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GEOLOGY AND COAL RESOURCES

OF THE

GALLUP-ZUNI BASIN, NEW MEXICO

BY

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GEOLOGY AND COAL RESOURCES OF THE GALLUP-ZUNI BASIN, NEW MEXICO

By Julian D. Sears

INTRODUCTION

The Gallup-Zuni Basin, in McKinley and Valencia counties, N. Mex., has great economic value as well as geologic interest. Its commercial importance is at present centered in the Gallup coal district, the natural wealth of the rest of the basin having been almost untouched. The Gallup district, in which active mining has been carried on for nearly half a century, is now the second largest producing district in the State, and owing to the adaptability of the coal to certain uses, the convenient shipping facilities, and the nearness of the coal beds to the mining camps of Arizona it is one of the most important coal-mining districts in the Southwest.

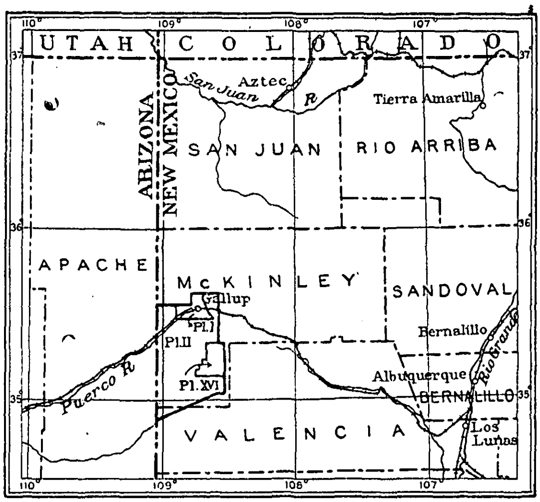


Figure 1.—Index map showing location of the Gallup-Zuni Basin, N. Mex.

This report describes the geology and resources of the whole basin in a general way and the coal beds of the Gallup district and the Zuni Indian Reservation in greater detail.

LOCATION AND EXTENT OF THE BASIN

The Gallup-Zuni Basin lies in the western part of McKinley County and the northwest corner of Valencia County, N. Mex., as shown on the index map (fig. 1). It forms a part of what has been called the Durango-Gallup coal field, which includes an area of over 11,000 square miles in northwestern New Mexico and a small area in southwestern Colorado. The Durango-Gallup field, known also as the San Juan River region,[1] is roughly circular in outline, with a narrow southward extension on its southwest side. This extension, which occupies a structural trough known variously as the Zuni Basin, the Gallup syncline, and the Gallup Basin, is crossed near its north end by the Atchison, Topeka & Santa Fe Railway, and the term "Gallup district," as used in this report, designates the belt along the railway, near the town of Gallup, to which commercial mining has been confined.

EARLIER INVESTIGATIONS

Certain prominent structural features and the presence of coal in this region were noted by early explorers, and the general geology and structure of the Gallup-Zuni Basin were described by Gilbert[2] and by Dutton.[3] During the field seasons of 1905 and 1906 reconnaissance surveys of the Durango-Gallup field were made by parties in charge of Schrader[4] and Shaler,[5] and brief descriptions of the Gallup-Zuni Basin are included in their reports. In 1907 Gardner examined parts of the field in greater detail, and one of the areas studied was a strip along the Santa Fe Railway eastward from the Hogback near Gallup.[6] Later views as to the geologic and structural relations of the Durango-Gallup field are expressed on reconnaissance maps by Darton[7] and Gregory.[8] In 1913 and 1914 C. T. Lupton made a detailed examination of scattered tracts within the Gallup-Zuni Basin, and his unpublished material was of much assistance to the writer during the present field work.

FIELD WORK

The field work on which the present report is based was done primarily for the purpose of classifying and valuing the public lands. In the course of the work much information was obtained that will aid in a clearer understanding of the relations to one another of the

[1] Campbell, M. R., The coal fields of the United States, general introduction: U. S. Geol. Survey Prof. Paper 100, p. 19, 1917 (Prof. Paper 100-A).

[2] Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 542-567, 1875.

[3] Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey Sixth Ann. Rept., pp. 105-198, 1885.

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

[5] 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.

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

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

[8] 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.

coal beds now mined and will also serve as a guide for future prospecting and development.

In 1912 the geology and coal beds of the Zuni Indian Reservation were mapped by D. E. Winchester, C. A. Bonine, and S. D. Greene, and their results have been incorporated in this paper. Township plats on a scale of 2 inches to the mile, showing topography with a contour interval of 50 feet, prepared by the General Land Office in 1911–12, served as the base maps for this work.

During the field seasons of 1919 and 1920 the Gallup district was examined in detail by parties in charge of the writer. In 1919 E. S. Bleecker gave able assistance in mapping the geology and B. H. M. White served as instrument man. In 1920 W. L. Russell acted as geologic aid and Langdon White as instrument man. The only topographic map covering the district, that of the Wingate quadrangle, was made in 1882–83, on a scale of 1:250,000 and with a contour interval of 200 feet, and is unsuitable for detailed use. As the section corners are so poorly marked that the land net can not be used as the basis of a detailed survey, a new base map was prepared. Owing to the number of coal beds examined and the complexity of the outcrops, the scale chosen for the field work was 1:15,840, or 4 inches to the mile. A Gale telescopic alidade and a 15 by 15 inch plane table were used, and stadia traverses were run through the district. The outcrops of coal beds were sketched between points located on them at short intervals, and the geologic structure was determined by many altitudes obtained by vertical angles. During the course of the work careful search was made for all land corners, and those found, both Government and private, were located by stadia methods. Drainage and culture were sketched from points located by intersection. The information thus obtained is shown on the accompanying large-scale map of the Gallup district (Pl. I, in pocket).

At the end of the season of 1920 a month was spent in a reconnaissance survey of 70 Indian allotments and school sections scattered throughout the Gallup-Zuni Basin. Most of the tracts are in the western part of the basin between Manuelito, Defiance Switch, Two Wells, and Cousins (Whitewater), and in this area fairly accurate geologic boundaries are drawn. In the eastern part of the basin, north of the reservation, observations were less thorough, and in consequence the boundaries must be regarded as tentative, though substantially correct; in this area the data consist of strike and dip readings and outcrops noted on the roads from Gallup to Zuni, Two Wells, and Ramah, the details seen on a score of Indian allotments, the topography shown on the map of the Wingate quadrangle, the geology from Shaler's reconnaissance map, and the location of the

Hogback and a few other details from an unpublished map by C. T. Lupton.

In 1921 C. P. Ross, under the general supervision of the writer, mapped the geology of about six townships lying between Manuelito and the Zuni Reservation.

All the information from detailed and reconnaissance surveys has been assembled in the accompanying general geologic map of the Gallup-Zuni Basin (Pl. II, in pocket).

ACKNOWLEDGMENTS

The writer wishes to express his deep indebtedness to S. E. Wood, mining engineer, and J. E. Hanes, chief engineer of the Gallup American Coal Co., for a large amount of information furnished, and to John M. Sully, vice president of the Gallup American Coal Co., for permission to publish logs of drill holes. Hearty thanks are due also to Messrs. Boardman, McDermott, Brown, Kaseman, and others connected with mines in the district, who have supplied valuable data concerning the mines.

The resignation of D. E. Winchester from the United States Geological Survey has delayed the final preparation and publication of a report on his work in the Zuni Indian Reservation. For the use of Mr. Winchester's material, which is incorporated in this report, the writer wishes to make grateful acknowledgment.

GEOGRAPHY

LAND FORMS

The surface of the Gallup-Zuni Basin is for the most part very broken and hilly. The rocks consist of many alternating layers of sandstone and shale, and the land forms are largely an expression of the relative resistance and attitude of these rocks. In areas of gentle dips the sandstone forms ledges and cliffs, and where much erosion has occurred steep, narrow ridges and high buttes are common. In areas of steeper dip the shale has been worn down faster than the sandstone, which is thus left in cuestas or hogbacks. The best example of the results of such action, as well as the most conspicuous surface feature of the district, is the Hogback (Pl. III), along the east border of the basin, where on account of their superior hardness some of the sharply upturned strata have been left in the form of two great sandstone ridges with a valley eroded in softer rocks between them. Other ridges of this nature are to be seen on the west flank of the small anticline at Gallup and east of the road from Gallup to Gibson.

The altitude of the basin ranges from 6,200 feet along Puerco and Zuni rivers at the State line to nearly 8,000 feet at places on the crest of the Hogback. The highest land within the basin is a plateau with an average altitude of 7,400 feet, stretching east and west over an area of nearly two townships between Cousins (Whitewater) and Jones (Fabro's). The surface of this plateau is flat or gently rolling and shows few exposures of the bedrock.

DRAINAGE

Puerco River, often called Rio Puerco of the West, and Zuni River are the principal streams of the basin. The Puerco flows westward across the north end of the basin, the Zuni across the south end, and both join the Little Colorado in Arizona. The courses of the rivers seem to bear no relation to the geologic structure of the basin, for they cross synclines and anticlines almost at right angles to the strike of the beds. This fact indicates that the Puerco and the Zuni are superposed rivers—that is, their courses were established on more nearly horizontal younger beds, which have now been largely removed by erosion. As the rivers cut downward through the overlying beds into the older folded rocks, they maintained approximately their earlier courses. Possibly the surface on which the rivers were established was formed by Tertiary beds, remnants of which now cap some of the high land between Gallup and Zuni. Some of the side streams show a closer adjustment to structure, such as the stream which flows northward in a synclinal depression from the Catalpa mine.

The rivers have scoured out wide valleys and refilled them with sandy clay, at some places to a depth of more than 100 feet. Alluvium has been deposited also in the valleys of the main streams, and through it deep arroyos have been trenched. Most of the affluent streams enter the rivers at right angles, but Defiance Draw and the arroyo east of Twin Cones turn and flow parallel to Puerco River for several miles. This change in course is probably due to the piling up by the parent stream of low natural levees during floods, thus diverting the side streams down the valley in search of an outlet.

All the streams of the basin are intermittent, although Puerco and Zuni rivers maintain a slight flow through short dry periods. During heavy rains, however, the channels quickly become filled with muddy torrents that cause much damage to railroad culverts and road bridges. The Santa Fe Railway has been forced to protect its line near bends of the river by concrete revetments. The inhabitants report that on several occasions the Puerco has risen above its banks and flooded large areas in the valley below Gallup.

CLIMATE AND VEGETATION

The climate of the Gallup-Zuni Basin is semiarid, the annual rainfall averaging 14 inches. In summer the days are usually hot, though tempered by cooling breezes; the nights are generally cool and pleasant. In winter the mean temperature is about 30°; the nights are very cold, but the days are generally sunny and warm, and outside work can be carried on with comfort during most of the year.

The dryness of the climate is expressed in the types of vegetation. Grass, sagebrush, greasewood, and Russian thistle are common in the lowlands; scrub cedar and piñon grow on the hills, especially where sandstone beds crop out. The number of trees increases rapidly from north to south; north of the river the trees are widely scattered along the ridges, whereas to the south they are more abundant and afford a livelihood to a number of Mexicans who supply firewood to the town of Gallup. Still farther south the growth of timber is even heavier, and much of the plateau south of Jones is thickly wooded. This plateau is included in the Zuni National Forest, which contains much yellow pine of commercial size and quality.

CULTURE

The greater part of the Gallup-Zuni Basin is thinly settled. There is little irrigation except in the Zuni Reservation, where water is held by the dam at Blackrock and used on the small farms of the Zuni Indians. In general, agriculture is carried on as dry farming by a few ranchers and homesteaders. These settlers have sunk shallow wells to get water for household uses and at some places have dammed the smaller streams to conserve a water supply for stock. Many Navajo Indians, who live in temporary hogans made of sod and rough timber, wander over the hills seeking pastures for their flocks of sheep and goats. Most of the population outside of the Zuni Reservation is gathered in the town of Gallup and in several mining villages, including Gibson, Heaton, Coal Basin, Allison, and Dilco. Gallup, the most important town of northwestern New Mexico, is a bustling, prosperous community with a population of 3,920, according to the census for 1920; it has grown especially fast since it was made a railway division point several years ago. The town serves as a center of supplies not only for the coal mines near by but also for the region within a radius of 50 miles or more, including part of the Navajo Indian Reservation, to the north, and Zuni Pueblo, to the south. A fairly satisfactory supply of excellent water is obtained from four town wells and three railroad wells, ranging in depth from 1,000 to 1,600 feet. The first well was originally artesian, but now all the wells are pumped. The water is obtained from the Dakota sandstone, which crops out on the east and west sides of the basin.

Ready access to the Gallup district is afforded by the main line of the Atchison, Topeka & Santa Fe Railway, which follows the valley of Puerco River for many miles. Eight standard-gage spurs connect the railroad with the principal coal mines, so that cars are loaded direct from the tipples.

The chief highway of the district is the National Old Trails Road, which keeps close to the railroad for several hundred miles. It is part of a transcontinental highway and carries much tourist as well as local travel. The road from Gallup southward to Zuni and Ramah and the one northwestward to Fort Defiance and the Navajo and Hopi reservations are also much used; the road to Farmington and Shiprock, on which a regular stage is operated, affords an important outlet to the north. These roads are fair in dry weather but become muddy and very rutty after rains. Numerous secondary roads and trails lead to coal mines, trading posts, ranches, and Indian hogans.

The largest settlement in the Zuni Reservation is Zuni Pueblo, which has a population of about 1,700 Indians and a few whites.

Other Zuni Indians are gathered in the villages of Nutria, Pescado, and Ojo Caliente. At Blackrock are the agency and school of the United States Indian Service and the office of the United States Bureau of Reclamation.

GEOLOGY

SEDIMENTARY ROCKS

GENERAL SECTION

Within the Gallup-Zuni Basin are exposed beds of rock ranging in age from Permian to Recent. The oldest rocks crop out on the flank of the Zuni Mountains and in an anticline near Ojo Caliente; younger and younger beds are exposed in turn toward the axis of the major syncline that forms the basin.

The areal distribution of the formations and members is shown on Plate II (in pocket). Their succession and character are given in the following general section, which is based on tables by Darton and Winchester, modified by the writer:

General section of geologic formations exposed in the Gallup-Zuni Basin, N. Mex.

System	Series	Formation and member		Thickness (feet)	Character
Quaternary.		Alluvium, drifted sand, and travertine			Sandy clay along streams and in valley bottoms. Loose drifted sand, largely from the Navajo sandstone. Hot-spring deposits, including white and yellow chalky shale and sandy clay.
		-Unconformity-			
Tertiary.					Unconsolidated reddish sand and clay; some soft white sandstone and light-gray clay shale; gravel.
		-Unconformity-			
Cretaceous.	Upper Cretaceous.	Mesaverde formation.	Allison barren member.	800+	Light-gray to white lenticular sandstone, light-gray clay shale, and thin irregular coal beds, but none of commercial importance.
			Gibson coal member.	150-175	Valuable coal beds throughout the basin. Light-gray to white lenticular sandstone, light-gray clay shale.
			Bartlett barren member.	330-400	Light-gray to white lenticular sandstone, light-gray clay shale, and thin irregular coal beds, but none of commercial importance.
			Dilco coal member.	240-300	Valuable coal beds throughout the basin. Light-gray to white lenticular sandstone, light-gray clay shale.
			Gallup sandstone member.	180-250	Three thick persistent cliff and ridge forming sandstones traceable throughout the basin. Upper and in places lower sandstones are pink on east side of basin; all three are generally light gray on west side of basin, but in places the upper sandstone is pink or red. The upper sandstone contains lenses of very coarse grains, in many places an arkose. Shale between the sandstones; the lower shale contains several thin coal beds: the upper shale contains at most places from one to three commercial coal beds.
		Mancos shale.		700-950	Mainly dark-gray marine shale. Several thin beds of muddy buff sandstone and some sandy shale near top; a thin impure limestone near base.
		Dakota sandstone.		50-250	Thick resistant gray and buff sandstone, some interbedded dark shale, and thin irregular coal beds.
		-Unconformity-			

Cretaceous (?).	Lower Cretaceous (?)	McElmo formation.	0–20	Greenish-gray and maroon sandstone and sandy shale. Cut out by unconformity southward. Not differentiated from Navajo sandstone on the map.
Jurassic.	Upper Jurassic.	Navajo sandstone.	450–600	Cream-colored, white, and pink sandstone, extremely cross-bedded.
		Todilto formation.	15–25	Thin-bedded limestone. Not differentiated from Navajo sandstone on the map.
Jurassic or Triassic.	(?)	Wingate sandstone.	260–400	Brick-red sandstone; massive to north, moderately thin-bedded to south.
Triassic.	Upper Triassic.	Chinle formation.	850–900	Red, gray, and purple shale; limestone concretions.
	Upper Triassic (?).	Shinarump conglomerate.	50–80	Gray to buff sandstone, locally conglomeratic. Not differentiated from Chinle formation on the map.
	Lower Triassic.	Moenkopi formation.	500–900	Shale, mostly sandy, and sandstone, mostly red, some gray. Thickens to southwest.
Carboniferous.	Permian.	Chupadera formation.	175+	Limestone underlain by hard gray sandstone; base not exposed.

CARBONIFEROUS SYSTEM

PERMIAN SERIES

CHUPADERA FORMATION

The oldest rocks seen in the Gallup-Zuni Basin are exposed on the west flank of the Zuni Mountain uplift near Nutria Pueblo and in an anticline a few miles southeast of Ojo Caliente. Only the upper part of the formation, consisting of 40 to 75 feet of light-gray, cream-colored, and brown fossiliferous limestone underlain by 100 feet of white to light-gray coarse, somewhat conglomeratic sandstone, is exposed at these localities. Fossils collected from the limestone by Winchester were determined by Girty[9] to be of Kaibab age. The limestone and sandstone are considered by Darton[10] to be the upper part of the Chupadera formation, of Permian age.

