GEOLOGY OF THE SAN JUAN OIL FIELD, UTAH.

By E. G. Woodruff.

INTRODUCTION.

LOCATION AND FIELD WORK.

The oil field described in this paper lies in southeastern Utah in the valley of the San Juan River and in the county of the same name. Goodridge and Mexican Hat are post offices recently established not far from the center of the field, and Bluff is an old Mormon settlement a few miles to the east. The location of the field is shown by the index map on Plate IX (p.100). The area represented by the large map is 300 square miles, but not all of this is regarded as possible oil-producing territory. On the other hand, it is believed that this area does not embrace all of the oil-bearing strata in the region, but it probably includes all of the area in which development will occur in the present decade. In fact this belief was the chief factor which induced the writer to place the limits of the field where they are drawn.

The data on which the report is founded were collected during June, July, and August, 1910, by the writer with the assistance of A. J. Jarrett, K. C. Heald, and C. A. Atwell. For a short time Herbert E. Gregory cooperated with the writer in a study of the formations in an attempt to correlate them with formations exposed in adjacent regions. Prof. Gregory was somewhat familiar with the geology of the region, from his observations made during the previous year in a reconnaissance investigation of the Navajo Indian Reservation. As a result of his investigation, the public land in this field was withdrawn from entry by order of the President, and a detailed investigation was authorized by the Secretary of the Interior. Pursuant to this order, the present examination was undertaken for the primary purpose of obtaining data upon which to classify the public land and, secondarily, to prepare a geologic report which might assist in the economic development of the field.

ACKNOWLEDGMENTS.

The men mentioned above are entitled to credit for hearty cooperation in collecting the data included in this report. The writer is also indebted to residents in the field who unhesitatingly offered every

possible assistance, especially to Messrs. E. L. Goodridge, A. L. Raplee, and L. H. MacMorran, who aided the party during the examination, supplied data concerning the early history of the field, and have kindly furnished information regarding development since the completion of the field work. The writer has made liberal use of the data presented in Prof. Gregory's preliminary report [1] and wishes to acknowledge his indebtedness for the information thus obtained.

HISTORICAL SKETCH.

Previous to the investigations noted in this report no detailed geologic examination of this field had been made. For a long time the region was well known only to the Navajo Indians who inhabit it but was visited occasionally by white traders who came to the Indians to exchange various articles for blankets of their weaving. Occasionally prospectors followed the river and examined the sand bars in search of gold. About 30 years ago a small Mormon colony was established at Bluff, and this has remained practically the only permanent settlement in the entire region. It is reported that some of the early prospectors found oil seeps and recognized their meaning, but they were not diverted from their search for what to them appeared to be the more valuable natural resource. Among these prospectors was E. L. Goodridge, who was attracted by the indications of oil and located the first claim in 1882. No drilling was done until 1907, when the first well, Crossing No. 1 (see Pl. IX), was begun. The development that followed is described in another place in this report.

The history of geologic investigation is brief and relates wholly to the last few years, though many of the earlier geologists examined surrounding areas. In 1897 Henry S. Gane [2] traversed the eastern part of the field while making a reconnaissance along the San Juan River valley from Mancos, Colo., to the junction of San Juan and Colorado rivers. Gane made a special study of the stratigraphy in order to correlate the formations with the strata exposed in the San Juan Mountains, but gave little attention to structure and was unattracted by economic conditions. In July, 1909, H. E. Gregory made the brief preliminary examination of the field already mentioned. In the short time at his disposal Prof. Gregory studied the structure and stratigraphy and gave especial attention to economic conditions, which he described briefly in his report.[3] Since the bringing in of the Goodridge well in 1908 several geologists engaged in

[1] Gregory, H. E., The San Juan oil field, San Juan County, Utah: Bull. U. S. Geol. Survey No. 431, 1911, pp. 11-25.

[2] Cross, Whitman, and Howe, Ernest, Red Beds of southwestern Colorado and their correlation: Bull. Geol. Soc. America vol. 16, 1905, p. 476.

[3] Op. cit

commercial work have visited the region and studied its structure and stratigraphy in order to determine its commercial importance. So far as the writer is aware, however, none of these men have contributed to the literature relating to it.

GEOGRAPHY.

The San Juan oil field lies in a sparsely settled semiarid region in southeastern Utah. It is isolated from regular lines of transportation and is reached with difficulty. The main line of the Denver & Rio Grande Railroad is 120 miles to the north and the Rio Grande Western narrow-gage line 80 miles to the east. It is necessary to travel a much greater distance, however, from these points to reach the field because the intervening country is rough. By stage it is 158 miles from Goodridge to Thompson and 106 miles to Dolores, the nearest points on the railroads above named.

The field is divided into about equal northern and southern portions by San Juan River. The portion north of the river is public land and subject to entry in the usual method; the area south of the river lies in the Navajo Indian Reservation, in which prospecting for oil and development can take place only by permission of the Commissioner of Indian Affairs.

TOPOGRAPHY.

The San Juan oil field is part of the Colorado Plateau, a great topographic unit drained by Colorado River and its tributaries. The province comprises broad, undulating plateaus, which are locally dissected into table-lands interrupted by cliffs and canyons. In places where the beds are tilted from the horizontal position there are ridges, hogbacks, combs, mesas, buttes, escarpments, and a great variety of youthful topographic forms. In the San Juan oil field the rocks are folded into gentle anticlines and synclines and have been eroded into the varied forms noted above.

The surface features of the field are shown by the reconnaissance contour map, Plate IX, which was made after the methods commonly employed in planetable mapping, but because the time at the disposal of the investigators was brief neither great accuracy nor much detail was possible. The main topographic features of the country are represented, and it is believed that locations are reliable and altitudes are sufficiently accurate for practical purposes. The contour interval is 100 feet. Because the altitude of the field had not been determined previously, the wagon bridge at Goodridge was taken as a datum, and all altitudes in the field were determined from this point. The altitude of the base was assumed to be 4,000 feet, which agrees closely with the altitude given on the Abajo reconnaissance topographic map of the United States Geological Survey.

The ground is not well protected from erosion because about 80 per cent of the land surface is destitute of a cover of vegetation. Rain seldom falls, and when showers come they are generally local but copious and produce considerable erosion. As a result the surface of the field is exceedingly uneven. It comprises broken plains, mesas, deep, narrow canyons and ravines, and monuments which remain after the surrounding rock has been eroded. Some of these features are portrayed by the topographic map, but others are too small to be represented on the scale used. In general, the field is an uneven plain, which is locally either sharply dissected or dotted with small mesas or buttes that rise above the general surface and render it very irregular. The most remarkable features are the two canyons of San Juan River, one between Comb Wash and Lime Creek, the other beginning at Goodridge Bridge and extending westward beyond the limit of the field. Across the eastern part of the field there is a high escarpment, the northern part of which is called Comb Ridge, which was formed by the unequal erosion of sharply upturned, unconsolidated sandy shale and massive hard sandstone above it. On the north the field is bordered by a high escarpment that forms the edge of Cedar Mesa. Besides these features there are many remarkable minor topographic forms, which give to the field a peculiar picturesqueness seen in few localities outside of the Navajo country. The most striking of these special features are Mexican Hat, Setting Hen, and Flag buttes and many minor buttes to the north of the field, where the name "Garden of the Gods" is applied to a group of erosion forms that are even more picturesque than those in the Garden of the Gods near Pikes Peak, Colo.

The surface is not so irregular as to prevent crossing it in certain directions. The river canyons, however, form absolute barriers except in the interval between Mexican Hat Butte and Goodridge Bridge, and also between the mouths of Comb Wash and Chin Lee Creek. The canyons are about 1,400 feet deep and have precipitous walls. In scenic beauty they are probably surpassed only by the greater canyon of the same type—the Grand Canyon of the Colorado—which lies about 150 miles southwest. The canyon cutting the east anticline is traversed with the greatest difficulty, although it can be penetrated easily for a considerable distance from either end. The canyon across the western part of the field can be traversed from Goodridge to a point 1½ miles downstream, but beyond that point it is impassable. Near the western limit of the field, however, the river can be reached by the Honaker trail, which was constructed by prospectors to reach the placer ground along the river. The trail is reported to cover a distance of about 3 miles to reach a point at the water's edge 1,400 feet almost directly below the place in the brink where the trail descends.

STRATIGRAPHY.

GENERAL OUTLINE.

Perhaps in no area in the world are the strata better displayed than in southeastern Utah, where the rocks are rapidly broken up and the débris quickly removed, leaving fresh exposures at almost every point. As previously stated, approximately 80 per cent of the surface is without vegetation; hence the stratigraphic relations are not obscured. San Juan River carries a large amount of sand, chiefly quartz, which acts as a corrasive agent. With this agent the stream has cut a magnificent gorge across the field and exposed with remarkable clearness more than 1,400 feet of Paleozoic strata in a nearly horizontal position. Erosion has swept away the softer beds above the Paleozoic from the greater part of the field, but these beds are exposed in great escarpments on the north and east. More than 5,000 feet of strata, ranging from Carboniferous to Jurassic, inclusive, are exposed in the field. The character of these formations is shown by the columnar section in Plate VIII, and their relative age, thickness, and character are shown by the following table:

Section of strata exposed in the San Juan oil field.

