GEOLOGY OF ALAMOSA CREEK VALLEY, SOCORRO COUNTY, NEW MEXICO, WITH SPECIAL REFERENCE TO THE OCCURRENCE OF OIL AND GAS.

By Dean E. Winchester.

INTRODUCTION.

During a detailed study of the coal resources of a part of northern Socorro County, N. Mex., made in 1913 and 1914, considerable information relative to the stratigraphy and structure of the region was collected. Recent interest in the oil and gas possibilities of New Mexico makes it desirable to record the observations made, so that they may serve as a guide in the search for petroleum and natural gas.

FIELD WORK.

In the field examination the writer was assisted by Heath M. Robinson, W. T. Thom, jr., S. D. Greene, and Delbert Williams, each of whom took an active part in the collection of the information.

Geographic as well as geologic features were mapped in the field on a scale of 2 inches to the mile, and the accompanying map (Pl. V) is the result of the compilation of this information. The rock beds are folded and faulted and are intruded by igneous rocks, and considerable time was spent in the study of the structure. Much time was also given to measuring stratigraphic sections and to collecting fossils upon which to base correlations. Many large collections of invertebrate and plant fossils were made in the field and have been studied by T. W. Stanton and F. H. Knowlton. All surveys were tied to section corners either by stadia traverse or by direct triangulation. A careful study of the chemical analyses of the coals of this region furnishes suggestions concerning the possibility of the presence of petroleum and natural gas in the formations of the region.

GEOGRAPHY.

Location and extent.—The valley of Alamosa Creek covers an area of approximately 600 square miles, mostly in Socorro County, N. Mex. It lies north of the Bear, Gallina, and Datil mountains, between the Sierra Ladron on the east and the Continental Divide on the west, and extends northward as far as the north line of T. 4 N.

Surface features.—The valley is bounded on the south and east by low rugged mountains. The Bear Mountain range, to the southeast, consists of a large number of peaks, the highest of which are more than 7,600 feet above sea level. The Tertiary bedded volcanic rocks, sandstones, and conglomerates of the Datil formation, which make up these mountains, have been dissected into innumerable conical peaks and present an entirely different landscape from that shown in the Sierra Ladron, which lies a short distance east of the area shown on Plate V.

Between the Bear Mountains and the Gallina Mountains, to the west, there is a comparatively broad area which is deeply dissected by small streams that flow into Alamosa Creek. The Gallina Mountains, like the Bear Mountains, consist of the Tertiary rocks, which have been dissected into innumerable conical peaks having altitudes of 9,000 to 9,500 feet above sea level.

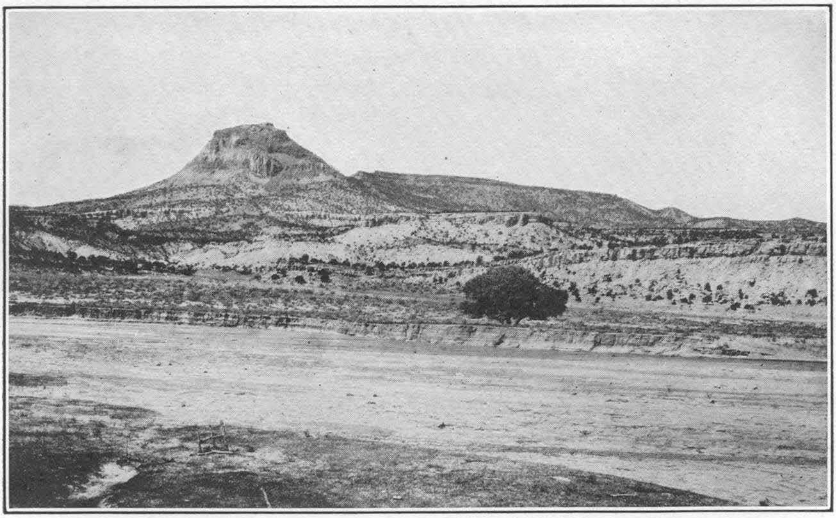
The Datil Mountains, west of the Gallina Mountains, are the highest and most rugged mountains in the area mapped. Like the Gallina and Bear mountains, they comprise a large number of high peaks carved from rocks of the Datil formation. Several of the higher peaks rise more than 9,600 feet above sea level. The east-west series of peaks shown on the map forms only a small part of the Datil Mountains. These mountains are clothed with pine timber, a considerable part of which is large enough to be of economic importance.

These three mountain ranges are separated from one another by comparatively low divides. That between the Bear and Gallina mountains is the lowest and accommodates the only wagon road by which the field may be entered from the south.

To the north of the main mountain ranges there are several high peaks which are locally designated mountains. D Cross Mountain (Pl. I, *A*), the highest of these peaks, is an igneous plug 2 miles north of Alamosa Creek, in the western part of T. 3 N., R. 8 W. It rises about 2,000 feet above the level of the creek, or 8,775 feet above sea level.

