorphism have obliterated all evidence of the former presence of fault fractures. It is almost certain that the material could not have been deposited in the form in which it is found, and a study of the roof of the old stopes gives no evidence of folding. Over the ridges, no corresponding irregularities are noticeable in the roof, but above the peculiar circular hump in the floor, the roof is arched, much as though the squeezing up of the floor at this point had lifted the ore beds and the overlying clay roof. Both the roof clay and the floor clay are sharply defined and distinct from the main copper-bearing sandstone.

The East orebody contains mostly malachite and azurite, with a small amount of chrysocolla and some tenorite (?), all replacing the cementing material of the sandstone, which is predominantly calcite. Some test results shown to the writer in 1927, when he spent a week at the mine making a private examination, indicated that 96 percent of the copper is soluble in a boiling solution of 5 percent sulphuric acid in 5 minutes, and that about 3.5 percent of the copper in the ore is present in the sulphide form. A few replaced logs have been found in the East orebody, and these were high grade ore containing approximately 47 percent copper, but in the aggregate, they constitute only a small part of the deposit. One log was reported as being 40 feet long and about 10 inches in diameter.

The West orebody differs considerably in appearance, as it contains a large number of ore nodules, but it averages about the same in total copper content as the East orebody. In addition to the oxides and carbonates of copper, it also contains some bornite, selected pieces of which were reported to contain 47 percent copper. In polished sections the writer noted chalcocite as a residual core in the centers of many of the nodules from this part of the deposit.

To the north the ore bed thins out, although it continues with a thickness of 4 to 5 feet for as far as the development headings have penetrated. The copper values decrease rather sharply with the thinning out of the beds; farther north, the beds are colored only by a light red stain of iron oxide. In places the bed goes from ore to waste in a distance of 4 to 5 feet. The southern limit of the mine workings is at the outcrop of the beds.

The ore is much fractured in all directions, but the major fractures appear to strike southwest, in the general direction of the strike of the enclosing sediments. Some of these fractures have a vein-like appearance, and are filled with rich ore. In others, the vein material and the adjacent wall rock are decidedly leached. In general, the richer ore is near the floor, with more or less leaching of the material near the roof, and in nearly every instance the ore is extremely rich for a distance of a few inches to a foot from the humps and bunches in the clay bed that makes the floor of the deposit.

The water level of the district lies about 300 feet below the present surface, and about 250 feet below the floor of the mine. The ground water contains considerable gypsum and is unfit for use. A small quantity of good water is found in the mine workings in sufficient quantity to supply the camp.

