UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary
GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Bulletin 860

GEOLOGY AND FUEL RESOURCES

OF THE

SOUTHERN PART OF THE SAN JUAN BASIN NEW MEXICO

BY

JULIAN D. SEARS, CHARLES B. HUNT, AND CARLE H. DANE

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CONTENTS

ILLUSTRATIONS

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PART 1. THE COAL FIELD FROM GALLUP EASTWARD TOWARD MOUNT TAYLOR

WITH A MEASURED SECTION OF PRE-DAKOTA(?) ROCKS NEAR NAVAJO CHURCH

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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.

CONTENTS

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ABSTRACT

The report describes the geology and coal deposits of the southwestern part of the San Juan Basin, N.Mex. The field lies northeast of the town of Gallup, on the Atchison, Topeka & Santa Fe Railway, and is an irregular tract of about 630 square miles in central and west-central McKinley County; it includes the southeast corner of the Navajo Indian Reservation. Settlement is confined to the white families at a few trading posts and the Indian agency at Crown Point and to scattered Navajo Indians. The land forms, drainage, vegetation, and climate are those typical of the highland in the semiarid Southwest.

The investigation disclosed complicated relations of the Mancos shale and the Mesaverde formation, of Upper Cretaceous age, and a marked variation in the stratigraphic boundary between them. At the western edge of the field, as in the adjoining Gallup coal district, the Mancos consists of about 725 feet of marine shale almost wholly of Benton (lower Colorado) age. It is overlain by about 1,800 feet of chiefly estuarine and fluviatile deposits that represent the lower part of the Mesaverde formation. In ascending order the Mesaverde here consists of the Gallup sandstone member (which includes local lenses of valuable coal), the Dilco coal member, the Bartlett barren member, the Gibson coal member, and the Allison barren member. Eastward through the field the outcrops extend obliquely across the trend of old shore lines out into the ancient basin of marine deposition, and some of the beds consequently show a progressive lateral change into rocks of littoral and marine types. The Gallup sandstone member is in part replaced by marine shale of the Mancos. The upper part of the Dilco coal member is replaced by the Dalton sandstone member, and still farther east the bottom of the Dalton and the top of the remaining Dilco are replaced by the Mulatto tongue of the Mancos shale. The Bartlett barren member becomes coal-bearing and thus merges with the Gibson. The Gibson coal member is split by the thick Hosta sandstone member, which toward the east and northeast is in turn split by the Satan tongue of the Mancos shale, of upper Niobrara (upper Colorado) age.

In general the structure of the rocks is simple, showing a gentle northward dip into the San Juan Basin. At the west edge of the field the rocks dip steeply west in the north end of the prominent ridges known locally as the Hogback. In the eastern part there is a series of pronounced folds, whose crests and troughs retain the gentle basinward dip but whose limbs are steep monoclines that in places are faulted.

The coal is of subbituminous rank and of fairly good grade. The coal beds are very irregular and lenticular. Those in the Gallup and Dilco members are of comparatively little importance, reaching a thickness of 4 to 5 feet in only a few places and in general being less than 3 feet thick. The coal beds of the Gibson, especially of its lower part, are more numerous and thicker, measurements of 4 to 6 feet thick being fairly common and one bed showing a thickness of 12 feet for more than a mile. No commercial mining has been undertaken in this field, but a few small mines have been used to supply trading posts and the Indian schools at Crown Point and Tohatchi.

INTRODUCTION

SCOPE OF REPORT

The following report describes the geology and coal deposits of a field in the southwestern part of the San Juan Basin, New Mexico, northeast of the town of Gallup and north of the Atchison, Topeka & Santa Fe Railway. The field (see pl. 2) is an irregular-shaped tract of about 630 square miles in central and west-central McKinley County and includes the southeast corner of the Navajo Indian Reservation.

The San Juan Basin, a broad, shallow topographic and structural bowl, covers thousands of square miles in northwestern New Mexico and extends a short distance into Colorado. In its central part the surface is made up of a thick series of Tertiary rocks. These are underlain by progressively older formations, which, following the upward curve of the bowl, show their exposed edges all around the basin in successive, crudely circular bands.

Several of the older formations have for many years been known to include coal of varying grades and thickness in their outcropping bands surrounding the basin. One of these coal-bearing formations is the Mesaverde. Toward the south the more valuable coals of the Mesaverde are found in its lower part and have been mined extensively in the vicinity of Gallup for half a century.

In 1919–20 the writer made a detailed examination of the coal beds in the Gallup district, the results of which have been published.[1] In 1929 he resumed this examination at the old Heaton mine in T. 16 N., R. 18 W., near Gallup, and carried it through the field herein described, which extends eastward past Crown Point to the east

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

range line of Tps. 15, 16, and 17 N., R. 11 W. On the east this field adjoins the area examined by Hunt [2] in 1930.

The information thus gained concerning the coal and the general stratigraphy and structure is useful in classifying the land and in estimating its present and future value for mining coal or seeking oil and gas. In addition, many observations of considerable stratigraphic significance were made on the numerous lateral variations in the rocks and particularly on the unexpectedly great stratigraphic rise of the boundary between the Mancos and Mesaverde formations from west to east.

EARLIER INVESTIGATIONS

The stratigraphy, structure, and coal deposits of this field and the surrounding region have been discussed in varying degrees of detail by several previous writers.[3] In 1907 Gardner [4] measured a number of coal sections in the area herein discussed; he also mapped the base of the coal measures in relation to the land net, which had not been done in the previous reconnaissance work of Schrader and Shaler.

FIELD WORK

From the middle of April to the middle of July 1929 the field examination was in charge of the writer, assisted by T. A. Hendricks, A. W. Quinn, and W. S. Pike, Jr. From the middle of July until the end of the season in September, direction of the party was delegated to Mr. Hendricks, who later also gave valuable assistance in the office compilation of maps and sections.

Mapping was done on 18- by 24-inch plane tables, with the use of telescopic alidades. Most of the locations were obtained by triangulation from a network of control flags, the base line being a 24-mile line between points on Hosta Butte and Pyramid Rock that had been established and used in geodetic work half a century earlier. Stadia traverses instead of triangulation were used over

[2] Hunt, C. B., The Mount Taylor coal field: U.S. Geol. Survey Bull. 860–B (in preparation).

[3] Gilbert, G. K., U.S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 542–567, 1875. Dutton, C. E., Mount Taylor and the Zuni Plateau: U.S. Geol. Survey 6th Ann. Rept., pp. 105–198, 1885. Schrader, F. C., The Durango-Gallup coal field of Colorado and New Mexico: U.S. Geol. Survey Bull. 285, pp. 241–258, 1906. Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U.S. Geol. Survey Bull. 316, pp. 375–426, 1907. Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U.S. Geol. Survey Bull. 435, 1910. Gregory, H. E., Geology of the Navajo country—a reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geol. Survey Prof. Paper 93, 1917. Darton, N. H., Geologic structure of parts of New Mexico: U.S. Geol. Survey Bull. 726, pp. 173–275, 1922; "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U.S. Geol. Survey Bull. 794, 1928.

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

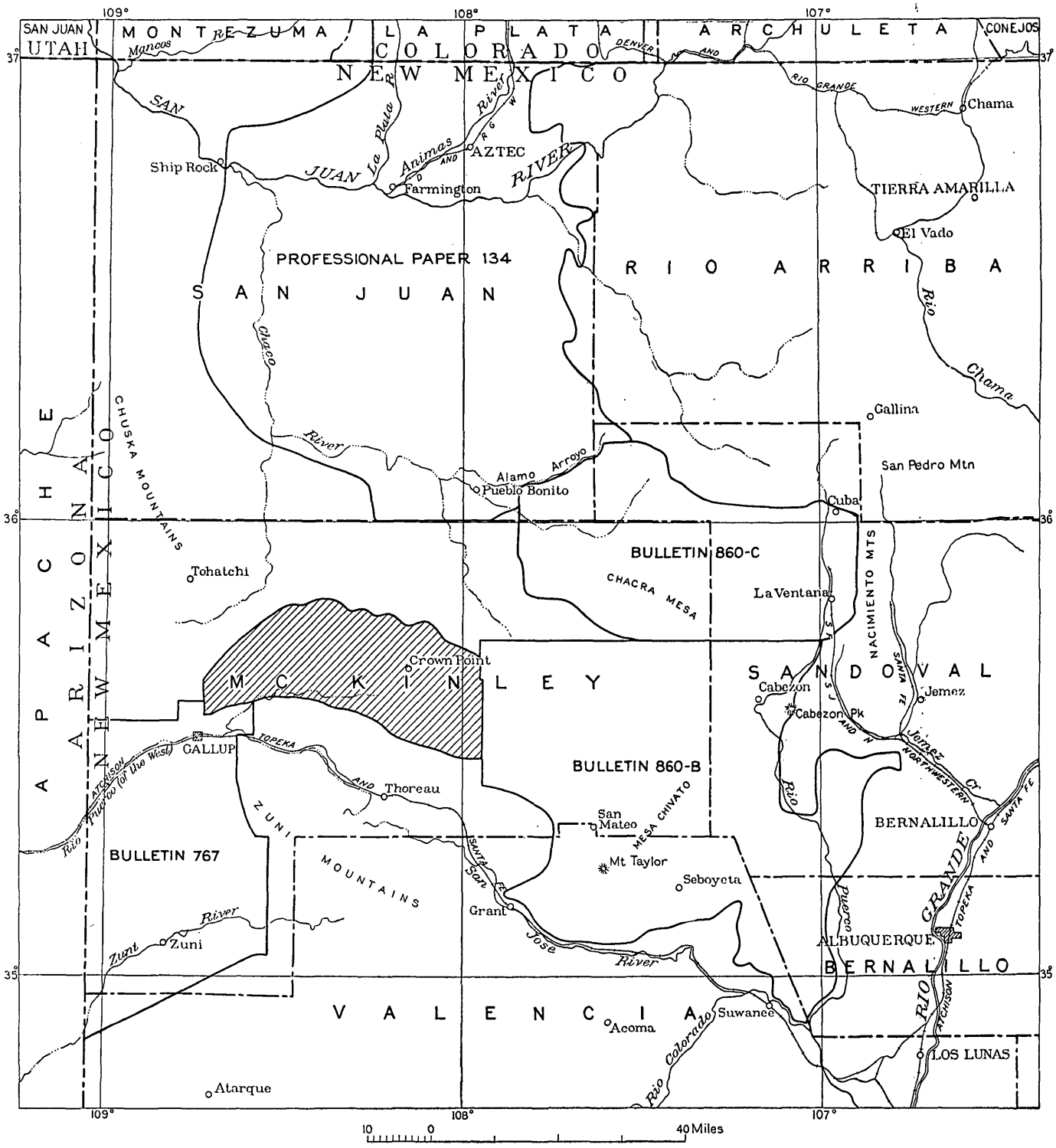
approximately a township at the west end of the area, because of the roughness of the country and the density of the timber. The geologic structure was determined by many altitudes obtained by vertical angles. In general the scale of the mapping was 1:62,500 (about 1 inch to the mile), but that scale was doubled for some of the stadia traverses.

During the course of the work search was made for all land corners, and those found and appearing reasonably reliable were carefully located with respect to the triangulation. Because of the age of the land surveys, made at a time when the task was done by contract, with untrustworthy results, authentic corners are difficult to find. The stones found and located fit well into the constructed land net, however, perhaps because some of them have been reset and remarked by later surveyors.