TRIASSIC SYSTEM

LOWER TRIASSIC SERIES

MOENKOPI FORMATION

Above the Chupadera formation are red and gray shale and sandstone 500 to 900 feet thick, which were identified by Winchester and Darton as the Moenkopi formation. Winchester found at the base of the formation near Ojo Caliente about 30 feet of pink conglomeratic sandstone, which may mark an unconformity between the Moenkopi and the underlying Chupadera.

UPPER TRIASSIC (?) SERIES

SHINARUMP CONGLOMERATE

The Moenkopi formation is succeeded by 50 to 80 feet of gray and buff sandstone and conglomerate which has been correlated with the Shinarump conglomerate. This conglomerate was recognized by Winchester, but he included it with the overlying beds. As within the Gallup-Zuni Basin the Shinarump conglomerate crops out only in the area mapped by Winchester, the formation is not differentiated on the general map accompanying this report.

UPPER TRIASSIC SERIES

CHINLE FORMATION

The name Chinle formation was proposed by Gregory[11] "for the group of shales, 'marls,' thin soft sandstones, and limestone conglomerates lying between the Shinarump conglomerate and the Wingate sandstone. The strata composing the formation are highly varied in structure and in composition, but as a whole they constitute a stratigraphic unit of unmistakable individuality. The entire formation is present in Chinle Valley, from which its name is

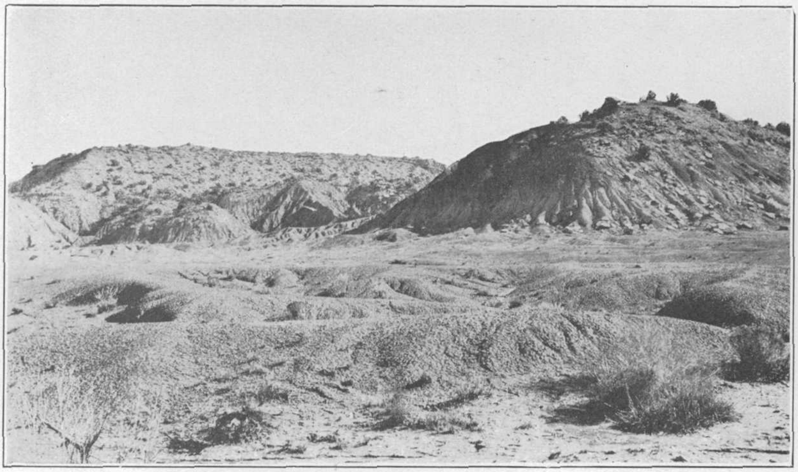
[9] Girty, G. H., letter of Feb. 21, 1913.

[10] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, fig. 41, p. 259, 1922.

[11] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 42, 1917.

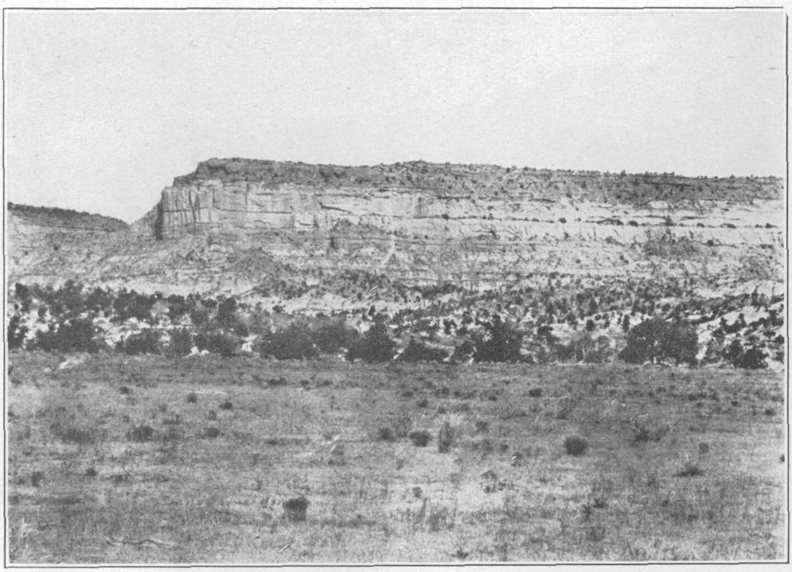
EAST RIDGE OF THE NUTRIA MONOCLINE, LOCALLY KNOWN AS THE HOGBACK

View south from a point 3 miles east of Gallup, N. Mex. Dakota sandstone forms the top of the ridge; older formations are exposed to the left, and Mancos shale in the valley to the right. Part of the west ridge is shown at the extreme right. Photograph by J. K. Hillers



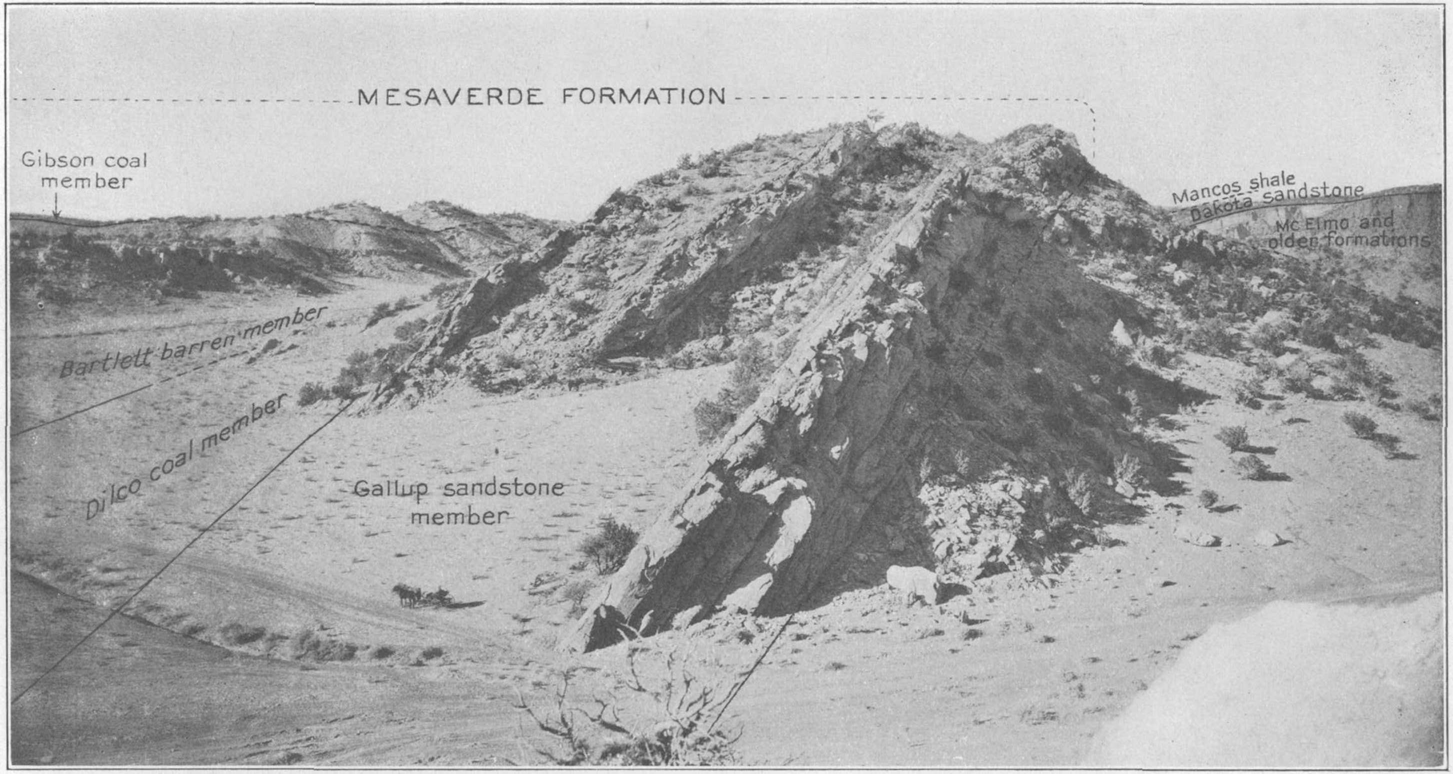
A. BADLANDS IN THE UPPER PART OF THE CHINLE FORMATION

View eastward from the Gallup-Zuni road, sec. 27, T. 11 N., R. 19 W., N. Mex.



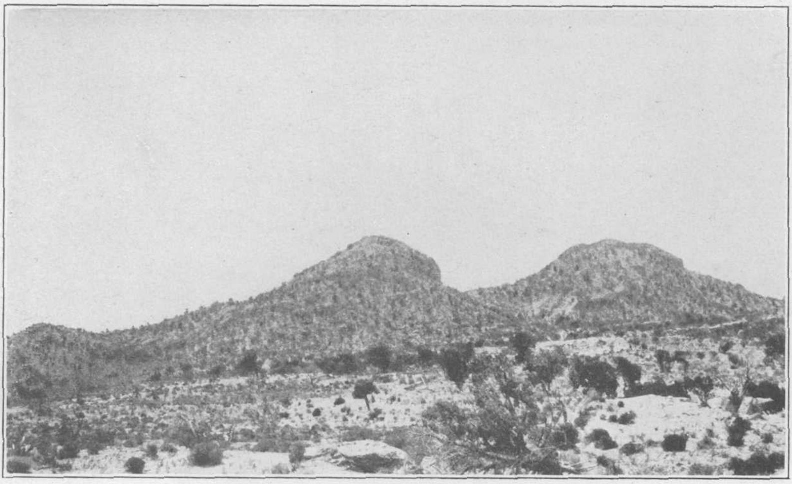
B. DAKOTA SANDSTONE LYING UNCONFORMABLY UPON McELMO (?) FORMATION, 4 MILES NORTHEAST OF GALLUP, N. MEX.

Photograph by D. E. Winchester



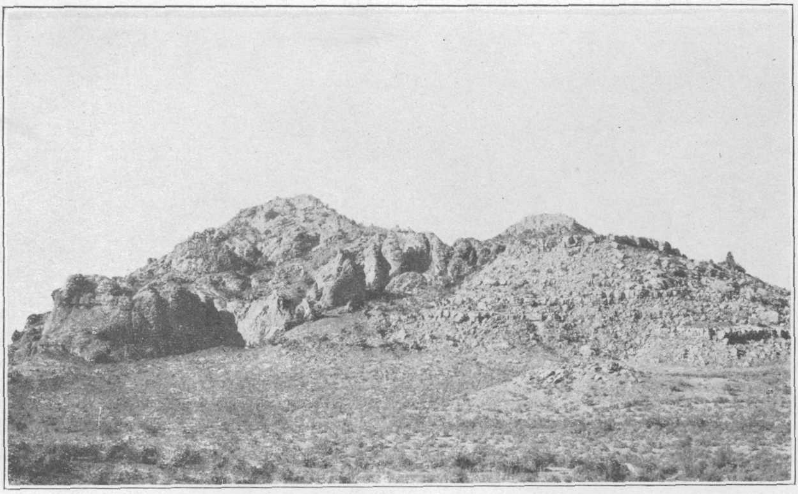
WEST RIDGE OF THE NUTRIA MONOCLINE (THE HOGBACK), SHOWING GALLUP SANDSTONE MEMBER OF MESAVERDE FORMATION AND ASSOCIATED BEDS, 2½ MILES NORTHEAST OF GALLUP, N. MEX.

Photograph by N. H. Darton



A. TWIN CONES, FROM THE NORTH

An igneous intrusion cutting the coal-bearing rocks



B. TWIN CONES, FROM THE SOUTH

Showing the contact between igneous and sedimentary rocks derived." In the Gallup-Zuni Basin the formation has essentially the same lithology as at the type locality; it is prevailingly red, gray, and purple but shows bands of lavender, white, and other colors. Its thickness is 850 to 900 feet.

The horizon chosen by Winchester for the upper boundary of the Chinle within the Zuni Reservation is thought by the writer to be too low. His boundary[12] is placed below a 2 foot 6 inch bed of lavender cross-bedded conglomerate which contains pebbles and clay balls 1 inch in diameter. Above this is more than 100 feet of red, purple, and mottled lavender and white clay and shale weathering into badlands (see Pl. IV, *A*), which the writer believes can not properly be included in the Wingate sandstone. Therefore, on the general map Winchester's boundary has been modified to conform as nearly as possible with that used by Ross and the writer in other parts of the basin.

JURASSIC OR TRIASSIC SYSTEM

WINGATE SANDSTONE

The Wingate sandstone was so named by Dutton[13] because of the excellent exposures north of Wingate station on the Atchison, Topeka & Santa Fe Railway. Its character in the northern part of the Gallup-Zuni Basin is shown by Gregory[14] in the following section:

Section of Wingate sandstone 1½ miles north of Wingate station, N. Mex.

	Feet
Todilto formation, with thin sandstones deposited on uneven surface of No. 1.	
Wingate sandstone:	
1. Sandstone, light red, composed of very small quartz grains weakly cemented by iron and lime; massive; highly cross-bedded in straight lines intersecting at various angles, also in curves of several different radii; with No. 3 forms cliff face from the Gallup hogback eastward for 25 miles	225
2. Sandstone, white, fine grained, friable; differs from No. 1 in color only; forms conspicuous band extending for some miles	1
3. Sandstone, dark to light red, uniformly fine grained, calcareous cement; massive; cross-bedded in varying amounts; marked throughout by specks and ribbons and by thin lenses of white; near the base is an irregular white band 6 inches to 1 foot in thickness	40
Shaly sandstones and limestone conglomerates of Chinle formation.	
	266

[12] Winchester, D. E., field notebook, p. 9, Sept. 28, 1912.

[13] Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey Sixth Ann. Rept., pp. 136, 137, 1885.

[14] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 54, 1917.

In the southern part of the basin the Wingate sandstone is less massive and shows thin and thick beds separated by partings of sandy shale.

The thickness of the formation ranges from 260 to 400 feet. Recent studies have raised some question as to the age of the Wingate sandstone, and pending further investigation it is now classed by the United States Geological Survey as of Jurassic or Triassic age.

JURASSIC SYSTEM

UPPER JURASSIC SERIES

TODILTO FORMATION

Gregory and Darton have described 2 to 25 feet of thin-bedded limestone lying between the Wingate and Navajo sandstones in Dutton Plateau and the vicinity of the Zuni Mountains; Gregory named these beds the Todilto formation. This limestone was not noted by Ross and Winchester in the western and southern parts of the Gallup-Zuni Basin and hence is not differentiated from the Navajo sandstone on the geologic map.

NAVAJO SANDSTONE

Overlying the Todilto formation is 450 to 600 feet of cream-colored, white, and pink sandstone, named by Gregory the Navajo sandstone. In this formation cross-bedding is developed to a remarkable degree. Where unprotected by younger beds, the sandstone readily weathers into characteristic beehive forms or breaks down into great stretches of deep loose sand such as that near Piñon Springs. In places one of the middle members is banded red and white and where cross-bedded gives rise to striking forms resembling peppermint candy.

CRETACEOUS (?) SYSTEM

LOWER CRETACEOUS (?) SERIES

MCELMO FORMATION

All the strata between the Wingate and Dakota sandstones were mapped by Dutton[15] as the "Zuni sandstone." As mentioned above, the lower part was called by Gregory the Navajo sandstone; the upper part he correlated with the McElmo formation of southwestern Colorado. The boundary between them, he states, can not be located with an error of less than 100 feet. In the Navajo country the McElmo of Gregory is prevailingly greenish-white sandstone. The beds below the Dakota near Manuelito and in the Hogback north of the railway (see Pl. IV, *B*) were found by the writer to be a white massive sandstone at the top, grading downward into buff sandstone;

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

more white sandstone, followed by gray sandstone with red and pink streaks; another white, very massive sandstone, underlain by white sandstone weathering into beehive forms typical of the Navajo. Southward from the railway all these beds are cut out by the unconformity above which lies the Dakota sandstone.

Because the typical McElmo of Colorado is largely clay shale, the writer has felt that the sandy McElmo of Gregory near Gallup may be older than the true McElmo. If this is so, the true McElmo has been cut out southward from Colorado by the pre-Dakota unconformity. Recent studies by Paige[16] in southeastern Utah have strengthened this feeling, but Darton[17] believes that the McElmo of Gregory can be traced eastward from Gallup into beds of clay shale that contain typical McElmo or Morrison vertebrate remains. As the question is in doubt, the nomenclature of Gregory and Darton is followed in this report, but the McElmo formation and Navajo sandstone are combined on the geologic map.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

DAKOTA SANDSTONE

The Dakota sandstone is the basal formation of the Upper Cretaceous series. It consists of massive buff and gray sandstone and some interbedded dark shale and thin irregular coal beds. On the west side of the basin the sandstone forms conspicuous ridges and hogbacks in a zone that crosses the railroad at Manuelito. Farther south it caps the Zuni Buttes and several ridges and hills in the Zuni Reservation. Along the Hogback it lies unconformably upon the older rocks and forms the crest and west slope of the east ridge, as shown in Plates III and IV, *B*. Darton[18] measured the thickness of the Dakota sandstone in the Hogback as 50 feet near the railroad and 250 feet at a point 8 miles southeast of Gallup.

In referring to the formation near Gallup, Lee[19] says: "It is probable that here, as in many other places in western New Mexico and Colorado, where the lowest sandstone of the Upper Cretaceous is called Dakota, the name has little time significance beyond the fact that the sandstone lies below shale referable to some part of the Benton. It seems probable that this sandstone may, at some places at least, be of Benton age." At any rate it seems clear that upon

[16] Paige, Sidney, unpublished paper presented before the American Association for the Advancement of Science, January, 1925.

[17] Darton, N. H., "Red Beds" in and associated formations New Mexico: U. S. Geol. Survey Prof. Paper — (in preparation).

[18] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 57, 1910.

[19] Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, p. 47, 1915.

the eroded surface of older strata, marked by slight channeling and local conglomerate, the Dakota sandstone was laid down near shore in the advancing Upper Cretaceous sea.

