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ANTICLINAL STRUCTURE

IN PARTS OF

COTTON AND JEFFERSON COUNTIES

OKLAHOMA

BY

CARROLL H. WEGEMANN

Work done in cooperation with
THE OKLAHOMA GEOLOGICAL SURVEY

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CONTENTS.

ILLUSTRATIONS.

PREFACE.

By DAVID WHITE.

The work of the United States Geological Survey on the geology of the oil and gas deposits of Oklahoma is of three kinds—first, detailed examinations of the geology, both areal and economic, by quadrangles, with mapping of the formations and the geologic structure on topographic base maps; second, special examinations of oil pools or of areas suspected to contain oil pools, with mapping of the configuration of the oil sands and with representation of the progress of exploration and development; third, reconnaissance exploration and study of areas that may contain oil or gas, undertaken to discover the localities where the geologic structure is, in general, favorable to their accumulation in commercial quantities.

Most of the earlier work of the Survey in the oil regions of Oklahoma belongs to the first type, the reports on which are exemplified by the Tahlequah and Muscogee folios, by J. A. Taff, published in 1905 and 1906. These folios have contributed effectively to the development of the oil and gas resources of these quadrangles and are still the main source of information as to the geology of the areas covered, though in this work, the first detailed survey in this great field, the structure of the oil-bearing formations was not contoured on the geologic maps. In later publications greater attention has been given to the graphic representation of structure. Geologic maps that show in detail the structure of the oil sands and the stage of exploration at the time of the field survey are now in preparation for publication in folios to cover the Vinita, Claremore, Nowata, Hominy, Pawhuska, Sansbois, and Sallisaw quadrangles, of which the first four mentioned were geologically surveyed in cooperation with the Oklahoma Geological Survey. Special descriptions and maps of the structure of the oil-bearing formations in several of these quadrangles are in progress for advance publication in Survey bulletins. The completion and publication of these reports have been delayed in order to obtain accurate topographic base maps.

The detailed description of the geologic structure in these quadrangles is important in the search for oil and gas in order to demonstrate the relations of the discovered oil and gas pools to the different structural features of the region, but its greatest direct value lies in its disclosure of the new areas in which the structure is favorable to

the occurrence of oil and gas, inviting search for new pools or pointing to extensions of pools already known but incompletely developed. On the other hand, economic benefits, possibly of far greater commercial value, are gained by the delimitation of large areas in which the structure is unfavorable and in which the search for oil pools is therefore less hopeful, if not absolutely hopeless.

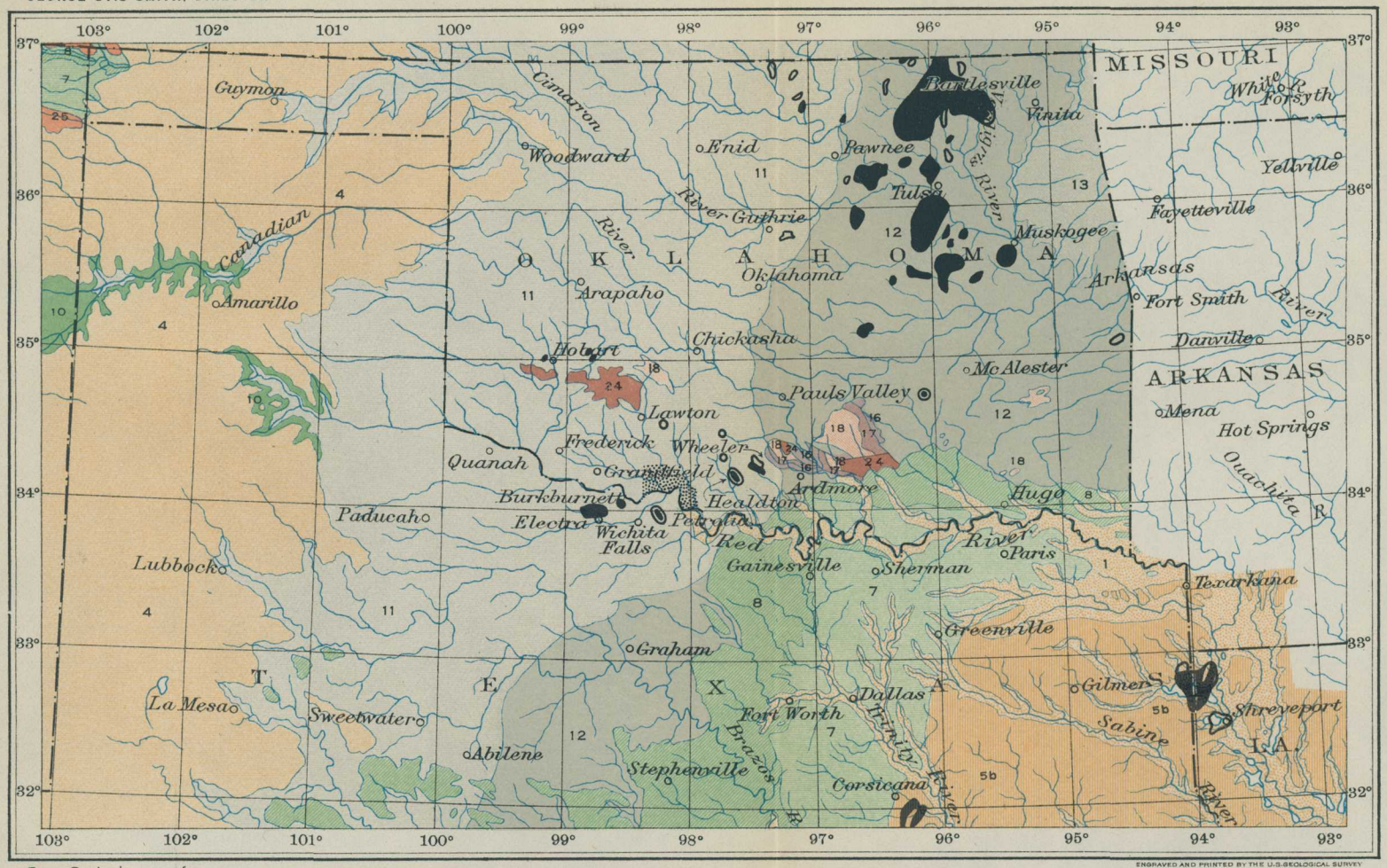
Most of the studies grouped in the second category given above are confined to discovered though perhaps undeveloped pools and are designed to afford first-hand, accurate information as to the geology of the particular area considered; the number, position, and characters of the oil sands; and the local structure, so far as it can be determined. Investigations of this kind have thrown most valuable light on the mode of occurrence of the oil and gas pools with reference to the structure. The editions of most reports on such studies—generally preliminary reports—are soon exhausted by the public demand, though not before their prompt publication has served its purpose of aiding the driller in developing the area. Examples of reports on oil and gas development in north-central Oklahoma may be seen in Bulletin 531–B, by R. H. Wood, both editions of which were quickly exhausted, and in the reports by C. D. Smith on the structure of the Fort Smith-Poteau gas field and on the Glenn oil and gas pool and vicinity, both printed in Bulletin 541–B. Some of these papers, like that on the Cleveland pool, now in preparation by Mr. Wood, are by-products of the detailed areal and economic survey of a quadrangle and are published as promptly as possible for the use of the driller, in advance of the more deliberate completion and publication of the folio.

Work of the third type—exploratory or reconnaissance work—consists in the preliminary examination by the geologist of regions which are not yet known to contain oil or gas but which, for one reason or another, are suspected to contain one or both. The object of the examination is to determine whether the geologic formations and geologic structure in the unexplored region are favorable to the accumulation of oil and gas in pools, and to indicate the places that should be tested by the driller as well as to point out the areas that are structurally least promising and that should be shunned by the driller in order to avoid needless loss of time and money. In short, these explorations are designed primarily for the guidance of the "wildcatter" in finding oil with greatest economy. It must always be remembered that though the geologic structure is a very important factor in the distribution of oil and gas pools, there are other factors, not all of which are yet understood, that participate in conditioning the presence of these hydrocarbons in commercial quantities in any region. Favorable structure does not assure an oil pool, but pools are seldom found where the structure is of an unfavorable type.

But two regions in Oklahoma have been explored for the special purpose of detecting anticlines and domes. One of these, the Grandfield district, in Cotton and Tillman counties, is described by M. J. Munn in Survey Bulletin 547. The other region is covered by the report here presented by Mr. Wegemann. The examinations that led to the preparation of these reports were made at the request of and in cooperation with the Oklahoma Geological Survey, which bore a part of the cost of the work.

Those who use these reports should bear in mind that the object of publication is to offer first aid to the prospector for oil in the areas covered; that the report is a result of a preliminary reconnaissance in a region where exposures of the strata are relatively few, discouragingly imperfect, and devoid of key rocks; and that the field geologist, in his effort to make out the structure, has had little, if any, aid from drill records, which are so valuable in work of this kind. Under such circumstances the opportunity for error in structural interpretation is unusually large, but despite the unfavorable conditions the geologist has done his best and, with the cautions and qualifications just made, the result of his work is offered to the public.

The anticlines and domes pointed out by Mr. Wegemann are believed to be the most promising areas of the region for testing, for nearly everywhere in Oklahoma accumulations of oil and gas are associated with such features of structure, though their exact relations to these features vary from area to area and even from pool to pool. Incomplete as the results necessarily are, on account of the difficulties encountered, the work of the State and Federal surveys will have been many times repaid if the use of this report will prevent a large part of the fruitless drilling that usually attends the geologically unaided search for oil and gas in undeveloped areas.



From Geologic map of North America, U. S. G. S. 1911

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

GEOLOGIC SKETCH MAP OF OKLAHOMA AND NORTHERN TEXAS

Showing general classification of the rocks and the location of the area covered by this report with reference to the adjacent oil and gas pools

Scale $\frac{1}{5{,}000{,}000}$

100 0 100 200 Miles

1915

TERTIARY

CRETACEOUS

CARBONIFEROUS

1	4	5b	7	8	10	11	12	13
QUATERNARY	LATE TERTIARY	MARINE EOCENE	UPPER CRETACEOUS	LOWER CRETACEOUS	TRIASSIC	PERMIAN	PENNSYLVANIAN	MISSISSIPPIAN

16	17	18	25	24				
SILURIAN	MIDDLE AND UPPER ORDOVICIAN	CAMBRIAN AND LOWER ORDOVICIAN	TERTIARY EFFUSIVES	PRE-CAMBRIAN ROCKS	OIL POOLS	GAS POOLS	AREA COVERED BY THIS REPORT	

ANTICLINAL STRUCTURE IN PARTS OF COTTON AND JEFFERSON COUNTIES, OKLAHOMA.

By CARROLL H. WEGEMANN.

INTRODUCTION.

Reports on adjoining areas.—The "Red Beds" area of northern Texas and southern Oklahoma has until recently received but little attention from geologists making explorations for oil, not because it was thought that the rocks contain no oil but rather because the delineation of structure, one of the controlling factors in the accumulation of oil, was considered an almost hopeless task in such beds. Recent investigations, however, have shown that the task, though difficult, is by no means hopeless. It is possible to determine with more or less accuracy the structure of the strata at many places throughout the "Red Beds" region, and thus to point out localities favorable or unfavorable to the accumulation of oil. It is with this object in view that the State surveys and the United States Geological Survey are making examinations of areas in this region in which the rocks may possibly contain oil. In 1912 the University of Texas published a report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.,[1] the area considered including the Electra, Burkburnett, and Petrolia fields, lying immediately south of Red River, which here forms the boundary between Texas and Oklahoma. In the fall of the same year the United States Geological Survey, in cooperation with the Oklahoma Geological Survey, made an examination of about 360 square miles lying north of Red River in southeast Tillman and southwest Cotton counties, the results of which were published by the United States Geological Survey.[2]

Location and extent of the area examined.—The present report is the result of examinations made in the summer and autumn of 1913. The area covered, about 270 square miles, lies in Oklahoma north of Red River and east of the Grandfield district. (See Pl. I.) It is limited on the north and east by the line of the Chicago, Rock Island & Pacific Railway, which passes through the towns of Ryan, Waurika, Hastings, and Temple. South of the area across Red River is Clay

[1] Udden, J. A., and Phillips, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, 1912.

[2] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, 1914.

County, Tex., which comprises the eastern part of the territory covered by the bulletin published by the University of Texas, above cited.

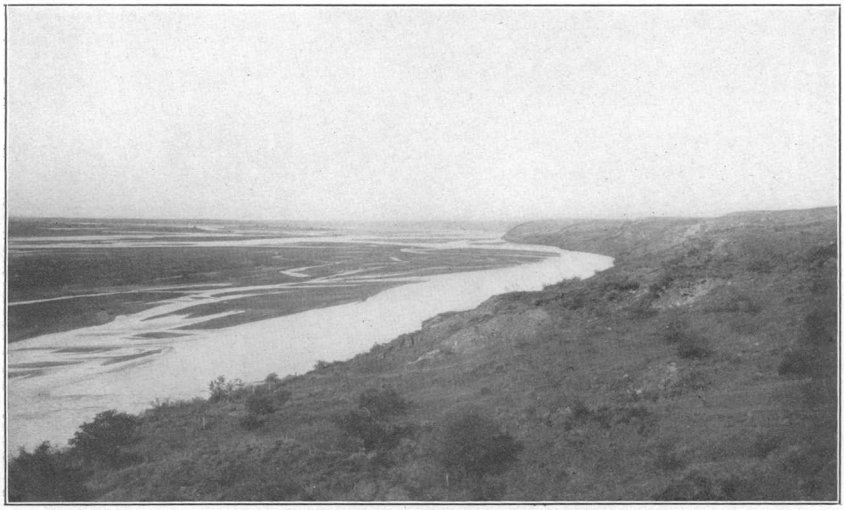
Acknowledgments.—The present investigation was made under a cooperative agreement between the United States Geological Survey and the State of Oklahoma, by which the State appropriated about one-third of the funds, the remainder being furnished by the United States Geological Survey. The writer was assisted in the field by Messrs. A. E. Fath and R. W. Howell, of whose careful and conscientious work he desires to express his appreciation. Mr. Fath compiled the map and made the microscopic examinations of the rocks, and also assisted in many other ways in preparing the report. Through the courtesy of officials of the Chicago, Rock Island & Pacific Railway a profile of that road was obtained, which was of material aid in carrying elevations over the field. Thanks are due to the Riverside Oil Co., the Green River Oil Co., and the West Virginia Petroleum Co. for logs of their wells. The writer is also indebted to many residents of Cotton and Jefferson counties for courtesies extended to him during his prosecution of the work.

Settlement and industries.—Although this part of the country has been open to settlement by white men but a few years, there is little Government land remaining. Stock raising, which only a few years ago was the principal industry, has given place almost entirely to farming. The rolling plains country, which is practically treeless, is divided into farms, most of which contain 160 acres. The roads follow the section lines. The principal product of the country is cotton, although much corn is raised. Several failures of the corn crop, owing to prolonged drought, have turned the attention of settlers to the raising of kaffir corn and other crops better suited to the climate.

The largest town in the area is Waurika, the county seat of Jefferson County. Ryan, Hastings, and Temple are smaller, but each supplies a considerable area. All four towns are on the Chicago, Rock Island & Pacific Railway. There are three country stores in the area, two at "the corners" known as Taylor, west of Cache Creek, and one belonging to C. Y. Wilson, 10 miles due west of Waurika.

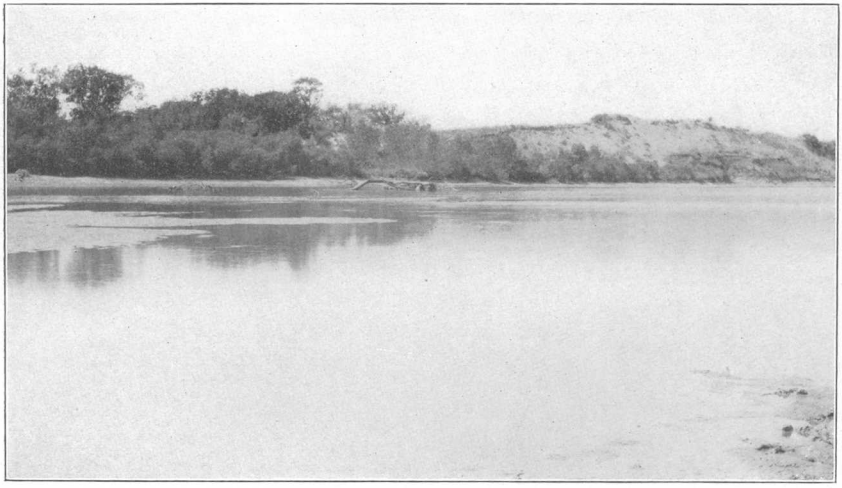
DRAINAGE AND TOPOGRAPHY.

Streams and their relation to structure.—Red River, the largest stream in this general region, forms the southern boundary of the area here described. It is remarkable for the great width of its channel in comparison with the width of its immediate valley, which is unusually narrow for a stream of its size; also for its quicksand and for the great variation in the amount of water it carries, the channel at many places being entirely dry during midsummer and carrying a rushing torrent of water charged with red mud at the first advent of the autumn rains.



A. RED RIVER, LOOKING WEST FROM SEC. 2, T. 5 S., R. 11 W.

Note level surface of upland plain.



B. MOUTH OF CACHE CREEK FROM EAST BANK.

The slight disturbance in the water in the left foreground is due to bubbles of gas.

The area here considered is drained by three streams, which flow into Red River and which, named in the order of size, are Cache Creek, Beaver Creek, and Whisky Creek. East Cache Creek, which heads northeast of the Wichita Mountains and crosses the western part of the area from north to south, is joined by Deep Red Run and West Cache Creek, the latter heading on the south flank of the Wichita Mountains. Beaver Creek, which heads east of the Wichita Mountains, parallels Cache Creek, lying 6 to 10 miles east of it, and flows nearly southward along the east side of the area. It has no large branches, such as those of Cache Creek. Whisky Creek is a small stream, not more than 12 miles long, which lies midway between Cache Creek and Beaver Creek in their lower courses.

The fall of Red River for the 39 miles of its course along the border of this field is 111 feet, the average fall in this stretch being 2.85 feet to the mile. The width of the channel, as marked by the borders of the stream at high water or by the width of the belt of barren sand at times of drought (see Pl. V), varies considerably from point to point along its course. Opposite the mouth of Cache Creek it is 3,500 feet wide, but in the great bend 6 miles southwest of Waurika it is contracted to a width of about 800 feet. The cause or causes of this variation in the width of the channel are not certainly known; it is probably due to the combined action of several factors, such as the hardness of the rock strata encountered by the stream at different places, the dip of the rock beds, the direction of the prevailing winds and hence the direction in which the sand of the river bed is drifted at times of low water, and the locations of the mouths of tributary streams, like Cache Creek, which add their load of material to the load carried by the main river.

It seems probable that Red River, a large stream, established its course on a base-level plain and maintained it, having been little affected by subsequent slight and gradual folding, whereas its smaller tributaries were unable to deepen their channels as rapidly as the strata were uplifted across their courses, and thus were compelled to readjust themselves to the folds. The present course of Red River is therefore independent of the structure, following an anticline through part of the area under discussion, whereas nearly all the smaller streams flow in synclines or follow the dip of the rock strata, even though their courses thus determined are directly away from the main stream, as are the courses of the streams in T. 4 S., R. 11 W.

Upland plain.—The channel of Red River has been cut about 100 feet below the level of a gently rolling plain which covers much of southwestern Oklahoma. (See Pl. II, *A*.) This plain is apparently the result of base leveling accomplished by streams flowing at grade when the land areas were relatively lower with reference to sea level than at present. Taff [1] gives the age of this peneplanation as prob-

[1] Taff, J. A., Geology of the Arbuckle and Wichita mountains, in Indian Territory and Oklahoma: U. S. Geol. Survey Prof. Paper 31, p. 17, 1904.

ably Tertiary. This upland surface slopes gently southeastward at about the grade of Red River. The flood plain of Red River, which in some places is 3 miles wide, as well as the flood plains of tributary streams like Cache Creek and Beaver Creek, represent a surface of planation now in process of formation.

STRATIGRAPHY.

"RED BEDS."

The stratigraphy of the exposed rocks of the region is comparatively simple. These rocks consist of two series of beds, the older composing part of the Wichita formation of the Permian "Red Beds" and the younger the more recent deposits, represented by surface soil, the upland gravels of old river terraces, and the alluvium of the present flood plains. The determination of the stratigraphy of the rocks beneath the Wichita formation, which are not exposed in the area considered, is more difficult, as it involves several unknown factors. It is, however, important in the study of the accumulation of oil in the area, inasmuch as these underlying rocks probably constitute the principal source of the oil found in adjoining fields.

AGE OF THE "RED BEDS."

The "Red Beds" of northern Texas and southern Oklahoma are now generally conceded to be of Permian age, although this judgment has not passed unquestioned. Of the fossil flora White makes the following statement:[1]

> In accordance with the paleobotanical standards of western Europe, I refer the plants of the Little Wichita in Texas to the lower Permian, the terranes being probably referable to the Chase group in Kansas.

Girty, however, in the same report comments on the evidence afforded by the invertebrate fossils as to the Permian age of the "Red Beds" as follows:

> I am therefore accepting the Permian age of the Kansas and Texas beds, but at present strictly on paleobotanical evidence. * * * An inspection of the faunas collected from the strata immediately concerned * * * shows a rather noteworthy change of facies between the Wichita and the Cisco, a change, however, which is more or less progressive and has its beginning in earlier beds. This shows itself rather in a limitation than in a change of fauna and in the prominence of certain groups more rare below.

Most vertebrate paleontologists have been inclined to consider the "Red Beds" as Permian. Case, however, prefers to call them Permo-Carboniferous, laying stress on their close relation to the underlying formation.[2]

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[1] Gordon, C. H., The Wichita formation of northern Texas, with discussions of the fauna and flora by G. H. Girty and David White: Jour. Geology, vol. 19, No. 2, pp. 110–134, 1911.

[2] For titles of papers containing a full discussion of the problem see the bibliography given on pages 103–105 of this bulletin.

DIVISIONS OF THE "RED BEDS."

The "Red Beds" were originally divided by Cummins [1] into three divisions which, from base to top, are the Wichita, the Clear Fork, and the Double Mountain. Of these, the Wichita only is present in the area here described, the higher divisions being found farther west. According to Cummins's description, the Wichita is composed of sandstones, clay beds, and a peculiar conglomerate. The sandstones are of various colors; the clays are red and bluish and are in places copper bearing, as are also those of the Clear Fork formation. There are iron concretions in the red clays, and the peculiar conglomerate is composed of clay or clay ironstone with a ferruginous matrix. The Clear Fork formation consists of limestones, clay and shale beds, and sandstones. The sandstones are not so abundant as in the Wichita. The clays are red and blue. There is a conglomerate like that in the Wichita, but it is less abundant. A few beds of gypsum are present. The Double Mountain formation, which overlies the Clear Fork, is said to consist of sandstone, limestone, sandy shale, red and bluish clays, and thick beds of gypsum.

WICHITA FORMATION.

In the area covered by this report the Wichita formation consists of beds of shale and sandstone and thin layers of shale conglomerate. The formation contains no limestone, although some of the sandstone beds are very calcareous. The stratigraphic thickness of the rocks exposed in the area here described is about 280 feet. The "Red Beds," however, extend to a depth of about 1,000 feet below the surface, as is shown by the logs of deep wells drilled in the vicinity of the field. How much of the Wichita formation has been removed by erosion it is impossible to say.

SHALE.

The individual beds of shale of the Wichita formation exposed in this field range in thickness from a few inches to 42 feet, and one bed of red shale, recorded at a depth of 100 feet below the surface in well No. 1 of the Riverside Oil Co., is 101 feet thick.

The shale is of many colors and shades. In some beds the color ranges from red to gray, in others from green to purple; in still others it is almost black. Much of the shale, especially where it is exposed to weathering, has a mottled appearance, the colors being red and light gray or even white. The change of color does not invariably conform to the bedding, which, though finely developed in certain strata, especially near sandstone beds, is not usually pronounced. Under the microscope a thin section of finely laminated shale closely

[1] Cummins, W. F., The Permian of Texas and its overlying beds: Texas Geol. Survey First Ann. Rept., pp. 83–197, 1890. Geology of northwestern Texas: Texas Geol. Survey Second Ann. Rept., p. 400, 1890.

associated with sandstone is seen to consist of dark-red amorphous material, particles of quartz, slender laths of a colorless mineral having parallel extinction (sericite?), and a greenish to bluish, highly refracting mineral. The red amorphous material increases in amount near the lamination planes to the practical exclusion of the other minerals. Very few of the particles of quartz in the section examined have a diameter of more than 0.02 millimeter, and the average diameter of the larger particles is 0.017 millimeter.

Scattered through the mass of the shale, in some places arranged along the bedding planes, there are concretionary masses, which are of various form and range in size from small grains to masses a foot or more in diameter. The material of these concretions, if such they really are, consists of shale resembling in most respects that in which they are embedded. The cementing material is calcium carbonate, but the masses contain considerable amounts of iron oxide and also of manganese oxide, which occurs in some places as dark brown or black dendritic forms penetrating the concretion from the surface toward the center. The concretions do not show concentric structure and are as variable in shape as they are in size. Some of them are almost round, have smooth surfaces, and resemble closely the pebbles of the concretionary conglomerate described below; others are flat, their longest diameter lying parallel to the bedding of the shale; still others are rounded in outline and have extremely rough surfaces, being covered by a deposit of calcium carbonate built out in a sharp edged network, as if the shale around the concretion had been broken by innumerable cracks which were filled by the deposit. Munn[1] referred to these forms as "clay-limestone concretions" (see Pl. III, *A*), and this term will be employed in the present report.[2]

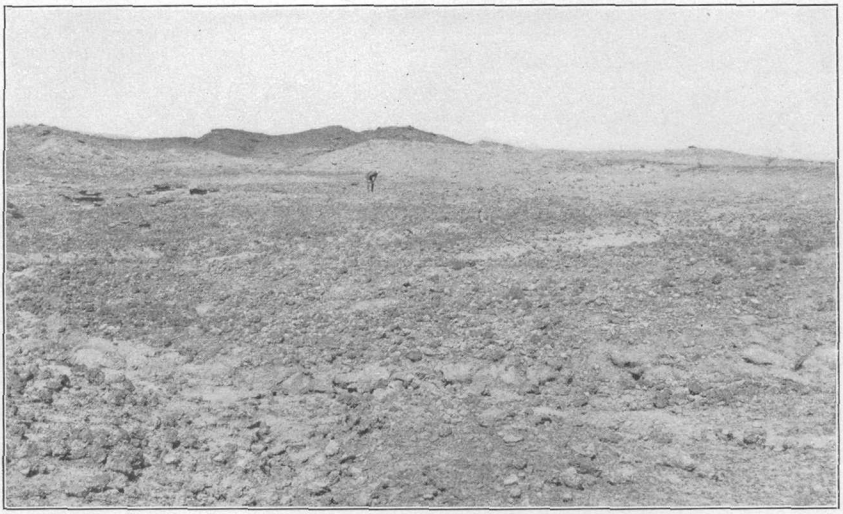
SANDSTONE.

The sandstones of the Wichita formation are composed principally of grains of quartz and very subordinately of grains of feldspar and zircon. Muscovite and biotite were found in 7 of the 12 thin sections of sandstone examined, and in all these slides only three grains of tourmaline were observed. Most of the grains of feldspar are weathered and, so far as could be determined, all are plagioclase. The grains of zircon are considerably smaller than the grains of quartz, being, in the sections examined, about one-third as large. Inclusions of apatite, rutile, and zircon occur in some of the quartz grains.