Significant stratigraphic units, especially the zones of coal, were traced carefully throughout the area, and numerous sections were measured through the coal zones. In general no attempt was made to trace each separate coal bed, and the coal outcrops as drawn on the map between points where sections were measured represent only approximate correlations. Very detailed work in tracing individual coal beds had been carried out in the Gallup district, for administrative reasons then existing, although the great irregularity and lenticularity of the beds made their tracing and correlation a slow and expensive task. Mapping of that detail in the area here described was neither required by the present leasing laws nor warranted by the present value of the coal. Some of the stratigraphic horizons—for example, the top or bottom of several of the sandstones—were mapped in detail, and many altitude readings were taken on them for determination of structure. Other horizons were traced but not accurately mapped; their approximate positions are, however, sketched on plate 1 to bring out certain stratigraphic relations and variations. The boundaries of the upper part of the Hosta sandstone member in T. 17 N., R. 11 W., and in the east half of T. 17 N., R. 12 W., were supplied by C. E. Dobbin, of the Geological Survey, who in 1931 examined that area.

ACKNOWLEDGMENTS

The writer wishes to express the appreciation of the party for hospitality shown to them and for information about roads, section corners, and coal prospects given by Messrs. Walker, Brown, Burnham, Westbrook, and Harvey, of trading posts in the area, and by Mr. Stacher, superintendent of the Indian agency at Crown Point.



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

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GEOGRAPHY

LAND FORMS

This is a region of sharp contrasts—of bare, lonely mesas and broad, flat valleys and plains, of bold cliffs and tortuous canyons. Everywhere the effect of erosion is conspicuous, and everywhere the shape of the surface is determined by the attitude and relative resistance of the rock beds. Throughout most of the field the rocks dip gently northward, and erosion has produced a series of inclined steps or benches. The softer beds have been worn down to valleys or to slopes, and the hard sandstone layers in general show their edges as southward-facing cliffs, with their resistant upper surfaces forming the tops of the benches and mesas.

Thus the southern margin of the area mapped is a zone of valleys and lowland worn from the soft shale (Mancos) that lies below the coal measures. Above this zone, to the north, rise several successively higher benches, each formed by one of the conspicuous sandstones in the lower part of the next younger (Mesaverde) formation.

The highest slope rises to a great sandstone cliff or rim that is perhaps the most striking topographic feature of the area. This sandstone (Hosta sandstone member) begins inconspicuously a few miles northwest of Walker's store, in the midst of an alternating series of thin sandstone, clay, and coal; from that vicinity it thickens rapidly eastward to more than 200 feet. Its southern edge forms the imposing cliff or rim that extends in a sinuous line to and far beyond the eastern limits of the area here discussed. For the most part this cliff is an impassable barrier, but at several places it is breached, notably in Satan, Mariana, and Dalton Passes.

In the central part of the field, west of Dalton Pass, the upper surface of this sandstone forms an inclined step, similar to those on the lower sandstones to the south but on a much larger scale, for the dip slope extends northward for about 6 miles before passing under a cover of still younger beds in the flat lands toward the center of the basin. East and west of this vicinity, however, the beds show other topographic expressions. To the east the dip slope of the capping sandstone has been eroded through, exposing the older beds and leaving an elongate, narrow ridge with the edge of the sandstone exposed in a cliff on the north side like that on the south. To the west a contrasting variation is found: erosion has not yet laid bare the complete dip slope of the sandstone, which is therefore still covered in part by a narrow ridge of younger beds that terminate northward in steep slopes cut by deep badland canyons.

The appearance of the several subordinate benches and the major rim, and particularly of the three topographic variations north of this rim, is pictured in the three north-south cross sections in plate 1.

Hosta Butte, capped by a remnant of the same sandstone that forms the major rim, is the highest and most conspicuous mesa within the field. Its altitude has been determined as 8,837 feet, and it is thus more than 2,000 feet higher than the lowest part of the area.

At the west end of the field the cliffs and benches swing southwestward and change into sharp ridges carved from the beds that there dip steeply to the west. These ridges form the north end of the Hogback, which, extending southward for many miles, is so conspicuous a topographic feature on the eastern margin of the Gallup-Zuni Basin.

DRAINAGE

The major east-west ridge held up by the Hosta sandstone member is the divide between the streams that flow northward into the Chaco River and those that flow southward into the Puerco and the San Jose. All the streams are intermittent, but after heavy rains their channels quickly become filled with muddy torrents. Many of the smaller valleys, as well as the larger ones, were at some time partly refilled with sandy clay; the present stream channels are deep arroyos trenched in this alluvium.

A stream that heads near Hosta Butte and flows westward in the soft shales on the southern margin of the field is the largest in the district. It turns southwestward and, to the south of this area, unites with another of similar size that flows in the valley which is followed by the railway. The combined stream breaks through the Hogback in a narrow gap and passes Gallup as the Rio Puerco, (sometimes called "Rio Puerco of the West" to distinguish it from the Rio Puerco that heads in the southeastern part of the San Juan Basin and flows into the Rio Grande). Which of the two branches east of the Hogback is the main Rio Puerco seems a matter of doubt. On the old topographic map of the Wingate quadrangle and on several other maps the name is printed too far downstream to be indicative. On the early township plats of the General Land Office and on several maps presumably based on these plats the name is applied to the northern branch. Yet several settlers in the area have told the writer that the northern branch has no name and that the southern branch, along the railway, is the Rio Puerco of local usage. This local terminology seems more logical to the writer, because the southern branch occupies a somewhat deeper and wider valley. In view of the uncertainty it seems preferable in this report to designate the northern branch the "North Fork of Rio Puerco." (See pl. 1.)

The courses of the larger streams in this field seem to be controlled largely by the structure—that is, they flow in strike valleys in

the softer beds. In secs. 15, 10, and 9, T. 16 N., R. 15 W., a curious diversion of the North Fork from its general course is worthy of note. The northward swing probably reflects an adjustment, as the valley level was lowered, to the dip slope of the sandstone exposed north of Battle Mesa. Other problems of geomorphic adjustment are suggested by the courses and relations of streams elsewhere in the field but cannot be considered in the present report.

CLIMATE AND VEGETATION

This district lies in a region of semiaridity, with rainfall averaging less than 15 inches a year. In summer the temperature generally rises high during the day, but discomfort is minimized by the dry air and by almost constant breezes; the nights, because of dryness and the high altitude, are usually cool and pleasant. In winter the nights are very cold, but the days are frequently sunny and warm, and outside work can generally be carried on with comfort.

The types of vegetation are those characteristic of such a climate. Grass, sagebrush, greasewood, Russian thistle, and several forms of cactus are common in the lowlands; juniper, piñon, and some larger pines rather thickly cover most of the sandstone ridges and benches.

SETTLEMENT AND ROADS

Settlement throughout the area is sparse and is confined almost wholly to Navajo Indians, both within and outside the reservation boundary. These Indians eke out a livelihood by raising flocks of sheep and goats, by weaving blankets and making ornaments and other articles of silver, and by a little agriculture. Their former crude hogans of sod and rough timber are gradually being replaced by more substantial houses, and some of them have substituted second-hand automobiles for their ponies and buckboards.

Except for the storekeepers and their families at half a dozen scattered trading posts, all the white people in the area are gathered at or near Crown Point. This is the site of the Eastern Navajo Indian Agency and of a boarding school attended by nearly 400 Indian children. The schoolhouse, dormitories, cottages for teachers and agency employees, shops, and stores make up a village of several dozen buildings. The post office near the agency is served six times weekly by a mail route from Thoreau.

Roughly paralleling the field, and from 3 to 10 miles distant from its southern margin, are the main line of the Atchison, Topeka & Santa Fe Railway and a transcontinental highway (U.S. Highway 66) that carries much tourist as well as local traffic. On the railway and highway are Gallup (the largest town in northwestern New Mexico, with a population of 5,992 according to the census for 1930)

and Thoreau, which form the nearest trading centers and points of entry to the field. A graded road, usually in good condition, extends from Thoreau northward about 29 miles through San Antonio and Satan Passes to Crown Point; beyond that place roads lead northward to the impressive Indian ruins at Pueblo Bonito and northeastward to the Seven Lakes oil field. Another graded road, leaving Highway 66 about 8 miles east of Gallup, crosses the cliffs and ridges of older rocks east of Navajo Church and extends to the Pinedale Indian School and Brown's store. From that point one road leads northward to Burnham's store; a second road extends eastward and then forks, one branch running northeastward through Dalton Pass to Shellenberg's store and Crown Point and the other branch running southeastward past Westbrook's and Smith's stores to the Thoreau-Crown Point road. Access to the extreme western part of the district is afforded by a road that leaves Highway 66 just east of the Hogback, passes under the railway, and extends northeastward to Walker's store. Minor roads branch from those described and lead to the scattered Indian dwellings. Thus practically all parts of the field can be reached or closely approached by automobile.

GEOLOGY

STRATIGRAPHY

As a study of the coals was the primary purpose of the survey upon which this report is based, mapping was confined to a district in which the outcropping rocks belong wholly to the lower part of the Mesaverde formation and the uppermost part of the Mancos shale, both of Upper Cretaceous age. Because the boundary between these formations and the character and thickness of members of the Mesaverde change greatly from place to place within the district, they are described in moderate detail.

The nature and thickness of the older rocks that underlie the field are discussed in a general way in the earlier reports by Gregory, Darton, and the writer listed on pages 2 and 3. As these older rocks have no bearing on the coal resources of the field, they received little additional study during the more recent survey. However, because of its stratigraphic interest, a section of the beds from the lower part of the Wingate to the lower part of the Dakota (?), measured by stadia east of Navajo Church, is presented below.

SECTION OF PRE-DAKOTA(?) ROCKS EAST OF NAVAJO CHURCH

Just north of the railway near Pyramid Rock and Navajo Church and roughly paralleling it for many miles to the southeast is a conspicuous cliff of red sandstone which Dutton [5] named the " Wingate

[5] Dutton, C. E., Mount Taylor and the Zuni Plateau: U.S. Geol. Survey 6th Ann. Rept., p. 137, 1885.

sandstone." Above this formation is a series of thick sandstones and subordinate clay and shale, of several colors. These beds rise in slopes, cliffs, and benches to the Dakota(?) sandstone that caps Pyramid Rock and the ridges to the east. The entire series between the Wingate and the Dakota(?) was named by Dutton the †"Zuni sandstones." [6]

Gregory [7] divided the series in this vicinity into three units. A thin hard sandy and limy layer at the base, which forms a bench above the cliffs of Wingate sandstone, was correlated with his Todilto formation of Todilto Park. The rest of the series he divided into Navajo sandstone below and McElmo formation above, by correlation with his Navajo sandstone of northeastern Arizona and the †McElmo of southwestern Colorado. The boundary between them, he stated, could not be determined with an error of less than 100 feet.

In his more recent papers Darton [8] followed Gregory's classification for this area and stated that the sandy †McElmo of the Pyramid Rock area can be traced eastward into beds of clay shale that contain typical †McElmo or Morrison vertebrate remains.

In a previous report the writer [9] suggested that, in view of the contrast between the predominantly clay shale of the typical †McElmo in Colorado and the conspicuous sandstones of the †McElmo of Gregory near Pyramid Rock, the latter are possibly older than the true †McElmo, which has perhaps been cut out southward from Colorado by the pre-Dakota(?) unconformity.

Still another concept has been formed by Reeside, Baker, and Dane [10] as a result of correlation studies in southeastern Utah, northeastern Arizona, and northwestern New Mexico. This concept is that the true Navajo sandstone, as found along the Utah-Arizona boundary, dies out southeastward, and that in the vicinity of Pyramid Rock all the beds between the Wingate and the Dakota(?)—in other words, all of Dutton's †Zuni sandstones—should be correlated with the Morrison.

Because of these divergent views, and for the use of future workers on this problem, a section of the beds from the lower part of the Wingate up to the lower part of the Dakota(?) was carefully meas-

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

[7] Gregory, H. E., Geology of the Navajo country: U.S. Geol. Survey Prof. Paper 93, pp. 52–68, 1917.