MANCOS SHALE

Lying conformably upon the Dakota sandstone is 700 to 950 feet of Mancos shale, laid down as the invading sea grew deeper. The name was first used by Cross [20] because of the prominent exposures of the shale near Mancos, Colo. The writer believes that in the Gallup-Zuni Basin the upper limit of the formation should be placed at the bottom of the massive sandstone that forms the crest of the west ridge of the Hogback. (See Pl. V.) Thus limited, the formation consists mainly of dark-gray, somewhat sandy marine shale. Near the base is a 10-foot bed of impure limestone which contains many broken shells of *Gryphaea* and *Ostrea*. Near the top is a transition zone of sandy shale, shaly sandstone in layers averaging 1 inch thick, and a 20-foot bed of buff "muddy" sandstone. On the west side of the basin and in the anticline at Defiance Switch the transition zone is thicker and contains several conspicuous sandstones, of which the uppermost has the same "muddy" appearance as that in the Hogback.

Some of the earlier workers in the field have extended the Mancos shale to include the overlying 250 feet of sandstone, shale, and coal, which in this report is called the basal member of the Mesaverde formation. The Mancos-Mesaverde boundary has never been traced in detail from the type locality in Colorado, and the paleontologic evidence is insufficient to decide the question. The writer is of the opinion, therefore, that in the Gallup-Zuni Basin the boundary should be drawn at the horizon where an abrupt change in lithology indicates a change in mode of deposition. Such a change occurred with the laying down of the massive basal sandstone of the Mesaverde as here defined and was foreshadowed by the deposition of the transition beds in the upper part of the Mancos shale. This division may be compared with that used in areas farther north. In the La Plata quadrangle, Colo., Cross [21] found the Mancos about 1,200 feet thick, "an almost homogeneous body of soft dark-gray or nearly black carbonaceous clay shale, varied only by the presence of a few thin bands or concretions of impure limestone. * * * 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

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

group." Farther south, where Hogback Mountain is cut by San Juan River, near Liberty, N. Mex., Bauer and Reeside[22] ound that the Mancos is predominantly shale but includes a transition zone of sandy shale and thin sandstone at the top; it is overlain by the alternating sandstone, shale, and coal of the Mesaverde formation, which is thicker than at the type locality. According to Reeside,[23] a fauna which at Durango, Colo., is found 700 to 1,000 feet below the top of the Mancos occurs at San Juan River in beds that lie just below the Mesaverde, showing that the rocks of the Mesaverde type were formed earlier at this point than in Colorado. The progressive thinning of the Mancos and thickening of the Mesaverde southward and southwestward from the type locality are shown in many sections quoted by Lee.[24] Taking into consideration the thickness, the lithology, and the mode of origin of the formations in the Gallup Basin, the writer believes that the Mancos shale and the Mesaverde formation as here defined are homogenetic equivalents of the formations in Colorado—that is, they were formed under the same conditions and at the same relative place in the stratigraphic succession; but that the Mesaverde rocks were already being laid down in what is now the Gallup-Zuni Basin while Mancos shale was still forming farther north.

In his examination of the Zuni Reservation, Winchester divided the Mancos shale into two members. The lower member, 425 feet thick, is almost entirely gray marine shale; the upper, 500 feet thick, contains shale, persistent massive sandstones, and several beds of coal. The top of the Mancos was placed at the base of a heavy red sandstone which is the uppermost bed of the Gallup sandstone member of the Mesaverde formation of this report. Comparison shows, therefore, that the upper Mancos of Winchester, containing valuable coal beds, is roughly equivalent to the Gallup sandstone member of the writer, and with enough areal adjustment to care for the discrepancies in boundaries, it is so mapped in this report. Winchester's lower Mancos and the lower part of his upper Mancos are retained as the Mancos shale of this report.

MESAVERDE FORMATION

General features.—The Mesaverde formation exposed in the Gallup-Zuni Basin comprises about 1,800 feet of alternating gray sandstone, drab clay shale, and coal beds. The three beds of sandstone near the base are massive and persistent; all the others are very

[22] Bauer, C. M., and Reeside, J. B., jr., Coal in the middle and eastern parts of San Juan County, N. Mex.: U. S. Geol. Survey Bull. 716, pp. 163-165, 1921.

[23] Reeside, J. B., jr., Upper Cretaceous and Tertiary formations of the San Juan Basin, Colo. and N. Mex.: U. S. Geol. Survey Prof. Paper 134, p. 13, 1924.

[24] 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, 1915.

irregular and nonpersistent, so that sections differ greatly from place to place. The coal beds range in thickness from a few inches to 10 feet, and the thicker beds are found in three groups.

Several hundred feet of the upper part of the formation has been removed by erosion, so that the rocks exposed do not represent the entire formation. However, the Mesaverde is much thicker in the Gallup-Zuni Basin than at its type locality in the Mesa Verde, Colo., where it includes only 1,200 feet. Collier[25] has called the Mesaverde deposits near Mancos, Colo., the Mesaverde group and subdivided them in ascending order into the Point Lookout sandstone, 250 to 300 feet thick; the Menefee formation, consisting of 400 feet of sandstone, shale, and coal beds; and the Cliff House sandstone. A similar but somewhat thicker section was measured farther south by Bauer,[26] who reports that "where the Great Hogback is cut by Chaco River, the thickness of the Mesaverde is 1,980 feet. * * * The formation is composed here of a lower sandstone member, which contains coal in its upper part; a middle shaly member, which comprises thin-bedded sandstone, shale, and coal; and an upper massive sandstone member."

In the present report the Mesaverde formation is divided into five members, partly because of the lithology and partly for convenience in description. The basal sandstone member, 180 to 250 feet thick, is possibly the homogenetic equivalent of the Point Lookout sandstone of Colorado, although formed at an earlier time. The persistence of the sandstone beds of this member and their position between marine shale and variable continental beds indicate that the sandstone member was formed as a littoral deposit when the sea retreated from this region. Above the sandstone member is approximately 1,600 feet of alternating light-gray sandstone, drab clay shale, and coal beds, which may represent the Menefee formation. The most striking feature of these rocks is their extreme variability. Massive cliff-forming sandstones die out laterally within short distances; the coal beds are lenticular, and the intervals between them differ widely from place to place. These variations indicate that the sediments were laid down on flood plains of great rivers which meandered across the nearly level surface left by the retreating sea. Coal beds are found throughout these rocks, but the beds of commercial thickness are in two groups, one at the base and the other near the middle. In the present report these rocks are divided into four members distinguished by the presence or absence of valuable coals.

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[25] Collier, A. J., Coal south of Mancos, Montezuma County, Colo.: U. S. Geol. Survey Bull. 691, pp. 296-297, 1919.

[26] Bauer, C. M., Contributions to the geology and paleontology of San Juan County, N. Mex.: 1, Stratigraphy of a part of the Chaco River valley: U. S. Geol. Survey Prof. Paper 98, p. 273, 1916.

Gallup sandstone member.—Lying conformably upon the Mancos shale is the Gallup sandstone member, 180 to 250 feet thick, comprising three massive sandstone and interbedded shale and coal. The member is named from the town of Gallup, part of which is built upon its uppermost bed of sandstone. The general character of the member is persistent throughout the basin. Along the Hogback (see Pl. V) the upper and lower sandstones are pink and the middle sandstone is light gray; the lower sandstone forms the crest of the west ridge. Only the upper sandstone is exposed in the anticline at Gallup, where it is commonly known as "the pink sandstone." The member is well exposed in the Torrivio anticline (see Pl. XII, *A*), at Defiance Switch; the lower sandstone is the most resistant and makes prominent abrupt cliffs above the shale on both sides of the river. At this place all three sandstones are light-gray to white, but farther south and in the exposure on the west side of the basin the upper bed is at places pink or even brick-red. Lenses of very coarse grains were noted at several localities in the upper sandstone.

The absence of pink color in the member near Defiance Switch has led to confusion in the correlation, and several workers have regarded the coal beds at the Richards mine as part of the "lower coal measures" or Dilco coal member. However, detailed study shows beyond doubt that the Myers (Richards) coal beds are equivalent to thin coals lying below the "pink sandstone" at Gallup and in the Hogback. The relations are well shown in the columnar sections of the east and west sides of the district. (See Pl. I, in pocket).

Dilco coal member.—The Dilco coal member, which ranges from 240 to 300 feet in thickness, contains valuable coals throughout the basin and includes the beds known locally as the "lower coal measures." The beds now mined range in thickness from 2 feet 6 inches to 7 feet. The member is named from the village of Dilco, where four of the beds have been worked in the Dilco mine (Direct Line Coal Co.).

Bartlett barren member.—The lower coal group is overlain by 330 to 400 feet of strata lithologically similar to those of the Dilco member. The coal beds in this member, however, are less than 14 inches thick, except in a few small lenses, and are of no commercial importance. These strata are here named the Bartlett barren member, because of the excellent exposures near the old Bartlett shaft mine, which penetrates the lower half of the member.

Gibson coal member.—The upper coal group includes a number of thick coal beds in 150 to 175 feet of strata which are here called the Gibson coal member. The name is taken from the village of Gibson which has been for many years the center of the largest mining operations in the coals of this group. The beds now mined range in thickness from 2 feet 6 inches to 6 feet, but a thickness of more than 8 feet was found at one place in the abandoned Clark mine, and the Aztec bed near the Aztec mine was measured by the writer as 10 feet thick.

Allison barren member.—Above the Gibson member are rocks that form the top of the Mesaverde formation exposed in the Gallup-Zuni Basin. They are similar in lithology to the three members below, but the coal beds they include are generally less than 14 inches thick and are not valuable for mining. These rocks are well exposed near the village of Allison and in this report are named the Allison barren member. The entire thickness of the member is not known, but about 800 feet is shown in two drill holes in sec. 32, T. 16 N., R. 18 W.

TERTIARY SYSTEM

Many square miles of the upland between Puerco and Zuni rivers is capped with unconsolidated reddish sand and clay, some soft white sandstone, light-gray clay shale, and gravel, lying unconformably upon the older formations. The largest cap is found in an east-west strip on the upland south of Whitewater Creek. The materials were observed by Ross and the writer during their field work but were not studied in detail; the beds in T. 13 N., R. 18 W., have been mapped by Shaler,[27] who referred them to the Tertiary system. At some places these beds are terminated by well-marked cliffs; at others their boundary can not be mapped with certainty.

QUATERNARY SYSTEM

The valleys of Puerco and Zuni rivers and the larger branch streams have been scoured out and partly refilled with Recent flood-plain deposits of sandy clay. Where the underlying strata have a gentle dip, much coal may have been removed from several beds during the erosion of the valleys, and the depth of the scour must be considered in estimating the amount of coal present in such areas. Unfortunately few data are available for use in calculation, but the alluvium in the Puerco Valley is known to reach a thickness of more than 100 feet.

In the southwestern part of the basin, near the State line, several townships are covered by a mantle of loose wind-blown sand, which almost completely conceals the bedrock.

On the hills southeast of Ojo Caliente, in the Zuni Reservation, Winchester found small caps of material that he interpreted as hot-spring deposits. The beds, which lie nearly horizontal, rest with marked angular unconformity upon older rocks. They consist of 10 to 20 feet of white and yellow chalky clay and harder, more siliceous

[27] 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, pl. 22, 1907.

beds which have a tubular structure and either a reniform or a pitted and porous exterior. Shells thought to be of Recent age are common in these deposits, and a few fragments of bone were found.

IGNEOUS ROCKS

Extrusive rock found in the Zuni Reservation is thus described by Winchester:[28]

> East of Blackrock is a tongue of lava which occupies the center of the valley of Zuni River and Pescado Creek. The lava evidently flowed down the valley after the present drainage system was defined and in places is covered by alluvium to a depth of at least 30 feet. Between the mouth of Nutria Creek and Lower Pescado village there is a distance of 4 or 5 miles where no lava is visible even in the channel of Pescado Creek. It is probable, however, that the lava is present beneath the alluvium, which shows a maximum depth of more than 30 feet along the channel of the creek. At Blackrock the lava stands up in a mesa-like mass, and mastodon remains are reported to have been found in alluvium which was in depressions in the upper surface of the lava.

Three small intrusions were seen south of the railroad between Allison and Defiance Switch. The largest of these, in secs. 27 and 34, T. 15 N., R. 19 W., is known as Twin Cones. (See Pl. VI.) A second intrusion is about a mile to the southwest, in sec. 3, T. 14 N., R. 19 W. A third mass of igneous rock, 3 or 4 miles southwest of the second, was noted during the reconnaissance but is not shown on the map. Specimens collected from Twin Cones by Darton were determined by Albert Johannsen[29] to be augite minette. The gently dipping beds of the Mesaverde formation are practically undisturbed by the intrusion, and the coal is not noticeably altered. The outcrops of the sedimentary beds are terminated abruptly by the intrusion (see Pl. VI, *B*), the contact being marked by a zone of friction breccia, which forms in some places a resistant wall.

A small plug of andesite intruded in the Mancos shale was observed by Winchester in sec. 31, T. 10 N., R. 17 W.

GEOLOGIC STRUCTURE

GENERAL FEATURES

The geologic structure of the rock strata is their present attitude. Most sedimentary beds are deposited in approximately horizontal position but in many regions are later warped into other positions by the great forces that slowly modify the earth's crust. Some beds have been uplifted thousands of feet without being tilted, but others have been inclined or bent into more or less complicated folds. Upward folds are called anticlines, or, if nearly equal in length and width, domes; downward folds are called synclines. Strata inclined

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[28] Winchester, D. E., office report to land-classification board, U. S. Geol. Survey, 1914.

[29] Letter to N. H. Darton, 1908.

in only one direction form a monocline. During their deformation many beds have been broken, and the rocks on one side of the fault have been raised or lowered with reference to those on the other side.

The structure must not be confused with the shape of the present land surface. At many places the surface bears a definite relation to the structure, but at other places synclines underlie the hills and anticlines are eroded to form valleys.

Knowledge of the structure in a coal district is important because the plan of the mine workings is usually determined by the dip and because the depth of any bed below the surface can be calculated from the structure of the rocks and the altitude of the surface.

METHODS OF REPRESENTING STRUCTURE

One method of representing structure is by symbols showing the amount and direction of dip at various points and by lines giving the position of anticlines and synclines. This method is employed on the general map accompanying this report.

A second method is the use of contour lines. 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 the map of the Gallup coal district the structure is shown by contour lines drawn on the top of the upper Otero coal bed. All points on the contour represented by one of these lines have the same altitude above sea level, and the dip of the beds at any place is toward the contours of lower altitude. Lines that are close together indicate steeply dipping beds, and lines that are farther apart beds that are more nearly horizontal. By carefully measured sections the relation of the Otero coal to underlying and overlying beds was determined, so that these beds could be used in calculating the position of the Otero coal where it is eroded or under cover. By the use of these sections (see Pls. VII–XI, in pocket) in connection with the structure contours, it is possible to estimate the altitude of any desired coal bed and, if the altitude of the surface is known, to calculate the depth of the coal below the surface.

STRUCTURE OF THE GALLUP-ZUNI BASIN

FOLDS

The major structure of the Gallup-Zuni Basin is that of a broad, shallow trough or syncline whose axis plunges gently toward the northwest. The syncline reaches a maximum width of 18 miles at the north end. It is a southward extension of the great San Juan Basin (which was called by Gregory[30] the Chaco downwarp), in which

[30] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 110, 1917.

lies the Durango-Gallup coal field. The regional relations of the syncline have been well shown by Darton. (See fig. 2.)

The west rim of the Gallup-Zuni Basin is turned up to form part of the Defiance monocline, which extends northward to Colorado along the west side of the San Juan Basin. A maximum dip of 70° is reached between Oak Springs and Hunter Point, Ariz., but near Puerco River the dips are in general less than 10°. On the east the basin is bounded by the Nutria monocline (see Pls. III and V), and the Hogback developed on this monocline forms the most striking topographic and structural feature of the basin. Along the Hogback the westward dips range from 30° to 80°, but a few miles north of

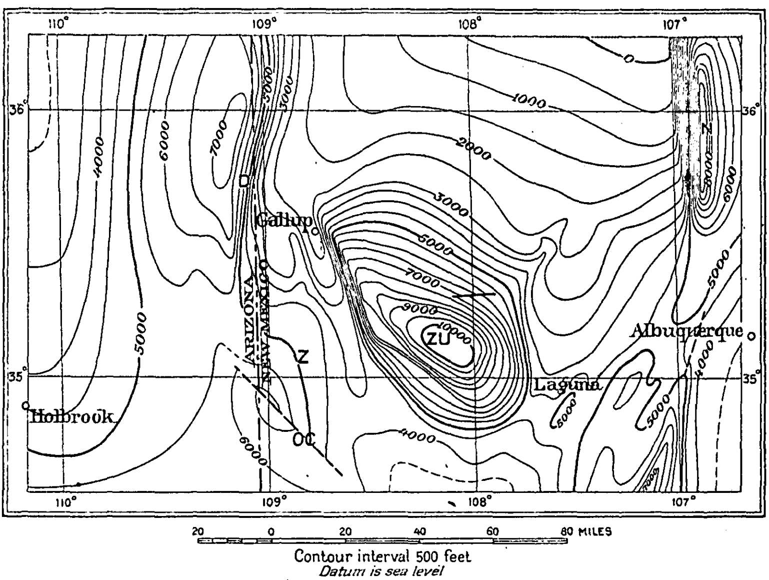


FIGURE 2.—Map showing structure of part of northwestern New Mexico. ZU, Zuni uplift; N, Nacimiento uplift; D, Defiance uplift; OC, Ojo Caliente uplift and fault; Z, Zuni. Contours represent top of Chupadera formation, which, however, is absent on the higher uplifts. (From N. H. Darton, U. S. Geol. Survey Bull. 726.)

the railroad the strike swings sharply to the east, and the beds dip gently northward into the San Juan Basin. The abrupt change in dip from the nearly horizontal beds of the syncline to the nearly vertical beds of the Hogback led several early workers to believe that they are separated by a fault; but the observations of the writer are in accord with those of later workers, who found no appreciable break.

Several minor folds interrupt the floor of the major syncline. One of these folds crosses Puerco River at Defiance Switch in a well-marked arch (see Pl. XII, *A*), for which Gregory[31] has proposed the

[31] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 110, 1917.