The grains of sand are almost invariably angular, their angularity increasing with decrease in size. Well-rounded forms are rare, being

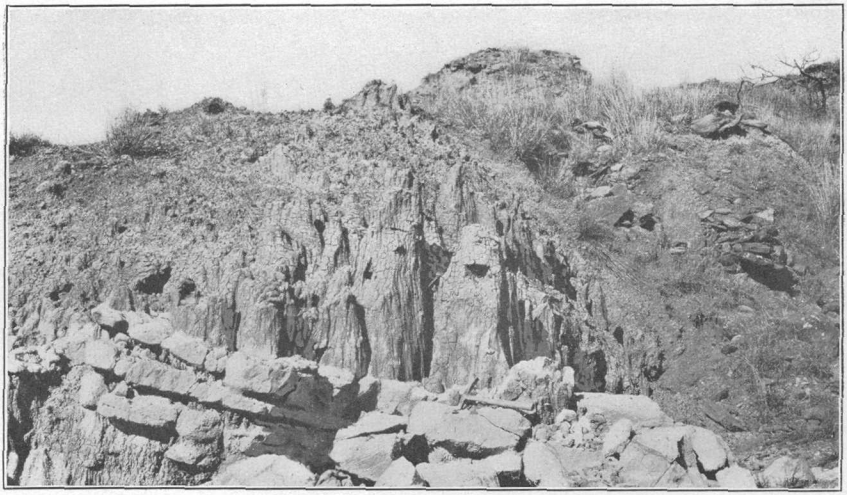
[1] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, p. 19, 1914.

[2] For theories in regard to the formation of concretions, see Gardner, J. H., The physical origin of certain concretions: Jour. Geology, vol. 16, pp. 452–458, 1908. Also Todd, J. E., Concretions and their geological effects: Geol. Soc. America Bull., vol. 14, pp. 353–368, 1903.



A. LOCALITY AT WHICH NUMEROUS BONES OF PERMIAN VERTEBRATES WERE FOUND, IN THE SW. ¼ NW. ¼ SEC. 36, T. 4 S., R. 9 W.

Surface of red shale covered by innumerable concretions.



B. FINE-GRAINED SANDSTONE IN RED AND PURPLE SHALE, IN SEC. 13, T. 5 S., R. 9 W.

The dip of the sandstone beds is probably depositional.

found only in grains whose diameter is greater than one-tenth of a millimeter, the lower limit to rounding by the action of water. Since eolian agencies are capable of rounding sand grains of smaller diameter than one-tenth of a millimeter, the fact that the finer particles of the sands of the Wichita formation are not rounded but invariably angular indicates at least that wind action has had little to do with their deposition.

The principal cementing material of the sandstones is calcite, but silica occurs in subordinate amounts. The relation of these two cements will be shown later. In the calcite-cemented sandstones iron oxide stains are common, and in a few specimens are so pronounced that the sandstone has a distinctly red color. Iron oxide was found to be more than a stain in the calcite cement in only one specimen, in which it formed practically all the cementing material.

The sandstone beds vary considerably in thickness from place to place, variations of several feet having been noted within horizontal distances of only a few yards. The greatest thickness measured for any one sandstone is 32 feet in the SE. ¼ SE. ¼ sec. 15, T. 5 S., R. 8 W. The average thickness is about 12 feet.

The sandstones are of two different types, which for convenience will here be termed the normal and the fine-grained sandstones. The two types differ in size of grain, cement, bedding, thickness, regularity, and in the associated conglomerate, the differences being due mainly to variations in the conditions under which they were deposited. There are many gradations between the two types, but the characteristics of the extremes are markedly distinct. The normal type exceeds the fine grained both in absolute amount of sediment and in the persistence of its beds over considerable areas. It is the important rock in geologic work as it furnishes the only key horizons in the field for the correlation of strata between outcrops and for the determination of structure. (See Pl. IV, *A*.)

The difference in size of grain of the two types is shown by the measurements given below. These sizes were determined by a series of Howard & Morse "Standard" sieves. The grains ranging in size between 0.5 and 0.25 millimeter pass through a 30-mesh sieve with an effective opening of 0.535 millimeter and are caught on a 60-mesh sieve with an effective opening of 0.231 millimeter. The grains measuring 0.25 to 0.125 millimeter pass through a 60-mesh sieve and are caught on a 120-mesh sieve with an effective opening of 0.120 millimeter. The grains measuring 0.125 to 0.0625 millimeter pass through the 120-mesh sieve and are caught on a 200-mesh sieve with an effective opening of 0.071 millimeter. Grains measuring less than 0.0625 millimeter pass through the 200-mesh sieve.

The first two specimens of sandstone are of the normal type, in which most of the grains range in diameter from 0.0625 to 0.25 milli-

meter. The third specimen represents the fine-grained type, in which most of the grains are smaller than 0.0625 millimeter.

Size of grains in sandstone of Wichita formation.

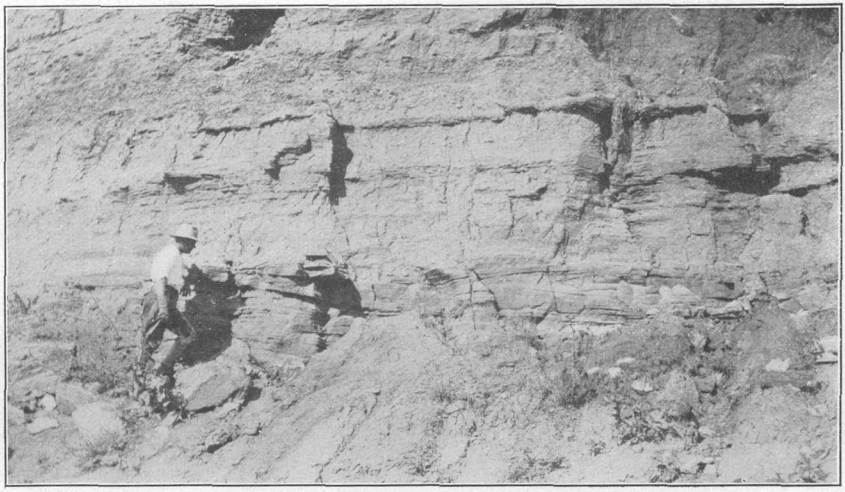
Diameter in millimeters.	1	2	3
	Per cent.	*Per cent.*	*Per cent.*
Less than 0.0625	22	9	57
0.0625 to 0.125	44	24	26
0.125 to 0.25	34	67	17

1. Sandstone containing nodules of copper, normal type, from SW. ¼ SE. ¼ sec. 35, T. 4 S., R. 10 W.
2. Sandstone containing concretions of manganese, normal type, from NE. ¼ SW. ¼ sec. 3, T. 5 S., R. 8 W.
3. Sandstone of fine-grained type, from NE. ¼ NW. ¼ sec. 3, T. 5 S., R. 8 W.

The cementing material differs in the two types of sandstone. The normal or medium-grained type is for the most part cemented by calcite; the fine-grained type is cemented principally by siliceous material, presumably quartz. A part of the cement of the normal type does not disintegrate in cold dilute hydrochloric acid and is probably quartz, as is apparent also from the examination of thin sections under the microscope. In like manner the cement of the fine-grained type is not all silica, as is shown by its effervescing on the application of hydrochloric acid. The cause for this difference in cementing material between the two types of sandstones is not clear. It appears to bear a direct relation to the size of the grains of the sandstone and may in some manner be controlled by the rapidity of the circulation of water through the rock, which would be greater in the coarser-grained material, or by the amount of rock surface exposed to water action, which would be greater in the finer-grained sandstone.

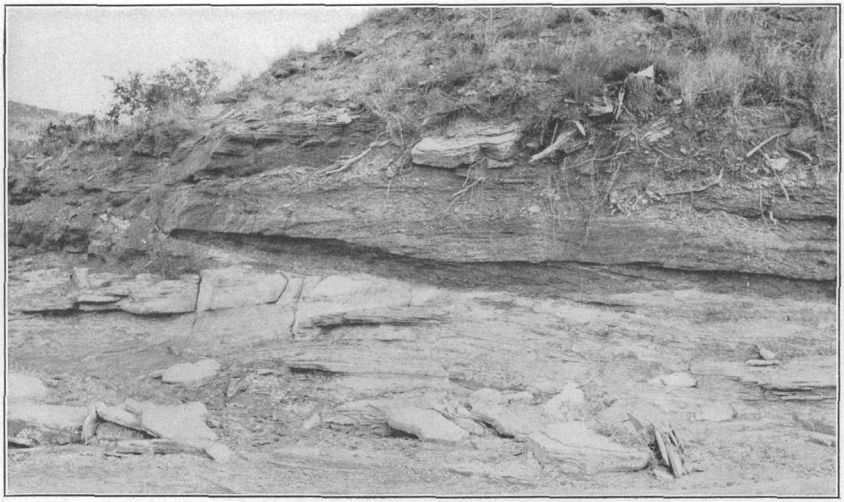
The two types of sandstone differ in bedding. The normal type shows the action of rather swift currents during its deposition—conglomerates are associated with it, it shows almost everywhere cross-bedding, and where it does not the horizontal bedding is more pronounced than that in the fine-grained type. The fine-grained type is not as a rule associated with conglomerate and shows little or no cross-bedding. In one exposure, in the NE. ¼ sec. 19, T. 5 S., R. 8 W., leaf impressions were found in this type of sandstone.

The normal sandstones are the most conspicuous beds of this region and average 10 to 15 feet in thickness. The fine-grained sandstone is usually found in comparatively thin beds, rarely if ever exceeding 6 feet in thickness and generally occurring as thin sandy layers or streaks in the red shales. Being less firmly cemented than the normal type, it does not resist the action of weathering so well, and being thin it is not generally conspicuous in exposures. It is therefore impossible to trace the beds of the fine-grained type for any considerable distance or to make observations on their



A. SANDSTONE BED OVERLAIN BY ALLUVIUM, IN EAST BANK OF CACHE CREEK, IN THE SE. ¼ NE. ¼ SEC. 5, T. 5 S., R. 10 W.

In front of the man, at the base of the bed, is a small lens of "concretionary" conglomerate, which appears to have been deposited along a channel in the underlying shale.



B. "CONCRETIONARY" CONGLOMERATE IN SANDSTONE ON TEXAS BANK OF RED RIVER, 1½ MILES SOUTHWEST OF THE MOUTH OF CACHE CREEK.

Note erosion of sandstone beds before deposition of conglomerate.

continuity, but it is believed from the study of single exposures that these beds vary greatly in thickness from place to place and are generally lenticular.

A common characteristic of the normal type of sandstone is its content of manganese minerals (oxides of manganese), which discolor the rock along the bedding planes and occur in concretionary masses. (See p. 101.) At certain localities copper minerals in small amounts form part of the cement of the normal sandstone. (See pp. 101–102.) These minerals do not occur in the fine-grained sandstones, possibly because they are less permeable to water solutions than the coarser sandstones.

The presence of so few minerals other than quartz among the sand grains, and these minerals only the most resistant ones, indicates a high degree of assortment of sediment, which is found only in beds deposited at some distance from the source of the material or in beds formed of material that had been agitated by water for a considerable time. The fineness of the sand grains, even in the normal type of sandstone, also shows that the assortment is of high order, and the extreme fineness of grain of the fine-grained sandstone is even more remarkable.

In summary: The sandstones of the normal type are composed of sand grains between 0.25 and 0.0625 millimeter in diameter, are cemented with calcite, and show cross-bedding, greater thickness of beds, and greater uniformity over large areas than those of the fine-grained type, are associated with conglomerates, and generally contain manganese or copper minerals. The sandstones of the fine-grained type are characterized by thin lenticular beds, absence of cross-bedding, and extremely fine grain, the grains measuring less than 0.0625 millimeter in diameter.

CONGLOMERATE.

Associated with the beds of normal sandstone and at some places interbedded with the shale are beds of conglomerate, which range in thickness from a fraction of an inch to 3 or 4 feet. (See Pl. IV.) The conglomerate is composed of roughly spherical pebbles, which bear a close resemblance to concretions and may, in fact, be concretionary in origin. Because of this resemblance and for the lack of a better descriptive term the rock will be referred to in this report as concretionary conglomerate. This use of the term conglomerate may be open to question, but it can not lead to confusion, as the rock, no matter what its origin, is conglomeratic in texture and has been described as conglomerate in several geologic reports.[1] The concre-

[1] Cummins, W. F., The Permian of Texas and its overlying beds: Texas Geol. Survey First Ann. Rept., p. 187, 1890. Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, p. 23, 1914. Udden, J. A., assisted by Phillips, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, p. 29, 1912.

tions range from fine grains to pebbles 2 inches in diameter, and some specimens of the conglomerate include subangular fragments of shale, the largest an inch in length. The so-called concretions range in color from red to brown and are highly calcareous. They resemble in appearance and composition the concretions that are scattered irregularly through the shale of the Wichita formation. (See p. 14.) The material filling the spaces between the shale fragments and the concretions is generally fine sand cemented by calcite, but in some places it is entirely calcite.

An examination of thin sections of the conglomerate under the microscope shows that the rounded concretion-like pebbles are of two principal types, shale pebbles and calcium carbonate pebbles. Calcite has been deposited in and about the pebbles of both types, considerably altering their form. The shale pebbles are brown to red, the color being due mainly to the presence of iron oxide. Some specimens contain what appears to be manganese oxide, which stains the shale velvety-black. Scattered through the pebbles are small angular grains of sand. In some specimens, as already noted, there is a suggestion of concentric arrangement in the positions of these grains, but in others the grains are scattered irregularly through the mass of the shale. Most of the pebbles are more transparent at the center than on the periphery, which is usually deeply stained by oxide of iron. The transparency of the center is due to the presence of minute crystals of calcite, or apparently, in some pebbles, to the presence of cryptocrystalline calcium carbonate. The centers of many of the pebbles are occupied by masses of calcite, each formed of several large crystals. These masses are irregular in outline and appear to fill cracks or openings which were formed near the centers of the pebbles and from which, as they were enlarged, fissures, also filled by calcite, extended toward the peripheries. Whether the shale pebbles were fractured by the growth of the crystals or whether, as suggested by Todd,[1] the fracturing was due to expansion of the periphery by the introduction of cementing material, it is impossible to state. The calcium carbonate seems to have been deposited in greater amount in the middle than at the exterior of the pebble, and the concentration of iron oxide at the surface may perhaps be due rather to its being forced out from the center in some way by the crystallization of the calcite than to its introduction from without. None of the pebbles show increase in size by the deposition of calcite on their surfaces, but the cementing material between the pebbles is calcite, even in specimens in which a part of the space between the pebbles is filled with sand grains.

The calcium carbonate pebbles are composed of cryptocrystalline calcium carbonate, which is as a rule but little stained by iron. They

[1] Todd, J. E., Concretions and their geological effects: Geol. Soc. America Bull., vol. 14, pp. 353–368, 1903.

contain scattered grains of sand, as do the shale pebbles. In many of them there are deposits of calcite similar to those in the shale pebbles; also there is no evidence of enlargement by deposits of calcite on the surfaces. Some pebbles, however, show growth through the deposition of cryptocrystalline calcium carbonate upon their surfaces.

Whether or not the calcium carbonate pebbles are distinct in origin from the shale pebbles is unknown. It is possible that they may have been formed from the shale pebbles by replacement of the fine material of the shale by calcium carbonate under slightly different conditions from those under which the crystalline form was deposited.

The conglomerate occurs as a rule at the base of a stratum of sandstone, in places as a single bed separating the sandstone from the underlying shale, and in places as several thin layers interbedded with both sandstone and shale. It is found not only at the base of sandstone beds but also within them or at their tops and in places is embedded in shale with which no sandstone is associated. Not infrequently fragments of bone are found in the conglomerate. The conglomerate at the base of sandstone strata or within them is in some places composed entirely of fragments of shale, no concretions being present, and in such places the conglomerate bed is usually gray or greenish gray.

The concretions are in places covered or cemented together with calcium carbonate, which was evidently deposited on and about them by percolating water since they were laid down in the bed, the calcium carbonate not only covering the separate concretions but cementing them together. In certain places salts of copper, iron, or manganese are deposited about the concretions in a similar manner.

The conglomerate has been described by several observers, and a hypothesis for its origin is put forward by Udden and Phillips,[1] who suggest that the concretions were in part formed in the red shale of the Wichita, which was afterward eroded and redeposited during Wichita time, the concretions being sorted by wave action and mixed with fragments of shale. They also regard the so-called concretions as in part "mud lumps" formed by the rolling of masses of mud along the bottom in currents overloaded with fine sediment.[2]

Some of the concretions show concentric structure to a slight degree, and many of them contain grains of sand, which are larger and more numerous than those in the finer-grained shales of the Wichita formation. The arrangement of the sand grains in some specimens also suggests concentric structure, indicating that the grains may have been taken up from the bottom by rolling balls of mud. It is apparent that the water currents which deposited the conglomerate,

[1] Udden, J. A., and Phillips, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, p. 31, 1912.

[2] See also Gardner, J. H., The physical origin of certain concretions: Jour. Geology, vol. 16, pp. 452–458, 1908.

although swift, as shown by the cross-bedding and the size of the concretions, did not transport the material for any considerable distance, as the shale fragments mingled with the concretions are subangular in outline. No foreign material other than fragments of bone or bits of coal representing fossil wood are found in the conglomerate, which appears to be composed entirely of material derived from the Wichita beds themselves.

CONDITIONS OF DEPOSITION AND CAUSE OF RED COLOR.

The conditions under which the "Red Beds" were deposited and the cause of their red color have never been satisfactorily determined. E. C. Case,[1] in a paper on the "Red Beds" of Texas, says: "It is very evident that this region, like the lower Permian of Africa and India, the Ecca and Talchir formations, is largely river-deposited material in some old delta or on some shallow tidal coast." In his opinion the sediments were derived from the elevation now represented by the Wichita Mountains. In a later article[2] Case regards the strata as deposited along the coast of a lagoon, into which were washed the remains of animals as well as débris from the land. He holds that the deposits are not, strictly speaking, estuarine. The beds were not laid down under arid conditions, but the more remote country from which the sediments were derived may have been arid. The vertebrate fauna he regards as made up of land animals, as is indicated by the structure of the feet of such forms as Dimetrodon and Naosaurus.

David White, on the other hand, argues that the red color of the beds and the layers of gypsum that occur in some of them do not necessarily indicate that an arid climate prevailed at the time of their deposition, for the fossil floras suggest an equability and uniformity of climate which is not compatible with aridity in a region as far north as England and the Gulf of St. Lawrence, the latitude of some of the Permian deposits of red shales. The lower Permian of Germany, France, Prussia, and Pennsylvania is commercially coal-bearing, and the Permian "Red Beds" of Kansas and Texas carry thin coals. Peat is formed in the United States to-day only in areas having at least 20 inches of rainfall, and it is therefore argued that beds that contain coal, in the formation of which peat is the first stage, must have been laid down in areas that had an annual rainfall of more than 20 inches. The fossil plants in the "Red Beds" of Pennsylvania are not different from those found in equivalent sediments, which are not red, 50 miles farther south. In conclusion Mr. White says:[3]

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[1] The character of the Wichita and Clear Fork divisions of the Permian "Red Beds" of Texas: Am. Mus. Nat. Hist. Bull., vol. 23, p. 659, 1907.

[2] Notes on a collecting trip in the Permian of Texas during the summer of 1908: Science, new ser., vol. 29, p. 195, 1909.

[3] White, David, The upper Paleozoic floras; their succession and range: Jour. Geology, vol. 17, No. 4, p. 340, 1909.

Is it not possible that in some instances the causes of red bed deposition lie to a large extent in relatively slow subsidence of the basin and in differential warping to permit exposure with some redeposition and dehydration. It is probable that there was aridity in certain regions and during certain intervals of the Permian, but there was evidently enough moisture to produce most extensive glaciation and later to promote the formation of coals over broad areas.

According to J. W. Beede [1] the sediments that formed the "Red Beds" were derived from the land mass now represented by the Arbuckle-Wichita uplift and those found at some distance from the mountains were deposited in shallow turbulent water or on vast tidal beaches under conditions inimical to life, since the sediments are for the most part devoid of fossils or carbonaceous matter.

Udden and Phillips,[2] in their description of the sandstones of Wichita and Clay counties, Tex., are of opinion that the presence of cross-bedding and flat and thin lamination of the beds, together with the occurrence of numerous local unconformities, indicate tidal action. They believe that the sandstones were originally submerged sand bars and that some of them were sandy beaches. The rarity of wave marks and marks of raindrops they regard as evidence that most of the sand banks were not above water. In discussing the clay limestone conglomerate, which at many places lies at the bases of sandstone beds or is interbedded with the sandstone, they suggest that "the absence of everything but indigenous material in conglomerates which clearly have been produced by currents of considerable strength suggests isolation of the coasts from mountain lands while the Wichita beds of this region were deposited."[1]

Gordon, in his study of the Wichita region,[3] states that "The character of the sedimentation and the contents of the strata in the 'Red Beds' area suggest that the region was a tidal flat or a low, swampy area subject to overflow and adjoining the open area which lay toward the south and west."

The results of the present investigations are in general in accord with the views above quoted. The shales and sandstones of the Wichita formation, even the coarsest of them, are extremely fine grained and exhibit a high assortment of materials. That they have been worked over many times by the agents of deposition seems evident. The presence of a limestone bed in the Wichita region in northern Texas, described by Udden and Phillips,[4] and its absence in the region under discussion would seem to indicate that the land area from which the sediments were derived lay to the north, in the

[1] Beede, J. W., Origin of sediments and coloring matter of the Red Beds of Oklahoma: Science, new ser., vol. 35, p. 350, 1912.

[2] Udden, J. A., and Phillips, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, p. 31, 1912.

[3] Gordon, C. H., Geology and underground waters of the Wichita region, north-central Texas: U. S. Geol. Survey Water-Supply Paper 317, p. 26, 1913.

[4] Op. cit., p. 31.

general region of the Arbuckle-Wichita uplift, whereas the clear, open water favorable to the deposition of limestone lay to the south, in Texas. Beede,[1] in his studies in northern Oklahoma, found that the limestones of the basal Permian of Kansas (which is probably the equivalent of the Wichita formation) gave place to sandstones farther south, indicating that the source of the sediments lay in that direction. It is fairly well established, therefore, that the source of the "Red Beds" sediment was a land mass that lay in part in the region of the present Wichita and Arbuckle mountains. That this land mass was far greater in area than the mountains as they now exist is shown by the amount of the sediments derived from it, and it is possible that a great part of the area lay farther east, along the Ouachita uplift, of which the Arbuckle and Wichita mountains are but a continuation. Part of the ancient land mass may now be covered by the more recent sediments of the Cretaceous period.

That the sandstones of the Wichita formation, particularly those of the normal type, were deposited in shallow water by the action of swift currents is indicated by the prevalence of cross-bedding and the occurrence at certain localities of ripple marks in the sandstone. At the base of sandstone beds in many places there are unconformities produced by the erosion of the underlying clay or shale prior to the deposition of the sandstone strata. That even the fine-grained shale was laid down in comparatively shallow basins is shown by the alternation of beds of sandstone and shale. The thickness of the beds of shale rarely exceeds 30 feet and averages about 15 feet. The occurrence also of beds of concretionary conglomerate underlain and overlain by shale would seem to show that the conditions under which the shale was deposited were not incompatible with the action for brief periods of strong currents.

The following notes on an exposure in the east bank of West Cache Creek, near the north line of sec. 7, T. 4 S., R. 11 W., may indicate the conditions under which the conglomerate beds of the Wichita formation were deposited. The complete section is described on page 44. Six feet of interbedded conglomeratic shale and limestone beds is exposed at this locality. The deposit is much cross-bedded and the inclination of the layers is to the north or northeast. It rests unconformably upon brownish-red shale which was channeled by erosion before the conglomerate was deposited, the depth of the channeling, as indicated in this exposure, which is about 200 feet in length, being about 5 feet. At one place in the exposure a wedge-shaped mass of gray sandstone a foot or more in length and several inches thick at its blunt end lies embedded in the shale a few inches below one of the layers of conglomerate. Its shape shows that it can hardly be a lens

[1] Beede, J. W., Origin of sediments and coloring matter of the "Red Beds" of Oklahoma: Science, new ser., vol. 35, pp. 348-350, 1912.

of sandstone deposited by swift water currents. It resembles more nearly a mass of sand caved from a bank which was being undercut by wave action.

That the "Red Beds" were not entirely submerged during their deposition, or at least that they were subject to periods of emergence, is indicated by the presence in them at certain localities of well-preserved fossil leaves. Most of the leaves are found in sandstone beds and are the remains of plants resembling in many respects the ferns of the present day. Their fair state of preservation indicates that they grew near the place where they were buried. Some of the skeletons that are found in these rocks represent, according to Case,[1] land animals, among them the primitive reptiles Dimetrodon and Naosaurus, which walked on land, as is shown by the construction of their feet.

There appears to be little evidence to support the theory that the beds of the Wichita formation were deposited in an arid climate. Beds of gypsum are not associated with them, as they are with the Clear Fork and Double Mountain formations of the Permian,[2] and the fossil flora indicates a rather moist climate.[3]

The red color of the shale, which is due to the presence of dehydrated oxide of iron, does not necessarily imply an arid climate on the land mass from which the sediments were derived, as is shown by the formation of red soils at the present time in the comparatively moist climate of the southern Appalachians. If aridity must be postulated to account for the association with some "Red Beds" of gypsum deposits, which are probably thrown down from rapidly evaporating water in wholly or partly inclosed basins, it is not necessary to assume an arid climate at the source of the sediments. These sediments may have been derived from high and well-watered mountain areas and transported by rivers to the arid coastal plains along the mountain foot, where they were deposited under conditions which would permit the formation of gypsum beds. The Wichita formation, however, includes no beds of gypsum, and the fair state of preservation of some of the plants indicates that they grew near the localities at which they are now found. It is possible that they may have grown near bodies of water that lay in an otherwise arid country, but the facts at hand hardly warrant the assumption of aridity. It is probable that the material forming the "Red Beds" was in great part red before it was deposited in those beds and that it was derived from the residual soil of some deeply weathered land surface. The formation of hematite rather than limonite by the alteration of the magnetite and other iron

[1] Case, E. C., Notes on a collecting trip in the Permian of Texas: Science, new ser., vol. 29, p. 195, 1909.
[2] Cummins, W. F., Texas Geol. Survey Second Ann. Rept., p. 400, 1890.
[3] White, David, The upper Paleozoic floras; their succession and range: Jour. Geology, vol. 17, No. 4, pp. 320-341, 1909.

minerals contained in igneous rocks, with the consequent production of red soils, is a process but little understood. Red soils, as has been already stated, are as a rule characteristic of warm, moist climates, in which the rocks are deeply weathered and the surface covered by luxuriant vegetation. The color of the soil formed by the weathering of the Archean rocks of the Appalachian province, for example, is redder in the south than in the north. On the other hand, the production of red soil is not characteristic of desert weathering. It is perhaps surprising that hematite, the dehydrated oxide of iron, should be formed in the presence of abundant moisture, but it appears to be so formed. The presence of vegetation and the products of its decomposition may be important factors in the change. The production of red color rather than the bluish gray, yellow, or brown of the hydrated oxides doubtless depends on a fine adjustment of various factors, an adjustment that was not everywhere effected during the deposition of these beds. In consequence not all the shale beds laid down were red, a considerable part of the shale exhibiting the other colors above mentioned, particularly bluish gray, which may be due in part to the presence of carbonate of iron. That red shale has been in some places altered to bluish-gray or greenish-gray shale is evident from the fact that bands of these colors follow joint planes which cut the beds and along which ground water circulates. Evidence of the change from gray to red may also be observed. The deoxidation of red shale to gray, forming small circular spots on the fractured surface, is probably due to the presence of minute particles of carbonaceous material in the shale, and such alterations are doubtless the cause of the mottled appearance observed at many places in the shales of the Wichita formation.

The sandstone beds of the Wichita are in some places white and in others red or brown, the color being due to the presence or absence of iron oxides in the calcite cement between the grains rather than to any staining of the grains themselves. The iron oxides may have been introduced by the ground waters which deposited the calcite cement and this suggestion is in a measure sustained by the fact that the fine-grained sandstones, the cement of which is silica, are nowhere, so far as observed, red or brown but invariably bluish gray in color. The iron oxide is not, however, evenly distributed through the calcite cement but is segregated in irregular patches, as if crowded to one side by the crystallization of the calcite. It is possible that it was present as fine mud deposited with the sand grains in certain of the beds in which the materials were not thoroughly assorted, and that it was entirely removed from other beds in which assortment was more perfect. The latter beds would form the white sandstones and the former the red or brown.

FOSSILS.

The fossils found in the area under discussion consist of remains of plants and of vertebrate animals. The marine invertebrate fossils[1] that occur farther south in Texas are not found here.