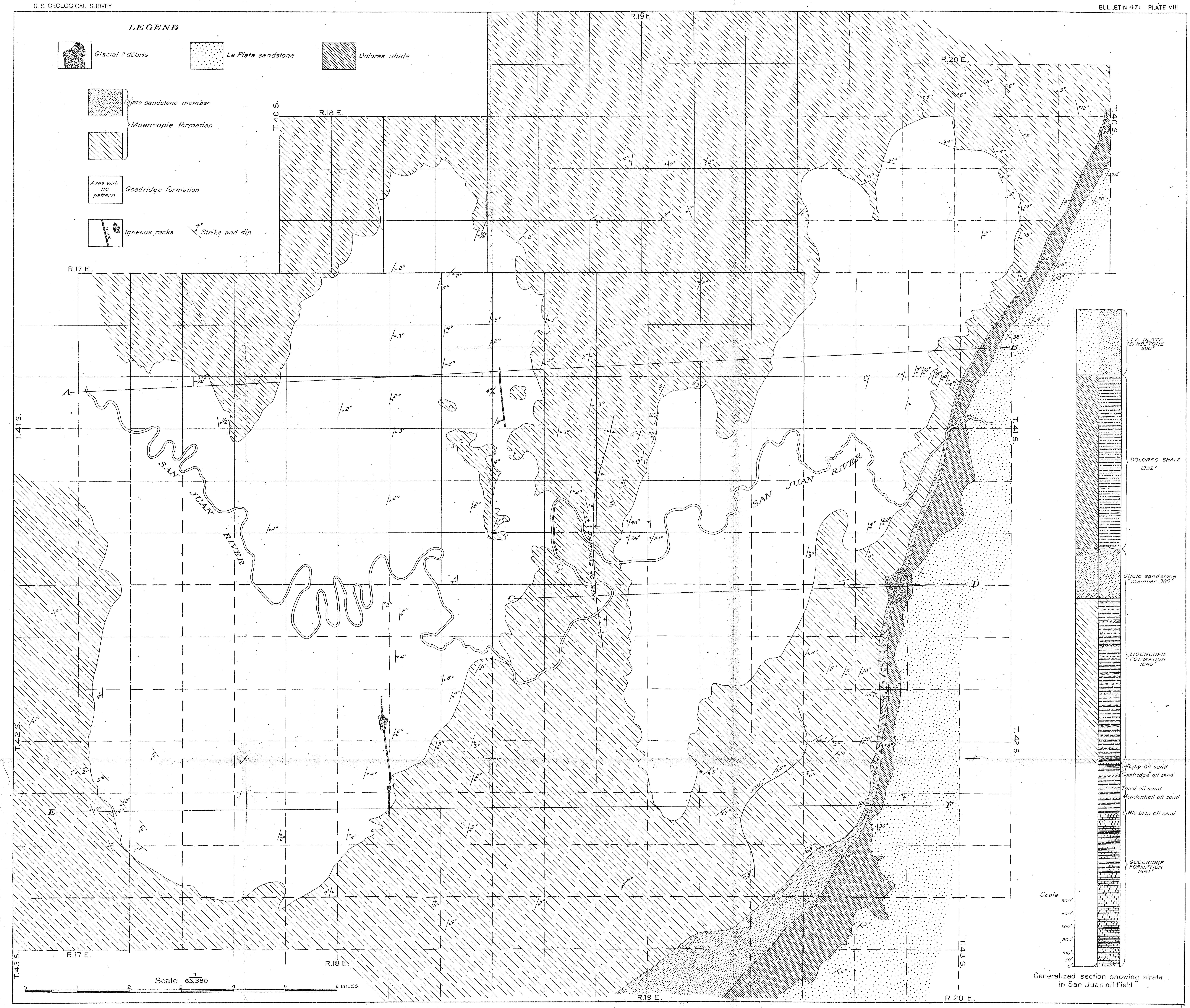
System.	Formation.	Member.	Thickness (feet).	Description.
Jurassic.	La Plata sandstone.		[a] 500±	Massive tan sandstone.
Triassic.	Dolores shale.		1,330	Very sandy, variegated shale. This formation contains saurian remains.
Unconformity?—				
Permian?	Moencopie formation.	Oljato sandstone.	20–380	Massive tan sandstone.
			1,260	Red sandy shale and massive tan sandstone beds.
Pennsylvanian.	Goodridge formation.		1,542	Massive-bedded crystalline limestone, soft, sandy shale and sandstone.

[a] Only lower part exposed.

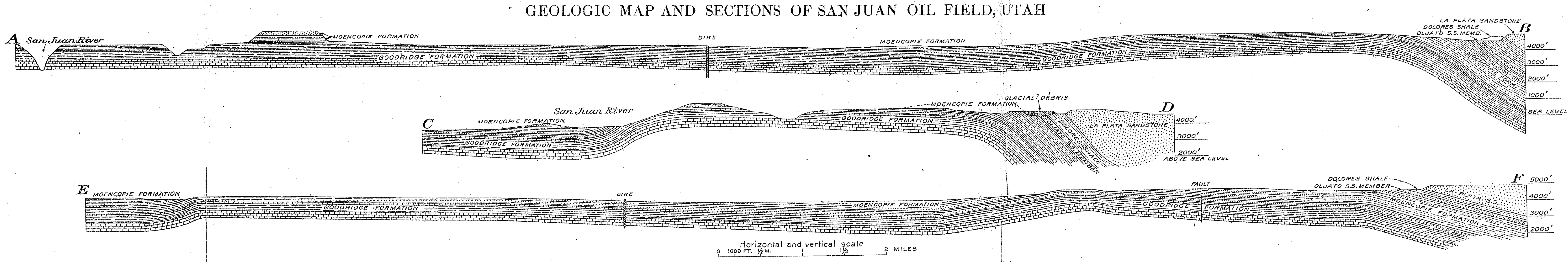
DETAILED DESCRIPTION OF FORMATIONS.

GOODRIDGE FORMATION.

A mass of strata comprising limestone, sandstone, and sandy shale is the lowest formation outcropping in the San Juan oil field. The beds are excellently exposed in the canyon in the western part of the field. They were studied along the Honaker trail, where the beds are clearly exposed in their undisturbed relations. This trail is taken as the type locality, but the name Honaker has been used previously for a geologic formation in another part of the United States



GEOLOGIC MAP AND SECTIONS OF SAN JUAN OIL FIELD, UTAH



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and consequently is not available here. The formation is therefore named from Goodridge post office, which is located near the center of the field and close to some excellent exposures of the upper part of the formation.

Section of the Goodridge formation from the top to the bottom of the Honaker trail.

	Feet.
68. Limestone, gray, hard, crystalline; fossil lot 155 (p. 83)	5
67. Shale, red, sandy; locally contains sandstone	24
66. Sandstone, gray, fossiliferous at base	9
65. Shale, sandy, red, merging into red sandstone at top	20
64a. Sandstone, gray, massive, fossiliferous; variable in thickness, being from 2 to 4 feet thicker than the normal at some places and an equal amount thinner at others	14
64. Limestone, crystalline, hard, gray, fossiliferous	2
63. Sandstone, pink, locally very shaly in middle; fossil lots 153 and 160	23
62. Sandstone, gray	3
61. Limestone, massive, gray; forms the "cap rock" at the head of the Honaker trail; fossil lots 152, 154, 156, and 179	25
60. Shale, sandy, pink	65
59. Sandstone, gray, shaly; fossil lots 157 and 178	6
58. Shale, sandy, pink	35
57. Sandstone, massive, gray; fossil lot 177	35
56. Shale, pink, sandy; locally becomes a sandstone in upper 8 to 10 feet	57
55. Limestone, hard, crystalline, drab; fossil lot 158	11
54. Shale, sandy, pink	24
53. Limestone, massive, crystalline, drab; Spirifer colored bright red by hematite abundant; fossil lots 159 and 176	19
52. Limestone, nodular, shaly	3½
51. Sandstone, gray	3½
50. Limestone, shaly, argillaceous, with intercalated beds of very sandy shale, which is salmon pink in lower part and gray in upper; contains Spirifer colored bright red by hematite; fossil lot 175	85
49. Limestone, massive, hard, crystalline, slightly shaly; nodular zone, 4 feet thick, 6 feet below top	33
48. Shale, dark gray, calcareous, very fossiliferous; fossil lot 174	9
47. Limestone, gray, crystalline in upper part and nodular in lower half	6
46. Shale, gray, sandy, with thin beds of shaly limestone	12
45. Limestone, hard, drab, massive, in two benches of about equal thickness; contains chert nodules; Fusulina abundant; fossil lot 173	14
44. Shale, gray, sandy	2
43. Limestone, hard, crystalline, nodular in upper and lower part, massive in middle	8
42. Shale, gray, sandy, soft	18
41. Limestone, crystalline, hard, drab, contains nodules of chert and jasper; fossil lot 172	3
40. Shale, soft, sandy, gray in upper part, drab below	59
39. Limestone, crystalline, gray, hard, massive; fossil lot 171	13

	Feet.
38. Shale, gray, soft, sandy	17
37. Limestone, drab, crystalline, containing nodules of chert	18
36. Shale, gray, sandy	10
35. Limestone, same as No. 23	8
34. Shale, gray, sandy	2
33. Sandstone, gray	9
32. Shale, gray, sandy	2
31. Limestone, same as No. 23	9
30. Shale, sandy, gray, soft	14
29. Limestone, drab, cherty	4
28. Shale, soft, sandy, gray	28
27. Limestone, cherty, nodular; fossil lot 170	8
26. Shale, same as No. 24	6
25. Limestone, similar to No. 23	4
24. Shale, gray, sandy, with beds of limestone 6 inches to 1 foot in thickness in lower part	42
23. Limestone, massive, drab, cherty, very fossiliferous in upper part, weathers very rough; top of this bed forms the prominent point overlooking the canyon; fossil lot 169	75
22. Limestone, similar to No. 20	5½
21. Shale, gray, sandy	3½
20. Limestone, massive, drab, cherty; weathers very rough	45
19. Limestone, faint pink, massive in upper part but shaly, sandy, and cherty in lower part; forms a pink band midway between top and bottom of canyon; there is a suggestion of unconformity at the base of this bed	136
18. Shale, black, fissile	5
17. Limestone, sandy and shaly in lower part, and pure, hard, drab in upper part; contains some particles of sulphur; fossil lot 168	34
16. Limestone, hard, crystalline in several layers; contains chert	61
15. Limestone, impure, gray, drab, argillaceous at base	12
14. Limestone, in several benches, contains layers of black chert; locally shaly and slightly sandy in irregular lenses; fossil lot 167	94
13. Sandstone, gray, soft, shaly	10
12. Limestone, massive, hard, crystalline, fossiliferous	23
11. Limestone, same as No. 9	3
10. Shale, greenish	3
9. Limestone, drab, crystalline, massive	24
8. Shale, black, carbonaceous, fissile	1½
7. Sandstone, greenish gray, nodular; fossil lot 166	5½
6. Limestone, drab, hard, crystalline; contains nodules of black chert	82
5. Sandstone, hard, greenish	9
4. Limestone, hard, drab, crystalline; weathers pitted in places; fossil lot 165	32
3. Limestone, drab, with 8 inches of shale at top	2
2. Limestone, drab, massive, crystalline; weathers pitted on surface	24
1. Talus	25
Water level.	
	1,541

