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# GEOLOGY AND FUEL RESOURCES
OF THE
# SOUTHERN PART OF THE SAN JUAN BASIN NEW MEXICO

## PART 2. THE MOUNT TAYLOR COAL FIELD

BY

CHARLES B. HUNT

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## NOTE

The Geological Survey in 1928, 1929, 1930, and 1931 reexamined and mapped the coal beds of the Mesaverde formation across the southern part of the San Juan Basin, in New Mexico, from Gallup on the west to Cuba, Grant, and the Rio Puerco on the east and southeast. The geologists have prepared separate reports on the areas for which they were responsible. However, as these areas are adjacent and form a real unit both geographically and geologically, the three reports are issued as parts of a single bulletin covering the southern part of the basin. No edition of the consolidated volume will be published, but the three parts can be bound together if desired.

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# GEOLOGY AND FUEL RESOURCES OF THE SOUTHERN PART OF THE SAN JUAN BASIN, NEW MEXICO

## PART 2. THE MOUNT TAYLOR COAL FIELD

By Charles B. Hunt

### ABSTRACT

Mount Taylor is in northwestern New Mexico, midway between Albuquerque and Gallup. The Mount Taylor coal field includes the rugged mesa country surrounding the mountain, north of the Atchison, Topeka & Santa Fe Railway, and embraces an area of about 2,000 square miles. This area has a semiarid climate and consequent sparse vegetation. Water is scarce and, except in the valleys immediately at the foot of the mountain, is either too alkaline or too scanty for irrigation. There are only a few inhabitants, most of whom are congregated in villages along the railway or at the mouths of canyons that bring water from the higher altitudes of Mount Taylor. Most of the inhabitants are engaged in raising stock. Mount Taylor receives sufficient moisture to support a fair growth of timber and has been set aside as a part of the Manzano National Forest.

The Mount Taylor coal field was studied primarily to determine its coal and other fuel resources. The exposed rocks range in age from Jurassic to Recent. The Jurassic, cropping out only locally, is represented by the Morrison formation, of variegated shale and some sandstone. Its top is marked by an erosional unconformity. The overlying Upper Cretaceous covers most of the area and is represented by three formations—in ascending order the Dakota (?) sandstone, the Mancos shale, and the Mesaverde formation. The Dakota (?) sandstone is a lenticular clastic deposit and is locally absent. The Mancos consists mostly of marine shale; three sandstones found in the lower 350 feet in the area east of Mount Taylor thin out to the northeast. The relations between the Mancos and the next younger formation, the Mesaverde, are complex. In the southern part of the field the Mancos is only 1,000 feet thick and represents only the earlier part of Colorado time (Benton and earliest Niobrara). It is overlain by the predominantly continental, coal-bearing Mesaverde formation, which, however, includes in its lower part two thick zones of marine shale. In passing northward there is a marked and rapid change in the lower part of the Mesaverde; the continental beds and the near-shore sandstones become thinner and less conspicuous, and the two marine shale zones become correspondingly thicker. This transition continues until, at the north edge of the field, the sandstones and continental beds practically disappear and the two shale units merge with the older shale to form an expanded Mancos about 2,000 feet thick. The shale units within the Mesaverde at the south are thus seen to be tongues

of the Mancos. In the northern part of the area the Mancos represents all of Colorado time and perhaps earliest Montana time as well. The main body of the Mesaverde continues northeastward as a coal-bearing formation. Late Tertiary clastic deposits are present in the eastern part of the area, and there are recent deposits of alluvium and gravel throughout the area.

Intense volcanic activity occurred in this area in middle and late Tertiary time, beginning with the eruptions on Mount Taylor. The huge depression covering nearly 4 square miles at the head of Water Canyon and just east of Mount Taylor Peak marks the old crater, now enlarged by erosion. The eruptions began with rhyolitic tuff, followed by a series of porphyritic latite and trachyte, and ended with porphyritic andesite. The eruptions continued until a cone at least 2,000 feet high had been built. However, with the gradual lessening of the activity of Mount Taylor lava was erupted from vents that broke out on the periphery of the old crater. These vents are marked by lava cones and volcanic necks. They surround Mount Taylor but are most numerous northeast of the mountain. None of these later vents seem to have been very long-lived, each supplying one or at most very few sheets of a relatively nonporphyritic andesite or basalt. This later activity was extended far to the north and northeast. The basaltic lava flows in the San Jose Valley, along the south border of this area, and the Albuquerque volcanoes, 10 miles east of this area, are very recent and not directly related to the volcanism on and around Mount Taylor.

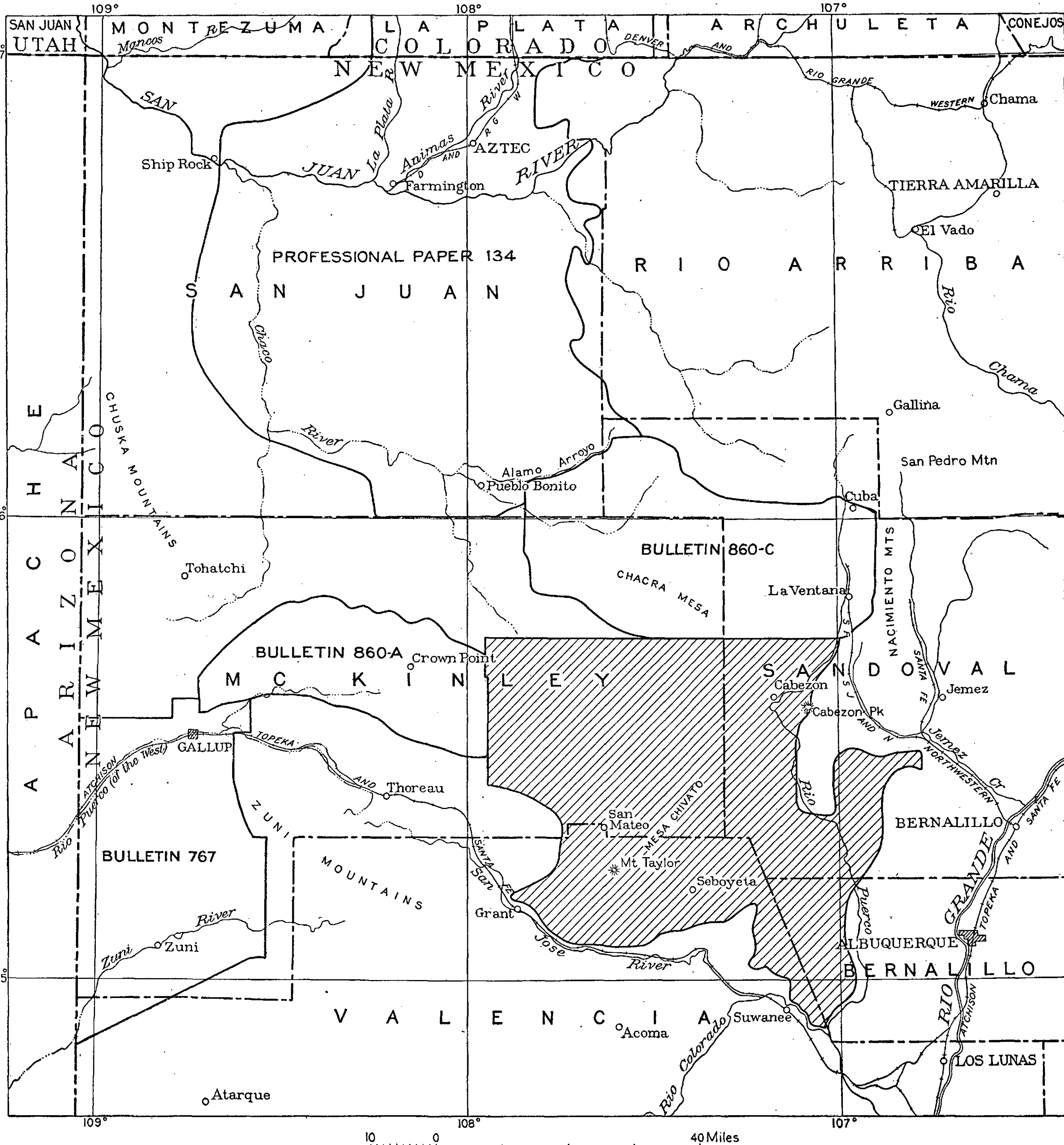
Most of the field lies in the southeastern part of the San Juan Basin where a gentle northward dip generally prevails. However, there are several domes which locally have steep dips and numerous faults. The shallower zones have been tested for petroleum in most of the domes, but no production has yet been obtained. The eastern part of the field lies in the Basin and Range province and has been severely faulted. All the faults, so far as known, are normal and have nearly parallel trends at the surface. The displacements reach a maximum of about 3,500 feet. In general the major faults within this part of the field produce a stepdown to the west. The faulted blocks generally dip east, although the amount of dip has considerable range. The deformation probably began in middle Tertiary time and continued until after the basal beds of the Santa Fe formation had been deposited in the eastern part of the field.

There is generally a sharp boundary separating the severely faulted eastward-tilted beds in the Basin and Range province and the slightly faulted northward-tilted beds of the San Juan Basin. The boundary lies chiefly along faults that have dropped the areas in the Basin and Range province with respect to those in the San Juan Basin.

The coal beds of the Mount Taylor field are confined to the Mesaverde formation. The coal is of subbituminous rank, and many beds are present. The usual thickness of the coal beds is about 15 inches, but there are numerous exceptions, and some are as much as 6 feet thick. The lack of good roads over most of the field precludes commercial mining on a large scale at this time. However, the south side of Mount Taylor is near the Atchison, Topeka & Santa Fe Railway and United States Highway 66, and the northeast corner of the field is near a State highway, and several small mines are active in these two localities.

## INTRODUCTION

Mount Taylor is in northwestern New Mexico, near the northeast corner of Valencia County. The Mount Taylor coal field, as described in this report, includes the country surrounding the mountain




INDEX MAP SHOWING LOCATION OF THE AREAS DESCRIBED IN THIS AND RELATED REPORTS.

in northeastern Valencia County, southeastern McKinley County, southwestern Sandoval County, and northwestern Bernalillo County. The coal field covers an area of about 2,000 square miles and in outline is roughly square, with Mount Taylor near the southwest corner. (See pl. 20.) The central and western parts of the field are in the San Juan Basin, and the eastern part is in the block-faulted Rio Grande Valley, a part of the Basin and Range province. (See pl. 27.)

Many beds of coal crop out within the Mount Taylor field, most of them lenticular and less than 18 inches in thickness. The central and northwestern parts of the area are too remote from convenient shipping points for profitable commercial mining of the coal beds at present. There are a few small mines along the southern border and at the northeast corner of the field. The rocks are locally folded, and some anticlines have been drilled to shallow depths to test their oil and gas possibilities, but no production has yet been obtained. The present report describes the general geology and the economic resources of the field. The area adjoining this on the west was mapped by Sears[1]; the area adjoining on the north was mapped by Dane.[2]

## EARLIER INVESTIGATIONS

Numerous reconnaissance examinations of parts of the Mount Taylor coal field have been made, but it has not previously been studied in detail. Dutton[3] was the first to give a full account of the general geologic features of the field, but his descriptions centered about the volcanic rocks, with only a brief mention of the sedimentary rocks. However, an observer cannot help but be impressed by the degree of accuracy of the general geologic map of Mount Taylor and the Zuni Plateau that was compiled by Dutton and included in his report. In 1898 Herrick[4] published the results of his study of the San Pedro and Albuquerque districts, including the east border of the Mount Taylor field, and made the first mention of the abundant faulting that characterizes that portion of the field. In 1900 Herrick and Johnson[5] briefly described a few of the prominent faults along the east

[1] Sears, J. D., The coal field from Gallup eastward toward Mount Taylor: U. S. Geol. Survey Bull. 860–A, 1934.

[2] Dane, C. H., The La Ventana-Chacra Mesa coal field, McKinley, Sandoval, and San Juan Counties: U. S. Geol. Survey Bull. 860–C (in preparation).

[3] Dutton, C. E., Mount Taylor and the Zuñi Plateau: U. S. Geol. Survey 6th Ann. Rept., pp. 105–198, 1885.

[4] Herrick, C. L., Papers on the geology of New Mexico: Denison Univ. Sci. Lab. Bull., vol. 11, pp. 75–92, 1898; New Mexico Univ. Bull., vol. 1, pp. 75–92, 1898; The geology of the San Pedro and the Albuquerque districts: Denison Univ. Sci. Lab. Bull., vol. 11, pp. 93–116, 1898; New Mexico Univ. Bull., vol. 1, pp. 93–116, 1898.

[5] Herrick, C. L., and Johnson, D. W., The geology of the Albuquerque sheet: Denison Univ. Sci. Lab. Bull., vol. 11, pp. 186–192, 1900; New Mexico Univ. Hadley Lab. Bull., vol. 2, pt. 1, pp. 12–18, 1900.

border of the Mount Taylor field. Johnson[6] has given the best single published statement summarizing the structure of the eastern portion of the field, describing it as "characterized by a beautiful set of easterly dipping blocks faulted along parallel planes." However, the statement was made in connection with a discussion of the broader structural features of the Rio Grande Valley, and details were not presented. In 1903 Reagan[7] published some general statements concerning the eastern part of the Mount Taylor field. A report in 1906 of reconnaissance work by Schrader[8] showed that the portion of this field that lies in the San Juan Basin is but a part of a coal field that extends continuously along the north, east, and south sides of the basin from Durango, Colo., to Gallup, N. Mex. The coal field is now known to extend continuously around the basin. In the same year Johnson[9] reported the results of a study of the volcanic necks in the Rio Puerco Valley, to determine some criteria for distinguishing volcanic necks from remnants of laccoliths or columnar sheets of lava. The stratigraphic sequence of faunas in the sedimentary beds of the Rio Puerco Valley was studied and described in 1908 by Shimer and Blodgett.[10] In 1909 Gardner[11] made a reconnaissance survey of that part of the coal field between Gallup and San Mateo, and the next year he extended his mapping to Cuba, N. Mex.[12] In this work Gardner examined the coal in a general way but made no attempt to study details of the stratigraphy or structure. As the result of reconnaissance examination Darton[13] gave some general statements concerning the eastern part of the Mount Taylor field. Lee and Stanton measured stratigraphic sections in the Rio Puerco Valley, and discussed the stratigraphy of this part of the field in subsequent papers[14] dealing with regional Upper Cretaceous stra-

[6] Johnson, D. W., Block mountains in New Mexico: Am. Geologist, vol. 31, p. 137, March 1903.

[7] Reagan, A. B., Geology of the Jemez-Albuquerque region, N. Mex.: Am. Geologist, vol. 31, no. 2, pp. 96–97, 1903.

[8] Schrader, F. C., The Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 285, pp. 241–258, 1906.

[9] Johnson, D. W., Volcanic necks of the Mount Taylor region, N. Mex.: Geol. Soc. America Bull., vol. 18, pp. 303–324, 1907.

[10] Shimer, H. W., and Blodgett, M. E., The stratigraphy of the Mount Taylor region, N. Mex.: Am. Jour. Sci., 4th ser., vol. 25, pp. 53–67, 1908.

[11] Gardner, J. H., The coal field between Gallup and San Mateo, N. Mex.: U. S. Geol. Survey Bull. 341, pp. 364–378, 1909.

[12] Gardner, J. H., The coal field between San Mateo and Cuba, N. Mex.: U. S. Geol. Survey Bull. 381, pp. 461–473, 1910.

[13] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 69, 1910.

[14] Lee, W. T., Stratigraphy of the coal fields of northern-central New Mexico: Geol. Soc. America Bull., vol. 23, pp. 622–629, 1912. Stanton, T. W., Some variations in Upper Cretaceous stratigraphy: Washington Acad. Sci. Jour., vol. 3, pp. 60–61, 1913. Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27–58, 1916. Lee, W. T., and Knowlton, F. H., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, pp. 195–198, 1917.

tigraphy. Darton[15] described the regional structure of parts of this area, and Bryan[16] studied the recent history of the Rio Puerco Valley in the southeastern portion of this field.

## FIELD WORK

The field work on which this report is based was done primarily for the purpose of classifying public lands as to their fuel resources. It was carried on during the summer and fall of 1930 and 1931. Both public and private land were included in the study. The field party was organized in 1930 by J. D. Sears, who remained in charge for the first month. Thereafter the writer was in charge of the field work and the preparation of the report. D. A. Andrews, R. W. Brown, and W. S. Pike, Jr., assisted in the field work in 1930, and H. R. Joesting, J. W. Wyckoff, G. F. Taylor, and R. C. Becker in 1931.

The area was mapped by plane-table methods on a scale of 1:62,500. In general the formations are well enough exposed to be traceable laterally. Some of the formations contain abundant fossil remains of ancient sea shells and fish; others contain petrified wood, leaves, and bones of land animals. About 1½ tons of fossil remains were collected from 200 localities distributed over the field and were studied to determine the types of life and the conditions they portray. As the presence or absence of fuel resources is directly dependent upon certain conditions of ancient climate and environment, the determination of the changing conditions through the geologic time represented is of practical as well as philosophic value. Numerous sections were measured across the strata in order to learn the direction and degree of thickening or thinning of the different formations. This study permits close delimitation of beds of potential commercial value and also the determination of depth to beds present below the surface.

Most of the coal beds in the area are very thin and lenticular and were not traced, but an attempt was made to trace the exceptionally thick beds. Some of these have been correlated in the columnar sections. Coal zones are shown on the map, but in general not individual beds of coal.

As the coal is of subbituminous rank and has a heating value of less than 12,000 British thermal units, beds less than 14 inches thick are of no significance for land classification and hence were ignored.

The section corners found were carefully located on the map. Other works of man and all drainage and alluvium were sketched.

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[15] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, pp. 220, 257–265, 1922.

[16] Bryan, Kirk, Historic evidence on changes in the channel of the Rio Puerco, a tributary of the Rio Grande in New Mexico: Jour. Geology, vol. 36, no. 3, pp. 265–282, 1928.

## ACKNOWLEDGMENTS

The writer wishes to express his thanks to the personnel of the Fernández ranch and the Evans ranch for the courtesies and cooperation extended by them to the party in the field. To J. D. Sears are due hearty thanks for guidance in starting the party and in the preparation of the report. R. W. Brown wrote the section describing the vegetation of the area. D. A. Andrews and A. K. Dashti assisted in drawing coal sections and checking altitudes.

## GEOGRAPHY

*Land forms.*—Dutton described the plateau country as " mesa, mesa everywhere—nothing but mesa ", and this description well fits the country around Mount Taylor. The largest and highest of the mesas is Mesa Chivato; its flat lava top, about 8,000 feet above sea level, covers an area of about 400 square miles. From the southern part of Mesa Chivato the roughly conical mass of Mount Taylor rises more than 11,300 feet above sea level and more than 5,000 feet above the valley of the San Jose River, to the south. At 14 miles east of Mesa Chivato is the similar but much smaller Mesa Prieta, whose lava cap is considerably lower.

Between Mesa Chivato and Mesa Prieta is a broad valley, whose surface consists of many low ridges and mesas, capped with resistant sandstone and separated by broad desolate shale flats. The Rio Puerco flows in the lowest part of the valley; it has an altitude of about 6,000 feet at the village of Cabezon and descends to about 5,000 feet at the southeast corner of the area. More than a score of dark volcanic necks rise above the general level of the valley floor as isolated peaks. (See pl. 22.) Some of these cylindrical or conical peaks rise almost to the level of the top of Mesa Chivato.