The fossil plants collected during the investigation are very meager, consisting of only a few fragments, representing Permian forms. The specimens were identified by David White, whose notes on them are as follows:

SE. ¼ NW. ¼ sec. 22, T. 4 S., R. 11 W.: Large fernlike fronds over 1 foot long and 2½ inches broad; probably Gigantopteris; occur in sandstone near a layer of concretionary conglomerate.

SW. ¼ NE. ¼ sec. 24, T. 5 S., R. 8 W.: Leaf fragments in sandstone; probably Gigantopteris.

SW. ¼ SE. ¼ sec. 36, T. 4 S., R. 9 W.: Fragments of small leaf in ferruginous sandstone. Pecopteris resembling *P. hemiteliodes*.

NW. ¼ NE. ¼ sec. 19, T. 5 S., R. 8 W.: Indistinct leaf impression in "fine-grained" sandstone. Neither border nor nervation is distinct, but the impression suggests Gigantopteris or Callipteris.

NE. ¼ NW. ¼ sec. 3, T. 5 S., R. 11 W.: Fossil wood replaced by copper ore. (See pp. 101–102.)

Vertebrate remains are more commonly found than remains of plants. The vertebrate fossils collected and the localities at which they were found are given below, the pages cited being those on which detailed sections are given. The specimens were identified by C. W. Gilmore, of the United States National Museum, and were examined also by E. C. Case, of the University of Michigan, who states that they all are typical Permian genera.

SW. ¼ SW. ¼ sec. 34, T. 4 S., R. 9 W. (see p. 73), in red shale. Vertebra and fragments of Dimetrodon bones.

NE. ¼ NW. ¼ sec. 2, T. 5 S., R. 9 W., just south of the road, in shale at base of sandstone near "concretionary" conglomerate: Caudal vertebra of Dimetrodon, species indeterminable.

SW. ¼ NW. ¼ sec. 36, T. 4 S., R. 9 W., on surface of gray shale 2 or 3 feet above a 4-inch bed of greenish-brown concretionary conglomerate, which is underlain by red shale containing great numbers of roundish calcareous concretions, the surfaces of which are extremely rough (see Pl. III, *A*):

Cricotus sp. indet. vertebræ.
Dimetrodon sp. indet. vertebræ.
Aspidosaurus sp. indet. fragment of vertebra.
Eryops sp. indet. intercentral.
Teeth of an extinct shark, which may be tentatively assigned to either the genus Diacranodus or Pleuranthus, neither of which is well defined, although based upon material essentially the same as that represented in this small collection.
Teeth of Dimetrodon sp. indet.
Scales of the fossil fish Platysomus sp. indet.
Eryops megacephalus.

[1] Gordon, C. H., The Wichita formation of northern Texas: Jour. Geology, vol. 19, No. 2, pp. 110–134, 1911.

Dimetrodon sp. indet.
Diadectes sp. indet.
Diplocaulus sp. indet.
Various fragmentary parts of Dimetrodon, Eryops, and Diadectes.
Some fish bones; not determinable.

NE. ¼ NW. ¼ sec. 8, T. 4 S., R. 9 W., on surface of red shale near concretionary conglomerate and fine-grained sandstone beds: Vertebræ and bone fragments of Dimetrodon sp. indet.

NE. ¼ sec. 3, T. 5 S., R. 11 W., in 8-inch bed of purple shale; fossil wood 2 feet below: Coprolites.

NE. ¼ NW. ¼ sec. 3, T. 5 S., R. 11 W. (see p. 52), in black carbonaceous shale containing impressions of plant stems: Coprolites and a fragment of a shark's tooth like that described above.

NW. ¼ NW. ¼ sec. 3, T. 5 S., R. 11 W., in shale: Vertebræ of Dimetrodon sp. indet.

N. ½ NE. ¼ sec. 13, T. 4 S., R. 12 W.): Greater part of two articulated skeletons representing the genus Diadectes. These specimens, from which the inclosing shale had been entirely removed by the wash of the rains, were found lying side by side on the smooth surface of a sandstone ledge. Like many of the "Red Beds" fossils, the bones were incrusted with a deposit of calcium carbonate. The greater part of them were undisturbed and the form of the animal was very evident.

The writer is indebted to Mr. C. W. Gilmore, of the United States National Museum, for the following notes on the amphibian and reptilian forms listed above. The descriptions are based principally on the works of Williston and Case.

Eryops megacephalus: An amphibian which, according to Williston, reached a length of 8 feet. It had a relatively large, broad, and flat head, no neck, a thickset body, and short, broad, probably webbed feet. Its skin was doubtless bare and its tail was flattened for use in the water, like that of a gigantic salamander, its nearest living relative.[1]

Dimetrodon: A primitive reptile. Case[2] says: "The carnivorous dentition and strong claws both tell of a predatory nature that must have demanded a swifter motion than could have been attained by an animal which dragged its belly in progression. * * * The semiupright form, the short tail, the well-developed articulations of the long bones, and the well-formed carpus and tarsus would indicate that the members of this genus were true land forms." The body is provided with a high-spined, sail-like fin that rises from the median line of the back. "For the rest the body was probably not unlike that of a smooth-bodied, finely scaled lizard, with a relatively large head, short body, and semierect posture."

Diplocaulus: An amphibian characterized by the peculiar crescent shape of the head. Case's description is as follows:[3] "The body was fairly short and heavy; the flat triangular head very disproportionate in size; and the limbs weak and useless. * * * It is probable that the animal could not raise its enormous head from the ground except by a short, paroxysmal effort. The head must have been pushed forward through the slime and mud at the bottom of some small body of water, as the animal fed on small, slow-moving creatures or vegetation."

[1] For skeletal and life restorations of this animal, see Case, E. C., Revision of the Amphibia and Pisces of the Permian of North America, pls. 9 and 10, Carnegie Institution of Washington, 1911.

[2] Case, E. C., Revision of the Pelycosauria of North America, pp. 115–116; also pl. 20, Carnegie Institution of Washington, 1907.

[3] Revision of Amphibia and Pisces of the Permian of North America, p. 90, Carnegie Institution of Washington, 1911.

Diadectes: Case [1] says: "The diadectids are perhaps the nearest to the turtles of the forms now known. The powerful head and jaws, with their numerous testudinate characters; the strong thoracic guard formed by the great scapula with its clavicle, cleithrum, and interclavicle; the short, powerful limbs; the loosely knit splay feet, with their ill-developed terminal phalanges, all give an impression of a compact body lying close to the ground and moving with a sprawling gait, much as in the turtles. * * * Lowly, sluggish, inoffensive, herbivorous reptiles, clad in an armor of plate to protect them from the fiercely carnivorous pelycosaurs."

Cricotus: An amphibian concerning whose habits little is known.[2]

Aspidosaurus: This genus is based upon portions of skeletons; no restoration has yet been made.

Sharks: The sharks mentioned in the list of identifications are not well known.

RELATION OF THE WICHITA FORMATION TO THE UNDERLYING ROCKS.

RELATION IN ADJOINING AREAS.

As no exposures of the rocks below the Wichita formation are found in the area under discussion the relation of that formation to the underlying beds can only be inferred from its relation in adjoining areas and from a few deep-well records. Of the contact of the "Red Beds" with the underlying rocks along the Arbuckle Mountains, J. A. Taff [3] writes:

> They lie in a nearly flat position across the eroded edges of several thousand feet of the Pennsylvanian, all of the Mississippian, Devonian, and Silurian, and a large part of the Ordovician rocks. These older formations were sharply folded and eroded prior to the deposition of the "Red Beds."

To the south, in Texas, the contact of the basal "Red Beds" with the underlying Cisco formation of the Pennsylvanian is conformable, the two formations grading one into the other in such manner that it is impossible to draw a definite line of division between them. Concerning this contact, C. A. White wrote in 1891:[4]

> The Texas Permian, while not contrasting strongly with the "Coal Measure" formation which underlies it, is readily distinguishable from it by general aspect and lithological character; and yet the Permian strata blend so gradually with those of the underlying "Coal Measures" and with the overlying gypsum-bearing beds, which are presently to be noticed, that it is difficult to designate a plane of demarkation in either case.

The relation of the beds is described by Udden and Phillips as follows:[5]

> We know that the upper 300 feet or more at Electra belong to the Wichita formation and that the shales and sands penetrated from 1,400 to 2,000 feet under the surface belong to the Cisco, but how much of the intervening 1,200 feet should be allotted to each we can only suggest from the lithologic appearance of the section as made known by the drillers' records.

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[1] Case, E. C., Jour. Geology, vol. 15, pp. 556–559, 1907.

[2] For figure of skeletons, see Case, E. C., op. cit., pl. 24, figs. 1 and 2.

[3] Taff, J. A., Geology of the Arbuckle and Wichita mountains, in Indian Territory and Oklahoma: U. S. Geol. Survey Prof. Paper 31, pp. 35–36, 1904.

[4] White, C. A., The Texas Permian and its Mesozoic types of fossils: U. S. Geol. Survey Bull. 77, p. 11, 1891.

[5] Udden, J. A., and Phillips, D. McN., A reconnaissance report of the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, p. 86, 1912.

DEEP-WELL RECORDS.

In or near the area covered by the present report several "wildcat" wells have been drilled in search of oil, the records of three of which, given here through the courtesy of the operators, throw considerable light on the nature of the beds that underlie the known Wichita formation. One of these wells is near Randlett, Okla., one near Hastings, Okla., and the third is in Texas, south of the junction of Cache Creek and Red River. A number of rock samples were obtained from the Randlett well, and in the record given below notes on these are published in addition to the driller's record. Too much importance can not be attached to the accurate recording of well logs. In general studies of oil accumulation as well as in examinations of particular fields accurate logs are invaluable to the geologist in solving problems most vital to the oil operator.

Log of well No. 1 of Green River Oil Co., 2 miles northwest of Randlett, Cotton County, Okla., in NE. ¼ NE. ¼ sec. 25, T. 4 S., R. 13 W., Indian meridian.

[Well begun Dec. 28, 1913; completed June 1, 1914.]

	Thickness.	Depth to bottom of bed.	Depth at which sample was taken.	Geologist's notes on rock samples.
	Feet.	*Feet.*	*Feet.*	
"Red Beds," variegated red, brown, and light.	600	600	.....	
Sand, brown	8	608	.....	
"Red Beds;" many colors	117	725	.....	
Sand	7	732	.....	
"Red Beds"	60	792	.....	
Sand	8	800	.....	
"Red Beds"	258	1,058	.....	
Sand; salt water; hole filled up	30	1,088	.....	
Slate or shale	32	1,120	.....	
Sand, dry	10	1,130	.....	
Shale, blue	30	1,160	1,150	Shale, bluish gray.
Do	20	1,180	.....	
Sand, dry	5	1,185	1,180	Shale, bluish gray, with a little sandstone.
Shale	22	1,207	.....	
Sand; salt water	58	1,265	1,215	Do.
Shale, pink; some called it "Red Beds"	5	1,270	.....	
Slate	68	1,338	.....	
Sand, white; salt water	17	1,355	.....	
Slate, blue	10	1,365	1,360	Sandstone with some shale, bluish gray.
Shale, pink	5	1,370	.....	
Slate, light color	78	1,448	1,400	Shale, bluish gray.
Shale, light pink	11	1,459	.....	
Shale, blue	11	1,470	.....	
White sand; oceans of salt water	23	1,493	1,475	Sandstone, white, medium grained; grains for the most part clear quartz, subangular, with a few well-rounded grains.
Slate, light color	22	1,515	.....	
Slate, pale yellow	35	1,550	1,515	Shale, bluish gray.
Slate, blue	15	1,565	.....	
Shale, brown	7	1,572	.....	
Shale, light thin "shell" on top; practically all blue shale.	158	1,730	1,625	Do.
			1,690	Shale, black, carbonaceous.
			1,720	Limestone, dolomitic, argillaceous, light brownish gray; not affected by cold hydrochloric acid, disintegrates in hot hydrochloric acid.
			1,725	Shale, bluish gray.
Shale, black, soft	15	1,745	.....	
Slate, blue, soft, changing to light	25	1,770	.....	
Shale, red, soft	31	1,801	.....	
"Shell," hard; sheet of water	10	1,811	.....	

Log of well No. 1 of Green River Oil Co., 2 miles northwest of Randlett, Cotton County, Okla., in NE. ¼ NE. ¼ sec. 25, T. 4 S., R. 13 W., Indian meridian—Continued.

	Thickness.	Depth to bottom of bed.	Depth at which sample was taken.	Geologist's notes on rock samples.
	Feet.	*Feet.*	*Feet.*	
"Shell" and bowlders, hard	20	1,831	1,815	Limestone, light gray, argillaceous; the sample contains some coarse limestone sand cemented with calcium carbonate and a little light bluish-gray shale.
Shale, brown, soft; pulled pipe up to ream.	9	1,840	.....	
Clay, blue, soft, light at bottom	44	1,884	.....	
Sand, light, hard; full of salt water	26	1,910	1,900	Sandstone, medium grained; grains subangular, a few well rounded; sample contains a little shale.
Shale, light red, soft; caved badly	15	1,925	.....	
Shale and thin shells; blue, soft	57	1,982	.....	
Lime, white, hard	21	2,003	.....	
Shale, blue, soft	4	2,007	.....	
Shale, brown, soft; thin "shells"	18	2,025	.....	
"Shell," hard	2	2,027	.....	
Shale, red, soft	3	2,030	.....	
Slate and "shells," soft	12	2,042	.....	
Sand, red, gritty; full of salt water	15	2,057	.....	
Shale and sand, "shells"	43	2,300	2,100	Sandstone, ferruginous, medium grained; grains coated with iron oxide, subangular, a few well rounded.
Sand, white, hard; full of salt water	18	2,318	.....	
Sand, dark, hard	5	2,323	.....	
Shale, blue, soft	37	2,360	.....	
Shale, sandy; "shell" at 2,364 feet; sheet of water.	165	2,525	.....	
Slate, light, soft	47	2,572	.....	
Shale, brown, soft cave	15	2,587	.....	
Sand, gray, hard; full of salt water to within 150 feet of surface.	10	2,597	2,592	In salt water.

Log of F. H. Marley well No. 1 of West Virginia Petroleum Co., near Hastings, Cotton County, Okla., in SE. ¼ SW. ¼ sec. 1, T. 4 S., R. 9 W.

[Well begun Feb. 16, 1914; completed June, 1914.]

	Thickness.	Depth to bottom of bed.		Thickness.	Depth to bottom of bed.
	Feet.	*Feet.*		*Feet.*	*Feet.*
"Red Beds," soft	185	185	Blue shale	10	1,635
Water sand	5	190	"Red Beds"	15	1,650
"Red Beds"	140	330	Blue shale	10	1,660
Water sand	5	335	"Red Beds"	40	1,700
"Red Beds"	290	625	Water sand	10	1,710
Water sand	10	635	"Red Beds"	75	1,785
"Red Beds"	200	835	White slate	5	1,790
Water sand	5	840	Water sand	8	1,798
"Red Beds"	33	873	"Red Beds"	25	1,823
Gas sand	10	883	Blue shale	22	1,855
"Red Beds"	17	900	Water sand	40	1,895
Brown shale	35	935	Blue shale	10	1,905
"Red Beds"	55	990	"Red Beds"	10	1,915
Gray slate	40	1,030	Blue shale	10	1,925
"Red Beds"	355	1,385	Black shale	25	1,950
White shale	25	1,410	Lime rock, fossils (?)	3	1,953
Water sand	22	1,432	Black sand	5	1,958
White slate	8	1,440	Blue shale	17	1,975
Brown slate	38	1,478	"Red Beds"	15	1,990
Water sand	27	1,505	Lime shell	15	2,005
Blue shale	25	1,530	Blue shale	20	2,025
Brown shale	30	1,560	"Red Beds"	25	2,050
Blue shale	12	1,572	Blue slate	95	2,145
Brown shale	8	1,580	Lime shell, hard	10	2,155
Blue shale	25	1,605	Blue shale	10	2,165
"Red Beds"	20	1,625	Red rock	20	2,185

Log of well No. 1 of Riverside Oil Co., in Texas, one-third mile south of Red River and 1½ miles southwest of mouth of Cache Creek.

[Well begun Dec. 7, 1912.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Surface soil	4	4	Same sand rock as above	9	1,529
Red mud	24	28	Dark-blue shale	9	1,538
White rock	2	30	Light-blue shale	12	1,550
Sand and gravel; water	8	38	Red shale	10	1,560
Red mud	12	50	Soft lime rock	8	1,568
Sand rock	60	110	Red shale	29	1,597
Brown shale, soft	25	135	Soft lime; 8 feet very hard	9	1,606
Red mud	35	170	Red clay	32	1,638
Soft sand	4	174	Sand rock; oil	12	1,650
Sand rock	41	215	Blue shale	12	1,662
Pack sand	15	230	Blue gumbo	5	1,667
Sand, soft	15	245	Sand rock	3	1,670
Red mud	11	256	Blue shale	4	1,674
Streak of rock and sand	39	295	Sand rock	9	1,683
Brown shale	85	380	Limestone, hard	3	1,686
White sand rock, hard	2	382	Blue shale	29	1,715
White sand; water	28	410	Sand rock	38	1,753
Red mud	62	472	Blue shale	34	1,787
Brown shale	73	545	Sand rock	6	1,793
Red shale	7	552	Mixed blue and red shale	42	1,835
Sand rock, hard	16	568	Blue shale	14	1,849
Brown shale	32	600	Sand rock	38	1,887
Sand rock, soft	6	606	Blue gumbo	46	1,933
Brown shale, soft	54	660	Blue shale	22	1,955
Red shale	48	708	Blue gumbo	12	1,967
Red clay	46	754	Blue shale	12	1,979
Blue gumbo	16	770	Blue gumbo	16	1,995
Blue shale	22	792	Blue shale	83	2,078
Blue clay	13	805	Slate rock	5	2,083
Mixed shale, blue and red	76	881	Gumbo	14	2,097
Sand rock	8	889	Blue shale	22	2,119
Red shale	101	990	Gumbo	9	2,128
Sand rock	2	992	Blue shale	25	2,153
Blue gumbo	51	1,043	Gumbo	22	2,175
Sand rock	13	1,056	Blue shale	40	2,215
Blue shale	33	1,089	Blue gumbo	11	2,226
Sand rock	14	1,103	Blue shale	16	2,242
Blue gumbo	36	1,139	Sand rock	13	2,255
Sand rock	39	1,178	Blue shale	11	2,266
Blue gumbo	39	1,217	Sand rock	21	2,287
Sand rock	9	1,226	Sand rock, red, hard	21	2,308
Blue gumbo	12	1,238	Gas sand, gray, hard	8	2,316
Slate rock	4	1,242	White sand rock	16	2,332
Blue shale	12	1,254	Blue shale and slate	16	2,348
Gypsum ("Gyp rock")	9	1,263	White sand rock	14	2,362
Blue gumbo	12	1,275	Brown and blue shale, mixed	4	2,366
Gumbo and bowlders	11	1,286	Bituminous coal	2	2,368
Blue shale	49	1,335	Lime rock	1	2,369
Sand rock	33	1,368	Blue and brown shale	10	2,379
Blue gumbo	12	1,380	Coal	3	2,382
Soft sand rock	8	1,388	Blue and brown shale	9	2,391
Blue shale	15	1,403	Lime rock	5	2,396
Sand rock and streaks of sand	12	1,415	Blue and brown shale	29	2,425
Blue shale	52	1,467	Gypsum and shale	15	2,440
Sand rock	9	1,476	Blue-black shale	11	2,451
Blue gumbo	6	1,482	Lime rock	5	2,456
Blue shale	12	1,494	Soft brittle lime	10	2,466
Sand rock	2	1,496	Hard lime	7	2,473
Do	13	1,509	Sand rock, white	13	2,486
Hard rock	4	1,513	Lime rock	12	2,498
Hard sand	4	1,517	Brown shale	10	2,508
Smooth and very hard (set 6-inch casing here)	3	1,520	Lime	7	2,515

The principal distinction between the upper and the lower beds, as recorded in the preceding well logs, is one of color, the beds in the well near Randlett being predominantly red to a depth of 1,058 feet and blue (probably bluish gray), with streaks here and there of pink or red, below that depth. The first limestone is recorded at 1,982 feet, or 924 feet below the red shale. In the well near Hastings the lowest thick bed of red shale was passed through at 1,385 feet and

the first limestone was struck 565 feet lower at a depth of 1,950 feet. In the well of the Riverside Oil Co. the lowest thick bed of red shale was passed through at 990 feet and the first limestone was encountered 607 feet lower, at a depth of 1,597 feet.

It is probable, although by no means certain, that the limestone is of Pennsylvanian age. The upper part of the red shales is Permian but the lower part may belong either to the Permian or to the underlying Pennsylvanian, which, as exposed farther north in the Texas region, contains near its top pink, red, and purplish shales.

That the distance between the base of the red shale and the top of the limestone series varies greatly at different localities is not necessarily evidence of unconformity. In northern Oklahoma and southern Kansas there is a vertical transgression of the red color across the rock strata.[1] In other words, a bed of shale which in one place is red may at another be gray, the beds being equivalent to each other but the color being variable. The same conditions may reasonably be expected to hold for the beds not exposed at the surface. That an unconformity is present, however, is very possible, although the facts at hand are not sufficient to prove or disprove its existence.

RELATION OF THE WICHITA FORMATION TO THE OVERLYING ROCKS.

No beds are found above the Wichita in the area under discussion, but higher strata are exposed farther south, in Texas. The relations of the Permian to the overlying and the underlying beds are so clearly described by C. A. White[2] that his complete description is here given. In this description, the 1,000 feet of strata underlying the gypsum-bearing beds are regarded as the probable equivalent of the Wichita formation:

* * * There is in the part of northern Texas to which special reference has been made a great conformable series of strata which has a gentle general dip toward the west, and which includes the strata that in this bulletin [Bull. 77] are referred to the Permian. It is overlain only by the débris resulting from its own disintegration except along the eastern and western borders of the region which it occupies, where Cretaceous formations lap upon it. This overlapping conceals its base, but the estimated thickness of the whole series, so far as it is exposed to view, is 3,050 feet. The lower 1,800 feet, together with an unknown thickness beneath, is referred to the Coal Measures. The next overlying 1,000 feet of strata are referred to the Permian; and the upper 250 feet of the whole series, commonly known as the gypsum-bearing beds, probably constitute the upper part of the Permian.

The Cretaceous strata referred to rest unconformably and with a contrary dip upon the earlier, eastern portion of the whole series; while upon the later, western portion of it they rest with apparent conformity, although their real conformity may well be questioned, because the Jura seems to be entirely wanting there.

[1] Beede, J. W., Origin of sediments and coloring matter of "Red Beds" of Oklahoma: Science, new ser., vol. 35, pp. 348-350, 1912.

[2] White, C. A., The Texas Permian and its Mesozoic types of fossils: U. S. Geol. Survey Bull. 77, pp. 13-14, 1891.

TERRACE GRAVELS, ALLUVIUM, AND SAND DUNES.

On many of the upland surfaces along the streams there are gravel deposits, which range in thickness from a few inches to several feet. The pebbles consist of quartzite, limestone, and rhyolite porphyry, the last named being generally broken along joint planes into angular forms. Fragments of silicified wood are common. The largest pebbles found are 5 inches in diameter and many of the pebbles are embedded in coarse sand, the whole deposit being slightly consolidated by calcium carbonate. The gravels appear to be stream deposits, representing material brought from the Wichita Mountains by the present streams at former stages of their development. These deposits, however, may be in part composed of reworked material derived from a widespread sheet of upland gravels that covers large areas in Oklahoma and northern Texas.[1]

The flats along all the streams are formed of alluvial deposits laid down by the streams, particularly at times of flood. Similar material is being deposited by the streams at the present time.

Along the course of Red River there are deposits of drifting sand known as dunes. During midsummer the channel of the river becomes practically dry and broad stretches of fine sand are exposed to the action of the wind, which piles it high upon the river banks, the mounds of sand shifting before the wind like drifts of snow. Such deposits have been formed on the alluvial flat 2 miles west of the mouth of Cache Creek within the memory of the present settlers.

STRUCTURE.

CHARACTER OF THE FOLDS.

The dip of the strata throughout the region is comparatively low. At two or three localities it is 50 or 60 feet in a quarter of a mile, but generally it does not exceed 10 or 15 feet in that distance. The dip is by no means constant in direction, the folds being most irregular, as would be expected in rocks so plastic as the "Red Beds" shales.

In secs. 25 and 26, T. 5 S., R. 8 W., there is some evidence of faulting, but if faults occur in this locality they are probably of small displacement. (See pp. 88, 89.) Owing to the nature of the exposures throughout the region faulting is difficult to detect and it may be more common than has been supposed.

The best exposed and perhaps the largest anticline in the field is crossed by Red River near the east side of T. 5 S., R. 9 W. Its crest, which extends approximately east and west, crosses sec. 13 of this township at about the east quarter corner. The east-west fold extends eastward for about 2 miles from Red River, where, in

[1] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, p. 28, 1914.

sec. 17, T. 5 S., R. 8 W., it is brought to an end by a north-south fold, the axis of which extends northward into sec. 8 and southward for an unknown distance across sec. 20 and probably into sec. 29. From this north-south fold the beds dip east and northeast toward the valley of Beaver Creek. On the north and northeast flanks of this anticline are two minor domes, one of which lies in the NE. ¼ sec. 31, T. 4 S., R. 8 W., and in adjoining sections, and the other in secs. 3 and 4, T. 5 S., R. 8 W.

South of the axis of the principal anticline, in sec. 13, T. 5 S., R. 9 W., there is a small syncline, which is produced by the change in the direction of the anticlinal axis from east to north. The continuation westward of the principal anticline can not be determined because of the lack of exposures. In the south half of T. 4 S., R. 11 W., and in most of fractional T. 5 S., R. 11 W., the dip is prevailingly to the north, the beds dipping away from an anticlinal axis which lies somewhere south of Red River in Texas. In sec. 12, T. 5 S., R. 11 W., a slight reversal of dip is indicated by elevations taken on a prominent bed of sandstone exposed in the river bluff, and it is possible that the axis thus defined represents the principal axis of the anticline. The anticline, wherever its axis, may perhaps be connected with that in sec. 13, T. 5 S., R. 9 W., 10 miles farther east, or may be entirely distinct from it. Because of the absence of exposures the exact relations of the features of the structure in this region are difficult to determine.

In secs. 1, 9, 16, 30, 31, and 32, T. 5 S., R. 12 W., dips to the northwest are indicated by Munn on his map of the Grandfield district,[1] and the anticlinal axis in Texas south of T. 5 S., R. 11 W., may swing from an east-west to a northeast-southwest direction toward the Burkburnett oil field. There is no indication in T. 4 S., R. 11 W., of the presence of the Devol anticline mapped by Munn unless the minor fold noted in the NW. ¼ sec. 19 represents the last vestige of it.

The northerly dip holds throughout the south half of T. 4 S., R. 11 W., and Deep Red Run and West Cache Creek may occupy the axis of a syncline which is a continuation of that mapped by Munn[2] as the Deep Red syncline. This is presumably indicated by the southwest dip of the beds in the west-central part of T. 4 S., R. 10 W., and by the pronounced dip in the same direction shown by exposures in sec. 27 of that township. The strike of these beds and of those in T. 4 S., R. 11 W., is northwest rather than west, and the synclinal axis west of T. 4 S., R. 11 W., therefore probably swings to the southeast. The syncline must die out farther east, as there is no indication of it

[1] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, pl. 4, 1914.

[2] Op. cit., pp. 32, 33; also pl. 4.

along the great bend of Red River in the northeastern part of T. 5 S., R. 9 W., unless it be represented by the flattening of the dip in this locality. Besides the pronounced dip to the southwest in sec. 27, T. 4 S., R. 10 W., there is in sec. 12 of the same township a pronounced dip to the northeast, the intermediate area being occupied apparently by a broad anticline which extends northwestward at least to the southwest corner of T. 3 S., R. 10 W., and apparently dies out toward the southeast, for no traces of it can be seen in the outcrops in the southeast quarter of T. 4 S., R. 9 W. This broad anticline appears to be bordered on the northeast by a shallow syncline, which is indicated by the dip of the beds to the southwest in secs. 8, 9, 16, and 17, T. 4 S., R. 9 W. No trace of this syncline can be found in the vicinity of Temple or farther northwest, and it appears to die out toward the southeast like the other features of structure above mentioned, being represented in the S. ½ sec. 23, T. 4 S., R. 9 W., by a very shallow syncline, which amounts to a little more than a flattening of the dip. The shape and extent of the anticlinal fold toward which the beds in secs. 8, 9, 16, and 17, T. 4 S., R. 9 W., appear to rise could not be determined.