This section is shown graphically on Plate VIII. Fossils collected from the beds are indicated by lot numbers in the above section. The fossils have been examined by George H. Girty, who makes the following statement concerning them:

With one exception all the collections are clearly of Pennsylvanian age and that lot (165) is an exception merely because it is not sufficiently diagnostic to show that it is not Mississippian. Furthermore, all the faunas have a facies resembling the Pennsylvanian of the Mississippi Valley rather than the later Carboniferous faunas of Asia and the Ural Mountains, to which many of our western faunas appear to be related. Consequently the faunas of these collections are to be compared rather with those of the San Juan region of Colorado (Rico, Hermosa) than with those of the Grand Canyon section (Kaibab limestone), which has a facies quite unlike the eastern Pennsylvanian. Wherever to my knowledge these two facies occur in the same section, the Asiatic comes above the typical Pennsylvanian facies.

I have already examined and reported upon a collection from the Honaker trail, where a good portion of Mr. Woodruff's material was obtained. This collection was made by Robert Forrester, of Salt Lake City, Utah. Mr. Forrester, who has done much work of a very accurate kind involving the Mesozoic and late Paleozoic rocks of Utah, reports that his fossils came from what was called Lower Aubrey group in the reports of the Wheeler Survey, their Upper Aubrey being our Kaibab limestone. The lists of fossils given by Meek as representing the fauna of the upper Redwall limestone show the same general facies as Mr. Woodruff's collection. The typical Redwall we know to be of Pennsylvanian age in the upper part and Mississippian age in the lower part, so that the facts at hand seem to indicate that the strata involved in Mr. Woodruff's collection represent the upper part of the typical Redwall limestone. I do not regard it as certain, however, that the marked dissimilarity of the Kaibab fauna to anything which Mr. Woodruff found in his section may not be regional and that by gradual modification some of his faunas may not pass into the Kaibab fauna at the same geologic level.

Some of Mr. Woodruff's faunas resemble those of the Hermosa formation and others resemble those of the Rico formation. Somewhat tentatively it may be inferred that both formations are represented in his section. It has always seemed to me, however, that the differences between the Rico and Hermosa faunas were such as might be regional, which might occur earlier or later in other areas or be connected by gradual transition instead of separated by a fairly abrupt change. In the Honaker trail section lots 165 to 176, inclusive, present the Hermosa facies, while lots 177 to 179 are more like the Rico facies. The other collections do not entirely fall in with a correlation of the upper part of the section with the Rico formation. Lot 159 especially, but also lots 154, 156, and 160 contain species which are not known to occur in the Rico formation.

Carboniferous fossils from the San Juan oil field.

Lot 152.

Echinocrinus aff. ornatus.
Composita subtilita?
Bellerophon sp.
Platyceras parvum.

Lot 153.

Polypora sp.
Productus nebraskensis?
Composita subtilita.
Bellerophon sp.
Fish remains.

Lot 154.

Productus nebraskensis.
Spirifer cameratus.
Ambocœlia sp.
Composita subtilita.
Aviculipecten sp.
Schizodus sp.
Bellerophon sp.

Lot 155.

Bellerophon crassus.

Carboniferous fossils from the San Juan oil field—Continued.

Lot 156.

Lioclema? sp.
Polypora sp.
Spirifer cameratus.
Composita subtilita.

Lot 157.

Composita subtilita.

Lot 158.

Derbya crassa?
Edmondia gibbosa.
Edmondia sp.
Leda arata.
Deltopecten occidentalis.
Myalina subquadrata.
Myalina subquadrata var.
Pseudomonotis kansasensis.
Schizodus sp.
Bellerophon sp.
Gastropod indet.

Lot 159.

Crinoidal remains.
Stenopora sp.
Fistulipora sp.
Rhombopora lepidodendroides.
Lingulidiscina sp.
Derbya? sp.
Productus semireticulatus.
Productus nebraskensis.
Productus cora.
Pugnax utah.
Spirifer cameratus.
Spiriferina kentuckyensis.
Composita subtilita.
Hustedia mormoni.

Lot 160.

Stenopora sp.
Spirifer cameratus.
Composita subtilita.
Edmondia? sp.
Pinna peracuta.
Myalina subquadrata.
Schizodus insignis?
Sanguinolaria? sp.
Aviculipecten sp.
Bellerophon sp.
Euphemus inspeciosus?
Pleurotomaria sp.
Orthoceras sp.

Lot 165.

Syringopora sp.
Echinocrinus sp.

Lot 166.

Echinocrinus sp.
Chonetes sp.
Marginifera muricata.
Marginifera wabashensis.
Spirifer cameratus.
Squamularia perplexa.
Composita subtilita.

Lot 167.

Echinocrinus cratis.
Rhombopora lepidodendroides.
Rhipidomella pecosi.
Productus semireticulatus.
Spirifer cameratus.
Squamularia perplexa.
Composita subtilita.

Lot 168.

Orthothetina n. sp.
Productus cora.
Productus punctatus.
Productus semireticulatus.
Spirifer rockymontanus.
Schizostoma sp.

Lot 169.

Polypora sp.
Rhombopora sp.
Lingulidiscina missouriensis.
Derbya? sp.
Chonetes mesolobus.
Productus semireticulatus.
Productus sp.
Marginifera splendens?
Pugnax rockymontanus?
Spirifer scobinus?
Ambocœlia planiconvexa?
Aviculipecten sp.
Fish remains.

Lot 170.

Fusulina sp.
Composita subtilita.

Lot 171.

Lophophyllum profundum.
Productus punctatus?
Productus cora.

Carboniferous fossils from the San Juan oil field—Continued.

Lot 171—Continued.

Productus sp.
Spirifer cameratus.
Composita subtilita.

Lot 172.

Fusulina sp.

Lot 173.

Fusulina sp.
Crinoidal remains.
Productus cora.

Lot 174.

Lophophyllum profundum.
Fistulipora? sp.
Rhombopora lepidodendroides.
Derbya? sp.
Productus cora.
Spiriferina kentuckyensis.
Composita subtilita.
Hustedia mormoni.

Lot 175.

Hydreionocrinus sp.
Stenopora sp.
Polypora sp.
Rhombopora lepidodendroides?
Productus cora.
Productus nebraskensis.
Pugnax osagensis.
Spirifer cameratus.
Spiriferina solidirostris.
Composita subtilita.

Lot 176.

Stenopora sp.
Productus cora.

Lot 177.

Leda arata.
Deltopecten occidentale.
Myalina aff. parattenuata.
Allerisma terminale.
Pleurophorus sp.
Bellerophon tricarinatus.
Bellerophon sp.
Euphemus carbonarius.
Naticopsis sp.

Lot 178.

Productus nebraskensis.
Edmondia gibbosa.
Cardiomorpha? sp.
Deltopecten occidentalis.
Myalina sp.
Pleurophorus subcostatus?
Schizodus meekanus.
Monopteria polita?
Bellerophon sp.

Lot 179.

Productus cora.
Myalina perniformis.
Small gastropod.

Lots 152 and 165 to 179, inclusive, were collected along the Honaker trail. The other lots were collected at various points in the field. The stratigraphic position of the fossils is shown by numbers in the section on pages 81–82.

The areal distribution of the Goodridge formation is shown on Plate VIII, and the structural attitude by dip and strike symbols and by structure sections on the same plate. The top of this formation is a limestone which forms a floor of hard material from which the softer shale above has been eroded in the western part of the area. It is evident from the columnar section that the lower part of the formation is predominantly limestone, whereas the upper part comprises also sandstone and sandy shale. The Goodridge formation contains the oil sands of the San Juan field. A discussion of this phase of the subject is presented in a later part of the report.

MOENCOPIE FORMATION.

GENERAL CHARACTER.

The Moencopie formation consists in the lower part of brick-red sandy shale and argillaceous sandstone and in the upper part of light-colored shaly sandstone and massive tan sandstone. Alkaline salts, especially gypsum, are scattered throughout the formation, but the gypsum rarely occurs in massive beds as it does in this formation elsewhere. Generally it seems to be a secondary accumulation in veins and stringers of the originally highly disseminated material. The following section is introduced to show the character of the Moencopie formation:

Section of Moencopie formation in San Juan oil field.

[Two upper members measured near junction of Chin Lee Creek and San Juan River; lower members at Cedar Point.]