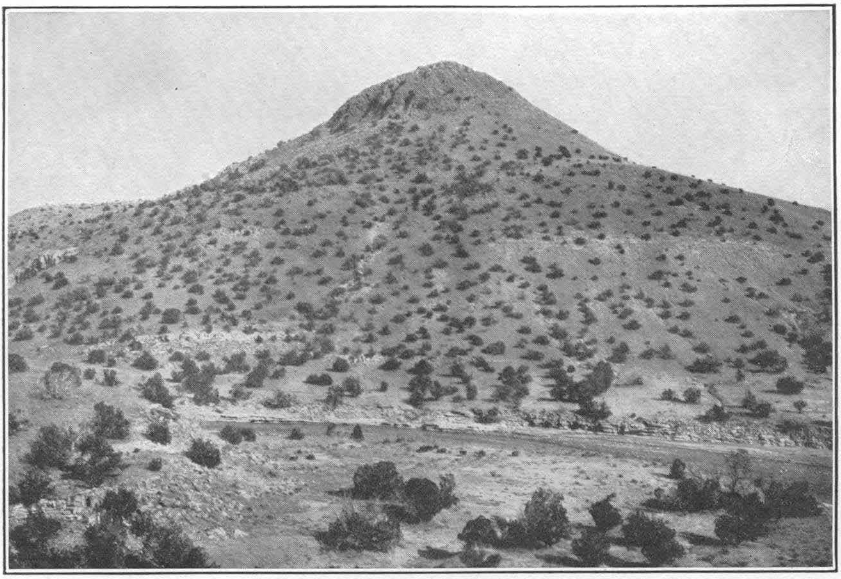
On the divide between Alamosa Creek and Miguel Canyon, 2 miles to the west of D Cross Mountain, is Bell Mountain, an igneous intrusive mass which rises to an altitude only a little lower than that of D Cross Mountain. Broom Mountain, 3 miles north of the area mapped, on the line between Rs. 7 and 8, is a flat-topped landmark capped by sandstones of Cretaceous age and stands about 8,400 feet above sea level.

Less conspicuous buttes in several parts of the field reach altitudes 200 feet or more above the general level of the surrounding area. Three of the most noted of these are the Tres Hermanos Buttes, in sec. 28, T. 3 N., R. 7 W. These buttes are formed of igneous rock which has been forced up into the Cretaceous strata. La Cruz Peak (Pl. I, *B*), in sec. 13, T. 2 N., R. 6 W., about 6,975 feet above sea level, and La Jara, in sec. 11, T. 2 N., R. 5 W., about 6,875 feet above sea



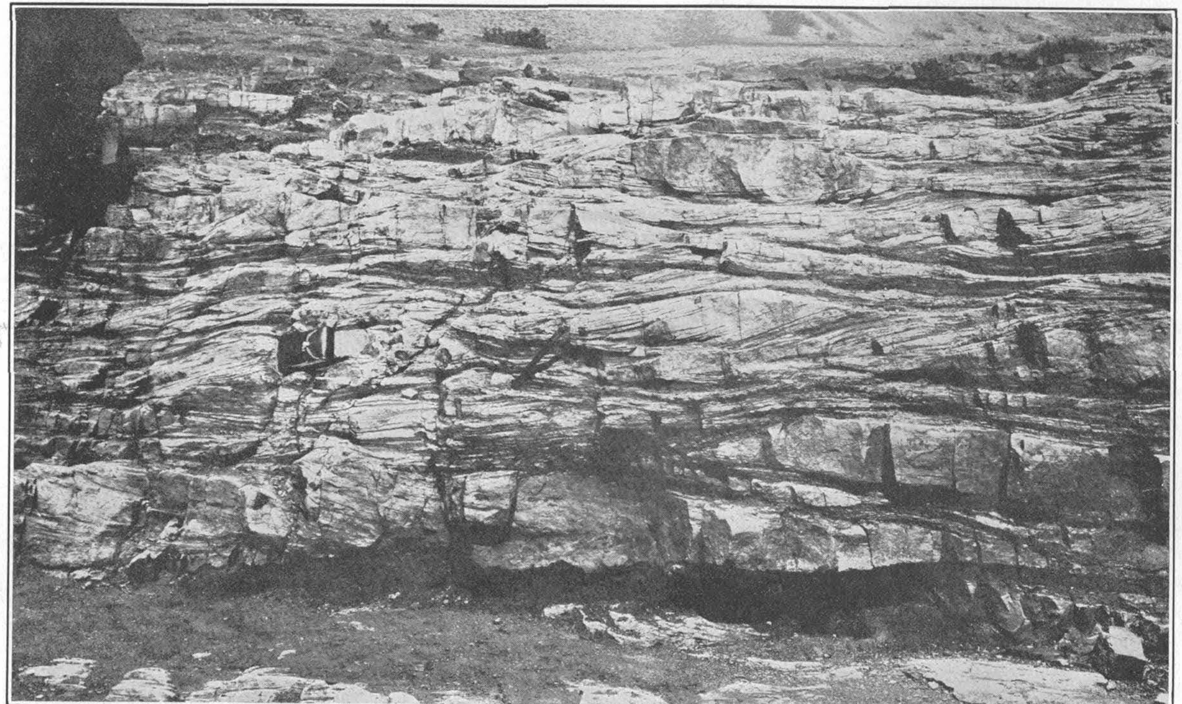
A. D CROSS MOUNTAIN, SOCORRO COUNTY, N. MEX.

Gallego sandstone member and one of the sandstones of the lower part of the Miguel formation shown in the foreground.



B. LA CRUZ PEAK, SOCORRO COUNTY, N. MEX.

A basalt plug.



CROSS-BEDDED SANDSTONE OF THE "RED BEDS" AT OJO DE LOS CHUPADEROS, IN SEC. 12, T. 2 N., R. 6 W., SOCORRO COUNTY, N. MEX.

level, are particularly good examples of volcanic necks which form prominent and well-known landmarks of the region. Innumerable small buttes or points formed by the unequal erosion of sedimentary rocks, gravels, etc., may be seen within the area described. The several steep-sided lava-capped mesas that rise abruptly above the surrounding country are in most places clothed with a good growth of grass and some scrub timber. Such mesas are conspicuous north and south of the Tres Hermanos Buttes, in Tps. 2, 3, and 4 N., R. 7 W., and north of Miguel Canyon, in T. 4 N., Rs. 8 and 9 W.

Within this area there are also a large number of ridges and hogbacks caused by resistant sandstones of the Miguel formation that dip at low angles. West of the little Mexican town of Puertecito successively higher beds of sandstone dipping at low angles to the westward give rise to several hogbacks. In the vicinity of the Chavez ranch, in T. 1 N., R. 5 W., and north of La Cruz Peak, the rocks have been faulted and tilted so that there are four or more parallel hogbacks, each capped by sandstone of the same bed.