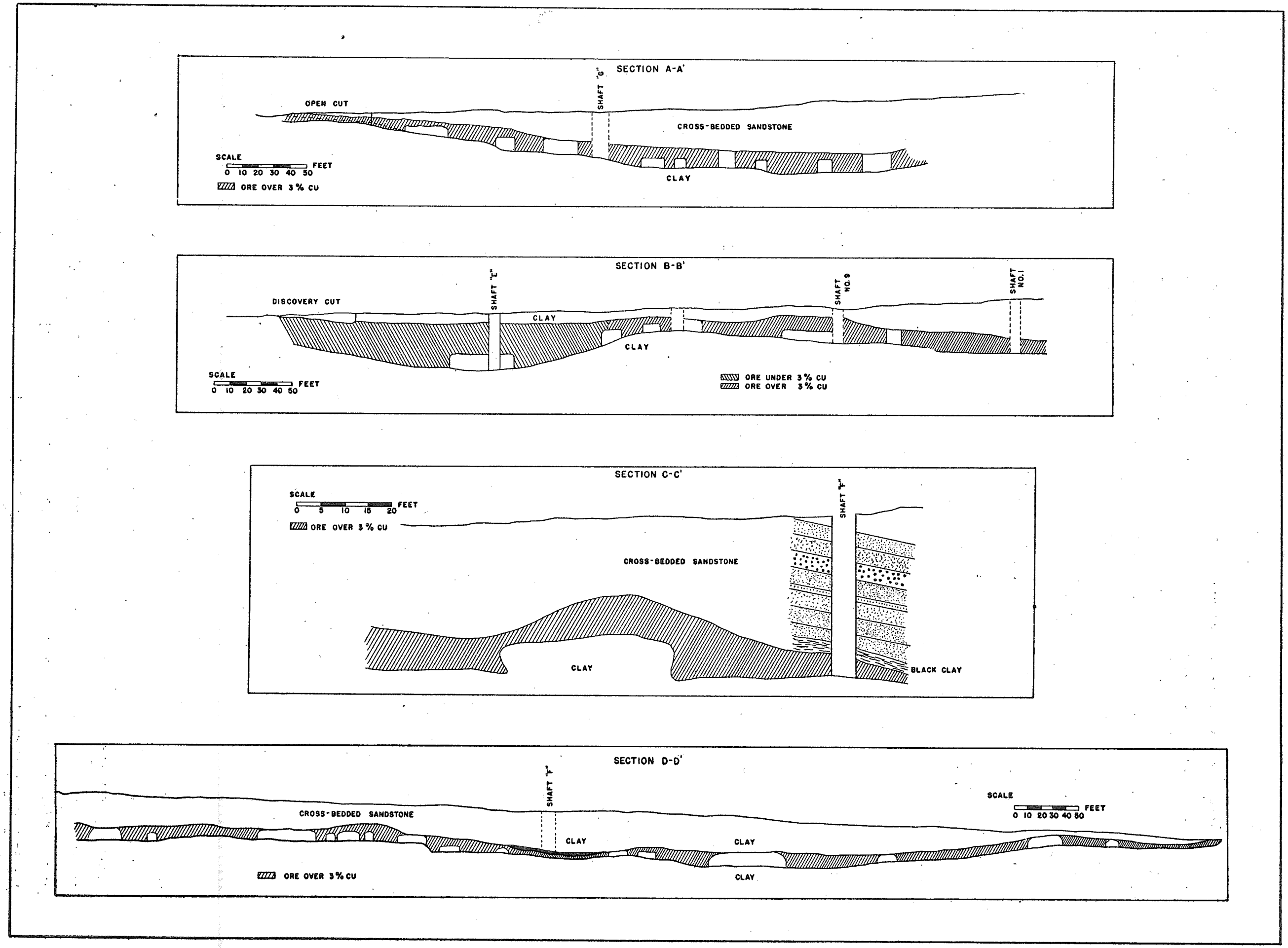


FIGURE 11.—Sections through the Stauber property

SOURCE OF ORE MINERALS

Regarding the origin of these deposits, opinions differ. The writer believes that in the Pintada Canyon district, the copper originated in old land masses to the north and west, and was removed from these either in solution or as disintegrated particles of the minerals. Surface waters in time took the material into solution and carried it to its present location, where it was caught in a natural trap. By precipitation from the stagnant solutions, the copper minerals replaced the cementing material and the organic matter in favorable beds; chalcocite was the principal mineral deposited, with minute quantities of bornite and chalcopyrite. Later elevation of these beds above water level caused the sulphides to oxidize to malachite, azurite, chrysocolla, and black oxide, with occasional masses of relict sulphides making up the cores of the larger nodules. Differences in the character of the East and West orebodies may be accounted for by the fact that the sandstone of the West orebody is more arkosic, and that the solutions replaced not only the cementing material between the grains, but also the grains of feldspar, thus allowing the copper sulphide to collect in concentrated, nodular masses. In the more siliceous part of the bed where the East orebody is located, only the cement was replaced, and hence the copper minerals are finely disseminated throughout the bed. Upon oxidation, the East orebody would be more completely and thoroughly altered to malachite and the associated minerals than would the West orebody, which would retain more of its original sulphide minerals.

The ore bed is a fairly coarse cross-bedded sandstone, with sufficient pore space to afford easy entrance for solutions. Although the structure has been in part obliterated by subsequent mineralizing and oxidizing action, the ore bed appears to the writer to have been laid down under conditions of shallow stream flow, probably toward the southwest. Above and below the ore bed other sandstones were laid down which differed in composition, probably being much more arkosic than even the most arkosic part of the ore bed.

Subsequent to the deposition of a thick sedimentary section over these beds, probably as late as Upper Cretaceous age, gentle movements occurred which squeezed and metamorphosed the overlying and underlying sediments, converting them into beds of impervious clay with the microtexture of quartz-sericite schist, so that they could act as retainers for any solutions that would migrate through the sandstone bed in which the ore is now found. At the time of this gentle folding and metamorphism, the lower bed was faulted and squeezed up into ridges and humps protruding into the ore bed, and at the same time making an impression of its larger features in the bed which forms the roof of the orebody. At the same time, and on a wider scale, the region was being warped into a series of gentle anticlines and synclines. In one of these basin-like depressions or synclines, the Stauber deposit was formed by the inflow of copper-bearing ground waters; here the solutions were impounded by impervious strata, and the minerals given time and opportunity to precipitate. Copper minerals were deposited by replacement of the calcite cement between grains of the sandstone, or by the replacement of feldspar and other easily soluble minerals in the more arkosic parts of the bed, or by the replacement of plant remains and possibly other organic matter which was trapped in the sediments of the ancient stream bed.

CONTROLLING STRUCTURES

As shown on the map (Fig. 10) the ore in the Stauber mine persists in good grade and thickness in the breasts of all stopes and workings as far southwest as the mine has been opened. It seems evident that the old stream bed in which the ore-bearing sandstone was laid down, and the gentle syncline in which the ore solutions were trapped and became stagnant, coincided in position. The axis of this syncline pitches gently to the southwest. To the south, one flank of this syncline rises to the surface and exposes the ore bed, where the original discovery of this deposit was made. The north flank of the syncline is buried under younger sediments, but in the opinion of the writer, it is quite possible that there are other synclines to the northwest of the productive Stauber mine, and that, given the same character of ore bed, with impervious floor and roof rocks to enclose it, there is no apparent reason why other valuable ore deposits should not be found in this district. Finding such ore bodies will be difficult and costly, however, as the work of discovery will involve many closely spaced drill holes, and a detailed mapping of the contours of the favorable horizon as it is traced out beyond the limits of the Stauber mine. It is possible also that favorable beds may be found at other elevations in the stratigraphic succession of this district. Furthermore, the ore in the Stauber mine has apparently not yet been exhausted, and under the incentive of a good market price for copper, further exploration in a southwesterly direction is clearly warranted.

MINING OPERATIONS

The original discovery of this property, according to Mr. Stauber, was made by an Old Mexico Mexican, who was employed as a section hand on the railroad. The outcrop covers an area about 100 feet in diameter and was the only local evidence of mineralization. Here the ore was of low grade, and operations consisted entirely of sorting out nuggets of copper ore. Operations under these conditions were carried on at a loss and only 12 tons of the closely sorted material was shipped. Later other miners put down a few shallow shafts to the north of the discovery pit, and in one, called the Tobe shaft (see Fig. 10) 5 feet of ore assaying 6 percent copper was uncovered. At about this time Mr. Stauber examined the property and decided that there might be a concentration of ore on the dip, as the discovery cut showed the ore-bearing sandstone dipping to the northwest, and the shafts in that direction showed a gradual improvement in the grade of ore. Mr. Stauber commenced his operations in March, 1925, with the following results:

Production of Stauber Copper Deposits

Year	Tonnage	Grade, percent	Copper, pounds
1925	3,278	5.24	344,000
1926	6,667	5.10	680,000
1927	6,511	4.60	599,000
1928	11,589	4.56	1,057,000
1929	16,187	4.75	1,537,000
1930	10,429	4.88	1,019,000
Totals	54,661	4.78	5,237,000

Owing to low market price for copper, Mr. Stauber was forced to suspend operations in August, 1930, and after a few months of development work, the mine was closed and has not operated since.