TIME OF THE FOLDING.

The date of the folding which produced the structure just described can only be inferred, the inference being drawn from the relation of the drainage of the region to the structure. Red River flows for a considerable distance near the crest of an anticline and probably established its course before the folding took place cutting down its channel more rapidly than the folds rose across its course. The smaller streams, however, which deepened their channels more slowly, were unable to keep pace with the folding and were consequently diverted into the synclines. The course of West Cache Creek across T. 4 S., R. 11 W., offers an excellent example of such adjustment. The fact that in this township and in the one to the south practically no streams enter Red River from the north is probably due to the influence of the structure on the drainage, the small streams having been thus diverted to the north, into Cache Creek, rather than having taken their natural courses to Red River.

Had the folding of the region taken place prior to the formation of the upland peneplain the course of the minor streams would probably not have exhibited so minute an adjustment to the folds. The folding, therefore, doubtless occurred later than the peneplanation, which is regarded by Taff as Tertiary. (See pp. 11, 12.) The warping of the strata may have occurred when the whole area was uplifted at the beginning of the present cycle of erosion. In many areas the present streams have changed the topography but little since the warping of the strata took place, and it may therefore be inferred that the

movement was comparatively recent. The direction of the stresses that produced the warping is indicated by the fact that the principal folds lie parallel to the Wichita-Arbuckle uplift, as if the beds had been bent by forces acting against the rigid mass of the mountains, or at least perpendicular to the major axis of the mountain uplift.

FIELD WORK.

The area was mapped with plane table and telescopic alidade. Primary triangulation was extended from the ends of a measured base line and altitudes were generally determined by vertical angle readings. The positions of outcrops and other points of interest were determined either by intersection from known points or by three-point location. At the beginning of the work a line of levels was run from a point of known elevation on the railroad at Devol station eastward to the area. The line was extended within the area along the road a mile north of the south township line of T. 4. S., R. 11 W. Near the east side of sec. 36 an offset was made 1 mile to the south and the south line of T. 4 S., R. 10 W., was followed to the southeast corner of sec. 33. From this point the line was carried northward to Temple, where it was checked on the elevation of the Chicago, Rock Island & Pacific Railway. The elevations given on the profile of this road were afterward corrected by a United States Geological Survey bench mark at Waurika. The altitudes along the level line were generally taken on rocks marking section corners, on stones at fence corners, or on fence posts, and the altitudes were marked on the posts in red paint. From points along this level line altitudes were carried throughout the field by vertical angles.[1]

The principal object of the work was to determine the structure, which was studied by making accurate determinations of altitudes at various points on any traceable geologic horizon. The bases of sandstone beds were ordinarily used as horizons, but as the exposures are generally poor it was at many places difficult to determine the precise location of the base of the sandstone. The fine-grained shales of the Wichita formation are extremely plastic when moist, and at some places on steep slopes they yield under the weight of the overlying sandstone, which may in this manner settle several feet below its original position without showing any signs of settling. At some places on grassy slopes beds of sandstone are indicated by slabs of the rock that lie on the surface, but the contact of the sandstone with the underlying shale is not exposed, and its position must be estimated.

A clear understanding of the difficulties of the work thus outlined is essential to a proper interpretation of the map. Some of the structure contours are drawn in disregard of slight variations in the alti-

[1] For a more detailed discussion of the method used see Wegemann, C. H., Plane-table methods adapted to geologic mapping: Econ. Geology, vol. 7, No. 7, pp. 621–637, 1912.

tudes of the beds, especially where settling of the sandstone or difficulty in determining the location of its base may have impaired the accuracy of the determinations. In areas where several sandstone beds of about the same thickness and lithologic character are exposed it is in places very difficult to distinguish between them, particularly if the stratigraphic distances between the beds are approximately the same. In such places it may be impossible to make correlations between exposures that lie only a short distance apart, especially if there is a slight dip between the exposures. The structure contours drawn on the map for such places are interrupted by question marks. Another source of difficulty in the work is introduced by the fact that on certain steep slopes the shale that overlies the sandstone may be washed down by rain so as to cover completely the sandstone, the subsequent weathering of the washed shale resembling that of shale in place. It therefore happens that a bed of sandstone that is prominent in one exposure may be obscure and may therefore pass entirely unnoticed in a neighboring exposure. It seems probable also that the stratigraphic distance between beds varies from place to place, so that the distance determined in one locality does not prevail over any considerable area, but must be constantly checked from point to point to avoid error.

The structure contours shown on the accompanying map are drawn at vertical intervals of 10 feet. They are not drawn on the same geologic horizon throughout the field, for not all the beds exposed in different parts of the area can be correlated. For example, the structure contours shown in T. 4 S., R. 11 W., south of West Cache Creek, are drawn on a stratigraphically higher sandstone than that shown in the northern part of T. 5 S., R. 11 W. The gradient shown by the contours should therefore be taken to represent direction and degree of dip rather than to mark the altitudes of a particular geologic horizon throughout the field. Correlations in the southeastern part of T. 4 S., R. 9 W.; T. 5 S., R. 9 W.; the southwestern part of T. 4 S., R. 8 W.; and the northern half of T. 5 S., R. 8 W., are more positive, and the structure contours on the parts of the map representing this area are based on a fixed horizon—the base of the upper of the two sandstones exposed in the southwestern part of T. 4 S., R. 8 W. Some difficulty was experienced in adjusting the variation of the stratigraphic interval between the beds in this particular area, and for the correlations and intervals at the exposures noted reference should be made to the "Description by townships" (p. 37). Contours that are represented on the map as solid lines are based on positive determinations; broken contours are less positively determined, and contours that bear question marks should be regarded as theoretical only, representing the best judgment of the geologist.

DESCRIPTION BY TOWNSHIPS.

In the following descriptions the townships are taken up in order from north to south and from west to east. The individual outcrops within the township are described first and the rock structure next.

T. 4 S., R. 12 W.

This township was mapped and described by Munn in his report on the Grandfield district.[1] The present examination was limited to secs. 13 and 24, as the outcrops in these sections have a bearing on the geologic structure of the township to the east.

In the prominent butte in the NE. ¼ sec. 24, which is capped by a thick bed of sandstone, the strata are fairly well exposed and the following composite section was measured at several places in this locality:

Section of rocks exposed in the NE. ¼ sec. 24, T. 4 S., R. 12 W.

	Ft.	in.
Sandstone, red and light gray, thin bedded; some pieces show a clay-conglomerate phase	2	0
Shale, grayish red		5
Sandstone, dull red, calcareous		4
Conglomerate concretionary; largest pebbles half an inch in diameter		5
Sandstone, red and light gray	1	4
Shale, red; very slightly conglomeratic with concretionary pebbles		8
Sandstone, light gray; weathers red		6
Conglomerate, concretionary; pebbles up to an inch in diameter		3
Sandstone, dark red, calcareous		2
Shale, arenaceous, red	1	0
Sandstone, dull red, calcareous		2
Shale, grayish red		9
Conglomerate; concretionary pebbles, the largest half an inch in diameter, in matrix of red clay	2	0
Sandstone, light gray, thin bedded, slightly cross-bedded in upper foot; contains a few thin red layers	3	9
Shale, red to gray; contains clay-limestone concretions and lenses of light-gray sandstone, the largest 4 or more feet thick	41	0
Concretionary zone; concretions of clay-limestone type, irregular and smooth	1	0
Shale, red; contains gray clay-limestone concretions	8	0
Sandstone lens, light gray; weathers into irregularly shaped, dark, ferruginous, concretion-like forms	2±	
Shale, grayish red; contains clay-limestone concretions	5+	

The base of the sandstone at the highest point of the butte in the NE. ¼ sec. 24 stands at an altitude of 1,045 feet. The same bed caps a small hill about a quarter of a mile to the north, where the

[1] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, pp. 68–70, 1914.

altitude of its base is 991 feet, or 54 feet lower than the same horizon in the large butte. The same bed caps a hill in the NE. ¼ SE. ¼ sec. 13, where its base stands at an altitude of 984 feet. A bed which appears to be the same outcrops near the west side of the NE. ¼ sec. 13, the altitude of its base being 991 feet. A stratigraphic section measured at this place is given by Munn.[1] At this outcrop a bed of sandstone 44 feet below the highest bed exposed resembles in character a bed that caps a small knoll just east of the butte in the NE. ¼ sec. 24 and is probably in place and should be correlated with it. It should be noted, however, that this bed is not exposed in two other outcrops in the vicinity. Whether or not it is concealed by surface wash it is impossible to say.

In the NE. ¼ NE. ¼ sec. 13 is exposed the lowest sandstone given in Munn's section,[2] and on its surface were found two almost complete skeletons of the Permian reptile Diadectes, which are more fully described on page 27.

The highest point of the butte, in the NE. ¼ sec. 24, appears to lie on the axis of an anticline, from which the beds dip to the north, as described above, and 500 feet south of this point the base of the sandstone capping the butte is 12 feet lower. The axis of the syncline that lies north of this anticline appears to run near the east quarter corner of sec. 13—perhaps a little south of it—from which place the beds rise to the outcrop in the northeast quarter of the section. The dip to the south from the crest of the anticline probably does not hold for any great distance, as at points 1,000 feet north of the southeast corner of sec. 24 shale is exposed up to an altitude of 1,035 feet, and the sandstone bed above mentioned is probably at a higher altitude, the axis of the shallow syncline lying somewhere between this place and the outcrop just south of the crest of the anticline. The northward dip seems to prevail as far south as the bluff of Red River.

T. 3 S., R. 11 W.

Most of T. 3 S., R. 11 W., consists of a gently undulating plain lying between the valleys of East and West Cache creeks and broken only by the shallow drainage ways of streams tributary to them. The rock exposures are few, and the best of them lie in the western part of the township, in secs. 6, 7, and 29. There are a few exposures also in the eastern half of the township, along the tributaries of East Cache Creek.

In secs. 6 and 7 two beds of sandstone were noted. The upper one is poorly exposed in the NE. ¼ SE. ¼ sec. 7, its base being at an altitude of 1,032 feet. The same bed is exposed in the road near the east quarter corner of this section, at practically the same elevation.

[1] Op. cit., pp. 25–26. [2] Idem, p. 26.

In the NE. ¼ SE. ¼ sec. 7 is a small knoll capped by the lower sandstone, the ledge being about 6 feet thick and containing several thin layers of concretionary conglomerate. The base of the sandstone is 1,014 feet above sea level.

In the SW. ¼ NE. ¼ sec. 7 the upper sandstone is exposed, its base lying at an altitude of 1,023 feet, or 9 feet lower than the same horizon half a mile to the southeast. The following section was measured at this place:

Section of rocks exposed in the SW. ¼ NE. ¼ sec. 7, T. 3 S., R. 11 W.

	Ft.	in.
Sandstone, red, and conglomerate of the concretionary type; poorly exposed.		
Sandstone, red, thin bedded		3
Conglomerate, concretionary; pebbles in part clay fragments in part concretionary, largest half an inch in diameter; cement very coarse sandstone		6
Sandstone, red, thin bedded; poorly exposed, may contain some interbedded red shale	7	0
Shale, red, sandy	1	3
Sandstone, light gray, thin bedded		7
Conglomerate, concretionary; dark dull red; largest pebbles an inch in diameter; thickness variable; altitude of base 1,023 feet above sea level		2½±
Shale, grayish red to red; 2 feet from base is a lenticular light-gray sandy layer; contains clay-limestone concretions	16	0

The lower sandstone is not exposed at this place, being covered apparently by wash from the red shale.

In the NE. ¼ NW. ¼ sec. 7 both sandstones are exposed, the interval between them being about 12 feet. The base of the upper sandstone is 1,033 feet above sea level, a rise of 10 feet over its altitude one-fourth of a mile southeast, at a place at which the bed is lower than at any other exposure in sec. 7.

Most of the exposures in sec. 6 are of the lower sandstone. The bed is exposed in the road east of the southwest corner of the section, where the elevation of the base is 1,007 feet above sea level. One-fourth of a mile farther north a sandstone which appears to be the same bed has an altitude of 1,020 feet. At the next point toward the north, however, at which it is exposed its altitude is but 1,002 feet. At this place the following section was measured:

Section of rocks exposed in the NW. ¼ SW. ¼ sec. 6, T. 3 S., R. 11 W.

	Feet.
Sandstone, red, calcareous; in part thin bedded, in part massive; slightly conglomeratic in certain beds	3
Sandstone; variable; at one place about 9 inches thick, light gray in color and thin bedded; at another 3 feet thick, light gray in color, coarse bedded, and massive	3±
Shale, red to gray; contains clay-limestone concretions, some of which weather out as irregular and rough, dark, ferruginous masses up to a foot in diameter	25

The lower sandstone bed in the above section is extremely variable in character and thickness. At another place in the same exposure it is represented by shale, sandstone, and conglomerate as follows:

Section of rock exposed in the NW. ¼ SW. ¼ sec. 6, T. 3 S., R. 11 W.

	Ft.	in.
Shale, red, containing in the middle an irregular conglomeratic clay about a foot thick; the pebbles, which are composed of arenaceous clay and may in part be concretionary, are closely packed in the clay matrix and the largest are a quarter of an inch in diameter. The conglomerate weathers out as dark, ferruginous masses	2	6
Sandstone, light gray, thin bedded		6

From this exposure the beds rise slightly toward the north, and at a place just west of the road a short distance north of the west quarter corner of sec. 6 the base of the same sandstone stands 1.010 feet above sea level.

For some distance in the stream bed northeast of the center of sec. 6 the same bed outcrops but its base is nowhere exposed. Farther east, up the small valley, the upper sandstone outcrops and at one place the elevation of the base is 1,021 feet above sea level. This bed is also exposed in the road on the east side of sec. 6, where it crosses the same stream valley. In the road on the north line of sec. 6 there is a small exposure of concretionary conglomerate a short distance west of the quarter corner and one of sandstone a short distance east of the same corner, but the relation of these beds to those of adjoining exposures can not be determined.

In the W. ½ sec. 29 a fairly thick bed of sandstone is exposed. Two outcrops are found in the SW. ¼ SW. ¼ sec. 29, but at neither is the base exposed, the lowest ledge in the outcrop being at an elevation of 970 feet. It is calcareous, gray to red in color, and contains a few red shale layers and at least one bed of shale conglomerate. At one point this conglomerate is 4 feet thick and some of the pebbles are 2 inches in diameter.

The beds apparently rise toward the north, for near the center of the SW. ¼ sec. 29 about 20 feet of shale is exposed, the top being 991 feet above sea level. The base of the sandstone, although not exposed here, must lie still higher. From this place the beds appear to dip to the north, for at the north side of the same quarter section the altitude of the sandstone base is 971 feet. Here the following section was measured:

Section of rocks exposed in the NW. ¼ SW. ¼ sec. 29, T. 3 S., R. 11 W.

	Ft.	in.
Red shale, grading laterally into red shaly sandstone and represented in another part of the exposure by 4 inches of concretionary conglomerate. The pebbles of this conglomerate are black and the largest are a third of an inch in diameter; they are embedded in an argillaceous, sandy cement. Maximum thickness of bed	1	0
Sandstone, light gray to greenish gray, coarse bedded and thin bedded; thickness variable; ranging from 6 inches to	1	0
Shale, yellowish gray to red; conglomeratic; pebbles, black; largest half an inch in diameter; bed very lenticular; maximum thickness	1	6
Shale, gray to reddish gray, yellowish gray, and greenish gray; contains clay-limestone concretions	9	0

Farther north, near the center of the NW. ¼ sec. 29, only the upper part of the bed is exposed; at an altitude of 959 feet, the base, which is not exposed, being still lower.

The exposures in the eastern half of the township are so poor that correlations between them are difficult to establish. One of the most complete exposures is that in the road on the east side of sec. 14 about 500 feet south of the creek. The section here is as follows:

Section of rocks exposed in road on east side of sec. 14, T. 3 S., R. 11 W., 500 feet south of the creek.

	Ft.	in.
Shale, red, streaked with white.		
Sandstone, bluish gray, containing hard concretionary masses	3	0
Sandstone, red and white, cross-bedded	5	0
Sandstone and concretionary conglomerate beds, red and comparatively soft	1	0
Sandstone, bluish gray; altitude of base, 984 feet		2
Shale, red		6
Shale, red, with concretionary conglomerate; pebbles, red shale, small light-brown concretions; matrix calcareous		2
Shale, bluish gray, weathering red, many small rough clay-limestone concretions	8	0
Sandstone, red, calcareous		8
Sandstone, white, with brown specks		6
Sandstone, red; contains several 2-inch beds, in which the sandstone is harder and more calcareous; altitude of base, 968 feet	7	0

About 1½ miles northwest of the above exposure a thin bed of bluish-gray concretionary conglomerate is exposed in the road and is overlain by about 6 feet of red sandstone. The elevation of the conglomerate base is 1,014 feet above sea level. In the SE. ¼ SE. ¼ sec. 10 one or two beds of concretionary conglomerate, each about 6 inches thick, are exposed on the south side of the valley. The altitude of the lowest bed is 1 001 feet in the creek bed. Southwest

of this exposure there is an outcrop of about 2 feet of light-gray sandstone that weathers red. It is not unlikely that the sandstone beds in this locality may represent the same group that is exposed on the east side of sec. 14, but owing to the nature of the intervening area such a correlation can not be established. About a quarter of a mile north of the south quarter corner of sec. 10 about 8 inches of concretionary conglomerate is exposed at an altitude of 999 feet. This may represent the same bed as that which outcrops at 1,001 feet a little less than half a mile to the east. Just southwest of the center of the section beds of thin sandstone and conglomerate are exposed at an altitude of 1,025 feet. The horizon may be traced for a quarter of a mile to the northwest, where the altitude of its base is 1,019 feet. This bed probably lies stratigraphically above the beds exposed in the southern part of the section. In the road a quarter of a mile north of the southwest corner of sec. 3 the following section is exposed:

Section of rocks exposed in the road a quarter of a mile north of the southwest corner of sec. 3, T. 3 S., R. 11 W.

	Ft.	in.
Sandstone, bluish white, speckled with brown		4
Concretionary conglomerate, red		4
Sandstone and shale, red	4	0
Sandstone, bluish white		6
Concretionary conglomerate, red, thin bedded		4
Sandstone, bluish white, weathers red		1
Sandstone, bluish white, soft	1	6
Shale and conglomerate, bluish gray		2
Shale, red, containing numerous clay-limestone concretions	10	0

A quarter of a mile farther east, in the creek bed, there is an exposure of 5 feet of red sandstone that contains about 1 inch of concretionary conglomerate. This bed apparently underlies the red shale at the base of the section given above. The succession of beds at this locality is very similar to that in the exposure on the east side of sec. 14, 2½ miles to the southeast, but whether or not the beds in the two exposures are to be correlated can not be determined. Seven hundred feet south of the quarter corner on the north side of sec. 23 about 3 feet of brilliant white sandstone is exposed in the creek bed. Below it lies 1 foot of red sandstone, which is in turn underlain by white sandstone, the base of which is not exposed. In the road 900 feet east of the southwest corner of sec. 23 the following section is exposed:

Section of rocks exposed in road 900 feet east of the southwest corner sec. 23, T. 3 S., R. 11 W.

	Ft.	in.
Sandstone, white, speckled with manganese; some red layers; cross-bedded; contains many large black irregular concretions	6	0
Sandstone, red	2	0
Sandstone, red, with red shale pebble conglomerate, thin bedded		8
Sandstone, red, and shale	2	0
Sandstone, greenish-white, with beds of bluish-white shale pebbles	1	0
Shale, weathering red, mottled with white; containing many clay-limestone concretions	0	13

It is not unlikely that the white sandstone exposed at the top of this outcrop is identical with that exposed in the northern part of sec. 23.

Concerning the structure of the rocks in T. 3 S., R. 11 W., but little can be said. In secs. 6 and 7, two small anticlines and three small synclines alternate with each other, their axes trending a little north of east. They are so small that in themselves they are unimportant. In sec. 29 there appears to be a rise of the beds to the south, which culminates near the middle of the southwest quarter, from which point the beds dip very gently to the south in the direction of the Deep Red syncline, described by Munn,[1] which is 3½ miles distant from this locality. Whether there is a constant dip to the south over this area or whether other structures intervene can not be determined. In the remainder of the township the rocks are so poorly exposed that nothing definite can be established in regard to the details of structure.

T. 4 S., R. 11 W.

This township is crossed from west to east by the valleys of West Cache Creek and Deep Red Run. Deep Red Run empties into West Cache Creek in sec. 17, and West Cache and East Cache creeks join in sec. 13 to form Cache Creek.

The northern third of the township slopes gently to the south toward West Cache Creek, except in its northeastern part, where the slope is to the southeast in the direction of East Cache Creek. The surface in the southern part of the township rises from West Cache Creek almost to the edge of the Red River bluff, thus throwing the divide between West Cache Creek and Red River much nearer to the larger stream; in other words, the side valleys tributary to Red River are shorter than those tributary to West Cache Creek. This peculiar drainage is probably the result of the structure of the underlying rock strata, as explained on page 34, Red

[1] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, pp. 32–33 and pl. 4, 1914.

River here flowing upon an anticline and Cache Creek following a syncline.

The exposures of Permian strata north of that part of West Cache Creek which has an eastward course are two in number. One is on the east bank of West Cache Creek near the north line of sec. 7, where the rocks show the section given below, a more complete discussion of which is presented on page 22.

Section of rocks exposed in east bank of West Cache Creek on north line of sec. 7, T. 4 S., R. 11 W.

	Feet.
Alluvium, unconsolidated red gravel and sand	12
Conglomerate, sandstone, and shale interbedded; conglomerate is composed of clay pebbles and concretions, the largest half an inch in diameter, red; the sandstone is coarse to fine and brownish red in color; the shale is red to gray	6
Shale; bedding distinctly marked; brownish red and, in places, bluish gray, especially along joint planes, as if the color were due to reduction by percolating water. The contact of the overlying conglomerate with this shale is unconformable, the shale having been considerably eroded before the conglomerate was put down. In this exposure, which is 200 feet in length, the differential erosion indicated by the uneven line of the unconformity amounts to about 5 feet	10

This isolated exposure could not be correlated with any other and hence has no value in determining structure. The second exposure is in the north bank of West Cache Creek just west of the east boundary line of sec. 15, where about 10 feet of sandstone overlies red shale. This exposure also is so far from all other exposures that the beds can be correlated with no others.

The sandstone member described under T. 4 S., R. 12 W., is well exposed in a short north-south ridge in the SE. ¼ sec. 18, where the following section was measured:

Section of rocks exposed in the SE. ¼ sec. 18, T. 4 S., R. 11 W.

	Ft.	in.
Sandstone, calcareous, cross-bedded, with round black spots or balls like buckshot of some black manganese mineral	1	6
Sandstone, calcareous, slabby, red and white, with dark streaks	1	0
Shale, sandy, red	3	0
Sandstone, calcareous, red, with dark streaks		6
Sandstone, red	1	6
Sandstone, pink and white, with dark streaks		4
Sandstone, bluish white, with dark streaks, probably due to particles of manganese; altitude of base, 964 feet		8
Shale, purple, greenish, and red, a few rough-surfaced concretions on the weathered surface	9	4

The elevation of the base of the sandstone as indicated in the section is 964 feet above sea level. To the southeast, in the NE. ¼ NE. ¼ sec. 19, the same sandstone is found, but its exact base is not well exposed. It is at least 10 feet higher than the same bed in the exposure just described, or 974+ feet. Between these exposures and the NE. ¼ NE. ¼ sec. 30 there are no recognizable outcrops, and it is therefore impossible to locate the anticlinal axis noted in sec. 24, T. 4 S., R. 12 W., if, indeed, it extends this far eastward.

In the NE. ¼ NE. ¼ sec. 30 a bed believed to be the same sandstone found at the head of a small "wash" presents the following section:

Section of rocks exposed in the NE. ¼ NE. ¼ sec. 30, T. 4 S., R. 11 W.

	Feet.
Sandstone, predominantly red, with some gray, thin bedded and somewhat cross-bedded; certain layers calcareous, others show a clay-conglomerate phase	8
Sandstone, light gray, in part thin bedded; altitude of base, 1,041 feet	2±
Shale, predominantly red; contains clay-limestone concretions	6
Shale, predominantly red; contains a few thin gray sandstone lenses and clay-limestone concretions	5±
Shale, red; slightly more resistant than that below, and exhibits bedding; contains clay-limestone concretions	10
Shale, red and gray; contains clay-limestone concretions	8
Shale, gray; contains clay-limestone concretions	9

The altitude of the base of the sandstone is 1,041 feet, showing that there is a rise to the south of 77 feet in 1¼ miles from the exposure in sec. 18, provided that the two exposures are on the same bed, as they appear to be. If any minor undulations occur between these outcrops nothing is known of them.

At the south quarter corner of sec. 17 the base of a sandstone that is believed to be the same bed as that just described is exposed at an altitude of 953 feet. This same sandstone covers the surface of a north-south ridge at the west side of sec. 21, but no outcrop could be found in which the base was exposed. The ridge slopes to the north, and this fact indicates a probable dip in that direction. In the SW. ¼ SW. ¼ sec. 21 the underlying red shales are found up to an altitude of 986 feet, showing that the sandstone base must be at a higher elevation.

At the top of a "wash" in the NE. ¼ NE. ¼ sec. 29 there is exposed a concretionary conglomerate that may represent the base of the sandstone bed above described. If such is the case the overlying sandstone has been removed by erosion, leaving the conglomerate at the surface. As no sandstone appears at a lower horizon in the adjacent gulches it is probable that the conglomerate marks either the base of the sandstone or a horizon somewhat below it, and in constructing the contour map (Pl. V) the altitude 1,023 feet, taken on

the conglomerate layer, was assumed to be the altitude of the sandstone base at this locality.

To the east no exposures are found between those described above and the "breaks" in the NW. ¼ sec. 22, where beds of sandstone and conglomerate are exposed which are believed to represent the sandstone thus far described as occurring in this township and which Munn[1] termed the Auger conglomerate lentil of the Wichita formation. In the outcrops in sec. 22 the sandstone and conglomerate beds vary greatly in character from place to place. The following stratigraphic section may, however, be considered as typical:

Section of rocks exposed in the NW. ¼ sec. 22, T. 4 S., R. 11 W.

	Ft.	in.
Sandstone, dark red with small black spots; calcareous; in places conglomeratic, with shale pebbles which usually weather out readily, leaving a pitted surface; the largest pebbles measure an inch in diameter. This sandstone overlies unconformably the beds below, the differences in erosion exhibited by the uneven line of contact showing variations amounting to about 6 inches in this one exposure....	4	0
Sandstone, light greenish gray, with black spots that are particularly numerous along bedding planes, as if deposited by percolating water; sandstone thin bedded and shaly, locally conglomeratic, with pebbles up to the size of a pea. Upper and lower surfaces unconformable with adjacent beds; lower surface shows irregularities amounting to 3 inches....	1	8
Shale, red and reddish gray.....	16	0

Within this quarter section the altitude of the base of the sandy beds varies regularly from 954 feet on the southwest to 933 feet on the northwest side of the exposure. On the east the altitude is 970 feet. There is therefore a marked dip to the northwest at this locality and a change in general strike from east to northeast. This change of strike probably indicates the occurrence of a minor or secondary fold on the north flank of the larger anticline to be described below. So far as known there are no other exposures of this uppermost sandstone in this township.

A sandstone whose position, dip, and strike indicate that it is lower than the bed above described is exposed at several points in the N. ½ sec. 26. The exact relation of this bed to the higher sandstone is not determinable. In T. 4 S., R. 12 W., a sandstone is found 40 or more feet below the uppermost sandstone bed exposed in that township, but it is not possible to determine whether the lower bed in T. 4 S., R. 12 W., and that exposed in sec. 26, T. 4 S., R. 11 W., are the same. This correlation is not improbably correct and has been assumed in drawing the structure contours shown on Plate V, where the bed exposed in sec. 26 is placed 40 feet stratigraphically below the bed exposed in sec. 22. The total thickness of the sandstone bed outcropping

[1] Munn, M. J., op. cit., pp. 23–28.

in sec. 22 is not exposed at any one locality. The best exposure is found along the "wash" in the SW. ¼ NW. ¼ sec. 26, where the following section was measured:

Section of rocks exposed in the SW. ¼ NW. ¼ sec. 26, T. 4 S., R. 11 W.