Alamosa Creek contains running water at a great many places throughout the year, and in most places where the bed of the stream appears dry, water may be found within a foot or so of the surface. In time of rains the stream is sometimes impassable.

Springs of good water issue from the sandstones of the region and have determined to a large extent the location of the ranches. In addition to the numerous small springs, the following are of note:

Ojo Alamo, in sec. 13, T. 2 N., R. 6 W.
Ojo de los Barrancos, in sec. 12, T. 2 N., R. 5 W.
Ojo de los Chupaderos, in sec. 2, T. 2 N., R. 5 W.
Abbey Springs, in sec. 8, T. 1 N., R. 5 W.
Jara Spring, in sec. 15, T. 2 N., R. 5 W.
Tres Hermanos Spring, in sec. 24, T. 3 N., R. 7 W.
Navajo Spring, in sec. 17, T. 3 N., R. 7 W.
I. N. M. Spring, on the south bank of Alamosa Creek in the NW. ¼ sec. 28, T. 3 N., R. 8 W.
Box Bar Springs, a small spring on the Box Bar ranch, in sec. 4, T. 2 N., R. 9 W. The water is appropriated largely for domestic purposes.
Los Terros, in sec. 1, T. 2 N., R. 10 W.
Miguel Spring, in sec. 33, T. 4 N., R. 9 W.
Cacho Springs, near Bodenheimer's ranch, in sec. 10, T. 4 N., R. 9 W.

Culture.—Several large cattle ranches in the western part of the field are owned by Americans, but the area east and south of Puertecito is occupied almost entirely by smaller ranches owned by Mexicans. In the vicinity of Ojo Alamo, in T. 2 N., R. 6 W., there is a small colony of Navajo Indians, whose chief occupation is the raising of small bands of goats and sheep. The region is not suited to cultivation and will therefore probably continue to be used largely for stock raising.

Puertecito, in sec. 29, T. 3 N., R. 5 W., is a small Mexican village composed of about a dozen adobe houses ranged along an east-west street. The town is the headquarters of a considerable Mexican and Indian trade and supports two small tiendas, or stores.

At present Burley is the only post office within the area. During the summer of 1913 this office was at a ranch on Felipe Gilbert Creek, in sec. 10, T. 2 N., R. 7 W., but at the end of the season it was moved to the I. N. M. ranch, on Alamosa Creek, in sec. 21, T. 3 N., R. 8 W. Since that time the post office has been again moved, so that it is now only 10 miles west of Puertecito. Mail is brought by stage from Magdalena, a distance of about 50 miles, twice a week. Magdalena, with 3,000 inhabitants, the nearest railroad town, is at the end of a spur of the Atchison, Topeka & Santa Fe Railway about 20 miles southeast of the area mapped and is the shipping point for stock from this area as well as a much larger area to the south and west.

Because of the extremely rough topography, wagon roads have been laid out along the valleys and in many places are very crooked as well as rough.

Climate and vegetation.—The field is in the arid region of the Southwest, and its climate is typical of that region. Rain usually comes in torrents, and therefore the run-off is great and erosion due to running water is very rapid.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The sedimentary rocks exposed within the area here described have a maximum thickness of about 8,000 feet and range in age from Carboniferous to Recent. The red clays and sandstones of the Triassic are overlain unconformably by Cretaceous sandstones and shales, the oldest of which is correlated with the Dakota sandstone. The Dakota is overlain by a series of shales and sandstones having an aggregate thickness of about 3,700 feet. This series is subdivided into two formations, the lower of which is here named the Miguel formation and the upper of which is here named the Chamiso formation. Unconformably overlying these Cretaceous sediments is a formation consisting of a series of tuffs, rhyolites, sandstones, and conglomerates, which is probably of late Tertiary age, although no fossils were found that lend evidence for this assumption. This formation is here named the Datil formation because it is the mountain-forming series of the Datil Mountains, along the southern margin of the field. Quaternary unconsolidated gravels and alluvium occur in small areas. The following table shows the character and relations of the sedimentary formations of the field:

Generalized section of the rocks exposed in Alamosa Valley, N. Mex.

System.	Formation.	Character of rocks.	Thickness (feet).
Quaternary.	Alluvium.	Valley filling.	20±
	Gravels.	Well-rounded and sorted pebbles.	25±
Tertiary.	Datil formation.	Well-indurated tuffs, rhyolites, cross-bedded sandstones, and conglomerates. Members are extremely variable.	2,000±
	Unconformity		
Cretaceous.	Chamiso formation.	Soft yellow sandstones and sandy shales, with intercalated carbonaceous beds. Contains abundant fossil leaves. Coal beds at three general horizons, but the one about 75 feet above the base is the only bed of importance.	1,850
	Miguel formation.	Yellow sandstones, drab and yellow sandy shales with a few beds of clay and several beds of coal in upper half. Abundant invertebrate fossils and a few plant remains. This formation contains four persistent massive yellow sandstone members, two of which are here named, the name Bell Mountain sandstone member being applied to the one at the top and Gallego sandstone member to the one near the middle.	2,080
	Dakota sandstone.	Quartzose gray to brown sandstone which in places contains pebbles and fragments of underlying sandstones. Contains a few plant remains.	0–40
	Unconformity, erosional and angular		
Triassic and Carboniferous.	"Red Beds."	Red argillaceous shale, interbedded with thin beds of lavender sandstone; at base thin conglomerate containing chert pebbles.	600+
		Limestone and gypsum beds, base not exposed.	300+

CARBONIFEROUS AND TRIASSIC ROCKS ("RED BEDS").