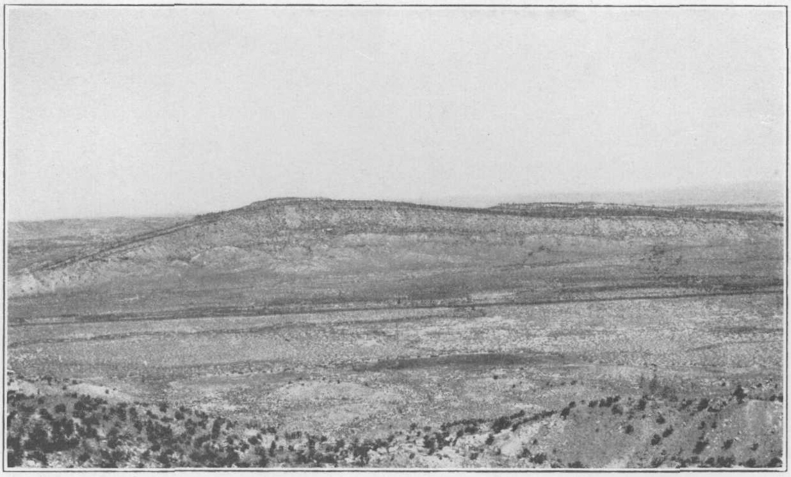
name Torrivio anticline. Part of the Mancos shale is exposed in this uplift, overlain by the Gallup sandstone member of the Mesaverde formation. The west limb of the anticline is short; the westward dip of approximately 10° dies out in a shallow syncline 2 miles from Defiance Switch. On the east side of the anticline the strata dip gently eastward as far as Gallup, where a second anticline crosses the Puerco. This arch, like the Torrivio anticline, is much steeper on the west side; the dips on the west limb range from 15° to 25°, but those on the east side do not exceed 3°. The anticline extends from a point north of Gibson southward almost to the Catalpa coal mine and reaches its highest point in a small dome in the SE. ¼ sec. 27, T. 15 N., R. 18 E. Beyond this dome the axis changes its direction, and the anticline continues toward the east and southeast, interrupted by a synclinal saddle in the southern part of sec. 26 of the same township.

A third anticline, the longest in the basin, is developed on the west limb of the major syncline. It crosses the railroad between Manuelito and the State line and extends southeastward, passing between Zuni and Blackrock. On the crest of the arch are exposed beds at the top of the Chinle formation. Maximum dips of 15° SW. and 12° NE. were seen near Piñon Springs. The anticline plunges toward the northwest and flattens out a few miles north of the railroad. It also flattens to the south and disappears within the Zuni Reservation. For this fold the name Piñon Springs anticline is suggested.

A fourth anticline begins near Ojo Caliente and extends southeastward. Just outside the reservation are exposed beds at the top of the Chupadera formation. The beds on the southwest limb dip as much as 54°, but those on the northeast limb dip 18° or less.

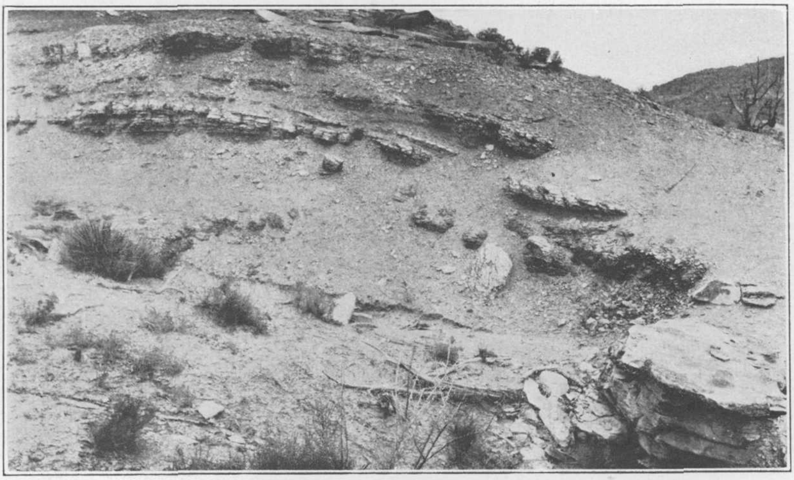
All four anticlines show steeper dips on their west limbs, and their axes are roughly parallel, the divergence toward the northwest tallying with the plunge and consequent widening of the major syncline in that direction. One possible explanation for these facts is that the folds are the result of movement along deep-seated faults, downthrown on the west side.

The Torrivio anticline dies out within 6 or 8 miles south of Puerco River; from Mitchell's, Two Wells, and Cousins (Whitewater) the strata dip northeast and pass under nearly horizontal Tertiary beds. Southwest dips near Jones (Fabro's), however, indicate that a shallow syncline extends southeastward from Remnant Mesa toward the Hogback. The details of the structure of this syncline are not known, but it seems to be related to the syncline between the Torrivio and Gallup anticlines, although separated from it by a very low east-west arch in the north half of T. 14 N., R. 18 W.



A. THE TORRIVIO ANTICLINE NEAR DEFIANCE SWITCH, N. MEX.

View northward across Atchison, Topeka & Santa Fe Railway

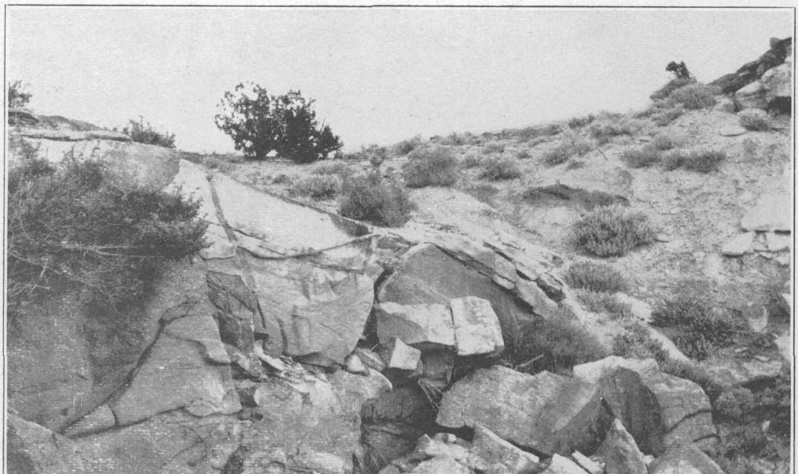


B. FAULT WITH REVERSED DRAG, SW. ¼ SEC. 11, T. 15 N., R. 18 W., N. MEX.

Sandstone in lower right corner is upthrown; beds on left show drag downward into fault plane

A. FAULT WITH REVERSED DRAG, SE. ¼ SEC. 31, T. 15 N., R. 18 W., N. MEX.

Beds on left are downthrown but show drag downward into fault plane



B. CLOSER VIEW OF SAME FAULT

Sandstone in upper right corner is same as that in left foreground

FAULTS

The rocks of the Gallup-Zuni Basin are broken by innumerable faults, most of which are too small to be mapped but which, in the Gallup district, greatly hindered the measurement of coal sections and at many places made correlation uncertain. The longest fault observed in the district cuts the Richards coal beds in secs. 19 and 20, T. 15 N., R. 19 W.; although the fault was traced for more than a mile, the throw is less than 15 feet. Another fault of almost the same length cuts the basal Mesaverde strata in sec. 32 of the same township. The faults shown on the maps range in throw from 5 to 30 feet. One of the largest is that in the SW. ¼ sec. 27, T. 15 N., R. 18 W., where the Black Diamond coal bed lies almost exactly opposite the upper bed of the Otero coals. Just south of the Navajo mines is a zone of complex faults which includes some torsional faults as a result of the rapid change of dip from north to west.

Many of the faults have disturbed only one or two of the coal beds, the movement having apparently been absorbed by the bodies of shale; this condition has been noted in several of the mines as well as in outcrops. An unusual feature is the fact that in a number of places the drag of the beds on one side of the fault is not in the direction in which the other side has moved but is reversed—in other words, the beds on the downthrown side bend down into the fault instead of up toward the raised beds. This feature is shown in Plates XII, *B*, and XIII. The writer believes that this condition may have come about by a double movement; at first the upthrown side rose higher than it is at present, and afterward it settled slightly to its present level; the second movement, though of smaller throw than the first, was accompanied by greater pressure, which caused a drag on the beds of the downthrown side. Several examples of such reversed drags in the mines were reported to the writer.

Winchester observed only one fault in the Zuni Reservation, in sec. 10, T. 10 N., R. 18 W. This fault has a northeasterly trend and cuts the Dakota and Navajo sandstones; the south side is downthrown about 50 feet.

Shaler[32] mapped near Ojo Caliente a fault with upthrow on the northeast side, which he described as bringing Carboniferous limestone into contact with the upper part of the Mancos. This fault had been inferred by Gilbert and Howell. Winchester denies the existence of this fault and thinks that the appearance is caused by the steepness of the southwest limb of the anticline near Ojo Caliente. The writer spent a day at this locality and found that south of the village red shale, red and white sandstone, and red conglomerate, probably of the Moenkopi, dip 54° SW. Half a mile farther west

[32] 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, p. 383, 1907.

are ledges of sandstone apparently belonging to the Mesaverde, which dip gently northeast. Unfortunately, the area between these outcrops is so covered by wash and drifted sand that no contact could be found. The writer leans toward the explanation of Shaler, but the question can be settled only by further work south of the reservation.

COAL IN THE GALLUP DISTRICT

GENERAL FEATURES

In the Gallup-Zuni Basin coal is present in the Dakota sandstone and the Mesaverde formation. The Dakota coal was observed by the writer at many places along the Defiance monocline between Manuelito and Two Wells; its occurrence is very erratic, and at only two places was it found to reach a thickness of more than 14 inches. Shaler[33] examined the Dakota coal "east of Gallup in the southward-facing escarpment north of the railroad" but found it "thin and full of partings." The coal of the Dakota sandstone may therefore be considered of no importance for mining.

The commercial coal of the Gallup district is contained in three members of the Mesaverde formation. (See Pls. VII–XI, XIV, XV.) All the coal beds are highly lenticular, and only a few can be traced for more than 1 or 2 miles. At one place the Gibson member contains eight coal beds more than 14 inches thick, whereas less than a quarter of a mile away it shows not even one bed of commercial size. The intervals between beds, as well as the thickness of individual beds, vary greatly from place to place. The writer believes that such changes of intervals point to deposition on sloping surfaces rather than to continual irregular warping. Deposition of this type might come about in small lakes and swampy depressions on broad flood plains, or even in climbing bogs such as those in Ireland, in which peat is now being laid down on slopes as great as 5°.

In some places there is distinct evidence that the coal beds after formation were trenched by streams, in the channels of which sand and silt were later deposited. Partings in many of the coal beds indicate that the swamps were subjected to periodic flooding by muddy water. Conspicuous "white bands" are found in several coal beds, notably the Black Diamond and the No. 5. These bands persist throughout comparatively large areas, with an average thickness of 2 inches. Samples of the material collected by the writer were determined by Larsen to be leverrierite, which has been described by Rogers[34] from material obtained from a coal bed in Montana. Rogers

[33] 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, p. 410, 1907.

[34] Rogers, G. S., The occurrence and genesis of a persistent parting in a coal bed of the Lance formation: Am. Jour. Sci., 4th ser., vol. 37, pp. 299–304, 1914.

suggests three possible modes of origin for this material—it may be an altered deposit of volcanic ash, or an alteration product of pure clay, or a chemical precipitate. He points out objections to all three hypotheses but believes that the third is the most tenable.

Here and there on the outcrop one or more of the coal beds have been burned for several hundred feet, as shown by the presence of ash, baked clay, and slag. Some of the slag has been used near Gibson for road metal and gives a good surface. Parts of several abandoned mines are now on fire, and the heat and fumes find their way to the surface through vents caused by caving. At the Caledonia mine the heat coming out in a gully is sufficient to attract in cold weather many horses and cattle for warmth.

THE COAL BEDS

COAL BEDS IN GALLUP SANDSTONE MEMBER OF MESAVERDE FORMATION

Myers (Richards) coal beds.—The coal of the Gallup sandstone member was first mined in 1886 by a trader, D. M. Smith, who shipped a few carloads from a small opening in the NE. ¼ SE. ¼ sec. 20, T. 15 N., R. 19 W. Later the Myers mine was opened near the southeast corner of the same section, but it is now abandoned. At present the only workings in this coal bed are in the Richards mine, which enters a few hundred feet northeast of the Myers mine. The coal in these mines is in two beds, each 2 feet 6 inches to 3 feet thick; the lower is rather impure. The coals are separated by a few feet of shale; farther west this shale interval is greater, and the coals are too thin to be of value. South of the river the lower bed is in general thin and worthless, but a third bed appears below the other two and at most places is of valuable thickness. The details of these coal beds are shown in columnar sections 156-161 (Pl. XI, in pocket). In the eastern part of the district the coal was mined for a short time near the brick plant at Gallup; the bed is reported as 2 feet 6 inches thick but proved to be merely a small lens. In the Hogback the Myers coal (162–171)[35] reaches a thickness of 3 feet, but near the railroad it is only a few inches thick.

As the Gallup sandstone member has by some writers been referred to the Mancos shale, the Myers coal beds have frequently been called Mancos coal. Other workers have mistaken the correlation within the basin and have called the coal under the "pink sandstone" near Gallup the Mancos coal, while referring the Myers coal beds in the west to the "lower measures" of the Mesaverde. Detailed study has convinced the writer that the correlation used in this report is undoubtedly correct; the relations are well shown in two general columnar sections (Pl. I, in pocket).

[35] Numbers in parentheses refer to columnar sections on Pls. VIII–XII, in pocket.

BEDS IN DILCO COAL MEMBER OF MESAVERDE FORMATION

The beds of the Dilco coal member have been called locally the "lower measures" of the Mesaverde formation. They have been mined for many years in both the eastern and the western parts of the district, but as correlation can not be made with certainty across the 6-mile stretch between Gallup and Dilco, different names have been applied to individual beds in the two parts of the district. Letters are used for the lowest three coal beds near Gallup, to which no local names have ever been given. At the Dilco mine the beds have been numbered; to avoid confusion with the well-known numbers of the upper coals near Gibson, the writer has prefixed the word Dilco to numbers of the coals in the western part of the district.

Detailed sections of the coals in this member are shown in Plates VII, VIII, and XI and also by records of drill holes in Plate XV.

C coal bed.—Just south of Gallup west of the road to Zuni the C bed shows about 1 foot 7 inches of impure coal (9); half a mile south, near the Gallup water tanks, the bed contains 1 foot 10 inches of clear coal (2). South of this place the bed is too thin to be worked, except in a small area near the quarter corner between secs. 22 and 27, where the bed is about 2 feet 2 inches thick, including a thin parting (21). East of Gallup and south of the river the C bed ranges in thickness from 6 inches to 3 feet (12–16); two prospects or country mines have been opened in this district. Under the road bridge in the northeast corner of sec. 23 the bed is 1 foot 5 inches thick, but the coal is rather impure (62). In the SE. ¼ sec. 26 a coal 1 foot 7 inches thick (74) was identified as the C bed. Elsewhere in T. 15 N., R. 18 W., the coal is too thin to be of value except in a few small lenses.

B coal bed.—At several places on the Zuni road south of Gallup the B bed ranges from 1 foot 2 inches to 2 feet 7 inches (2, 10, 11, 21); the maximum thickness is seen near the Gallup water tanks, but here the coal is very impure. In the Hogback, 1 mile north of the railroad, the B bed is 2 feet 3 inches thick, broken by a 5-inch parting (60). At no other place in T. 15 N., R. 18 W., is the bed of commercial thickness, except in a small shaft in the NE. ¼ sec. 24, where it is 2 feet 4 inches thick, including a 6-inch parting. In T. 15 N., R. 17 W., part of the SW. ¼ sec. 30 is underlain by two coal beds at this horizon, measuring at one place 1 foot 5 inches and 2 feet 2 inches thick, respectively (32). In the southern part of sec. 29 and the E. ½ sec. 32 there is a coal 2 feet 3 inches or more thick (35), which is doubtfully identified as the the B bed.

A coal bed.—Like the coals below it, the A bed is very irregular in thickness and distribution. In T. 15 N., R. 18 W., it is of commercial thickness in a number of small areas. Just south of Gallup, near the Zuni road, the A bed is about 1 foot 6 inches thick (2, 11). Near the southwest corner of sec. 26 its thickness ranges from 1 foot 5 inches to 2 feet 4 inches (25, 28). In the SE. ¼ sec. 26 two measurements show 1 foot 9 inches and 1 foot 6 inches of coal (69, 74); a similar thickness is shown by one measurement just west of the Rocky Cliff mine (50). In T. 15 N., R. 17 W., the bed is somewhat thicker; a doubtful measurement in the NW. ¼ sec. 19 shows 4 feet of coal (64), but the bed is known to be very lenticular in this area. Near the southwest corner of the same section the coal is about 1 foot 5 inches thick (66). In the SW. ¼ sec. 30 the A bed is 1 foot 10 inches thick (32); in the SE. ¼ of the same section a small abandoned mine was opened in two coal beds at this horizon; the upper bed is 2 feet 3 inches and the lower bed 2 feet 8 inches thick, separated by about 2 feet of shale and coal (34).

Otero coal beds.—The lowest two of the more valuable coal beds in the eastern part of the district are named from the old Otero mine, in which the main or lower Otero bed was once extensively worked. The upper Otero bed is very thin north of the river. In the Otero mine the lower bed contains 1 foot 2 inches of coal at the top, 9 inches of shale, and 3 feet 2 inches of coal at the base, according to a measurement by M. R. Campbell.

Near the mine the lower bed is 4 feet 2 inches thick, including a 4-inch parting (55). An almost identical thickness was observed at the Rocky Cliff mine (51), but westward from this place the bed splits up and within half a mile becomes of no value except in a small area near the McDermott mine, where it is 1 foot 6 inches thick (40). East of the Otero mine the bed is under cover and nothing is known of its thickness except on the Hogback, where a mile north of the railroad it is about 2 feet thick but rather impure (60). Where seen in a small shaft in the Crown Point mine the coal is in two beds, the upper 1 foot 3 inches and the lower 1 foot 6 inches thick, separated by several feet of shale (54).