[8] Darton, N. H., Geologic structure of parts of New Mexico: U.S. Geol. Survey Bull. 726, pp. 173–275, 1922; "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U.S. Geol. Survey Bull. 794, 1928.

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

[10] Reeside, J. B., Jr., Baker, A. A., and Dane, C. H., personal communication.

ured east of Navajo Church, along the graded road that extends from U.S. Highway 66 northeastward to the Pinedale Indian School. This section is recorded in detail as follows:

Stratigraphic section of pre-Dakota(?) rocks east of Navajo Church, in northeast corner of T. 15 N., R. 17 W.

	Feet
Dakota(?) sandstone:	
1. Sandstone and shale. Upper part of formation eroded. At base, a yellowish-gray medium to coarse grained sandstone, poorly exposed; above this, gray shale and thin sandstones; then a sandstone capping the ridge	36+
Unconformity.	
†McElmo formation and Navajo sandstone (according to Gregory):	
2. Clay, mostly light green but purplish just at base, only slightly sandy; a soft tan sandstone, 4 or 5 feet thick, poorly exposed, about 10 feet above base	35
3. Sandstone, pink, in several ledges with intervening soft slopes; medium to coarse grained, with zones and lenses of grit and some pebbles as much as 2 inches in diameter. Near top a few included bodies of clay, rectangular in cross section (one noted as 30 feet long and 4 feet high), yellow, mauve, pink, and red, some fine-grained and some sandy	176
4. Sandstone, pink and buff, in part prominently cross-bedded (see pl. 3, *A*)	96
5. Sandstone, white, cross-bedded; 38 feet above base, a lens of maroon or chocolate-brown clay 1 to 4 feet thick (see pls. 3, *B*, and 4, *A*)	212
6. Sandstone, in layers a few inches to 4 feet thick; mostly white, but interspersed with layers of green and pinkish sandstone in lower part and of maroon clay that gives a banding of white and deep red to the upper part (see pl. 4, *B*)	43
7. Sandstone; lowest 10 feet is predominantly light red; all the rest is alternately pink and light gray in bands 4 inches to 2 feet wide; base of the unit at many places forms an overhanging projection (see pl. 5, *A*)	194
8. Sandstone; light-red 4-foot bed at top; lower part is massive and is light red except for a gray zone in its upper part (see pl. 5, *A*)	28
9. Sandstone, fairly coarse grained, somewhat cross-bedded	2
10. Interval, poorly exposed, but apparently chiefly soft medium-grained gray to pink sandstone	11
Total thickness of †McElmo formation and Navajo sandstone	797

	Feet
Todilto formation (according to Gregory):	
11. Sandstone and limestone; lower 15 inches is gray to white thin-bedded limy sandstone, which, just at its base, includes scattered colored pebbles, poorly rounded to subangular, as much as half an inch in diameter; upper part (with gradational change from the lower sandy part) is thin-bedded gray to white limestone. Contact between this formation and the underlying Wingate sandstone does not appear to be sharp (see pl. 5, *B*)----------	2
Unconformity (?).	
Wingate sandstone:	
12. Sandstone, vermilion or orange-red of slightly lighter tone than unit 14, below; large-scale tangential cross-bedding which scarcely shows in the sheer cliffs but which is conspicuous in other outcrops; fine well-rounded grains (see pl. 6, *A* and *B*)-----	236
13. Sandstone, of same type of grain as that above and below, from which it is separated by no sharp bedding lines; it is, however, of much lighter tone, which at a distance, by contrast, seems almost white (see pl. 6, *B*)----------	1
14. Sandstone, light brick-red of slightly darker and less orange tone than unit 12, above, but of same type of grain; cross-bedding much less conspicuous; between vertical joints, weathers into somewhat rounded pillowy surfaces. About 40 feet below top of unit is a light-colored zone 6 inches to 1 foot thick, of general appearance like unit 13 but somewhat coarser-grained, slightly micaceous. Base of unit not exposed in cliff (see pl. 6, *B*)----------	43+
Total thickness of Wingate sandstone------	280+

About 20 feet of basal Wingate above the Chinle formation is unexposed at this point; thus unit 14 is about 63 feet thick and the whole Wingate sandstone about 300 feet thick. Units 2 to 11 inclusive are, as already indicated, considered by Reeside, Baker, and Dane to represent the Morrison formation.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

DAKOTA (?) SANDSTONE

The rocks that have been correlated with the Dakota sandstone lie unconformably on a somewhat wavy surface of the rocks described in the foregoing section. As its outcrop is outside of the area surveyed in 1929, this sandstone was not mapped or in general studied during that survey. A section measured through the formation near the north end of the Hogback is recorded on page 13 and suffices to show the character of the formation in this region.

MANCOS SHALE

As identified by the writer,[11] the Mancos shale in the vicinity of Gallup consists mainly of dark-gray, somewhat sandy marine shale, lying conformably between the Dakota (?) sandstone below and the Mesaverde formation above. Only the upper part of the Mancos, in relation to its boundary with the Mesaverde formation, was mapped during the survey in 1929.

In the eastern part of the Gallup district the writer placed the boundary between Mancos and Mesaverde "at the bottom of the massive sandstone that forms the crest of the west ridge of the Hogback." (See pl. 7.) He recorded that at the top of the Mancos (as thus defined) there is "a transition zone of sandy shale, shaly sandstone in layers averaging 1 inch thick, and a 20-foot bed of buff 'muddy' sandstone."

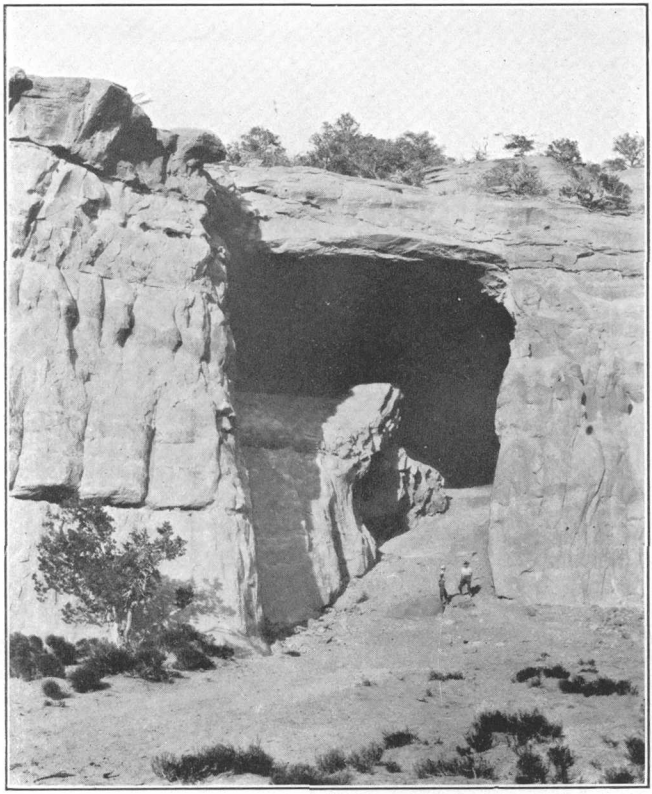
The following section measured near the north end of the Hogback shows the nature and thickness of the Mancos and Dakota (?) in that vicinity:

Section of Mancos shale and Dakota(?) sandstone near the north end of the Hogback, in sec. 1, T. 15 N., R. 18 W.

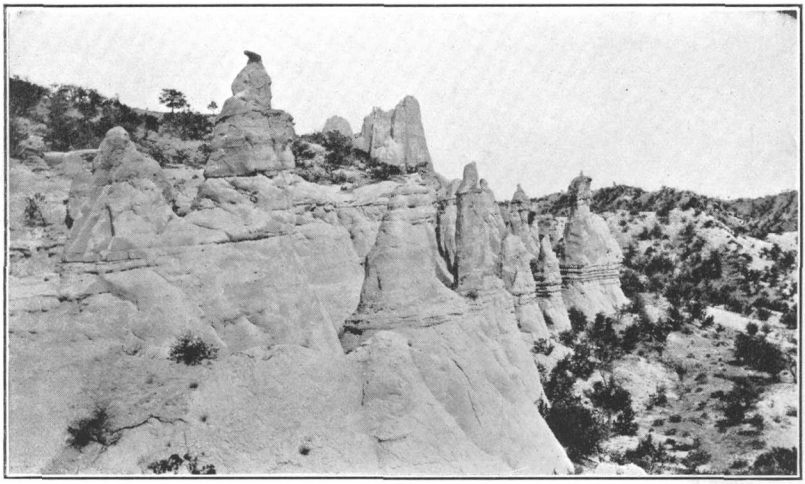
[Approximate location]

	Feet
Mesaverde formation (base of Gallup sandstone member): Sandstone, buff below, pinkish above; massive.	
Mancos shale:	
Shale, olive-gray to drab, mostly sandy	176
Sandstone, very shaly, and sandy shale	7
Shale, olive-gray to drab	67
Sandstone, gray, soft, poorly bedded	4
Shale, olive-gray to drab	16
Sandstone, gray, soft, poorly bedded	3
Shale, olive-gray to drab	157
Sandstone, very shaly; concretionary band at top	4
Shale, drab	40
Shale, bluish gray to drab	101
Sandstone, calcareous, and marl, containing many shells of *Gryphaea newberryi*	10
Shale, sandy, gray and buff	6
Sandstone, buff, massive	25
Shale, sandy in upper part, bluish gray and fissile in lower part	109
Total thickness of Mancos shale	725

[11] Sears, J. D., Geology and coal resources of the Gallup-Zuni Basin, N.Mex.: U.S. Geol. Survey Bull. 767, pp. 14–15, 1925.



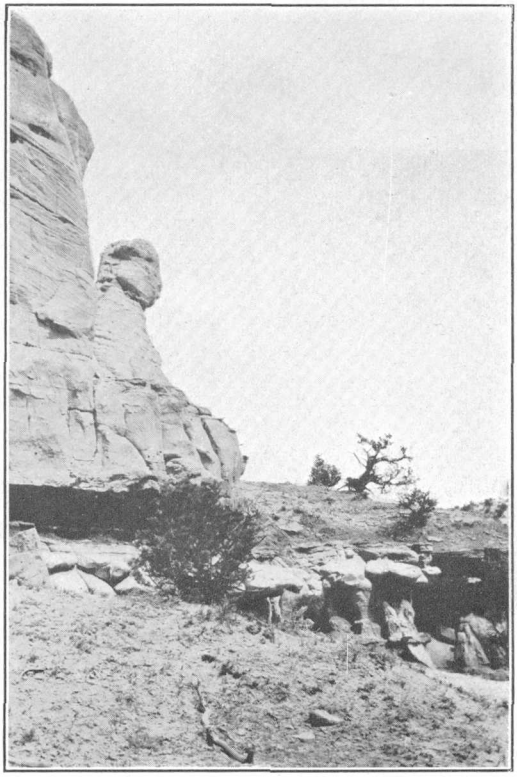
A



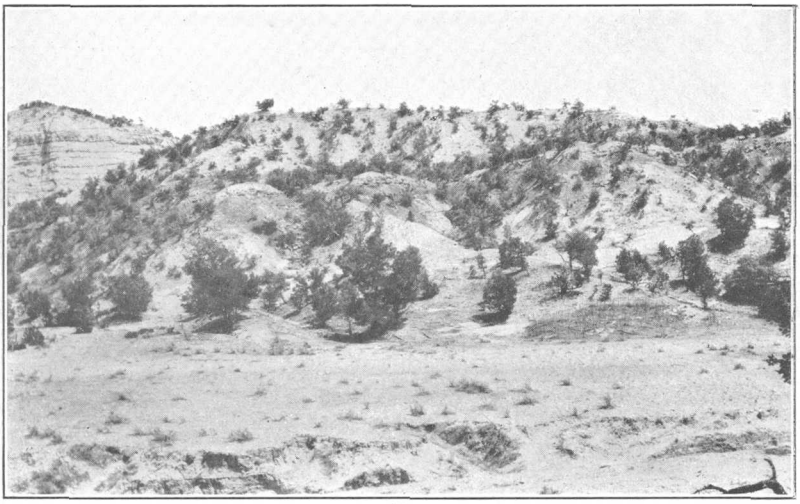
B

WIVES OF THE MEASURED SECTION OF PRE-DAKOTA(?) ROCKS NEAR NAVAJO CHURCH.