The basal part of the section as exposed in the Alamosa Valley is composed of sediments which are predominantly red and include a great thickness of red, vermilion, and lavender clay shales, coarse cross-bedded sandstones (see Pl. II), and thin beds of conglomerate, with some limestone and gypsum in the lower part. In some places there is, about 600 feet below the top of the series, a thin bed of conglomerate which may represent the Shinarump conglomerate of northwestern New Mexico and northeastern Arizona. No fossils were found upon which to make a correlation, but from the lithology it is assumed that the beds above the conglomerate are Triassic and that those below may belong to the Manzano group, of Permian age.

CRETACEOUS ROCKS.

DAKOTA SANDSTONE.

Resting unconformably on the "Red Beds" just described is a sandstone ranging in thickness from 0 to 40 feet, which is correlated with the Dakota sandstone of other areas on the basis of its fossil flora, lithology, and stratigraphic position. In some places this sandstone is almost a pure quartzite; in others it is very conglomeratic; but in most places it is simply a coarse well-cemented ferruginous sandstone which contains a few pebbles as large as half an inch in diameter. Along the west side of the Red Lake fault the sandstone is thin and in places entirely absent.

MIGUEL FORMATION.

In this field the 3,900 feet of Cretaceous rocks that occur above the Dakota sandstone are subdivided into the Miguel and Chamiso formations, on the basis of their lithology and fossil content. The lower half of the series, here named the Miguel formation, from Miguel Creek, which crosses the beds in the northwestern part of the area, is composed of a succession of massive persistent sandstones, soft sandstones, and dark shales with coal, which contains an abundant Benton (early Colorado) fauna throughout and a sparse flora that F. H. Knowlton regards as probably of Montana age. These beds have the stratigraphic position of a large part of the Mancos shale but are lithologically quite different, being chiefly sandstone, whereas the Mancos in its type locality is almost entirely shale. According to the invertebrates it contains the Miguel is entirely of Colorado age, but the Mancos includes beds of Montana age in addition to those representing the whole Colorado group. For these reasons the local name Miguel formation is here introduced.

The upper portion of the series, here named the Chamiso formation, from Chamiso Creek, in T. 2 N., R. 9 W., is composed of soft sandstones and sandy shales containing an abundant Montana (Mesaverde) flora but no invertebrates, and is wholly of nonmarine origin; the Mesaverde formation, which is in part equivalent, consists of alternating beds of marine and nonmarine origin.

The Miguel formation includes four thick resistant and persistent beds of sandstone. The two lower may represent the Tres Hermanos sandstone of Lee,[1] but they are the least conspicuous of the sandstones of this area and were therefore not mapped. They are exposed a mile east of the Tres Hermanos Buttes. The Gallego sandstone member, named from Gallego Creek, occurs near the middle of the formation and is well exposed in Pueblo Viejo (Pl. III, *A*), a small mesa in sec. 17, T. 4 N., R. 7 W., which was once used as a stronghold by a small group of Indians. It is also exposed on the south and east sides of the Tres Hermanos Buttes, near the base of the buttes. This sandstone occurs about 900 feet above the Dakota and ranges in thickness from 50 to 90 feet. The Bell Mountain sandstone member (see Pl. III, *B*), which is well exposed near the foot of Bell Mountain, in T. 3 N., R. 9 W., is at the top of the Miguel formation and is about 80 feet thick.

[1] Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27-58, 1916.

A section of the Miguel formation was measured in the gap south of D Cross Mountain as follows:

Section of Miguel formation 2 miles west of I. N. M. ranch.

	Feet.
Sandstone, thick bedded, yellow to gray, coarse; *Halymenites* at the top, *Inoceramus* at the base (Bell Mountain sandstone member)	79
Shale, greenish and drab, fissile, containing hard brown concretions near the top; fossil shells 10 feet below the top	175
Sandstone, brown, hard	2
Sandstone, yellow, shaly, slightly carbonaceous at the base	34
Shale, yellow to drab, with thin beds of sandstone	35
Sandstone, brown, hard, coarse	1
Sandstone, yellow, massive	25
Shale, yellow and drab, with thin beds of sandstone	584
Sandstone, yellow, and dark to yellow shale, with 10 feet of carbonaceous shale at the top	80
Sandstone, yellow, thin bedded, and drab shale, sandy at the top, carbonaceous below, containing leaf fragments and 6 inches of coal near the top	47
Sandstone, yellow, massive, containing *Halymenites* (Gallego sandstone member)	93
Sandstone and shale, mostly covered	380
Sandstone, yellowish, massive, coarse, gray; fossil shells, 20 feet above the base	78
Sandstone and shale	6
Shale, yellowish gray and drab, fissile	134
Covered	50
Sandstone, with gastropods	15
Shale, drab, with oysters and shark teeth	50
Sandstone, yellowish gray, conglomeratic and cross-bedded	23
Shale, drab, argillaceous, with oysters 10 feet below the top	82
Covered, mostly shale	109
Dakota sandstone.	
	2,082

Section of lower part of Miguel formation south of Puertecito, N. Mex.

		Feet.
Miguel formation:		
Sandstone, thin bedded		5
Shale, sandy		75
Sandstone, shaly; fossil shells	Gallego sandstone member	3
Sandstone, yellow, massive	Gallego sandstone member	43
Sandstone, friable	Gallego sandstone member	17
Covered but composed of drab shale at top; fossil shells at top		87
Sandstone		5
Shale, sandy		25
Sandstone		10
Shale		50
Sandstone		5
Shale; fossil shells		9
Sandstone, yellow, thin bedded		42
Shale and sandstone, shaly		52
Sandstone; fossil shells		10
Shale and sandstone, shaly		136
Sandstone, heavy bedded, yellow		75

	Feet.
Miguel formation—Continued.	
Shale, light to slate-colored	90
Shale and sandstone, calcareous	35
Sandstone, thin bedded, brown, calcareous	10
Shale, largely covered	40
	824
Dakota sandstone:	
Sandstone, massive, angular grains	26
Sandstone, gray, thin bedded	5