	Feet.
72. Shale, light pink, sandy, and sandstone, slightly darker	475
71. Shale, sandy, and brick-red argillaceous sandstone	370
70. Shale, red, sandy, containing many layers of shaly sandstone	190
At this point there occurs a 6-inch bed of conglomerate composed of angular fragments of sandstone and limestone, which vary from half an inch to 1½ inches in greatest diameter.	
69. Shale, red, sandy, containing many layers of sandstone	225
	1,260

The lower part of the formation, Nos. 69 and 70 in the section given above, displays remarkable uniformity in character and thickness throughout the field. In contrast to this regularity the upper part presents considerable variation. To the south it is composed chiefly of soft light-pink sandy shale, with darker shaly sandstone interbedded. To the north, however, the upper part of the formation consists of massive tan-colored sandstone beds forming Cedar Mesa and projecting southward into Cedar Point. The transition of the shale of the south into the sandstone of the north begins in the area of red beds north of San Juan River and southwest of Navajo Spring. In this area the shale beds that predominate to the south are interstratified with thin sandstone lenses which thicken rapidly to the north and replace the shale. In the northeastern part of the area represented by the map, in secs. 19, 20, 29, and 30, T. 40 S., R. 20 E., Salt Lake base and principal meridian, the lenses have developed into massive sandstone beds that have replaced the greater part of the shale. They are exposed on the divide between Comb Wash and Lime Creek in high cliffs and also in buttes which are outlier remnants of the formation. In this part of the field the massive sandstone beds in the upper part are less easily eroded than the shale below and they give rise to the escarpment which is so prominent a feature of this region. Westward from this point the shale gives way to the developing sandstone members until in Cedar Point the whole upper part of the Moencopie formation below the Oljato sandstone member consists of a massive sandstone. The topographic features which result from the erosion of the formation are very different in the two parts of the field. To the south the shale in the upper part of the formation breaks down into soft, loose débris which resembles crusted snow, whereas the sandstone to the north forms escarpments, monuments, spires, and turrets.

OLJATO SANDSTONE MEMBER.

The Oljato sandstone is a massive, brown, slightly ferruginous, gritty, cross-bedded, lenticular sandstone, which increases in thickness from the northeast toward the southwest. In the northwest corner of the field it is only 20 feet thick, but at Navajo Spring it is 175 feet and at Moses Rock it forms a single massive bed 382 feet thick. Gregory states that this sandstone increases in thickness to the southwest and is one of the prominent formations in northeastern Arizona. In it is carved the famous Canyon de Chelly and at Oljato it forms the cliffs in Moonlight Valley. As a much better section is displayed at the latter place than at any point in the San Juan field the name Oljato is given to this member. Nothing was found in the sandstone to show its age. It contains fragments of fossilized wood and pieces of charcoal, but they are not well enough preserved to indicate the types of plants which existed when the sandstone was deposited. It is probable that there is an unconformity at the top of the bed and possibly one marks the base, but no positive evidence of such unconformities was obtained in the San Juan field. The Oljato sandstone is tentatively assigned to the Moencopie, though there is meager evidence for so doing, and it is recognized that a study of this sandstone over a greater region may develop evidence to show that it is a distinct formation and later in age than the Moencopie.

CORRELATION.

The age of the Moencopie was not determined because no fossils were found in it. It is assigned tentatively to the Permian because there is a sharp lithologic break between it and the Goodridge (Pennsylvanian) below and because it seems to be distinct from the Dolores (Triassic) above. The formation represents, in this area, the "Red Beds" which extend over a great area in Arizona, Utah, Colorado, and adjacent States. These beds have been studied in many localities and have received several names. The name adopted in this report was proposed by L. F. Ward[1] for a formation, similar in lithologic character and identical in stratigraphic position, exposed in

[1] Ward, L. F., Am. Jour. Sci., 4th ser., vol. 12, 1901, p. 403.

Moencopie Wash near Little Colorado River, Ariz. The correlation between the type locality and the San Juan oil field is based on lithologic similarity of the formations in the two areas, on their sharp differentiation from the Pennsylvanian strata below, and on oral information furnished by Prof. Gregory, who made reconnaissance examinations of both areas and the intermediate region during the summers of 1909 and 1910. None of the examinations, however, have produced any evidence to prove the age of the Moencopie.

The red beds of the San Juan field also closely resemble and occupy approximately the same position in the stratigraphic column as the Cutler formation described by Cross [1] in his folio on the Rico quadrangle, Colorado. However, they more closely resemble the Moencopie than the Cutler, and the covered interval separating the San Juan field from the region containing exposures of Moencopie is much shorter than that separating it from the nearest outcrop of Cutler. For these two reasons, proximity of outcrop and closer similarity of lithologic character, the formation is correlated with the Moencopie rather than the Cutler.

DOLORES SHALE.

The Dolores shale consists of a mass of variegated sandy shale which is easily eroded, hence the formation usually outcrops in a valley. In the eastern part of the field, north of San Juan River, it occupies Comb Wash valley, at the base of the escarpment to the east of the oil field, and south of the river the formation lies along the valley of Chin Lee Creek. The areal extent of the Dolores shale is shown on Plate VIII, and its character is shown by the following detailed section:

Section of Dolores shale in San Juan oil field.

	Feet.
85. Shale, red, sandy; this bed is a loose aggregation of sand grains with a little clay	590
84. Sandstone, shaly, fissile	2
83. Shale, pink, sandy	8
82. Limestone, impure, nodular	3
81. Shale, sandy, homogeneous	230
80. Shale, gray, sandy, unconsolidated, homogeneous	315
79. Shale, maroon, sandy, unconsolidated, homogeneous	27
78. Shale, variegated, with red and gray bands 1 to 8 inches thick, sandy, thinly bedded	75
77. Sandstone, gray, cross-bedded, gritty	1½
76. Shale, sandy, red	4½
75. Sandstone, gray, cross-bedded, gritty	6
74. Shale, dark red, sandy, slightly fissile	70
	1,332

[1] Cross, Whitman, Rico folio (No. 130), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 4.

The determination of the age of the Dolores rests upon the identification of small collections of fossils which were submitted to T. W. Stanton and C. W. Gilmore for examination. Mr. Stanton reports as follows:

6780. No. 163. Three-quarters of a mile northeast of Moses Rock in strata 50 feet below top of Dolores shale:

Unio cristonensis Meek?
Viviparus? sp.
Fragments of reptilian bones.

Probably Triassic. Similar invertebrates occur in the Dolores formation of the La Plata Mountains.

Mr. Gilmore examined three small collections containing fragments of bones of vertebrate animals but found nothing which could be identified without some doubt. He says "The reptile bones, while not certainly identifiable, are suggestive of some of the Triassic dinosaurs."

LA PLATA SANDSTONE.

The highest formation exposed in the field comprises two massive beds of sandstone separated by pink shale. The lower sandstone is estimated to be 500 feet thick, the shale 100 feet, and the upper sandstone 400 feet. Only the lower sandstone is exposed in the San Juan oil field, and therefore that part alone was studied. The upper bed of sandstone is exposed in the walls of the canyon at Bluff but not in the oil field. The lower bed consists of a massive cross-bedded coarse-grained sandstone with local thin layers of conglomerate composed of small, well-rounded grains of quartz and feldspar. The La Plata sandstone forms the mesa along Chin Lee Creek, in the southeastern part of the field, and is exposed near San Juan River, where the steeply upturned sandstone forms a high, sharp point known as the Sawtooth, which stands out as a prominent landmark. This bed is better known, however, as the massive sandstone that forms Comb Ridge, the escarpment in the northeastern part of the field. No fossils were found in the sandstone and consequently its age could not be determined. Stratigraphically and lithologically it is correlated with the La Plata sandstone of the Rico quadrangle, Colorado, which has been determined to be Jurassic.

GLACIAL(?) DEPOSITS.

In the southeastern part of the field there is a small area covered by débris which is believed to be of glacial origin. This material consists chiefly of fragments of sandstone, but includes also a considerable amount of shale and lesser amounts of interbedded limestone, conglomerate, and igneous rocks. The conglomerate is of two types—(1) well-rounded pebbles, in general similar to the Dakota conglomerate which is exposed to the northeast of the field, and (2) apparently metamorphosed conglomerate. Neither type resembles any of the other rocks exposed in this field. The igneous rocks comprise schist and gneiss. The deposit is a heterogeneous mass which shows no evidence of bedding, though some of the constituent blocks show traces of their original stratification. Fragments vary in size. One large block of conglomerate was found to be more than 100 feet in length. The mass rests in an old channel carved in the Moencopie and Dolores formations. The general trend of the channel is north and south, and it terminates at the south abruptly against a wall of shale and sandstone. Small garnets were found in the anthills on the top of the débris. These garnets are of interest in a study of the origin of the deposit, because similar ones were found scattered over the surface and in fragments of schist in the southeastern part of the field on the divide between Gypsum and Chin Lee creeks, where it is crossed by the wagon road. Sterrett[1] suggested the glacial origin of garnet beds immediately south of the San Juan field, where rocks similar to the igneous rocks in this field are scattered over the surface. Sterrett says:

> The source of the garnet over the mesa country is in a stratum of coarse, unconsolidated drift or gravel that rests on the more elevated part of the red sandstone on the northwest of the area examined. This drift is over 100 feet thick and is composed of bowlders, which vary from stones weighing many tons to cobble size, mixed through a matrix of pebbles and sand. The gravel and bowlders consist of biotite granite gneiss, porphyritic biotite granite gneiss, hornblende or diorite gneiss, partly epidotized trap and basaltic rocks, epidote hornstone, soapstone, tremolite asbestos, sugary quartz, and large blocks of light-gray fossiliferous limestone of Carboniferous age. Just where the origin of this conglomeration is to be sought is not known. The general appearance of the drift is that of a glacial deposit. Glaciation has taken place in the San Francisco Mountains[2] of Coconino County, Ariz., and moraine deposits have been formed. The latter are thought to be of rather recent age, probably Quaternary. Whether there has been glaciation in the slightly higher country west and northwest of the garnet deposits is not known. It is probable that the garnet-bearing drift deposits are of greater age than the glacial deposits of the San Francisco Mountains, for the former are covered with a stratum of hard white sandstone and are at almost as great an elevation as any of the surrounding region. The presence of such quantities of crystalline and ancient rocks in the drift can not be explained by very recent action, as these rocks do not outcrop near the locality.

IGNEOUS ROCK.

Igneous rocks intrude sedimentary beds and come to the surface as dikes at three places in the field. The character of these rocks is described by E. S. Larsen, as follows:

> The two specimens of augite minette from the Alhambra dike are dense greenish-gray rocks with prominent hexagonal plates of brown mica nearly a millimeter across.