	Feet.
Sandstone, dark, dull red; cross-bedded, in part thin bedded; some layers conglomeratic with concretionary pebbles and clay fragments; the whole thickness not visible; exposed	2+
Sandstone, light greenish gray with black spots and streaks, cross-bedded. This sandstone grades upward into that above. Elevation of base, 979 feet above sea level	3
Shale, red and reddish gray; contains thin layers of light-gray sandstone; base not exposed	27

The altitude of the base of the sandstone at this locality is 979 feet above sea level. The base of the same sandstone in the prominent knoll in the NW. ¼ NW. ¼ sec. 26 lies at an altitude of 955 feet, and the bed therefore dips to the north about 22 feet in a third of a mile. Six hundred feet east of the north quarter corner of sec. 26 two thin beds of sandstone separated by about a foot of shale are exposed. These form part of the lower sandstone bed, but their exact position within that bed is not known. The elevation of the lower of the two is 943 feet. About 600 feet south of the northwest corner of sec. 25 there is a fair exposure of the lower sandstone in and near the road. The rocks at this place are considerably slumped, but at one point in the road the sandstone overlies 8 feet of red and gray shale and is probably in place. The base of the sandstone is 946 feet above sea level. The same bed is exposed at the head of a "wash" in the SE. ¼ NE. ¼ sec. 26, where the altitude of the base is 956 feet, or 10 feet higher than in the exposure last described. At this locality the following section was measured:

Section of rocks exposed in the SE. ¼ NE. ¼ sec. 26, T. 4 S., R. 11 W.

	Feet.
Sandstone, gray, with streaks and irregular black spots probably due to manganese; poorly exposed	2+
Concealed	6
Sandstone, light gray and speckled with black and red spots; a few thin beds show a conglomeratic phase, the pebbles being largely shale but in part concretionary. The unweathered sandstone is probably gray, although some masses are dark red, the color probably the result of weathering. Altitude of base, 956 feet	5
Shale, reddish and yellowish gray	4
Concealed	3
Shale, reddish gray near base and becoming more red near the top; contains large numbers of clay-limestone concretions; 14 feet from the base is a concretionary conglomerate about 4 feet thick, the largest pebbles in which are three-fourths of an inch in diameter	26

In the NW. ¼ NE. ¼ sec. 27 is an outcrop in which several ledges of sandstone are poorly exposed. Their relation to the beds exposed in sec. 26 could not be determined.

In the SW. ¼ SE. ¼ sec. 26 is an exposure of 1½ feet of sandstone overlying 8 feet of red shale. This bed appears to be stratigraphically lower than any of the sandstone beds heretofore mentioned and it may be identical with the upper of the two sandstone beds exposed in the cliff near the center of sec. 36, but this presumption could not be established.

Just east of the center of sec. 36 two ledges of sandstone form a prominent bluff. The lower of the two can be traced northwestward into the northwest quarter of the section, also southward almost to the township line, beyond which the upper bed is the more prominent. The following section is compiled from two measurements made near the center of sec. 36:

Section of rocks exposed near the center of sec. 36, T. 4 S., R. 11 W.

	Ft.	in.
Sandstone, yellowish brown to brownish red, thin bedded	3	0
Sandstone, brown to gray, friable	1	0
Concealed	3	6
Sandstone, yellowish gray	1	3
Concealed	3	0
Sandstone, light gray, thin bedded	2	4
Concealed	4	6
Sandstone, gray, calcareous; weathers out massive	1	6
Shale, red, sandy	1	0
Sandstone, streaked gray and black; elevation, 914 feet above sea level		3
Conglomerate, bluish gray, consisting of shale fragments and small concretions		3
Shale, red, containing many rough surfaced clay-limestone concretions	11	0
Shale with thin beds of white sandstone	5	0

The altitude of the bed of conglomerate exposed at this locality is 921 feet. About one-third of a mile farther south, in the first gulch north of the township line, a layer of conglomerate is exposed which apparently represents the same bed. It is a very little higher than the same bed at the more northern exposure. The upper bed appears to rise slightly from this point toward the south, but the structure in this section can not be positively determined. The upper bed is probably the equivalent of the upper bed exposed in the river bluff in the W. ½ sec. 2, T. 5 S., R. 11 W., and if so the bed has a general northerly dip from its exposures in the river bluff to those in sec. 36.

In the short valley leading back into secs. 32 and 33 from Red River three sandstone beds are exposed which appear to be stratigraphically lower than the sandstone and conglomerate beds outcropping along West Cache Creek, 2 miles farther north. This

conclusion is based on the fact that the dips observed in the exposures in secs. 22 and 32 are sufficient to carry the beds in sec. 32 considerably below those in sec. 22, unless the dip is reversed between the two exposures, but no indication of reversal is given either by the topography or the drainage in this area, and the beds in sec. 32 differ considerably in lithologic character from those exposed in sec. 22.

The highest of the three sandstone beds exposed in sec. 32 is about 10 feet in thickness. It outcrops along a gulch in the northeast quarter of the section, and near the north end of the exposure the altitude of the base of the bed is 984 feet. About 1,300 feet farther southwest its altitude is 1,000 feet, a rise of 16 feet in that distance. The bed may be traced to the southeast for about a mile to a point where it has an altitude of 1,026 feet. At a point west of the gulch in the east part of sec. 32, about 9 feet below the ledge just described, there is a second sandstone 8 feet in thickness. This sandstone is not seen in all the exposures, but it appears to form a distinct ledge of considerable extent.

In the bed of the gulch, about 50 feet below the base of the highest sandstone bed, the top of a sandstone ledge is exposed, at an altitude of 943 feet. The same bed is exposed at an altitude of 956 feet in the gulch that crosses the south line of sec. 33. It is the same bed that is exposed farther south, in the river bluff, and it can be traced across the greater part of T. 5 S., R. 11 W. It is correlated, rather doubtfully, with the upper sandstone in sec. 36, T. 4 S., R. 11 W.

In the SE. ¼ SE. ¼ sec. 30, T. 4 S., R. 11 W., the Riverside Oil Co. drilled in 1912 a well to the reported depth of 400 to 500 feet. No record was obtained.

To review briefly the correlation of the sandstone beds exposed in T. 4 S., R. 11 W., it may be said that the lowest of the three beds in sec. 32 can be traced southward to the river bluff in T. 5 S., R. 11 W., and thence to the middle of sec. 2 in the same township, between which point and the exposures of sandstone in the SW. ¼ sec. 36 its outcrop appears to be rather uncertainly indicated by the topography. The upper bed in the SW. ¼ sec. 36 is believed to represent the same bed, and the lower sandstone in sec. 36 should probably be correlated with that exposed in the vicinity of "Charlie Crossing" in the township to the south. Because of the absence of exposures the exact relations of these beds to those exposed in sec. 26 can not be determined. The beds in sec. 26 are probably higher stratigraphically than these beds, and they appear to be at least 40 feet lower than the beds exposed in sec. 22. The exposures in the NW. ¼ sec. 22, the SW. ¼ sec. 21, the NE. ¼ sec. 29, the NE. ¼ sec. 30, the northern part of sec. 20, and the SE. ¼ sec. 18 are all believed to be outcrops of one bed of sandstone, which is identical with that

exposed west of the township line in secs. 13 and 24, T. 4 S., R. 12 W. If this correlation is correct, the beds in the south half of T. 4 S., R. 11 W., dip northward at the rate of 40 to 45 feet to the mile. The general easterly strike of the rocks is interrupted at certain localities by minor folds, which are essentially cross folds imposed upon the main structure. Examples may be seen in the minor fold in sec. 22, where the strike in the northwest quarter of the section is about N. 45° E., and the slight fold in the NE. ¼ sec. 24, T. 4 S., R. 12 W., which extends into sec. 19, T. 4 S., R. 11 W. The major bed at this locality dips to the north from the crest of the butte in the NW. ¼ sec. 24, but there is also a slight dip to the south, which must be reversed in a short distance, in the long gentle rise of the beds toward the bluff of the Red River.

In his hurried reconnaissance of this township Munn [1] correlated the prominent sandstone-conglomerate bed that is exposed along Red River in T. 5 S., R. 11 W., with the sandstone-conglomerate beds on the south side of the Cache Creek valley. He therefore placed the axis of an anticline midway between these two localities, in secs. 29 and 30, T. 4 S., R. 11 W., believing that the anticline so indicated was the extension of his Devol anticline in the Grandfield district. The present more detailed work seems to show conclusively that the beds along Red River are stratigraphically lower than those along Cache Creek, and that the axis of the principal anticline in the region probably lies 1 to 2 miles south of T. 4 S., R. 11 W. The Devol anticline apparently dies out along the western border of T. 4 S., R. 11 W., being possibly represented by the minor fold observed in sec. 24, T. 4 S., R. 12 W. It seems evident from the three exposures noted in the E. ½ sec. 13, T. 4 S., R. 12 W., that the axis of a syncline crosses this section near its center. It may be inferred that West Cache Creek follows in general the axis of this syncline, but since the two exposures found on the north side of this stream in T. 4 S., R. 11 W., can not be correlated with any other exposures in the township, it is impossible to determine more definitely the synclinal axis, which is doubtless the continuation of the structure mapped by Munn,[2] as the Deep Red syncline.

T. 5 S., R. 11 W. (FRACTIONAL).

The exposures in this township are confined practically to the northern bluff of Red River and are here described in order from west to east along this bluff. In the NW. ¼ NW. ¼ sec. 7 a bed of bluish-white sandstone 4 feet thick is exposed about 10 feet above the flood plain, its base lying at an altitude of 947 feet. The sandstone is under-

[1] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, p. 7, 1914.
[2] Op. cit.

lain by 10 feet of reddish-gray shale and overlain by about 18 feet of dull-red shale. About half a mile to the northeast what appears to be the same bed is exposed at an altitude of 931 feet. The base of a higher bed lies at an altitude of 954 feet. One-fourth mile farther northeast, in the E. ½ sec. 6, the following section is exposed:

Section of rocks exposed in the E. ½ sec. 6, T. 5 S., R. 11 W.

	Ft.	in.
Dune sand.		
Shale, red, containing lenses and thin layers of gray and red sandstone	16	0
Sandstone, red, grading laterally in certain places into light-gray cross-bedded and concretionary conglomeratic sandstone, particularly near its base; altitude of base, 969 feet	6	6
Sandstone and shale, interbedded	4	0
Shale, gray, in certain beds red; contains lenses of bluish-gray sandstone 4 feet above the base	12	0
Shale, red; contains thin lenses of light-gray sandstone	20+	

The lenticular sandstone 24 feet above the base of this section probably lies at or little above the same horizon as the thin sandstone bed above described. The bed of sandstone 6 feet 6 inches thick at this place is exposed also in the river bluff in the NW. ¼ sec. 5, where it is from 12 to 15 feet thick. The altitude of its base is here 967 feet. In the NW. ¼ sec. 4 the following detailed section was measured:

Section of rocks exposed in the NW. ¼ sec. 4, T. 5 S., R. 11 W.

	Ft.	in.
Conglomerate, concretionary, dark brown		6
Sandstone, greenish, weathering red	5±	
Shale, red	5	0
Sandstone, pink and white, cross-bedded, containing in certain layers particles of manganese and near its base thin layers of conglomerate composed of shale pebbles and concretions	6	0
Sandstone and shale beds, the sandstone coarse and calcareous and containing thin layers of concretionary conglomerate; altitude of base, 959 feet	2	6
Shale, red and green, containing clay-limestone concretions, the largest 1½ inches in diameter	3	0
Sandstone, white and pink	1	6
Shale, red	3	0
Sandstone, white and brownish red, medium grained, thin bedded	2	0
Shale, gray and green at base, changing to pink above; contains roundish black ferruginous clay-limestone concretions	19	0
Covered to river level	27	0

Half a mile farther east, in the NW. ¼ NE. ¼ sec. 4, the beds of sandstone, shale, and conglomerate aggregate 20 feet in thickness, and the altitude of the base is 971 feet. Below the beds is 40 feet of shale. Near the east line of sec. 4 the base of the sandstone and conglomerate beds is at an altitude of 964 feet.

In the NE. ¼ NW. ¼ sec. 3 the following detailed section was measured:

Section of rocks exposed in the NE. ¼ NW. ¼ sec. 3, T. 5 S., R. 11 W.

	Ft.	in.
Sandstone, white	17	0
Shale, gray	9	0
Sandstone, reddish, containing in its upper part large cannon-ball-like concretions; lower part contains one or more bands of concretionary conglomerate	8	0
Shale (?), covered, containing in several places thin streaks of coal, which seem to be the remains of single logs rather than continuous beds. The carbonaceous material has in many places been replaced by copper in the form of chalcocite	18	0
Shale, black, carbonaceous, containing plant stems, sharks' teeth, and coprolites (see p. 26)	3	0
Coal, probably in a continuous bed		1
Shale, gray, calcareous, containing plant stems	2	6
Shale, gray	4	0
Conglomerate, concretionary, brown		4
Shale, gray		4
Conglomerate, concretionary		1
Shale, gray		4
Sandstone, brown, coarse		2
Shale, dark gray	1	0
Conglomerate, concretionary, small pebbles		4
Shale, greenish, weathers gray, lower part reddish	5	0
Concealed to river level	5	0

In this section the sandstone horizon which has been traced thus far appears to be represented by the upper of the two sandstone beds, the base of which is at an altitude of 961 feet. The base of the lower bed is at an altitude of 940 feet.

Near the east side of sec. 3 the following section was measured:

Section of rocks exposed in the NE. ¼ sec. 3, T. 5 S., R. 11 W.

Dune sand.	Ft.	in.
Sandstone, white to yellowish	10	0
Shale, red, containing in upper part clay-limestone concretions, the surfaces of which are very irregular	10	0
Sandstone, greenish white		6
Shale, sandy, red	2	0
Sandstone, greenish gray, containing certain thin beds darkened by particles of manganese, having also at its top lenticular beds of concretionary conglomerate impregnated with copper. Altitude of base, 979 feet	4	0
Shale, red, containing long rodlike concretions	13	0
Sandstone, white		6
Shale, red	2	0
Sandstone, medium grained, white at base, pink above	5	0

	Ft.	in.
Conglomerate, concretionary, 8 inches to	1	4
Sandstone, medium grained, thinly bedded, bluish white, containing near the top a 2-inch bed of concretionary conglomerate	5	0
Shale, gray, purplish near top, containing, 6 feet above its base, 6 inches of black, carbonaceous shale	15	0
Shale, red	10	8
Shale, red, with thin beds of white sandstone		5
Shale, red	1	6
Sandstone, white		6
Shale, red	2	0
Sandstone, white		6
Large ferruginous clay-limestone concretions, weathering black; surfaces irregular		6
Shale, red and gray	8	0
Concealed to the river level	5	0

The lowest pronounced bed of sandstone and conglomerate in the above section, the base of which lies at an altitude of 944 feet, should probably be correlated with the 8-foot bed of sandstone and conglomerate occurring above the middle of the previous section, one-third of a mile to the west, but the exact relations of the overlying beds to the beds in that section are uncertain. If the correlation suggested is correct it seems evident that whereas the lower sandstone ledge has become thicker toward the east, the upper ledge, which in the previous section was 17 feet thick, has been reduced to 4 feet and that a higher bed of sandstone, 10 feet thick, has appeared, which was not noted in the previous section. This highest sandstone bears the same relation to the lower bed, on which altitudes have been taken, that the middle bed in the east part of sec. 32, T. 4 S., R. 11 W., bears to the lowest bed in that locality.

On the river bluff near the east side of sec. 2, T. 5 S., R. 11 W., the section is as follows:

Section of rocks exposed near west side of sec. 2, T. 5 S., R. 11 W.

	Feet.
Sandstone, white	2
Shale, red	2
Sandstone, red	15
Shale, red, gray, sandy at base	14
Sandstone, interbedded with concretionary conglomerate	11
To river level	58

The altitude of the base of the sandstone and conglomerate ledge, which is the principal horizon thus far traced across the township, is 984 feet.

A comparison of this section with the preceding section shows that the overlying beds have become more sandy, the 15-foot bed of sand-

stone replacing part of the upper 10-foot bed of shale in the preceding section. Near the middle of sec. 2 the following section was measured:

Section of rocks exposed near the middle of sec. 2, T. 5 S., R. 11 W.

	Ft.	in.
Conglomerate, concretionary		6
Shale, red	5	0
Shale, sandy, red	10	0
Conglomerate, concretionary, brown	1	0
Sandstone, shaly, red	2	0
Sandstone, white	10	0
Shale, red, containing many rough-surfaced clay-limestone concretions	40	0
Sandstone, dirty white, containing numerous cannon-ball-like concretions	11	0
Shale, gray to reddish, to river level	22	0

In this section the horizon that marks the base of the principal sandstone lies at an altitude of 974 feet. About 22 feet above the river level there is also a bed of sandstone, 11 feet thick, which was not noted in sections farther west. The river bluff at this locality trends somewhat south of east and the strata rise in this direction. The bed of sandstone that here lies 22 feet above the river level lies but little above the surface of the water at a point a short distance to the northwest, where it is perhaps in part hidden by the alluvium and talus of the river bluff. It is possible that the bed is lenticular, and the fact that it is not exposed farther northwest may be accounted for by the thinning of the bed in that direction, but it is equally possible that its outcrop near the middle of sec. 2 is due to a rise of the bed toward the east. As the upper sandstone at this locality is practically horizontal, a rise of the lower bed presupposes a variation in the stratigraphic distance between the two beds. The data at hand are not sufficient to establish the exact relations. The contours on Plate V have been drawn as if the beds at this locality had a general southeastward rise.

The outcrop of the beds of sandstone and conglomerate which lie at the top of the cliff near the middle of sec. 2 swings to the northeast, away from the river, and can be traced somewhat uncertainly to the uppermost sandstone exposed at the south line of sec. 36, T. 4 S., R. 11 W. The sandstone bed in the middle of sec. 2 that lies 40 feet below the one last mentioned may be traced along the river bluff into the NW. ¼ sec. 12, T. 5 S., R. 11 W. It rises steadily toward the southeast, its base near the southwest corner of sec. 1 standing at 948 feet and at a point a quarter of a mile farther southeast at 961 feet. From this point, however, the beds appear to dip slightly in the opposite direction, and on the river bluff near the middle line of sec. 12 the altitude of the base is 935 feet. Southeast of this point this bed is

concealed by dune sand, so that it is impossible to tell whether or not the southeasterly dip continues farther.

The beds in the central part of fractional T. 5 S., R. 11 W., are evidently almost horizontal from east to west. Observations made in T. 4 S., R. 11 W., show that the strata have a general northerly dip, but the axis of the fold here lies nearly parallel to the river bluff. In the extreme western part of the township the strike of the beds appears to swing somewhat to the southwest, but the observations on which this conclusion is based are meager, for the only bed which can be followed is a lenticular sandstone, the outcrops of which are widely separated. In the eastern third of the township Red River swings somewhat to the southeast, cutting diagonally across the fold, and the rock strata here rise from the middle of sec. 3 to the NW. ¼ sec. 12, Near the middle of sec. 12 there is a slight reversal of dip, but it is impossible to say whether or not this indicates the axis of the principal anticline or merely a minor fold on the flank of the principal structure.

PART OF T. 3 S., R. 10 W.

Only the part of T. 3 S., R. 10 W. that lies south of the Chicago, Rock Island & Pacific Railway was examined. The western part of this area is drained by East Cache Creek and the eastern part by Whisky Creek. The town of Temple is in secs. 22 and 27.

The principal rock exposures are in the "breaks" on the east side of East Cache Creek. Near the middle of the E. ½ SW. ¼ sec. 33 there is an exposure of about 5 feet of grayish sandstone and 6 feet of underlying red shale. The altitude of the base of the sandstone is 990 feet. The character of the intervening area indicates that this bed of sandstone is the one that is exposed on the butte a quarter of a mile east of the southwest corner of sec. 5 of the township to the south (T. 4 S., R. 10 W.). It may be the same bed that is exposed at the side of the road near the west quarter corner of sec. 2 of the same township.

The next exposure to the northwest is in the NE. ¼ NE. ¼ sec. 32, where the following section is found:

Section of rocks exposed in the NE. ¼ NE. ¼ sec. 32, T. 3 S., R. 10 W.

	Ft.	in.
Sandstone, very light gray, weathering red	3±	
Shale, red		8
Conglomerate, concretionary	1	6
Sandstone, red		4
Shale, red		8
Conglomerate, concretionary; thickness variable	1±	
Sandstone	1	0
Shale, light bluish gray mottled with red, sandy	2	8
Conglomerate, concretionary; altitude of base, 1,001 feet	1	0
Shale, red	10±	

The beds are not well exposed but appear to vary greatly in character and thickness from place to place. The base of the sandstone member is 1,001 feet above sea level, or 10 feet higher than the same bed three-fourths of a mile to the southeast. West of this point the sandstone and conglomerate beds outcrop in a prominent ledge for about half a mile. In the road near the north quarter corner of sec. 32 the altitude of the sandstone base is 994 feet. The following section was measured at this place:

Section of rocks exposed in the road at south quarter corner of sec. 29, T. 3 S., R. 10 W.

	Ft.	in.
Surface gravel consisting of clay-limestone concretions and gray sandstone fragments.		
Shale, red	5	0
Sandstone, dark gray, calcareous; thickness about		6
Shale, red	5	0
Sandstone		3
Shale, red	8	0
Sandstone with some conglomerate and shale	11	0
Shale, lower 6 feet red and the remainder more or less grayish red	33	0

The 11-foot bed of sandstone in the above section is light greenish gray, in part cross-bedded and thin bedded, although a little north of the road it appears massive and weathers into roundish concretionary forms. The sandstone contains little calcareous material. The conglomerate is of the concretionary type and is variable in thickness and in vertical position. About 100 feet north of the road there is a foot of conglomerate at the base of this bed. In the road the base is composed of sandstone and a few feet above the base there is a lens of conglomerate having a maximum thickness of 9 inches. The shale is red and at one place in the road there is a lens having a maximum thickness of about 2 feet, divided in the middle by a thin sandstone. The base of this bed lies 994 feet above sea level.

In the NE. ¼ SW. ¼ sec. 32 there is an isolated butte formed of red clay and capped by residual fragments of sandstone. How far below their original position these fragments may lie is not known. The bed from which they were derived must have lain some feet above the present elevation of the top of the butte, which stands 994 feet above sea level.

In a small butte in the SW. ¼ sec. 29, the base of the same sandstone bed is exposed at an altitude of 977 feet, which is 17 feet lower than the same horizon exposed at the outcrop in the road on the south side of the section. From this outcrop the bed can be traced half a mile to the northeast, to a point where it is rather poorly exposed in the road near the east quarter corner of sec. 29. The base, as nearly as it could be determined at this locality, lies 974 feet above sea level.

From the altitudes of the sandstone bed at the three exposures in the S. ½ sec. 29 it is evident that the bed dips to the north. If the northward dip continues, it is not unlikely that the sandstone exposed at an altitude of 947 feet in the road just east of the northwest corner of sec. 29 represents the same bed, but inasmuch as there are no exposures in the intervening area this correlation can not be established. The section as measured near the northwest corner of sec. 29 is as follows:

Section of rocks exposed in the road just east of the northwest corner of sec. 29, T. 3 S., R. 10 W.

	Ft.	in.
Sandstone, light greenish gray, massive	3	6
Interbedded thin sandstone, shaly sandstone, and shale. The sandstone weathers red and black. The shaly sandstone is for the most part red and the shale is mottled red and light greenish gray. Elevation of base, 947 feet above sea level	4	0

In the railroad cut northwest of the southeast corner of sec. 17 there is an exposure of sandstone showing rather remarkable inclined bedding. The cut is about 1,000 feet long and throughout its length in a vertical distance of 18 feet the beds show a persistent southeastward or possibly eastward dip of about 10° to 15°. At the northwest end of the cut the base of the sandstone is in contact with the underlying red shale, the elevation of this contact being 988 feet above sea level. In sec. 21, about half a mile southeast of the above exposure, there is another and shallower railroad cut, where about 4 feet of the same bed is exposed. Southwest of the west end of the larger railroad cut the sandstone bed can be traced for more than half a mile into sec. 20. It rises gently in this direction, and in a prominent knoll in the northeast corner of the SE. ¼ NW. ¼ sec. 20 the top of the underlying shale lies at an elevation of at least 995 feet above sea level, a rise of 7 feet or more. This rise is in conformity to that observed in sec. 29. The sandstone probably lies above the sandstone bed exposed in that section, but the stratigraphic interval between the two could not be determined.

In the road about a quarter of a mile north of the southwest corner of sec. 26 a bed of sandstone is poorly exposed. What appears to be the same bed outcrops at two places near the north line of sec. 35, one-third and two-thirds of a mile, respectively, east of the northwest corner. The sandstone at the three exposures is about 982 feet above sea level, and if the three are on the same bed it is evident that the strata are practically horizontal at this locality.

The strata southeast of Temple, as shown by the exposures in secs. 26 and 35, are practically horizontal. There appears to be a slight rise in the beds from the exposure of sandstone in the south part of sec. 33 to the exposure in the NE. ¼ sec. 32, from which point they dip gently to the northwest. If the beds of the various

exposures have been correctly correlated, this dip—about 50 feet to the mile—continues as far as the northwest corner of sec. 29. In the northern part of sec. 20 the beds dip in a northerly direction, as they do in sec. 29. It seems probable that the anticlinal axis toward which the beds rise in the southwest part of T. 3 S., R. 10 W., is the continuation of that which crosses T. 4 S., R. 10 W., in a northwesterly direction.

T. 4 S., R. 10 W.

This township lies between the southward-flowing Cache Creek and its eastern tributary, East Cache Creek, on the west, and Whisky Creek on the east. The entire township is drained by these streams, although Red River, the principal drainageway in the region, lies but 2 miles south of the south township line.

The sandstone beds that reach the surface in this township are poorly exposed, and most of the outcrops are so far separated from one another that correlations between them are somewhat uncertain. The best exposure in the northeastern part of the township is in the range-line road a quarter of a mile north of the southeast corner of sec. 12, where the following beds are exposed:

Section of rocks exposed in the road a quarter of a mile north of the southeast corner of sec. 12, T. 4 S., R. 10 W.

	Ft.	in.
Shale, red, sandy; poorly exposed	1	0
Concealed	1	0
Sandstone, light greenish gray		2
Concealed		6
Sandstone, light greenish gray to brownish black		6
Concealed	1	0
Shale, red, arenaceous; contains one or two thin streaks of sandstone; about		9
Concealed	1	0
Sandstone, light greenish gray		6
Shale, light gray, arenaceous		6
Sandstone, light greenish gray to dark gray, in places banded with these colors; very calcareous	1	6
Sandstone, light gray, argillaceous, friable; elevation of base, 942 feet above sea level		8
Shale, red	2	6

The base of the sandstone is 942 feet above sea level. The sandstone is traceable for a quarter of a mile to the southeast, into sec. 7 of the township to the east, and rises 16 feet in this distance, to an altitude of 958 feet.

In the road north of the above section, on the opposite side of the valley, the sandstone is found down to an elevation of 933 feet. How near this elevation is to the base is uncertain, but it indicates that the northward dip, mentioned above, continues across the valley. To the west, on the south side of the valley, the exposures are very poor. The

sandstone rises in this direction, and in the W. ½ SE. ¼ sec. 12 an outcrop exposes the base at an elevation 973 feet above sea level. From this point the sandstone dips to the north, and in the point between the forks of the valley in the SE. ¼ NW. ¼ of the section the base is found at an elevation of 957 feet above sea level. The dip continues along the same horizon farther west-northwest and the bed is encountered in the well near the center of the NW. ¼ sec. 12, where the altitude of the surface is 955 feet, and the base of the sandstone lies still lower.

In the road near the east quarter corner of sec. 2 there are fragments of sandstone, and at one point there is a marked change of color from red to gray in the soil of the road, which is probably the contact between red shale below and sandstone above. This horizon is 942 feet above sea level. Whether these beds are to be correlated with those exposed in sec. 12 is uncertain, but the correlation was assumed in sketching the structure contours shown in Plate V.