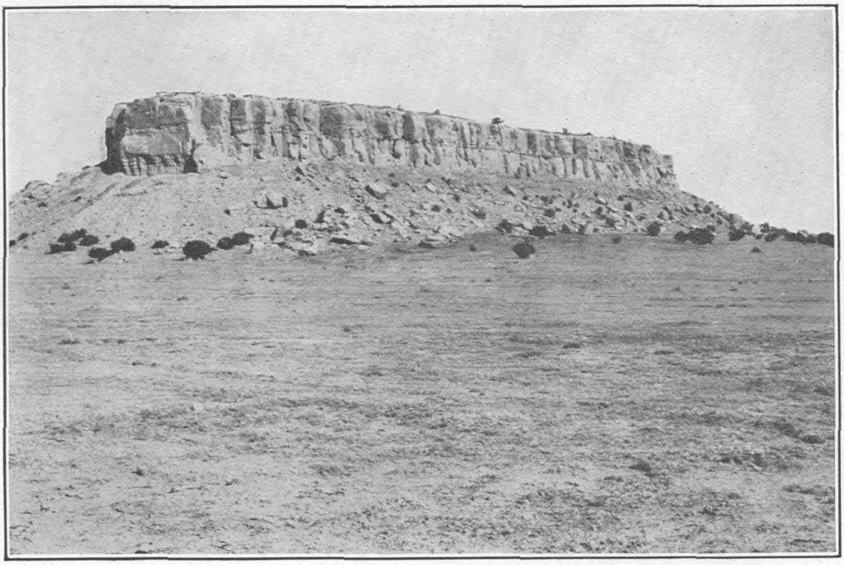
CHAMISO FORMATION.

Above the Bell Mountain sandstone, which marks the top of the Miguel formation, is a series of yellow sandstones, sandy shales, and coal beds that contains no persistent indurated beds like the underlying formation. This series on the basis of the fossil leaves which it contains might be correlated with the Mesaverde formation, but its lithologic character is quite different from that of the Mesaverde in its type locality; the deposits are wholly of nonmarine origin, whereas the Mesaverde consists of alternating marine and nonmarine sediments; and as the underlying beds (Miguel formation) are all of Colorado age, while the typical Mesaverde is underlain by beds of early Montana age, it is probable that rocks older than the typical Mesaverde are included in this series. The local name Chamiso formation is therefore introduced, from Chamiso Creek, in T. 2 N., R. 9 W.

One of the best coal beds in the field occurs about 75 feet above the base of the Chamiso and is extensively exposed west and northwest of D Cross Mountain. Other zones of carbonaceous material are present at several horizons in the formation, but none are of more than local importance. About 1,300 feet above the base there is a carbonaceous zone which contains coal in several places. The thickest coal bed is exposed in Red Canyon 3 or 4 miles south of the Box Bar ranch. The following detailed section was measured in the north side of Blue Mesa and shows the general character of the formation:

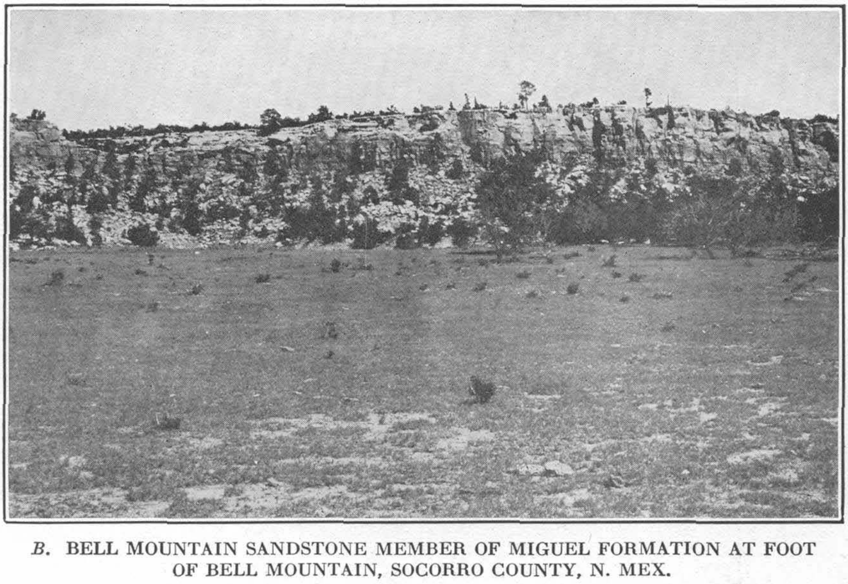
Section of Chamiso formation north of Blue Mesa, in T. 2 N., R. 8 W.

	Feet.
Sandstone, yellow to greenish, soft, and shale, sandy, yellow to green	440
Sandstone, gray, coarse	4
Coal and carbonaceous shale	1½
Shale, and sandstone, soft	46
Coal and carbonaceous shale	2
Shale	20
Shale, yellow, and sandstone, thin bedded	175
Sandstone, massive, yellow, cross-bedded	30
Shale, greenish yellow and drab, argillaceous; fossils	50
Shale and sandstone	145



A. PUEBLO VIEJO, SOCORRO COUNTY, N. MEX.

A typical development of the Gallego sandstone member of the Miguel formation.



B. BELL MOUNTAIN SANDSTONE MEMBER OF MIGUEL FORMATION AT FOOT OF BELL MOUNTAIN, SOCORRO COUNTY, N. MEX.

DATIL FORMATION (CONGLOMERATE AND SANDSTONE) IN ALAMOSA CREEK VALLEY, N. MEX.