[1] Sterrett, D. B., Mineral Resources U. S. for 1908, U. S. Geol. Survey, 1909, pp. 823–827.

[2] Ward, L. F., Glaciation of the San Francisco Mountains, Arizona: Jour. Geology, vol. 13, 1905, pp. 276–279. Robinson, H. H., Geology of the San Franciscan volcanic field, Arizona: Prof. Paper U. S. Geol. Survey No. 76 (in preparation).

The pocket lens reveals nearly or quite as many prisms of pale-green pyroxene in an aphanitic ground. The biotite plates are in approximately parallel arrangement and tend to give the rock a platy fracture. Inclusions of quartzite, limestone, etc., are present in the hand specimen.

A study of the thin section under the microscope shows that the rock is porphyritic and that the phenocrysts are in moderate excess over the groundmass. The most prominent phenocryst is biotite; augite is nearly as abundant. A very few phenocrysts of orthoclase and sodic plagioclase are present. Small inclusions of limestone are rather abundant. The groundmass has a trachytic texture and is made up chiefly of very small orthoclase laths, with some diopside, biotite, and opacite. The biotite is much lighter in color and less strongly pleochroic than normal biotite, its axial angle is very small, and the axial plane is parallel to the plane of symmetry. Basal sections are hexagonal in appearance and show a narrow border which is much more strongly colored than the main crystal. These data indicate that it is poor in iron and it is probably near phlogopite. It carries a few inclusions of apatite.

The pyroxene is also zoned. The main part of the crystals are nearly colorless in the thin section and show an extinction angle on the side pinacoid of 40° ($Z \wedge c$); the borders of the crystals are pale green and show extinctions as high as 52°. There is in places a succession of thin shells with alternating large and small extinction angles. Twinning is common. In some parts the biotite and augite are intergrown after the manner of graphic granite; in others the inclusions of limestone have a fringe of augite rods projecting out from the calcite and intergrown with biotite, and these augite rods may grade outward into a crystal of augite. It is possible that the limestone simply acted as a nucleus about which the augite and biotite crystallized, but it seems more probable that these minerals were formed here by an interaction between the magma and the limestone.

The specimen from the dike in secs. 7, 18, and 19, T. 41 S., R. 19 E., differs somewhat from the rock of the Alhambra dike but was derived from a very similar magma. It is brownish green in color, has a very prominent original schistose texture from the fluidal arrangement of the biotite, and shows with the pocket lens very many light-brown hexagonal plates of biotite, much pale-green augite, little feldspar, and some small rounded areas of calcite. A microscopic examination of the thin section shows that the rock differs from that of the Alhambra dike chiefly in the presence of ægirite and of scattered rounded areas of secondary calcite, analcite, and a birefracting zeolite. The groundmass is coarser and the feldspars are not so well developed. The ægirite occurs as fringes about the augite phenocrysts and here and there completely replaces the augite rods of the groundmass; it also occurs as crystals piercing the calcite and analcite. It is probably secondary. It is grass-green, is strongly pleochroic, and has an extinction angle ($X \wedge c$) of 3°. The roundish areas of calcite and zeolites are probably derived from primary leucite. The zeolite occurs in small lath-shaped crystals piercing the calcite and analcite and collected along the border of the original crystal. It has two perfect cleavages parallel to the elongation and another across it. The extinction is nearly parallel and the elongation is negative. The mean index of refraction as determined by the immersion method is 1.515; the birefringence is about equal to that of orthoclase. It is probably a zeolite. The analcite occupies an intermediate zone; the calcite occupies the core of the original crystal. There is probably a little analcite in the groundmass. Except for the presence of a small amount of altered leucite(?) the rock is a normal augite minette.

The position and extent of the dikes are shown on the map (Pl. VIII). In general, the dikes are narrow, varying from 2 to 10 feet in width. Here and there, however, they are enlarged to 15 or 20 feet, and at one point the dike of which the Alhambra dike is a part reaches a maximum width of 100 feet. No perceptible displacement of the strata has occurred where the dikes traverse them and only slight metamorphism of the including rock. Within the igneous rocks there is a large amount of clastic material believed to be derived from the rocks below, through which the igneous magma passed. This material consists of granite and gneiss from the igneous rocks and sandstone and limestone from the sedimentary rocks. The fragments are generally angular and range from a fraction of an inch to 1 foot in greatest diameter.

So far as observed there is no connection, either direct or indirect, between the occurrence of petroleum and the igneous rocks. It is recognized that genetically oil may have come from the igneous rocks, but if this is the true source in the San Juan field, all surficial trace of such origin has disappeared. Furthermore, the accumulation of the oil does not seem to have been effected to any great extent by the dikes acting as a dam to the movement of the oil in the strata and consequently forcing its accumulation along the dike, as has been found in some of the Mexican oil fields. Practically no prospecting has been done in the vicinity of the intrusions, but no seeps or escaping oil have been found there to encourage prospecting.

STRUCTURE.

The structure of the San Juan oil field is only moderately complicated by north-south folds. In the western part of the field the beds lie approximately horizontal or dip very gently to the west. Near the central north-south line of the field they are moderately depressed into a syncline, the eastern limb of which rises abruptly and merges with the western slope of a slightly elevated flat-topped anticline. On the east side of the anticline the strata dip abruptly to the edge of the field, but a short distance beyond the eastern border the beds are flexed sharply again into a horizontal position and maintain that general attitude far to the east. The strata are folded most near the center of the field and gradually flatten into horizontal beds along both the north and south sides of the field. The apex of the anticline is south of San Juan River and southeast of Mexican Hat Butte and the lowest point in the syncline is a short distance south of the river, on the axis of the syncline shown on Plate VIII. The structure of the beds is shown by dip and strike symbols and by cross sections on Plate VIII.

The minor structural features of the field are unimportant. The beds are not perceptibly disturbed where traversed by dikes and are only slightly displaced by a fault in the southeastern part of the field. This fault is $1\frac{3}{4}$ miles long but has only a small displacement, with the upthrow on the west side. The maximum amount of throw is about 200 feet, but in general it does not exceed 20 or 30 feet. The character of the fault is not clearly displayed, but it is believed to be of the thrust type. To the north the fault is a clear break of the strata, but to the south the displacement has taken place in a narrow zone 100 to 200 feet wide. No traces of oil or water springs were revealed by a careful examination of the line of the fault. It is believed that the conditions affecting the accumulation of petroleum in the strata have not been seriously disturbed by this small break.

PETROLEUM.

GEOLOGIC OCCURRENCE.

All the oil found in the San Juan field is in the Goodridge formation. It generally occurs in sandstone, though traces have been found in limestone in several wells. The formation contains nine beds of sandstone, all of which are supposed by the prospector in the field to contain enough oil to supply wells when they are drilled. The writer was unable to verify this supposition, but from the data obtained he is inclined to think that probably all the sandstone beds contain some oil, but that the quantity in most of them is insufficient to warrant commercial exploitation. Seven of the nine oil sands have been named by operators in the field, but the writer was unable to identify satisfactorily more than five of them. These are listed in the following table. The stratigraphic distance between the sands is shown in the section on pages 81–82.

Names, stratigraphic position, and thickness of five important oil sands in the San Juan field.

Name.	Number in columnar section on p. 77.	Thickness (feet).
Baby	66	9
"Goodridge"	62 and 63	26
Third	59	6
Mendenhall	57	35
Little Loop	51	3½

Of the four oil sands not shown in the above table, two have not been named; the other two are called Honaker sand and Blue Shale sand. The Honaker is reported to occur just below water level at the bottom of the Honaker trail and was not exposed at the time of examination. The Blue Shale, if properly described to the writer, should occur immediately below No. 18 in the section, but it is not represented along the Honaker trail. The Baby oil sand is very near the top of the Goodridge formation and shows in the Honaker trail section, where it is 9 feet thick. It varies moderately in thickness, but the average is about that given in the Honaker trail section. At Goodridge bridge it is slightly thinner. Most of the wells in the field have penetrated the Baby sand, and a considerable number of them extend through it to lower beds. Several of the wells report finding oil in this sand, but none of them obtained enough to be productive. The "Goodridge" sand is reported to be one of the most productive oil sands in the field. It is 26 feet thick along the Honaker trail and seems to be fairly uniform throughout the field. It is made up chiefly of grains of clear quartz with calcareous cement and seems to be generally porous, though locally the interstices appear to be completely filled. A list of the wells that have penetrated this oil sand is presented in the discussion of development (p. 98). Opportunity was not afforded to study the other oil sands as minutely as the two described above, but they were observed in considerable detail, and their character is generally represented by the above description. It is believed also that the stratigraphy of the Goodridge formation is fairly uniform throughout the field, and that consequently a correct record of the strata at one point will not vary far from the true conditions at other points. If this supposition is true the columnar section already given will present to anyone investigating the field a fairly accurate idea of the character of rocks to be expected through a distance of 1,500 feet below the top of the Goodridge formation.

CHARACTER OF THE OIL.

Physical and chemical properties.—Samples of the oil were collected from four wells in the oil field and submitted to David T. Day, of the United States Geological Survey, under whose direction physical and chemical examinations were made as shown in the following table:

Chemical and physical properties of oil in the San Juan oil field, Utah.

Serial No.		Depth (feet).	Physical properties.		
			Gravity.		Color.
			Specific.	Degrees Baumé.	
Utah 4	Well No. 4, Goodridge townsite; E. L. Goodridge, Goodridge..	263	0.8264	39.4	Black.
Utah 5	Jackson well, sec. 5, T. 42 S., R. 19 E.; stray sand; Monumental Oil Co., Bluff.	625	.8314	38.4	Do.
Utah 6	Anderson well, sec. 5, T. 42 S., R. 19 E.; Baby or "Goodridge" sand; South Side Oil Co., Mexican Hat.	300	.8202	40.7	Do.
Utah 7	Arcola well No. 2, T. 42 S., R. 19 E; Mendenhall sand; Bluff.	600	.8388	36.9	Dark green.