Very little description of the mine workings appears to be necessary. Stauber presented a paper[53] in which the occurrence, geology, early development, and mining methods of the deposit were clearly set forth. Koschmann has briefly summarized the geology[54] of the deposit. At the start, about 50 drill holes were put down to determine the grade, location, and thickness of the deposit. These factors, in addition to the information obtained from shafts already on the property, made it possible to determine limits of mineable ore and to plan a method for development in which all headings could be advanced in shipping ore. There are no waste dumps on the property and all drifts were made large; consequently, the ore was produced just about as cheaply as from stoping operations. At first, hoisting was through shafts by means of buckets and horse-operated whims, the buckets being loaded by hand at the face and brought to the shaft in wheelbarrow frames. Shafts did not require timber and, as the top of the ore lay within 15 to 25 feet of the surface, it was cheaper to sink several shafts and keep all tramming distances down to less than 100 feet. Mining was by room and pillar with recovery of the pillars on retreat and with occasional use of stulls and headboards. It has been estimated that about 10 percent of the ore was lost in mining, left in pillars, and in caves.

[53] Stauber, I. J., A sandstone copper deposit: Min. Cong. Jour. vol. 16, pp. 928-931, 1930.
[54] Koschmann, A. H., Copper resources of the world: XVI Int. Geol. Cong., vol. 1, p. 343, 1935.

After mining through shafts had progressed for some time, a flat incline was substituted for the shafts, and cars were put in operation underground. These cars were loaded at the face and trammed by mules to the incline, up which the mules took the cars to surface to be dumped directly on the loading platform.

Stauber, in his paper, submitted an average analysis of a six months' composite sample of the shipping ore, taken in 1930, which is reproduced here.

Insol	83.0	percent
SiO_2	80.0	
Fe & Mn	1.8	
CaO	0.5	probably gypsum
Zn	1.7	
S	0.3	
Al_2O_3	1.7	
Ag	0.2	oz.
	89.0	percent

INDEX

A

Abbott dome, 45.
Abo formation, 20, 49, 57, 62.
Acknowledgments, 9.
Actinolite, 73, 84.
Aerial tramway, 70, 71, 88.
Albite, 74.
Alteration, of feldspars, 57.
Altitudes, 10.
American Metal Co., 7, 9, 19, 50, 69, 70, 71.
Amphibolite, 26; schist, 73.
Anderson, E. C., 9; cited, 88.
Andesine, 73.
Andreas, A. H., 9; cited, 31.
Anticlines, 30, 34, 36, 40, 45, 67.
Apatite, 73.
Apishapa shale, 24.
Aplite, 76.
Arching, 49, 61, 67.
Areas designated, 10.
Arkose, 16, 20, 42, 52, 57, 58, 60, 61, 91, 94.
Assay results, 37, 38, 54, 61, 62, 63, 83, 97.
Atchison, Topeka and Santa Fe Ry., 11, 24, 57, 62, 69.
Axes, of folds, 31.
Azure-Rising Sun mine, 54.
Azurite, 36, 37, 51, 53, 56, 58, 60, 61, 63, 67, 92, 94.

B

Baca anticline, 45.
Baldy Peak, 71.
Basalt, 27, 30, 45; flows, 33, 34, 35, 42, 45, 48; in canyons, 36, 40, 48.
Bell Ranch, 12.
Bemis, H. D., 9.
Benton formation, 24, 30, 34, 40, 41, 45, 48, 49, 50.
Bernal Creek, 29, 57, 61.
Bibliography, 17, 69.
Biotite, 54, 73, 74, 78; schist, 53, 77.
Bismuthinite, 56.
Black Bear claim, 54.
Black Mesa district, 36.
Blake mine, 60.
Bornite, 37, 54, 60, 61, 62, 84, 92, 94.
Brady, C. R., 9.
Bureau of Mines, State, 8.

C

Calcite, 43, 54, 57, 58, 91.
Camptonite, 26.
Canadian anticline, 41; escarpment, 22, 23, 24, 34, 46, 48, 64, 67; plateau, 25; river, 11, 12, 21, 24, 27, 30, 33, 39, 40, 44, 45, 47, 48, 50, 66, 67.
Capulin volcanic cone, 27, 33, 35; National Monument, 33.
Carbonaceous matter, see Plant remnants.
Carbon dioxide, 45.
Carlile shale, 24, 29.
Carrizo Creek, 33.
Cassidy, D. J., 9.
Cattle raising, 11, 14, 39, 44, 47, 64, 66.
Cedar, on Dakota sandstone, 14, 34, 44, 62, 64.
Cerro Cuervo, 22; dike, 26, 65, 87, 91.
Chalcocite, 36, 42, 43, 46, 51, 54, 58, 60, 61, 62, 92, 94; nodules, 67; sooty, 37.
Chalcopyrite, 37, 51, 52, 53, 54, 56, 57, 60, 61, 71, 85, 94.
Chlorite, 73, 74, 78, 84.
Chrysocolla, 37, 92, 94.
Chupadera formation, 21, 49, 58, 62, 64, 65, 66, 91.
Cimarron dome, 37; mountains, 10; river, 22, 23, 28, 33, 34, 35, 36; Valley anticline, 36.
Clayton, 11.
Cleveland, 29.
Climate, 12.
Climatological data, 13.
Coal, 11, 41.
Colfax County, 10, 11, 27, 41.
Colorado and Southern Railroad, 11.
Colorado group, 24.
Colorado, state line, 10, 33.
Comanche age, 23.
Compression, 49.
Conchas dam, 12; river, 21.
Conglomerate, 24.
Contact metamorphic minerals, 54.
Cooper district, 50.
Copper, 14; in sediments, 16, 35, 42, 62, 91-97.
Copper Chief Mining Co., 37.
Cores, granite, 47, 49; sulphide, 51, 60, 94.
Costs, 88.
Counties discussed, 10, 11.
Cowles, A. H., 70.
Coyote Creek, 39; district, 42.
Cretaceous system, 23-25, 48; intrusives, 26.
Crites mine, 53.
Cross-shear zone, 80, 83.
Cuervo Hill, 22.
Cuestas, 41.

D

Dakota sandstone, 14, 23, 27, 28, 29, 30, 32, 34, 36, 40, 41, 42, 45, 49, 50, 64, 65, 67.
Darton, N. H., cited, 19, 21, 23, 26, 41.
Dawson, 11.
Development, 87, 88.
Diabase, 19, 53, 54, 72, 73, 76; dikes, 26; sills, 26, 52.
Dikes, 48; diabase, 26; felsite, 53; granite, 76.
Dip-slopes, 40.
Dips, oversteepened, see Upturned beds.
Dips, regional, 28, 30, 34, 44, 45, 48, 64, 67.
Dockum group, 21, 27, 28, 32. 34, 36, 40, 41, 42, 45, 48, 49, 64, 65, 66, 67, 91.
Dolliver, C. M., 9.
Dolomite, 58.
Domes, 30, 34, 45.
Drill cores, 9, 72; holes, 96; logs, 41, 65.
Drilling, 7, 31, 95; methods, 87.
Dripping Springs anticlines, 67.
Dry-farming, 11, 12, 40, 44, 47, 66.
Dust Bowl, 14, 26, 33.
Dykers, M. D., 9.