West of Mount Taylor and Mesa Chivato is a nearly continuous ridge formed by a series of mesas extending northwestward. These mesas, capped by resistant sandstones, present a steep scarp on the south side, and their tops slope northward. (See pl. 21.) The ridge has a mean altitude of about 8,000 feet. To the north and south of this ridge are broad flats of shale; that on the south is 1,000 feet lower than the ridge. The flat land north of the ridge is interrupted by broad valleys, giving a broken surface about 7,700 feet above sea level. The two flats are connected by three canyons that cut through the intervening ridge and divide it into the mesas.

*Drainage.*—There are no perennial streams in the area. Some of the streams carry water near their heads in the canyons cutting Mesa Chivato and Mount Taylor but lose it by seepage and evaporation before they get far into the lower country.

The Rio Puerco, a tributary of the Rio Grande, draining the west flank of the Nacimiento Mountains, is the largest stream of the area but flows continuously only during the wet season. The canyons on the south side of Mount Taylor and the valley extending northwestward from San Mateo are drained by the San Jose River, which flows eastward across the south border of the field and joins the Rio Puerco.

All the main streams and tributaries have trenched themselves into arroyos cut in the alluvial fill of the valleys. Immediately after heavy rains these arroyos carry off tremendous quantities of water. Occasionally the waters rise over the banks and spread out as sheet floods.

*Climate and vegetation.*—The climate of the greater part of the area is semiarid, with an average annual rainfall of about 14 inches. Mount Taylor, however, receives much more moisture, as is indicated by its heavily wooded sides. In summer the days are usually hot, but the dry atmosphere and almost continual breeze keep the high temperatures from being disagreeable. The nights are invariably cool. Freezing temperatures prevail during most of the winter nights, but as a rule the days are comparatively warm and pleasant.

The lowest valley and mesa areas surrounding Mount Taylor exhibit the vegetation characteristic of the Upper Sonoran life zone. In spring and during the rainy season much of the land is covered with a profusion of flowers and grasses, but with the coming of drier weather this showy pageant of color changes into one composed of the dull grays of sagebrush, the straw-color of dried grasses, and the yellows of such composites as goldenrod, rabbitbrush, and sunflowers. The trees of this zone, generally on hillsides and mesas, are the one-seeded juniper, the nut pine, and the cane cactus, a woody species of cactus sometimes reaching a height of 10 feet. On alluvial flats adjacent to watercourses greasewood is common, and there are groups of the common valley cottonwood. In the deep, watered canyons that extend back into the high lava-covered mesas are alders, boxelders, and oaks. The grasses and herbs of the Upper Sonoran zone support herds of cattle, sheep, and goats. The nut pines periodically yield large quantities of edible nuts.

Ascending from the Upper Sonoran zone onto Mount Taylor one passes into the Transition zone, characterized by the presence of the western yellow pine. In the Canadian and Hudsonian zones, at a still higher altitude, these stands of pine are replaced by trembling aspen, Douglas spruce, Engelmann spruce, Colorado blue spruce, balsam fir, and cork-bark fir. Finally these in turn yield to dwarf shrubs and herbs at the summit of the mountain. Mount Taylor has been set aside as a part of the Manzano National Forest.

*Settlement.*—The field is only sparsely inhabited, but there are several small villages. West of Mount Taylor, at the very foot of Mesa Chivato, is the village of San Mateo. There are several ranches in the broad flat west of this village, and a few scattered ranches in the vicinity of San Miguel Creek. Most of the people living on the west side of the mountain are engaged in raising sheep, but, where water is available, have small gardens.

East of Mount Taylor there are several small villages. The settlements of Seboyeta,[17] Bibo, and Moquino, and the Indian pueblo of Paguate are near together in the southern part of the Cebolleta grant. San Ignacio, Marquez, Casa Salazar, Guadalupe, Cabezon, and Dominguez are widely separated villages in the area east of Mesa Chivato. The last four named are along the Rio Puerco. Casa Salazar, south of Cabezon, is on the broad alluvial flat of the Rio Puerco and has not been located accurately on this map. There are but few ranches in the intervening areas.

Poor roads traverse practically all portions of the area. Fair graded dirt roads connect the villages of Seboyeta and San Mateo with United States Highway 66 in the San Jose Valley. A graded road connects Cabezon and Dominguez with New Mexico State Highway 44, northeast of this area. Only very poor roads connect these widely separated villages with the other villages of the area. Each year during the rainy seasons flooded arroyos take a heavy toll of bridges and make travel increasingly difficult during such seasons.

Telephone lines have been extended to San Mateo and Bibo. The gas pipe line, road, and telephone line of the Southern Union Gas Co. cross the northeastern part of the area.

The nearest railroad is the main line of the Atchison, Topeka & Santa Fe Railway, which follows the San Jose Valley along the south border of the area. There are numerous towns along the railway and United States Highway 66, which parallels it. A branch railroad extends from Bernalillo to San Ysidro near the northeast corner of this area.

## STRATIGRAPHY

The rocks exposed in this area range in age from Jurassic to Recent. The Jurassic is represented by the Upper Jurassic Morrison formation, in isolated exposures in the southern and eastern parts of the field. Most of the area is covered by Upper Cretaceous beds belonging to the Dakota (?) sandstone, Mancos shale, and lower members of the Mesaverde formation. Higher formations of the Upper Cretaceous are absent. The Tertiary is represented by an abundance of volcanic rocks, principally tuffs and lavas; by the clastic Santa Fe formation; and by scattered gravel deposits whose

[17] "Seboyeta," the post-office name, is a phonetic spelling of the Spanish "Cebolleta" (tender onion), the original name.

relations to the Santa Fe formation are unknown. The Quaternary is represented by lava and terrace gravel.

North of this area late Upper Cretaceous and Eocene formations are exposed. South of the area Triassic, Permian, and Pennsylvanian beds successively crop out, but in the Zuni Mountains, to the southwest, the Pennsylvanian is absent, the Permian resting directly upon pre-Cambrian granite and schist.[18] To the northeast, toward the Nacimiento uplift, are exposed rocks of the same age as are present to the south, toward the Zuni uplift.

## SEDIMENTARY ROCKS

### JURASSIC SYSTEM

#### *UPPER JURASSIC SERIES*

##### MORRISON FORMATION

The Morrison formation consists of variegated shales interbedded with more or less sandstone. The shale is in beds of striking colors—green, pink, and maroon—that stand out in sharp contrast to the generally somber colors of the Upper Cretaceous. The sandstones are generally massive, light-colored, and at many places coarse-grained. The thickness of the formation ranges from 300 to 500 feet.

Ordinarily the Morrison formation crops out in a steep slope beneath a cliff of Dakota (?) sandstone. The best exposures are found in the steep scarps around the south and east sides of Mesa Gigante and in the eastward-draining canyons located north of the mesa. Less extensive exposures of the upper part of the formation may be seen in the faulted blocks east of the Alamosa and Reservoir faults, particularly in the blocks about 1½ miles northeast of Suwanee.

The Morrison is poorly exposed in Tps. 11 and 12 N., R. 9 W., and there are similar poor exposures just south of the area mapped, at the western border of the field.

### CRETACEOUS SYSTEM

#### *UPPER CRETACEOUS SERIES*

##### DAKOTA (?) SANDSTONE

The Upper Cretaceous overlies the Morrison formation with an erosional unconformity. Generally the basal unit of the Upper Cretaceous is a buff-tan sandstone referred to as the Dakota (?) sandstone. Where present, it attains a maximum thickness of 75 feet, but locally it is absent, the overlying Mancos shale resting directly upon the eroded top of the Morrison. (See pls. 26, *B*, and 23, *A*.) The lower beds of the Dakota (?) are everywhere coarse-

[18] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, figs. 31, 48, pl. 26, 1928.

grained, commonly gritty, and locally conglomeratic. The upper beds are finer grained. In the eastern part of the field some difficulty in determining the base of the Dakota (?) sandstone is caused by the fact that the top member of the Morrison formation is commonly a thick white sandstone. The two sandstones can generally be distinguished by the presence of grit or conglomerate in the basal part of the Dakota (?), the generally tan color of the Dakota (?) in contrast with the bright white color of the top sandstone of the Morrison, and the crenulated contact.

The Dakota (?) sandstone crops out almost continuously across the southern part of the field and in the faulted blocks east of the Alamosa and Reservoir faults. These outcrops are generally in the form of a somber-colored sandstone cliff at the top of a scarp of brighter-colored beds of the Morrison.

East of Mount Taylor there are three prominent sandstones in the lower 350 feet of the Mancos shale, overlying the Dakota (?) sandstone, to each and all of which the name "Tres Hermanos sandstone" has been applied. These sandstones are not present west of the mountain. Opportunity for studying the relations of these sandstones to the Dakota (?) sandstone was not available, but it seems probable that the Dakota (?) sandstone west of Mount Taylor is at the horizon of one of these sandstones, and therefore that the Dakota (?) sandstone west of Mount Taylor is younger than the sandstone called by the same name east of the mountain. How this suspected rise to the west takes place is a problem awaiting further study.

#### MANCOS SHALE

The name "Mancos shale" was first used by Cross [19] for a very thick shale unit near Mancos, Colo., which he later described [20] as

> an almost homogeneous body of soft dark-gray or nearly black carbonaceous clay shale. * * * The Mancos is therefore a lithologic unit which it is necessary to recognize in the mapping of this region. It is limited below by the Dakota sandstone and above by the lowest sandstone of the Mesaverde formation of alternating sandstones and shales. * * * This lithologic unit embraces the Colorado group and a part of the Pierre division of the Montana group.

As the Mancos was defined on a lithologic basis, its boundary with the overlying Mesaverde varies, as their lithology changes from place to place, and cuts across time lines. In northwestern New Mexico, as recognized for some years, the lower part of the Mesaverde is much older than the Mesaverde at the type locality. However, the lower part of the Mancos shale body can be traced continuously between the
part of the Mancos shale body can be traced continuously between the
ately extended to this portion of New Mexico.

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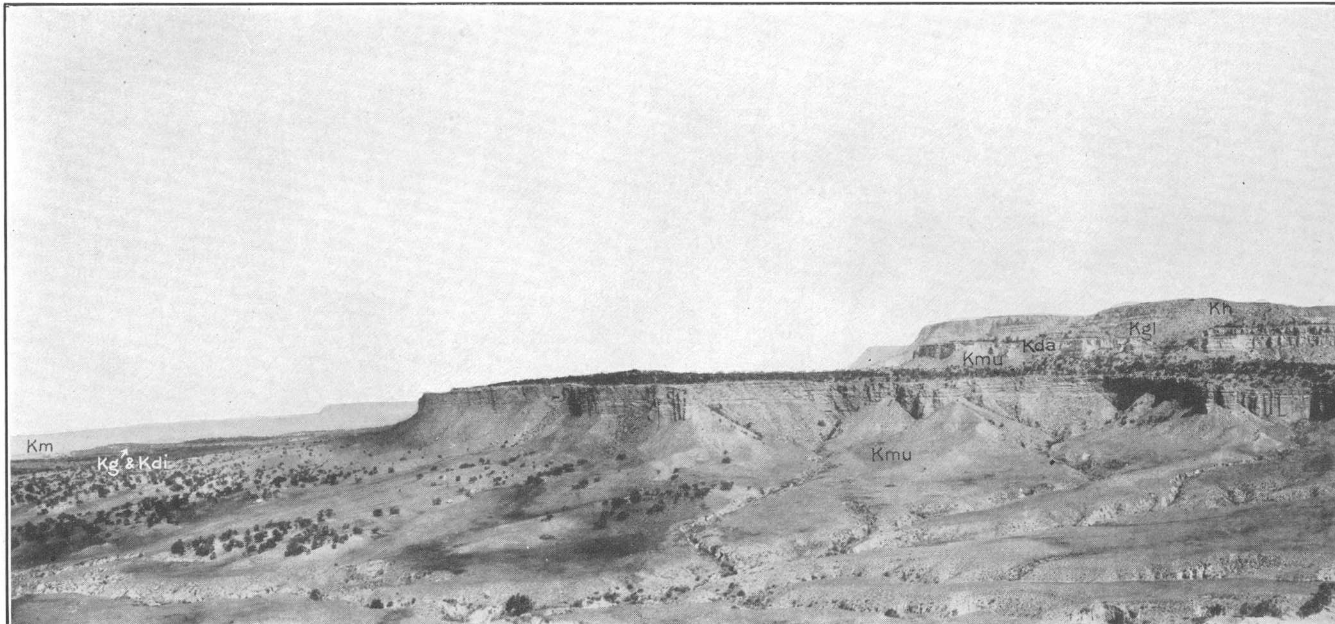
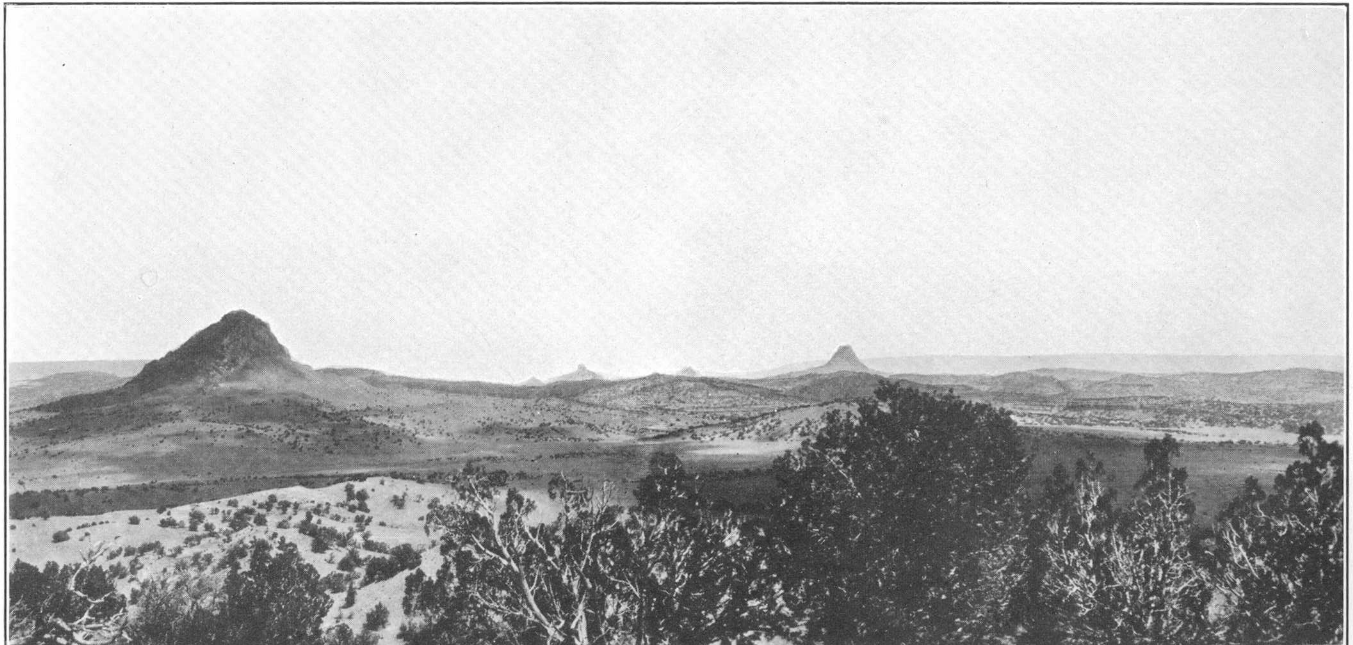
[19] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Telluride folio (no. 57), p. 4, 1899.
[20] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, La Plata folio (no. 60), p. 4, 1899.



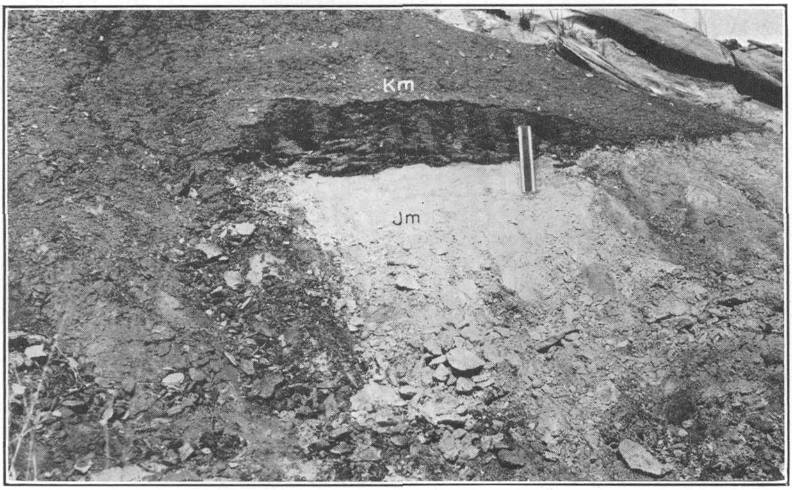

VIEW SHOWING INTERTONGUING RELATIONS OF MANCOS AND MESAVERDE FORMATIONS IN THE SE¼ SEC. 5, T. 13 N., R. 8 W.

Looking northwest. Km, Mancos shale; Kg and Kdi, Gallup sandstone member of the Mesaverde formation and overlying Dilco coal member; Kmu, Mulatto tongue of the Mancos, with prominent sandstone lentil; Kda, Dalton sandstone member; Kgl, lower part of the Gibson coal member; Kh, Hosta sandstone member.



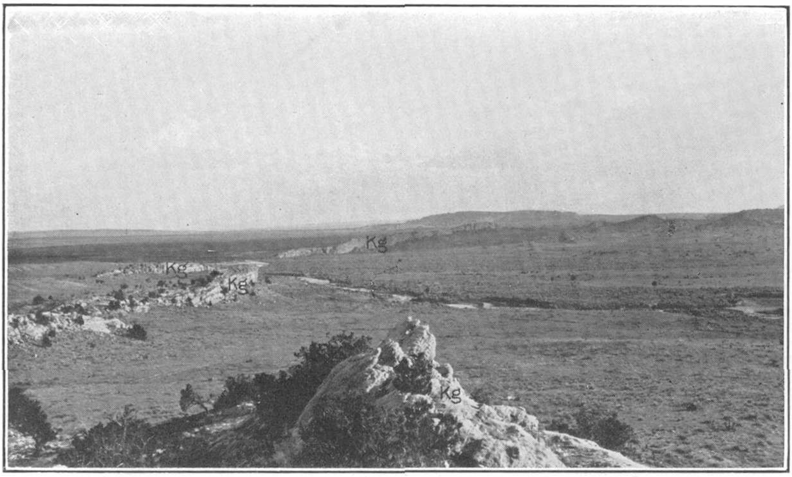
VIEW ON LAGUNITAS GRANT FROM THE VOLCANIC NECK 3 MILES NORTH OF SLEEPING HOUND BUTTE.

Looking north. The prominent neck in right center is La Senora Peak. It is 5 miles away, and the peak is about 1,000 feet above the base.