	Feet.
Sandstone, coarse, massive	25
Sandstone, gray, thin bedded, with thin beds of indurated brown sandstone	205
Sandstone, yellow, massive, coarse	3
Shale, yellow and drab, sandy	20
Sandstone, gray, soft, thin bedded	15
Shale, carbonaceous at the top	25
Shale and sandstone, with beds of hard brown concretions	126
Sandstone	4
Sandstone, thin bedded; fossils	5
Covered	106
Sandstone, yellow to brown, coarse	7
Sandstone, thin bedded, and shale	100
Shale, drab	50
Sandstone, thin bedded to shaly	97
Sandstone, yellowish gray, coarse	5
Sandstone, yellow, coarse, soft, thin bedded	103
Sandstone, massive (Bell Mountain member of Miguel formation).	
	1,809½

Section of part of Chamiso formation in Triangulation Butte, northwest of Box Bar ranch, in sec. 31, T. 3 N., R. 9 W.

	Feet.
Sandstone, yellow, cross-bedded	25
Shale, sandy, and sandstone, soft	10
Sandstone, yellow, coarse	27
Shale	14
Sandstone, yellow	2
Shale	2
Coal	½
Shale, light drab	10
Sandstone, yellow; fossils	20
Shale, greenish yellow, concretionary	9
Sandstone, greenish yellow	2
Shale, greenish gray to drab	55
Sandstone, yellow, coarse; fossils	5
Sandstone, friable	30
Sandstone, yellow, coarse; fossils	8
Shale.	
	219½

TERTIARY ROCKS.

DATIL FORMATION.

Resting unconformably upon the older formations and giving rise to rugged mountainous topography is a series of tuffs, rhyolites, conglomerates, and sandstones, which so far as known contain no fossils. Their age is regarded as probably late Tertiary, but more definite correlation is impossible. At most places the beds of this formation are practically horizontal, but none of the members are persistent, cross-bedding and steep depositional angles being common. (See Pl. IV.)

The following section was measured at the north end of the Bear Mountains near the east boundary of the field and illustrates the general character of the formation:

Section of the Datil formation at the north end of the Bear Mountains.

	Feet.
Quartz rhyolite	120
Conglomerate and sandstone, reddish, friable; Conglomerate contains angular fragments of igneous rock	40
Sandstone	35
Conglomerate with pebbles as large as 1 foot in diameter	50
Sandstone and conglomerate in alternating beds	25
Sandstone, argillaceous	4
Tuff, conglomeratic, with pebbles and angular fragments as much as 18 inches in diameter	60
Rhyolite, vitreous, light colored	4
Andesite, light purple, vesicular	8
Agglomerate with igneous pebbles as much as 1 foot in diameter	17
Tuff, similar in composition to 65-foot bed below but gray and rather porous and slightly more basic	105
Tuff, red, compact, with groundmass of glass, iron ore, feldspar, and secondary calcite; inclusions of glassy material containing phenocrysts of feldspar, biotite, and iron ore	65
Sandstone, friable, containing earthy material	127
Covered	60
Tuff, conglomeratic, dark, slate-colored; angular fragments of igneous rock; maximum diameter of rounded pebbles 18 inches	420
Sandstone, red, argillaceous; contains streaks of gypsum	210
Covered but contains some yellow sand	190
Conglomerate like 4-foot bed below	5
Sandstone, thin bedded, with clay	1½
Clay, red, with sand and mica	12
Conglomerate, reddish, pebbles as much as 4 inches in diameter in matrix of clay, feldspar, and quartz	4
Clay, red, with sand and mica specks	15
Not exposed	175
Conglomerate, reddish gray, with well-rounded fragments of igneous and sedimentary rocks, including limestone	8
Conglomerate, white, well-rounded pebbles, maximum diameter 6 inches, of granite, obsidian, feldspar, and quartz	64

QUATERNARY DEPOSITS.

The Quaternary deposits consist of unconsolidated terrace gravels, such as are present in areas many feet above the valley levels both north and south of Alamosa Creek, and alluvium, such as is present along several of the larger stream valleys. Little attention was paid to deposits of this character, and the distribution as shown on the accompanying map probably does not include all the areas.

IGNEOUS ROCKS.

Younger than the Datil formation and younger even than at least some of the terrace gravels are the lava flows that cap several of the high mesas of the field. From the vesicular character of the material in certain parts of these lava caps it is assumed that the vents through which the lava was extruded are near at hand. Dikes and sills of basic material cut the Cretaceous rocks, as shown on the map (Pl. V).

STRUCTURE.

GENERAL FEATURES.

The field here described forms the southeastern part of San Juan Basin, a broad structural depression that occupies a very large area in northwestern New Mexico and southwestern Colorado. The Zuni Mountain uplift, which has a general northwesterly trend in McKinley and Valencia counties, to the north of this area, almost isolates the area of Cretaceous rocks south of the Atchison, Topeka & Santa Fe Railway, of which this field is a part, from the larger portion of the basin north of the railway.

The formations within the Alamosa Creek valley have a general dip toward the west, so that the oldest rocks are exposed at the eastern edge of the area. The attitude of the beds at numerous points within the area is indicated on the map by strike and dip symbols. Many faults and minor folds, most of which have a trend roughly parallel to the axis of the Zuni Mountains, interrupt the general structure of the area. Irregularly distributed over the field are dikes which have a trend practically parallel to the direction of the faults in the immediate vicinity and which fill fissures that apparently were formed by forces of the same character as those which gave rise to the faults. Because of the fact that in places cross faults cut and displace dikes, it is assumed that the forces which produced the faults were effective at a somewhat later period than those which caused the fissures that were filled with igneous rock to form dikes. Both dikes and faults cut the rocks of the Datil formation, but neither were found cutting the younger gravel deposits.

FOLDS.

Nearly all the anticlinal folds within this area are broken by faults, so that the faults become the most conspicuous part of the structure.