E

East orebody, 91, 92.
El Porvenir district, 56.
Emery Gap, 11.
Eocene, 25.
Epidote, 54, 73, 74.
Esterito dome, 65.
Evangeline orebody, 80, 81, 82, 83, 85.
Experimental farm, 66.

F

Farming, 11, 14, 40, 44, 47.
Fault blocks, 41, 48; scarps, 40. 49.
Faulting, 21, 28, 29, 30, 40, 41, 52, 57, 61, 65, 67, 72; major, 49.
Feeder dikes, 48.
Feldspars, altered, 73; replaced, 42. 53, 94, 95.
Floor clay, 91.
Flotation, selective, 88.
Folding, 30, 40, 41, 50, 58, 61, 65, 67.
Folsom, 11; district, 35.
Fort Pitt Copper Co., 37. 38.
Fowl Canyon anticline, 45.
Fresh water shells, 21.

G

Gabbro, 19.
Galena, 52, 83, 84, 85.
Gallinas Canyon, 29, 49; River, 47, 48.
Gangue minerals, 84.
Garnet, 54, 73.
Gascon, 29.
Geophysical prospecting, 16, 87.
Glorieta, 30; sandstone, 21, 41, 58, 60, 62, 63.
Gneiss, 19, 57, 72, 73.
Gold, 14, 43, 52, 54, 62, 63, 68, 83, 84; in basalt, 16, 17, 35, 36, 45.
Goodrich-Lockhart Co., 70.
Gouge, 77.
Graneros shale, 24, 29.
Granite, 19, 29, 30, 47, 74; 26, 49, 52, 56, 57, 76; dikes, 72; ridges, 16, 31, 32, 41, 50, 67.
Granitization, 76.
Graton, L. C., cited, 19, 57.
Greenhorn limestone, 24, 29.
Guadalupe anticline, 65; County, 8, 64-66.
Guy, Leon, 9.
Gypsum, 23, 42, 60, 92.

H

Hadley, O. A., 54.
Hamilton mine, 70.
Harding County, 10, 44-46.
Harris, K. V., 9.
Heaton, Ross L., cited, 19.
Hematite, 54.
Hermit Mountain district, 56.
Hoag, C., 9; quoted, 87.
Hoisting, 88, 96.
Holman, 29.
Hoover, L. B., 56.
Hornblende, 73.
Hornblendite, 62.
Humps, in floor, 91, 94.
Hurley project, 12.

I

Igneous rocks, 18, 26-28; see also under rock names.
Impounding, 95.
Inoceramus, 24.
Intrusive rocks, 26, 48, 72; granite, 57, 74; sills, 52.
Irrigation, 11, 64.

J

Jaritas dome, 45.
Joe Matt mine, 53.
Johnny Jones group, 50, 51.
Jurassic system, 22; rocks of, 34, 36, 40, 42, 48.
Just, Evan, cited, 19.

K

Kaolin, 58, 74.
Katydid orebody, 80, 81, 83, 85.
Koschmann, A. H., cited, 96.
Krieger, Philip, quoted, 71, 74, 77, 84.

L

Las Vegas, 11; Mountains, 28, 48, 49, 57, 61, 62, 71.
Leached outcrops, 51.
Leaching plant, 60.
Leucoxene, 73, 74.
Llano Estacado, 24, 25, 32, 65, 66, 67.
Logan, 11; anticline, 67.
Logs, of wells, see Drill logs.
Logs, replaced, 91, 92; see also Plant remnants.
Lost anticline, 45.
Lujan Creek, 43.
Lumbering, 11, 39, 47.

M

Magdalena formation, 20, 52, 58, 60, 61, 72; limestone, 40, 50, 51, 54, 57, 71.
Magnetite, 73, 74.
Malachite, 36, 37, 42, 46, 51, 53, 56, 58, 60, 61, 63, 67, 92, 94.
Manzano group, 20, 21.
Marmatite, 84.
Martin, J. P., 9.
Matson, J. T., 9; quoted, 87.
Maxson cone, 27, 40, 48.
McKay, James, 9.
Melaconite, 37.
Metals, 15.
Metamorphic minerals, 73; rocks, 18; see also under mineral and rock names.
Microcline, 58, 74.
Microscopic studies, 7, 69.
Miedanner, Rev. A. J., 61.
Mill, leaching, 60; see also Pecos mill.
Mineral Hill district, 62.
Mineralization, pre-Cambrian, 52.
Mineralized areas, 14-17; districts, 35, 42, 45, 50, 66, 67.
Mining, 43, 47; operations, 85, 95.
Mining districts, 15.
Molybdenum, 14.
Molybdenite, 52, 54, 56, 57.
Molybdite, 56.
Montana group, 25.
Montezuma Hot Springs, 19, 29, 49.
Mora, 11; County, 39-44; Mountains, 49, 71; River, 27, 39, 40, 47, 48, 49.
Morrison formation, 22, 23, 34, 36, 41, 49.
Mosquero, 11.
Mountain area, 12, 28.
Muscovite, 56, 74, 78; shipped, 62.
Mutual boundaries, 85.

N

New Mexico State College, 66.
Nodules, copper ore, 42, 63, 92.
Nuevo anticline, 50.

O

Ocate cone, 40; crater, 42; creek, 25.
Ogallala formation, 25, 28, 32, 34, 45, 48, 65, 67.
Ogilvie, I. H., cited 26.
Oil and Gas Map, 31.
Oklahoma, 21, 37; state line, 10, 33.
Old Hickory Mining Co., 37.
Olivine basalt, see basalt.
Operations, Pecos mine, 85; Stauber mine, 95.
Orchards, 47.
Order of deposition, 84.
Ore deposits, relation to structure, 31; at Pecos Mine, 83; at Stauber mine, 91.
Ore shoots, 85, 87.
Organic matter, see Plant remnants.
Orientation in schist, 78.
Orthoclase, 56, 58, 74.
Otero County, 8.
Oxidation, 42, 51, 54, 56.