A, "Kit Carson's Cave," eroded in unit 4. *B*, Erosion forms in upper part of unit 5.



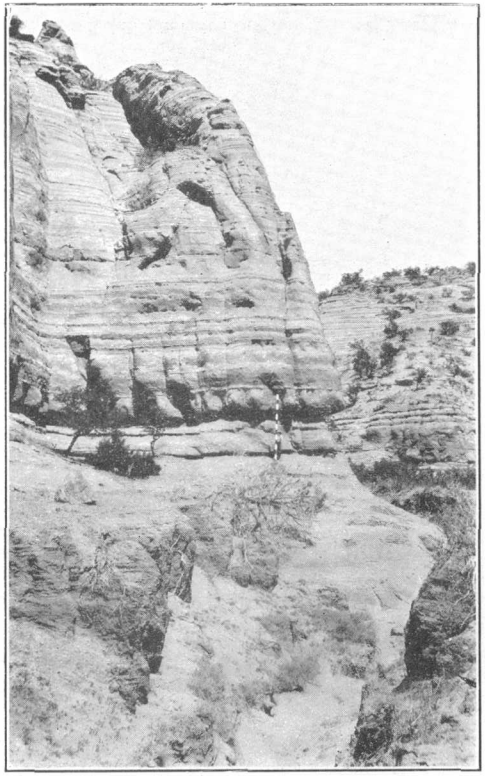
A



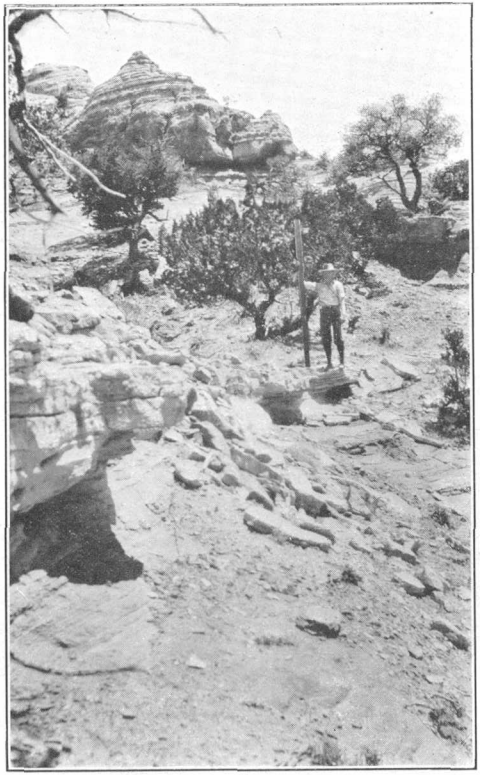
B

VIEWS OF THE MEASURED SECTION OF PRE-DAKOTA(?) ROCKS NEAR NAVAJO CHURCH.

A, Lower part of unit 5 with lens of maroon clay to left of prominent bush. *B*, Unit 6 in the rounded hills and base of unit 5 in hill in left background.



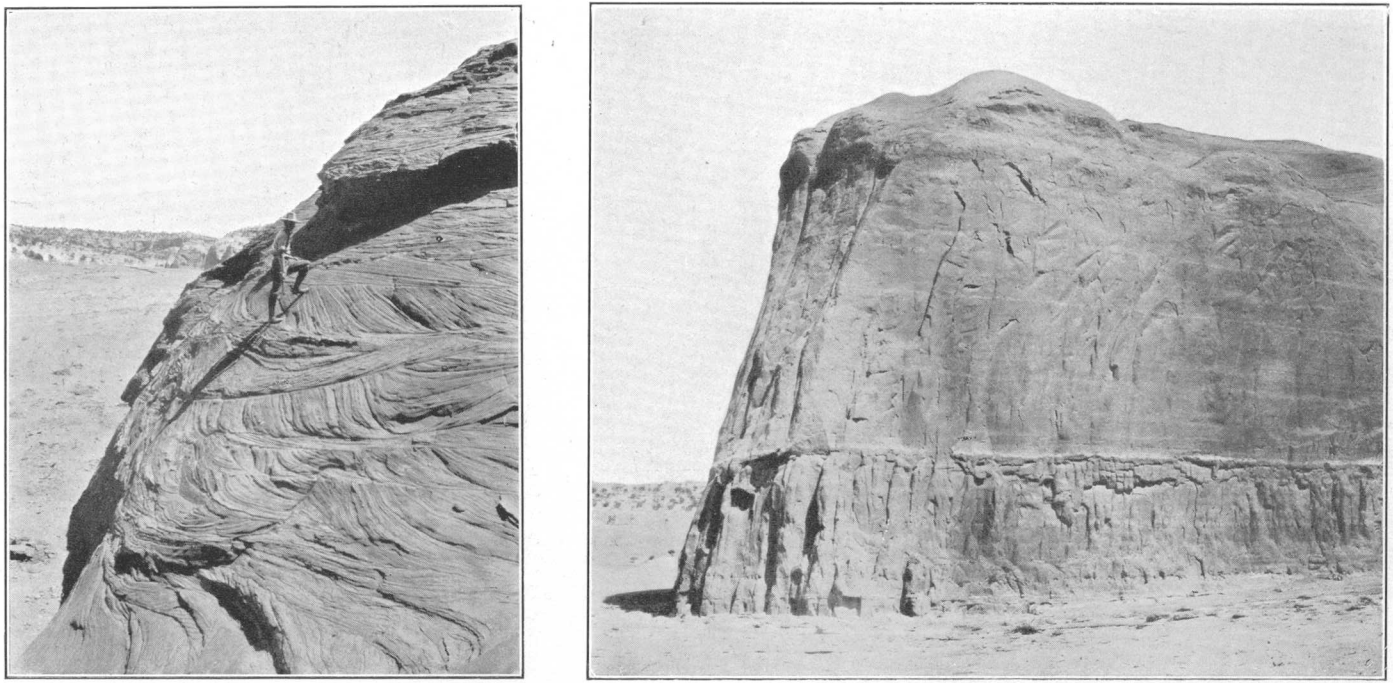
A



B

VIEWS OF THE MEASURED SECTION OF PRE-DAKOTA ROCKS(?) NEAR NAVAJO CHURCH.

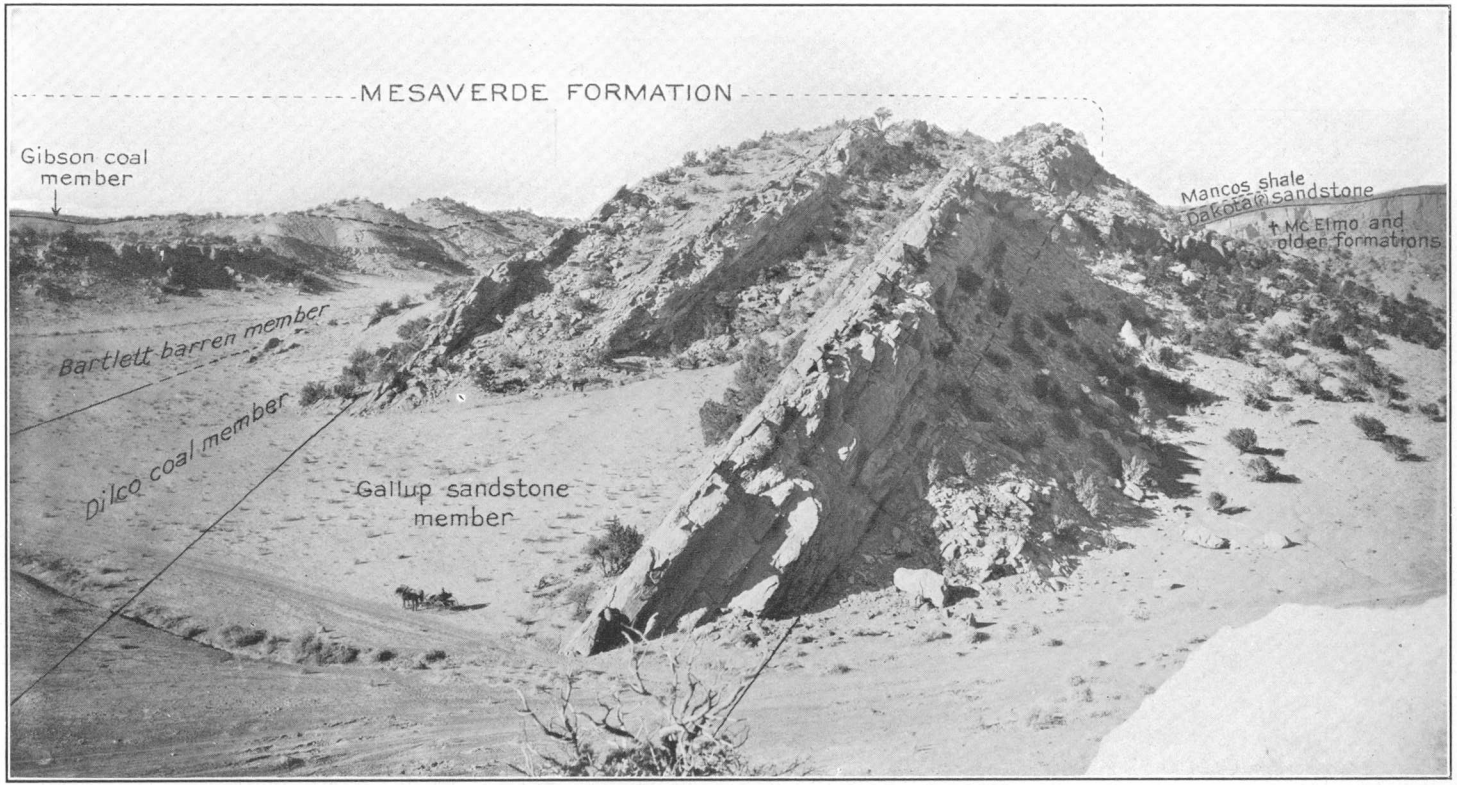
A, Lower part of unit 7 and top of unit 8, with the boundary 9 feet above base of rod. *B*, Unit 11 (Todilto formation), just beneath rod, and associated beds; unit 7 makes the conical hill in background.



A *B*

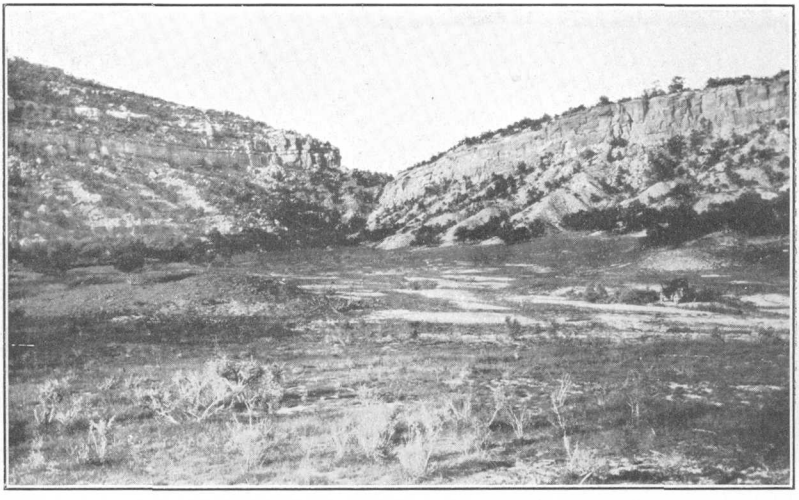
VIEWS OF THE MEASURED SECTION OF PRE-DAKOTA(?) ROCKS NEAR NAVAJO CHURCH.