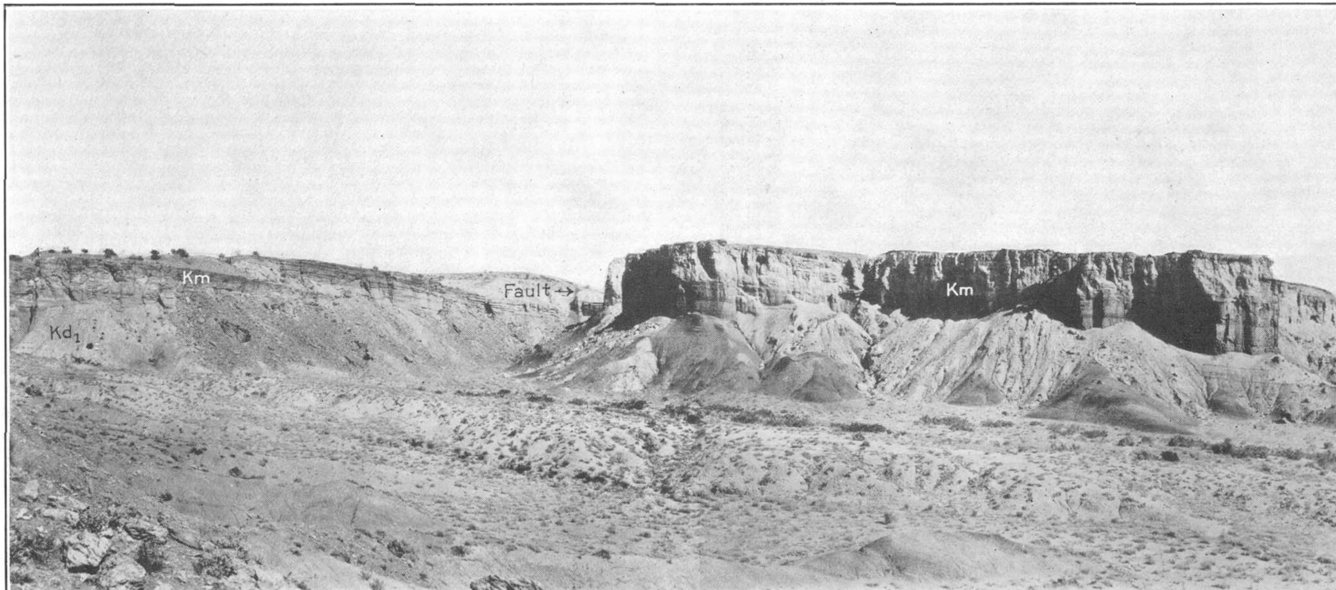

*A*. MANCOS SHALE (Km) RESTING UNCONFORMABLY ON WHITE SANDSTONE OF THE MORRISON FORMATION (Jm) IN THE SE¼ SEC. 35, T. 15 N., R. 1 W.

The Dakota (?) sandstone is absent. Scale is 6 inches long.




*B*. VIEW LOOKING SOUTH ALONG THE SAN IGNACIO MONOCLINE, IN THE NE¼ SEC. 13, T. 10 N., R. 3 W.

Hogbacks of Gallup sandstone member (Kg) repeated by faulting. The mesa on the right skyline consists of nearly flat-lying sedimentary rocks capped with lava.




MANCOS SHALE (Km) FAULTED DOWN ABOUT 300 FEET AGAINST SANDSTONE NO. 3 ($Kd_1$) IN LOWER PART OF MANCOS, SEDILLO GRANT, 2 MILES NORTHEAST OF SUWANEE.

Looking north. The sandstone in the Mancos contains abundant Carlile fossils. It is 25 feet thick. Beneath the sandstone, near the base of the slope of shale, there is a zone of calcareous concretions containing abundant ammonites. The zone can best be seen at the right. This zone is believed to be of Greenhorn age.

This concept of the Mancos as a unit of variable thickness but of fairly constant lithology is borne out in the area covered by the present report. In the northeastern part of the field the Mancos, somewhat more than 2,000 feet thick, is predominantly shale and seems entirely of marine origin. It includes only rocks of Colorado and lowermost Montana age. The overlying Mesaverde is of Montana age. As traced southward and southwestward the upper half of the Mancos shale becomes intertongued with wedges of continental sandstone, shale, and coal that represent earlier deposition of the Mesaverde in those directions. (See fig. 1.) Still farther south the upper tongues of the Mancos shale die out, and in the southern part of the field the lower or main body of Mancos shale, between the Dakota (?) sandstone and the thickened Mesaverde, is only about 1,000 feet thick and is of Benton and lower Niobrara age.

The Mancos is chiefly a shale formation, but east of Mount Taylor it includes in its lower part from one to three beds of sandstone. The main body of shale crops out on the west, south, and east sides of Mount Taylor; in the Rio Puerco Valley between Mesa Chivato and Mesa Prieta; and in fault blocks in the eastern part of the area.

*Lower part of Mancos shale.*—East of Mount Taylor are the three prominent sandstones in the lower 350 feet of the Mancos shale to which the name "Tres Hermanos sandstone" has been applied in previous reports. Apparently this name was first used by Herrick and Johnson,[21] though without recording a type locality. These sandstones are medium and fine-grained buff sandstones. They are prominent in the vicinity of Seboyeta but thin out to the east and northeast. Fossils collected from them suggest Graneros age. In the following brief description of the lateral variations of these sandstones they will be referred to by the numbers given in the accompanying composite section; the thicknesses of the several units vary considerably from place to place.

*Composite section in Montaño grant to illustrate stratigraphic position of the sandstones in the lower part of the Mancos shale*

| | Feet |
|---|---|
| Main body of Mancos shale | 830± |
| Lower 350 feet of Mancos shale: | |
| Sandstone no. 3 | 30 |
| Shale | 30 |
| Sandstone no. 2 | 75 |
| Shale | 65 |
| Sandstone no. 1 | 50 |
| Shale | 15 |
| Sandstone, gastropod zone | 2 |
| Shale | 55 |
| Dakota (?) sandstone | 0–50 |

[21] Herrick, C. L., and Johnson, D. W., The geology of the Albuquerque sheet: New Mexico Univ. Hadley Lab. Bull., vol. 2, pt. 1, p. 14, 1900.

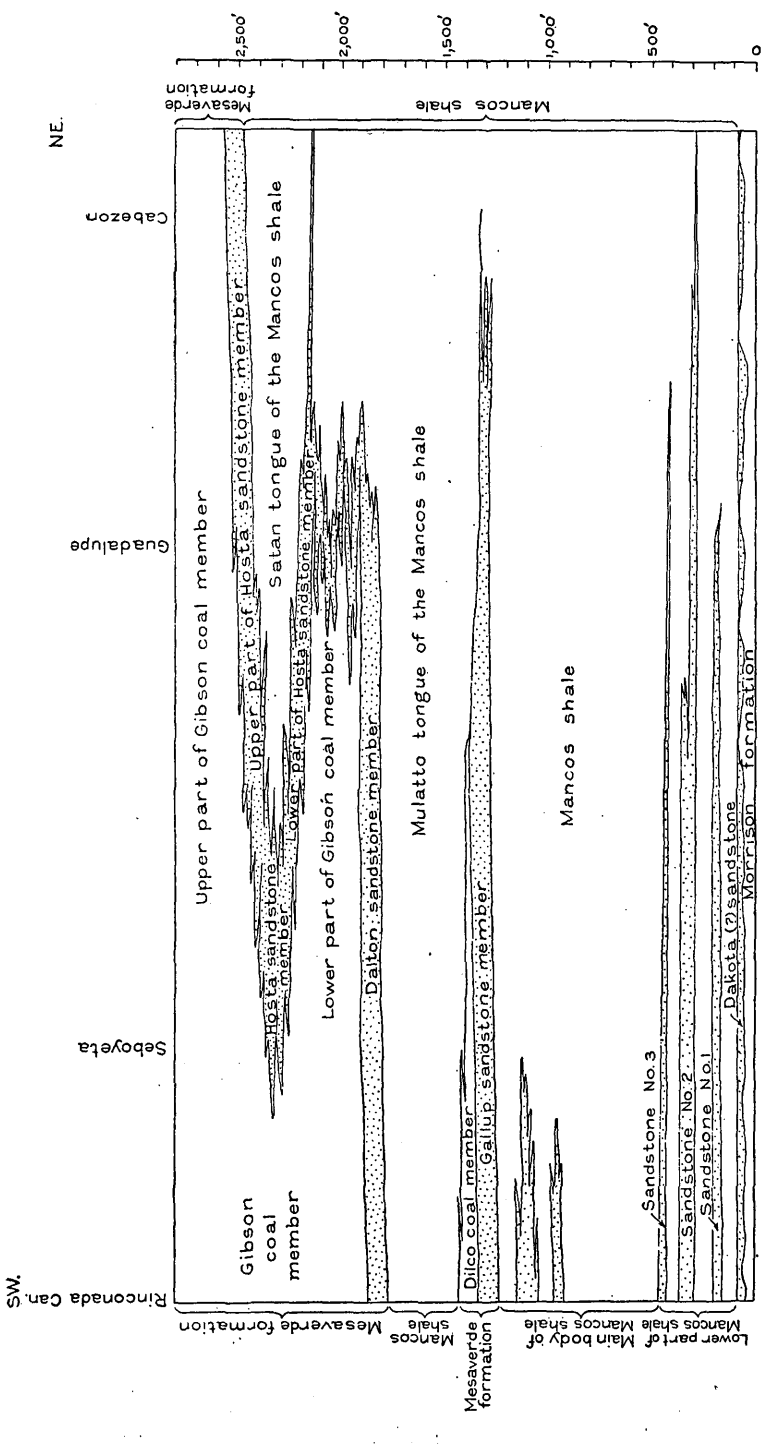



FIGURE 1.—Diagrammatic section illustrating the intertonguing relations of the Mancos and Mesaverde formations east of Mesa Chivato.

Of the material underlying sandstone no. 1 the lower part was probably deposited in brackish water, and the higher part, which is increasingly sandy, probably had a marine origin. A persistent bed of sandstone, generally about 2 feet thick and containing abundant remains of gastropods, was named the "gastropod zone" by Herrick and Johnson.[22] This thin bed is commonly present about 15 feet below sandstone no. 1 and provides a means for identifying it—a fortunate circumstance, for sandstone no. 1 is generally poor in fossil remains. It is thick and massive in the vicinity of Paguate and Moquino, is present over most of Mesa Gigante, and caps small but conspicuous mesas to the north. However, it thins out in the western part of the Antonio Sedillo grant and in T. 15 N., R. 1 E.

The shale overlying sandstone no. 1 is of marine origin, and its lithology is typical of the Mancos shale.

Sandstone no. 2 is the most persistent of the three sandstones and is usually thick and massive, cropping out as a prominent capping of mesas or ridges over most of the area east of Mount Taylor. It can be seen grading over to marine shale in T. 15 N., R. 1 E. Abundant fossils in it are generally scattered through large ferruginous concretions, many of which are as much as 10 feet in diameter and so hard and resistant to erosion that they commonly form conspicuous loose boulders.

The shale overlying sandstone no. 2 is of marine origin and, like that overlying no. 1, is lithologically typical of the Mancos shale.

Sandstone no. 3 is the least conspicuous of the three. It is commonly thin and is absent in the eastern and northern parts of the area east of Mount Taylor. It is best recognized by its tendency to show bedding and by the abundant fossil oysters (*Gryphaea newberryi*) in the 30 feet of shale next overlying the sandstone. Plate 24 shows a view of this sandstone.

The relation between these three sandstones and the Dakota (?) sandstone west of Mount Taylor is discussed on page 40.

*Main body of Mancos shale.*—The main body of the Mancos shale is generally exposed in broad valleys in the southern and eastern parts of the field. The shale is invariably dark gray. A few thin beds of light-colored calcareous sandstone present locally through the shale (see pl. 24) are generally fossiliferous. Small fragile fossil shells, though scarce, can locally be found in the shale itself. About 300 feet above the top of sandstone no. 3 is a 20-foot zone of limestone concretions. The concretions vary in size, the largest being 2 feet in diameter, and commonly contain an abundant and excellently preserved ammonite fauna, which, however, has not yet been fully studied and described; the age and correlation are therefore

[22] Herrick, C. L., and Johnson, D. W., op. cit., p. 13.

not known. In the southern part of the field this zone of concretions is overlain by 500 feet of dark-gray marine shale with thin, abundantly fossiliferous calcareous sandstones, up to the Gallup sandstone member of the Mesaverde formation. Most of this shale zone is of Carlile age, but the uppermost beds are of Niobrara age.

West of Mount Taylor there are two prominent sandstone beds in the upper part of this shale body. In 1929 Sears[23] found that far to the west, in the Hogback, near Gallup, these beds converge and form the lowest sandstone of the Gallup sandstone member of the Mesaverde formation. In the area covered by the present report the lower of the two thins out eastward at a locality near the north-south fault in T. 14 N., R. 10 W. The upper sandstone can be traced to a point 7 miles farther east, where it also thins out. Both sandstones reappear along the south side of Mount Taylor and can be traced discontinuously eastward to a point near the mouth of Water Canyon, where they again thin out.

In the northern part of the field the Mancos shale is much thicker than in the southern part, just described. This increase is due to the introduction and northward growth of two wedges of marine shale within the lower part of the Mesaverde; still farther north, as this part of the Mesaverde gradually thins out, the shale wedges merge into the main body of the Mancos, forming a continuous shale series about 2,200 feet thick. The lower wedge of shale is called the "Mulatto tongue" and the upper wedge the "Satan tongue" of the Mancos shale.

*Mulatto tongue.*—The Mulatto tongue lies between the Dilco coal member and the Dalton sandstone member of the Mesaverde formation. (See pl. 21.) The name is here given for exposures at the south end of Canyon Mulatto, 9 miles northwest of San Mateo. The best exposures of this tongue are in the southward-facing scarp extending northwestward from San Mateo. Other out-crops may be seen along the south and east sides of Mount Taylor and in the faulted blocks east of the Alamosa and Reservoir faults.

Toward the southern part of the field the tongue is made up largely of light-tan marine sandy shale with some thin sandstones and very local grits. Northward the proportion of shale increases until, where the Gallup and Dilco members of the Mesaverde thin out, the Mulatto tongue is composed entirely of dark-gray shale and cannot be distinguished lithologically from the main body of the Mancos shale. Accordingly, at the north end of the field the Mulatto tongue is mapped with the rest of the Mancos shale. The thickness of the Mulatto tongue ranges from 250 feet in the southern

[23] Sears, J. D., The coal field from Gallup eastward toward Mount Taylor, N. Mex.: U. S. Geol. Survey Bull. 860–A, p. 15, 1934.

part of the field to 400 feet at the north. It is of middle Niobrara age.

*Satan tongue.*—The Satan tongue was named by Sears [24] from the exposures in Satan Pass 12 miles west of this field. The member is best exposed along the north side of the ridge extending northwestward from San Mateo and in the crest of the Miguel Creek dome. Less extensive exposures may be seen along the east side of Mount Taylor and in the faulted blocks east of the Reservoir fault.

The Satan tongue of the Mancos shale wedges into the Hosta sandstone member of the Mesaverde formation and separates it into an upper and a lower part. To the north the tongue attains a thickness of 300 feet. Lithologically the Satan is like the Mulatto, and to the north it becomes more and more like the main body of the Mancos shale. Where the underlying members of the Mesaverde grade over to marine shale the Satan is continuous lithologically with the rest of the Mancos shale and is therefore mapped with it at the north end of this field. The lower and middle beds of the Satan are of late Niobrara age; the top beds may be basal Montana.

### MESAVERDE FORMATION

The Mesaverde formation was named by Holmes [25] from the exposures in what is now the Mesa Verde National Park, in Montezuma County, southwestern Colorado. Holmes recognized three divisions of the Mesaverde, which Collier [26] subsequently named, in ascending order, the "Point Lookout sandstone", the "Menefee formation" (an intermediate coal-bearing shale unit), and the "Cliff House sandstone." As used extensively over the West the name "Mesaverde" designates a formation in the midst of the Upper Cretaceous, with variable upper and lower limits but characterized by alternating beds of sandstone, clay, and coal; it is largely of continental origin.

In the area covered by the present report the rocks that are classified as Mesaverde comprise those sediments, largely continental, that were deposited near and landward from the old strand line that marked the southwest shore of the early Upper Cretaceous sea. This strand was continually shifting back and forth, but in general over a long period of time it advanced seaward, to the northeast. The fluctuations of the old strand line are recorded by the intertonguing of portions of the Mancos and Mesaverde. The general retreat of the sea to the north and east is well shown in the regressive

[24] Sears, J. D., op. cit., p. 14.

[25] Holmes, W. H., Geological report on the San Juan district, Colo.: U. S. Geol. and Geog. Survey Terr. 9th Ann. Rept., p. 244, 1877.

[26] Collier, A. J., Coal south of Mancos, Montezuma County, Colo.: U. S. Geol. Survey Bull. 691, p. 296, 1919.

overlapping of the Mesaverde over the Mancos in that direction. It follows that the base of the Mesaverde to the north and east is younger than the base to the south and west.

The Mesaverde formation is at the surface over most of the western and northern parts of the field. Less extensive exposures of the Mesaverde are found along the south and east sides of Mount Taylor and in the faulted blocks east of the Alamosa and Reservoir faults.

*Gallup sandstone member.*—The base of the Mesaverde in the southern part of the field is placed at the base of the Gallup sandstone member. The name "Gallup" was used by Sears[27] for the basal member of the Mesaverde near the town of Gallup, where it comprises three or more beds of massive sandstone and interbedded shale and coal. In 1929 Sears[28] traced the member eastward from the type locality. The lowest sandstone near Gallup was found to split into two beds, which could be followed almost continuously to the eastern limits of the field described by Sears. These two sandstones are discussed on page 44 of this report as sandstones in the Mancos shale. The continental shale overlying the lowest sandstone of the Gallup grades laterally eastward into marine shale. The middle and upper sandstones of the member at the type locality were found to join eastward, pinching out the intervening continental shale. The unit herein called the "Gallup sandstone member" is the equivalent of the middle and upper sandstones of the type locality.

The Gallup member in this field is a massive sandstone, averaging about 65 feet in thickness, lying conformably above the main body of the marine Mancos shale. In the southern part of the field it is overlain by continental shale and sandstone, which to the north and east grade into marine shale. Locally there is a sharp lithologic break between the Gallup and the underlying Mancos shale, but generally there is a transitional zone, 1 to 6 feet thick, of interbedded thin sandstones and shale. As a general rule the sandstone in the transitional beds is finer-grained than that of the massive bed above. The Gallup is a rather clean sandstone with locally an abundance of flakes of muscovite. The quartz grains are well rounded and, when examined on fresh fractures, appear clean and free of iron stain. The Gallup forms a gray cliff, but it is a soft, friable bed, and its upper part commonly weathers into rounded beehive forms.

The member contains few fossils in the southern part of the field, but toward the north the upper beds commonly contain large fossil clams and oysters.

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[27] Sears, J. D., Geology and coal resources of the Gallup-Zuni Basin, N. Mex.: U. S. Geol. Survey Bull. 767, p. 17, 1925.

[28] Sears, J. D., The coal field from Gallup eastward toward Mount Taylor: U. S. Geol. Survey Bull. 860–A, pp. 15–16, 1934.

The Gallup member crops out across the southern part of the area west and south of Mount Taylor, but the northward regional dip buries it under younger beds before any marked lithologic changes occur. East of Mount Taylor the Gallup can be traced northward on both sides of Mesa Prieta nearly to its north end. Northward the standstone loses its massive character and becomes bedded and even shaly, and still farther north, just beyond the edge of the field, it completely grades over to marine shale.

*Dilco coal member.*—In the southern part of the field the Gallup sandstone member is overlain conformably by a zone of continental shale and thin sandstone, locally with coal beds. (See pl. 26, *A*.) This zone is the equivalent of the lower part of the Dilco coal member of the Gallup-Zuni Basin, as shown by recent mapping,[29] and therefore it is given the same name in the present report. At the southwest corner of the field, where the Dilco attains its maximum thickness of 150 feet, a conspicuous sandstone some 50 feet thick, separates the shale of the Dilco from the Mulatto; elsewhere in the field the marine shale of the Mulatto tongue generally rests directly upon the continental beds. The continental shale, sandstone, and coal beds of the Dilco are variable in composition. There is generally considerable carbonaceous material throughout the zone, although coal beds are few. To the north the carbonaceous shale beds become increasingly sandy and the coal beds are completely absent as the zone thins out. The Dilco thins northward and is completely replaced by marine shale. (See pl. 26, *C*.) This change can readily be seen in the exposures east of the Rio Puerco in the Montaño grant and in the northern part of the Lagunitas grant west of Casa Salazar. These relations are shown in figure 1.