P

Pecos Copper Co., 70; district, 50, 69.
Pecos mine, 69-89; 7, 8, 19, 30, 49, 50; mill, 69, 71.
Pecos River, 11, 19, 39, 47, 48, 50, 62, 64, 69, 71, 72; canyon, 50, 65; Mining Co., 70.
Pegmatite, 60, 77; dikes, 56, 57, 63.
Peneplane, pre-Cambrian, 72.
Pennsylvanian system, 20; sediments, 18, 29, 47, 48, 49.
Permian system, 20; sediments, 40, 41, 42, 47.
Perthite, 74.
Pierce Ranch, 67.
Pierre shale, 25.
Piñon, on Dakota sandstone, 14, 44, 64, 66.
Pintada Canyon district, 66, 94.
Pintada Creek, 65.
Placers, gold, 17, 35, 43, 45, 63.
Plagioclase, 58, 73.
Plains area, 14, 32.
Plant remnants, 37, 42, 43, 46, 95; replaced, 92, 94.
Plateau area, 12, 14, 30.
Pleistocene, 26.

Pliocene, 25.
Poikilitic texture, 78.
Population (1930), 11; Guadalupe Co., 64; Harding Co., 44; Mora Co., 39; Quay Co., 66; San Miguel Co., 46; Union Co., 33.
Porphyry, 26, 53, 65.
Porvenir district, 26; fault through, 29.
Potter, Col. J. M., 9.
Pre-Cambrian rocks, 18, 19, 28, 29, 40, 47, 50, 51, 52, 56, 57, 71, 72, 74; gold in, 43; intrusive, 26; ores in, 14, 16, 83-85.
Production, 7, 15, 43, 85; Pecos mine, 86; Stauber mine, 96.
Prospecting, 16, 87, 95.
Pumping plant, 70.
Purgatoire formation, 23, 34, 41, 42, 49.
Purpose of report, 7.
Pyrite, 37, 52, 53, 54, 57, 60, 61, 68, 71, 83, 84, 85.
Pyroxene, 73, 74.
Pyrrhotite, 84.

Q

Quartz, 51, 54, 58, 62, 73, 74, 78, 83, 84; gold-bearing, 35, 43, 45.
Quartz lenses, 53; veins, 52, 56, 57, 63.
Quartz-chlorite schist, 78, 83; -sericite schist, 77, 81.
Quartzite, 19, 53.
Quaternary system, 26; igneous rocks, 16, 18, 27, 48.
Quay County, 66-68.

R

Rackmil, L. H., 9.
Ranching, 40, 47.
Raton coal basin, 41; formation, 25; Pass, 11; Range, 10.
Recent age, 26; sediments, 18.
Recovery, Pecos mill, 85.
Redbeds, 21; copper in, 36, 67.
Repetition by faulting, 40, 52, 57.
Replacement, of cement, 37, 42, 43, 46, 67, 94; in schists, 81, 83; in shear zone, 82; of ore minerals, 85; of feldspars, 42.
Reverse faults, 21, 50.
Rimrock, 36, 45, 65, 66, 67.
Rincon Range, 10, 19, 20, 28, 39, 40, 41, 42, 43, 48, 49, 71.
Rio Grande, 25, 71.
Rio la Casa, 43.
Rising Sun claim, 54.
Rociada district, 26, 52.
Rocky Mountains, 19, 31, 35, 40, 46, 47.
Roof clay, 92.
Room-and-pillar mining, 96.
Roscoelite, 84.
Roy, 11.
Rutile, 73.

S

Sampling, 8.
San Andres limestone, 21.
San Miguel Co., 46-63.
Sangre de Cristo Mountains, 10, 20, 39, 40, 48, 49, 52, 71.
Santa Fe formation, 25; National Forest, 70.
Santa Rosa, 11; anticline, 65; sandstone, 21, 28, 32, 34, 45, 48, 64, 65, 67, 91.
Sapello Creek, 52.
Sater Copper Co., 37.
Saussurite, 73, 74.
Scheelite, 56.
Schists, 19, 52, 54, 57, 72, 73, 76; see also under type names.
Schistosity, 51, 53, 54, 72.
Scope of report, 7.
Sedimentary rocks, 20-26; ores in, 7, 8, 91.
Sericite, 57, 73, 74, 78, 84; schist, 53.
Shafts, Pecos mine, 87; Stauber mine, 96.
Shale, 20.
Shearing, 57, 58, 77; zones of, 51, 74, 78, 81, 85, 87, 89.
Sheep raising, 47, 62.
Shells, fresh water, 21.
Sierra Grande, 27, 33; uplift, 30, 35, 41.
Sierra Negra anticline, 45.
Silver, 14, 62, 83, 84.
Slate, 19.
Smith mine, 53.
Southern Pacific Railway, 11, 66.
Specularite, 54.
Sphalerite, 52, 53, 71, 84, 85.
Staining, by copper salts, 36, 37, 42, 51, 60, 63; by iron oxides, 53, 54, 56, 58; by molybdite, 56.
Stauber, I. J., cited, 96.
Stauber mine, 91-97; 7, 8, 66.
Steatite, 53.
Stevens, Horace J., quoted, 38.
Stoping, 88.
Stott, Chas. E., cited, 73, 76.
Structural features, 28-32; Guadalupe Co., 65; Harding Co., 45; Mora Co., 40; Quay Co., 67; San Miguel Co., 48; Union Co., 34.
Structure sections, 91.
Stumpage, 70.
Sulphide minerals, 14.
Syenite, 26.
Syncline, deposition in, 95.
Syntectic rocks, 76, 78, 81, 82.