A, Tangential cross-bedding in unit 12 (Wingate sandstone). *B*, Entire Wingate sandstone, units 12, 13, and 14, except for 40 feet at top and 20 feet at base.



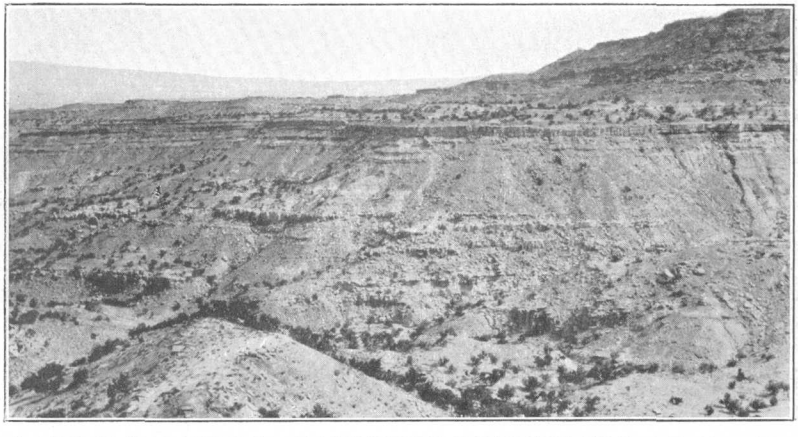
THE HOGBACK 2½ MILES NORTHEAST OF GALLUP, SHOWING LOWER MEMBERS OF THE MESAVERDE FORMATION IN THE EASTERN PART OF THE GALLUP COAL DISTRICT AS NAMED IN BULLETIN 767.

Photograph by N. H. Darton.



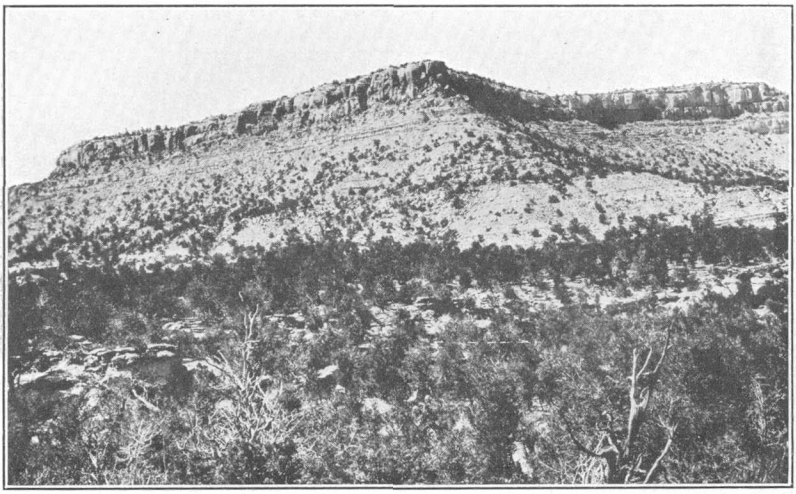
A. FAULT IN SEC. 35, T. 16 N., R. 12 W.

To right (upthrown side), Dalton sandstone member of Mesaverde formation, underlain by Mulatto tongue of Mancos shale. To left (downthrown side), Hosta sandstone member underlain by lower part of Gibson coal member of Mesaverde.



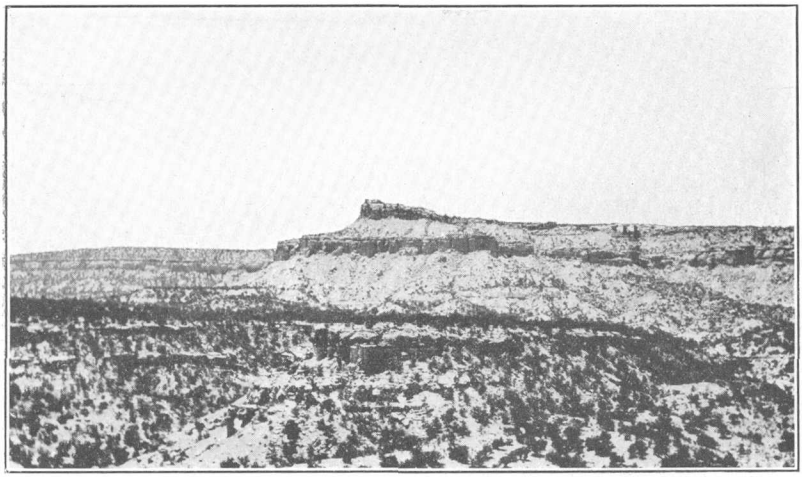
B. GIBSON COAL MEMBER OF MESAVERDE FORMATION IN T. 17 N., R. 17 W.

West of area in which it is split by the Hosta sandstone member.



A. WEST SIDE OF SOUTH END OF DALTON PASS.

Cliff at top, Hosta sandstone member; slope, lower part of Gibson coal member; tree-covered bench in foreground, Dalton sandstone member.



B. WEST SIDE OF NORTH END OF SATAN PASS, SOUTHEAST OF CROWN POINT.

Same units as in *A* except that Hosta sandstone member (upper two ledges) is split by Satan tongue of Mancos shale.

	Feet
Dakota(?) sandstone:	
Sandstone; marks sharpest lithologic change in section and is therefore taken as top of Dakota(?)	2
Shale, very sandy	3
Sandstone, very lenticular	0–8
Shale, sandy and carbonaceous	2
Sandstone, thin-bedded	3
Shale, sandy, carbonaceous	9
Sandstone, in beds 6 to 18 inches thick with thin shale partings	25
Shale, sandy, and sandstone in thin layers, interbedded	2
Sandstone, massive	6
Shale, carbonaceous	2
Sandstone, thin-bedded, irregular	5
Shale, carbonaceous, and a little poor coal	3
Sandstone	2
Shale, sandy	9
Sandstone; at places this lies directly on a wavy surface of older rocks; at places 1 to 2 feet of clay, underlain by 6 inches to 1 foot of grit, intervenes between sandstone and the contact	2–8
Total thickness (average) of Dakota(?) sandstone	82

Unconformity—wavy contact.

†McElmo formation (of Gregory's mapping).

A series of fossils was collected from the Mancos shale near Gallup during the measurement of the foregoing section. The youngest fossils found, at 590 feet above the base, are of Carlile (late Benton) age. Thus, even if the uppermost 135 feet of the shale (in which no fossils were found) is of Niobrara age, the Mancos in this vicinity represents only a part of the Colorado group, and the Mancos-Mesaverde contact here is much older than had hitherto been supposed. At its type locality in southwestern Colorado the Mancos shale represents all of Colorado time and the earlier part of Montana time; on the southeastern border of the San Juan Basin the dividing line between rocks of Colorado and Montana age lies approximately at the Mancos-Mesaverde boundary as there mapped. It is therefore evident that the Mancos-Mesaverde boundary rises stratigraphically and becomes progressively younger from Gallup northward, northeastward, and eastward. The rise eastward was proved in the field during the surveys of 1929 and 1930 by lateral tracing of beds and by the evidence of numerous fossil collections. The change is effected by large-scale intertonguing of Mancos and Mesaverde. During the deposition of the sediments the successive shore lines seem to have remained roughly parallel, with a direction of N. 50°–60° W. Thus in going eastward from Gallup the observer is proceeding obliquely seaward into the ancient basin of

marine deposition. Correspondingly, the continental and littoral beds in the lower part of the Mesaverde are found to die out eastward, being replaced by or wedged out between tongues of shale from the thicker mass of Mancos shale far to the east. (The connection between these marine shale tongues and the main body of Mancos cannot be seen in the area covered by the present report but is found in the area mapped by Hunt [12] in 1930.) The seaward rise of the Mancos-Mesaverde boundary and the relations of the tongues are indicated in the diagrammatic west-east cross section in plate 1 and, it is planned, will be discussed fully in a later report by the writer and his associates. The two principal tongues of marine shale that enter the Mesaverde are of sufficient extent to warrant distinctive names. The upper is here named the "Satan tongue of the Mancos shale" because its beginning and growth are well shown in Satan Pass. The lower is named by Hunt [13] the "Mulatto tongue of the Mancos shale" from its excellent exposures at the mouth of Canyon Mulatto, in T. 14 N., R. 9 W.

In reporting on the coal field from the Hogback eastward to San Mateo, Gardner [14] stated that the upper part of the Mancos is coal-bearing through much of the area. The writer's observations indicate that the coal beds classed by Gardner as Mancos are instead a part of the Mesaverde. This difference does not mean merely that two observers have chosen different horizons as marking the correct formation boundary, nor is it directly related to the seaward rise of the boundary which is described above. The earlier mapping seems inconsistent within itself through an error in tracing beds across the valley that extends southwestward past Walker's store and crosses T. 16 N., R. 17 W.; the coal zone in question was mapped by Gardner's party as in the Mancos east of that valley and as part of the Mesaverde west of it.

MESAVERDE FORMATION

In the Gallup district the upper part of the Mesaverde formation has been removed by erosion, leaving some 1,800 feet of the lower part. For convenience in describing them, the rocks of the lower part were divided by the writer [15] into five members. (See pl. 7.) At the base is the Gallup sandstone member, 180 to 250 feet thick, comprising three or more massive, rather persistent sandstones and interbedded clay and coal. Above this member is about 800 feet of extremely irregular and lenticular beds of gray and buff sandstone,

[12] Hunt, C. B., The Mount Taylor coal field: U.S. Geol. Survey Bull. 860–B (in preparation).

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

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

[15] Sears, J. D., Geology and coal resources of the Gallup-Zuni Basin, N.Mex.: U.S. Geol. Survey Bull. 767, pp. 16–18, 1925.

gray and drab clay, and coal. Within this body the middle portion contains in general only thin worthless coal, whereas the upper and lower portions contain a number of coal beds several feet thick. The lower unit, 240 to 300 feet thick, was called the "Dilco coal member"; the middle unit, 330 to 400 feet thick, the "Bartlett barren member"; and the upper unit, 150 to 175 feet thick, the "Gibson coal member." Above the Gibson coal member is 600 to 800 feet of alternating sandstone and clay similar to that below, but with very little coal; this unit, the top of which is eroded, was named the "Allison barren member."

These five members of the Mesaverde formation, as exposed at the northeast corner of the Gallup district near the old Heaton mine, were traced from that point northeastward and eastward during the survey of 1929. The lateral changes of these members and the coming in of other beds are shown in the diagrammatic east-west cross section on plate 1 and are described briefly in the following pages.

Gallup sandstone member.—From the north end of the Hogback eastward across T. 16 N., R. 17 W., the Gallup sandstone member is rather variable. The lower sandstone, so conspicuous in the Hogback, becomes somewhat less resistant and at places separates into two benches. The middle sandstone is much thicker and forms a striking cliff. The upper sandstone is highly irregular. In the western part of the township it locally thins to disappearance or thickens and merges with the middle sandstone to form an unbroken cliff; in general, however, it is 25 feet or more thick and is separated from the middle sandstone by 30 to 40 feet of shale and one or two coals, the lower of which reaches a thickness of 4 feet. Near the valley in sec. 11 the middle and upper sandstones draw closer together, and on the south side of the promontory in sec. 14 they form a sheer unbroken cliff, with no included shale or coal. Beneath this cliff, from the point of the promontory toward the eastern range line of the township, the lower portion of the Gallup member changes rapidly. The upper part of the lower sandstone and the basal part of the middle sandstone separate from the main beds as tongues that die out eastward within a mile. The lower part of the lower sandstone continues as a prominent bench-forming ledge, but the clay or shale above it, in the slope up to the cliff of combined middle and upper sandstones, becomes more fissile and contains calcareous concretions, being thus a typical marine shale.