Chemical and physical properties of oil in the San Juan oil field, Utah—Continued.

Serial No.	Distillation by Engler's method.								Sulphur (per cent).	Paraffin (per cent).	Asphalt (per cent).	Unsaturated hydrocarbons (per cent).	
	Begins to boil (°C).	By volume.											
		To 150° C.		150°-300° C.		Residuum.		Total cubic centimeters.					
		Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.					Crude.	100°-300° C.
Utah 4	70	12.0	0.7245	36.0	0.7941	49.3	0.8974	99.3	0.26	6.09	0.80	20.4	1.0
Utah 5	78	11.0	.7235	35.0	.7976	51.0	.8946	97.0	.18	5.29	.60	14.8	6.0
Utah 6	73	12.0	.7130	36.0	.7941	49.5	.8975	97.5	.20	3.25	1.11	14.4	8.0
Utah 7	97	10.0	.7395	37.0	.8021	52.0	.8986	99.0	.40	6.79	.49	19.2	6.0

Concerning the character of the oil, Mr. Day further remarks:

These oils, as shown by the analyses, are unusually light in specific gravity. They yield more than the average amount of gasoline and of burning oil. The light specific gravity of the burning oil fraction compared to the average, the considerable amount of paraffin wax, and the comparatively low proportion of unsaturated hydrocarbons show that these oils are somewhat similar to the oil from Lima, Ohio, with a smaller proportion of sulphur. In fact, the amount of sulphur is less than in many oils in Illinois, which are refined without special apparatus for eliminating sulphur. Taken altogether, these oils are well suited for the manufacture of gasoline and kerosene, and there is every indication that the residuum would yield valuable lubricating oils.

FUEL VALUE.

It is believed that when oil from the San Juan field enters the commercial market its principal use will be as a refining oil, because it contains a relatively high percentage of gasoline. But the field is distant from commercial centers where the more volatile oils in the petroleum are demanded, and consequently its oil will probably also come into competition as a fuel with petroleum from Texas on one side and from California on the other and with coal from several fields in Utah and adjacent States.

It is of interest, therefore, to know first the relative fuel value of the San Juan oil compared with other oil, and second the fuel efficiency of oil compared with coal. According to Mr. Day, it is probable that for heating purposes no material difference exists between oil from the San Juan field and that from Texas or California.

Some very exhaustive tests have been made by the United States Navy [1] on the fuel efficiency of oil and incidentally the relative efficiency of coal and oil. The conclusions of the board which conducted these tests were that the relative evaporative efficiency of oil and coal as a fuel is practically in the proportion of 15 to 10, but that as oil can be stowed in somewhat less space than bituminous coal,

[1] Report of the U. S. Naval Liquid Fuel Board, Bur. Steam Eng., Navy Dept., 1904.

the relative efficiency of oil and good steaming coal as fuel supply in warships may be regarded as in the ratio of 18 to 10.

SOURCE AND ACCUMULATION OF THE OIL.

The source of the oil is undetermined, and so far as the author was able to ascertain there are no peculiar conditions which give any direct evidence concerning its origin. The Goodridge formation, in which the oil is found, is locally very fossiliferous. The animals from which the fossils came may have contained the oil and have given it up when decaying. Then, the oil may have accumulated in the sandstone beds, which are porous and present favorable structural conditions. These are possibilities which can be taken by the believer in the organic origin of oil to support his theory. On the other hand, the strata are intruded by igneous rocks, which may have produced the oil, if oil is of inorganic origin and is derived from igneous rocks, as some are inclined to believe. There is no evidence, however, that such has been the origin of the petroleum in this field.

Whatever the initial source of the oil may have been, it certainly has followed definite structural lines in accumulating in its present position. The principles which have governed this accumulation follow the laws laid down in the well-known anticlinal theory. The basic principle of this theory is that oil will remain above water underground as it does aboveground. In regions where there is enough water to fill the rocks the oil is carried to the surface if it is not interrupted by some barrier. At many places, however, its escape is obstructed by impervious beds, especially if they are folded into an anticline. In such places the oil collects on the top of the water and accumulates under the arch of the anticline in any stratum which will serve as a reservoir under the impervious bed. In regions where there is insufficient water to raise the oil to the crest of the arch the uplift is only partly filled and the oil remains along the sides of the anticlines. An ultimate analysis of the theory requires that in strata which contain very little or no water, but in which oil occurs, the oil collects in the bottom of the synclines. The height to which the oil is raised, therefore, depends to a certain extent on the character of the oil-bearing stratum, but chiefly on the amount of water and oil available to fill it. This theory is believed to apply to the accumulation of oil in the San Juan field, and as there seems to be little water in the strata of that field it is assumed that the oil collects in the syncline or at least not far up the sides. Accordingly, it is believed that the chance of finding oil is better in the syncline than it is in the anticline, because in this region there is very little precipitation and there is ample opportunity for the water in the rocks above river level to escape into the canyons. The accumulation of the oil is also unusually influenced by the canyons, whose effect in draining water and oil from the strata demands the most careful consideration. Such deep incisions in the strata afford ample opportunity for the escape of all fluids from the strata adjacent to them. Of course the drainage extends to the lowest level and is most complete next to the canyon, but undoubtedly it is effective for a considerable distance from the canyon, though possibly not to so great depth. Figure 2 is introduced to show the supposed conditions.

Within the area drained in this way there is no hope of finding an accumulation of oil. Such drainage is believed to be especially effective in the San Juan field, because this field lies in an arid region where rainfall is very light but the storms are violent and the percentage of run-off is high, therefore the strata do not receive much water. The water which enters the strata has abundant opportunity to escape. Near the canyons water wells will be dry until river level is reached, but away from the river the depth at which water or oil may occur is less. Except in a few places there are no springs above

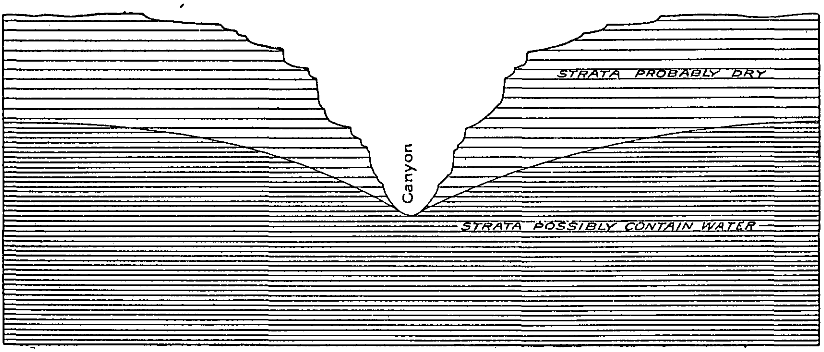


FIGURE 2.—Diagram showing the plane above which neither water nor oil may be expected in the San Juan field, Utah.

river level. This condition is accepted as an indication that the strata near the canyons are dry above the river and therefore that the oil is not held under the crest of the anticline, as in humid regions, but has sought lower levels in the syncline. From this consideration it is believed that the most productive wells in the field will be found in the syncline rather than along the crest of the anticline.

OIL SPRINGS.

Along San Juan River, west from Goodridge to the boundary of the field, there are several oil springs. All these springs are near the level of the river but not in the same strata because the beds rise to the west and the river cuts into successively lower beds, some of which are oil sands and give rise to oil springs. The highest seeps stratigraphically that were noted in the field are from the "Goodridge" oil sand, where it is exposed along San Juan River, near Goodridge bridge, and the lowest reported is at the foot of the Honaker trail. The stratigraphic distance between these two springs is 1,450 feet. The group of springs in the "Goodridge" sand occurs at intervals for about 200 feet along the river near the bridge. The seeps are discharging a little oil, which impregnates small areas of the rocks. At some places the oil seems to follow crevices; at others it saturates the unbroken rock. No evidence was found to show that the entire thickness of the "Goodridge" sand is impregnated with oil nor that any one part contains more oil than another. A close study of the sand, however, leads to the conclusion that some parts are better reservoirs than others. Locally the sand seems to be very calcareous and the interstices between the sand grains are completely filled. It is to be noted also that the oil does not come from any distinct horizon in the sandstone, as proved by the presence of seeps at several places between the top and bottom of the bed. It is believed, therefore, that the quantity of oil is variable in the sandstone and that locally there are barren areas. If this is true, a drill hole in any of these areas may penetrate the sandstone or pass completely through it without encountering oil; whereas an abundance of oil may be found in the same bed a short distance away. This variable character of the oil sand also renders it possible for adjacent wells to vary greatly in the amount of oil found, though structural conditions are identical.

The oil residue found in the seeps is black when exposed at the surface, but in the rocks and in unexposed crevices it is of a dark-brown color.

DEVELOPMENT.

Though oil springs must have been seen by prospectors and traders who operated along San Juan River, they seem to have received only casual notice until 1882, when E. L. Goodridge made the first location of a claim. No drilling was done, however, until the fall of 1907, when the first well, Crossing No. 1, was begun. This well encountered oil March 4, 1908, at a depth of 225 feet. It was a gusher, throwing oil to a height of 70 feet above the floor of the derrick, and led to considerable excitement. Other wells followed in rapid succession in 1908 and 1909, but most of them were only prospect holes put down to validate the titles to claims and not with serious intention of determining the oil resources of the field. By the summer of 1910 considerable capital had been enlisted to exploit the field. One standard rig was in operation and others were reported to have been ordered. There were 10 portable deep-well rigs in the area and several more on the way to it. During midsummer active development was somewhat retarded on account of the heat, but in the later part of August preparations were made to renew operations with greater vigor than before. Reports received from reliable sources during the winter of 1910-11 indicate that the expectation of activity has been fully realized. On February 1, 1911, according to a report by A. L. Raplee, there were 27 drilling rigs in the field and equipment for more on the way. Two oil wells were brought in during the winter and there was considerable improvement at old wells. A small town had been established near Mexican Hat and the roads and general facilities much improved.