A mile west of the above exposure, near the east quarter corner of sec. 3, the following section is exposed:

Section of rocks exposed near east quarter corner of sec. 3, T. 4 S., R. 10 W.

	Ft.	in.
Surface covered with loose, light-gray fragments of sandstone	4	0
Sandstone, light greenish gray, thin bedded	1	6
Concealed	2	0
Sandstone, light greenish gray, thin bedded	1	0
Shale, red	3	0
Sandstone; not more than		6
Concealed	2	0
Conglomerate, concretionary; thickness not determinable.		

About 500 feet northwest of the above exposure, in the SE. ¼ NE. ¼ sec. 3, more than 12 feet of red shale is exposed at the same altitude. In this exposure the sandstone and conglomerate beds do not appear. There is either a pronounced dip to the northeast at this locality or the rocks at the eastern exposure have been lowered by slumping from a former higher position. The latter seems the more probable.

In the NE. ¼ SE. ¼ sec. 10 there is exposed about 10 feet of red shale carrying a few irregular layers of concretionary conglomerate. The relation of this shale to the rocks in other exposures could not be determined. Its top is at an altitude of 991 feet. In the valley bed in the NE. ¼ sec. 15 there is the following section:

Section of rocks exposed in the SE. ¼ NE. ¼ sec. 15, T. 4 S., R. 10 W.

	Ft.	in.
Sandstone, light gray, weathering dark gray and brown, cross-bedded	2	0
Sandstone, light gray, friable, thin bedded, lenticular; maximum thickness	2	6
Conglomerate, concretionary, lenticular; concretions weather black; line of the base irregular, its general altitude being about 976 feet; maximum thickness		9
Shale, red, contains clay-limestone concretions	3	0

The character of the beds in the above section varies considerably in two other exposures at this locality. The sandstone can be traced southeastward through sec. 14, by loose surface material and here and there a poor exposure, to an outcrop in the road about a quarter of a mile west of the southeast corner of sec. 14, where the base of the sandstone is at an elevation of 973 feet. The following section was measured at this place:

Section of rocks exposed in road a quarter of a mile west of the southeast corner of sec. 14, T. 4 S., R. 10 W.

	Ft.	in.
Dark gray streak, probably indicating a bed of sandstone		6
Concealed	4	0
Sandstone, banded dirty yellowish gray and black; cross-bedded		6
Very poorly exposed but possibly gray sandstone	6	0
Sandstone, yellowish gray, banded with thin almost black streaks; elevation of base, 973 feet above sea level	1	0
Shale, gray	1	6
Shale, red	10±	

The same sandstone caps the butte in the SW. ¼ sec. 13, where the base is at an altitude of 965 feet, only 8 feet below the exposure in the road five-eighths of a mile west-southwest. The section measured here is as follows:

Section of rocks exposed in SW. ¼ sec. 13, T. 4 S., R. 10 W.

	Ft.	in.
Sandstone, loose surface material	2±	
Sandstone, light gray; contains a few thin black bands		2
Concealed; probably shale, red, sandy	3	6
Sandstone, dirty yellowish green, cross-bedded		2
Concealed	1	0
Sandstone, dirty yellowish green, cross-bedded		3
Conglomerate, red; the pebbles are fragments of shale, red, the largest half an inch in diameter, and some appear to be concretionary		5
Sandstone, banded light greenish gray and dark gray, cross-bedded, thin bedded		6
Sandstone, dirty yellow, shaly	2	0
Sandstone, red, shaly	1	1
Sandstone, yellowish gray, shaly		1
Sandstone, red, shaly	1	6
Sandstone, light gray weathering reddish brown, thin bedded; lower part streaked with a dark-gray mineral	2	6
Shale, red, contains a few thin light-gray sandy streaks	14	0

This sandstone, which can be traced for more than 1½ miles, resembles in some respects the bed outcropping in sec. 12. That it is identical with it, however, may be doubted. The northeasterly dip observed in sec. 12 is suggested also between the exposures in the SW. ¼ sec. 13 and in the SE. ¼ sec. 14, and if it exists in these

localities it is probable that the bed in these sections is below that in sec. 12.

About a quarter of a mile east of the northwest corner of sec. 8 there is a prominent butte in which is well exposed the following section:

Section of rocks exposed in butte a quarter of a mile east of northwest corner of sec. 8, T. 4 S., R. 10 W.

	Ft.	in.
Sandstone, banded dark gray and red		6
Sandstone, grayish red, argillaceous	1	0
Sandstone, conglomeratic, light gray; pebbles composed largely of gray shale, although some appear to be concretionary	2	0
Sandstone, light gray, in part banded light gray and dark gray, cross-bedded, thin bedded	5	0
Conglomerate, concretionary; elevation, 987 feet above sea level		5
Shale, red, some layers grayish red to gray; contains many thin lenticular layers of light-gray sandstone that weather to a reddish brown. Two of these layers, 12 feet above the base and 10 feet below the top, respectively, attain a maximum thickness of 2½ feet and are cross-bedded and thin bedded. The shale contains red clay-limestone concretions, those near the top being conspicuous for their number	42	0

The sandstone capping the butte is possibly the same as the one exposed in the township to the north in NE. ¼ sec. 32, but correlation over a distance so great is subject to error.

In the SW. ¼ SE. ¼ sec. 20 the following section is exposed:

Section of rocks exposed in SW. ¼ SE. ¼ sec. 20, T. 4 S., R. 10 W.

	Ft.	in.
Shale, red to gray	1	0
Sandstone, gray to red, thin bedded, cross-bedded	1	0
Sandstone, light gray; upper 3 feet weathers red on surface; lower 2 feet is conglomeratic, the pebbles, which are few in number, consist of gray shale	5	0
Sandstone, conglomeratic, light gray, friable. Pebbles consist of gray shale. Elevation, 956 feet above sea level		8
Shale, red	8	0
Sandstone, light gray, thin bedded, lenticular; maximum thickness	1	6
Shale, reddish gray near base and red in upper part; contains gray clay-limestone concretions, which are most numerous near the top	14	0
Sandstone, light gray, thin bedded, lenticular; maximum thickness		6
Shale, red; contains numerous thin, light gray, sandy streaks and clay-limestone concretions which weather black on the surface	14	0

Stratigraphically overlying the above section there is a thin-bedded red sandstone represented only by loose fragments. Overlying this there appears to have been a bed of dark-red sandstone, now largely

removed by erosion. This sandstone probably furnished the large cannon-ball concretions which are fairly abundant in the bottom of the "wash." The round concretions are 18 inches in diameter and others, which are more or less flattened, measure as much as 3 feet in their greatest diameter.

The lowest bed of sandstone in the section given above lies 956 feet above sea level. The base of a sandstone that is believed to be the same bed is exposed at an altitude of 973 feet near the center of sec. 21. If this correlation is correct, the bed here dips to the southwest at the rate of 17 feet to the mile.

Two hundred feet south of the east quarter corner of sec. 17 there is exposed in the road, at an elevation of 980 feet above sea level, about 3½ feet of sandstone, neither the base nor the top of which is exposed. This sandstone may represent part of the bed exposed in secs. 20 and 21, described above.

In the bank of the stream crossing the SE. ¼ SE. ¼ sec. 19 there is an outcrop of a sandstone which is lower than the bed just described. The section is as follows:

Section of rocks exposed in the SE. ¼ SE. ¼ sec. 19, T. 4 S., R. 10 W.

	Ft.	in.
Shale, light gray; contains several lenticular, thin, light-gray, sandy layers	6+	
Sandstone, light gray, thin bedded, cross-bedded; thickness variable; elevation of base, 916 feet above sea level. This sandstone forms a prominent ledge in the bank of the creek. Maximum thickness	6	
Shale, red in lower 10 feet and gray in upper 4 feet; contains numerous thin, lenticular light-gray, sandy layers and clay-limestone concretions	14+	

The base of this sandstone is 916 feet above sea level, or about 40 feet below the higher sandstone exposed a little over half a mile to the east, in sec. 20. This lower sandstone is provisionally correlated with a somewhat similar sandstone exposed in the northeast bank of Cache Creek in the W. ½ SW. ¼ sec. 29, the base of which lies 898 feet above sea level. This correlation is based not only on similarity of the beds, but on the fact that the dip indicated between the sandstone horizons of secs. 20 and 21 would, if it continues to the southwest, bring the base of the lower sandstone to about this elevation in the bank of Cache Creek.

If the same inclination of the strata occurs in secs. 8 and 18, the sandstone exposed in the stream bed at an altitude of 935 feet in the SE. ¼ NE. ¼ sec. 18 may be the same bed that is exposed in the SW. ¼ SW. ¼ sec. 8 at an altitude of 953 feet. The structure contours on Plate V are drawn on this supposition, the validity of which could not, however, be established in the field.

In the SW. ¼ SE. ¼ sec. 35 the following section is exposed:

Section of rocks exposed in SW. ¼ SE. ¼ sec. 35, T. 4 S., R. 10 W.

	Feet.
Sandstone, light gray and banded light and dark gray, cross-bedded; poorly exposed	1±
Concealed	6
Sandstone, yellowish gray to light gray; in places slightly conglomeratic, some of the pebbles being of gray shale and locally weathering to masses of yellowish iron oxide. The largest of these pebbles are an inch in diameter. The sandstone is massive, except in its lowest part, which weathers into roundish concretion-like masses or bowlders. Some of the bowlders that are not in place contain numerous nodules of green copper, the largest as big as a pea, and some bowlders bear thin crusts or patches of copper on the surface. Elevation of approximate base, 945 feet above sea level	7

In the road just west of the southeast corner of sec. 35 there are 3 or 4 inches of concretionary conglomerate at an elevation of 944 feet. It probably forms part of the sandstone horizon described above.

Twelve hundred feet east of the southwest corner of sec. 35 the beds of this same horizon are exposed. The lowest bed exposed is at an elevation of 945 feet.

To the north and northwest this bed of sandstone rises gradually, and in the W. ½ NW. ¼ sec. 35 is exposed in an extended outcrop, showing at one place the following section:

Section of rocks exposed in W. ½ NW. ¼ sec. 35, T. 4 S., R. 10 W.

	Feet.
Sandstone, light to dark gray and yellowish to reddish gray; in part thin bedded but in places massive; weathering into roundish concretion-like forms	4
Concealed	1
Sandstone, yellowish gray; elevation of approximate base, 957 feet above sea level	1
Shale, red; very poorly exposed	3+

The sandstone horizon can be traced northwest to the SW. ¼ SE. ¼ sec. 27, where the following section is exposed:

Section of rocks exposed in SW. ¼ SE. ¼ sec. 27, T. 4 S., R. 10 W.

	Ft.	in.
Sandstone; loose fragments on surface.		
Sandstone, light gray, cross-bedded; surface honeycombed by weathering; contains concretion-like forms, the largest a foot in diameter	1	6
Shale, red, sandy		4
Sandstone, light gray, cross-bedded; contains concretion-like forms, the largest a foot in diameter. Several thin gray beds are resistant and stand out prominently. The surfaces of the dark gray slabs are honeycombed by weathering. Elevation of base, 934 feet above sea level	6	0

The same bed is exposed a quarter of a mile to the northeast, where the altitude of its base is 961 feet, showing a pronounced rise of the

strata in that direction. In the SW. ¼ NE. ¼ sec. 27 the base of the same bed lies 972 feet above sea level.

In the bed of Whisky Creek, in the NE. ¼ NE. ¼ sec. 36, about 5 feet of a friable greenish-white sandstone is exposed. The base of the bed is not exposed, but the base of the ledge is 881 feet above sea level. This sandstone is probably the one that outcrops in the bed of the small valley at the south side of the N. ½ SE. ¼ sec. 25, where it is represented by 12 feet of rather heavy bedded light-grayish sandstone. The base of the exposed part of the bed lies at an altitude of 887 feet. On the south side of this small valley, about 200 feet from the exposure last mentioned, there is an outcrop of 6 inches of shale conglomerate overlain by a 3-inch bed of calcareous dark-gray sandstone. The base of the conglomerate is at an altitude of 919 feet. The two beds above described should probably be correlated with part of the section exposed in the SW. ¼ sec. 24.

In the SW. ¼ sec. 24 and in the SE. ¼ sec. 23 there are numerous outcrops of sandstone, but several of them have slumped so much that it is difficult to interpret their relations to one another or to near-by outcrops. They show no marked structure, but seem to dip slightly to the east at the rate of not more than 5 or 10 feet to the mile.

Because of the nature of the outcrops and the difficulty of correlating between them it is impossible to determine the structure in T. 4 S., R. 10 W., except in a most general way. In sec. 12 there is a pronounced dip to the northeast, and there is a like dip in sec. 2 if the two exposures on the east and west sides of the section represent the same bed. In secs. 27 and 35 there is a marked dip in the opposite direction to the southwest. It is therefore evident that the axis of an anticline must cross the eastern part of the township between these two localities. If the shale bed exposed in the SE. ¼ sec. 10 is to be correlated with that in the northeast quarter of the section to the south, there is a marked dip to the south or southwest between these two localities, in which case the anticlinal axis probably lies north of the northern exposure or passes through it. In T. 3 S., R. 10 W., there appears to be a rise of the beds toward the south in sec. 29, which may culminate in sec. 31, and this structure may possibly be a continuation of the fold in T. 4 S., R. 10 W.

In the western part of T. 4 S., R. 10 W., there appear to be at least two beds of sandstone represented. The lower is exposed in the SE. ¼ sec. 19 and should perhaps be correlated with the bed in the SW. ¼ sec. 29, as well as with the bed exposed in the SW. ¼ sec. 8 and the NE. ¼ sec. 18. The upper bed is present in the southern part of sec. 20, the central part of sec. 21, and on the western boundary of sec. 16. It is possibly the same bed as that exposed in the knoll on the south side of sec. 5. Such correlations are tentative only, as they can not be proved, so that they are little more than conjectures as to the

relations of the exposures. If they are correct, there is in secs. 17 and 20 a gradual dip to the southwest in the direction of Cache Creek. The syncline in the southwestern part of the township, if it exists, is a continuation of that which is marked by the course of West Cache Creek in T. 4 S., R. 11 W., and which is the same structure as that termed by Munn[1] the Deep Red Run syncline.

T. 5 S., R. 10 W. (FRACTIONAL).

This fractional township, which covers about 12 square miles, borders Red River, its southern part being occupied by the flood plain of that stream. Near the west side it is crossed by Cache Creek. The broad flat lying west of the course of this stream evidently represents a former stream channel. This flat is now being invaded along its western border by sand dunes, which are drifted from the Red River channel on the southwest.

At the sharp bend in Cache Creek in the eastern half of sec. 5 a bed of sandstone 8 feet thick outcrops in the east bank of that stream. At the base of the sandstone is a thin bed of concretionary conglomerate which is underlain by red shale. The bed of conglomerate is variable in thickness and at some places is entirely absent. At one place where the conglomerate is 4 inches thick the sandstone bed overlying it is thicker than at points on either side, as if the conglomerate had been deposited along a channel cut in the underlying shale. The bed dips a little west of north at the rate of 4 feet in 105 feet and apparently continues to rise to the south, for in the next bluff only the underlying shale is exposed, the sandstone lying at a higher altitude and having been removed by erosion. About 1,000 feet south of the bend and 5 feet above water level there is exposed 4 feet of thin-bedded lenticular sandstone associated with concretionary conglomerate. The beds above and below are shale. This sandstone appears to be at a lower horizon than the bed exposed in the outcrop to the north. In the NE. ¼ sec. 8, in the east bank of Cache Creek, a ledge of sandstone is exposed for more than a quarter of a mile just above water level, the bed appearing to be horizontal. At one place the section is as follows:

Section of rocks exposed in the east bank of Cache Creek, in the NE. ¼ NE. ¼ sec. 8, T. 5 S., R. 10 W.

	Ft.	in.
Shale weathering red.		
Sandstone, dirty white		6
Shale, greenish gray	10	0
Conglomerate, concretionary	1	6
Shale, reddish, sandy	1	0
Sandstone, white	9	0
Water level.		

[1] Op. cit., pp. 32–33.

In the middle of the conglomerate in the above section there is a 3-inch seam of subbituminous coal which appears to represent a single log rather than a continuous bed. The concretionary conglomerate above and below this coal is stained green by a deposit of copper. The conglomerate at this locality can be traced for only 25 feet along the outcrop. The sandstone is very much cross-bedded.

In the SW. ¼ sec. 8, on the west bank of Cache Creek, about 10 feet of reddish sandstone is exposed, having at its base a foot of concretionary conglomerate. The altitude of this sandstone is practically the same as that exposed in the NE. ¼ sec. 8 and may represent the same bed.

Opposite the mouth of Cache Creek, on the Texas side of Red River, there is exposed the following section:

Section of rocks exposed in south bank of Red River opposite the mouth of Cache Creek.

	Ft.	in.
Sandstone, gray above, red below	10	0
Conglomerate, concretionary, brilliant red, pebbles small		2
Shale, red above, bluish gray below	15	0
Conglomerate, concretionary, with some shale; pebbles red and brown, fine grained		6
Shale, brownish red	4	0
Sandstone, white, streaked with red	15	0
Concealed to river level	7	0

A mile west of the above locality, in the bank of Red River, the following section is exposed:

Section of rocks exposed in south bank of Red River 1¼ miles southwest of the mouth of Cache Creek.

	Ft.	in.
Sandstone, red	5	0
Sandstone, white	1	6
Shale, red, sandy	2	0
Sandstone, white	3	0
Shale, gray	4	0
Sandstone, white and red	5	0
Conglomerate consisting of shale pebbles and concretions, the largest 3 inches in diameter. The conglomerate contains thin beds of sandstone, in one of which was found an impression of the stem of a plant	4	0
Sandstone, light green, thinly laminated and cross-bedded	5	6
Water level of Red River.		

The sandstone beds at each of the two exposures last mentioned appear to be horizontal and the beds at the two exposures should probably be correlated with each other, but the beds are so variable in character that positive correlation is impossible, particularly as they can not be traced from one exposure to the other. The relation of the beds to those exposed near the mouth of Cache Creek is also unknown. If the strata are flat, they probably represent the same group.

The north bluff of Red River, in which thick-bedded sandstones are exposed, crosses secs. 10 and 11. Near the west side of sec. 10 the section is as follows:

Section of rocks exposed near west side of sec. 10, T. 5 S., R. 10 W.

	Ft.	in.
Conglomerate.		
Sandstone, yellowish gray		6
Shale, dirty yellow	1	6
Sandstone, concretionary		6
Shale, dirty yellow	1	0
Sandstone, dark gray		8
Shale, red, slightly arenaceous	2	
Sandstone, red		6
Shale, red, arenaceous	3	0
Sandstone, light gray, at some horizons containing black or dark-gray streaks; weathers red on the surface; in part thin-bedded and in part massive, certain beds weathering in roundish forms	18	0
Concealed	5	0
Sandstone, light gray, thin bedded	3	6
Shale, red, in some places gray; contains clay-limestone concretions in its upper part, which weather black	42	0

The altitude of the base of the lowest sandstone bed in the above section is 939 feet.

Near the middle of sec. 11 a ledge of sandstone 24 feet thick is exposed, having, about 4 feet above its base, 1 foot of conglomerate in a matrix of red shale. The pebbles of the conglomerate consist of concretions and shale pebbles. The sandstone ledge is underlain by red shale. The sandstone exposed in secs. 10 and 11 probably represents the same bed, as it is similar in lithologic character at the two exposures and is of unusual thickness, but the bed can not be traced from one exposure to another.

On the terrace along the east side of Caché Creek in secs. 5 and 8, about 40 feet above the stream, there is a deposit of stream gravel, the pebbles of which consist in part of rhyolite porphyry, which may possibly have been derived from the Wichita Mountains.

At the mouth of Cache Creek, in sec. 8, bubbles of gas rise in the water about 10 feet from the east side of the stream. The flow of gas appears to be constant and is said to continue through winter and summer. The movement of the water caused by the bubbles has excavated in the mud of the stream small hollows, which are from 18 inches to 2 feet in diameter and about 4 inches in depth. In the middle of each depression there is a hole about an inch in diameter, from which the gas issues. About 2,100 feet north of this gas spring the depression formed by a similar spring was noted in the mud flat on the east side of Cache Creek, and others are said to have been observed between these two localities.

The constant flow of the gas and the absence in it of any odor of decaying vegetation were taken as indications that it was derived from a considerable reservoir and was probably natural gas, but analyses made in the chemical laboratories of the United States Geological Survey and of the Bureau of Mines show that it contains a much higher percentage of carbon dioxide than is found in natural gas. According to the analysis made by the Bureau of Mines the carbon dioxide content of the gas is 18.70 per cent. Through the courtesy of the same bureau a list of the percentages of carbon dioxide (CO_2) in 22 samples of natural gas from Oklahoma has been furnished to the writer. The content of carbon dioxide in these samples ranges from 0 to 4.10 per cent. As a relatively small content of carbon dioxide is one of the features that distinguish natural gas from that which is derived from decaying vegetable matter and which is known as swamp or marsh gas, there is little doubt that the gas which rises at the mouth of Cache Creek is swamp gas and is not in any way connected with a deposit of natural gas or petroleum. It is probably derived from the decay of logs or other vegetable matter buried in the mud of the creek bottom.

In a preliminary statement of the results of work done in this field, issued in June, 1914, before reports on the analyses of the gas were received, the gas that rises in Cache Creek at this place was referred to as apparently natural gas, which might reasonably be assumed to rise along an anticlinal fold. The rocks exposed in this vicinity show that there has been warping of the strata, but the inferences in regard to structure, in so far as they were drawn from the occurrence of the gas seeps, have in the light of the analyses proved incorrect. The analysis gave the results shown below:

Analysis of sample of gas that rises in seeps at mouth of Cache Creek, Cotton County, Okla.

[Analysis made in chemical laboratory of Bureau of Mines, G. A. Burrell, chemist, August, 1914.]

CO_2	18.70
O_2	.50
CH_4	77.10
N_2	3.70

The sample appears to be a marsh gas. An odor of hydrogen sulphide was noticed in the gas, but a quantitative determination of hydrogen sulphide was not made. The small amount of oxygen found was undoubtedly due to intrusion of air into the sample.

The only evidence of structure within the township is a dip to the north, shown by the outcrops along Cache Creek in the E. ½ sec. 5. The beds in sec. 8 appear to be horizontal. The outcrop of the thick sandstone bed in secs. 10 and 11 is also horizontal from east to west, and the thickness of the bed indicates that it is not to be correlated with any of the beds exposed along Cache Creek.

T. 4 S., R. 9 W.

The valley of Whisky Creek crosses the western side of T. 4 S., R. 9 W., from north to south. A tributary of Red River drains the southeastern part of the township, and tributaries of Beaver Creek drain its eastern part. The town of Hastings is in secs. 2 and 11.

At the northwestern corner of sec. 8 there is exposed at least a foot of concretionary conglomerate, 3 feet below which is 2 feet of light-gray calcareous sandstone. The conglomerate bed can be traced for some distance to the southeast, but its exposures are poor. Altitudes at the top of the bed rather than at the base are recorded, for the position of the top is more easily determined in outcrops where the wash of the rains has concealed the base and carried fragments of the bed far down the slope from their original position. The top of the conglomerate at the northwest corner of sec. 8 is 948 feet above sea level. One-third of a mile east of this exposure, in the road where it crosses the valley east of the schoolhouse in sec. 5, the conglomerate is found at a higher elevation, not accurately determined. A point in the NW. ¼ NE. ¼ sec. 8 is capped by the conglomerate, which here lies 962 feet above sea level, a rise of 14 feet in two-thirds of a mile from the exposure at the northwest corner of the section. To the southeast this bed is still higher, and in the SE. ¼ NE. ¼ of this same section it is 970 feet above sea level. A sandstone, possibly the bed 3 feet below the conglomerate, outcrops in the NW. ¼ SE. ¼ sec. 8, but the conglomerate is not exposed at this place. It is exposed, however, in the road a short distance east of the south quarter corner of sec. 8, where it is 955 feet above sea level. From this point the conglomerate bed rises to the east. It is found in the road a quarter of a mile east of the exposure last mentioned and again just east of the northwest corner of sec. 16, where it lies at an elevation of 968 feet. It outcrops at several places in the road on the north line of this section and one-third of a mile west of the northeast corner is at an elevation of 976 feet. The bed caps the low ridge east of the road, south of the northwest corner of sec. 16, and its altitude at the east quarter corner is 949 feet. This bed was not recognized at other localities in the township.

In the north-central part of sec. 9 there is a thick sandstone, which appears to lie stratigraphically above the bed just described. No good exposures were found and its relation to other beds could not be established.

On the south side of the east-west valley tributary to Whisky Creek, in secs. 16 and 17, there are a few "breaks" in which sandstones are exposed at several horizons.

Near the center of the SE. ¼ sec. 17 an exposure shows the following section:

Section of rocks exposed near center of the SE. ¼ sec. 17, T. 4 S., R. 9 W.

	Ft.	in.
Fragments of gray calcareous sandstone lying on the surface.		
Sandstone, gray, calcareous	1	0
Concealed; probably sandstone	2	0
Sandstone, yellowish gray, cross-bedded and thin bedded	3	0
Conglomerate; poorly exposed; the pebbles are composed of greenish-gray shale; elevation, 961 feet above sea level		3
Shale, yellowish-gray		10
Shale, red	3	0

This sandstone should probably be correlated with the sandstone found at the head of the small "break" in the NE. ¼ SW. ¼ sec. 16, where the bed may perhaps be slumped a few feet from its original position. The base as exposed is 970 feet above sea level. From this exposure the sandstone can be traced southward up the "draw" to a point where it outcrops in the road one-fifth of a mile east of the southwest corner of sec. 16. At this place the base of the sandstone is 974 feet above sea level, the section being as follows:

Section of rocks exposed in road one-fifth of a mile east of the southwest quarter corner of sec. 16, T. 4 S., R. 9 W.

	Ft.	in.
Sandstone, light greenish gray, calcareous; contains several thin beds of greenish gray calcareous conglomeratic sandstone, the pebbles of which are composed in part of greenish-gray shale and are in part of concretionary origin	4+	
Conglomerate; in places concretionary and at other places represented by greenish-gray shale		6
Shale, red	2+	

In the road about a quarter of a mile west of the southeast corner of this section there are 3 feet of a light-greenish sandstone near the bottom of the "draw." The base is not exposed, but the lowest bed lies at an elevation of 970 feet above sea level. Whether this sandstone should be correlated with that of the exposures to the west and northwest could not be determined.

The point in the field just west of the road about a quarter of a mile north of the southeast corner of sec. 16 is capped by 3 to 4 feet of gray to light-gray sandstone. This is probably at the same horizon as the bed in the NE. ¼ SW. ¼ sec. 16. The base is not well exposed but is probably about 980 feet above sea level.

In the SW. ¼ sec. 17, and the SE. ¼ sec. 18 there are several exposures of sandstone. The best of them is in the north-south ridge in the northern part of the SW. ¼ sec. 17, where the base of the bed appears to lie at the approximate altitude of 956 feet. The bed is probably the same that is exposed in the southeast quarter of the

same section. The correlation of the beds of the other exposures in these quarter sections could not be determined.

In the SW. ¼ SW. ¼ sec. 7 there is exposed a bed which is the same as that in the SE. ¼ sec. 12, T. 4 S., R. 10 W. The altitude of its base is 958 feet. The bed was not recognized at other places in T. 4 S., R. 9 W.

In the road on the north side of the valley about 500 feet north of the west quarter corner of sec. 20 the base of a sandstone is exposed at an altitude of 930 feet. About 1,000 feet southeast of this exposure what appears to be a higher ledge outcrops, its base being at an altitude of 942 feet. The sandstone can be traced southwestward to a point near the schoolhouse at the southeast corner of sec. 19, where its base is perhaps 2 feet lower than at the northern exposure. A bed of concretionary conglomerate exposed in the road a short distance west of the south quarter corner of sec. 19 at an elevation of 937 feet above sea level may possibly represent this bed.

In the road 1,000 feet east of the northwest corner of sec. 31 the following section was measured:

Section of rocks exposed in road 1,000 feet east of the NW. ¼ sec. 31, T. 4 S., R. 9 W.