Thus within the width of T. 16 N., R. 17 W., there is a striking change in the make-up of the Gallup sandstone member. From this township eastward across the field there is much less change in its appearance. The basal bench-forming sandstone gradually dies out eastward, and the tongue of shale above it merges with the main

body of Mancos shale. The main part of the Gallup member continues as a sandstone unit, which in places divides into two or three benches separated by clay and some coal that is only locally more than 14 inches thick.

Dilco coal member.—In the eastern part of the Gallup coal district the Dilco coal member contains as many as nine lenticular coal beds that reach thicknesses of 14 inches to 6 feet. However, at the northeast corner of the district, where work was begun in the survey of 1929, all but the Black Diamond and Thatcher (?) beds are thin and worthless. The Thatcher (?) bed dies out within a short distance. The Black Diamond bed continues, with a thickness of 2 to 5 feet, for about 2 miles northward along the Hogback, but farther north it is replaced by carbonaceous shale.

Immediately below the Black Diamond coal is a thick massive sandstone which, in the Gallup district, is a thin persistent bed between the Black Diamond and Otero coals. As the strata are traced northeastward through the area where the steep westerly dips of the Hogback change to the gentle northerly dips of the basin, this sandstone and others above it (which come in and replace the upper part of the Dilco coal member) form a zone about 180 feet thick in which there is little clay or shale and no coal. This sandy zone is described below as the Dalton sandstone member. The coal-bearing rocks between the Gallup and Dalton sandstone members continue eastward across the field; for them the name Dilco coal member is retained in this report, although it must be borne in mind that they represent only the lower portion of that member as defined in the Gallup district.

The coals of the Dilco member are rather thin, the greatest thickness recorded being but 3½ feet. In the western part of the field, from the Hogback nearly to Hosta Butte, the coal is generally in two beds or zones of beds, with other scattered lenses. Eastward from Hosta Butte the lower zone continues as a coal-bearing unit, but the upper zone is represented only by sandy and somewhat carbonaceous shales and thin sandstones that mark a transition to the overlying Mulatto tongue of the Mancos shale (see p. 14); in or partly replacing this transition zone in the eastern part of the field is a massive sandstone that reaches a thickness of 50 feet.

Dalton sandstone member.—As already noted, where the strata curve from the Hogback to the northward-dipping benches and slopes there is a rapid lateral replacement of the upper part of the Dilco coal member by massive sandstones. In the northern part of T. 16 N., R. 17 W., this sandstone body is about 180 feet thick, including only two thin beds of softer sandstone and sandy shale.

A few miles to the east, in sec. 5, T. 16 N., R. 16 W., the member is divided into two distinct cliff-forming sandstones, separated by 44 feet of shale. The intervening shale and about 20 feet of the shale immediately below the lower sandstone are fissile and of marine appearance; in the lower zone of shale were found a few fossils of Niobrara (Colorado) age. These zones of shale are the west end of the Mulatto tongue of Mancos shale.

At this locality the lower sandstone is 72 feet thick. It continues with little change eastward for several miles, but north of the Pinedale Indian School it becomes rapidly thinner and more shaly and wedges out in the midst of shale of the Mulatto tongue. Thus across the greater part of the field the Dilco coal member of the Mesaverde and the Mulatto tongue of the Mancos shale are in direct contact. The relations of these units are shown in the geologic map and diagrammatic cross section (pl. 1).

From T. 16 N., R. 16 W., the upper sandstone (see pl. 8, *A*) continues to the eastern border of the field, with a rather uniform thickness of about 100 feet. From its excellent exposures at Dalton Pass, where it supports the divide and forms a conspicuous bench in the canyon draining to the north, the unit is here named the "Dalton sandstone member of the Mesaverde formation." (The member includes the lower sandstone where present.)

Bartlett barren member.—In the Hogback at the west end of the field, as in the Gallup district, the Dilco and Gibson coal members are separated by several hundred feet of similar rocks in which the coal beds are very thin and worthless; these make up the Bartlett barren member. Northeastward and eastward from the Hogback, where the upper part of the Dilco is replaced by the Dalton sandstone member, the Bartlett rests upon the Dalton.

By the terms of its original definition, both the upper and lower limits of the Bartlett barren member are flexible, varying from place to place as coal beds more than 14 inches thick appear or are absent in the stratigraphic section. According to this concept the Bartlett barren member thins eastward and practically vanishes within 10 miles from the Hogback, for as thicker coals come in lower in the section the base of the Gibson member must be drawn downward to include them. In T. 16 N., R. 15 W., and to the east the Gibson may thus be considered to include all the rocks down to the Dalton sandstone member. Because of these relations between the two members, the Bartlett and Gibson are grouped with a single pattern on plate 1.

Gibson coal member.—In the Gallup district the Gibson coal member is but 150 to 175 feet thick. As the beds in the north end of the Hogback swing to the northeast, the coal-bearing zone gradually thickens to about 300 feet. (See pl. 8, *B*.) A few miles farther east

(northwest of Walker's store) there commences in the midst of the coal series a thin sandstone—the Hosta sandstone member—that thickens rapidly eastward and divides the coal member into two distinct parts.

The lower part of the Gibson may be readily traced from that vicinity to the eastern border of the field, being exposed in the slope (see pl. 9, *A*) below the prominent cliff or rim of the Hosta sandstone that is described on page 5. It is exposed also in several deep canyons carved through the sandstone in the northwestern part of the field and as bands around wide areas of still deeper erosion east and west of Crown Point. Toward the east the lower part of the Gibson thickens downward at the expense of the Bartlett barren member, and in T. 16 N., R. 15 W., and thence eastward it extends down to the Dalton sandstone member. The thickest coal beds of the field are found in the lower part of the Gibson. At several places one or two of the beds reach a thickness of 6 to 7 feet, and at the northwest end of the field a lens maintains a thickness of 12 feet for at least a mile.

The upper part of the Gibson, above the intervening Hosta sandstone, is preserved in a narrow east-west ridge about 11 miles long, north of Walker's store and the Pinedale Indian School; the east end of this outcrop may be seen where the road to Burnham's store crosses the ridge. Elsewhere the upper part of the Gibson member is eroded back toward the north, and only scattered outcrops of its coal beds were found in the low mesas that rise above the flat lands of the basin—for example, in the vicinity of Burnham's store.

Hosta sandstone member.—The sandstone that appears in the midst of the Gibson coal member northwest of Walker's store thickens rapidly to the north and east; within 10 miles northeastward it reaches a thickness of about 250 feet. To this unit the writer is here applying the name "Hosta sandstone member," because it caps the prominent Hosta Butte. It also forms the major cliff or rim (see pl. 9, *A*) and the top of the northward-sloping ridge behind it, as described on page 5.

In the southward-facing cliffs the member everywhere consists almost wholly of sandstone, with the lower part very massive and the upper part weathering into ledges. As the member is traced northward—for example, in Satan and Dalton Passes—it is found to split within a few miles into two distinct sandstone units or tongues, separated by a wedge of marine shale that forms the Satan tongue of the Mancos. (See pl. 9, *B*.) Fossils collected at several localities indicate that this shale is the uppermost of the rocks of Colorado age in this region, and that the upper sandstone tongue of the Hosta is of earliest Montana age.

The two tongues of the Hosta sandstone member and the intermediate shale may be traced in the northward-facing cliffs from Dalton Pass and Crown Point eastward through the field and into the adjoining area mapped by Hunt in 1930. In the latter area, northeast of Mount Taylor, the upper sandstone tongue of the Hosta forms the basal sandstone of the Mesaverde formation as there mapped by Hunt[16]; the lower tongue of the Hosta and all the underlying beds of the Mesaverde as developed to the west change eastward and merge into an expanded Mancos shale.

Allison barren member.—In the vicinity of Gallup the uppermost beds of the Mesaverde formation that now remain consist of 600 to 800 feet of alternating sandstone and clay with little or no coal; the unit was there named the "Allison barren member."

Within the field covered by the present report the basal beds of the Allison are exposed immediately west of the narrow zone of the Gibson coal member at the north end of the Hogback and are also preserved along the top of the narrow east-west ridge north of Walker's store and Baker's (abandoned) store. These areas of Allison outcrops are shown on plate 1.

Forming the northern edge of the field, the upper part of the Gibson coal member occupies a wide zone, but it is so poorly exposed that its contact with the Allison could not be traced; consequently, no attempt was made to show the Allison in that part of the map. The only attention given to the upper portion of the Mesaverde north of that part of the field was in several reconnaissance trips northward from Burnham's store and from Crown Point to Pueblo Bonito. The northernmost exposure of coal noted in the Gibson was in the center of T. 18 N., R. 12 W. From that point northward for many miles there is an unknown thickness of gently dipping, progressively younger beds up to the massive sandstone that forms the top of the Mesaverde at Pueblo Bonito, on the Chaco River. This whole series from the Gibson up to the top sandstone seems to have here essentially the same character as shown by its lower portion, the Allison barren member in the Gallup district. It might therefore be appropriate to extend the name Allison to include the whole series.

QUATERNARY SYSTEM

Beginning at the north end of Dalton Pass and extending northeastward for about 7 miles is a line of low, narrow, and elongate mesas, capped with gravel, which seem to be the remnants of old stream terraces. For the most part the gravel is well cemented into a rather resistant conglomerate, which reaches a thickness of 10 feet.

[16] Hunt, C. B., The Mount Taylor coal field: U.S. Geol. Survey Bull. 860–B (in preparation).

The gravel consists of more or less angular and unsorted fragments of brownish and lighter sandstone, which may have been derived from the Hosta sandstone member. Comparable gravel and conglomerate are found on other low mesas west and southwest of Burnham's store. This material is supposed to be of Pleistocene (?) age.

The valleys of the larger streams and of the lower portions of their branches have been partly filled with Recent flood-plain deposits of sandy clay, in which the streams are now rapidly cutting deep arroyos.