There are several factors which exert an unusual influence in the development of the San Juan field. The area is isolated, and practically all supplies of every kind used in the field must be transported from the railroad by wagon across an almost desert country, where only ungraded roads exist and where travel is insufficient to warrant the proper construction or maintenance of roads. The places to which supplies for the field are shipped by railroad are as follows:

Dolores, Colo.: Rio Grande Western Railway (Denver & Rio Grande System) narrow gage, 106 miles; stage daily.

Mancos, Colo.: Denver & Rio Grande Railroad, about the same distance.

Thompson, Utah: Denver & Rio Grande Railroad, standard gage, 158 miles; stage triweekly.

Farmington, N. Mex.: Denver & Rio Grande Railroad, 110 miles.

Gallup, N. Mex.: Atchison, Topeka & Santa Fe Railway, 175 miles.

Among these places Dolores is the most easily reached but is not the best place from which to obtain supplies, because it is situated on a narrow-gage railway which does not extend to any of the large cities from which material can be obtained. This railway connects with standard-gage lines, but supplies must be transferred from the standard gage to the narrow gage with considerable delay and additional expense.

Another factor which has retarded development is the exceptional aridity of the region. There is very little vegetation and no cultivated area in or near the field large enough to furnish food for horses employed in the work of development, consequently all hay and grain must be hauled by wagon at large expense. It is reported that the current price for hay is $70 a ton and for oats $90 to $100 a ton. Provisions for men likewise must be obtained from distant points. The aridity of the country further increases the cost of prospecting, because generally water must be hauled from the river to the camps. There are, however, small seeps of alkaline water from which a moderate quantity can be obtained for drilling. San Juan River furnishes almost the only potable water in the field.

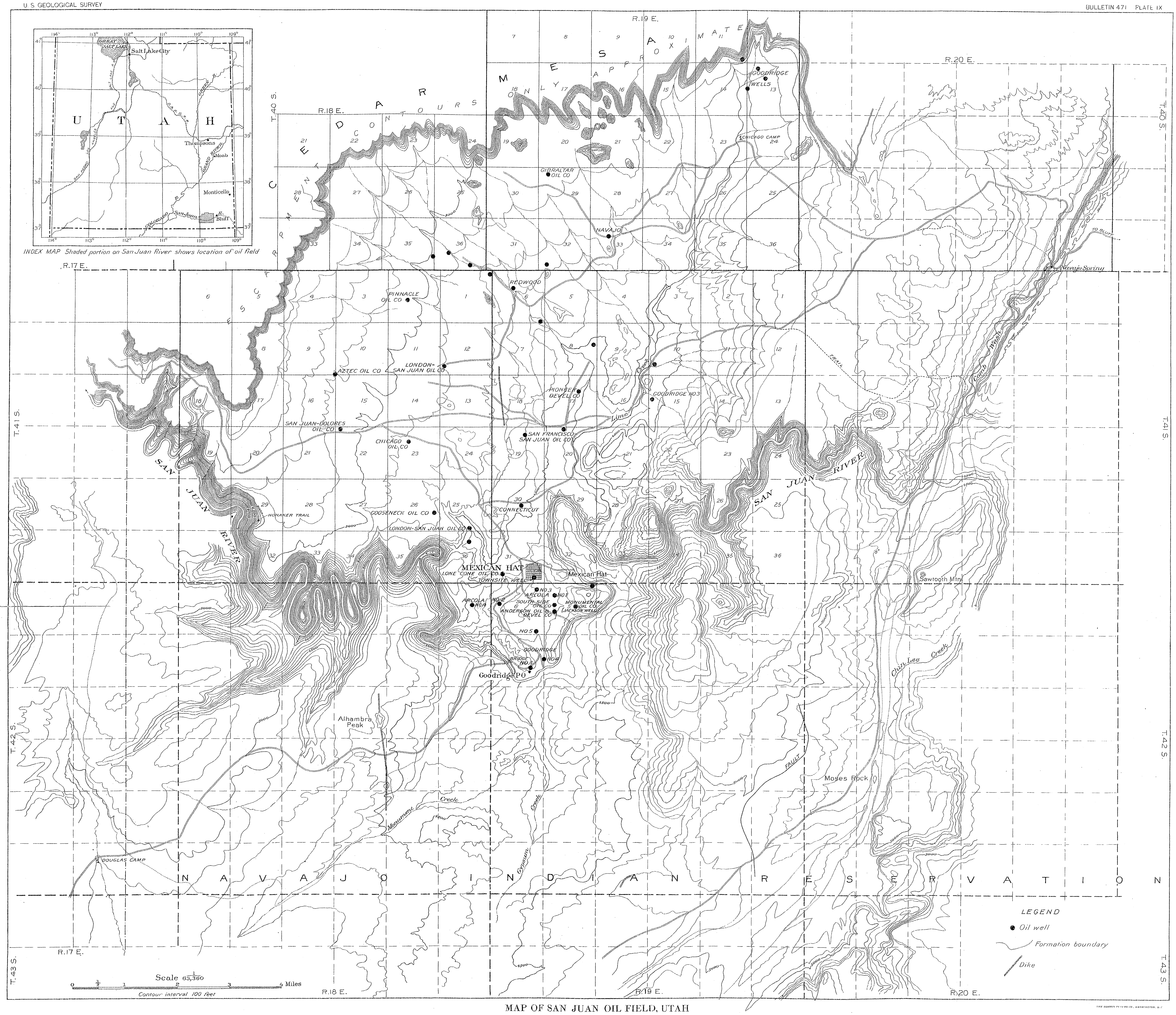
Fuel is scarce. There are a few piñon on Cedar Mesa and a scant growth at the base of the escarpment around the mesa, but the accessible wood is rapidly disappearing and there is probably no coal within a reasonable distance. The fuel most commonly used is oil from the producing wells in the field, which is hauled in barrels from the wells to the place where it is consumed. The common price of oil in the field is $1.25 a barrel.

Because the region is isolated and generally uninviting, the supply of labor is scarce and wages are high. Experienced drillers are obtained from oil fields in other States, mostly from California and Texas, though some come from more distant fields. These men can not be induced to come into this region unless they are promised high wages, and generally expenses while on the way; therefore experienced help is scarce, expensive, and retained with difficulty. Common labor can be obtained from settlements elsewhere in Utah and in adjacent States. So far as known, there has been no attempt to employ the Navajo Indians, who inhabit the region immediately to the south. These Indians are generally industrious and fairly intelligent. It is believed that their employment may help to settle the labor question so far as unskilled labor is concerned.

Transportation for the oil is requisite before the field can become commercially productive or economically important. The present method of hauling by team is so expensive that the oil can not be marketed profitably by that means even if an exceptionally high grade of oil is found in large quantities. In extensive fields two general methods are employed to transport oil—pipe lines and tank lines. Both of these methods are possible in the San Juan field. A pipe line could be constructed to any one of the railroad points mentioned on page 99. At least two lines of railroad into the field have been under consideration, both of which are pronounced practicable by engineers. There is little doubt that the transportation problem can be solved, but it will require considerable initial expense. It remains therefore with the prospector to show that there is enough oil in the field to warrant the expense of the pipe line or the railroad.

The following notes and well records, arranged in chronologic order, are prepared from data collected by Gregory in 1909, and by the writer in 1910, and also from information kindly supplied by Messrs. L. H. MacMorran, A. L. Raplee, and E. L. Goodridge. The locations of the wells are shown on Plate IX, with figures to correspond to the number used below.

1. Crossing No. 1 well, Oil Co. of San Juan; 226 feet deep; 8-inch hole; gusher, oil spouting to height of 70 feet. Oil now stands 95 feet from surface. Water was encountered immediately above the Baby sand and oil in the "Goodridge" sand.



MAP OF SAN JUAN OIL FIELD, UTAH

Log of Crossing No. 1 well.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, red	130	130
Limestone	4	134
Sandstone (Baby sand)	5	139
Shale, red	60	199
Limestone	21	220
Sandstone ("Goodridge" sand)	6	226

2. Chicago well, Oil Co. of San Juan; 213 feet deep; 8-inch hole; gas encountered in the first shale penetrated by the drill. Touches top of "Goodridge" sand. "Well abandoned because water could not be controlled."

Log of Chicago well.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandstone, red	20	20
Shale	71	91
Sandstone and limestone	23	114
Sandstone	17	131
Shale, red	7	138
Shale, brown	7	145
Shale, pink	10	155
Shale, red	7	162
Limestone	2½	164½
Sandstone ("Goodridge" sand)	49	213½

3. Golden Gate No. 7 well, Oil Co. of San Juan; sec. 15, T. 41 S., R. 19 E.; 105 feet deep; 8-inch hole. Slight flow from brown Baby sand. This well was sunk as assessment work. Encountered a strong flow of artesian water and a trace of oil. Good location for obtaining artesian water.

4. Monticello well; 263 feet deep. Oil stands 75 feet from surface. Oil from "Goodridge" sand. Data from Gregory's report; location not given.

Log of Monticello well.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale	137	137
Landstone (Baby sand)	6½	143½
Simestone and red shale	9½	153
Shale, red	9	162
Sandstone, containing oil	3	165
Shale, red	11	176
Sandstone and shale	7	183
Sandstone, oil-bearing	10	193
Unreported	17	210
Sandstone ("Goodridge" sand penetrated to a depth of 53 feet)	53	263

5. Burlap well, Oil Co. of San Juan; 244 feet deep; 8-inch hole. Strong flow of gas and trace of oil was found at the top of the "Goodridge" sand and a "showing" of oil in the Baby sand. Work in progress August 1, 1909.

Log of Burlap well.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, red	151	151
Limestone	5	156
Sandstone (Baby sand)	9	165
Shale, red	75	240
Limestone	4	244
Sandstone ("Goodridge" sand encountered at a depth of 244 feet).		