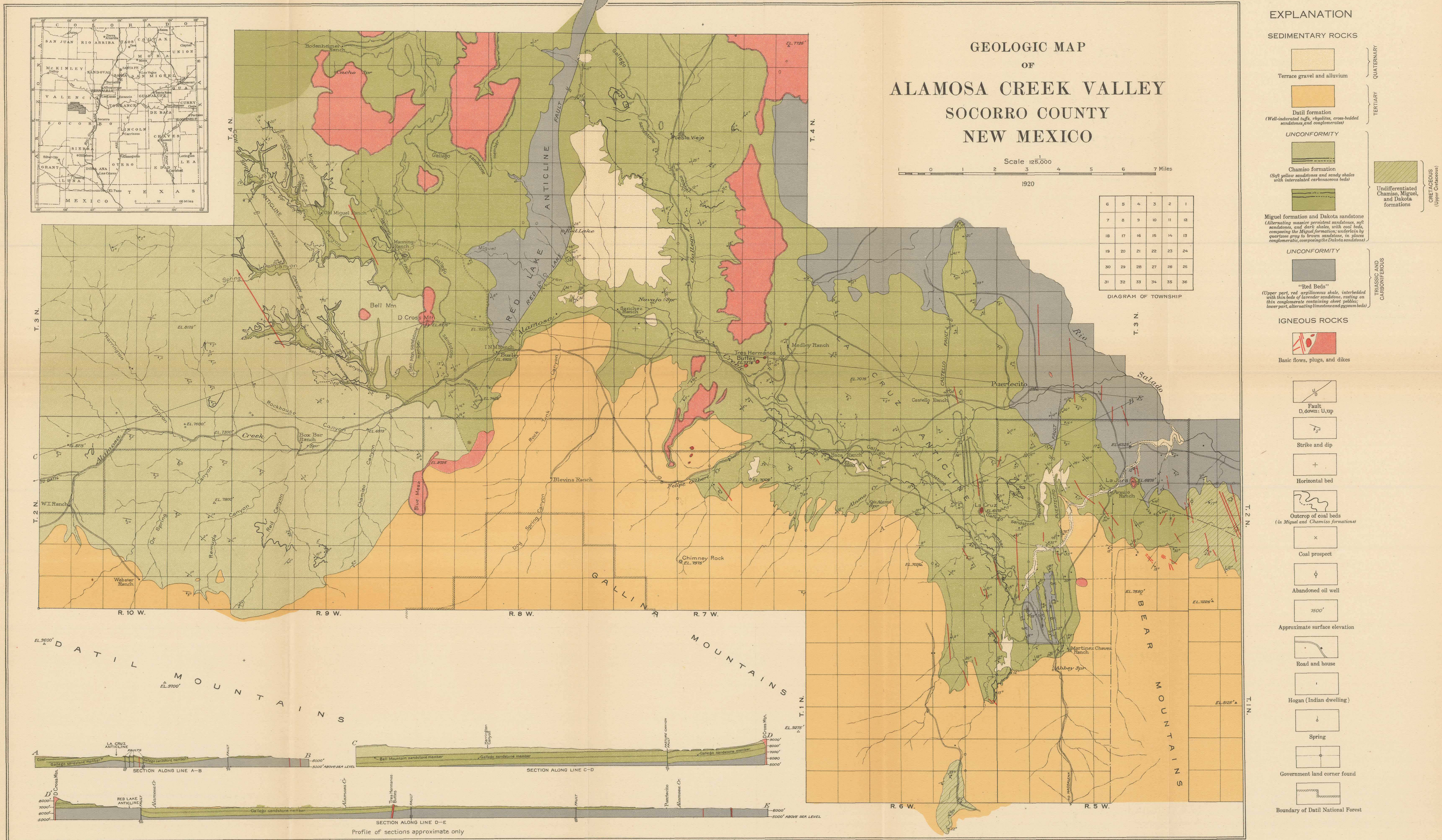
Red Lake anticline.—The Red Lake anticline is the largest fold in the area and extends northward from a point near old Burley post office, in sec. 21, T. 3 N., R. 8 W., to Broom Mountain, a distance of about 13 miles. The rocks along the west side of the fold dip at relatively low angles (3°–8°) to the west; the beds on the east side of the fault that marks the crest of the anticline dip as steeply as 48° E. but flatten appreciably within a mile or so. The fault, which is the most conspicuous feature of the structure, has a throw of several hundred feet, sufficient to bring beds of the upper half of the Miguel formation into contact with red clays and shales that are at least 200 feet below the Dakota sandstone. If petroleum exists in the rocks below the Dakota sandstone in this area, this fold provides what appears to be a fairly good place for its accumulation. It is probable that the beds are entirely sealed along the fault plane, and there is thus provided an effective barrier to migration of any oil and gas that may be present. Structure section *D–E* on the accompanying map (Pl. V) is drawn across the south end of the anticline.

La Cruz anticline.—The La Cruz anticline is a long irregular fold that extends into the field from the north, past the Tres Hermanos Buttes and La Cruz, into the northwest corner of T. 1 N., R. 5 W. This fold is cut by a large number of small faults, notably north of La Cruz and near the Chaves ranch, most of which strike parallel to the axis of the fold and none of which have a throw of much over 100 feet. Careful study of the structure will probably make it possible to separate this fold into several domes or small anticlines separated by low saddles; for example, the high part of the fold at the south end, where the Dakota sandstones and underlying "Red Beds" are exposed, is distinctly separated from the main portion of the anticline north of Alamosa Creek by the saddle near La Cruz, in sec. 13, T. 2 N., R. 6 W., where the Gallego sandstone (near the middle of the Miguel formation) is exposed on both sides of a narrow canyon. Dips of 2° to 18° prevail on the southwest side of this uplift and similar or steeper dips occur on the opposite side. Structure sections *A–B* and *D–E* on the map (Pl. V) illustrate the rock conditions across this anticline.

Cow Springs anticline.—A large number of small folds were noted within the area, one of the most promising of which appeared to be the one near Cow Springs, in the southwestern part of T. 4 N., R. 9 W., where the Bell Mountain sandstone and underlying shale of the upper part of the Miguel formation are exposed in two small areas. This fold appears to be free from faults and should provide an excellent place for the accumulation of oil in the sandstones of the lower half of the Miguel formation. The Dakota sandstone should be less than 2,000 feet below the surface in secs. 19 and 30, T. 4 N., R. 9 W.