GEOLOGIC STRUCTURE

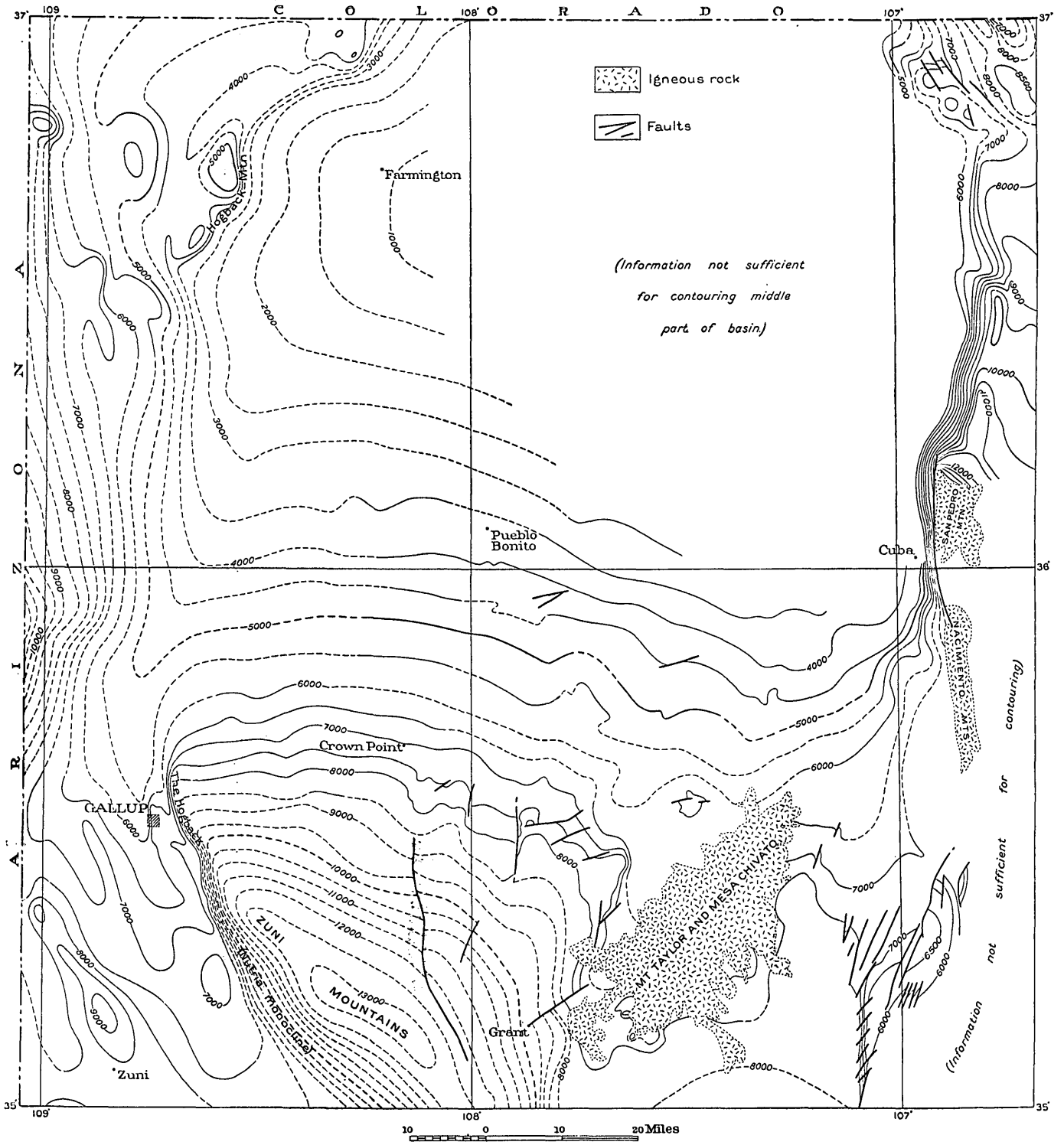
MEANING AND REPRESENTATION OF STRUCTURE

Beds of sedimentary rock, which were originally deposited in approximately horizontal position, have at many places been uplifted, tilted, folded, or broken. Their present attitude is called their geologic structure. This must not be confused with the shape of the present land surface, which has been carved out of the rock layers and cuts across them at many angles.

One method of representing structure is by the strike and dip symbol, which consists of a bar showing the strike or direction of a level line on the bed, and an arrow and figure showing the direction and amount of the dip (or variation from a horizontal position). A second method is the use of structure contours drawn on a key horizon. Such contours are lines connecting points of equal altitude on the horizon; they are far apart where the dip is gentle and are closer where the dip is steep. As the beds of a conformable series are roughly parallel, the structure of the whole series can be indicated by showing the structure of a single bed. On plate 1 the key horizon chosen is the top of the Dalton sandstone member; the contours represent the surface of that sandstone as it would appear if it were laid bare in the areas in which it is still under cover and if it were restored in the areas from which it has been eroded.

STRUCTURE OF THE SAN JUAN BASIN

The San Juan Basin is, as its name implies, a crudely circular area in which the rock beds have been warped into the shape of a shallow bowl. Its outline and shape are indicated in plate 10. In the central part of the basin the beds lie essentially flat, but around its margins they are turned up to varying degrees. The eastern margin is formed by very steeply dipping beds, caused in part by the Nacimiento and San Pedro Mountain uplifts. The west side is marked by eastward-dipping beds which, dipping steeply where they cross the San Juan River between Shiprock and Farmington, form a prominent ridge known as Hogback Mountain. The southern margin of



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.

59016—34. (Face p. 20.)

the basin is somewhat more complex. For the most part it is formed by the gently dipping beds on the north flank of the Zuni Mountain uplift. However, two extensions of the main basin project southward as narrow synclines immediately adjoining the Zuni Mountains on the east and west. This relation suggests that perhaps the basin was at first more oval in outline, extending farther to the south, and that at a later time the Zuni Mountain area was uplifted, leaving parts of the earlier depression as the present synclines.

STRUCTURE OF AREA DESCRIBED IN THIS REPORT

The coal field described in the present report lies in the southwestern part of the San Juan Basin. (See pl. 10.) The structure of the field in detail is shown on plate 1.

At the southwest corner of the field, in T. 16 N., R. 18 W., the beds dip steeply to the west. This zone of steep dips, known as the Nutria monocline, continues far to the south; it is the west flank of the Zuni Mountain uplift and the eastern margin of the syncline in which are Gallup and the pueblo of Zuni. The edges of the upturned Dakota(?) sandstone and the Gallup sandstone member of the Mesaverde stand as two prominent ridges known locally as "the Hogback."

At the northern end of the Hogback the strike swings abruptly to the east, and the rocks assume the gentle northward dip, into the basin, that is the predominant structural feature of the field. Between the Hogback and Satan Pass this approximate east-west strike and gentle northward dip show notable regularity, being interrupted in a major way only in a narrow zone extending northwestward from the center of T. 16 N., R. 15 W. In that zone there are several swings of the strike to the northwest and northeast, causing low undulations or folds in the beds, and within the Navajo Indian Reservation, in what would be sec. 3 of T. 17 N., R. 16 W., there is a local reversal to a southward dip of 4°. A minor reversal, with southward dips of as much as 21°, was noted in a small area near the intersection of the reservation boundary with the east line of sec. 32, T. 17 N., R. 17 W.

From Satan Pass to the eastern edge of the field the prevailing gentle northward dip is interrupted by a series of pronounced folds whose axes trend somewhat east of north. The crests and troughs of these folds retain the regional gentle northward dip, but the flanks are monoclines dipping steeply to the east or west. At places the folding was too sharp for the strength of the rocks, which broke in series or zones of faults; some of these faults have throws of as much as 250 feet, and several grabens or fault troughs were developed.

Space cannot be given in this report to more than a brief reference to possible causes of the structure, nor, indeed, could an explanation be proposed with confidence until broader regional studies have been made. However, curiosity is excited and further study is invited by the nature and distribution of the structural features—the steep Nutria monocline at the west end; the eastern area in which a crumpling, superimposed on the gentle regional dip, has given a scalloped or fluted structure to the beds; and the wide intermediate area of regular structure, interrupted only at its middle by a zone of low undulations of a type comparable to the folds in the eastern area but of lesser magnitude. The arrangement and relation of these features suggest that perhaps the Nutria monocline was first formed as the steep west limb of the Zuni Mountain uplift, and that subsequently lateral pressure from the east acted first on the eastern area, causing the notable crumpling, and then, with greatly diminished strength, caused a slight buckling in the middle of the broad area that stretches to the Nutria monocline.

COAL

GENERAL FEATURES

Within the field here described the coal is found wholly in the lower part of the Mesaverde as that formation is defined in this report. Several previous workers assigned some of the lowest coals to the Mancos; with such an interpretation the writer disagrees, partly because of the intertonguing of the Mancos and Mesaverde as herein described and partly for the reason set forth on page 14.

In this field, as in the adjoining Gallup district, the valuable coal is found in three members of the Mesaverde—the Gallup sandstone member, the Dilco coal member, and the Gibson coal member. However, owing to the lateral variations of the members and the extreme lenticularity of the coals, the individual coal beds mapped and named in the Gallup district cannot be traced eastward, nor can their names be used in the present report.

All the coal occurs in irregular overlapping lenses that appear, thicken and thin rapidly, and die out again within short distances along their outcrop. Intervals between them likewise change rapidly as the coals diverge, come together, or are replaced by sandstone and clay.

For purposes of land classification, 14 inches was chosen as the minimum thickness that coal of this grade must have to be of value for possible future mining. Hence the outcrops of "classifiable" beds 14 inches or more thick were mapped with solid or broken lines, and some of the thinner coals were ignored and others were shown with short dashed lines. (See pl. 1.)

The few coal beds or thin zones of coals in the Gallup sandstone member and the Dilco coal member are relatively easy to distinguish and trace, and the mapping of their outcrops is therefore in general accurate. The beds of the Gibson coal member present a more difficult problem. The coals are scattered through a zone of sandstone and clay 250 to 425 feet thick; their lenticularity is such that at one locality there may be as many as a dozen beds that are of classifiable thickness, whereas a few hundred yards away there may be only four or five. Under such conditions accurate mapping of all the individual beds, with correct determination of their overlapping and their thickness with relation to the classifiable minimum, would be possible only by extremely detailed, hence slow and expensive study, which was considered to be unwarranted, either by administrative needs or by the present value of the coal. The survey of the Gibson coal member therefore consisted of tracing and mapping its outcrop, measuring detailed sections through it at fairly close intervals, and tracing one or two separate coal beds between the points of section measurement. Thus the lines of outcrop for individual coal beds as drawn on the map between the localities of measured sections are not claimed to be precise determinations but represent diagrammatically the geologists' interpretations of the conditions and the proper correlation of beds, and they are as accurate as they could be drawn with this method of work.

All the measured columnar sections that include the thicknesses of coal beds are shown graphically in plates 11–17.

In general the coal beds in this field are free from extensive burning on their outcrops, but at places one or more beds have been burned for distances of some hundreds of yards. However, the location of the burned portions of the coal have not been shown on the map, partly because the scale of the map is too small to permit such additions, and partly because experience in the Gallup district indicates that as a rule the burning did not extend under cover far back from the outcrop.

Although in the adjoining Gallup district coal mining has been carried on extensively for half a century, there is no commercial mining in the field covered by this report, presumably because of its greater distance from the railway and the relative difficulty of access to some of its thicker beds. The only developments consist of a few small mines opened to supply coal to the Indian agency and school at Crown Point, the Indian school at Tohatchi, and some of the trading posts and the nearby Indians.

COAL IN GALLUP SANDSTONE MEMBER OF MESAVERDE FORMATION

In several land sections west, northwest, and north of the center of T. 16 N., R. 17 W., a coal bed 2 to 4 feet thick, herein called for convenience "bed A," rests directly upon the prominent cliff-forming middle sandstone of the Gallup sandstone member. (See columnar sections 5–8, 10, 11, 13, 14, 16–19, 21, pl. 11.) This coal dies out westward (12)[17] approximately at the centers of secs. 18 and 19. Toward the northeast it thins to 1 foot 5 inches (27, 29, 32); thence, crossing the main valley in sec. 11, it thins still more (34–36) and is finally pinched out by the convergence of the middle and upper sandstones in the cliffs in sec. 14 (37).

In part of the area where coal bed A is found (the southern part of sec. 9, the northern part of sec. 16, and the NE¼ sec. 17), at places where the upper sandstone of the Gallup is thin and the interval between it and the middle sandstone is large, another coal is found 26 feet above bed A. This coal, designated on the map and columnar sections "bed B," seems to be a lens that reaches a maximum thickness of a little more than 2 feet (9, 18, 19). Farther west it is perhaps represented by a lens exposed in and near the SW¼ sec. 24, T. 16 N., R. 18 W., ranging in thickness from 1 foot 6 inches to 2 feet 11 inches (1–3). Coal B and the lens just mentioned are approximately at the horizon of the Myers (Richards) coal bed in the eastern part of the Gallup district, but correlation is uncertain.

Except for scattered worthless lenses, the only other coal found in the Gallup sandstone member crops out for about a mile along the southern edge of secs. 8 and 9, T. 16 N., R. 14 W., where it ranges in thickness from 1 foot to 2 feet 2 inches (79–83).