	Ft.	in.
Sandstone, yellowish gray	1	0
Shale, red	4	6
Sandstone, gray, calcareous; contains a few flat pebbles of greenish-gray shale	1	6
Sandstone, light gray; thickness about	3	0
Shale, red	4	0
Concealed	3	0
Sandstone, light gray and yellowish gray weathering to a dark gray; weathers out into roundish concretion-like forms; elevation of base, 927 feet above sea level	3	0

The sandstone outcrops extend into the fields both north and south of the road, but the exposures are poor. The sandstone was traced southward into the SE. ¼ SW. ¼ sec. 31, where its base is exposed at an elevation of 923 feet. The bed is the same that is exposed in the SW. ¼ NW. ¼ sec. 6 of the township to the south, where its base is at an altitude of 926 feet. Its base in the NE. ¼ sec. 6 could not be accurately determined.

In the road on the north side of sec. 32, 400 feet west of the north quarter corner of that section, there is a bed of concretionary conglomerate whose base lies at an altitude of 921 feet. The conglomerate occurs in three or four thin beds with red shale between, the whole being about 3 feet thick. There appears to be a bed of white sandstone 5 or 6 feet above the top of the conglomerate, but the

exposure is extremely poor and the relations of the beds could not be accurately determined. Half a mile southeast of this locality, in the SW. ¼ NE. ¼ sec. 32, at the southern end of a ridge, a bed of sandstone is exposed, the base of which lies at an altitude of 940 feet. The sandstone is thin bedded and weathers into concretion-like forms. As exposed it is about 9 feet thick and is underlain by red shale. No conglomerate was observed at this locality, and the bed of sandstone probably lies somewhat higher than the bed of conglomerate exposed in the road to the northwest.

Near the quarter corner on the east side of sec. 32 there is exposed a bed of sandstone the base of which is at an altitude of 932 feet.

About 1,800 feet farther north a good exposure of the base of this bed occurs along the road, also at an altitude of 932 feet. This bed of sandstone appears to be identical with that in the ridge half a mile to the west. What appears to be the same bed caps a pronounced bluff in the southern part of sec. 33. At the west end of this bluff the following section was measured:

Section of rocks exposed at the west end of bluff in the southern part of sec. 33, T. 4 S., R. 9 W.

	Ft.	in.
Sandstone, yellow and black, calcareous, thin bedded	1	0
Shale, red		6
Sandstone, yellowish green and red in alternating beds	1	6
Sandstone, yellowish green and red, calcareous, with black streaks and containing a few shale pebbles	1	0
Sandstone, white, thin bedded	5	0
Conglomerate, concretionary		2
Sandstone, greenish white, very minutely bedded	1	0
Shale, reddish gray		4
Shale, red, with numerous layers of concretionary pebbles	1	4
Conglomerate, concretionary; altitude, 933 feet		1
Shale, red and gray, containing numerous clay-limestone concretions	40	0

Nine hundred feet southeast of this locality the altitude at the base of the sandstone and conglomerate beds is 936 feet. The lowest part of the sandstone group may be traced 1,000 feet farther east in a low ridge, the altitude of the base at the eastern end of the ridge being 930 feet. At this locality a few fragments of concretionary conglomerate were observed. Thirty-one feet below the base of the sandstone and conglomerate beds, or at an altitude of 899 feet, there is in the bed of a gully, which here runs northward, a lower bed of concretionary conglomerate. The bed is underlain and overlain by sandstone. From this locality a detailed stratigraphic section was measured to the top of the bluff, 800 feet to the northeast, and is as follows:

Section of rocks exposed in the SE. ¼ sec. 33, T. 4 S., R. 9 W.

	Ft.	in.
Sandstone, yellow; altitude of base, 966 feet	15	0
Shale, red	32	0
Sandstone, white		8
Shale, red, sandy	3	0
Sandstone, white	1	0
Shale, red	10	0
Shale, brown	1	0
Shale, gray, weathers light blue	7	0
Shale, red, sandy	2	0
Sandstone, white	1	0
Shale, red, sandy	1	0
Sandstone, calcareous	3	0
Shale, green		4
Sandstone, dirty yellow, almost white, containing many large, round concretions	9	0
Conglomerate, concretionary, dark red and black, concretions up to 2 inches in diameter; altitude, 899 feet		10
Sandstone, bluish white, shaly	3	0
Sandstone, bluish white, with red shale	2	0

The lower half of the above section was measured in the bed of a dry stream. The exposures appear to be good, but, as will be noted by comparing the section with that just described, to the west, the ridge-forming bed of sandstone 31 feet above the lowest conglomerate does not appear or is represented by two beds, 8 and 12 inches in thickness. It seems very strange that these beds, which are so pronounced a short distance to the west, should be entirely concealed in this section. Certain it is that it is impossible to correlate the beds across the narrow valley of the intermittent stream. A fault may extend along the line of the valley, but its existence can not be demonstrated. The sandstone at the top of the measured section given above may be traced southeast for about a quarter of a mile into the SW. ¼ sec. 34, where the following section was measured:

Section of rocks exposed in the SW. ¼ sec. 34, T. 4 S., R. 9 W.

	Feet.
Sandstone, white, capping the bluff; altitude of base, 971 feet	10
Shale, red	17
Sandstone, white	8
Shale, red, with thin beds of white sandstone; fragments of bones of reptiles in the shale	23
Sandstone, white	8
Shale, red	8
Sandstone, white, with thin beds of red and purple shale	32

It will be noted that this section contains, at a point 17 feet below the top sandstone, a bed of sandstone that does not appear in the preceding section. Because of the extreme fineness of many of these sediments the surface is in places concealed by a veneer of wash from the beds above, which simulates closely the appearance of strata in

place and which may conceal outcrops of even prominent beds. The top sandstone in this section may be traced northeastward for about half a mile to a point near the center of the section, where the altitude of its base is 962 feet. Near the middle of the northeast quarter of the section a bed that is believed to represent the same horizon lies at an altitude of 954 feet, and a quarter of a mile farther east, in the SW. ¼ NW. ¼ sec. 35, the bed is at the same elevation above sea level. Slumping has obscured the outcrop to some extent north of this locality, but in the road 150 feet east of the northwest corner of sec. 35 the base of a sandstone that is supposed to be the same bed is exposed at an altitude of 940 feet. The section measured at this locality is as follows:

Section of rocks exposed east of the northwest corner of sec. 35, T. 4 S., R. 9 W.

	Ft.	in.
Sandstone, white	6+	
Shale, red, with one or more sandstone beds	16	0
Sandstone, white	1	0
Shale, red	4	0
Sandstone, white	1	6
Shale, red, with one or more thin sandstone beds	5	0
Sandstone, white	5	0
Conglomerate, concretionary, and shale, red and brown, shale pebbles predominating		3
Sandstone, white	11	6
Conglomerate, concretionary; altitude, 940 feet		6
Shale, red.		

The lowest bed of sandstone in the above section is the one that was traced from the southwest. The highest bed, 44 feet above its base, caps the hill and may be traced northwestward across sec. 27. In the SE. ¼ NE. ¼ of this section its base is at an altitude of 966 feet. As the base of this bed is 44 feet above the base of the lowest bed in the measured section given above, the base of the lowest bed at this locality is 921 feet, or 19 feet lower than the base of the same bed at the southeast corner of sec. 27. At the conical butte in the NW. ¼ NW. ¼ sec. 26 the following section was measured:

Section of rocks exposed at conical butte in the NW. ¼ NW. ¼ sec. 26, T. 4 S., R. 9 W.

	Ft.	in.
Sandstone, white	10+	
Conglomerate, concretionary, lenticular, in places entirely absent; altitude, 985 feet		6
Shale, red	21	0
Sandstone, white	10	0
Shale, red, streaked with bands of yellow, thin bedded	17	0
Conglomerate, concretionary	1	0

The lower sandstone exposed in the above section appears to be the same as that exposed in the SE. ¼ NE. ¼ sec. 27. The bed capping the conical butte is well exposed in a bluff a quarter of a mile north

and may be traced westward to the SW. ¼ SE. ¼ sec. 22, where its base is at an altitude of 996 feet. In the SE. ¼ SW. ¼ sec. 23, the base of the same bed is exposed at an altitude of 966 feet, or 19 feet lower than the altitude of the same horizon in the conical butte. Five hundred feet farther northeast the base of this sandstone lies at an altitude of 954 feet. There appears to be a pronounced dip toward the northeast at this locality. One thousand feet farther north, however, the same bed lies at an altitude of 964 feet, indicating a slight reversal of dip. Near the south line of the NE. ¼ sec. 23 the base of a lower sandstone bed, which probably represents the lower bed exposed in the conical butte, lies at an altitude of 947 feet. In the road 500 feet south of the east quarter corner of sec. 23 the base of a sandstone bed, which apparently should be correlated with that capping the conical butte, lies at an altitude of 959 feet. This bed is rather doubtfully traced to the SW. ¼ SW. ¼ sec. 24, where the altitude of its base is 966 feet. The bed can be traced for more than half a mile southward, and in the NW. ¼ SW. ¼ sec. 25 its base lies at an altitude of 982 feet. The sandstone bed that caps the isolated butte a quarter of a mile to the northwest, just east of the road, lies at an altitude of only 962 feet, but the bed here may have settled from a former higher position. In the SW. ¼ SE. ¼ sec. 25 the base of what appears to be the same bed is exposed at an altitude of 980 feet. In the SW. ¼ NE. ¼ sec. 36 the base of a sandstone bed that lies stratigraphically lower than the bed just described is exposed at an altitude of 956 feet. This bed may represent the lower sandstone exposed in the conical butte in the NW. ¼ sec. 26. In the NW. ¼ SE. ¼ sec. 36 the same horizon is exposed at an altitude of 960 feet. At this locality the following section was measured:

Section of rocks exposed in the NW. ¼ SE. ¼ sec. 36, T. 4 S., R. 9 W.

	Feet.
Sandstone, white, containing in certain thin calcareous beds dark concretions about the size of buckshot; altitude of base, 960 feet	32
Shale, red	8
Sandstone, white, with concretions similar to those in the sandstone above	6
Sandstone and shale interbedded	4
Shale, weathering gray; a little below its middle a bed of concretionary conglomerate and at its base a second bed; altitude of base, 935 feet	11
Shale, red, containing numerous clay-limestone concretions with pitted surfaces	20
Sandstone and shale interbedded, the sandstone white and very fine grained, the shale red	10+

The beds of concretionary conglomerate noted in the above section appear to be represented half a mile northwest of this locality, in a small knoll in the SE. ¼ NW. ¼ sec. 36. Beds of concretionary conglomerate in red shale, which contains enormous amounts of rough-

surfaced clay-limestone concretions, were noted in the SW. ¼ NW. ¼ sec. 36. These conglomerate beds are probably somewhat below those just described. Associated with them are fragments of the bones of reptiles, together with sharks' teeth. (See pp. 25–26.)

In the SE. ¼ SE. ¼ sec. 26 there is exposed a thin bed of sandstone and concretionary conglomerate overlying red shale and forming a pronounced ledge. The base of the bed is at an altitude of 919 feet. It appears to be the same bed that is exposed across the creek, half a mile farther west. It is probably, also, at about the same horizon as the conglomerate beds exposed in the knoll in the SE. ¼ NW. ¼ sec. 36. Thirty-six feet below the base of this bed, and 300 feet north of the quarter corner on the south side of sec. 26, there is exposed in the creek bed the base of a bed of white sandstone 15 feet thick, the altitude of the base of which is 883 feet. About 1,600 feet farther south, on the east bank of the creek, the same bed is poorly exposed, its base being at an altitude of about 889 feet. The bed can be traced southward across the section, rising gently in that direction to the steep hill crossed by the road on the south line of sec. 35, where its base lies at an altitude of 904 feet. This bed forms a prominent bluff north of the township-line road, in sec. 34, where its outcrop is practically horizontal for about a mile and its base is approximately 900 feet above sea level. At its base in most places there is a bed of concretionary conglomerate, which may represent the lowest bed in the SE. ¼ sec. 33.

The sandstone bed exposed in the road 1,500 feet south of the northeast corner of sec. 23 is probably higher stratigraphically than the other beds noted in that section, the altitude of its base being 977 feet. Exposures of what appear to be four different beds of sandstone occur in the vicinity of Hastings, in secs. 1, 2, 11, and 12; but, so far as could be determined, the beds are practically horizontal. The lowest of the beds may possibly be the one exposed in secs. 6 and 7, T. 4 S., R. 8 W., and if the outcrops are properly correlated the altitudes taken on its base seem to show a slight dip to the north in these sections.

Since the field work for this report was completed a well has been drilled in the SE. ¼ SW. ¼ sec. 1, T. 4 S., R. 9 W., near the town of Hastings, by the West Virginia Petroleum Co. The well reached a depth of 2,185 feet without encountering either oil or gas in commercial quantity. For the complete log of the well see page 29.

In the southeast quarter of this township there is a gradual dip toward the north or northeast, which is apparent from the outcrop of sandstone that can be traced along the east side of the valley that crosses sec. 35 from north to south and may also be noted in the decrease of elevation from southwest to northeast in the sandstone ledge whose outcrop crosses sec. 34 in that direction. From the

sandstone butte in the NW. ¼ NW. ¼ sec. 26 a pronounced dip to the northeast may be observed in the sandstone that caps the butte and outcrops along the bluff north of it.

In the southern part of sec. 23 there is a slight reversal of dip, as noted along the sandstone outcrops, which appears to indicate a narrow and shallow syncline at this locality. The structure of the beds northeast of this place could not be determined, but there is some indication in the SW. ¼ sec. 24 that a sandstone exposed along the bed of a small gulch dips to the north or northeast. These outcrops are not shown on Plate V. If the sandstone beds exposed in secs. 24, 25, and 36 have been correctly correlated, the beds in these sections also dip to the north or northeast, but not so obviously as in the places mentioned above.

Altitudes taken on the outcrops of conglomerate in secs. 8, 9, and 16 indicate a rather pronounced dip to the southwest. Positive correlations between the conglomerate bed exposed on the north side of the valley that crosses secs. 16 and 17 from east to west with the sandstones exposed on the south side of the valley could not be made, and it is therefore impossible to determine whether or not the beds in that locality dip to the southwest.

In the SW. ¼ sec. 7 there is a pronounced dip to the northeast, and this dip suggests that the valley in secs. 16 and 17 lies along the axis of a syncline that trends to the northwest, crossing the middle of sec. 7. If this suggestion is correct the beds on the south side of the valley in sec. 17 dip to the northeast. The strata in the vicinity of Hastings appear to be horizontal, but the exposures are poor and positive determinations could not be made.

T. 5 S., R. 9 W. (FRACTIONAL).

This township lies along the great bend of Red River. Most of its western part, south of Whisky Creek, which crosses secs. 4, 5, and 6 from west to east, is covered by sand dunes. The high bluffs of Red River, along the east township line, present some of the best rock outcrops in the region.

The two outcrops of sandstone in the N. ½ sec. 6 have been already mentioned in the description of T. 4 S., R. 9 W., and probably represent the same bed that is exposed in sec. 31 of that township. Just south of the north quarter corner of sec. 2 there is exposed in the bluff of Red River the following section:

Section of rocks exposed south of the north quarter corner of sec. 2, T. 5 S., R. 9 W.

	Feet.
Sandstone, white, having at its base a thin bed of concretionary conglomerate; altitude of base, 904 feet	12
Shale, red, having about 5 feet above its base a few inches of concretionary conglomerate	30
Sandstone, white, massive	19
Covered to river level	8

The upper bed is the one that was traced along the east bank of the stream in sec. 35, T. 4 S., R. 9 W., as described under that township. The lowest bed of the section may be traced southeastward for half a mile along the bank of Red River. It is concealed for a short distance near the east line of sec. 2, but outcrops in the river bluff in the SW. ¼ sec. 1, at Byers Ferry and farther southeast. In the NE. ¼ NW. ¼ sec. 12 this sandstone and the overlying shale is exposed, the section being as follows:

Section of rocks exposed in river bluff in NE. ¼ NW. ¼ sec. 12, T. 5 S., R. 9 W.

	Ft.	in.
Shale, red.		
Conglomerate, concretionary		2
Shale, red	6	0
Conglomerate, concretionary		3
Shale, red	7	6
Sandstone, white; altitude of base, 854 feet	19	0
Covered to river level	13	6

The sandstone bed noted in the above section is exposed on the opposite side of the valley of a small stream tributary to Red River. In the SW. ¼ NE. ¼ sec. 12 the rock section is as follows:

Section of rocks exposed in bluff of Red River in the SW. ¼ NE. ¼ sec. 12, T. 5 S., R. 9 W.

	Feet.
Sandstone; altitude of base, 920 feet	14
Shale, red	33
Sandstone, white; base interbedded with thin beds of concretionary conglomerate	3+
Shale	10
Sandstone, white; altitude of base, 859 feet	15
Shale, red, to river level	12

In tracing these beds southward along the river bluff the sandstone and conglomerate horizon becomes more conspicuous, and at the point in the NW. ¼ SE. ¼ sec. 12 the rock section is as follows:

Section of rocks exposed in the NW. ¼ SE. ¼ sec. 12, T. 5 S., R. 9 W.

	Feet.
Shale, red, containing great numbers of small rough-surfaced clay-limestone concretions	10+
Sandstone, white	1
Shale, red	2
Sandstone, white	3
Shale, red	4
Sandstone, white; top ripple marked; altitude of base, 893 feet	10
Conglomerate, concretionary	1
Shale, red; top unevenly eroded before the deposition of the conglomerate; lower part covered to river level	50

The lower sandstone bed of the above section can be traced a quarter of a mile farther south, to the point in the SE. ¼ SE. ¼ of the section, where the altitude of the base is 912 feet. The same bed is exposed in the high river bluff in the NE. ¼ SE. ¼ sec. 13, where the rock section is as follows:

Section of rocks exposed in river bluff in the NE. ¼ SE. ¼ sec. 13, T. 5 S., R. 9 W.

	Feet.
Sandstone, white, containing near its middle about a foot of red shale; base is interbedded with concretionary conglomerate; altitude of base, 944 feet	8
Shale	14
Sandstone, white; altitude of base, 919 feet	11
Shale, red; basal 3 feet containing many small rough-surfaced clay-limestone concretions	24
Sandstone, white	5
Shale, red	13
Shale, purplish gray, containing many large rough-surfaced clay-limestone concretions	5
Shale, red, containing a 10-inch bed of white sandstone 5 feet above its base	13
Sandstone, white, to river flat	2

The beds described in the above section can be traced for a quarter of a mile farther south, where the altitude of the base of the highest sandstone is 938 feet. From this place the outcrop of the highest bed swings to the southeast. The next lower bed can be traced along the bluff to the south, in which direction the beds dip at the rate of 200 feet to the mile. In the SE. ¼ SE. ¼ sec. 13 the altitude at the base of the sandstone is 881 feet. Across the valley to the south, in the NE. ¼ NE. ¼ sec. 24, the same bed is exposed a little above the river flat, where the altitude of its base is 853 feet. In the SW. ¼ NE. ¼ sec. 24 there is an outcrop of a higher bed, which probably represents the highest sandstone exposed in the bluff in sec. 13. The base of the sandstone here lies at an altitude of 875 feet. The lower bed is concealed by talus at the foot of the slope.

In the SW. ¼ SE. ¼ sec. 24 two beds of sandstone separated by red shale are poorly exposed. The upper bed should possibly be correlated with the bed last described, in the northwest quarter of the same section. The altitude of its base here is 892 feet. Thirteen hundred feet east and a little north of this locality, at the east end of a prominent bluff, the following section is exposed:

Section of rocks exposed in the SE. ¼ SE. ¼ sec. 24, T. 5 S., R. 9 W.

	Feet.
Sandstone, white	8
Concealed, probably shale	4
Sandstone, white; altitude of base, 915 feet	15
Shale, gray	6
Shale, red	6
Sandstone, white	3
Shale, red, containing clay-limestone concretions	11

The sandstone and shale beds at the top of this section may represent the highest sandstone exposed in sec. 12 of this township, but there is little on which to base such a correlation except the relation of the bed to the lower sandstone exposed in the river bluff to the west, which on its lithologic character is correlated with the highest

sandstone in sec. 13 or the middle sandstone exposed in sec. 12. From its exposure in the river bluff on the south line of sec. 24 this bed may be traced southward into sec. 25, in the NW. ¼ NE. ¼ of which its base lies at an altitude of 890 feet. Six hundred feet to the south the same horizon is at an altitude of 879 feet and in the SW. ¼ NE. ¼ sec. 25 the rock section is as follows:

Section of rocks exposed in the SW. ¼ NE. ¼ sec. 25, T. 5 S., R. 9 W.

	Feet.
Sandstone; altitude of base, 917 feet	20
Covered, shale (?)	33
Sandstone	10

The upper sandstone in the above section should probably be correlated with that capping the butte in the SE. ¼ SE. ¼ sec. 24, which is correlated with the highest sandstone in sec. 12. The lower bed is the same that has thus far been traced across sec. 25. One-third of a mile farther south, in the SE. ¼ sec. 25, the base of this bed lies at an altitude of about 895 feet. There appears to be a reversal of dip in this locality, the beds here dipping to the north. In the river bluff in the NE. ¼ sec. 36, two beds of sandstone are poorly exposed, the altitude of the base of the upper bed being 889 feet. This bed should probably be correlated with the bed in sec. 25, last described. It can be traced rather uncertainly for a quarter of a mile farther south, where the altitude of its base is 882 feet. Across the valley to the south the base of a sandstone that probably represents the same bed lies at an altitude of 887 feet.

A bed of sandstone about 19 feet thick is exposed a little above water level in the north bank of Red River, in sec. 2 of this township. The same bed is exposed in the vicinity of the Byers Ferry, in the SW. ¼ SW. ¼ sec. 1, and may be traced southeastward across the south line of this section. Throughout this distance of almost a mile and a half the bed is practically horizontal. Its outcrop may be traced southward across sec. 12, where the bed dips northward at the rate of about 40 feet to the mile. The northerly dip continues to the middle of the east side of sec. 13, where the base of the bed stands 919 feet above sea level, or about 70 feet above its altitude in sec. 1. The outcrop at the middle of the east side of sec. 13 is at the crest of the anticline. From this point the bed dips to the south, the dip increasing in the SE. ¼ SE. ¼ sec. 13 to 40 feet in a quarter of a mile. The outcrop of the same bed may be traced for about a quarter of a mile southward into sec. 24, the dip to the south decreasing. In the SW. ¼ NE. ¼ sec. 24 there appears to be a slight reversal of dip, the beds rising toward the south. The sandstone bed thus far described is not exposed south of this point.

In sec. 25 a sandstone bed that lies 15 feet above that just described is exposed for three-quarters of a mile. Its outcrop is practically horizontal, but it forms a slight syncline in the SW. ¼ NE. ¼ sec. 25.

The same bed is exposed along the north side of a valley which crosses sec. 36 from east to west, and its outcrop may be traced east into sec. 31 of the township to the east. The beds in this vicinity appear to be horizontal.

T. 6 S., R. 9 W. (FRACTIONAL).

No rock outcrops are found in this township, which is adjacent to Red River and contains only 4 square miles, practically all of which is river bottom.

PART OF T. 4 S., R. 8 W.

Only that part of T. 4 S., R. 8 W., lying south of the line of the Chicago, Rock Island & Pacific Railway was examined in detail. A few exposures in secs. 6 and 7, which have a bearing on the structure of T. 4 S., R. 9 W., were examined, and a description of them is included in the description of that township.

Good rock exposures are found along Beaver Creek and its tributaries, which drain practically the entire township. Only two sandstone beds are represented in the part of the township south of the railroad. These are separated by about 25 feet of shale. The southernmost outcrop of the upper sandstone is found on the point in the SW. ¼ SE. ¼ sec. 34. The stratigraphic section at this place is as follows:

Section of rocks exposed in the SW. ¼ SE. ¼ sec. 34, T. 4 S., R. 8 W.

	Feet.
Sandstone, greenish yellow; contains near base a variable thickness of conglomerate, the pebbles of which are shale; elevation of base, 934 feet above sea level	6
Shale, red; poorly exposed; thickness about	4

The strata evidently rise toward the south, for the lower sandstone is exposed at an altitude of 927 feet above sea level in a "wash" a quarter of a mile to the southwest, in the NE. ¼ NW. ¼ sec. 3, T. 5 S., R. 8 W.

The bed can be traced northwestward from the locality of the measured section given above to the small knob just west of the east quarter corner of sec. 33, where the altitude of its base is 923 feet, or 11 feet lower than the same horizon three-quarters of a mile to the southeast. At this place the stratigraphic section is as follows:

Section of rocks exposed in SE. ¼ NE. ¼ sec. 33, T. 4 S., R. 8 W.

	Feet.
Sandstone, in part dirty yellow and in part gray and calcareous, thin bedded and cross-bedded; in places the calcareous gray sandstone is spotted with dark-gray manganese oxide; elevation of base, 923 feet above sea level	12
Concealed; probably red shale	15
Shale, red to grayish red; contains clay-limestone concretions; exposed thickness	10
Sandstone, bluish white, sugary; complete thickness not exposed.	2

The lower sandstone forms the surface rock over the S. ½ NE. ¼ sec. 33. It can be traced eastward into the NE. ¼ SW. ¼ sec. 34, where its top is at an altitude of 912 feet. Near the creek, on the east side of sec. 33, the elevation of the same horizon is 877 feet above sea level. About a quarter of a mile west of this point it is 885 feet, and near the center of the east half of the section it is 893 feet above sea level.

On the east side of the "draw" that crosses the south boundary of sec. 33 and about a third of a mile east of the southwest corner, 4½ feet of the lower sandstone is exposed at an elevation of 918 feet above sea level and overlies more than 7 feet of light-red shale, which contains numerous clay-limestone concretions.

About a quarter of a mile north of the southwest corner of the same section, in the north side of a "draw" and just east of the road, this same sandstone outcrops, its base lying 909 feet above sea level. This bed rises both to the southwest and northwest. In the road, about a quarter of a mile west of the southeast corner of sec. 32, its altitude is 929 feet, and still farther west, in the road and just south of it, near the south quarter corner of the section, it is 934 feet above sea level. In the "draw," running southeastward across the N. ½ sec. 32, the only exposures of the lower sandstone are found on the east side of the NE. ¼ NW. ¼ sec. 32, where the elevation is 944 feet above sea level.

The upper sandstone is exposed at the west side of the road about an eighth of a mile south of the northeast corner of sec. 32, where it measures 8 to 10 feet in thickness and overlies red shale. Its base is at an altitude of 950 feet. A short distance to the west the outcrop of this bed becomes obscure, but to the northeast it is readily followed for about half a mile to a point beyond which it is concealed as far as Beaver Creek, where it is again exposed in the SE. ¼ sec. 28. At this place the section is as follows:

Section of rocks exposed in west bank of Beaver Creek, in SE. ¼ sec. 28, T. 4 S., R. 8 W.

	Feet.
Sandstone; poorly exposed	7
Alternating beds of concretionary conglomerate and sandstone, cross-bedded; elevation of base, 909 feet above sea level	3
Shale, red; contains a few clay-limestone concretions	15

The outcrop can be traced northwestward across the section. About 800 feet northwest of the last locality the altitude of the base of the bed is 906 feet. In the NE. ¼ NW. ¼ sec. 28 slumping has greatly affected the outcrops, but at one place the probable base of the sandstone is exposed at an elevation of 923 feet above sea level. In the road a short distance south of the northeast corner of sec. 29 the sandstone and shale contact is well exposed at an elevation of 925 feet.

Along the valley that crosses sec. 29 from southwest to northeast there is a continuous outcrop of the upper sandstone, but at only a few places is its base well exposed. One of these is on the northwest side of the stream bed and in the SW. ¼ NE. ¼ sec. 29, where the contact of the shale and sandstone is at an elevation of 928 feet. A second exposure is in the stream bed 1,000 feet east of the west quarter corner, where the altitude of the sandstone base is 953 feet, and a third is in the deep gully near the center of the SW. ¼ sec. 29, where the shale-sandstone contact lies at an elevation of 964 feet. The dip in this part of the section is evidently to the northeast.

In the road a short distance west of the northeast corner of sec. 30 the sandstone base lies about 973 feet above sea level, and from this exposure the strata dip to the north and east. In the NE. ¼ SE. ¼ sec. 19, just west of the road, the elevation of the sandstone base is 955 feet above sea level, and 1,300 feet to the northeast, near the center of the N. ½ SW. ¼ sec. 20, the elevation, at a poor exposure, is about 948 feet above sea level. In the SE. ¼ NW. ¼ sec. 20, at another poor exposure, the elevation is about 950 feet above sea level.