PASTURE CANYON FAULT.

To the south, along the west side of the Pasture Canyon fault, the Bell Mountain sandstone is again exposed along Pasture Canyon and Pine Spring Canyon, while on the east side of the same fault younger beds form the surface, so that if the beds are sealed along the fault



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plane, the area immediately west of the fault presents structural conditions favorable for the accumulation of oil. Sandstones in the lower half of the Miguel formation should be reached here by the drill at depths of less than 2,000 feet. (See section *C–D*, Pl. V.)

OIL AND GAS POSSIBILITIES.

The accumulation of oil and gas in commercial quantities in any area is dependent on two very important factors—the presence of oil or gas in the rocks and conditions favorable for their accumulation. In untested regions like that described in this report it may be possible to say positively that oil or gas is or is not present in the sediments below the surface, but a careful study of the available information regarding the character of those rocks at their outcrop, the degree to which they have been affected by metamorphism, and their structural attitude should afford grounds for certain conclusions as to the possibilities of the area.

Two theories have been advanced to explain the origin of petroleum, but the one that is most commonly accepted is that petroleum is a product of the alteration of certain organic materials which were laid down at the same time as the clay and sand which have since been consolidated into the shale and sandstone of the rock formations. Evidence has been presented to show that organic materials of certain types upon alteration become coal and carbonaceous shale, whereas materials of other types are transformed into oil shale and petroleum. White[1] points out that the quantity and quality of the petroleum are determined (1) by the composition of the organic deposit at the beginning of its dynamo-chemical alteration, and (2) by the stage of progress of the dynamo-chemical alteration of the organic substances—that is, in effect, by the extent to which the initial products have been either fractioned underground or filtered incident to migration. He also points out that the progressive devolatilization (carbonization) of the carbonaceous (coal) beds of the region corresponds to the progressive regional metamorphism, so that in areas where the regional metamorphism has progressed the farthest the coal shows the highest percentage of fixed carbon and the lowest percentage of volatile matter. White shows that if the percentage of fixed carbon in a normal coal or in the organic débris of a richly carbonaceous shale exceeds 65 per cent (pure coal basis) the possibilities that the coal-bearing formation or the rocks that underlie it may contain petroleum will be exceedingly small. He calls attention to the fact that wherever the regional alteration of the carbonaceous residues has passed the point marked by 70 per cent of fixed carbon in the pure coal, only gases and solid residues remain, and

[1] White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, pp. 189–212, 1915.

no commercial deposits of petroleum may be found. In fact, the commercial oil line seems to fall somewhat below the 65 per cent carbon point, though the exact percentage has not yet been fully determined. According to these conclusions oil deposits of commercial value will not be present, though gases may persist, in areas where the coals in or above the formations where the oil is hoped for are carbonized beyond the point indicated by 65 per cent of fixed carbon in the pure coal, and it is doubtful if commercial amounts of petroleum occur where the carbonization is as high as that.

Within the Alamosa Creek valley so far as known there are no oil seeps, asphalt deposits, or gas occurrences, but the shales of the lower part of the Miguel formation are of dark color and contain remains of organic material, both animal and vegetable, so that it is not inconceivable that there may be liquid petroleum and natural gas in the rocks. Coal occurs in both the Chamiso and the Miguel formations, and although it has not been mined and therefore unweathered material can not be obtained for fully trustworthy chemical analysis, the proximate analyses of two samples obtained from shallow prospects are available[1] and give a general idea as to the character of the coal and the stage of its devolatilization. Coal from a bed near the base of the Chamiso formation, in sec. 20, T. 3 N., R. 9 W., contains 55 per cent of fixed carbon (pure coal basis), and the coal near the middle of the Miguel formation, in sec. 8, T. 2 N., R. 6 W., shows 53 per cent on the same basis. Therefore oil may be present in these rocks. In fact, it seems probable that if petroleum is found in this area it will be of high grade and that it will be accompanied by natural gas.

Reservior sands of excellent quality and rather exceptional continuity are present in the Miguel formation. The Bell Mountain sandstone at the top, the Gallego sandstone near the middle, and at least two unnamed but persistent sandstones in the lower part of the formation furnish beds almost unrivaled as sands in which oil may accumulate. These sands can be tested at points where the geologic structure is favorable for the accumulation of oil by drilling comparatively shallow holes, less than 2,000 feet in depth, in Cow Spring Canyon, near the center of sec. 30 or near the south line of sec. 19, T. 4 N., R. 9 W. Unfortunately these localities are so situated topographically that some road building will be necessary in order to get rig and materials to them, but it is probable that the necessary water can be obtained in the vicinity and fuel for the boilers can be mined within sight of the rig. Careful search will

[1] Campbell, M. R., Analyses of coal samples from various fields in the United States: U. S. Geol. Survey Bull. 541, p. 499, 1914. Campbell, M. R., and Clark, F. R., Analyses of coal samples from various parts of the United States: U. S. Geol. Survey Bull. 621, p. 332, 1916.

perhaps disclose other localities where the structure is equally favorable and where transportation conditions are more advantageous.

The formations older than the Cretaceous contain sands that may be worthy of testing, but in the work upon which this report is based little attention was paid to these lower formations. The Carboniferous includes some sand, as does also the overlying Triassic. The general character of at least one of these older sandstones is shown on Plate II. The cross-bedded character of this particular sand seems to be against it as an oil reservoir, but other sands may be much more favorable. A well 3,000 feet deep drilled near Red Lake, in sec. 2, T. 3 N., R. 8 W., should furnish satisfactory proof as to the oil possibilities of the formation below the Dakota. This locality, being on the west side of the fault and near the crest of the great anticline, is most favorable for a test of the lower rocks.