South of the river the Otero coals have been worked at only two places, but they reach a valuable thickness at other localities. The upper bed shows its maximum thickness, 3 feet 5 inches (16), in the small isolated hill south of the Caretto mine. Near the Gallup water tanks it is 1 foot 7 inches thick (2); in the southern part of sec. 27 two measurements show 1 foot 10 inches and 1 foot 4 inches (22, 24). The greatest thicknesses of the main Otero bed south of the river are seen at the Caretto mine, 3 feet 9 inches, including a 3-inch parting (16); at the Boardman mine, 3 feet (61); and a quarter of a mile east of the Catalpa mine, two benches each 2 feet 5 inches thick separated by 1 foot 2 inches of shale. In the SW. ¼ sec. 19, T. 15

N., R. 17 W., the Otero coal group includes several valuable coals, of which the best is 3 feet 3 inchess thick (66).

Black Diamond coal bed.—The Black Diamond bed is the most valuable of the commercial beds in the Dilco member. It has been more widely exploited than any other coal in the district, and its outcrop is dotted with active and abandoned mines. The bed can be traced with certainty from the Hogback north of the river west to the Keeper mine at Gallup; here the outcrop swings to the south and is concealed by the alluvium of the Puerco Valley, but the bed can be readily identified at the Gallup Southwestern mines and traced south beyond the Catalpa mine nearly to the township line. Throughout this distance of almost 7 miles the bed has in general a thickness of clear coal ranging from 3 to 5 feet, as shown by many measurements. (See Pls. VII and VIII, in pocket.) However, near the Otero mine the bed is less than 2 feet thick (55, 56); near the Rocky Cliff mine it is almost wholly replaced by a downward thickening of the heavy overlying sandstone (51, 52); and near the quarter corner between secs. 10 and 15 it is very thin or missing. In the area south of the river, between the Hogback and the stream that runs northward from the Catalpa mine, correlation is less certain; much of the coal has been eroded, and the bed is now found as small patches in isolated hills and narrow ridges, ranging in thickness from 1 inch to 4 feet 7 inches (30–33, 61–75).

The Black Diamond bed is the best horizon marker in the Dilco coal member, because of its continuity and the presence of a fairly persistent "white band" of leverrierite near the top. At places where the coal has been burned the leverrierite is hard and porcelaneous. In the Hogback and in the belt along the river the Black Diamond bed is further identified by its position about 10 feet above an iron-stained sandstone which on weathered surfaces has a peculiar gnarled, mottled appearance. In the western part of the district, near the Dilco mine, the thin coal lying between the Dilco 3 and the Dilco 4 beds is tentatively identified as the Black Diamond bed because it carries a persistent white streak near its top and because at two places the sandstone below it has the characteristic mottled appearance.

Thatcher coal bed.—The Thatcher coal bed was named from the Thatcher mine, where it is 4 feet 2 inches thick (59). Near the Otero mine it was measured by the writer as 2 feet 11 inches thick (55), but inside the mine it is 4 feet thick, according to M. R. Campbell. In this area the coal contains near its top a white band similar to that in the Black Diamond bed. The persistence of the Thatcher bed under cover toward the north is indicated by a measurement in a prospect shaft dug below the workings of the Crown Point mine, where the bed is 4 feet thick, including two partings (54). West of the

Otero mine the bed splits into several benches, and within half a mile it becomes thin and worthless. In the NE. ¼ sec. 34, T. 15 N., R. 18 W., a thick coal bed appears at the Thatcher horizon, and at the Catalpa mine it shows 5 feet 8 inches of clear coal (27). Eastward from the Catalpa mine the bed can be traced for more than 2 miles, gradually thinning to 1 foot 3 inches (29–31, 33). Except in this area, the Thatcher bed has been almost entirely eroded south of the river in T. 15 N., Rs. 17 and 18 W.

Crown Point coal bed.—The workings of the old Crown Point mine were in a bed 3 to 5 feet thick known as the Crown Point bed. This coal was mined also in the upper slope of the Otero mine, where, according to Campbell, it is 5 feet 6 inches thick, including an 8-inch shale parting 1 foot 5 inches above the base. East and west from the Otero mine, however, the bed thins rapidly, so that it is of commercial importance in only a small area.

Between the Zuni road and the Hogback south of the river a few of the highest hills show small patches of Crown Point coal, and on the outcrop from the SE. ¼ sec. 27, T. 15 N., R. 18 W., to the SW. ¼ sec. 31, T. 15 N., R. 17 W., a bed ranging in thickness from 1 foot 2 inches to 2 feet 3 inches (23, 29–31, 33) may represent the Crown Point bed.

Brown coal bed.—The Brown bed is a lens that crops out in sec. 11, T. 15 N., R. 18 W., where it is about 1 foot 7 inches thick (55). This bed may be represented in the Crown Point shaft (54) by a coal bed 3 feet 6 inches thick, but if so the interval between the Brown and Crown Point beds is much greater here than at the outcrop near the Otero mine. In those areas where the Brown bed has a thickness greater than 14 inches this bed forms by definition the upper limit of the Dilco member.

Dilco 5 coal bed.—In a well at the Dilco mine the Dilco 5 bed is represented by thin streaks of coal and bone. At its outcrop, half a mile west, the bed is impure and worthless (151), but toward the north it rapidly thickens (150), and at an abandoned mine in the SW. ¼ sec. 16 its thickness is 4 feet 5 inches, including a 7-inch parting near the top (149). Northwest of the Defiance mine the Dilco coals are concealed by the alluvium of Defiance Draw but reappear in sec. 8. The upper of two beds that crop out in an east-west line across sec. 7 may be the Dilco 5 bed; it ranges in thickness from 2 feet 3 inches to 3 feet (144, 146).

Dilco 4 coal bed.—In 1920 the No. 3 slope of the Dilco mine was extended, and a little coal was taken from the Dilco 4 bed, which is 4 feet thick (153). On the outcrop between the Dilco and Defiance mines the bed ranges in thickness from 2 feet 10 inches to 3 feet 9 inches (149–151) and has been opened in two prospect drifts.

In this area the Dilco 4 bed contains a white band near the bottom. West of Defiance Draw the bed is probably too thin to be of value (146).

Dilco 3 coal bed.—A map of the Dilco mine furnished by Mr. Wood shows that the Dilco 3 bed averages slightly less than 4 feet in thickness. On the outcrops between the Dilco and Defiance mines the bed is extremely variable in thickness; near the center of sec. 21 it is missing (151), but in a prospect drift a quarter of a mile west it shows 4 feet 8 inches of clear coal (150). The bed is absent west of Defiance Draw (146).

From 2 to 14 feet below the Dilco 3 bed is a coal that is tentatively correlated with the Black Diamond bed because it carries a conspicuous white band. In the Dilco mine this bed is thin and worthless, but to the west along the outcrop its thickness ranges from 1 foot 3 inches to 2 feet (149–151).

Dilco 2 coal bed.—The writer measured the thickness of the Dilco 2 bed in the Dilco mine as 3 feet 4 inches (153); this is somewhat less than the thickness shown on the mine map, which ranges from 3 feet 6 inches to 4 feet 7 inches. The bed thins gradually toward the northwest, as shown by several measurements (149–152), and in the NE. ¼ sec. 8 it is of no value (148); farther northwest the bed becomes thicker, and in the SW. ¼ sec. 6 it shows 2 feet 3 inches of clear coal (143).

Dilco 1 (Defiance) coal bed.—Although partly or entirely replaced by heavy sandstone at a few places, the Dilco 1 (Defiance) bed in general is a thick and valuable coal (145–153). In the Dilco mine the thickness ranges from 2 feet 6 inches to 4 feet. Mr. Morris reports that at one place in the Defiance mine the coal is 7 feet thick, the maximum for any bed in the Dilco member.

Between the Dilco 1 and Dilco 2 beds are several lenses which at a few places reach valuable thickness (143, 152).

BEDS IN GIBSON COAL MEMBER OF MESAVERDE FORMATION

The coal beds known locally as the "upper measures" are included in a group of strata herein called the Gibson coal member. In the mines near Gibson the beds have received numbers, in descending order, which will be used in this report. No. 1 and No. 2 beds can be traced with comparative ease from the Heaton mine to a point near the Bartlett mine, as they are little disturbed by faults and are in general well exposed. The lower beds are much more difficult to correlate, for they have no striking characteristics and are variable in occurrence and thickness (see columnar sections, Pl. IX, in pocket); furthermore, they are broken by many faults in the area south of the Navajo mines and are concealed by alluvium and large waste piles in the valleys near the Navajo, Weaver, and Heaton mines. Near Gallup and south of the river the old Summit, Aztec, and Schauer mines were opened in a thick coal known as the Aztec bed, which the writer believes is probably the No. 2 bed of the Gibson section. In this area are found several other thick lenses, not exploited or named, which are shown in the columnar sections.

The coal beds in the western part of the district can not be satisfactorily correlated with those in the eastern part, even by the aid of many available drill records. The thicker coals are known as the Clark, Enterprise, and Old Enterprise beds; these and associated coals can be traced from the Clark and Enterprise mines northwestward to the township line and also southeastward to Puerco River; the belt of alluvium is too wide, however, to permit certain correlation with the coals south of the river, which are shown in a number of columnar sections (132–142).

No. 5 coal bed.—The No. 5 bed was first worked in the Gallup mine, at Gibson, and is now the principal coal in the Navajo and Weaver mines. The bed shows underground an average thickness of about 6 feet and includes a persistent "white band" of leverrierite near the top. Unfortunately this white parting is not conspicuous in the outcrop, and the tracing of the bed on the surface is difficult and unsatisfactory. The coal is exposed at the mouth of the Gallup mine in two benches, the upper 1 foot 6 inches and the lower 3 feet 6 inches thick, separated by 3 feet 5 inches of shale (100); southwest from this mine it can be traced only to the NE. ¼ sec. 4, where it is cut by a large fault. South of the fault zone in sec. 4 the No. 5 bed seems to be thin or missing, for a section (92) near the Caledonia mine shows no valuable coal at its horizon. Northeast of the Gallup mine, the outcrop of the No. 5 bed is concealed in the valley near Weaver; its horizon is exposed in the ridges south of the Weaver and Heaton mines, but the beds are lenticular and correlation is very uncertain. The surface observations, however, corroborate those made underground, that the No. 5 bed does not maintain commercial thickness as far northeast as the Heaton mine.

No. 4 coal bed.—A thin coal found above the No. 5 bed at some places in the mines near Gibson is known as the No. 4 bed. Messrs. Hanes and Wood, who are thoroughly familiar with conditions in these mines, report that the No. 4 bed is nowhere of commercial importance. Owing to the irregularity and poor exposures of the coals, the writer was not able to identify the No. 4 bed with certainty. Near the abandoned mine in the NW. ¼ sec. 2, T. 15 N., R. 18 W., three or four beds more than 14 inches thick are found below the No. 3 bed, and one of these may represent the No. 4 bed (109–111).

No. 3½ coal bed.—In the Weaver mine a thick coal bed was found between No. 3 and No. 4 beds and was called No. 3½ bed. West of the center of sec. 34 this bed becomes thin and worthless, but toward the east it persists as a thick bed and has been worked in the Heaton mine. In the ridges south of the Weaver and Heaton mines the No. 3½ bed may be represented by the thick coal lying a few feet below the No. 3 bed; here it ranges in thickness from 1 foot 3 inches to 2 feet 11 inches (109–112).

No. 3 coal bed.—The No. 3 coal bed can be identified more confidently than the lower beds, partly because of somewhat better exposures and partly because of its position below the No. 2 bed. The maximum thickness noted in outcrop is nearly 6 feet (101, 102), in the SW. ¼ sec. 34, T. 16 N., R. 18 W.; at the abandoned mine in the NW. ¼ sec. 2, T. 15 N., R. 18 W., the bed is nearly 5 feet thick (110). Near the center of sec. 3 it is thin and worthless (105), and near Gibson it is locally replaced by heavy sandstone (100). The No. 3 bed furnishes much of the coal taken from the Weaver and Heaton mines.

No. 2 coal bed.—The No. 2 bed crops out almost continuously between the Caledonia and Heaton mines; the greatest thickness was observed near the Navajo and Gallup mines, where the bed contains from 4 feet 6 inches to nearly 6 feet of clear coal (97, 98, 100). Near the Caledonia and Baudino mines, where the bed was formerly worked, it is also about 6 feet thick but is broken by several partings (93, 95). South of the Caledonia mine the bed is burned on the outcrop for a quarter of a mile. Farther south the No. 2 bed is concealed for about a mile but probably is identical with the Aztec bed at the Summit mine.

In the ridges south of the Heaton and Weaver mines the No. 2 bed is generally too thin to be of value, but in the NW. ¼ sec. 2, T. 15 N., R. 18 W., it reaches a thickness of more than 2 feet (110, 111). Much coal has been taken from the No. 2 bed in the Heaton mine.

No. 1 coal bed.—The No. 1 bed, sometimes known as the "big dirty," has not been mined, although prospected at several points north of Gibson. In the SW. ¼ sec. 34, T. 16 N., R. 18 W., the bed ranges in thickness from 4 feet 9 inches to 6 feet 11 inches, but the upper half is much broken by partings (99,101,102). In the SW. ¼ sec. 35 a lens at this horizon shows nearly 2 feet of good coal (112), and a quarter of a mile south the No. 1 bed is about 1 foot 3 inches thick (109,110). Elsewhere on the outcrop the bed is thin and worthless. In the eastern part of the Gallup district the No. 1 bed forms the upper limit of the Gibson coal member.

Aztec coal bed.—South of the Puerco the most valuable coal bed of the Gibson member is the Aztec bed, which as stated above is probably the same as the No. 2 bed of the Gibson section. Near the abandoned Aztec mine the bed is 10 feet thick, including two partings near the top (86); this is the greatest thickness of coal observed in the Gallup district. At the Summit mine, north of the Puerco, the bed is nearly 4 feet thick (87). From the Aztec mine south to the township line the Aztec bed ranges in thickness from 1 foot 11 inches to 4 feet 7 inches (76–85), the maximum being found at the abandoned Schauer mine. Several other valuable beds, not named, crop out in this area and are shown in the columnar sections (76–79, 82, 85, 86).

Old Enterprise coal bed.—In the SW. ¼ sec. 14, T. 15 N., R. 19 W., a bed of coal 2 feet 6 inches thick (121) was once worked in the old Enterprise mine. At places in the workings the sandstones above and below the coal were found so close together that operation was not profitable and the mine was abandoned. The bed becomes very thin on the outcrop a quarter of a mile south of the mine. In the SE. ¼ sec. 14 a coal bed 1 foot 11 inches thick (126), seen near the foot of the hill, is probably the Old Enterprise bed.

Lying 50 to 60 feet above the Old Enterprise bed is an unnamed coal, which is 2 feet 5 inches thick (121) in a prospect drift near the Enterprise mine. This coal crops out as a commercial bed in approximately the same area as the Old Enterprise coal (120, 126).

Enterprise coal bed.—After the old Enterprise mine was abandoned, work was begun in the Enterprise bed, stratigraphically nearly 100 feet higher. This bed is 3 feet 10 inches thick (121) at the mouth of the mine but is reported to average 3 feet in the workings. The Enterprise bed gradually thins toward the northwest and is only 1 foot 6 inches thick (117) at the center of sec. 10; from this point to the township line it is concealed by alluvium. East of the Enterprise mine it was not recognized as a valuable bed.

Clark coal bed.—The Clark bed was formerly worked extensively in the Clark mine, northwest of Gallup, where it is reported to range from 4 feet 6 inches to 8 feet 6 inches in thickness. At the mouths of two of the old slopes the bed shows about 6 feet of clear coal (122, 124). The Clark bed can be traced northwestward to the township line and southeastward to the river, but along most of the outcrop it is not much over 14 inches in thickness, and at a few places it is even thinner and worthless (114–121, 126–131).

Several lenses of coal above the Clark bed have valuable thickness at many places in the western part of the district; measurements of these beds are given in the columnar sections.

South of Puerco River the Gibson member contains a number of valuable beds whose thickness is shown in the columnar sections (132–142). One of these beds has been opened in a small mine in the SE. ¼ sec. 31, T. 15 N., R. 18 W.

PHYSICAL AND CHEMICAL CHARACTERISTICS

The coal of the Gallup district is a subbituminous coal of good grade. It is black and lustrous and in places contains jetlike woody layers. Small irregular lumps of amber-colored resin are common in the coal, especially in the No. 5 bed of the Gibson member. The coal is hard and brittle and breaks readily on handling; in former years the small pieces and dust were discarded, but in 1919 much of it was salvaged from the old waste piles and used in a cement plant at El Paso, Tex. 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 cars. The coal of the Gallup district is a good steaming variety, but attempts to coke it have not met with success.

Additional light on the character of coal is given by the chemical analyses. Samples of coal for analysis were obtained by "selecting a representative face of the bed to be sampled; cleaning the face, making a cut across it from roof to floor, and rejecting or including impurities according to a definite plan as these are included or excluded in mining operations; reducing the gross sample, by crushing and quartering, to about 4 pounds; and immediately sealing the 4-pound sample in an air-tight container for shipment to the laboratory."[36] A proximate analysis is then made to determine the percentages of moisture, volatile matter (gases), fixed carbon, ash, and sulphur; an ultimate analysis, which involves more complex and hence more expensive processes, may also be made to show the percentages of the actual elements composing the coal, such as carbon, hydrogen, nitrogen, oxygen, and sulphur. In addition, the heating efficiency is determined and expressed in British thermal units. In the production of heat the volatile matter and the fixed carbon are to be considered as the valuable constituents, and the moisture, ash, and sulphur as injurious constituents.

[36] U. S. Bur. Mines Bull. 22, p. 8, 1913.