T

Technical advice, 8.
Tecolote district, 29, 57.
Temperatures, 12.
Tenorite, 92.
Tererro, 11, 30, 48, 69.
Tertiary system, 25; igneous rocks, 18, 26, 27.
Texas, 11, 21; state line, 10, 33, 64.
Thicknesses: Colorado group, 24; Dakota Sandstone, 24; Dockum group, 21; Magdalena group, 20; Morrison formation, 23; Purgatoire sandstone, 23.
Tilted flows, 27.
Timber, 11, 12, 70.
Timpas limestone, 24.
Titanite, 73, 74.
Todilto formation, 22, 49.
Torrance County, 8.
Tourmaline, 54, 73, 84.
Tramway, aerial, 70, 71, 88.
Treatment plants, 43; processes, 60.
Tres Hermanos Canyon, 62.
Triassic system, 21, 48; sediments, 32, 40, 42, 57.
Truchas Range, 10, 19, 30, 39, 40, 48, 50, 51, 71.
Tucumcari Creek, 66.
Turkey Mountain, 10, 30; dome, 41.

U

Union County, 33-39.
Upturned beds, 28, 29, 41, 48, 49, 57.
Uralite, 73, 74.
Ute Creek, 33, 34, 44, 45, 66; canyon, 22.

V

Valley Ranch, 70.
Vanadium mica, 84.
Vegetation, 12.
Vertical beds, 40, 42, 48, 49, 52, 57.
Volcanic rocks, 27; cones, 30, 33, 34, 35, 40.

W

Wagner ranch, 36.
Wagon Mound, 11; anticline, 41.
Wall rock alteration, 53.
Warping, 41, 91, 95.
Water level, 92.
Wells, drilled, 20; logs, see Drill logs.
West orebody, 91, 92.

Willow Creek, 48, 69, 70, 72, 73; canyon, 76; district, 26, 50, 69.
Winchester, D. E., cited, 19, 31, 35.
Window, eroded, 50, 65, 66, 72.
Wingate sandstone, 22, 41, 49.
Winsor's Ranch, 30.
Wootton, T. P., 9.

Y

Yeso formation, 21.
Young, E. J., 35, 36.

Z

Zircon, 73.
Zoisite, 73, 74.
Zoning, in ores, 60; of feldspar, 73.
Zummach, A. G., 9, 54.

NEW MEXICO SCHOOL OF MINES PUBLICATIONS

PUBLICATIONS OF THE MINERAL RESOURCES SURVEY

No.	*Title and Author*	*Date*	*Price*
1	The Mineral Resources of New Mexico; Fayette A. Jones	1915	Out of print
2	Manganese in New Mexico; E. H. Wells	1918	Out of print
3	Oil and Gas Possibilities of the Puertecito District, Socorro and Valencia Counties, New Mexico; E. H. Wells	1919	Out of print

PUBLICATIONS OF THE NEW MEXICO BUREAU OF MINES

BULLETINS

No.	*Title and Author*	*Date*	*Price*
4	Fluorspar in New Mexico; W. D. Johnston, Jr.	1928	$ .60
5	Geologic Literature of New Mexico; T. P. Wootton	1930	.25
6	Mining and Mineral Laws of New Mexico; Charles H. Fowler (Superseded by Bulletin 16)	1930	Out of print
7	The Metal Resources of New Mexico and Their Economic Features; S. G. Lasky and T. P. Wootton	1933	.50
8	The Ore Deposits of Socorro County, New Mexico; S. G. Lasky	1932	.60
9	The Oil and Gas Resources of New Mexico; Dean E. Winchester	1933	1.50
10	The Geology and Ore Deposits of Sierra County, New Mexico; G. T. Harley	1934	.60
11	The Geology of the Organ Mountains with an Account of the Geology and Mineral Resources of Dona Ana County, New Mexico; Kingsley Charles Dunham	1935	1.00
12	The Non-Metallic Mineral Resources of New Mexico and their Economic Features (Exclusive of Fuels); S. B. Talmage and T. P. Wootton	1936	.50
13	Geology and Economic Features of the Pegmatites of Taos and Rio Arriba Counties, New Mexico; Evan Just	1937	.50
14	Some New Mexico Fusulinidae; C. E. Needham	1937	.50
15	The Geology and Ore Deposits of Northeastern New Mexico (Exclusive of Colfax County); G. Townsend Harley	1940	.60
16	Mining, Mineral and Oil Laws of New Mexico; C. H. Fowler (Supersedes Bulletin 6)	In preparation (probably .75)	

CIRCULARS

1	An Outline of the Mineral Resources of New Mexico; E. H. Wells	1930	Out of print
2	Geology and Ore Deposits of the Ground Hog Mine, Central District, Grant County, New Mexico; S. G. Lasky	1930	Out of print

No.	*Title and Author*	*Date*	*Price*
3	First, Second, and Third Annual Reports of the Director, and Preliminary Report for the Fourth Year; E. H. Wells	1931	Out of print
4	The Hobbs Field and Other Oil and Gas Areas, Lea County, New Mexico; Dean E. Winchester	1931	Out of print
5	Gold Mining and Gold Deposits in New Mexico; E. H. Wells and T. P. Wootton, 1932; revised by T. P. Wootton	1940	No charge
6	Carbon Dioxide in New Mexico; E. H. Wells and and A. Andreas, 1938; undergoing revision by A. Andreas and T. P. Wootton	1940	No charge
7	Outlook for Further Ore Discoveries in the Little Hatchet Mountains, New Mexico; S. G. Lasky	1940	No charge

MAPS

Oil and Gas Map of New Mexico, Dean E. Winchester, 1931; revised by A. Andreas to July, 1936 (This map is included in Bulletin 9.)	1936	.75 (paper) 1.25 (cloth)
Geologic Map of New Mexico, N. H. Darton, scale about 8 miles to 1 inch. Contour interval 100 meters. U. S. Geological Survey, Washington, D. C.	1938	1.50
Topographic Map of New Mexico, N. H. Darton, scale about 8 miles to 1 inch; contour interval 100 meters (326 feet). U. S. Geological Survey	1925	.75
Geographic Map of New Mexico, scale 12 miles to 1 inch. General Land Office, Washington, D .C.	1936	.35
Topographic maps of approximately 65 quadrangles in New Mexico and adjacent parts of Arizona. Scales vary from 1,000 feet to 1 inch, to 4 miles to 1 inch. U. S. Geological Survey		.10