6. Oil City No. 5 well, San Francisco-San Juan Co.; 595 feet deep; 8-inch hole. Cuts "Goodridge" sand and goes into No. 3 sand. Gas was encountered. Well now full of oil and plugged.

7. Oil City No. 6 well, San Francisco-San Juan Co.; 165 feet deep; 8-inch hole. Cuts into top of Baby sand, where oil was struck. "Enough oil to hold claim."

8. Oil City No. 7 well, San Francisco-San Juan Co.; 140 feet deep; 8-inch hole. Cuts Baby sand, in which oil was found. "Enough oil to hold claim."

9. Oil City No. 8 well, San Francisco-San Juan Co.; 126 feet deep; 8-inch hole. Cuts Baby sand, where small flow of oil was found.

10. Conejos well, San Francisco-San Juan Co.; 450 feet deep; 8-inch hole. Cuts "Goodridge" sand and Baby sand, both of which yield oil. Oily water running from well July 23, 1909. Data from Gregory's report; location not given.

11. Bryce No. 1 well, Western Investment Co.; 165 feet deep; 8-inch hole. Cuts Baby sand, which yields oil. Drilling stopped for repairs. Well sunk in April, 1910, to a depth of 500 feet.

12. Bryce No. 2 (Oil Johnny No. 1) well, Western Investment Co.; 500 feet deep; 8-inch hole. Well sunk in a wash below the horizon of the "Goodridge" sand. At 200 feet oil was encountered in No. 3 sand. This oil and the water were cased off. Oil was again struck in the Mendenhall sand. Oil stands 150 feet from the surface. The well is plugged and shows strong flow of gas when cap is removed. Drilling continued in March, 1910.

13. MacMorran well; 200 feet deep; 8-inch hole. Cuts "Goodridge" sand, where oil and some gas were encountered.

14. Bitter Springs No. 1 well; 200 feet deep; 8-inch hole. Struck oil in "Goodridge" sand. Well is plugged. Data from Gregory's report; location not given.

15. Bitter Springs No. 2 well; 160 feet deep. Drilling stopped on account of repairs to rig. Data from Gregory's report; location not given.

16. Galloway well, Norwood Co.; Johns Canyon; 1,425 feet deep; 8-inch hole. Strong flow of gas encountered in "Goodridge" sand. Some oil in this and other sands. No water below 100 feet. Attempt made to reach the Honaker sand was abandoned because of lost tools. Drilling resumed March, 1910. This is the westernmost and also the deepest well in the field. It was put down with a standard rig to a depth of 1,425 feet. Operations were still in progress at the time of this survey. The well is situated at the top of the Goodridge formation. Traces of oil were found at 85, 600, and 1,170 feet. Only a small amount of gas was encountered. Operations were stopped for a month during the spring of 1909 on account of loss of tools. When the work was resumed it was found that oil had collected on the surface of the water in the well. This oil was taken from the well and bottled. It is believed by operators that the oil came from the sand at a depth of 1,170 feet.

17. Lone Cave Oil Co. well, drilled to a depth of 700 feet. This well was shot at a depth of 415 feet. It is reported that a good "show" of oil was obtained but no production.

18. Gooseneck Oil Co. has put a rig in place and made necessary preparations to drill.

19. San Juan-Dolores Co. has put a rig in place to drill.

20. Aztec Oil Co. has reached a depth of 610 feet with a large portable rig and has obtained a small "show" of gas at 237 feet and some oil at 495 feet. At the maximum depth no water had been encountered.

21. Pinnacle Oil Co. has entered into contract with a driller to sink a hole to a maximum depth of 5,000 feet. The contractor has erected a rig and completed most of the preparations for drilling.

22. Gibraltar Oil Co. has entered a contract for a deep hole.

23. London & San Juan Oil Co. drilled to a depth of 450 feet and obtained a good "show" of oil, but loss of tools in the well interrupted operations temporarily.

24. Pioneer Development Co. drilled in 1908 to a depth of 215 feet. A small amount of oil was reported at the maximum depth from a sand believed to be the "Goodridge." Recently this company has set a rig in place and is prepared to continue operations to a greater depth.

25. Jackson well; Monumental Oil Co. drilled to a depth of 635 feet. An oil sand was encountered at 525 feet. A fine "showing" of oil is reported in the "Goodridge" sand at 292 feet and again in a stray sand at 550 feet. At this lower point the well was shot. Oil now stands 90 feet below the surface. The writer is inclined to think that when proper correlation is made the sand encountered at a depth of 550 feet will be found to be not a stray sand but probably the Little Loop sand.

26. Anderson Oil & Developing Co. has drilled to a depth of 420 feet. A good "showing" of oil was found at a depth of 260 feet, and some oil was baled out for drilling, but the quantity was considered insufficient and it was cased off and the well drilled deeper.

27. Arcola No. 3 well, drilled to the "Goodridge" sand at 210 feet, where oil was found.

CONCLUSION.

Much remains to be determined before the San Juan field can be classed as a success or failure. However, the evidence gained in the examination described in the preceding pages points to certain conclusions regarding the most probable places for the accumulation of oil. As all the wells containing more than a good "showing" of oil are in the syncline, it is believed that the basin structure probably contains most of the oil. This condition has been demonstrated to exist regarding the upper oil sands and is believed to be true of the lower beds, though the lower ones may contain oil over a greater area. Furthermore, if there is a small amount of water present in the bottom of the syncline, the oil forms a border at the edge of the water, and no oil will be found in the lower beds in the center of the basin. Very little gas accompanies the oil and probably very little will be found, though wells in the anticline may find a moderate quantity but it will not show much pressure. Such gas is believed to be derived from the oil which is now in the syncline and to have risen into the anticline because it has a relatively low specific gravity. Practically all the geologic conditions point to the conclusion that very few flowing wells will be obtained. Reports of the wells drilled include one "gusher." For this well no adequate explanation has been offered. From his study of the field the writer is inclined to believe that the areas in which the most favorable conditions occur are as follows:

T. 41 S., R. 18 E.: Secs. 23, 24, 25, 26, 35, 36.
T. 41 S., R. 19 E.: Secs. 19, 20, 21, 28, 29, 30, 31, 32.
T. 42 S., R. 18 E.: Secs. 1, 2, 11, 12, 13, 14, 24.
T. 42 S., R. 19 E.: Secs. 5, 6, 7, 8, 17, 18, 19, 20.

Surrounding areas may contain oil, but it is believed that the quantity will be less than in those listed above. The area south of the river is not surveyed, and the locations given are based on projections of the survey covering the area north of the river. The grade of the oil obtained from this field will most probably be high, but it is not expected that the production will be great.

POSSIBILITIES OF OIL FIELDS IN THE SURROUNDING REGION.

From personal observations and conversation with investigators who have visited southern Utah and northern Arizona, and also from a study of the geologic literature relating to the region, the writer is led to believe that this region contains other fields with geologic conditions similar to those of the San Juan field. Similar stratigraphic conditions were noted by the writer as occurring to the north as far as Moab, Utah, and to the west strata very much like those in the San Juan field are reported by Richardson [1] and others.

The writer has received from Mr. L. W. Galloway a sample of petroleum residue from an oil spring at a point on San Juan River 18 miles west of Mr. Galloway's well in Johns Canyon, and apparently reliable reports are received concerning oil springs near the junction of Escalante and Colorado rivers. It seems probable, therefore, that oil in varying quantities is distributed over a large area in southern Utah and contiguous regions to the south. If this supposition is true, conditions favorable to the accumulation of oil are to be sought by the prospector and geologist in this area. Present knowledge is insufficient, however, to do more than point out the geologic conditions to be desired. Wherever uniform stratigraphic conditions are known to exist, probably favorable locations will be found on anticlines and synclines, but as there are igneous intrusions and faults in the region, as well as other conditions which are known to affect the accumulation of petroleum elsewhere in productive fields, structural conditions alone are not sufficient to determine the character of a field. The writer is inclined to believe that this is a region in which arrested monoclines may offer favorable opportunities for the accumulation of oil.

[1] Richardson, G. B., Petroleum in southern Utah: Bull. U. S. Geol. Survey No. 341, 1908, p. 343.

MARSH GAS ALONG GRAND RIVER NEAR MOAB, UTAH.

By E. G. Woodruff.

While passing through Moab, Utah, in August, 1910, the writer was informed that natural gas was escaping along Grand River in that vicinity. Accordingly, a hasty investigation was undertaken to determine, if possible, the geologic conditions near the gas springs and the source and nature of the gas.

In this region Grand River is confined to a deep, moderately broad canyon, along the sides of which the structure of the rocks is clearly displayed. An examination showed the strata to be similar to those described in the preceding paper, on the San Juan oil field, Utah. About 12 miles above Moab the beds are bent into a slight anticline, which is a favorable structure for the accumulation of petroleum. As the stratigraphic and structural conditions were found to be favorable, and as gas was escaping from the surface of the water, prospectors were led to believe that the gas originated in rocks at considerable distance below the surface and that petroleum had accumulated in the deep-seated strata.

The writer's examination led him to believe that the gas did not have its origin in petroleum but from buried débris in the river channel and is marsh gas. In this area the river flows slowly and considerable débris has collected in the channel. At the request of the writer, a sample of the gas was collected by Mr. A. H. Rogers, of Moab, and analyzed in the laboratory of the United States Geological Survey, with the following results:

Analysis of gas from Moab, Utah.

CO_2	3.5
O_2	0
CO	0
CH_4	90
N	6.5
	100

From this analysis it is evident that the gas is marsh gas. It should be noted, however, that although the gas escaping along the river is not derived from petroleum, this does not render the location impossible for the accumulation of oil and gas in subterranean strata. The character of the escaping gas indicates that its source is not deep-seated and that if the strata contain petroleum it is held in the reservoirs and not gradually liberated as has been supposed. The escaping gas is in no way an index of conditions below the river channel.