In general the Dilco is poorly exposed, cropping out as a gentle slope of shale above a cliff of the Gallup sandstone.

*Dalton sandstone member.*—As already described, the Dilco coal member is overlain by the Mulatto tongue of the Mancos shale. The Mulatto is in turn overlain by the Dalton sandstone member of the Mesaverde, named[30] from the exposures at Dalton Pass, about 9 miles west of the village of Crown Point. The member crops out as a cliff of massive sandstone ranging in thickness from 75 to 125 feet. (See pl. 21.) In the central and western parts of the field it generally weathers in big blocks along a buff cliff, rather than in the gray beehive forms that are so characteristic of the Gallup. Along the east border of the field it is 100 feet thick but so friable that it is a very inconspicuous unit. Cross-bedding is clearly shown. North-

[29] Sears, J. D., The coal field from Gallup eastward toward Mount Taylor: U. S. Geol. Survey Bull. 860–A, p. 16, 1934.

[30] Idem, p. 17.

ward the sandstone becomes shaly and marine as the overlying continental beds grade into a marine facies.

*Lower part of the Gibson coal member.*—The Dalton sandstone member is overlain by several hundred feet of continental deposits—gray shale, carbonaceous shale, coal beds, and sandstone—which crop out typically as a steep and dark-colored slope beneath a conspicuous cliff of the Hosta sandstone member. The relation of this continental series to the units named in the Gallup-Zuni Basin is as follows: In the area between Gallup and the Mount Taylor region the Bartlett barren member was found to merge eastward with the overlying Gibson coal member, and the expanded Gibson member was found to be split toward the east and northeast by a thick massive sandstone unit, the Hosta sandstone member.[31] That part of the expanded Gibson which lies below the Hosta is referred to as the lower part of the Gibson coal member, and that part overlying the Hosta as the upper part of the Gibson coal member. South of Mount Taylor and in the southeast corner of the field, in the Antonio Sedillo grant, the Hosta sandstone is not recognizable, and hence the Gibson in those localities has not been separated into lower and upper parts.

The lower part of the Gibson contains many coal beds. The coals are shown graphically in the columnar sections in plates 29–33 and are discussed by townships on pages 66–77.

The only fossils found in the lower part of the Gibson are poorly preserved plants and bones of land animals.

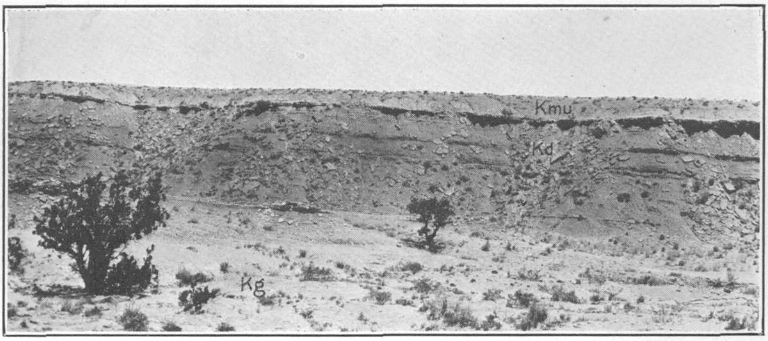
Northward the lower part of the Gibson passes over to marine shale (see fig. 2), and there is a slight thinning of the member as a whole. The transition to a marine facies takes place in a very short distance by the introduction of a series of small tongues of marine shale and sandstone within the unit. Many of the small tongues of sandstone are split by marine shale still farther north. The increasingly sandy character of the lower part of the Gibson toward the north is conspicuous, and the whole transition from continental to marine facies is fairly well exposed along the east side of Mesa Chivato in T. 14 N., R. 4 W.

*Hosta sandstone member.*—The Hosta sandstone member was named [31] from the type locality at Hosta Butte. The member shows considerable variation from southwest to northeast. In the southwestern part of the field it is represented by a series of sandstones about 300 feet in total thickness. To the north the marine Satan tongue of the Mancos shale wedges in about the middle of the unit and thickens rapidly northward until it is nearly 300 feet thick. The thickening of the shale is effected in part at the expense of the sandstone above, much more at the expense of the sandstone below, but

[31] Sears, J. D., op. cit. (Bull. 860–A), p. 18.

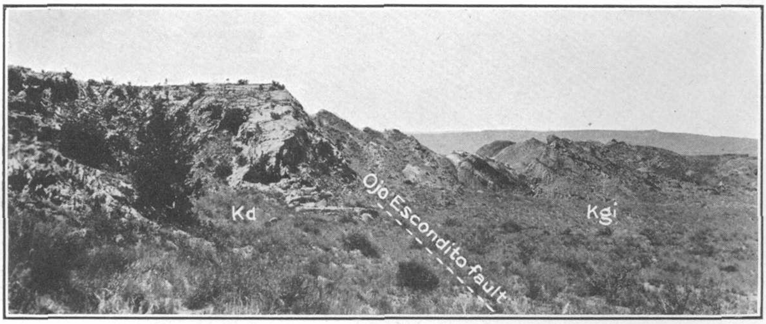

VIEW LOOKING NORTH ALONG THE OJITO FAULT, IN THE S½ SEC. 10, T. 11 N., R. 2 W.

Lower sandstone of the Hosta member (Khl) with underlying coal-bearing lower part of the Gibson member (Kgl) faulted down against the tan shale of the Mulatto tongue (Kmu). The Ojito fault dips 45° W.




*A*. TYPICAL EXPOSURE OF THE DILCO COAL MEMBER OF THE MESAVERDE FORMATION (Kd), SEDILLO GRANT, 4½ MILES NORTHEAST OF SUWANEE.

Looking northeast. A typical exposure lying between the Gallup sandstone member (Kg) and the Mulatto tongue (Kmu).




*B*. VIEW LOOKING SOUTHWEST ALONG THE OJO ESCONDIDO FAULT, SEDILLO GRANT, 4 MILES EAST OF SUWANEE.

Gibson coal member (Kgi) faulted down about 2,500 feet against Dakota (?) sandstone (Kd).

*C*. MULATTO TONGUE OF MANCOS SHALE RESTING DIRECTLY ON GALLUP SANDSTONE, IN THE NE¼ SEC. 16, T. 12 N., R. 1 W.

Looking northeast. The sandstone is in the foreground; the butte is entirely Mulatto. The Dilco has thinned out.

mostly by a thickening of the whole unit. In the vicinity of the Miguel Creek dome, for example, the lower sandstone of the Hosta has a thickness of but a few feet, the Satan tongue is over 200 feet thick, and the upper sandstone of the Hosta is about 75 feet thick. The same relative thicknesses are well exposed in the western part of T. 14 N., R. 4 W., and the western part of T. 16 N., R. 10 W. In the southeastern part of T. 14 N., R. 1 W., the lower sandstone of the Hosta is 150 feet thick, the Satan tongue is 220 feet thick, and the upper sandstone of the Hosta is 85 feet thick. Plate 25 shows a typical exposure of the lower sandstone of the Hosta in the Montaño grant.

The Hosta sandstone member is present nearly everywhere in the field. The lower sandstone changes in the northeastern part of this field to a thin bed of sandstone that persists for several miles into the area adjoining on the northeast. The upper sandstone of the Hosta member, however, continues northward along the east flank of the San Juan Basin and there forms the basal member of the Mesaverde formation, overlying the expanded body of the Mancos shale.

*Upper part of the Gibson coal member and overlying barren beds.*—Above the wedge of Hosta sandstone is a series of continental beds—shale, carbonaceous shale, and generally thin coal beds and sandstones. Within this field the coal beds are confined to the lower 300 feet of the series, in a zone approximately representing the upper part of the Gibson coal member as mapped by Sears to the west. The upper part is a thick barren zone, in part equivalent to the Allison barren member of the Gallup-Zuni Basin but not separated as such in this report. The coal beds are discussed in some detail by townships on pages 66–77 and are shown graphically in the columnar sections of plates 34–37.

In the area west of Mesa Chivato the lower beds of the unit consist of a repeated series suggesting cyclic sedimentation. A typical section is given below.

*Section of upper part of Gibson coal member in T. 15 N., R. 8 W.*

| | *Ft.* | *in.* |
|---|---|---|
| Sandstone, platy, fine-grained, ferruginous | | 10 |
| Sandstone, massive, cross-bedded, coarse-grained, buff | 8 | |
| Sandy shale, transitional, with sandstone above and gray shale below | 10 | |
| Gray shale, dull and drab | 6 | |
| Carbonaceous shale | | 4 |
| Coal, with lenticles of shale and sand | 1 | 4 |
| Carbonaceous shale | 10 | |
| Gray shale, dull and drab | 10+ | |

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This sequence of sedimentation is repeated about 12 times. None of the beds are continuous over long distances. The thickness and lithology are both found to change rapidly as the beds are traced laterally. Numerous fossil plants are preserved in the ferruginous sandstone at the top of the sequence. Brown [33] reported that these plants included such forms as *Cornus*, *Platanus*, *Populus*, *Diospyros*, and *Juglans*, from which a mild humid climate was inferred.

In this field the base of the upper part of the Gibson is of very early Montana age. The unit is probably equivalent to part of the Menefee formation at its type locality in Colorado, where the basal beds of the Menefee are of Pierre age but at some distance above rocks that carry Telegraph Creek and Eagle faunas.

## TERTIARY SYSTEM

### SANTA FE FORMATION

The Santa Fe formation, generally regarded as of upper Miocene and Pliocene age and so classified by the United States Geological Survey, is present in a belt 20 miles wide that trends southward along the east border of the field and in outliers within the field near the east border. The sediments of the formation in this area are mostly clastic. They are of fluviatile origin and were brought in by streams flowing from the north. They apparently filled the topographic depression that resulted from the down-faulting of the Rio Grande Valley. As the depression was filled younger and younger beds gradually overlapped onto the sides of the depression. Earlier investigators who have studied the Santa Fe have collected vertebrate remains from scattered localities in the Rio Grande Valley and concluded that the formation is of upper Miocene and Pliocene age.

Probably only the upper part of the Santa Fe extends into the Mount Taylor field. Locally, thin deposits are present lying on erosion surfaces about 100 feet above present drainage levels. The possibility must be considered that unless the original thickness of the Santa Fe was far greater than any of the preserved remnants, only slightly more than 100 feet of downcutting has taken place since Santa Fe time. This is probably too little for all of the Quaternary period and in addition an indefinite fraction of Pliocene time. Accordingly some uncertainty is introduced regarding the age of the upper part of the Santa Fe. The uppermost beds may be as young as Pleistocene.

The Santa Fe is poorly consolidated, and wherever present it weathers into abundant loose sand that is soon whipped into dunes by the winds. The formation therefore gives rise to a featureless surface and a soil incapable of supporting any but the hardiest of plants.

[33] Brown, R. W., oral communication, 1930.

### SCATTERED GRAVEL DEPOSITS

The highest gravel beds in the area are found on Mesa Chivato underlying the oldest bed of ash and lava. Discontinuous beds of gravel occupying this position were observed on the east side of Mesa Chivato in the neighborhood of Marquez, where they attain a thickness of 15 feet. The average diameter of the pebbles is about 1 inch, although there is a range from one-eighth inch to 4 inches. The pebbles are mostly quartzite, chert, or silicified wood. Only one specimen of water-worn andesite was found—a significant feature in view of the abundance of later andesitic lavas. The deposits now rest about 2,000 feet above the present level of the Rio Puerco. Gravel can be found locally at about this same level on the mesas of the Mesaverde formation northwest of San Mateo. The gravel is not in beds but consists of scattered though locally abundant pebbles and boulders as large as 6 inches in diameter. The materials are of the same kinds as the gravel on Mesa Chivato, and no pebbles of andesite were found. The relations of these gravel deposits to the Santa Fe formation are not known.

### QUATERNARY SYSTEM

Sloping away from the high lava-capped Mesa Chivato is a series of gravel terraces. They are best preserved on the Bartolomé Fernández grant at the head of San Miguel Creek, where the several sets of terraces nearly come together, as the higher terraces slope down about 350 feet to the present level of drainage. The older terraces begin about 500 feet above the present drainage level and slope down to about 150 feet above it. The younger terraces start much lower. Terraces standing about 150 feet above the present drainage level are discontinuous, being broken through by erosion. Along San Miguel Creek as far as the Miguel Creek dome are scattered remnants of what seem to be the same series of terraces. Within the dome there are no terraces, although gravel can be found locally on some of the rock-protected ledges. East of the dome are other remnants of the same terraces, which can be traced discontinuously along Chico Arroyo to its junction with the Rio Puerco, 5 miles southwest of the village of Cabezon. Boulders of andesitic material derived from flows on Mount Taylor and Mesa Chivato predominate throughout these terraces.

West of the Rio Puerco there is a similar series of gravel terraces, of predominantly andesitic boulders, which slope down steeply from the high mesas. Nearly all are discontinuous, having been cut into remnants by the subsequent erosion. Several distinct levels of terraces can be seen here, but they can be separated only by a detailed study of their altitude and slope.

South of Mount Taylor and north of highway 66 between McCarty and Cubero there is an extensive plain, which is probably in part a pediment cut in the soft Mancos shale but in part has been built up by the confluence of fans deposited at the mouths of the canyons that cut back into the mountain. The materials are coarse near the mouths of the canyons but become finer on the plain. Recent erosion has left terraces. A similar plain is present northeast of Grant.

All the streams in the area are trenched in arroyos cut into aggraded flood deposits. Conglomeratic material is rare in these deposits, which are composed almost entirely of fine sand and silt. At least some of the trenching has occurred within the history of the settlement of the region, for inhabitants tell of the Rio Puerco formerly meandering back and forth across a fertile flood plain,[34] into which the arroyos have since been cut.

## IGNEOUS ROCKS

Volcanism played a dominant part in the later stages of the geologic history of the Mount Taylor field. The field has been the scene of intermittent volcanic eruptions from the time when Mount Taylor was an active volcano down to the incision of the streams into their present valleys. Only a general description of the volcanic rocks thus formed will be given here. The details of the petrography and field relations will be discussed in a subsequent technical paper.[35]

*Mount Taylor.*—Viewed from a distance Mount Taylor appears as a conical mass surrounded by flat-topped foothills. The highest part of the mountain is an arcuate ridge forming a rim nearly surrounding a topographic depression about 2,000 feet deep and covering 4 square miles. This depression is the site of the crater of the earliest volcano in the region. Erosion has since enlarged the crater to produce the amphitheater form, and Water Canyon Creek has cut through the east side of the rim to provide an outlet for drainage.

Mount Taylor Peak, with an altitude of 11,330 feet, a mile higher than the nearby tracks of the Atchison, Topeka & Santa Fe Railway, is the highest of a series of peaks that form the rim surrounding the amphitheater. The sides of the cone, held up by a thick series of lava flows, slope away from the peaks at angles of about 10°. These earliest lava flows are porphyritic and range from andesite to trachyte. The eruptions began with rhyolitic tuff, followed by at least one trachyte, then a series of porphyritic latites and trachytes, and finally porphyritic andesite. This, however, is only a general sequence, for there were many interruptions of it. Except on the southeast side, where

[34] Bryan, Kirk, Historic evidence on changes in the channel of the Rio Puerco, a tributary of the Rio Grande in New Mexico: Jour. Geology, vol. 36, no. 3, pp. 265–282, 1928.

[35] Hunt, C. B., Igneous geology and structure of the Mount Taylor volcanic field, New Mexico: U. S. Geol. Survey Prof. Paper (in preparation).

porphyritic lavas cap the ridges on both sides of Water Canyon and Lumber Canyon, the earliest lava flows are now confined to the flanks of the cone. This is probably in part due to erosion and removal of the early flows but also to burial of possible remnants by later flows that nearly surround the cone.

*High flows surrounding Mount Taylor.*—Extending northward from Mount Taylor and partly enclosing it on the west and east sides is a tremendous area covered by sheet basalts and andesite that rest high above the surrounding country. The northern part of this lava field is known as "Mesa Chivato." The mesa covers about 400 square miles, and its top is about 1,500 feet above the general drainage level. Studding the top of the otherwise flat lava cap are scores of conical hills, cinder cones marking the old vents that supplied the lava. Some of these cones attain a height of 600 feet above the surrounding flats, and their sides in places slope as much as 25°, though most of them have gentler slopes, as low as 10°. The cinder cones in the northern part of Mesa Chivato are clustered in groups that in plan are arranged roughly in three arcs concave to the west. Between the arcs are broad flats on which the lava flows have spread out in thin sheets. In some places flows from the cones extend as tongues onto the surrounding flats. Several examples were found of flows from different vents interfering with each other. The flows are basalt or andesite, and their maximum thickness is about 100 feet. Most of them, however, are around 65 feet thick. Interbedded with some of the older flows is pumiceous ash. These flows are later than the eruptions of the Mount Taylor volcano and at several localities lap onto the earlier porphyritic lavas composing the cone of Mount Taylor.

Lava flows occupying a similar position are present along the south side of Mount Taylor also. An easily accessible locality 6 miles northeast of Grant is especially noteworthy. The highest mesa northwest of the Forest Service road contains several vents, marked on the upper surface of the mesa by lava cones. The southernmost of these cones has been eroded to produce a natural cross section of the cone, exposing the edges of the flows on the surface and the lava congealed in the pipe that led downward to the reservoir below.

About 15 miles east of Mesa Chivato is another high lava-capped mesa, Mesa Prieta. This mesa, occupying an area of about 40 square miles, lies in a shallow syncline, and the tilted sedimentary rocks are truncated by the lava. Dutton [36] and later Johnson [37] suggested

[36] Dutton, C. E., Mount Taylor and the Zuñi Plateau, N. Mex.: U. S. Geol. Survey 6th Ann. Rept., p. 175, 1885.

[37] Johnson, D. W., Volcanic necks of the Mount Taylor region, N. Mex.: Geol. Soc. America Bull., vol. 18, p. 308, 1907.

that the lava caps on Mesa Chivato and Mesa Prieta were once connected.

*Volcanic necks in the Rio Puerco Valley.*—Within the valley separating Mesa Chivato and Mesa Prieta there are numerous volcanic necks of dense andesite or basalt, many of which stand out as prominent topographic features. The highest rise about 2,000 feet above the valley. Plate 22 shows many of these necks. The andesite forming the central core of the high necks is invariably well jointed in columns. In most of the necks this jointing is very irregular, although in general nearly vertical positions predominate. About the base of the highest necks there are generally exposed masses of breccia composed of boulders of sedimentary rock and highly scoriaceous andesite or basalt. Many of the less conspicuous necks contain no exposed central core of andesite but are composed entirely of breccia. The breccias commonly are banded, and locally thin bands of scoriaceous andesite or basalt occur along the planes of banding. At nearly every locality where breccia is associated with andesite or basalt the breccia is the older of the intrusive rocks.

The adjoining Upper Cretaceous sediments do not show the slightest indication of having been disturbed by these intrusions. Metamorphism is limited to a minimum of baking, amounting to merely an induration, and there is practically no evidence of tilting. The writer believes that the intrusions rose by a stoping process, absorbing the country rock overlying the intrusion, and that the breccias are the products of that process. This problem is discussed more fully in another paper.[38]

Another type of igneous activity in the Rio Puerco Valley has manifested itself by the intrusion of numerous basaltic dikes. Not uncommonly these dikes have a chilled basaltic border with a central portion composed of breccia. Most of the dikes are less than 2 feet thick.