COAL IN DILCO COAL MEMBER OF MESAVERDE FORMATION

In the extreme southwest corner of the field only the Black Diamond and Thatcher(?) coal beds of the Gallup district are present in classifiable thickness (1). The Thatcher(?) bed dies out within a short distance, but the Black Diamond bed, with its characteristic white band of the clay mineral leverrierite, continues northward for 2 miles in the Hogback with a thickness of more than 4 feet (2, 3), finally being replaced by carbonaceous shale. Eastward from the Hogback, as described on page 16, the upper part of the Dilco coal member is replaced by sandstone (Dalton), so that there are no representatives of the Black Diamond, Thatcher, and higher coal beds of that member. Throughout the greater part of the field, therefore, the Dilco coal member (as the term is used in this

[17] Numbers in parentheses refer to columnar sections on plates 11–17.

report) is equivalent only to the lower part of the member as developed in the Gallup district.

From the Hogback eastward to the point where the member is crossed by the road between Mariana Lake and Mariana Pass, the coal of the Dilco is found principally as two beds, of which the lower is herein designated "bed C" and the upper "bed D." The interval between these beds is about 45 feet at the west but gradually increases eastward to about 80 feet in the area north of Mariana Lake. Although these two beds are the most persistent coals of the field, their persistence is only relative and seems noteworthy only by contrast with the other beds of the Mesaverde. Both beds are very irregular in thickness, as shown in the columnar sections (1–84), and at many places are thin and worthless. Across stretches of poor exposures the writer could not be certain that he was following a single bed instead of a series of lenses. In fact, what is mapped as bed C is a carbonaceous zone some 20 feet thick in which there are at many places two or more bands of coal, one or more of which may from place to place be found of classifiable thickness. (For examples see 33–36, 49, 50.) The maximum thicknesses noted in coal C are 3 feet 3 inches (43) in the NE¼ sec. 8 and 3 feet 1 inch (49) in the NE¼ sec. 2, T. 16 N., R. 16 W., but both of these measurements were made on lenses that thin to worthlessness within short distances. Coal bed D reaches a maximum thickness of about 3 feet (40) in the SW¼ sec. 7, T. 16 N., R. 16 W.

In the central part of the field, for a distance of 7 miles west and south of Hosta Butte, classifiable coal was found in the Dilco only in one local lens (85). The thin worthless beds were not traced and mapped across this area, and hence the coal beds in the eastern part of the field cannot be correlated with those in the western part. From Hosta Butte southeastward to the eastern margin of the field the upper half of the Dilco is practically barren of coal, but the lower half at many places includes 1 to 3 beds of classifiable thickness (86–101). The lowest of these coals (86–89, 91, 94, 97) rests directly upon the Gallup sandstone member. The uppermost coal, about 80 feet higher (86–89, 92), is approximately at the stratigraphic horizon of bed C farther west, which it possibly represents.

COAL IN GIBSON COAL MEMBER OF MESAVERDE FORMATION

The Gibson coal member contains the thickest and hence the most valuable coal beds of the field.

In the extreme western part of the field (in the north end of the Hogback and for a few miles to the east) the coal is included in a zone more than 300 feet thick, as contrasted with the 150 to 175 feet of rocks that constitute the Gibson coal member in the Gallup

district. At a number of places where sections were measured the member was found to contain as many as 6 to 9 coal beds of classifiable thickness (102–120). Within this area is found the thickest coal bed of the entire field; it occurs at the base of the member and crops out with a thickness of 12 feet (116–120) for a distance of more than a mile. For some years coal for the Indian school at Tohatchi has been taken from a small mine in this bed (119). At several places there are other lenses that reach thicknesses of more than 3 feet (102, 104, 105, 108, 111–114, 116, 117).

Throughout the greater part of the field the Gibson coal member is split into two parts by the great wedge of the Hosta sandstone member, as described on page 18. The upper part has been eroded from most of the field but crops out along its northern edge as a broad, poorly exposed band in the flat lands east and west of Burnham's store and the Mulholland ranch. In that area the coals can in general be seen only in small scattered hills and mesas; correlation of beds and the presence or absence of coal in the intervening concealed stretches are therefore indeterminate. At several places the beds were found to be of classifiable thickness (277–286). The thickest bed noted is about 5 miles west of Burnham's store, where a small mine, intermittently worked by a nearby Indian, has been opened in a 6-foot coal (278).

A remnant of the upper part of the Gibson is preserved in a narrow east-west ridge near the southern boundary of the Navajo Indian Reservation, in what would be T. 17 N., Rs. 15–17 W. In this area were found several beds of classifiable thickness (260–276); one of the coals at the east end of the ridge, near the road leading to Burnham's store, shows locally a thickness of 5½ feet (275).

The lower part of the Gibson is exposed through the length of the field in the slope below the conspicuous southward-facing cliff of the Hosta sandstone member. Similar exposures are found below the northward-facing cliffs where erosion has cut through the Hosta southeast and west of Crown Point and in several deep canyons carved through the sandstone in the northwestern part of the field.

Near Walker's store and for several miles eastward the classifiable coals of the lower Gibson are confined to a 200-foot zone beneath the Hosta sandstone member, as in this area a well-marked barren zone about 200 feet thick, representing the Bartlett barren member, persists between the Gibson and the Dalton sandstone member. At a number of places in this area measurements showed coals ranging in thickness from 2 to 4 feet (137–152).

East of this area valuable coal beds appear lower in the stratigraphic section, so that the Bartlett barren member changes laterally and becomes a part of the lower Gibson. Between secs. 32 and 36, T. 17 N., R. 15 W., the entire 400-foot zone between the Dalton and

Hosta sandstone members seems properly assignable to the lower Gibson. In this vicinity it contains classifiable beds at various horizons (153–158); the thicker beds, however, continue to be found in the upper part, and at one locality there are two beds each over 7 feet thick, separated by 10 feet of sandstone and clay (156).

In sec. 31, T. 17 N., R. 14 W., several thin sandstones in the upper 100 feet of the lower Gibson thicken rapidly eastward and converge to a single unit, which, in the south end of Dalton Pass, merges with the Hosta sandstone member. The lower Gibson, thus diminished, continues from this vicinity to the eastern border of the field with a thickness ranging in general from 250 to 300 feet. In this eastern half of the field—in the slopes on the south side of the main ridge, in Dalton and Satan Passes, and on the north side of the ridge where erosion has cut through the Hosta east and west of Crown Point—the coal beds of the lower Gibson (159–259) are comparable in number and thickness to those in the western half of the field. At two localities—one on the east side of Dalton Pass (176) and the other in sec. 36, T. 16 N., R. 12 W. (239)—the maximum thickness of 6 feet 2 inches was noted; at three other places (163, 168, 234) the thickness is 5 feet or more; and at a score of other places the coal was found to be 4 feet or more in thickness.

Some good beds of coal were observed in the lower Gibson where it is partly exposed in the sides of the narrow, deep canyons carved through the Hosta in the northwestern part of the field (121–136). The maximum thickness found was 8 feet of clean coal, at a locality about 5 miles north of Walker's store (123), and beds ranging in thickness from 4 feet to 6 feet 6 inches were noted in half a dozen other sections.

PHYSICAL AND CHEMICAL CHARACTERISTICS

The coal of the lower part of the Mesaverde formation in this field, as in the adjoining Gallup district, is a subbituminous coal of fairly good grade. It is black and lustrous and in places contains jetlike woody layers, as well as many small irregular lumps of amber-colored resin. As described in the report on the Gallup district,[18] "the coal is hard and brittle and breaks readily on handling. * * * Subbituminous coal, owing to its high moisture content, breaks down or 'slacks' on exposure to weather; this is a feature of the Gallup coal, which makes a perceptible crackling noise when brought into the air. In spite of this fact, the coal stocks fairly well, and most of the product of the larger mines is shipped in open

[18] Sears, J. D., Geology and coal resources of the Gallup-Zuni Basin, N.Mex.: U.S. Geol. Survey Bull. 767, p. 34, 1925.

cars. The coal of the Gallup district is a good steaming variety, but attempts to coke it have not met with success."

As shown by analyses, the coal in the field covered by the present report is very similar in chemical characteristics as well as in physical appearance to the coal in the Gallup district.[19] Owing to the scarcity of mines and prospects within the field it is difficult to obtain samples of fresh, unweathered coal. The analyses given below represent samples collected in 1928 by C. L. Duer, of the United States Geological Survey, from the mine of the Indian agency at Crown Point and the mine of the Tohatchi Indian School in what would be sec. 22, T. 17 N., R. 17 W. The samples were obtained in the standard manner by making a cut from roof to floor, exclusive of partings thrown out in mining; the cuttings were pulverized and quartered down in the mine and then sealed in cans for shipment to the laboratory. In the table the analyses are reported in three forms. Form A represents the sample as it comes from the mine; this form shows in a general way the condition of the coal as it reaches the consumer. Form B represents the coal after all the moisture has been theoretically eliminated, and form C the coal after all moisture and ash have been theoretically eliminated; these forms, which are obtained from the other by recalculation, are useful chiefly to engineers.

It will be noted that the heating value of the three samples in the condition "as received" at the laboratory (the condition closest to that of the coal as it reaches the consumer) averaged 10,620 British thermal units, which is somewhat lower than the average of 11,110 British thermal units found in 27 representative samples from the Gallup district.[20] The heating value of the three samples on a "moisture and ash free" basis, however, averaged 13,950 British thermal units, which compares much more favorably with that of the Gallup coals on the same basis.

[19] Sears, J. D., op. cit., pp. 36–39.
[20] Idem, p. 43.

Analyses of coal samples from the coal field from Gallup eastward toward Mount Taylor, N. Mex.

[Analyst, H. M. Cooper, U.S. Bureau of Mines. Coal of the lower part of the Gibson coal member of the Mesaverde formation]

Mine	Location			Laboratory no.	Air-drying loss	Form of analysis	Proximate				Ultimate					Heating value (British thermal units)
	Sec.	T.N.	R.W.				Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Mine of Tohatchi Indian School	[a] 22	17	17	A46443	6.7	A	11.3	35.6	42.6	10.5	0.7	6.2	60.9	1.1	20.6	10,830
						B		40.2	48.0	11.8	.7	5.6	68.7	1.2	12.0	12,220
						C		45.6	54.4		.8	6.3	77.9	1.3	13.7	13,850
Mine of Eastern Navajo Indian agency at Crown Point	30	17	12	A46444	9.0	A	14.3	37.1	38.9	9.7						10,700
						B		43.3	45.4	11.3						12,480
						C		48.8	51.2							14,070
				A46445	10.4	A	16.6	35.8	38.3	9.3						10,330
						B		42.9	46.0	11.1						12,390
						C		48.3	51.7							13,940
				A46446	9.7	A	15.4	36.1	39.0	9.5	1.3	6.1	58.7	1.0	23.4	10,520
						B		42.7	46.1	11.2	1.5	5.2	69.4	1.2	11.5	12,440
						C		48.0	52.0		1.7	5.9	78.1	1.4	12.9	14,010

[a] Approximate location. Land in Navajo Indian Reservation, and township not surveyed.

A46443. Collected from face of main entry, 105 feet from mine mouth, by C. L. Duer in 1928. Section at point sampled (all coal sections are given as measured from roof to floor): Coal (sampled), 2 feet 10 inches; bone, 1¼ inches; coal (sampled), 1 foot 8 inches; bone, ¾ inch; coal (sampled), 1 foot 7 inches.

A46444. Collected in room no. 6 left, 350 feet from entry, by C. L. Duer in 1928. Section at point sampled: Coal (sampled), 3 feet 2 inches; bone, 6 inches; coal, 6 inches.

A46445. Collected from face of main entry, 750 feet from mine mouth, by C. L. Duer in 1928. Section at point sampled: Coal (sampled), 3 feet 1¾ inches; bone, 5 inches; coal (sampled), 5 inches.

A46446. Composite of samples A46444 and A46445.