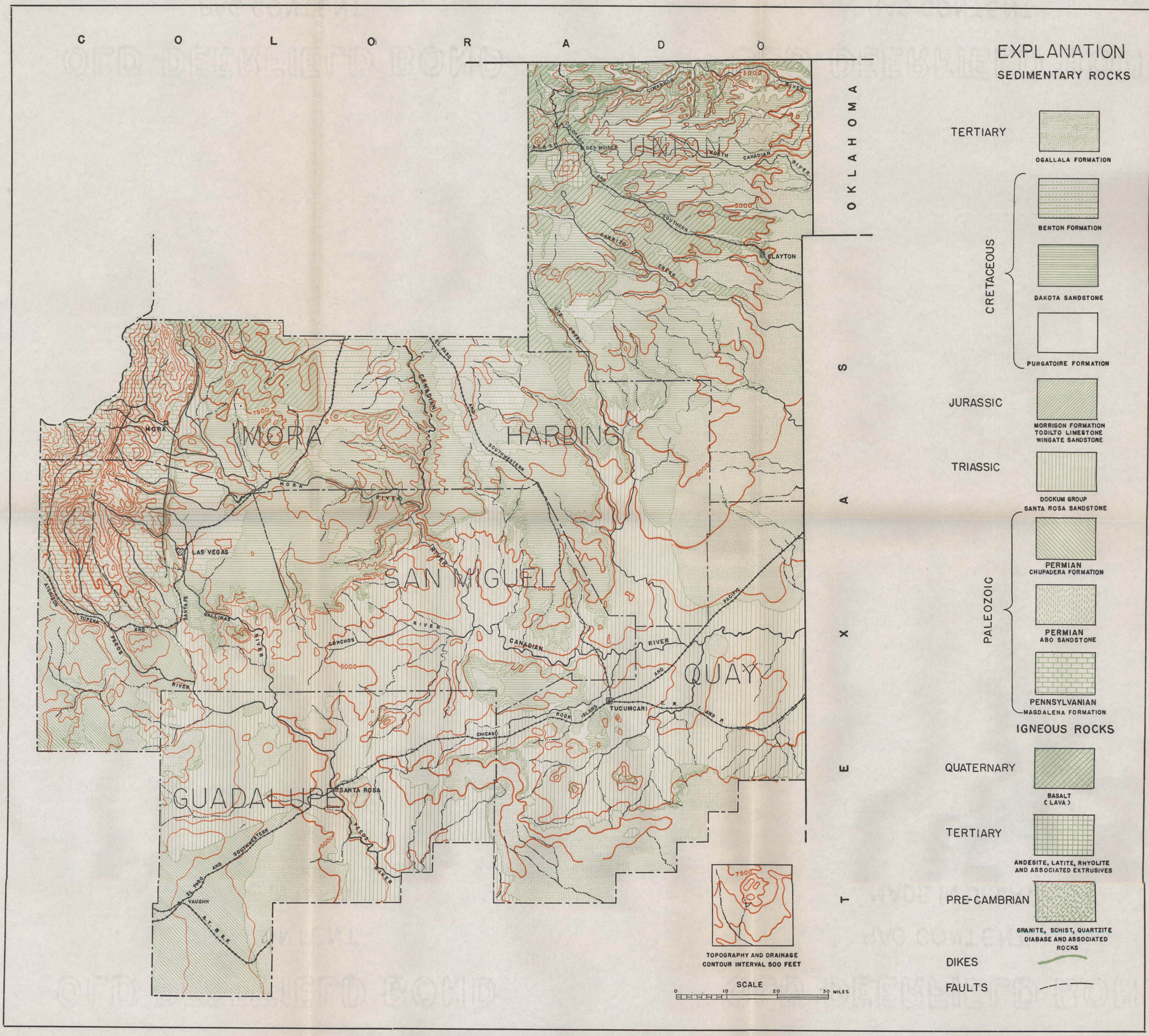
WELL LOGS

Over 4,000 typed well logs of wells drilled in New Mexico	Prices on request

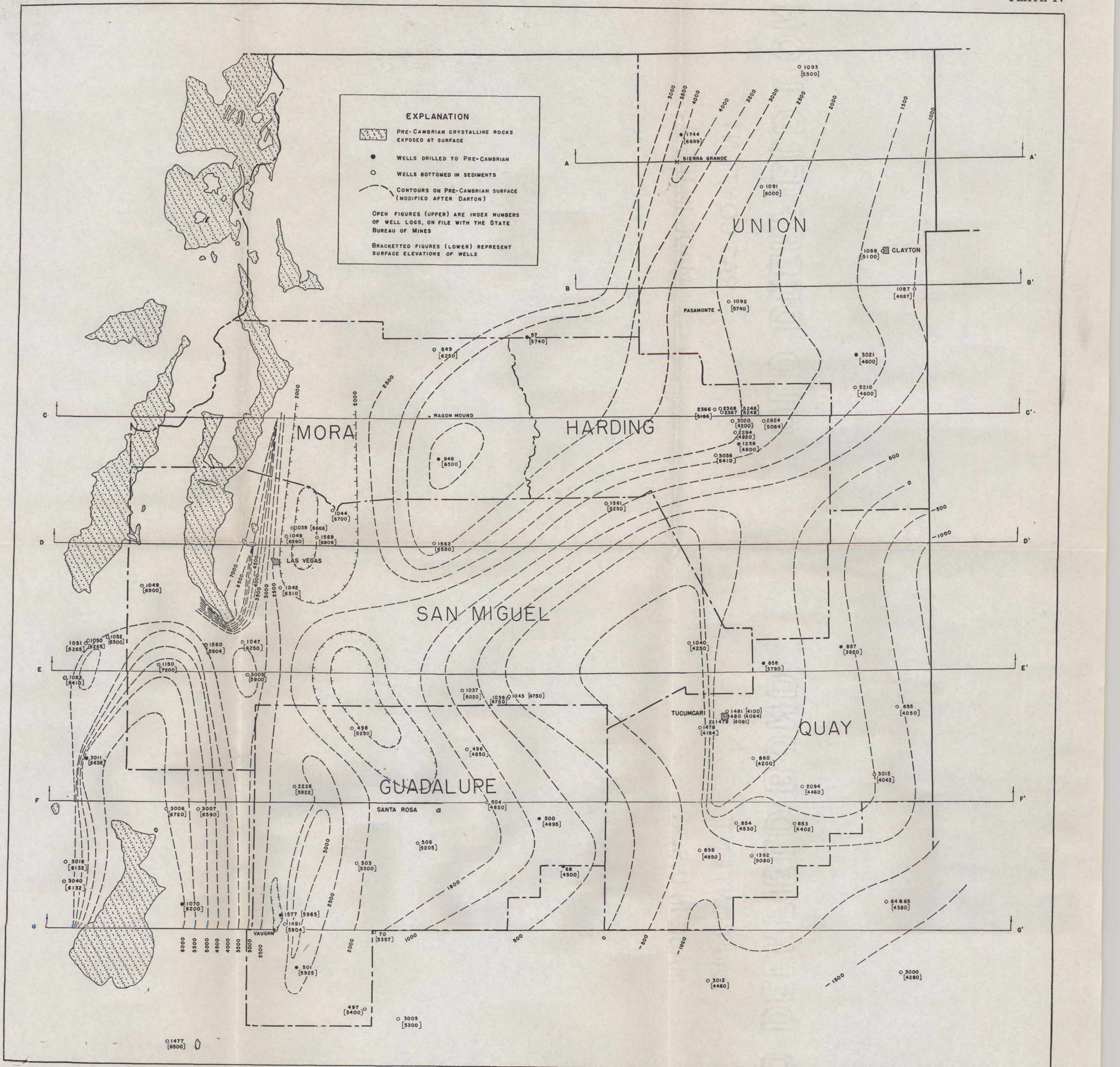
INDEX MAP OF NORTHEASTERN NEW MEXICO

NEW MEXICO SCHOOL OF MINES
STATE BUREAU OF MINES AND MINERAL RESOURCES