*Age of the eruptions.*—No direct evidence is available concerning the age of the eruptions. Dutton[39] considered the evidence of the amount of erosion and found reasons for believing that the volcanoes were active in middle Tertiary, probably Miocene time. Indirect evidence indicates that the volcanic activity began perhaps in Miocene time but that the basalt eruptions continued, intermittently, nearly to the present time. These problems are discussed in another paper.[40]

*Recent flows in the San Jose Valley.*—South of the Mount Taylor region there are Recent flows of lava in the valley of the San Jose River. These flows are not related to the volcanism on or around

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[38] Hunt, C. B., Igneous geology and structure of the Mount Taylor volcanic field, New Mexico: U. S. Geol. Survey Prof. Paper (in preparation).

[39] Dutton, C. E., Mount Taylor and the Zuñi Plateau: U. S. Geol. Survey 6th Ann. Rept., p. 177, 1885.

[40] Hunt, C. B., op. cit.

Mount Taylor and were not closely examined by the writer. Their chief sources apparently were vents along the southeast side of the Zuni Mountains, about 12 miles south of Grant.

## STRUCTURE

### METHODS OF DETERMINING AND REPRESENTING GEOLOGIC STRUCTURE

The accompanying structure contour maps (pls. 18 and 19) were constructed by drawing contours on known stratigraphic horizons. The vertical interval between contours is 100 feet, and the datum is mean sea level. Because the surface rocks of most of the area northwest of Mount Taylor are younger than most of the rocks east of the mountain, it was advisable to use two different horizons for contouring. Northwest and south of the mountain the contours have been drawn on the top of the Dalton sandstone member; east of the mountain, on the base of the Upper Cretaceous.

For the area west of Mount Taylor altitudes were carried in from the primary control points used by Sears in the adjoining field. For the area northeast of Mount Taylor altitudes were taken from a United States Geological Survey bench mark on the north side of the road about a mile northeast of Cabezon village. For most of the eastern portion of the area altitudes were taken from United States Geological Survey bench marks along the Rio Puerco. For the area south of Mount Taylor altitudes were taken from United States Coast and Geodetic Survey bench marks along the Atchison, Topeka & Santa Fe Railway.

Control for drawing the contours was provided by about 1,750 readings of altitude, some of them directly on the horizons contoured, others on higher or lower beds at known intervals from those horizons. Most of these readings were taken in areas with the greatest variation in structure.

The indicated positions of the faults on the structure contour map are their positions at the surface, and thus probably most of them differ from the true positions at depth on the contoured horizon. Information as to the dips of the fault planes is limited to observations made at the surface. There are no mine workings to permit subsurface studies.

Where the beds dip less than 12°, altitudes taken on horizons other than the contoured horizon were corrected by subtracting or adding the appropriate stratigraphic interval. Where the dip exceeds 12° the vertical distance to the contoured horizon was obtained by dividing the stratigraphic interval by the cosine of the angle of dip.

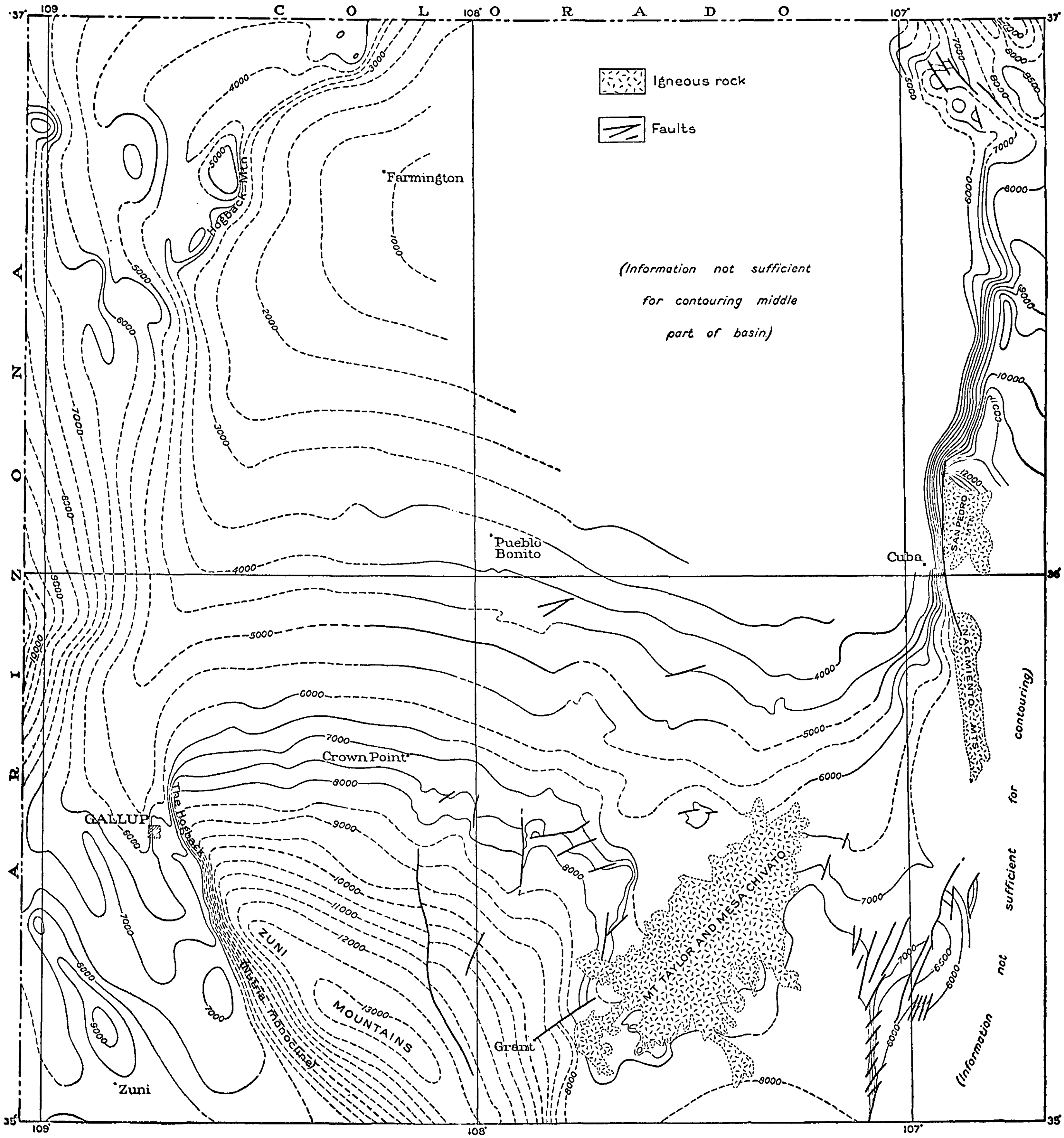
## REGIONAL STRUCTURAL SETTING OF THE FIELD

On the basis of type of structural deformation the Mount Taylor coal field can be divided into two units. The larger unit, lying west and northwest of a generally well-marked line extending from Suwanee past San Ignacio to the northeast corner of the field, lies in the San Juan Basin, a part of the Colorado Plateau. The eastern and southeastern portions of the field, east of this line, are in the Basin and Range province.

The San Juan Basin is a structural basin nearly 100 miles broad, mostly in northwestern New Mexico but partly in southwestern Colorado. The beds in the interior of the basin are little disturbed and lie nearly horizontal. On the east and north sides of the basin the beds rise gently toward the bordering mountains, and at the foot of the mountains they are turned up abruptly into steep monoclines. On the north side, against the San Juan Mountains of Colorado, the monocline has a dip of about 25° S. Along the east side, at the foot of the Nacimiento Mountains, the dips toward the interior of the basin range from about 25° in the north to vertical and even locally overturned in the south. Nearly everywhere along these flanks the monoclines are extremely sharp flexures with little or no gradual transition between the steep dips of the monoclines and the gentle dips of the interior of the basin.

The west side of the basin structurally resembles the north and east sides in that the beds are flexed into a steep monocline against the bordering mountains. However, paralleling this outer monocline is a second eastward-dipping monocline at Farmington, known as "the Hogback." Between the two monoclines is an area 30 miles wide with a prevailing gentle eastward dip. A large number of subordinate folds occur in this intervening area. Volcanism has occurred here, but, so far as is known, the local structural features bear no relation to the igneous activity. The nearly horizontal attitude of the beds in the interior of the basin continues right up to the base of the steeply dipping monocline at Farmington. The general effect of the west side of the San Juan Basin is therefore that of a double flexure, whereas the east and north sides each have but a single monocline.

The south flank of the San Juan Basin presents a marked departure from the remarkably similar structure of the other three sides. Roughly the effect is that of a broad domal uplift, the Zuni Mountains, with a northward trending syncline on the west side of the uplift and another on the east side. Plate 27 is a generalized structure contour map of the southern part of the San Juan Basin. All three of these structural features grade northward into a gentle regional northward dip. This northward dip in few places exceeds 3° and is usually less. Along the northward-trending synclines,




# MAP SHOWING STRUCTURE OF THE NEW MEXICO PORTION OF THE SAN JUAN BASIN.

Contours adjusted to the top of the Dalton sandstone member of the Mesaverde formation.

however, steep dips are common. This is especially noticeable in the westward-dipping hogback at Gallup and the eastward-dipping hogback north of San Mateo.

The age of the deformation of the San Juan Basin is problematic. The deformation of the south and east flanks, however, can be limited as later than early Eocene and earlier than late Miocene.[41]

All of southwestern New Mexico is in the Basin and Range province, which is continuous across southern Arizona and Nevada. In the southwest quarter of New Mexico the structural relations are complicated by overthrusts, folds, and intersecting sets of normal faults. Eastward, along the Rio Grande Valley, the relations are less complicated, and north-south folds and strike faults are present. Northward along the Rio Grande Valley the relations are still less complicated, and deformation is confined to a homoclinal eastward tilting and block faulting. The faults, so far as known, are all normal strike faults that in general produce a step-down to the west. The eastern part of the Mount Taylor field lies in this part of the Basin and Range province.

## STRUCTURE OF PORTION OF MOUNT TAYLOR COAL FIELD WEST OF SUWANEE AND SAN IGNACIO

The portion of the Mount Taylor coal field west of Suwanee and San Ignacio, which lies in the San Juan Basin, is structurally an area of transition, in which north-south anticlines and synclines plunge northward and die out into the gentle regional northward dip along the southern margin of the basin. The broad syncline under Mount Taylor is the most prominent of the north-south folds. Northwest of Mount Taylor there are several domes with which are associated numerous faults.

### FOLDS

*Syncline under Mount Taylor.*—Beginning near the north end of Mesa Chivato there is a broad syncline that plunges southward and gradually deepens until at the south side of Mount Taylor it is a structural trough about 1,000 feet deep. North of the Mount Taylor crater the evidence suggests that the syncline has a nearly flat bottom, with most of the depth provided by abrupt and steep monoclines on each flank. From the crater south there are much more gradual dips toward the axis of the syncline, and several minor folds make this part of the syncline very irregular. These are discussed more fully under " Minor folds " on page 59.

[41] Hunt, C. B., Tertiary structural history of parts of northwestern New Mexico [author's abstract]: Washington Acad. Sci. Jour., vol. 24, pp. 188–189, 1934.

*Miguel Creek dome.*—Almost due north of Mount Taylor, in the western part of the Ignacio Chaves grant and the northeastern part of the Felipe Tafoya grant, there is a faulted dome known as the "Miguel Creek dome" or the "San Miguel dome." It is named from San Miguel Creek, which flows through the eroded crest. The dome has a closure of 500 feet. It is roughly circular in plan but is asymmetric in that the east flank dips much more steeply than the other flanks. Irregular dips along the flanks are striking, and the contours pursue a sinuous course around the fold. The flanks of the dome are cut by a series of nearly parallel east-west faults. The faults could not be traced across the crest, nor could they be found extending far into the rocks away from the dome.

The south and east flanks of the Miguel Creek dome join the northwestern part of the syncline under Mesa Chivato, and the west flank joins the east side of a broad, shallow north-south syncline. The north flank may be considered a continuation of the regional northward dip of the southern San Juan Basin. The dip slopes on the flanks are formed by the upper sandstone of the Hosta sandstone member of the Mesaverde formation, and the lower edges of the slopes contain exposures of continental shale and sandstone of the upper part of the Gibson coal member of the Mesaverde. In the center of the dome are exposed the upper beds of a very sandy facies of the continental zone of the lower part of the Gibson coal member.

*San Mateo dome.*—The San Mateo dome, in T. 14 N., R. 8 W., was named for the town of San Mateo, 7 miles to the south. The dome has a closure of 150 feet. The north and east flanks descend steeply for a vertical distance of about 1,500 feet. The east flank is highly fractured by a complicated system of faults, which have vertical displacements as great as 300 feet. Most of these faults trend about 45° to the strike of the beds, but some of them are either parallel with or normal to the strike. The broad crest and the southwest flank of the dome are not faulted. The east flank coincides with a part of the west side of the syncline under Mount Taylor. The north flank dips into the trough of the broad, shallow syncline west of the Miguel Creek dome, and the southwest flank constitutes but a slight reversal of dip before the beds resume their gentle regional rise to the Zuni Mountains. In the center of the dome is exposed the top of the Dilco coal member of the Mesaverde formation. On the north and east sides there is a hogback composed of the Hosta sandstone member of the Mesaverde.

*Ambrosia anticline and Walker dome.*—In the eastern part of Tps. 14 and 15 N., R. 10 W., is the Ambrosia anticline, a northward-plunging anticlinal fold which rises and broadens southward until, south of the mapped area, it probably merges gradually into the regional dip on the north flank of the Zuni Mountain uplift. In the northern part of the anticline its west flank dips steeply into the north-south Ambrosia fault, which extends through the center of Tps. 14 and 15 N., R. 10 W. The beds west of the Ambrosia fault, on the upthrown side, are not affected by the anticlinal structure.

As the axis of the fold rises southward, the Mancos shale is exposed in the flat lands south of the mapped area. These flats were examined to discover possible reversal and closure in that direction, but none of appreciable magnitude was found. Locally, dips to the south provide small highs along the anticline; these reversals of dip are generally accompanied by minor faults that apparently die out into the major fold. An east-west fault supposed to close the south side of the anticline has been reported by a commercial geologist but could not be found by the writer and his party.

Considerable faulting along the northeast flank of the anticline has given rise to a series of horsts (lifted blocks) and grabens (dropped blocks). In the central part of T. 15 N., R. 10 W., a fault runs westward across the anticline into the fractured zone bordering the Ambrosia fault. To the north is a second and nearly parallel fault, which, however, dies out three-quarters of a mile east of the Ambrosia fault. These two east-west faults form a graben, with downthrow of about 300 feet, which cuts off the north end of the anticline and thus forms the Walker dome, which lies north of the graben. The west flank of the dome dips into the Ambrosia fault, and the north flank, which is broken by a second north-south fault, merges into the regional northward dip. The closure of the Walker dome is about 500 feet. In its highest part is exposed the Mulatto tongue of the Mancos shale.

*Minor folds.*—From the Walker dome a small anticlinal nose extends northward to the west-central part of T. 16 N., R. 9 W., and a second, somewhat larger anticline extends northeastward across T. 16 N., Rs. 8 and 9 W. On the western nose small local domes or highs are formed by slight reversals of dip, such as those noted in sec. 19, T. 16 N., R. 9 W., but their closure is too small to be shown by means of contours on the structure map. No reversals of dip that might cause closure were noted on the east anticlinal nose.

Just east of the center of T. 16 N., R. 10 W., there is a small dome whose closure is not more than 100 feet and is probably nearer to 50 feet. This dome seems to bear no relation to any of the major folds. On the west side it is broken by a graben, formed by faults that have the northward trend common in the region.

Along the south side of Mount Taylor there are three domes which, though they cover but small areas, have considerable structural relief. Their closure cannot be determined, however, because their north sides are partly concealed beneath the extensive lava flows that are spread out south of the peak of Mount Taylor. The dome in the NW¼ sec. 13, T. 11 N., R. 8 W., seems to have not less than 300 feet of closure and perhaps considerably more. If there are any associated faults, they must be confined to the flanks, for the crest evidently is not broken by any major fault. The second dome is in the SE¼ sec. 25, T. 11 N., R. 8 W. Here a possible closure of 900 feet is suggested by the south and west flanks, but the north and east flanks are covered. The westward-dipping flank can be seen from United States Highway 66. The most striking feature of this dome is the abruptness with which the west and south flanks flatten out into nearly horizontal rocks. Numerous minor faults are associated with this fold. Little is known of the third dome, in sec. 33, T. 11, N., R. 7 W., and its location, shape, and closure as indicated on the structure map must be considered only approximate.

Little is likewise known of the fold that lies immediately east of the Mount Taylor crater. Continental shale and sandstone, believed to be a part of the Gibson coal member of the Mesaverde formation, are exposed over a small area. Dips to the north, east, and south were observed.

Reversals of dip in the Gibson coal member in secs. 28, 29, 32, and 33, T. 12 N., R. 8 W., suggest the presence of a dome with its crest near the corner between these four sections. There are some associated faults of indeterminate amount. As the exposures are very scattered and consist only of continental beds that show no identifiable horizons, details of the dome could not be ascertained.

East of Marquez there is a broad anticlinal fold trending northward. The highest part of the anticline is in the Lagunitas grant along Santa Rosa Creek, but it probably does not have more than 150 feet of closure.

## FAULTS

There has been considerable faulting in the portion of the Mount Taylor field west of Suwanee and San Ignacio—the portion that lies in the San Juan Basin. All the faults are normal and dip about 85°. Their trends follow a definite pattern, which is so conspicuous that it suggests an intimate relationship of the faulting over the entire area. The parallelism of faults of the same set has given rise to a series of horsts and grabens. The faults are most abundant in the areas of local folding.

In general there is little brecciation along the fault planes, but there seems to be some relation between the amount of displacement and the amount of brecciation. The Ambrosia fault has a displacement of about 400 feet in sec. 27, T. 15 N., R. 10 W., bringing the Hosta and Dalton sandstone members into juxtaposition. At this locality the zone of brecciation is 6 to 8 feet in thickness. This is the thickest observed zone of breccia. In sec. 17, T. 15 N., R. 9 W., along the south fault of the east-west graben, the Hosta and Dalton sandstone members are again brought opposite one another, but owing to the thinning of the lower part of the Gibson the displacement here is only 300 feet. The zone of breccia is 4 to 6 feet wide. A comparable thickness of breccia is present along the north fault of the graben. Faults of small vertical displacement are accompanied by little or no brecciation.

A feature of the faulting that is certain to impress one visiting this part of the area for the first time is the frequency with which beds of sandstone of different age on opposite sides of faults are so perfectly matched as to give the appearance of a single continuous bed of sandstone. This is not entirely a coincidence of erosion, for the dip slopes show that at numerous localities the different sandstones are thus in contact for considerable distances, even as much as a mile.

Another notable feature of the faulting is that at many localities the down-faulted beds dip into the faults. The expected upward drag on down-faulted beds adjacent to a fault was observed at only one locality, in sec. 27, T. 15 N., R. 10 W., where a distinct basin structure was produced on a sufficient scale to show on the contour map. Elsewhere the faults either fail to disturb the strike and dip of the beds, or else the broken edges of the beds dip into the fault. No similar reversal of drag was noted on the upthrown side. Sears[42] has reported this same structural feature in the Gallup-Zuni Basin. Thus it seems to be a common feature of the structure throughout the southern part of the San Juan Basin, but it is probably more striking in the Mount Taylor field than elsewhere in the basin, because the faults here are, in general, of greater displacement than those to the west.