The accompanying table gives analyses of 43 samples of coal from the Gallup district. In this table the analyses are given in three forms, marked A, B, and C. 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 removed; these forms, which are obtained from the others by recalculation, are useful chiefly to engineers. The analyses made by the Geological Survey and the Bureau of Mines have been carried out at three different laboratories under different sets of conditions. Determinations bearing laboratory Nos. 1 to 5146 were made at the St. Louis laboratory, where gasoline gas was used for fuel. Analyses Nos. 5147 to 7100 were made in the laboratory of the Carnegie Technical Schools, Pittsburgh, where the fuel was natural gas under a pressure of about 10 inches of water. Analyses Nos. 7101 to 9120 were made at the present laboratory of the Bureau of Mines in Pittsburgh, during a period in which the natural gas had a very low pressure. Analyses Nos. 9121 to 16400 were made also at the Pittsburgh laboratory, but the pressure of the gas was kept at 10 to 14 inches of water. Owing to the different conditions, determinations of fixed carbon and volatile matter in these analyses are not strictly comparable. In analyses Nos. 1–5146 and 9121–16400 the determinations agree fairly closely; in Nos. 7101–9120 the determinations are distinctly lower in volatile matter and higher in fixed carbon; and in Nos. 5147–7100 the determinations fall about midway between those of the other groups. In analyses later than No. 16400 all volatile-matter determinations at the Pittsburgh laboratory of the Bureau of Mines have been made in an electric furnace, thus insuring more stable conditions and a higher percentage of volatile matter.

Analyses of coal samples from the Gallup coal district, N. Mex.

[By the U. S. Geological Survey and the Bureau of Mines]

Coal of the Gibson coal member of the Mesaverde formation

Bed	Mine	Location: Quarter	Location: Sec.	Location: T. N.	Location: R. W.	Laboratory No.	Air-drying loss	Form of analysis	Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Proximate: Ash	Ultimate: Sulphur	Ultimate: Hydrogen	Ultimate: Carbon	Ultimate: Nitrogen	Ultimate: Oxygen	Heating value (British thermal units)
No. 1	Navajo	SE.	33	16	18	19131	4.8	A	12.5	38.9	39.4	9.17	0.43	5.89	60.85	1.09	22.57	10,800
								B		44.4	45.1	10.49	.49	5.15	69.58	1.25	13.04	12,350
								C		49.7	50.3		.55	5.75	77.73	1.40	14.57	13,800
No. 2	Heaton	NW.	35	16	18	19286	6.7	A	14.6	38.8	40.9	5.7	0.60					11,030
								B		45.4	47.9	6.7	.70					12,920
								C		48.7	51.3		.75					13,840
Do	do	NW.	35	16	18	32378	4.3	A	15.2	38.2	42.1	4.50	0.41	6.15	62.95	1.15	24.84	11,070
								B		45.1	49.6	5.31	.48	5.26	74.27	1.36	13.32	13,060
								C		47.6	52.4		.51	5.56	78.44	1.44	14.05	13,790
Do	Weaver	SE.	34	16	18	19137	5.5	A	14.1	39.2	41.9	4.8	0.49					11,300
								B		45.6	48.8	5.6	.57					13,150
								C		48.3	51.7		.60					13,940
Do	Navajo	SE.	33	16	18	19132	5.7	A	14.1	39.7	42.2	4.00	0.58	6.13	64.15	1.16	23.98	11,320
								B		46.2	49.1	4.65	.67	5.32	74.64	1.35	13.37	13,170
								C		48.5	51.5		.70	5.58	78.28	1.42	14.02	13,810
No. 3	Heaton	NW.	35	16	18	19288	8.5	A	16.0	38.1	41.3	4.6	0.85					10,980
								B		45.3	49.2	5.5	1.01					13,070
								C		47.9	52.1		1.07					13,830
Do	Weaver	SE.	34	16	18	1024		A	12.2	41.7	43.1	3.1	0.53					
								B		47.5	49.1	3.5	.60					
								C		49.2	50.8		.63					
Do	do	SE.	34	16	18	19138	6.4	A	15.8	38.0	43.1	3.14	0.45	6.28	64.08	1.11	24.94	11,300
								B		45.1	51.2	3.73	.53	5.37	76.12	1.32	12.93	13,430
								C		46.9	53.1		.55	5.58	79.07	1.37	13.43	13,950
Do	do	SE.	34	16	18	32332	4.8	A	14.2	39.0	43.3	3.52	0.53	6.17	64.39	1.04	24.35	11,390
								B		45.4	50.5	4.10	.62	5.35	75.07	1.21	13.65	13,280
								C		47.3	52.7		.65	5.58	78.28	1.26	14.23	13,850

No. 3½	Heaton	NW.	35	16	18	19287	7.5	A	15.0	38.1	43.6	3.3	0.53	----	----	----	----	11,350
								B	----	44.8	51.3	3.9	.62	----	----	----	----	13,350
								C	----	46.6	53.4	----	.65	----	----	----	----	13,890
Do	Weaver	SE.	34	16	18	1026	----	A	11.0	42.6	42.5	3.9	0.55	----	----	----	----	11,890
								B	----	47.9	47.7	4.4	.62	----	----	----	----	13,350
								C	----	50.1	49.9	----	.65	----	----	----	----	13,970
Do	do	SE.	34	16	18	19139	5.5	A	13.5	37.8	42.5	6.24	0.36	5.95	63.37	1.10	22.98	11,140
								B	----	43.6	49.2	7.21	.42	5.14	73.26	1.27	12.70	12,880
								C	----	47.0	53.0	----	.45	5.54	78.95	1.37	13.69	13,880
No. 5	do	SE.	34	16	18	19140	5.7	A	13.9	39.0	40.6	6.5	0.47	----	----	----	----	11,100
								B	----	45.3	47.2	7.5	.55	----	----	----	----	12,890
								C	----	48.9	51.1	----	.59	----	----	----	----	13,940
Do	do	SE.	34	16	18	32335	5.2	A	13.8	37.5	40.7	8.04	0.64	6.04	61.18	1.04	23.06	10,840
								B	----	43.5	47.2	9.32	.74	5.23	70.93	1.21	12.57	12,570
								C	----	48.0	52.0	----	.82	5.77	78.22	1.33	13.86	13,860
Do	Navajo	SE.	33	16	18	19133	6.1	A	14.0	39.5	41.1	5.4	0.49	----	----	----	----	11,260
								B	----	45.9	47.8	6.3	.57	----	----	----	----	13,100
								C	----	49.0	51.0	----	.61	----	----	----	----	13,980
Do	do	SE.	33	16	18	19134	5.3	A	12.4	39.1	39.5	9.0	0.44	----	----	----	----	10,980
								B	----	44.6	45.1	10.3	.50	----	----	----	----	12.540
								C	----	49.7	50.3	----	.56	----	----	----	----	13,980
Do	do	SE.	33	16	18	19135	5.7	A	13.2	39.1	40.5	7.21	0.45	6.04	62.73	1.13	22.44	11,100
								B	----	45.1	46.6	8.31	.52	5.26	72.26	1.30	12.35	12,780
								C	----	49.2	50.8	----	.57	5.74	78.81	1.42	13.46	13,940
Do	Navajo No. 1	SE.	33	16	18	32350	4.3	A	13.7	38.5	41.3	6.54	0.56	6.06	62.85	1.11	22.88	11,120
								B	----	44.6	47.8	7.58	.65	5.25	72.81	1.29	12.42	12,880
								C	----	48.2	51.8	----	.70	5.68	78.78	1.40	13.44	13,930
Do	Navajo No. 2	SE	33	16	18	32338	4.0	A	12.2	37.9	41.7	8.2	0.46	----	----	----	----	10,980
								B	----	43.1	47.5	9.4	.52	----	----	----	----	12.510
								C	----	47.6	52.4	----	.57	----	----	----	----	13,800
Do	do	SE	33	16	18	32339	4.1	A	13.1	37.7	41.3	7.9	0.44	----	----	----	----	10,890
								B	----	43.4	47.6	9.1	.51	----	----	----	----	12,540
								C	----	47.7	52.3	----	.56	----	----	----	----	13,780
Do	do	SE.	33	16	18	32340	5.5	A	14.4	36.4	41.3	7.9	0.51	----	----	----	----	10,710
								B	----	42.6	48.2	9.2	.60	----	----	----	----	12,510
								C	----	46.9	53.1	----	.66	----	----	----	----	13,780
Do	do	SE.	33	16	18	32341	3.4	A	13.0	39.1	40.6	7.3	0.47	----	----	----	----	11,010
								B	----	44.9	46.7	8.4	.54	----	----	----	----	12,650
								C	----	49.0	51.0	----	.59	----	----	----	----	13,810

Analyses of coal samples from the Gallup coal district, N. Mex.—Continued

Coal of the Gibson coal member of the Mesaverde formation—Continued

Bed	Mine	Location				Laboratory No.	Air-drying loss	Form of analysis	Proximate				Ultimate					Heating value (British thermal units)
		Quarter	Sec.	T. N.	R. W.				Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
No. 5	Navajo No. 2	SE.	33	16	18	32342	4.3	A	13.2	37.8	41.1	7.94	0.50	5.87	61.99	1.01	22.69	10,920
								B	----	43.5	47.4	9.15	.58	5.08	71.40	1.16	12.63	12,580
								C	----	47.8	52.2	----	.64	5.59	78.59	1.28	13.90	13,850
Aztec (?)	Beddow (Coal Basin)	SW.	8	15	18	19222	10.0	A	16.2	38.1	40.8	4.9	0.61	----	----	----	----	11,000
								B	----	45.4	48.7	5.9	.73	----	----	----	----	13,120
								C	----	48.2	51.8	----	.78	----	----	----	----	13,930
"Coal Basin No. 1" [Aztec ?].	do	SW.	8	15	18	32272	3.9	A	14.4	38.9	41.3	5.4	0.50	----	----	----	----	11,190
								B	----	45.4	48.3	6.3	.58	----	----	----	----	13,070
								C	----	48.5	51.5	----	.62	----	----	----	----	13,950
Do	do	SW.	8	15	18	32273	4.1	A	14.3	38.8	40.0	6.9	0.43	----	----	----	----	10,990
								B	----	45.2	46.7	8.1	.50	----	----	----	----	12,830
								C	----	49.2	50.8	----	.54	----	----	----	----	13,960
Do	do	SW.	8	15	18	32274	4.0	A	14.4	38.8	40.8	6.04	0.46	6.12	62.63	1.21	23.54	11,110
								B	----	45.3	47.7	7.05	.54	5.28	73.14	1.41	12.58	12,970
								C	----	48.7	51.3	----	.58	5.68	78.68	1.52	13.54	13,950
Aztec (?)	Allison (Diamond)	SW.	18	15	18	19217	9.3	A	15.2	38.1	40.6	6.1	0.58	----	----	----	----	10,950
								B	----	44.9	47.9	7.2	.68	----	----	----	----	12,920
								C	----	48.4	51.6	----	.73	----	----	----	----	13,910
Do	do	SW.	18	15	18	19218	9.0	A	14.8	35.4	38.0	11.8	0.43	----	----	----	----	10,150
								B	----	41.6	44.5	13.9	.50	----	----	----	----	11,910
								C	----	48.3	51.7	----	.58	----	----	----	----	13,830
Do	do	SW.	18	15	18	19219	8.2	A	14.3	38.6	40.3	6.8	0.40	----	----	----	----	10,950
								B	----	45.1	46.9	8.0	.47	----	----	----	----	12,770
								C	----	49.0	51.0	----	.51	----	----	----	----	13,880
Do	do	SW.	18	15	18	19220	8.8	A	14.8	37.2	39.7	8.30	0.50	6.02	60.78	1.07	23.33	10,700
								B	----	43.7	46.6	9.74	.59	5.14	71.31	1.26	11.96	12,560
								C	----	48.4	51.6	----	.65	5.69	79.00	1.40	13.26	13,910
"Diamond No. 1"	do	SW.	18	15	18	32278	3.2	A	14.5	38.5	40.4	6.63	0.45	6.09	62.62	1.08	23.13	11,010
								B	----	45.0	47.3	7.75	.53	5.24	73.20	1.26	12.02	12,870
								C	----	48.8	51.2	----	.57	5.68	79.35	1.37	13.03	13,950

"Diamond No. 2"	do	SW.	18	15	18	32279	4.3	A	16.0	36.7	38.9	8.37	0.44	6.04	59.63	1.10	24.42	10,510
								B	--------	43.7	46.3	9.97	.52	5.07	71.01	1.31	12.12	12,520
								C	--------	48.5	51.5	--------	.58	5.63	78.87	1.46	13.46	13,910
Clark	Clark	NE.	14	15	19	2434	9.3	A	14.0	38.4	42.1	5.5	0.54	--------	--------	--------	--------	--------
								B	--------	44.7	48.9	6.4	.63	--------	--------	--------	--------	--------
								C	--------	47.7	52.3	--------	.67	--------	--------	--------	--------	--------
Coal of the Dilco coal member of the Mesaverde formation																		
Crown Point	Otero	NW.	14	15	18	1027	--------	A	9.1	40.8	40.2	9.9	1.27	--------	--------	--------	--------	--------
								B	--------	44.9	44.3	10.9	1.40	--------	--------	--------	--------	--------
								C	--------	50.3	49.7	--------	1.57	--------	--------	--------	--------	--------
Thatcher	do	NW.	14	15	18	1028	--------	A	9.7	41.4	40.8	8.1	1.55	--------	--------	--------	--------	11,620
								B	--------	45.9	45.2	8.9	1.72	--------	--------	--------	--------	12,870
								C	--------	50.4	49.6	--------	1.88	--------	--------	--------	--------	14,130
Black Diamond	Gallup Southwestern	SE.	21	15	18	19162	4.0	A	11.4	39.9	42.2	6.5	0.75	--------	--------	--------	--------	11,640
								B	--------	45.0	47.7	7.3	.85	--------	--------	--------	--------	13,140
								C	--------	48.5	51.5	--------	.92	--------	--------	--------	--------	14,180
Black Diamond (?)	Bartlett	SE.	4	15	18	19136	4.6	A	11.8	38.1	39.7	10.40	0.65	5.71	61.57	1.14	20.53	10,900
								B	--------	43.2	45.0	11.79	.74	4.99	69.80	1.29	11.39	12,360
								C	--------	49.0	51.0	--------	.84	5.66	79.13	1.46	12.91	14,010
Otero	Otero	NW.	14	15	18	1038	--------	A	10.8	40.3	42.8	6.1	1.06	--------	--------	--------	--------	--------
								B	--------	45.3	47.9	6.8	1.19	--------	--------	--------	--------	--------
								C	--------	48.5	51.5	--------	1.28	--------	--------	--------	--------	--------
Do	Caretto	SW.	14	15	18	19163	3.4	A	10.6	40.6	44.4	4.40	0.59	5.95	68.16	1.11	19.79	12,100
								B	--------	45.4	49.7	4.92	.66	5.33	76.22	1.24	11.63	13,530
								C	--------	47.7	52.3	--------	.69	5.61	80.16	1.30	12.24	14,230
Dilco 1 (Defiance)	Dilco (Jones)	NW.	22	15	19	19221	10.6	A	15.4	38.2	41.3	5.11	0.92	6.25	62.95	1.13	23.64	11,130
								B	--------	45.1	48.9	6.04	1.09	5.37	74.40	1.34	11.76	13,160
								C	--------	48.0	52.0	--------	1.16	5.72	79.18	1.43	12.51	14,000
Do	Defiance	SE.	16	15	19	19223	5.9	A	10.6	40.9	41.4	7.1	0.79	--------	--------	--------	--------	11,510
								B	--------	45.7	46.4	7.9	.88	--------	--------	--------	--------	12,880
								C	--------	49.7	50.3	--------	.96	--------	--------	--------	--------	13,990
Coal of the Gallup sandstone member of the Mesaverde formation																		
Myers (Richards)	Myers	SE.	20	15	19	19213	7.6	A	12.7	36.4	43.4	7.47	0.72	5.78	64.18	1.10	20.75	11,230
								B	--------	41.7	49.7	8.56	.82	5.01	73.52	1.26	10.83	12,870
								C	--------	45.7	54.3	--------	.90	5.48	80.40	1.38	11.84	14,070

19131. Collected 1,400 feet N. 21° W. of mouth of old slope by C. T. Lupton in 1914. Section[37] at point sampled: Coal (sampled), 1 foot 8½ inches; shale, ¾ inch; coal (sampled), 1 foot 8¾ inches; shale, 1 inch; coal, base not exposed (sampled), 2 feet 2+ inches.

19286. Collected 2,300 feet N. 30° W. of slope mouth by C. T. Lupton in 1914. Sample dry; represents 2 feet 11 inches of coal, entire thickness of bed.

32378. Collected from the face of the seventh west main entry by J. J. Forbes in 1919. Section at point sampled: Slate, 11 inches; bone, 5 inches; coal (sampled), 3 feet 1 inch; bony coal, 6 inches; slate, 7 inches.

19137. Collected 3,900 feet N. 6° W. of mine mouth by C. T. Lupton in 1914. Sample dry; represents 3 feet 8 inches of coal, entire thickness of bed.

19132. Collected 2,300 feet N. 21° W. of mouth of old slope by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal (sampled), 1 foot 8 inches; bone, ¾ inch; coal (sampled), 1 foot 2 inches; bone, ½ inch; coal (sampled), 1 foot 3½ inches.

19288. Collected 4,000 feet N. 37° W. of mine mouth by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal, bony, 7 inches; coal (sampled), 2 feet 4 inches; coal, bony, 8 inches; coal (sampled), 5 inches.

1024. Collected about 2,000 feet in mine by M. R. Campbell in 1904. Sample represents 4 feet 1 inch of coal, entire thickness of bed.

19138. Collected 3,450 feet N. 12° W. of mine mouth by C. T. Lupton in 1914. Sample dry; represents 4 feet 11 inches of coal, entire thickness of bed.

32332. Collected from the face of the sixth back entry by J. J. Forbes in 1919. Section at point sampled: Slate, 1 inch; bony coal, 3 inches; rock, 4 inches; bony coal, 5½ inches; bone, 6 inches; coal (sampled), 3 feet 2½ inches.