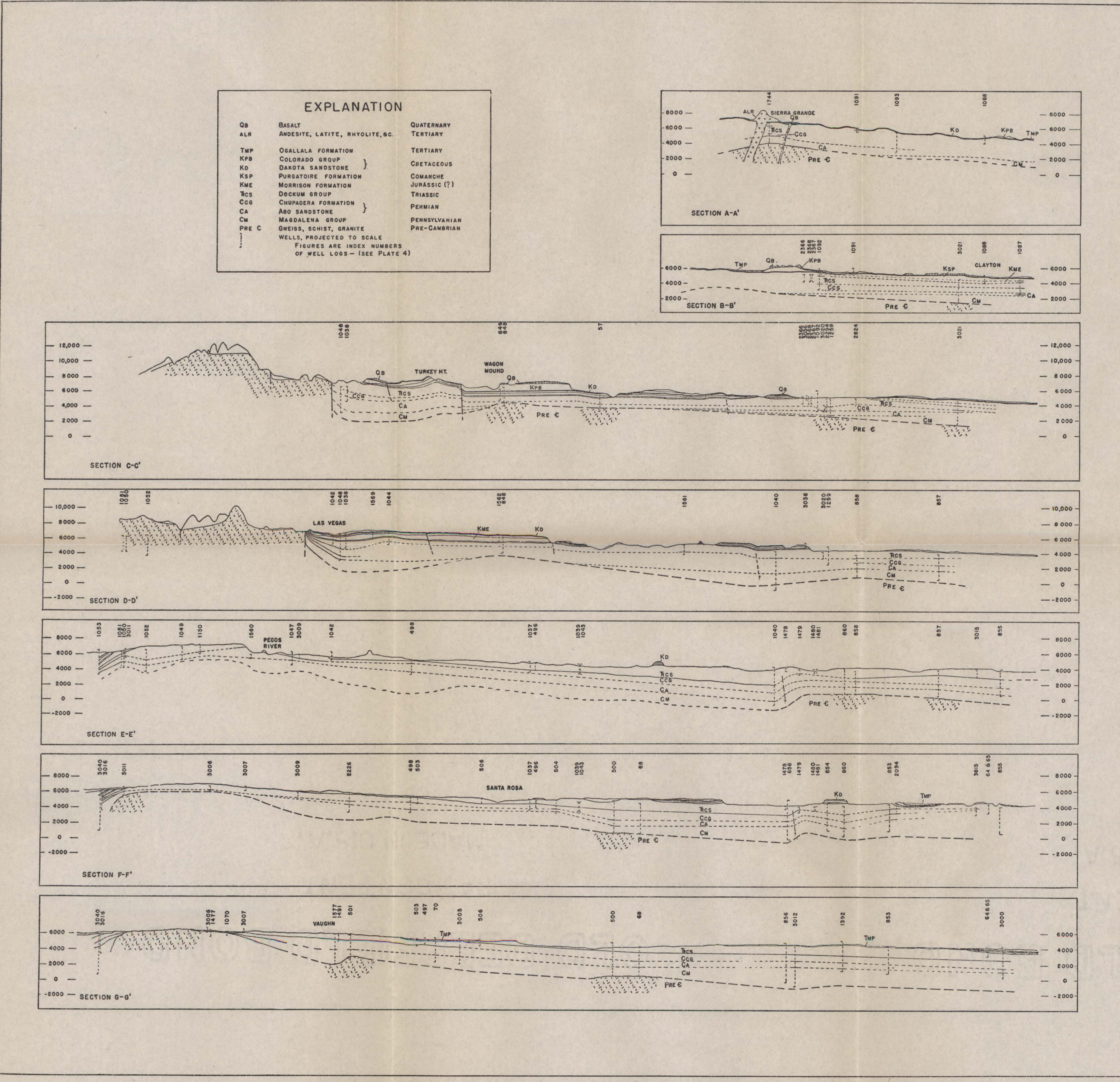
BULLETIN 15
PLATE III



GEOLOGIC AND TOPOGRAPHIC MAP OF NORTHEASTERN NEW MEXICO



STRUCTURE CONTOUR MAP ON SURFACE OF PRE-CAMBRIAN BEDROCK
(Modified after Darton)



GEOLOGIC CROSS SECTIONS IN NORTHEASTERN NEW MEXICO
(Lines of Sections indicated on Plate IV)