The amount of displacement along the faults ranges from a few inches to 750 feet. Only the largest faults are here described.

Through the central portion of Tps. 14 and 15 N., R. 10 W., a northward-trending fault can be traced for about 10 miles. This is the Ambrosia fault, which has its downthrow on the east side. The vertical displacement is 200 feet at the southern edge of the field and increases to 400 feet in the central part of T. 15 N., R. 10 W. The fault finally passes out into a fold in the southern part of T. 16 N., R. 10 W. Ten faults branch from the main Ambrosia fault; still another crosses it. Five of the branching faults are arranged en échelon, with northwest trends, a marked variance from the trends of most of the faults of the area.

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[42] Sears, J. D., Geology and coal resources of the Gallup-Zuñi Basin, N. Mex.: U. S. Geol. Survey Bull. 767, p. 23, pl. 13, 1925.

The graben south of Walker dome has been dropped a maximum of 500 feet. In sec. 16, T. 15 N., R. 9 W., the two faults of the graben join, but a single normal fault with downthrow on the south side continues toward the east.

The northwest flank of the San Mateo dome is broken by a fault trending east-northeast, which has a maximum displacement of 350 feet and downthrow on the north side. The fault cuts the hogback on the north flank of the dome and has brought together the lower sandstone of the Hosta and the Dalton sandstone member. The fault trend lacks only 10° of being parallel to the scarp of the hogback, the result being that the Hosta and Dalton members have been eroded as a single bed of sandstone capping the scarp. Eastward the fault dies out rapidly into steep dips. To the west it passes out into a gentle fold.

Three miles west of the village of San Mateo there is a north-south fault with a maximum displacement of 725 feet down on the east side. Toward the north several faults branch off to the northeast from this one, and the displacement along the main fault decreases until the fault dies out in sec. 4, T. 13 N., R. 8 W. Toward the south the fault is lost in the wooded talus slope below the lava-covered ridge southwest of San Mateo. The fault cannot be traced right up to the lava, but there is no break in the lava that might be ascribed to this fracture.

There is a fault that roughly follows the southeast talus slopes of the series of lava-capped mesas lying north and northeast of the village of Grant. The only locality where this fault could be mapped and studied is in sec. 8, T. 11 N., R. 9 W. Here it consists of a series of small faults having an aggregate displacement of 1,000 feet. Apparently the fault dies out northeastward in the steeply dipping monocline in the southeastern part of T. 12 N., R. 9 W.

### AGE OF THE FOLDS AND FAULTS

A close genetic relationship between the folds and faults is inferred, for the amount of faulting is roughly proportional to the degree of folding. Faults are not common in the parts of the field where the gentle regional northward dip prevails, but wherever folds have been produced faults are prominent.

The exact age of the structural features in that part of the field which lies west of Suwanee and San Ignacio cannot be determined, for this determination seems contingent upon knowing the age of the volcanic eruptions, which (see p. 54) can only be estimated as middle Tertiary.

The sheets of andesite and basalt that surround the porphyry cone of Mount Taylor flowed across the eroded upturned edges of the Upper Cretaceous formations along the flanks of the syncline under

Mount Taylor. The syncline, therefore, had been formed prior to these late eruptions. Some of the minor movements, however, involve the sheet eruptions and are therefore of later date. This problem of age is treated by the writer in a forthcoming paper.[43]

### STRUCTURE OF PORTION OF MOUNT TAYLOR COAL FIELD EAST OF SUWANEE AND SAN IGNACIO

The eastern part of the Mount Taylor field—east of a line connecting Suwanee and San Ignacio—is an elongate belt marked by abundant block faulting. So far as known the faults are normal, and the step-down of the major faults is to the west. Commonly the fracture surfaces of these faults dip west at low angles. The trends of the faults are remarkably parallel. Of 250 faults recorded in this part of the field, all except a bare dozen trend between N. 15° E. and N. 20° E. Striae found along fault faces are nearly vertical, indicating that there was but little horizontal motion along the faults. The strata in the faulted blocks dip east; the amount of dip, however, has considerable range. Only the major faults of this portion of the region will be described.

The Ojo Escondido fault, in the Antonio Sedillo grant, pursues a sinuous course across an area of little topographic relief. It is a normal fault, with the west block dropped. The displacement increases northward to about 3,500 feet. Locally along the fault there is a wide shatter zone, as much as 300 feet thick. The material in this zone ranges from finely crushed rock to boulders measurable in scores of feet. Where this shatter zone thins out and the fault is a single clean break the plane dips west at low angles, hading 20° to 45° from the vertical. Plate 26, *B*, shows a view along the Ojo Escondido fault.

About 2½ miles west of the Ojo Escondido fault is the Suwanee fault, which has considerable stratigraphic displacement down to the west. Where it emerges from the alluvial cover at the south the trend of the fault is N. 10° E. and the displacement is 500 feet. The field relations suggest an increase in displacement both northward and southward from this locality. A mile to the north, the fault trends N. 20° E. and the displacement increases to nearly 1,200 feet where the fault passes under cover.

East of San Ignacio there are nine nearly parallel faults, in general producing a step-down to the west. The most westerly of this group, the Ojito fault, 4 miles east of San Ignacio, has a stratigraphic displacement of 500 feet down to the west (see pl. 25), and the fault plane dips 45°–50° W. The planes of most of the other faults dip between 70° and 85°.

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[43] Hunt, C. B., Igneous geology and structure of the Mount Taylor volcanic field, New Mexico: U. S. Geol. Survey Prof. Paper (in preparation).

The San Fernando fault is traceable for only a short distance in T. 12 N., R. 1 W. It is worthy of special mention, because it is the one fault within the faulted area known to have considerable stratigraphic displacement down on the east side, except, of course, the border faults. The amount of the displacement is uncertain, although it is probably near 1,500 feet. Locally along the fault there are shatter zones 200 feet wide. Southward the fault branches into several minor faults. To the north it passes under cover.

The Garcia fault, observed only in secs. 30 and 31, T. 14 N., R. 1 E., has a minimum stratigraphic displacement of 2,200 feet down to the west. The actual amount is probably nearer 3,000 feet. The fault is poorly exposed and passes under the cover of the Santa Fe formation both to the north and to the south of this locality.

The boundary between this area of abundant faulting and the little-faulted portion of the coal field to the west is generally sharp. In the southern part of the field the boundary follows the Alamosa fault and the San Ignacio monocline, into which the fault grades toward the north. The Alamosa fault, indicated trending northward near the west border of the Antonio Sedillo grant, could not be located closely. Its general direction of trend and amount of displacement as mapped are at best approximate. A few thousand feet east of the suggested position of this fault were found outcrops of the Mulatto tongue and the Dalton sandstone member, and a few hundred feet west of the fault were found outcrops of the basal part of the Morrison formation. The displacement is, therefore, around 2,000 to 2,500 feet, with downthrow to the east. Northward the displacement decreases and the fault probably grades into the San Ignacio monocline. The monocline has 2,000 feet of structural relief and is broken by numerous faults. The rocks involved in the monocline dip about 40° E. (See pl. 23, *B*, and fig. 2.) There is but little suggestion of transition between the monocline and the fault blocks that lie east of the fold. Also there is essentially no transition between the monocline and the gently dipping beds of the country to the west—the San Juan Basin. Northward in the Lagunitas grant the San Ignacio monocline dies out into gentle folds and minor faults.

Between the San Ignacio monocline and the Reservoir fault the structure of the San Juan Basin is transitional with the fault blocks. The Reservoir fault, like the Alamosa fault provides a sharp boundary between the essentially nonfaulted, gently dipping beds of the San Juan Basin and the fault blocks. The Reservoir fault is a high-angle normal fault with a maximum displacement of 2,000 feet down to the east. Northward the fault dies out into a fold with minor faults. Southward it passes under cover.

Very few of the fault blocks have been folded. In general there is a fairly uniform east dip within any single block, but the amount of dip of different blocks is highly variable. There are few prominent exceptions to this generalization. The southern part of the fault block lying west of the Ojo Escondido fault has been folded to a syncline. The axis of this syncline trends about N. 45° E., and the syncline plunges northeastward into the fault. In the Cañada de los Álamos grant there is a syncline lying immediately east of the San Ignacio monocline. The axis of the syncline trends northward across the middle of the grant. At the northeast extremity of the Mount Taylor field there are two prominent synclines and an equally prominent anticline. All these folds plunge southward. The striking feature of these folds is that the steep dip of the flanks continues without decreasing nearly to the axis. The axis therefore

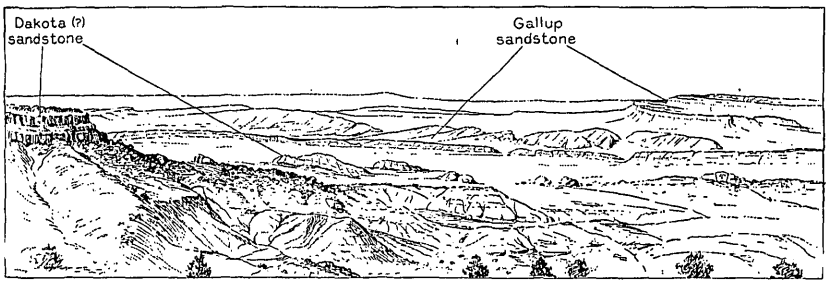


FIGURE 2.—View northeast across the San Ignacio monocline in sec. 3, T. 11 N., R. 3 W. At the left and in the immediate foreground is undisturbed Dakota (?) sandstone overlying shale and sandstone of the Morrison formation. The prominent sandstone forming the syncline in the center of the picture and the dip slope at the right is the Gallup sandstone member, which is dropped down 2,000 feet by the monocline. Hogbacks of Dakota (?) sandstone can be seen near the center and right of the picture. From photograph by R. C. Becker.

represents a zone, generally but a few feet wide, separating opposed steep dips. This portion of the area was influenced by the uplifting of the Nacimiento Mountains, and so the numerous steeply dipping folds can be considered local phenomena that would not be expected elsewhere in the area of block faulting.

The structural movements in the portion of the field east of Suwanee and San Ignacio began prior to the deposition there of the Santa Fe formation and ceased shortly after the deposition had been extended into that part of the field. The basal members of the formation are locally faulted and folded, but at these localities the Santa Fe is much less deformed than the Upper Cretaceous and the two are separated by a distinct angular unconformity. The structural movements accordingly are interpreted as beginning in the late Miocene and continuing into Pliocene time and possibly into the

Quaternary (p. 50). The details of the evidence on which this conclusion is based will be fully presented in a forthcoming paper.[44]

No direct evidence was found indicating whether or not these late movements were contemporaneous with the structural movements in the portion of the field west of Suwanee and San Ignacio.

## COAL IN THE MOUNT TAYLOR FIELD

The coal beds of the Mount Taylor field are limited to the three zones of continental rocks in the Mesaverde formation. (See pp. 47–49.)

The lowest of the three zones, the Dilco coal member, which has a maximum thickness of 150 feet, is recognizable as a continental deposit over all the southern part of the area. It is, however, of little value as a coal-bearing unit in this field. In the extreme western part of the field a bed of coal 2 feet thick (see p. 67) in this zone can be traced over approximately a section of land. Coal beds in excess of 14 inches, the minimum thickness that was mapped, were found in this zone at only four other widely separated localities west of Mount Taylor. East of the mountain this member contains no coal beds more than 14 inches thick.

The lower part of the Gibson coal member is the most abundantly coal-bearing unit in the field. Its thickness ranges from 200 to 300 feet. Everywhere in the southern part of the field there are coal beds in this zone. As previously described (p. 48 and fig. 1), this unit passes northward into marine shale and ceases to be coal-bearing. Along the east side of Mesa Chivato the lower part of the Gibson is traceable as a coal-bearing zone to a locality about 3 miles north of Marquez. Farther north the zone grades first into a sandy facies and finally into marine shale.

The upper part of the Gibson coal member includes the greatest thickness of coal-bearing rocks in this area. Only the lower part of the unit is present in this area, a thickness of about 1,000 feet. Despite the considerable thickness of these continental rocks the upper part of the Gibson coal member carries but few worth-while beds of coal. In general the coals occur near the base of this part of the member, with a thick barren zone above. Most of these coal beds occur in carbonaceous zones, some of which can be traced for considerable distances. The more persistent of these carbonaceous zones have been recorded on the map.

Owing to the extreme lenticularity of the coal beds little attempt was made to correlate beds between measured sections. In a few localities, where they were distinctly traceable or of sufficient thickness to warrant tracing, the beds were followed and mapped continuously. These have been recorded on the coal sections.

[44] Hunt, C. B., Igneous geology and structure of the Mount Taylor volcanic field, New Mexico: U. S. Geol. Survey Prof. Paper (in preparation).

No areas suitable for strip mining were found. It seems probable that any future mining in this area will be done by tunnel mines.

*T. 14 N., R. 10 W.*—Mapping in this township was confined to the northwest quarter, where beds of the lower Mesaverde crop out. The central and southern parts of the township are underlain by the marine Mancos shale and are non-coal-bearing. The Dilco coal member of the Mesaverde is the only continental zone present in this township, and no coal beds were found in it.

*T. 15 N., R. 10 W.*—This township includes two coal-bearing zones, the Dilco and the lower part of the Gibson coal member of the Mesaverde. The upper part of the Gibson coal member is absent, having been removed by erosion. Continental rocks of the Dilco coal member crop out in an irregular belt trending east across the southern tier of sections. In the western part of sec. 31 a bed of coal ranging in thickness from 14 to 26 inches can be traced about the canyon (1–3, pl. 28). At locality 3 this bed has been prospected and contains 2 feet 4 inches of coal with a 2-inch shale parting 8 inches below the top. The prospect is accessible by car from either the east or the west. The coal bed does not extend south into the adjoining township, nor can it be traced eastward. No other coal beds were found in the Dilco member in this township.

Coal beds of the lower part of the Gibson coal member occur in varying numbers and thicknesses around and under the high mesas in the west half of the township (4–32, pl. 29). These mesas are capped by the Hosta sandstone member, which ranges in thickness from 100 feet in the north to 275 feet in the south. An easily accessible and rather thick bed of good-grade coal occurs in the NW¼ sec. 9 (20–23, pl. 29). Beds high in the lower part of the Gibson coal member are also exposed across the northern tier of sections in the eastern half of the township (30–32, pl. 29) and these beds are easily accessible.

*T. 16 N., R. 10 W.*—The lower part of the Gibson coal member is the only coal-bearing zone in this township. Outcrops of coal occur in the canyon in secs. 18, 19, and 20 and along the sides of the big valley in secs. 25 and 36. Coal sections were measured at localities 33–39 (pl. 30). Coals of this zone underlie the dip slope of the Hosta sandstone member in the central part of the township. The amount of cover ranges from 50 feet in the southeastern part of the township, where only the lower part of the Hosta is present, to 300 feet in the western and northern parts, where the upper part of the Hosta is the capping rock.

*T. 17 N., R. 10 W.*—The surface rocks of this township are all of the upper part of the Gibson coal member except along the southern margin, where the upper part of the Hosta sandstone member and the underlying Satan tongue crop out. Two locally coal-bearing carbonaceous zones were mapped in this township. The lower of these zones is about 40 feet above the top of the upper part of the Hosta sandstone. Valuable coal beds of this zone were found only in the southwestern part of the township (40–42, pl. 34). There is a higher coal-bearing carbonaceous zone about 150 feet above the top of the upper part of the Hosta sandstone. Coal section 43 (pl. 34), however, records the only coal bed in excess of 14 inches found in this zone. For purposes of correlation the approximate line of outcrop of these and other locally coal-bearing carbonaceous zones of the upper part of the Gibson coal member have been recorded on the map. The reader is cautioned that these lines of correlation refer to carbonaceous zones and not to coal beds.

*T. 18 N., Rs. 9 and 10 W.; T. 17 N., Rs. 7 and 8 W.*—These townships were examined in reconnaissance, but no coal beds as much as 14 inches thick were found. Although it is possible that some of the observed thin beds may thicken to 14 inches or more, probably none of them are of any considerable lateral extent.

*T. 13 N., R. 9 W.*—The Gallup sandstone with a thin covering of Dilco beds crops out in secs. 1 and 12 of this township, but no coal beds were found. Any coal beds that might be present under the thin cover in these sections would be so altered from weathering that they would be valueless. The marine Mancos shale crops out in the rest of the township.

*T. 14 N., R. 9 W.*—The Dilco coal member and the lower part of the Gibson coal member comprise the coal-bearing zones of this township. The Dilco member crops out in a northwest-southeast belt across the central part of the township, and the outcrop of the lower part of the Gibson coal member parallels this 1 mile to the northeast. The coal in the Dilco member is of little value, however, and only two local coal beds of minable thickness were found (44, 45, pl. 28). Rather thick soil cover in this zone may conceal other minable coal beds. Enough of the section was exposed to warrant the generalization that any coals present in this zone are only local lenses.

The lower part of the Gibson coal member crops out as a thick unit consisting predominantly of shale that underlies the high mesas in the northeast quarter of the township. These mesas are capped by the Hosta sandstone member, which has a gross thickness of about 275 feet along the southwest front of the mesas. The thickness of the sandstone above the lower part of the Gibson decreases to about 100 feet in the northeastern part of the township, where only the lower part of the Hosta sandstone is present. The coal beds of the lower part of the Gibson coal member in this township are very difficult of access. Their thicknesses are indicated in coal sections 46–54 (pl. 30).

*T. 15 N., R. 9 W.*—This township includes all three of the coal-bearing continental zones of the Mesaverde formation—the Dilco member, the lower part of the Gibson member, and the upper part of the Gibson member. The Dilco member crops out only in the extreme southwest corner of the township, and but one small lens of coal was found there (55, pl. 28).

Exposures of the lower part of the Gibson coal member are abundant, and coals of this zone underlie much of the township, especially the east half. This part of the township is a dip slope formed by the Hosta sandstone member. The thickness of this member above the coal member ranges from 250 feet in the southern part of the township to 75 feet in the central part and increases again to 300 feet in the northern and eastern parts. Outliers of the lower part of the Gibson coal member are capped by the partly eroded Hosta sandstone member in the western part of the township. The coals of the lower part of the Gibson coal member are represented by coal sections 56–97 (pl. 31). A thick and persistent coal bed, recorded in coal sections 68–83, is traceable almost continuously on both sides of the eastward-draining valley in secs. 21 and 22. All portions of this valley could easily be made accessible by car. The outcrop of the coal bed, however, is in the steep shale slope and generally about 100 feet above the valley bottom.

A locally coal-bearing carbonaceous zone occurs in the lowest beds of the upper part of the Gibson coal member in secs. 1 and 12 near the east line of the township. Coal section 125 (pl. 34) was measured just across the line, in sec. 6 of the adjoining township.

*T. 16 N., R. 9 W.*—This township has only two widely separated coal localities. In the southwest corner of the township the topmost beds of the lower part of the Gibson coal member are exposed. A coal section was measured at locality 98 (pl. 32). This zone dips north and is covered by the Satan tongue and upper part of the Hosta sandstone member. In the northern part of the township the lower carbonaceous zones near the base of the upper part of the Gibson coal member are exposed, but the only coal bed found exceeding 14 inches in thickness is in sec. 6 (99, pl. 34).