19287. Collected 3,300 feet N. 15° W. of mine mouth by C. T. Lupton in 1914. Sample dry; represents 3 feet 11 inches of coal, entire thickness of bed.

1026. Collected 600 feet in mine by M. R. Campbell in 1904. Sample represents 6 feet 3 inches of coal, entire thickness of bed.

19139. Collected 2,750 feet N. 2° W. of mine mouth by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal, bony (sampled), 11 inches; coal (sampled), 7 inches; bone, 6 inches; coal (sampled), 3 feet 8 inches.

19140. Collected 2,800 feet N. 42° W. of mine mouth by C. T. Lupton in 1914. Sample dry. Section at point sampled: Bone, 5½ inches; coal, bony, 5 inches; coal (sampled), 5 feet 2 inches.

32335. Collected from room 1 off second dip off seventh left entry by J. J. Forbes in 1919. Section at point sampled: Coal (sampled), 3½ inches; sandstone, 1½ inches; bony coal, 4 inches; coal (sampled), 5 feet 6 inches.

19133. Collected 2,500 feet N. 2° W. of mouth of No. 5 slope by C. T. Lupton in 1914. Section at point sampled: Coal (sampled), 11 inches; sandstone, 1½ inches; coal (sampled), 6 feet 3 inches.

19134. Collected 1,300 feet N. 55° W. of mouth of No. 5 slope by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal, bony, 5 inches; coal, 4 inches; coal, bony, 1 foot 2 inches; coal (sampled), 5 feet 3½ inches.

19135. Composite of samples Nos. 19133 and 19134.

32350. Collected from face of main slope by J. J. Forbes in 1919. Sample represents 6 feet 6 inches of coal, entire thickness of bed.

32338. Collected from face of main slope by J. J. Forbes in 1919. Section at point sampled: Bone, 5½ inches; rock, 6 inches; bony coal, 7½ inches; coal (sampled), 6 inches; slate, 6 inches; sandstone, 2 inches; coal (sampled), 5 feet 3½ inches.

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[37] All coal sections are given as measured from roof to floor.

32339. Collected from face of sixth west main entry by J. J. Forbes in 1919. Section at point sampled: Bone, 3½ inches; sandstone, 1½ inches; bone, 1½ inches; coal (sampled), 6 feet 1½ inches.

32340. Collected from face of fourth cross entry off fifth east entry by J. J. Forbes in 1919. Section at point sampled: Slate, 7 inches; sandstone, 2 inches; coal (sampled), 6 feet 3 inches.

32341. Collected from room 4 off first dip off fifth west entry by J. J. Forbes in 1919. Section at point sampled: Coal (sampled), 8 inches; slate 2 inches; coal (sampled), 3 feet 4 inches; bone, 2 inches; coal (sampled), 2 feet 4 inches.

32342. Composite of samples Nos. 32338–32341.

19222. Collected 300 feet west of shaft by C. T. Lupton in 1914. Sample dry; represents 3 feet 10½ inches of coal, entire thickness of bed.

32272. Collected from face of cut off entry by J. J. Forbes in 1919. Section at point sampled: Soapstone, 5 inches; coal (sampled), 4 feet 10 inches.

32273. Collected from face of straight east entry by J. J. Forbes in 1919. Section at point sampled: Bony coal, 1 foot 7 inches; coal (sampled), 2 feet 7 inches.

32274. Composite of samples Nos. 32272 and 32273.

19217. Collected 2,600 feet N. 55° W. of shaft by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal (sampled), 1 foot 4 inches; bone, ½ inch; coal (sampled), 2 feet 8½ inches.

19218. Collected 1,400 feet S. 85° W. of shaft by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal (sampled), 1 foot; bone and bony coal, 9 inches; coal (sampled), 7½ inches; bone, ½ inch; coal (sampled), 11 inches; coal, bony, 4 inches; coal (sampled), 2 feet 3 inches.

19219. Collected 3,300 feet N. 45° E. of shaft by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal and bone interbedded, 1 foot; coal (sampled), 11 inches; bone, ¾ inch; coal (sampled), 3 feet 9 inches; bone, 3½ inches; coal (sampled), 2 feet 2½ inches.

19220. Composite of samples Nos. 19217–19219.

32278. Collected in room 1 off twelfth cross entry off eighth cross entry by J. J. Forbes in 1919. Section at point sampled: Bony coal, 4 inches; slate, 1 inch; coal (sampled), 6 inches; slate, 1 inch; coal (sampled), 3 feet 10 inches.

32279. Collected from face of straight dip entry by J. J. Forbes in 1919. Section at point sampled: Coal (sampled), 9½ inches; slate, 4½ inches; coal (sampled), 2 feet 7 inches.

2434. Collected by M. K. Shaler in 1906. Section at point sampled: Coal (sampled), 2 feet; coal, bony, 1 foot; coal (sampled), 2 feet; shale, 3 inches; coal (sampled), 3 feet 3 inches.

1027. Collected 400 feet from mine mouth by M. R. Campbell in 1904. Section at point sampled: Coal (sampled), 3 feet 5 inches; shale, 8 inches; coal (sampled), 1 foot 5 inches.

1028. Collected 500 feet from mine mouth by M. R. Campbell in 1904. Sample represents 4 feet of coal, entire thickness of bed.

19162. Collected 1,200 feet south of mine mouth by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal, 2 inches; bone, 2 inches; coal (sampled), 10 inches; bone, 1½ inches; sandstone, 2 inches; coal (sampled), 3 feet 11 inches.

19136. Collected 430 feet south of shaft by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal (sampled), 2 feet 3 inches; sandstone, 1½ inches; coal (sampled), 1 foot 8 inches; bone, 2 inches; coal (sampled), 1 foot 9 inches.

1038. Collected 2,000 feet from mine mouth by M. R. Campbell in 1904. Section at point sampled: Coal (sampled), 1 foot 2 inches; shale, 9 inches; coal (sampled), 3 feet 2 inches.

19163. Collected 350 feet S. 15° E. of mine mouth by C. T. Lupton in 1914. Sample dry. Section at point sampled: Coal, 4 inches; shale, 3 inches; coal (sampled), 3 feet 2 inches.

19221. Collected 250 feet north of mine mouth by C. T. Lupton in 1914. Sample damp; represents 2 feet 6 inches of coal, entire thickness of bed.

19223. Collected 880 feet N. 85° E. of mine mouth by C. T. Lupton in 1914. Sample dry; represents 5 feet 9½ inches of coal, entire thickness of bed.

19213. Collected 205 feet N. 45° W. of mine mouth by C. T Lupton in 1914. Sample dry. Section at point sampled: Coal, hard and very bony, 3 inches; coal, slightly bony (sampled), 2 inches; coal (sampled), 2 feet 4 inches; bone, 1 inch.

COMPARISON WITH COAL FROM OTHER DISTRICTS

At present the Gallup coal can be shipped only by the Atchison, Topeka & Santa Fe Railway. Toward the east it must pass the Raton-Trinidad field of New Mexico and Colorado, which contains high-grade coking coal. Any Gallup coal shipped to the Pacific coast must compete with coals from California, Washington, and Utah. If the proposed railroad from Gallup to Colorado is built, the coal of the Gallup district will come into competition with the Durango and other coals of Colorado and Wyoming.

For comparison of the coal from the Gallup district with coal from other possibly competing fields the following table is useful. This table is believed to be fairly representative of the fields listed, as it is composed mainly of averages from a number of analyses. The figures refer to the condition of the coal "as received" at the laboratory, as this is closest to that of the coal purchased by the consumer.

Characteristics of coal from fields possibly competing with Gallup district

District	Moisture	Ash	Sulphur	Heating value (British thermal units)
New Mexico:				
Raton	3.0	12.5	0.65	12,670
Colorado:				
Durango	4.2	6.3	1.42	13,460
Hesperus	7.1	5.9	.60	12,670
Crested Butte	3.1	6.7	.67	13,650
Somerset	5.6	9.2	.43	12,430
Newcastle	7.1	5.2	.45	12,620
Sunlight	5.3	8.8	.76	12,420
Trinidad	1.7	13.0	.53	13,040
Canon City	9.1	7.5	.62	11,550
Lafayette	19.3	5.8	.35	9,840
Wyoming:				
Rock Springs	11.1	4.1	.92	11,820
Kemmerer	5.2	7.0	1.04	12,600
Utah:				
Sunnyside	8.2	6.7	1.15	13,060
Castlegate	4.3	5.7	.51	12,790
Hiawatha	6.3	6.5	.75	12,470
Washington:				
Renton	14.2	7.6	.68	10,550
Ravensdale	9.3	9.2	.57	11,440
Wilkeson-Carbonado	3.6	12.6	.58	12,800
Roslyn	3.9	12.2	.38	12,460

Consumers are in general most interested in coal for its heat-producing quality, and therefore comparisons are best made on the basis of the heating value. Such a comparison is shown graphically in Figure 3. In this diagram the heating value of the Gallup coal

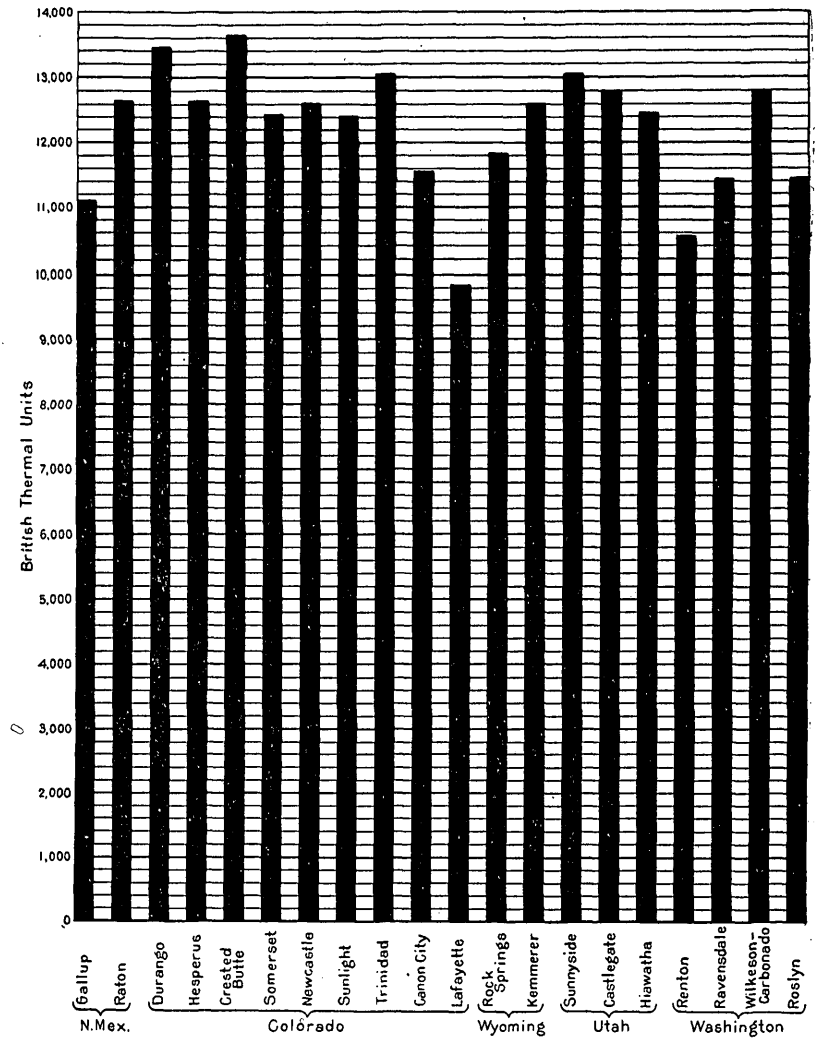

FIGURE 3.—Diagram showing heating value of coal from the Gallup district, N. Mex., and from possibly competing districts

(11,110 British thermal units), is an average of the figures from 27 analyses of samples from No. 2, No. 3, No. 3½, No. 5, Aztec, Black Diamond, and Dilco 1 beds, which furnish most of the coal mined in the Gallup district.

In using the figures given in the table of analyses it should be remembered that the sampler is much more careful in excluding impurities than the miner or even the operator in times of great scarcity of coal, and consequently the coal that reaches the market from these mines is liable to contain much more ash than that shown in the mine samples.

A comparison of results obtained on mine samples and on railroad car samples shows that on the average the ash in the car sample may be from 30 to 50 per cent greater than it is in the mine sample. Thus coal which shows 6 per cent ash in the mine sample is likely in the car sample to run from 7.8 to 9 per cent, but if the difference exceeds 50 per cent it indicates gross carelessness in mining or preparing for the market.

The composition of the mine sample may be regarded as the ideal toward which the commercial coal of the mine will approach more and more closely as better methods and more care is exercised in mining, and these two will agree whenever the best methods are used and every employee cooperates with the management in excluding impurities from the commercial output of the mine.

MINING DEVELOPMENT

HISTORY OF THE DISTRICT

"The first report of coal production in New Mexico was contained in the inaugural volume of Mineral Resources, covering the calendar year 1882. No output was reported by the Tenth United States Census, 1880, and though it is probable that some coal was taken out by ranchmen and miners for their own use prior to 1882, there had been no development on a commercial scale until that year." [38]

In 1882 the production of the Gallup district was 33,373 tons, most of which was used by the railroad. The annual output mounted steadily, and in 1886 the Gallup district became the largest producer in the State. This position was held until 1891, when a prolonged strike permitted Colfax County to take the lead; two years later the Gallup district again forged ahead, and it maintained first place for the next decade. In 1903 Colfax County once more took the lead, and in 1918 it produced nearly four times as much coal as the Gallup district. The production of the Gallup mines has risen steadily, however, with only a few fluctuations (see fig. 4), and in 1923 the output was 821,415 tons. The total production of the Gallup district from 1882 to the end of 1923 was 19,561,551 tons, or approximately one-fourth of the total output of the State during the same period.

[38] U. S. Geol. Survey Eighteenth Ann. Rept., pt. 5, p. 557, 1897.

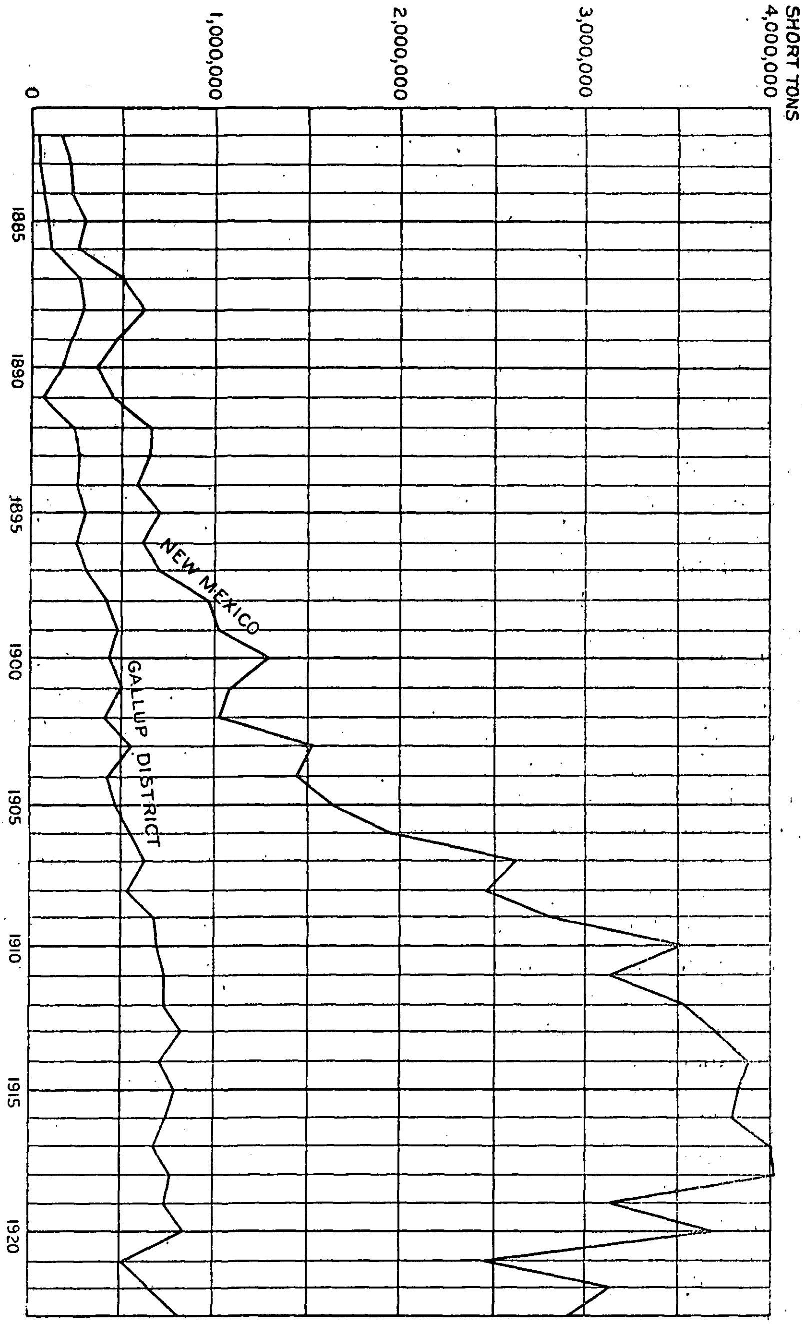

FIGURE 4.—Diagram showing annual production of coal in the Gallup district and in New Mexico, 1882-1923

Shortly after mining operations began, Gallup coal was being shipped by railroad to points in New Mexico and Arizona and even as far west as California. Later the low price of fuel oil caused a decrease in the demand for coal, and the market became somewhat more localized. At present much of the coal is being shipped to copper smelters in Arizona.

During the development of the district many mines have been worked out, and others were abandoned because of mining troubles or low prices. In years of greater demand new mines were opened and operations were resumed in some of the abandoned mines.

ACTIVE MINES

The following notes cover conditions in 1920, modified by such later information as has been obtained.

The Allison (Diamond) mine of the Diamond Coal Co. is in the SW. ¼ sec. 18, T. 15 N., R. 18 W., at the town of Allison. It is operated by a shaft 80 feet deep to the Aztec (?) bed of the Gibson coal member. Another bed, 4 feet thick, is reported to lie 20 feet below the bed now worked. The daily output of the mine in 1919 was about 500 tons. The mine is connected with the Santa Fe Railway by a standard-gage spur.

The Beddow (Coal Basin) mine of the Diamond Coal Co. is in the SW. ¼ sec. 8, T. 15 N., R. 18 W., at the village of Coal Basin. The bed now worked is thought to be the same as that in the Allison mine; it is reached by a shaft 315 feet deep. The bed is reported to range in thickness from 2 feet 6 inches to 3 feet 6 inches north and west of the shaft and to average about 4 feet 6 inches to the southeast. In 1919 the daily output was about 300 tons. A spur connects the mine with the railway.

The Boardman mine, owned by the Boardman Coal Co., is in the SE. ¼ sec. 14, T. 15 N., R. 18 W. The mine is opened as a slope in the main Otero bed of the Dilco coal member. About 25 tons daily is taken from the mine and moved by truck to a railroad siding half a mile distant.

The Brown mine, now owned by Louis Kauzlarich, is in the SW. ¼ sec. 10, T. 15 N., R. 18 W. The mine is a slope in the Black Diamond bed of the Dilco coal member. Coal is taken out during the winter and sold for local use in Gallup. The mine is equipped with a short tramway to the tipple.

The Bubany mine, owned by the Bubany Brothers, is in the SW. ¼ sec. 10, T. 15 N., R. 18 W. It is a small wagon mine in the Black Diamond bed of the Dilco coal member and is worked intermittently. The mine has broken through into the workings of the abandoned Sunshine mine.

The Caretto mine, owned by Dominic Caretto, is in the SW. ¼ sec. 14, T. 15 N., R. 18 W. It is a small wagon mine, operated when prices warrant. The mine is in the main Otero bed of the Dilco coal member.

The Defiance (Morris) mine of the Defiance Coal Co. is in the SE. ¼ sec. 16, T. 15 N., R. 19 W. The mine is a slope in the Dilco 1 (Defiance) bed of the Dilco coal member. Mr. George Mix reports that in February, 1921, the daily output was 700 to 800 tons. The coal is moved by tramway to the tipple at the abandoned Dilco mine, which is on a spur of the railroad.

The Gallup Southwestern mines of the Gallup Southwestern Coal Mining Co. are in the E. ½ sec. 21, T. 15 N., R. 18 W. They are slopes driven in the Black Diamond bed of the Dilco coal member. The workings have been extended southward, and coal is now being taken from the lower part of the Gallup Fuel Co.'s mines in sec. 27. In 1919 the daily output was 180 tons. The mines are on a spur of the Santa Fe Railway.

The Heaton mine of the Gallup American Coal Co. is in the NW. ¼ sec. 35, T. 16 N., R. 18 W. Coal is taken from No. 2 and No. 3 beds of the Gibson coal member. The slope enters No. 2 bed, then runs through No. 3 bed to No. 3½ bed; after a short distance it encountered a fault, and the slope was carried back through a rock tunnel to No. 3 bed. In 1920 the daily production was 275 tons. A 4-mile spur connects the mine with the railroad near Gallup.

The Kauzlarich mine, leased from the Gallup American Coal Co. by Louis Kauzlarich, is in the SW. ¼ sec. 10, T. 15 N., R. 18 W. It is a wagon mine in the Black Diamond bed of the Dilco coal member, from which 30 to 40 tons daily is produced during periods of operation. The mine has broken through into the abandoned Black Diamond mine.

The Keeper mine, owned by George Keeper, is in the NE. ¼ sec. 16, T. 15 N., R. 18 W. It is a slope in the Black Diamond bed of the Dilco coal member. The coal was found to be rather badly oxidized for 200 to 300 feet down the slope; beyond this it is of good quality, but the parting is much thicker than is usual in the Black Diamond bed. The daily production is about 50 tons, which is hauled by wagons.

The McDermott mine, owned by James McDermott and others, is in the SE. ¼ sec. 9, T. 15 N., R. 18 W. It is a wagon mine in the Black Diamond bed of the Dilco coal member; a 500-foot tramway connects the mine with the tipple.

The Manning mine, owned by C. C. Manning, is in the SE. ¼ sec. 34, T. 15 N., R. 19 W. It is a small wagon mine in the uppermost bed of the Dilco coal member (possibly the Dilco 1 bed).

The Morelli (Red Hill) mine is in the NE. ¼ sec. 24, T. 15 N., R. 18 W. It is opened in the Black Diamond bed of the Dilco coal member. The daily output is 25 tons, which is hauled by truck and sold in Gallup.

The Navajo No. 1 and No. 2 mines of the Gallup American Coal Co. are in the SE. ¼ sec. 33, T. 16 N., R. 18 W. The mines are slopes almost a mile in length, connected near their lower ends. The No. 5 bed of the Gibson coal member supplies about 550 tons a day, which is shipped over a branch of the spur that runs to the Weaver mine.

The No. 5 mine of the Gallup American Coal Co., in the SE. ¼ sec. 32, T. 16 N., R. 18 W., was opened in 1922. It is operated through a shaft 785 feet deep and is equipped for a maximum output of 4,000 tons a day. At present about half that quantity daily is taken from the No. 5 bed of the Gibson coal member.

The new Otero mine, owned by S. E. Wood, is in the NE. ¼ sec. 14, T. 15 N., R. 18 W. This mine, which is on the spur to the Heaton mine, was opened in 1920 in the Thatcher bed of the Dilco coal member.

The Richards mine of the H. Richards Coal Mining Co. is in the SW. ¼ sec. 21, T. 15 N., R. 19 W. It was opened in 1919 in the Myers (Richards) beds of the Gallup sandstone member, and a short spur was built from the railroad in 1920. The daily output in 1919 was 30 tons.

The Rocky Cliff mine, leased by Zambarelon Brothers from the Gallup American Coal Co., is in the NE. ¼ sec. 15, T. 15 N., R. 18 W. This mine was abandoned for many years but was reopened in 1920. About 20 tons daily is taken from the Otero bed of the Dilco coal member and moved by wagon half a mile to the railroad.

The Weaver mine of the Gallup American Coal Co. is in the SE. ¼ sec. 34, T. 16 N., R. 18 W. It produces about 500 tons daily from No. 3 and No. 5 beds of the Gibson coal member. The mine is connected by a spur to the railroad near Gallup.

The Winter mine is in the NW. ¼ sec. 21, T. 15 N., R. 18 W. It is a small wagon mine, begun late in 1920.

Two small wagon mines that bear no names are in the SE. ¼ sec. 31 and the NE. ¼ sec. 24, T. 15 N., R. 18 W.

ABANDONED MINES

For various reasons operations have ceased in many mines of the Gallup district. A brief summary of the abandoned mines is given in the following table:

Abandoned mines in the Gallup coal district, N. Mex., 1920

Mine	Locality	Bed	Member of Mesaverde formation	Remarks
Aztec	SW. ¼ sec. 16, T. 15 N., R. 18 W.	Aztec	Gibson	Slope.
Bartlett	SE. ¼ sec. 4, T. 15 N., R. 18 W.	Black Diamond (?).	Dilco	Shaft 200 feet deep.
Baudino	NW. ¼ sec. 4, T. 15 N., R. 18 W.	No. 2	Gibson	Slope. Workings broken through into Caledonia mine.
Black Diamond	SW. ¼ sec. 10, T. 15 N., R. 18 W.	Black Diamond.	Dilco	Slope.
Caledonia	W. ½ sec. 4, T. 15 N., R. 18 W.	No. 2	Gibson	Slope. Old workings now on fire.
Casna	NW. ¼ sec. 19, T. 15 N., R. 18 W.	Aztec (?)	Gibson	Slope.
Catalpa	NE. ¼ sec. 34, T. 15 N., R. 18 W.	Thatcher	Dilco	Slope. Large waste piles indicate important development.
Clark	NE. ¼ sec. 14, T. 15 N., R. 19 W.	Clark	Gibson	Slope and drift. Formerly a large mine, with several openings.
Crown Point	NW. ¼ sec. 11, T. 15 N., R. 18 W.	Crown Point	Dilco	Shaft 200 feet deep. Bed 3 to 5 feet thick; thinned out east of shaft.
Dilco (Jones)	NW. ¼ sec. 22, T. 15 N., R. 19 W.	Dilco 1, 2, 3, 4.	Dilco	Three slopes. Daily output in 1919, 125 tons. Abandoned early in 1921. On spur of railroad.
Enterprise	SW. ¼ sec. 14, T. 15 N., R. 19 W.	Enterprise and Old Enterprise	Gibson	Drifts. Began about 1914. In 1919 daily output was 50 tons from Enterprise bed, hauled on 1-mile tramway to spur of railroad. Abandoned in 1920.
Gallup (Gibson).	SW. ¼ sec. 34, T. 16 N., R. 18 W.	No. 5	Gibson	Slope 5,000 feet long. One of best mines in district; abandoned in 1904 because of fire.
Gallup Fuel Co.	NW. ¼ sec. 27, T. 15 N., R. 18 W.	Black Diamond.	Dilco	Several slopes.
Myers	SE. ¼ sec. 20. T. 15 N., R. 19 W.	Myers (Richards).	Gallup	Slope.
Otero	N. ½ sec. 14, T. 15 N., R. 18 W.	Crown Point, Thatcher, Otero.	Dilco	Slope in Crown Point bed, slope in Thatcher bed, two slopes in Otero beds.
Schauer	SE. ¼ sec. 28, T. 15 N., R. 18 W.	Aztec	Gibson	Slope.
Sharp	NE. ¼ sec. 16, T. 15 N., R. 18 W.	Black Diamond.	Dilco	Slope.
Smith	SE. ¼ sec. 20, T. 15 N., R. 19 W.	Myers (Richards).	Gallup	Slope. Few cars of coal shipped in 1886.
Stewart	SE. ¼ sec. 9, T. 15 N., R. 18 W.	Black Diamond.	Dilco	Slope.
Summit (Graveyard).	NW. ¼ sec. 16, T. 15 N., R. 18 W.	Aztec	Gibson	Slope.
Sunshine	SE. ¼ sec. 10, T. 15 N., R. 18 W.	Black Diamond.	Dilco	Slope. First slope entered at horizon of Thatcher bed; second slope directly on Black Diamond bed.
Thatcher	NW. ¼ sec. 13, T. 15 N., R. 18 W.	Thatcher	Dilco	Slope. Black Diamond also reached in this mine.
	NW. ¼ sec. 2, T. 15 N., R. 18 W.	Nos. 2 and 3.	Gibson	Slopes. Workings on fire.
	SW. ¼ sec. 14, T. 15 N., R. 18 W.	C	Dilco	Small wagon mine.
	SE. ¼ sec. 30, T. 15 N., R. 17 W.	A	Dilco	Called on old map "Navajo Jim's mine."
	SW. ¼ sec. 16, T. 15 N., R. 19 W.	Dilco 5	Dilco	Slope.
	SE. ¼ sec. 34, T. 15 N., R. 19 W.		Dilco	Several small tunnels.

COAL IN THE ZUNI INDIAN RESERVATION

In the Zuni Reservation coal beds of commercial importance are found in the Gallup sandstone member and the Dilco coal member of the Mesaverde formation. The upper part of the Mesaverde has been entirely eroded from the reservation, and the lower members have been removed from the west half, so that the coal is present only in three townships and parts of four others in the east half, as shown on the map (Pl. XVI, in pocket).

The most valuable coal is found in a zone of very lenticular coal beds below the "pink sandstone" at the top of the Gallup sandstone member. These beds, which lie at the same horizon as the Myers beds of the Gallup district, were called by Winchester in his field notes the School Mine coal group, from the name of a small mine in sec. 6, T. 11 N., R. 17 W., from which coal has been taken for use at the Indian school at Blackrock. About 70 feet lower is a second zone of very lenticular beds, the Pescado coal group, which in general are too much broken by partings to be of value.

In T. 12 N., R. 17 W., coal is found at three horizons above the School Mine coal group. The beds, which are very irregular in thickness, have been assigned by the writer to the Dilco coal member but may belong in part to a higher member of the Mesaverde formation.

Measurements of coal beds in the reservation are shown graphically in Plate XVII (in pocket).

Two analyses are available to show the quality of coal in the Zuni Reservation:

Analyses of coal samples from School mine of U. S. Indian Service, sec. 6, T. 11 N., R. 17 W., N. Mex.

Laboratory No.	Air-drying loss	Form of analysis	Proximate				Ultimate					Heating value (British thermal units)
			Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
3952	3.9	A	7.7	37.6	38.7	15.98	1.48	5.67	60.55	0.99	15.33	11,250
		B	-------	40.8	41.9	17.32	1.60	5.21	65.65	1.07	9.15	12,190
		C	-------	49.3	50.7	-------	1.94	6.31	79.40	1.30	11.05	14,750
15032	11.0	A	14.7	34.9	41.6	8.82	.79	5.82	60.93	1.12	22.52	10,760
		B	-------	41.0	48.7	10.34	.93	4.91	71.42	1.31	11.09	12,670
		C	-------	45.7	54.3	-------	1.04	5.48	79.65	1.46	12.37	14,130

3952. Sample collected in standard manner 50 feet in mine by M. K. Shaler in 1906. Sample represents 3 feet 4 inches of coal, entire thickness of bed.

15032. Sample collected in standard manner from room 2 west of main entry by D. E. Winchester in 1912. Section at point sampled in descending order: Bone, 2 inches; coal (sampled), 1 foot 10 inches; bone, 2 inches; coal (sampled), 1 foot.

These samples show the coal to be of approximately the same quality as that mined in the Gallup district. However, the comparative thinness and irregularity of the beds, the small tonnage available, and the distance from the railroad make it improbable that the coal of the Zuni Reservation will ever have more than a local use.

OTHER ECONOMIC RESOURCES OF THE GALLUP-ZUNI BASIN

Although coal is the greatest natural resource of the Gallup-Zuni Basin, other resources have a present or future value.

Fire clay.—The New Mexico Fire-Brick Co. maintains a plant on the east edge of Gallup and takes about 35 tons of fire clay daily from the Gallup sandstone member of the Mesaverde formation. Some fire brick are sold locally, but most of those produced are shipped to smelters in Arizona. From 200 to 300 tons of ground fire clay annually is also sent to the smelters.

Sand.—The Gallup Crushed Sand Co., on land leased from the New Mexico Fire-Brick Co., operates a crusher and produces daily about 25 cubic yards of silica sand. The output is sold for mortar and concrete work and for locomotive and railroad use.

Building stone.—The "pink sandstone" at the top of the Gallup sandstone member is quarried at several places near Gallup and used by local builders. A quarry in the Wingate sandstone, in sec. 20, T. 10 N., R. 18 W., has furnished material for several Government buildings at Black Rock.

Adobe.—A number of houses in Gallup and several mine villages are built either wholly or in part of adobe brick. Zuni Pueblo and the villages in the reservation are almost entirely of adobe. The use of the clay is purely local.

Crushed rock.—Augite minette from Twin Cones has been crushed and successfully used for concrete street paving in Gallup.

Water.—In a semiarid country like northwestern New Mexico the problem of obtaining sufficient water for irrigation, mining, and domestic use is very serious. The streams and rivers are dry except at times of flood, and then their water is unfit for man's use. Springs that once satisfied the needs of the Indians fall short of supplying the modern demands of a growing town. Gallup is especially fortunate, therefore, in obtaining a fairly satisfactory amount of excellent water from the Dakota sandstone at depths of 1,000 to 1,600 feet. Four town wells and three railroad wells have been drilled; the original well was at first artesian, but now all must be pumped. Other wells, ranging from shallow holes to those several hundred feet deep, supply the villages, mine camps, and scattered settlers in the basin.

Petroleum.—Three unsuccessful attempts have been made to find petroleum in the Gallup-Zuni Basin. In 1918 a well 1,155 feet deep was drilled in the SW. ¼ sec. 29, T. 15 N., R. 19 W., near Defiance Switch on the Santa Fe Railway. This well, located on the Torrivio anticline, began in the upper part of the Mancos shale and penetrated more than 200 feet of the Navajo sandstone. At 1,030 feet artesian water was found, flowing 25 gallons a minute. The well has been purchased for its water by the Santa Fe Railway.

In 1919 a well was drilled in the SW. ¼ sec. 17, T. 11 N., R. 19 W., near the highest part of the Piñon Springs anticline. Beginning a short distance below the top of the Chinle formation, this well reached a depth of 1,980 feet. According to Darton[39] the log of the well should be interpreted as follows:

Log of well in the SW. ¼ sec. 17, T. 11 N., R. 19 W., N. Mex., as interpreted by N. H. Darton

	Feet
Chinle, Shinarump, and Moenkopi formations:	
Shale, all red	0–1, 006
Sandstone, gray to white	1, 006–1, 010
Shale, red	1, 010–1, 070
Chupadera formation:	
Limestone	1, 070–1, 100
Sandstone, gray	1, 100–1, 355
Shale, red	1, 355–1, 630
Abo sandstone:	
Limestone, very hard; some grit	1, 630–1, 650
Shale, red	1, 650–1, 980

The writer is doubtful whether the Abo sandstone could be reached at a depth of 1,630 feet, unless the thicknesses of the Chinle, Moenkopi, and Chupadera formations as shown in Darton's table[40] and corroborated by Winchester are much too great. Drilling was stopped mainly because the drillers supposed the bottom of the hole to be near the base of the sedimentary rocks. It is unfortunate that drilling did not continue far enough to test all the possibilities of the Permian rocks and the Pennsylvanian beds if present.

It is reported that in 1923 a well drilled in sec. 25, T. 15 N., R. 18 W., reached a depth of 2,265 feet, without success. The lower part of the Mesaverde formation is at the surface in this vicinity.

[39] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 262, 1921.

[40] Idem, p. 259.

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