*T. 17 N., R. 9 W.*—All of this township is underlain at the surface by the upper part of the Gibson coal member. Coal beds exceeding 14 inches in thickness were found in the southern part of the township in two carbonaceous zones (100–104, pl. 34). The lower of these zones is about 150 feet above the upper part of the Hosta sandstone member, and the higher zone is about 225 feet above the Hosta sandstone.

*T. 13 N., R. 8 W.*—All three of the Mesaverde continental and coal-bearing zones are represented in this township. However, coal beds were not found in either the upper part of the Gibson member or the Dilco member, although there is considerable carbonaceous material in each of these units. It is probable that local coal beds are present in each of these zones, concealed under a heavy cover. Just across the line, in the township adjoining this on the north, coal section 106 (pl. 28) was measured in the Dilco member. The lower part of the Gibson member is exposed in several fault blocks. In the graben and horst blocks in secs. 9 and 10 the top of the lower part of the Gibson is well exposed. Coal sections 105 and 111–112 (pl. 32) were measured in sec. 3. Reports of Government mineral examiners filed with the Geological Survey also record measurements of coal in both the lower and upper parts of the Gibson coal member as follows:

"In the SE¼ sec. 32 there are three coal beds, ranging in thickness from 3 to 5 feet, in the lower part of the Gibson coal member. The lower part of the Gibson coal member in the N½ sec. 9 contains a coal bed 3 feet thick. The upper part of the Gibson coal member contains two coal beds, each 1 foot 3 inches thick, in the N¼ sec. 12. This outcrop is in a steep slope below a lava-capped mesa."

All of the east half of the township is underlain by the upper part of the Gibson coal member, which is everywhere a potential coal-bearing unit, but it is mostly concealed beneath a thick cover of soil and alluvium.

*T. 14 N., R. 8 W.*—This township includes an area that is largely composed of high mesas separated by canyons, and the difficult accessibility would interfere with commercial mining of the coal beds. The southwest corner of the township includes a narrow belt of the Dilco coal member, in which was found a 14-inch bed of coal (106, pl. 28). It is probable that the top of the same zone is again exposed in secs. 11, 14, and 23, where the Dilco member is exposed in the San Mateo dome, but no coal beds were found here, and it is doubtful if any are present in the Dilco member this far to the northeast. Coal beds of the lower part of the Gibson member crop out around and underlie the high mesas of the township (107–110, 113–123, pl. 32). The thickness of the rocks above the Gibson member ranges from 250 feet in the southern portion of the township, where both the upper and lower parts of the Hosta sandstone member are present, to about 100 feet in the north where the capping rock consists only of the lower part of the Hosta sandstone. The base of the high mesas is easily accessible in the southern and eastern parts of the township, but the coals occur in various positions high in steep shale slopes.

*T. 15 N., R. 8 W.*—The upper part of the Gibson coal member covers the greater part of this township and is the only coal-bearing zone present. Three principal carbonaceous and coal-bearing zones are recognizable within the lower part of this member. In the lowest of these, which is about 80 feet above the upper part of the Hosta sandstone member, two coal sections (124, 125, pl. 34) were measured. Coal sections were measured at two localities in an intermediate zone 130 feet above the upper part of the Hosta sandstone member (126, 127, pl. 34). The third and highest zone is about 300 feet above the upper part of the Hosta sandstone member, where three coal sections (128–130, pl. 34) were measured. In general, all these coals are of low grade, dirty, and highly lenticular, so that despite the ready accessibility of the whole township and the generally thin cover under which most of the coals are found, it is doubtful if these coals could be commercially mined. The lack of good exposures introduces some uncertainty, however, and fair coal beds may be present.

*T. 16 N., R. 8 W.*—This township lies on the west flank of the broad, shallow syncline west of the Miguel Creek dome. The western tier of sections consist mostly of a dip slope of the upper part of the Hosta sandstone member. To the east successively younger carbonaceous zones of the upper part of the Gibson coal member crop out, three of which were traced across this township. Two of these contain coal beds exceeding 14 inches in thickness, as shown in plate 34, sections 131–133.

*Bartolomé Fernández grant.*—The central and eastern portions of this grant are covered with talus, terrace gravel, and alluvium that conceal the underlying beds of the upper part of the Gibson coal member. A large ridge, about 600 feet high, occupying the southwestern and southern parts of the township, is partly capped with lava. The upper part of the Gibson coal member underlies the lava but is mostly concealed by the heavy talus in the steep slopes. A single coal exposure was found amid this talus (135, pl. 34). In the northwestern part of the grant, however, the upper part of the Gibson coal member is well exposed, but very few coal beds can be found (136, 137, pl. 34). A narrow belt of the lower part of the Gibson coal member is exposed in the hogback in the northwestern part of the grant (134, pl. 32).

*T. 15 N., R. 7 W.*—This township is underlain by the lower beds in the upper part of the Gibson coal member. The beds are generally well exposed, lying on the west and southwest flanks of the Miguel Creek dome. There is little relief, and the whole township is easily accessible by car. Some fairly clean coal beds are exposed in the western and southern parts of this township (138–145, pl. 35). The remainder of the township is non-coal-bearing.

*T. 16 N., R. 7 W.*—Coal beds in the base of the upper part of the Gibson coal member are poorly exposed in the southeastern part of this township, along the northwest flank of the Miguel Creek dome. The coal is in lenses as much as 2 feet thick. The greater part of the township, however, is covered by the younger and non-coal-bearing beds of the upper Gibson.

*T. 15 N., R. 6 W.*—The southeastern part of this township lies on the high lava-capped Mesa Chivato. The upper part of the Gibson coal member crops out along the steep slopes below the lava and is mostly covered with thick talus. In the valley of San Miguel Creek there are good exposures of the upper part of the Gibson member on the southeast flank of the Miguel Creek dome (146–147, pl. 35). There is an abandoned prospect mine at locality 146. Both of the recorded beds are accessible, but road work would be necessary before the coal at either of these localities could be commercially mined.

*Felipe Tafoya grant.*—A very sandy facies of the lower part of the Gibson coal member crops out on the dome in the northeastern part of this grant (148, pl. 32). In the southwestern part of the grant coal in the upper part of the Gibson member is exposed on the southwest flank of the dome (149, pl. 35). The coals of the upper part of the Gibson member are easily accessible. The coals of the lower part of the Gibson member west of San Miguel Creek are also accessible, but road work across several deep arroyos would be necessary to prospect the better coal exposures east of the creek.

*Ignacio Chaves grant.*—The lower part of the Gibson coal member is exposed in the western part of this grant, in the crest of the dome where coal section 148 (pl. 32), on the adjoining Felipe Tafoya grant, was measured. Farther east the upper part of the Gibson member crops out over much of the Ignacio Chaves grant. The central portion of the grant is occupied by the north end of the high lava-capped Mesa Chivato. The upper part of the Gibson member underlies this mesa, but the outcrops around the sides of the mesa are concealed by a heavy talus. The east quarter of the grant includes only marine beds and therefore does not contain coal.

*T. 16 N., R. 6 W.*—The southwestern part of this township includes the north flank of the Miguel Creek dome. Within this portion of the dome the lower part of the Hosta sandstone member crops out just above the level of alluvium in the Miguel Creek Valley, and the very top of the lower part of the Gibson coal member is locally exposed. Only very thin coal beds are present.

The rest of this township is overlain by well-exposed shale, coal, and sandstone belonging to the upper part of the Gibson member. The coal beds are limited to a zone 100 feet thick overlying the upper part of the Hosta sandstone member. A thin coal bed was found just north of Rancho de la Punta. The carbonaceous zone in which it was found could be traced discontinuously around the north flank of the dome and correlated with the carbonaceous zone about 50 feet thick that lies about 10 feet above the upper part of the Hosta sandstone along the west flank of the dome. No coal beds exceeding 14 inches in thickness were found in the younger beds in the northern and eastern parts of this township, where the country is mostly desolate badlands trenched with deep arroyos. These badlands are the western border of a desert and badland area, roughly 12 miles square, that extends eastward into Sandoval County for 2 miles.

*T. 17 N., Rs. 5 and 6 W.*—These townships were examined in reconnaissance, and no coals exceeding 14 inches in thickness were found. Gardner [45] indicated several coal exposures north of Chico Arroyo. Two sections given by him refer to coal beds 2 feet 6 inches and 3 feet 2 inches thick. The four main valleys north of Chico Arroyo and all the more accessible portions of these townships were examined, but the coal beds mentioned by Gardner were not found.

*T. 16 N., R. 5 W.*—This township is in a broad synclinal area and is underlain by the upper part of the Gibson coal member. There is little vegetation, and numerous deep arroyos make the township difficult of access by car. Two principal coal-bearing zones are recognizable, but their exact stratigraphic position above the upper part of the Hosta sandstone member is not known. An estimate of the minimum interval places the lower zone at about 70 feet above the upper part of the Hosta, and the upper zone is 40 feet higher. This upper zone is mostly in the western part of the township. Coal beds found in this zone are recorded in sections 150–154 (pl. 35). Coal beds in the lower zone are exposed chiefly in the eastern portion of the township, and four measurements of their thickness were obtained (155–158, pl. 35). An isolated occurrence of coal beds above the upper zone is recorded in section 159 (pl. 35).

*T. 16 N., R. 4 W.*—The Mancos shale crops out in the central and eastern parts of this township. The Hosta sandstone caps the southward-facing cliffs in the northern part of the township, and the base of the upper part of the Gibson coal member is exposed on the north dip slope back of the cliffs (160, pl. 36). A gravel-covered dip slope of the upper part of the Hosta sandstone

[45] Gardner, J. H., The coal field between San Mateo and Cuba, N. Mex.: U. S. Geol. Survey Bull. 381, pp. 467, 468, pl. 22, 1910.

occupies the southwestern part of the township. Neither of the carbonaceous zones of the township adjoining on the west could be traced far into this township, and no coal beds exceeding 14 inches in thickness were found in these zones. In sec. 5, north of the Chico Arroyo, a coal bed was found (161, pl. 36), that is probably a part of the lower zone (about 70 feet above the upper part of the Hosta sandstone member) of the area to the west.

*T. 17 N., R. 4 W.*—Nearly all of this township is underlain by the upper part of the Gibson coal member, in which there are three distinct coal-bearing carbonaceous zones that can be traced across the two southern tiers of sections. The stratigraphic positions of the three zones are 10, 70, and 230 feet above the top of the Hosta sandstone member. Coal sections 162–164 (pl. 36) were measured at localities along the zone 10 feet above the upper part of the Hosta sandstone member. The thicknesses of the coal in the zone 70 feet above the Hosta sandstone are shown in sections 165–167 (pl. 36). A single measurement of coal in the zone 230 feet above the Hosta sandstone is recorded in section 168 (pl. 36).

*T. 16 N., R. 3 W.*—Most of this township is underlain by marine shale of the Mancos which is non-coal-bearing, but parts of some of the north tier of sections include areas of the upper part of the Gibson coal member, in which coal beds were found at some places (169–170, pl. 36). The upper part of the Gibson member in this township forms only a thin veneer of soft rocks on the dip slope of the upper part of the Hosta sandstone, so that nowhere within this township would there be much possibility of finding coal beds that are not affected by weathering. As these same coals crop out in the township immediately north of this at localities much more favorable for mining, it is not likely that the coal beds of this township will be mined. The village of Cabezon lies in the eastern part of this township.

*T. 17 N., R. 3 W.*—A north dip slope of the upper part of the Hosta sandstone and the upper part of the Gibson coal member crosses the southern part of this township. Coals of the lower beds of the Gibson member crop out in a nearly east-west belt across the southern tiers of sections (171–181, pl. 36). Two carbonaceous zones were traceable across the township. They are 10 and 70 feet above the Hosta sandstone member. The lower of these zones contains good coal beds at localities 171–175, and the higher one has good coal beds at localities 176–179. In the eastern range of sections two higher coal beds were found (180–181, pl. 36), but they were not traceable to the west. The northern part of this township, comprising about two-thirds of the area, is covered with the middle beds of the upper part of the Gibson coal member, and no coals were found.

*T. 17 N., R. 2 W.*—A marked change in the strike of the rocks takes place in this township. To the west the strike is a little south of west, but in this township it changes to nearly north. Three coal-bearing carbonaceous zones in the upper part of the Gibson member are recognizable at 10, 70, and 230 feet above the Hosta sandstone. The highest of these zones, however, could not be traced to the north line of the township. At localities 182–188 (pl. 37) coal beds exceeding 14 inches in thickness were found in these zones. The northwestern part of the township is covered by the higher and barren beds of the upper part of the Gibson coal member.

*Tps. 14 and 15 N., Rs. 3 and 4 W.*—These townships include outcrops of each of the coal-bearing members of the Mesaverde formation. The Dilco and the lower part of the Gibson member grade northward into marine shale within the townships, as described on pages 47–48. No coal beds were found in the Dilco, and none exceeding 14 inches were found in the lower part of the Gibson.

The upper part of the Gibson is probably present beneath the lava cap in T. 15 N., R. 4 W., but no outcrops of that part of the member were found.

*Lagunitas and Agua Salada grants.*—These grants, covering an irregular area of about three townships, lie mostly in areas of the Mancos marine shale, which is non-coal-bearing. A small area of Dakota (?) and Morrison occurs in the eastern part, but neither of these formations is coal-bearing. The greater part of the two grants lies on the east flank of a broad anticline. The Nuestra Señora de la Luz de las Lagunitas grant extends far enough west to include the crest and a small portion of the west flank of the northern part of this anticline.

*Cebolleta grant.*—The towns of Marquez, Seboyeta, Bibo, and Moquino are located in this grant. There are no through-flowing streams, although several streams have water in their headward portions in Mesa Chivato. Water Canyon, Cebolleta Canyon, and the canyon west of Marquez each carry water, but the streams dry up as soon as they emerge into the open country away from Mesa Chivato. The west half of this grant includes part of the lava-covered Mesa Chivato. In Water Canyon, in the southwestern part of the grant, the Gibson member crops out locally along the talus-covered slope below the lava. The few exposures were examined with considerable care, but no coal beds were found. However, there are probably some beds of coal concealed beneath the heavy talus, because in Lumber Canyon, a mile to the west, 2 feet of coal was found at locality 278.

The lower part of the Mesaverde formation and upper part of the Mancos shale are exposed in this grant. The areas of the Mancos are in the low country in the eastern and southeastern parts of the grant. The Mesaverde crops out mostly in the high and steep shale slopes and cliffs below the lava that caps Mesa Chivato. Both the Dilco member and the lower part of the Gibson coal member are present. The Dilco does not contain coal anywhere in this grant, but the lower part of the Gibson member contains many coal beds. Coal sections 189–196 (pl. 32) record most of the coal exposures, for nearly everywhere the lower part of the Gibson member is covered with a heavy talus.

Coal is mined in the canyon north of Seboyeta. The coal bed there is near the top of the lower part of the Gibson member, being about 64 feet below the Hosta sandstone member. A road has been built to the mine. In general, the base of the steep shale slopes is easily accessible, but the slope is generally too great to permit ready access to the coals.

*T. 11 N., Rs. 4 and 5 W.; T. 12 N., Rs. 3 and 4 W.; T. 10 N., Rs. 4 and 5 W.*—Some of these townships were mapped only in part. However, no coals were found in the Mesaverde within these townships. Also coals were not found in the Dakota (?) where it was examined, nor in other formations that are potentially coal-bearing.

*T. 12 N., R. 9 W.*—Most of the central and western sections of this township lie in an alluvial flat. The Dilco member and the lower part of the Gibson member are the only coal-bearing rocks present. They are poorly exposed and are confined to the central and southern sections of the two eastern tiers. The Dilco crops out at places along a thin northward-trending belt in the eastern part of secs. 14, 23, and 26. It dips east and underlies the more eastern sections. Coal section 197 (pl. 28) was measured in the Dilco in the NE¼ sec. 26. The lower part of the Gibson is present in the eastern part of secs. 24, 25, and 36 but is largely concealed beneath terrace gravel, alluvium, and talus. No coal was found in the few exposures present.

*T. 11 N., R. 9 W.*—Both the Dilco and Gibson members are present in this township. They underlie the lava cap on Horace Mesa and crop out at places along the thickly wooded side of the mesa. None of the exposures contain coal beds exceeding 14 inches in thickness. The Dilco is present in sec. 10 and along the west side of Horace Mesa, but only thin coals were found in it (198, pl. 28). Similar thin beds occur in the NE¼ sec. 15. The Gibson is present along the northwest side of Horace Mesa, but everywhere along this side the relations are obscured by landslides.

In the SE¼ sec. 8 and SE¼ sec. 17 there has been some prospecting in the Morrison formation for bentonite. It is reported that the pits were opened about 1910. They have all been abandoned.

*T. 10 N., R. 9 W.*—This township was mapped by reconnaissance surveys. The Dilco coal member is present under Horace Mesa in the northeastern sections of the township, but no exposures of coal beds were found. The rest of the township includes only non-coal-bearing formations.

*T. 12 N., R. 8 W.*—All of this township is underlain by coal-bearing formations, but the coal-bearing rocks are buried for the most part beneath thick lava flows. No exposures were found in the thick talus that covers the greater part of secs. 5 and 6. The southwest quarter of the township is in a valley where locally there are good exposures of the coal-bearing Gibson member. However, even in this portion of the township there is a considerable cover of gravel, alluvium, and talus that limits the extent of the outcrops. Exposures of coal beds were found in secs. 28, 29, 31, 32, and 33 (217–227, pl. 38). These exposures are 9 miles from Grant and with a little road work could be made easily accessible.

*T. 11 N., R. 8 W.*—Nearly all of this township is underlain by coal-bearing formations. Lobo Canyon, in the northwest corner of the township, and Canyon Rinconado, in the east half, contain many coal outcrops.

A carbonaceous and coal-bearing zone of the Gibson coal member crops out at many places along Lobo Canyon and its tributaries (207–216, pl. 38). Three tunnel mines are at present working the thicker beds of the zone, and in addition there are numerous prospect pits that have been abandoned. The extensive cover of talus prevents lateral tracing of the coal beds, so that correlation of individual beds is uncertain, Attempted tracing, however, indicates with some certainty that the coals are all of the same general zone in the Gibson coal member, estimated about 350 feet above the Dalton sandstone member.

A sample was collected from the Boone mine, in the NE¼ sec. 6, to determine the possible alteration of coal by the abundant volcanic activity of the immediate vicinity. The analysis indicates little or no alteration, the coal being similar to other coals in the southern San Juan Basin.

*Analysis of sample of coal from Boone mine, in the SE¼ sec. 6, T. 11 N., R. 8 W.*

[Analyst, H. M. Cooper, of the Bureau of Mines]

| | Air-dried | As received | Moisture-free | Moisture- and ash-free |
|---|---|---|---|---|
| Moisture | 11.2 | 13.5 | | |
| Volatile matter | 38.9 | 37.9 | 43.8 | 46.9 |
| Fixed carbon | 44.1 | 42.9 | 49.6 | 53.1 |
| Ash | 5.8 | 5.7 | 6.6 | |
| | 100.0 | 100.0 | 100.0 | 100.0 |
| Calorific value: | | | | |
| Calories | 6,494 | 6,333 | 7,317 | 7,833 |
| British thermal units | 11,690 | 11,400 | 13,170 | 14,100 |
| Specific gravity, 1.292. | | | | |

All the outcrops in Lobo Canyon are easily accessible by car from Grant.

Both the Dilco and Gibson members crop out in Canyon Rinconado. Coal sections 200–202 (pl. 10) were measured in the Dilco near the mouth of the canyon. No coal was found in the Dilco exposed in the dome in secs. 13 and 14. Coal sections 203–206 (pl. 38) were measured in the Gibson coal member, which is present throughout the head of the canyon. The thick coal bed shown in sections 205 and 206 and the coal beds shown in section 204 are in a carbonaceous zone that is probably the same as that in Lobo Canyon.

In the SE¼ sec. 22, along the north bank of Canyon Guadalupe (a branch of Canyon Rinconado) there is a small deposit of alum. The deposit is an encrustation covering a few square feet around a seep at the top of a shale parting in the sandstone at the base of the Mulatto tongue of the Mancos shale.

The outcrops of the thickest coal beds in Canyon Rinconado are very difficult of access. An old road leading as far as Red Farm could be reconditioned with little work, but to mine the coal it would be necessary to build a road from Red Farm to the head of the canyon, a difficult project.

*T. 10 N., R. 8 W.*—This township was mapped by reconnaissance surveys. The northwestern sections of the township lie on the lava-capped Horace Mesa, on whose slopes the Dilco member is exposed. The Dilco is also present in the N½ sec. 1. No other coal-bearing members are present in the township. Coal section 199 (pl. 28) was measured in the SW¼ sec. 4. The thickness of the rocks overlying the Dilco in Horace Mesa ranges from about 250 feet at the south to 400 feet at the north. In sec. 1 the Dilco is largely concealed by talus. The coal exposures along the east side of Horace Mesa are high on the steep, generally talus-covered shale slope below the lava cap, but possible coal in sec. 1 is easily accessible.

*T. 10 N., R. 7 W.*—The Dilco coal member crops out in secs. 3, 4, 5, and 6 of this township, but no other coal-bearing formation is present in the township. The Dilco member probably contains no coal beds exceeding 14 inches in thickness. It is very difficult of access, for it crops out high in the steep slopes of lava-capped mesas.

*T. 11 N., R. 7 W.*—Only the southern sections of this township have outcrops of sedimentary rocks; the northern sections are on the rugged lava-covered country lying immediately south and southeast of Mount Taylor Peak. Around the southern rim of the lava country the thickness of the lava ranges from 50 to 150 feet, but it probably increases considerably northward, toward the source of the flows. Below the lava there are many exposures of the Dilco coal member, and the Gibson coal member also is probably present, although no exposures of the Gibson were found. A single coal bed (277, pl. 28) in the Dilco was measured at an easily accessible locality in sec. 24.

*T. 12 N., R. 7 W.*—Mount Taylor Peak, the north slope of Mount Taylor, and the crater of the old volcano lie within this township. Mount Taylor and the north slope from the mountain are covered with volcanic rocks, pyroclastic rocks, and flows. At the east side of the crater, in sec. 27, shale, sandstone, and coal are exposed. The coal is in beds less than 6 inches in thickness, which are believed to be a part of the Gibson coal member of the Mesaverde formation. Its presence indicates the possibility that more of the member, possibly coal-bearing, is present in this part of the crater.

*Cubero grant.*—The Dilco coal member is present in a small area at the mouth of Water Canyon. Elsewhere this grant includes only non-coal-bearing formations.

*T. 10 N., R. 6 W.*—This township was not examined in detail. It appears certain, however, that there are only non-coal-bearing formations within it.

*T. 11 N., R. 6 W.*—A lava-capped ridge extends southeastward across the center of this fractional township, and beneath it is exposed the Dilco coal member, which locally crops out along each side of the ridge. Exposures are few, and no coal beds as much as 14 inches thick were found, but there may be some places beneath the abundant talus where the lenticular coal beds thicken to about 14 inches. The Dilco member is, however, difficult of access, for it is high in the steep slopes beneath the lava cap. Non-coal-bearing rocks crop out in the rest of the township.

*Antonio Sedillo grant.*—Over most of this grant the coal-bearing rocks are buried beneath the non-coal-bearing Tertiary and Recent deposits, but Upper Cretaceous rocks, some of which are coal-bearing, are exposed in the western part of the grant. Both the Dilco and Gibson coal members of the Mesaverde formation are present in these western exposures, and they probably underlie the Tertiary and younger deposits to the east. No coal beds exceeding 14 inches in thickness were found in the Dilco coal member anywhere within the grant. There are coal beds in the Gibson member. The field studies indicate that the thicker beds occur in the lower 300 feet of the member (228–233, pl. 38). Higher beds in the Gibson are exposed at numerous places, but they do not contain coal except at a few places. The only measurements in excess of 14 inches were obtained at two localities (234–235, pl. 38).

The Cretaceous rocks of the grant have been broken by numerous faults, but only the major faults are recorded on the map. Although there are innumerable other minor faults that could not be indicated on this scale of mapping, these would locally provide serious obstacles to commercial mining of the coal beds.

The grant is an area of low relief, and all parts of it could be made easily accessible with but little road work. It is crossed by the main line of the Atchison, Topeka & Santa Fe Railway, United States Highway 66, and New Mexico Highway 6.

*Tps. 9 and 10 N., R. 2 W.*—The Gibson coal member is the only coal-bearing unit exposed in these townships. Both townships contain exposures of the Gibson, and the soil cover above it is generally only a thin veneer. Beds of coal were found in only one part of T. 10 N., R. 2 W. (pl. 38, 236–238), but other coal beds may be expected in the Gibson beneath the thin cover. There is an abandoned mine at locality 238. All parts of the townships are easily accessible from New Mexico Highway 6.

*T. 9 N., R. 3 W.*—No coal-bearing formations are exposed in this township.

*T. 10 N., R. 3 W.*—There are many exposures of the Dilco member along the San Ignacio monocline in the eastern tier of sections in this township, but none of them contain coal in beds exceeding 14 inches in thickness. In the Antonio Sedillo grant the lower beds of the Gibson coal member contain minable coals (see above), and this part of the Gibson may underlie the surficial soil along the east border of this township.

*T. 11 N., R. 3 W.*—The Dilco coal member is well exposed at places along the San Ignacio monocline in the eastern part of this township, but no coal beds were found in it. No other coal-bearing units are exposed in the township.

*T. 11 N., R. 2 W.*—In this township there are locally good exposures of Upper Cretaceous rocks, but the broad intervening areas are covered with soil. The Dilco coal member is present in the northwestern sections, but no coal beds were found in it. The central and eastern sections are underlain by the Gibson coal member, and many of the exposures contain coal (239–247, pl. 33).

*Tps. 12 and 13 N., R. 2 W.*—The Dilco coal member crops out across the two southern tiers of sections in these townships, but no coal was found in it. None of the other formations in the townships contain coal.

*Tps. 9, 10, and 11 N., R. 1 W.*—Tertiary or later deposits cover practically all of these townships. They are undoubtedly underlain by the Gibson coal member, probably in part coal-bearing, although the very few exposures of Gibson that were found contain no coal.

*T. 12 N., R. 1 W.*—Coal beds in the Gibson coal member are exposed immediately east of the San Fernando fault (259, pl. 38), and this member underlies the younger and non-coal-bearing formations in the eastern part of the township. The member is also present in the northeast sections of the township, but no coal was found there.

*T. 13 N., R. 1 W.*—Continental shale and sandstone from the upper part of the Gibson coal member are exposed in fault blocks in the eastern tier of sections of this township. No coal beds were found, however. The remainder of the township includes only non-coal-bearing formations.

*Bernabé Montaño grant.*—Most of the portion of this grant lying in Sandoval County includes only non-coal-bearing formations. The Dilco coal member is present just north of the Sandoval-Bernalillo County line, but it is thin and contains no coal beds exceeding 14 inches in thickness. There is a small area of the Gibson coal member east of the Rio Puerco, and coal section 258 (pl. 33) was measured here. In the portion of the grant lying in Bernalillo County there are many outcrops of the Gibson coal member containing beds of coal (248–257, pl. 33). The coal-bearing and other Cretaceous rocks of the grant are broken by numerous faults. Minor faults, which are not recorded on the map, may make mining operations difficult.

*Tps. 14 and 15 N., R. 2 W.; T. 15 N., R. 1 W.*—There are no coal-bearing formations in these townships.

*T. 14 N., R. 1 W.*—No coal-bearing formations are exposed west of the Reservoir fault in this township, but east of the fault is a large area containing many small outcrops of the upper part of the Gibson coal member, separated by broad areas covered with a thin veneer of soil. No coal beds exceeding 14 inches in thickness were found in these exposures, but it is probable that good coal is present, for in T. 14 N., R. 1 E., there are numerous thick coal beds in the lower 300 feet of the upper part of the Gibson member.

Although many faults, as shown on the map, break the Upper Cretaceous rocks in this township, it is probable that there are many more faults that could not be located because the outcrops of the rocks are sparse and widely separated.

*T. 15 N., R. 1 E.*—Practically all of this township is covered by non-coal-bearing formations, but the upper part of the Gibson member, possibly coal-bearing, may be present at places underneath the soil cover along the south boundary of the township.

*T. 14 N., R. 1 E.*—Upper Cretaceous coal-bearing formations are exposed along the west and north tiers of sections in this township, and also in some of the adjacent sections. The rest of the township is covered with the Santa Fe formation, which contains no coal.

Many thick beds of coal are fairly well exposed in the upper part of the Gibson coal member (260–276, pl. 37). Some of the coal beds are being worked at a few mines, and they have been opened and worked at many abandoned mines and prospect pits. A reconnaissance examination showed that the southeastern sections of the township are covered by the Santa Fe formation, but it is probable that the upper part of the Gibson coal member is present beneath the Santa Fe.

## PETROLEUM POSSIBILITIES OF THE MOUNT TAYLOR FIELD

Several of the domes in the Mount Taylor coal field have been tested by drilling for petroleum, but thus far commercial production has not been attained. Altogether about 20 wells have been drilled. Most of these were on the larger domes, although a few were drilled into minor domes. Several of the wells have had showings of oil, but in such minor quantities that they seemed of little value, and most of the wells have been abandoned. The Dysart well no. 1, in sec. 21, T. 14 N., R. 9 W., and the Walker Dome Oil Co.'s well, in sec. 14, T. 15 N., R. 10 W., have been temporarily shut down. The Johnsonwood Oil Corporation's well, in sec. 12, T. 15 N., R. 10 W., is the only active well at the time of writing (winter, 1932).

### FORMATIONS MOST LIKELY TO CONTAIN OIL OR GAS

*Pennsylvanian.*—The Pennsylvanian has not been tested within this area.[45a] Its presence is a matter of some question. In the Nacimiento Mountains the Pennsylvanian is represented by the Magdalena group,[46] with a minimum thickness of 500 feet consisting mainly of limestone but including also more or less shale, limy shale, and sandstones that are locally conglomeratic. In the Sandia Mountains the group is present[47] as two formations with a gross thickness of about 1,200 feet. The lower of these two, the Sandia formation, is composed of about 400 feet of alternating beds of limestone, sandstone, and shale. Above the Sandia rests the Madera limestone, about 800 feet thick. The Sandia rests directly upon pre-Cambrian granite and gneiss. In the Zuni Mountains the Pennsylvanian beds are absent.[48] The Pennsylvanian has been found present under the Rattlesnake oil field, west of Farmington. As so little is known of the extent of the Pennsylvanian in this region, its presence or absence under this area can only be inferred and cannot be determined except by drilling.

*Morrison formation and underlying red beds.*—Only traces of oil have been encountered in sandstones of the Morrison formation and underlying red beds. This, together with the failure thus far to obtain commercial production from them elsewhere in northwestern New Mexico, does not seem to lend encouragement for production from these formations in the Mount Taylor coal field.

*Dakota (?) sandstone and sandstones in lower part of Mancos shale.*—The sandstones at or near the base of the Upper Cretaceous are valuable as petroleum reservoirs at many places in the Rocky Mountain States. Similar stratigraphic relations prevail in the Mount Taylor coal field, but to date these sandstones have yielded no more than traces of oil in this field, and generally on drilling they have been found to yield only water.

*Mesaverde formation.*—The Gallup sandstone appears most promising among the members of the Mesaverde formation as a possible reservoir for petroleum. Traces of oil have been found in the sandstone in the Miguel Creek dome, and a good showing of oil was encountered in the sandstone in the Hospah field, adjoining the northwest side of the area here described. Higher members of the Mesaverde have been in general too deeply dissected by erosion to be considered potential reservoirs in this field.

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45a See p. 80, last paragraph.

46 Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 158, 1928.

47 Ellis, R. W., Geology of the Sandia Mountains: New Mexico Univ. Bull. 4, Geol. ser. 3, pp. 21–29, 1922.

48 Darton, N. H., op. cit. (Bull. 794), figs. 31, 48, pl. 26.

## DRILLING ON FOLDS

*Miguel Creek dome.*—Three wells drilled into the Miguel Creek dome have been abandoned. In 1923 the Midwest Refining Co. drilled a well 2,154 feet deep in the western part of the Ignacio Chaves grant. Drilling was started near the base of the Satan tongue of the Mancos shale. The Gallup sandstone member of the Mesaverde, about 80 feet thick in this well, was encountered at a depth of 785 feet. Drilling was continued through the Mancos to test the sandstones in the lower part of the Mancos shale and the Dakota (?) sandstone at the base of the Upper Cretaceous. According to local newspapers a 15-barrel production of oil was obtained from what is probably sandstone no. 3 of the lower Mancos. Drilling ceased in red shale at the top of the Morrison.

In 1926 the Marland Oil Co. and Prairie Oil & Gas Co. drilled a joint test in the western part of the Ignacio Chaves grant. Drilling began at the top of the lower part of the Gibson coal member and was continued to 1,772 feet, testing the sandstones of the Mesaverde and the upper sandstones of the lower part of the Mancos shale.

In 1930 the Milholland well was drilled to 1,540 feet in the Felipe Tafoya grant. Drilling began near the base of the Satan tongue and ceased apparently in the lower part of the Mancos.

*San Mateo dome.*—In 1924 the Midwest Refining Co. drilled a well into the San Mateo dome at the southeast corner of the NE¼ sec. 15, T. 14 N., R. 8 W. Drilling began near the top of the Dilco coal member and continued for 1,320 feet, to the top of the Morrison formation. Water only was reported from the sandstone, in the lower Mancos and the underlying Dakota (?) sandstone.

*Ambrosia anticline.*—Five wells have been drilled into the Ambrosia anticline, and all but one have been abandoned or converted to water wells. In 1925 the Schleuter well was started in the NE¼NW¼NW¼ sec. 4, T. 13 N., R. 9 W. The location of this well was not found by the writer. Drilling began near the middle of the Mancos shale and went down 500 feet.

In 1926 the New Mexico Royalty Co. drilled a well at the northeast corner of sec. 30, T. 14 N., R. 9 W. Drilling began in the upper part of the Mancos shale and went down 925 feet, to the sandstones at the base of the Upper Cretaceous. The well was plugged back and is now used as a water well at the Carter ranch.

In 1927 the New Mexico Royalty Co. drilled its no. 3 well in the NW¼SE¼SE¼ sec. 20, T. 14 N., R. 9 W. This well began in the upper part of the Mancos and went down 668 feet, where it was abandoned.

In 1926 drilling was begun by S. Dysart in sec. 21, T. 14 N., R. 9 W. The well was started in the upper part of the Mancos and has gone down nearly 1,700 feet, probably into the Triassic formations.

In 1928 a well was drilled by S. Dysart in sec. 14, T. 14 N., R. 10 W. This well was started in the upper part of the Mancos shale but was abandoned after drilling 1,285 feet, probably testing nearly all the Jurassic formations.

*Walker dome.*—In 1923 the Midwest Refining Co. made the first test of the Walker dome. There is some confusion regarding the location of this and other wells drilled into this dome. Inhabitants of the region agree that the first test well is in sec. 14, T. 15 N., R. 10 W., as recorded on the map, but the well has been variously reported as located in sec. 15 and in sec. 13. Drilling was begun in the Mulatto tongue of the Mancos shale and went down 1,460 feet, to the Morrison formation. Only water was encountered in the sandstones at the base of the Upper Cretaceous.

In 1925 the Pierce well was drilled at a location given as the SE¼ sec. 14, T. 15 N., R. 10 W. The location of the well was not found by the writer. Drilling is reported to have gone down 1,100 feet.

In 1930 the Walker Dome Oil Co. began to drill a well in the NE¼ sec. 14, T. 15 N., R. 10 W. Drilling began near the base of the Mulatto tongue and went down 1,014 feet. Some oil was encountered at 993 feet in what is probably one of the three sandstones in the lower Mancos, but the well has been temporarily shut down.

In 1913 the Johnswood Oil Corporation began drilling a well at the southeast corner of sec. 12, T. 15 N., R. 10 W. This well was started after the writer's party had surveyed this portion of the field and has not been recorded on the map because of the uncertainty of the land net. Drilling has gone down 865 feet, probably to the lower part of the Mancos, and is being continued.

*Minor folds.*—In 1927 the Hogback Oil Co. drilled a well in the SE¼NW¼ sec. 12, T. 16 N., R. 10 W. Drilling began near the base of the upper part of the Gibson coal member and went down 2,350 feet, to the Dakota (?) sandstone. Water was encountered in the sandstone members of the Mesaverde, and some oil was found in the Dakota (?) sandstone, but the well was abandoned.

In 1928 the Paramount Oil Co. drilled a well in the SE¼SE¼ sec. 15, T. 16 N., R. 10 W. Drilling was begun at the top of the upper part of the Hosta sandstone and went down 1,035 feet, probably to the Gallup sandstone member, and there was abandoned.

In 1927 the Ohio Oil Co. drilled a well in the SE¼SW¼ sec. 18, T. 16 N., R. 9 W. Drilling was started near the middle of the Satan tongue of the Mancos shale and went down 1,380 feet, through the Gallup sandstone member of the Mesaverde formation.

In 1927 the Jenkins Oil Co. drilled a well in sec. 1, T. 16 N., R. 9 W. This well has not been located on the map. Drilling began near the base of the upper part of the Gibson coal member and went down 1,655 feet, probably through the Gallup sandstone member.

In 1928 the John A. José well was drilled in sec. 24, T. 15 N., R. 9 W. Drilling began near the base of the upper part of the Gibson coal member and went down about 300 feet, to the lower part of the Satan tongue.

In 1925 the McCroden well was drilled near the northwest corner of sec. 20, T. 12 N., R. 2 W. Drilling was started in the lower part of the Mancos shale, although the precise horizon within the Mancos is uncertain. The well was drilled to a depth of 500 feet, which was probably sufficient to test at least the upper two sandstones of the lower Mancos (nos. 3 and 2).

In 1925 the Leonard well was drilled at a location given as the SE¼SW¼SE¼ sec. 18, T. 12 N., R. 2 W. The location of this well was not found by the writer's party. At the location given drilling would be started at the top of sandstone no. 3 of the lower Mancos. The well was drilled to a depth of 500 feet, passing through the Dakota (?) sandstone into the Morrison formation.

*Domes south of Mount Taylor.*—The domes along the south side of Mount Taylor provide satisfactory closure to serve as petroleum reservoirs, but any prospecting of them should not be undertaken without considering the general lack of success of drilling the larger domes in the region and the difficult access to the crests of the domes.

*Anticline 4 miles east of Marquez.*—The crest of the anticline 4 miles east of Marquez exposes sandstones in the lower part of the Mancos. Since this report was prepared the Continental Oil Co. has drilled a well on the anticline and, according to reports published in the Oil and Gas Journal, encountered the top of the Pennsylvanian 4,525 feet below the Dakota (?) sandstone and drilled through 1,400 feet of Pennsylvanian rocks before reaching schist in the crystalline basement. The thick series of Pennsylvanian rocks now known under this area may yet prove a possible source of petroleum. However, the depth to the Pennsylvanian and the unconformity at its top imply that its structure probably does not agree closely with the structure of the surface rocks.

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