The sandstone, about 26 feet thick, in the railroad cut a short distance northeast of the exposure last named, is probably not in place, but a short distance southeast of the cut 20 to 30 feet of red shale is exposed and is overlain by the same sandstone, practically in place. The contact between the two is 935 feet above sea level. North of the railroad and farther down the gulch near the head of which this exposure is found, some light-gray sugary sandstone was observed, which probably represents the lower sandstone, although its distance below the higher and thicker bed was not measured.

In the NW. ¼ SE. ¼ sec. 20 the upper bed is represented by a few feet of sandstone overlying red shale, the elevation of its base being 942 feet above sea level.

In the SE. ¼ NE. ¼ sec. 19 there is a poor exposure of the upper sandstone, the base of which lies about 945 feet above sea level. At the head of the valley, in the SE. ¼ SW. ¼ sec. 19, red shale is exposed to an elevation of 955 feet above sea level, and stratigraphically higher, probably at the horizon of the upper sandstone, there appears to be a sandstone exposed a short distance to the west, in the west branch of the valley. At the east-west quarter-line fence, down this valley to the north, the base of this sandstone lies 938 feet above sea level. Between this last exposure and an 11-foot sandstone bed that outcrops in the road a short distance south of the northwest corner of sec. 19 and probably represents the upper sandstone there are no exposures. No accurate elevation on the outcrop in the road was determined.

All the evidence gathered in this township indicates a strike which in general parallels the valley of Beaver Creek and also the large,

broad tributary valley on the west in secs. 18 and 17, toward which the strata dip as if these valleys lay in a syncline. The axis of the anticline toward which all the strata rise can not be determined from exposures in this township alone, but these exposures in conjunction with those in the townships to the west and south indicate that the axis of an anticline lies in the eastern parts of secs. 30 and 31.

South of the railroad and west of Beaver Creek in this township only two beds of sandstone are exposed. The upper bed is the more prominent, being 25 to 30 feet thick. It appears to be the same bed that is exposed across the Beaver Creek-Red River divide, in the SW. ¼ SW. ¼ sec. 31 of this township and in the NE. ¼ sec. 6 of the township to the south. This correlation is, however, somewhat uncertain, for the exposures are poor. If it is correct, the crest of the dome probably lies somewhere in the northeastern part of sec. 31 and the southeastern part of sec. 30. The crest may also extend into the NE. ¼ sec. 32. From the crest of this dome a projection extends north across sec. 30 into the SE. ¼ sec. 19. The structure is irregular, a second projection appearing to extend across the SE. ¼ sec. 29, as represented on the map (Pl. V) by the structure contours. The dip to the southwest in sec. 31 is probably gradual, although, because of the lack of exposures, the structure at this locality is more or less a matter of conjecture.

A hurried examination was made of a sandstone outcrop in secs. 6 and 7 of this township about 2 miles east of Hastings. If the exposures are correctly correlated there appears to be a rather general dip to the north in this locality. If a bed outcropping in the northern part of sec. 7 is the same as that exposed in the SE. ¼ sec. 12 of the township to the west, there is a dip to the south or southwest in sec. 7, T. 4 S., R. 8 W. These observations would indicate a very gentle anticlinal roll trending east and west across the northern part of sec. 7. This structure was not noted in the outcrops near Hastings and is probably of very minor importance.

T. 5 S., R. 8 W.

This township is bounded on the east by the valley of Beaver Creek, from which the surface rises westward to the Red River–Beaver Creek divide, which crosses the township from north to south a little west of its middle. The western part of the township is drained by small tributaries of Red River.

Along the road a short distance north of the west quarter corner of sec. 4 there is exposed a bed of sandstone, which probably represents the upper of the two beds exposed in the township to the north. The altitude of its base is 961 feet. The same bed was encountered in a well dug at the southwest corner of sec. 4, which passed through this sandstone into the underlying shale at about 970 feet above sea

level. In another well, in the SW. ¼ NW. ¼ sec. 9, at least 19 feet of sandstone representing this bed was encountered, the base lying 981 feet above sea level. From this well the bed dips northeastward, for in a shallow well in the SE. ¼ SE. ¼ sec. 4, 8 feet of sandstone representing the same bed was found, the base lying 931 feet above sea level. A quarter of a mile southeast of the well this sandstone, which overlies 20 feet of red shale, is exposed at the head of a small gully just north of the road in the SW. ¼ SW. ¼ sec. 3, where the sandstone base lies 934 feet above sea level. In the valley that crosses the N. ½ S. ½ sec. 3 the sandstone has a fairly continuous outcrop, but the exposures are so poor that the elevations of the base can not be accurately determined. In the NE. ¼ SW. ¼ sec. 3 the underlying shale is exposed to an elevation of 920 feet above sea level. North of this valley there is a marked rise of the strata to the northwest, for in the NE. ¼ NW. ¼ sec. 3 a sandstone which represents the lower bed mapped in the township to the north, and which is approximately 30 feet lower than the bed just described, is exposed at an elevation of 927 feet above sea level.

In the NE. ¼ NE. ¼ sec. 10 the upper of the two sandstone beds described above is exposed south of the road, where the base of the sandstone lies at an elevation of 913 feet above sea level.

In the SW. ¼ SW. ¼ sec. 2 the upper sandstone outcrops for some distance along the bed of the gully, but the rock is apparently not in place, having slumped from a higher position. Just east of the center of sec. 11 the base of the same sandstone is found in a poor exposure at an elevation of 901 feet. In the point near the center of the SE. ¼ of the same section the base of the bed lies at an altitude of 911 feet, and at the abrupt rise in the road a quarter of a mile west of the southeast corner of the section its altitude is 917 feet above sea level. Here the following section was measured:

Section of rocks exposed in road a quarter of a mile west of the southeast corner of sec. 11, T. 5 S., R. 8 W.

	Feet.
Sandstone, light yellowish to greenish gray, weathers dark gray, cross-bedded and in part thin bedded, very friable except where weathered; elevation of base, 917 feet above sea level	15+
Shale, red; thickness probably much greater than that given	10+

The strata rise toward the west, for in the field just northeast of the south quarter corner of sec. 11 the elevation of the sandstone base is 924 feet, and in a dug well in the NE. ¼ NE. ¼ sec. 15 it is 935 feet. In this well 14 feet of sandstone was penetrated before the underlying shale was reached. In a well drilled in the SW. ¼ SW. ¼ sec. 10 the base of a sandstone 10 feet thick, which may represent the same bed, is reported to lie at a depth of 28 feet, the altitude of this base being 960 feet.

The upper sandstone forms a low escarpment along the west side of the NW. ¼ sec. 13. The altitude of the base of the bed at the north end of this escarpment is 898 feet, and at the south end it is 905 feet. The sandstone outcrop may be traced into the SE. ¼ sec. 14, where at one place its base lies 903 feet above sea level. To the northwest across the section the outcrop is obscure.

Just southeast of the northwest corner of sec. 24 an east-west escarpment is capped by this same sandstone, the base of which lies 912 feet above sea level. At the east end of this escarpment, in which the bed dips to the east, the altitude of its base is 901 feet, and in the rather poor exposures in the NE. ¼ NE. ¼ sec. 24 is 888 feet. Twenty-eight feet below the upper sandstone at this place there is a lower sandstone which may represent the lower sandstone in the township to the north. Another poor exposure of the upper sandstone is in the SW. ¼ NE. ¼ sec. 24, where its base lies 895 feet above sea level.

The beds rise toward the west, for in the butte in the NE. ¼ sec. 23, where the following section was measured, the base of the upper sandstone lies 917 feet above sea level.

Section of rocks exposed near north side of NE. ¼ sec. 23, T. 5 S., R. 8 W.

	Feet.
Sandstone, greenish gray, weathering yellowish gray; cross-bedded; in places calcareous and in other places practically unconsolidated; elevation, 917 feet above sea level; thickness exposed.	11
Shale, red	33
Sandstone, light bluish gray, thin bedded; thickness variable	3±
Shale, red	2+

Here the base of the lower sandstone is 36 feet below the upper. The top of the bluff extending across the N. ½ sec. 23 is probably capped by the upper sandstone, but no exposures are found in this part of the section. At the west side of the road a few hundred feet north of the southeast corner of sec. 15 the following section was measured:

Section of rocks exposed near the southwest corner of sec. 15, T. 5 S., R. 8 W.

	Ft.	in.
Sandstone; poorly exposed; individual beds were not measured; lower part greenish yellow, and one place where a few feet were well exposed bed appeared to be practically unconsolidated; upper part gray and calcareous, weathering to a dark gray	30+	
Conglomerate, concretionary; largest pebbles 2 inches in diameter; elevation, 942 feet above sea level; thickness variable		3±
Shale, red	4+	

The base of the sandstone member at this place is 942 feet above sea level, or about 30 feet higher than the same horizon a mile farther east.

In the valley to the south, in secs. 22, 25, and 26, the upper sandstone, which is easily traced over the region to the northwest, is of no value as a horizon marker. In fact, although the exposures are good, the bed can not be identified with certainty.

On the south side of the valley, in the S. ½ NW. ¼ sec. 25, there is exposed for two-fifths of a mile a thick bed of sandstone. One-eighth of a mile east of the west line of the section the following stratigraphic section was measured:

Section of rocks exposed in SW. ¼ NW. ¼ sec. 25, T. 5 S., R. 8 W.

	Feet.
Surface of grassy slope covered with dark-gray fragments of sandstone	16
Sandstone, light dirty yellow, even bedded; contains horizontally elongated concretion-like forms, which weather dark gray; elevation of base, 914 feet above sea level	12
Shale, red	20+

To the east the shale that underlies the sandstone is sandy and at the eastern end of the exposure the section is as follows, the top sandstone being the same bed noted in the preceding section:

Section of rocks exposed in SE. ¼ NE. ¼ sec. 25, T. 5 S., R. 8 W.

	Feet.
Sandstone, yellowish gray; elevation of base, 907 feet above sea level	3+
Shale, red	5
Sandstone, light greenish gray, friable; upper 4 feet interbedded with red sandy shale	10
Shale, red	27
Sandstone, light greenish to light bluish, interbedded with red sandy shale; sandstone is cross-bedded and friable; thickness variable	3+
Sandstone, light greenish to light bluish, cross-bedded, friable	4

The elevation of the base of the top sandstone is 907 feet above sea level, indicating a fall of 7 feet in a quarter of a mile from the exposure previously mentioned.

To the west, in sec. 26, the beds, as shown in the following section, differ so widely from those in sec. 25 that it is impossible to make correlations between them:

Section of rocks exposed in the SE. ¼ NE. ¼ sec. 26, T. 5 S., R. 8 W.

	Ft.	in.
Slope covered with dark gray, thin bedded and cross-bedded sandstone.		
Sandstone, greenish to yellowish gray, thin bedded and even bedded	3	0
Shale, red and greenish gray, apparently mottled with these colors	21	0
Shale, yellowish green, sandy	3	0
Sandstone, light greenish gray to yellowish gray; weathers into dark-gray roundish, concretion-like forms	6	6

The base of the upper sandstone in this section lies at an elevation of 906 feet above sea level. The lower sandstone can be traced for

three-quarters of a mile along the north side of the valley and for one-third of a mile along the south side and appears to be practically level. This bed is exposed on the south side of the valley just west of the road between secs. 25 and 26. The base of the bed is not exposed, lying a little below the altitude of 879 feet, taken on the base of the ledge. A few hundred feet east of the road, on the north side of the valley, the following section was measured:

Section of rocks exposed in west-central part of the NW. ¼ sec. 25, T. 5 S., R. 8 W.

	Feet.
Sandstone, greenish gray to yellowish gray, thin bedded and cross-bedded, poorly exposed	12
Shale, red	3+

The shale-sandstone contact is 880 feet above sea level. To the west, in sec. 26, on the north side of the valley near the point where it turns to the northwest, the base is 880 feet above sea level, and in the stream bed a short distance southeast of the north quarter corner of sec. 26 the lowest part of the sandstone is exposed at an altitude of 883 feet above sea level. On the south side of the valley, at the lower end of the large wash in the SW. ¼ NE. ¼ sec. 26, the top of a bed that probably represents this sandstone is exposed at an elevation of 883 feet. As the exposures are poor but little can be inferred from the above observations other than that the strata at this locality are practically horizontal.

Just west of the road, near the east quarter corner of sec. 26, a bed of yellowish-gray and greenish-gray even-bedded sandstone 16 feet thick is exposed, the base of which lies at an altitude of 899 feet. It should probably be correlated with the thick upper sandstone in the section to the east, but its position at this locality can be accounted for only by extensive slumping or by faulting.

A fault running northeastward from the east quarter corner of sec. 26, with downthrow on the north side, would bring the beds into their present relations. So far as observed faulting is not common in this region of soft rock beds and gentle folding. Its occurrence in some places, as in that here under discussion, is difficult to determine because of the absence of good exposures.

In the NW. ¼ SE. ¼ sec. 26 there are two gullies which run northward, separated by a narrow divide. On the east side of the east gully the section is practically the same as in that given on page 87, the upper sandstone measuring about 10 feet in thickness. As exposed the bed is a yellowish and rather massive sandstone. At the head of the gully this bed is abruptly terminated and in the west side of the gully its place is taken by a variable bed, about 2 feet thick, of bluish-white sugary sandstone, not at all like the thick ledge on the east side. This sugary sandstone is underlain by red shale and overlain by 4 to 6 feet of similar rock, and the beds are well exposed and apparently horizontal. The divide between the two

gullies is covered by a thin deposit of terrace gravel and there are no exposures on it. In the west gully, at an elevation 12 feet below the thick-bedded sandstone in the east gully, there is a sandstone that differs greatly in character from this bed. It is a bluish-white, highly cross-bedded and thin-bedded, more or less sugary rock from 12 to 15 feet thick. The peculiar relations of these beds, as noted at a place half a mile farther east, may be due either to the slumping of large surficial masses or to true faulting. Correlations have not been attempted in this locality, as no easily recognizable beds are at any place present and the exposures at each place show only a few feet of strata; nor can definite correlations be made between the exposures in this valley and those to the west and north.

A sandstone that seems to be a different bed from any exposed to the east and south outcrops a short distance west of the north quarter corner of sec. 26, where the base of the exposure lies at an elevation of 914 feet above sea level. This bed appears to rise toward the west, and in a cut bank in the NW. ¼ NW. ¼ sec. 26 its base is exposed at an elevation of 920 feet above sea level. On the north side of the valley, in the SW. ¼ SW. ¼ sec. 23, the elevation is the same, the bed appearing to lie horizontal as far as the exposure in the cut bank in the SE. ¼ SE. ¼ sec. 22. Southwest of this point the sandstone rises, and in a gully in the north side of the NE. ¼ sec. 27 its elevation is 933 feet. The following section was measured at this place:

Section of rocks exposed in small valley at north side of the NE. ¼ sec. 27, T. 5 S., R. 8 W.

	Feet.
Surface slope covered with loose, yellowish-gray sandstone; elevation of base, 933 feet above sea level	3
Concealed	4
Shale, red	6

North of the schoolhouse, near the south quarter corner of sec. 22, the section exposed is as follows:

Section of rocks exposed north of south quarter corner of sec. 22, T. 5 S., R. 8 W.

	Feet.
Sandstone, yellowish gray; elevation of base, 939 feet above sea level	5+
Shale, red	12+

From this outcrop the bed dips toward the west, and just south of the road where a draw leads back into sec. 27, a quarter of a mile east of the northwest corner, the base is exposed at an elevation of 930 feet above sea level. The section here is as follows:

Section of rocks exposed in small valley on north side of the NW. ¼ sec. 27, T. 5 S., R. 8 W.

	Feet.
Sandstone, gray, weathers yellowish gray to dark gray, in places banded, calcareous; thickness exposed	10
Shale, drab, lenticular; maximum thickness	2
Sandstone, yellowish gray, lenticular; elevation of base, 930 feet above sea level; maximum thickness	2
Shale, red	6

The outcrop of the sandstone can be traced down the "draw" to the larger valley and thence westward into sec. 21, the bed rising in this direction. About one-fifth of a mile west of the southeast corner of sec. 21 the base is exposed at 944 feet above sea level. The section at this place measures as follows:

Section of rocks exposed in SE. ¼ SE. ¼ sec. 21, T. 5 S., R. 8 W.

	Feet.
Sandstone, greenish gray weathering yellowish gray, calcareous, thin bedded; weathers into roundish, concretion-like forms; elevation of base, 944 feet above sea level	10
Shale, red	1

In the road near the east quarter corner of sec. 21 the following section is exposed:

Section of rocks exposed at east quarter corner of sec. 21, T. 5 S., R. 8 W.

	Feet.
Sandstone, light greenish gray, weathering yellowish gray; elevation at base, 953 feet above sea level	3+
Shale, red, contains ferruginous clay-limestone concretions	12+

North of this outcrop the sandstone is not easily followed, but the bed exposed on the west side of the valley, one-eighth of a mile west of the northeast corner of sec. 21, is probably the same bed. The base of the bed is not exposed at this locality but the base of the exposure lies 950 feet above sea level.

In the valley that crosses secs. 35 and 36 there are outcrops of three different sandstone beds. The highest bed is poorly exposed in the SE. ¼ SW. ¼ sec. 35, where its base is probably a little lower than the base of the ledge, which is 923 feet above sea level.

The middle and lowest sandstone beds are exposed in the southeast corner of sec. 35, where the section is as follows:

Section of rocks exposed in SE. ¼ SE. ¼ sec. 35, T. 5 S., R. 8 W.

	Feet.
Sandstone, greenish gray; poorly exposed; elevation of base, 891 feet above sea level	14+
Shale, red	9
Sandstone, greenish gray; poorly exposed but appears massive; elevation at base of exposure, 872 feet above sea level	10+

The base of the higher sandstone lies at an altitude of 891 feet at this exposure and at the same elevation a quarter of a mile farther west in the same section. A quarter of a mile east of the west quarter corner of sec. 35 the base of the same bed lies 899 feet above sea level.

At the locality where the last section was measured the lower sandstone as exposed is 10 feet thick, its base being covered. The base of the ledge stands 872 feet above sea level. The only other place where this lower sandstone was noted is a short distance east of the south quarter corner of sec. 36, where 7 to 9 feet of sandstone is poorly exposed, the base lying at an elevation of 864 feet.

In the NE. ¼ sec. 6, a little west of the road between secs. 5 and 6, the rock exposure is as follows:

Section of rocks exposed in NE. ¼ sec. 6, T. 5 S., R. 8 W.

	Ft.	in.
Sndastone, white, containing concretions about the size of buckshot	5	0
Conglomerate, concretionary; altitude of base, 971 feet		8
Shale, sandy, greenish gray	1	0
Shale, red, containing fragments of bone	22	0
Sandstone, white, breaking in thin slabs	4	0
Shale; base not exposed.		

The outcrop of the sandstone at the top of the above-measured section can not be clearly traced to the northwest. Blocks of sandstone are scattered over the grassy slopes, but no particular horizon can be traced. In the SW. ¼ SW. ¼ sec. 31, T. 4 S., R. 8 W., there is an exposure of 8 feet of white sandstone overlain by 4 feet of red shale, which in turn is overlain by 15 feet of white sandstone. The lower bed in this exposure may correspond to the upper bed in the section measured in the NE. ¼ sec. 6. The bed at this locality appears to be overlain by sandstone. The distance between the 5-foot bed at the top of the section in the NE. ¼ sec. 6, T. 5 S., R. 8 W., and the 4-foot bed near its base is about 23 feet, which corresponds approximately to the distance between the upper and lower sandstones mapped in the valley of Beaver Creek, a short distance to the northeast, in T. 4 S., R. 8 W. It therefore seems possible that the upper bed in the NE. ¼ sec. 6 is the equivalent of the upper sandstone in T. 4 S., R. 8 W., and is the same bed that was noted in the SW. ¼ sec. 31, of that township, which in turn is correlated with the highest bed mapped in sec. 36, T. 4 S., R. 9 W. In the NW. ¼ SW. ¼ sec. 6, T. 5 S., R. 8 W., a 10-foot bed of white sandstone is exposed, and 6 inches below its base is the top of an 8-inch bed of concretionary conglomerate in red shale. The base of the sandstone lies 883 feet above sea level. A little less than half a mile to the southeast there is a bed of white sandstone 7 feet thick, having at its base what appears to be a thin layer of concretionary conglomerate. The base of the sandstone lies at an altitude of 896 feet. This bed may represent the one just described in sec. 6, but the correlation is doubtful. If correct, there is a rise of the beds to the south or southeast. A quarter of a mile east of this locality, near the top of a knoll, the base of a sandstone is exposed at an altitude of 959 feet. On the northeast side of this knoll what appears to be the lower bed of sandstone is exposed, its base lying at an altitude of 924 feet. The bed appears to be in place and to be identical with the bed of white sandstone exposed in the creek bed a short distance farther east. Its base lies 15 feet lower than the base of sandstone exposed in a westward-facing point 1,600 feet to the north, where 12 feet of white sandstone having

at its base a foot of gray and green concretionary conglomerate is underlain by 22 feet of red shale. If this bed should be correlated with the one last described, the beds here dip to the south, or in the opposite direction from that mentioned as probable between the two exposures half a mile farther west. The location is on the north flank of the large dome, the crest of which lies 2 miles farther south, in sec. 18, and a dip to the south in sec. 6 would imply the presence of a minor roll and an accompanying syncline on the flank of the larger anticline. The beds in sec. 6 are not horizontal, but it is impossible to determine exact correlations between beds at different exposures and thus to establish the direction of dip. In the absence of positive information it seems more reasonable to assume that the dip is constant to the north in accord with the major structure. In the NW. ¼ NE. ¼ sec. 7 the base of the sandstone that caps the hill lies at an altitude of 962 feet. The bed appears to be the same as that capping the small knoll to the northwest. A quarter of a mile to the southeast the same bed is exposed, its base being 966 feet above sea level. In the SW. ¼ NE. ¼ sec. 7 a white sandstone several feet thick is exposed, its top being at an altitude of 915 feet. It is overlain by 10 feet of red shale, which contains numerous concretions. Above the red shale is 6 inches of concretionary conglomerate, which is overlain by gray shale. About half a mile farther west, or about 300 feet east of the west quarter corner of sec. 7, there is exposed in a well a bed of sandstone, the base of which lies at an altitude of 926 feet. This bed should perhaps be correlated with that just described, but the nature of the exposures does not permit positive correlation. The bed in the well appears to be the same as the highest bed exposed a little farther west, in the river bluff in the SW. ¼ NE. ¼ sec. 12, T. 5 S., R. 9 W.

This bed forms the prominent ledge that crosses the road a quarter of a mile north of the southwest corner of sec. 7, T. 5 S., R. 8 W. From this place it can be traced eastward along the north rim of the short valley that lies in secs. 7 and 18. In the SW. ¼ SE. ¼ sec. 7, where the outcrop turns to the south, the base of the sandstone lies at an altitude of about 949 feet. Beyond this point the bed can be traced but a short distance. A bed which on the river bluff in sec. 12 of the township to the west lies next below the one just described is also exposed in this valley. Although its exposures are poor, it can be traced around the valley and out to the river bluff in sec. 13, T. 5 S., R. 9 W., where it forms the highest sandstone of the section there exposed. (See p. 79.) This sandstone and the one next below it are exposed at several places in the valleys to the southeast. In the NW. ¼ NW. ¼ sec. 19 both beds are exposed, the base of the upper sandstone lying at an altitude of 897 feet, almost 50 feet lower than on the crest of the anticline in sec. 13, T. 5 S., R. 9 W. Both sandstones are exposed on the knoll between the forks of the valley in the

NE. ¼ NW. ¼ sec. 19. The base of the upper bed lies at an altitude of 899 feet and the top of the lower bed is 15 feet lower. The base of the lower bed is not exposed at this place, but is exposed north of the road about a quarter of a mile to the east, where its altitude is 888 feet. Both sandstones are exposed on the south side of the valley in the S. ½ N. ½ sec. 19. In the SE. ¼ NW. ¼ sec. 19 the base of the upper sandstone lies at an elevation of 906 feet. The lower sandstone is exposed east of this place at an altitude of about 888 feet. The upper sandstone is readily traced to the southwest from this place, and where the outcrop turns to the south the base of the bed lies at an altitude of about 905 feet. In the NE. ¼ NW. ¼ sec. 20 18 feet of the upper sandstone underlain by 5 feet of grayish and pinkish sandy shale are exposed. The altitude of the base of the sandstone at this place is 926 feet. In the NE. ¼ SW. ¼ sec. 18 the base of the upper sandstone is exposed at an altitude of 930 feet. About half a mile to the east, near the bottom of the north fork of the valley, the lower sandstone outcrops on both sides of the stream bed, and at both exposures the altitude of the base is about 906 feet. From its eastern outcrop the bed can be traced northward almost to the northeast corner of sec. 18, where, in the creek bed, its base is exposed at an altitude of 908 feet. The upper sandstone bed is poorly exposed on the knoll across the road to the east, in the northwest corner of sec. 17, where its base lies at an altitude of about 931 feet. From this place the upper bed is readily traced eastward, being well exposed at the side of the road a short distance west of the south quarter corner of sec. 8. At a point about 600 feet northwest of this quarter corner its base lies at an altitude of 936 feet. This same sandstone bed is also exposed in the road about 420 feet north of the southwest corner of sec. 8 and along the valley to the east, where its base lies at an altitude of 920 feet. This altitude is somewhat lower than that of the same bed farther south, so that this outcrop must be on the north flank of the anticline. A sandstone that may be correlated with the upper sandstone exposed in the S. ½ N. ½ sec. 19 outcrops in the NE. ¼ NW. ¼ sec. 30, where its base lies at an altitude of about 910 feet. The same bed may be somewhat doubtfully traced along the river bluff in the township to the west into the valley crossing the NW. ¼ sec. 31, T. 5 S., R. 8 W. It is best exposed on the north side of the stream bed. Just east of the north-south road in the NW. ¼ NW. ¼ sec. 31 the base of the bed lies at an altitude of 889 feet, and 1,600 feet farther east it is only 5 feet lower, the strata lying practically horizontal. Near the top of the south slope of the valley in the NE. ¼ SW. ¼ sec. 31 the presence of another sandstone bed is indicated by loose fragments scattered over the surface. The base of this sandstone lies at an altitude of about 946 feet. Farther northeast in this same valley, at a place where it crosses the SE. ¼

sec. 30, there is an exposure of a sandstone bed that shows a marked westerly dip, but from the nature of its exposures and the lack of outcrops in intervening areas its relation to the beds of adjacent outcrops could not be determined. In and near the north-south road at the east side of this quarter section a 5-foot bed of sandstone underlain by red shale containing thin sandy streaks is exposed. Manganese oxides form conspicuous nodules in the sandstone and give the rock a black color along the bedding planes. Just west of the road the altitude of the base of the sandstone is 928 feet. The bed can be traced westward by poor exposures to the bend of the valley, where its outcrop bends to the south. On the west side of the valley at this place the base lies at an altitude of 904 feet.

In the NW. ¼ sec. 6, T. 5 S., R. 8 W., a deep well has been drilled in which it is reported that a flow of gas was encountered at 1,300 feet. Elevation of the top of the casing is 940 feet above sea level. No other information could be obtained about this well.

In the SE. ¼ SE. ¼ sec. 34, T. 5 S., R. 8 W., a shallow and a deep well were drilled in 1911–12 by the Ryan Oil Co. The records of these wells could not be obtained.

The outcrops of the two sandstone beds exposed along the southwest side of Beaver Creek in T. 4 S., R. 8 W., may be traced southward into the northeast part of T. 5 S., R. 8 W., where they are exposed along the bluffs of Beaver Creek and along the small valleys tributary to that stream. The anticline to be described below as existing in the west-central part of this township ends in a north-south fold, the highest part of which lies in sec. 17. From this fold the beds dip a little north of east toward Beaver Creek, and the outcrops along that stream indicate that the same dip extends to a point within half a mile of the creek. There are minor irregularities in the general northeastward dip. The crest of a dome appears to lie in the NW. ¼ sec. 3 and probably extends into the NE. ¼ sec. 4. South of this dome is a narrow syncline, which crosses the south half of sec. 3 from west to east. On the line between secs. 11 and 14 there appears to be a minor roll.

It is impossible to correlate the beds exposed in the valley that crosses secs. 25 and 26 with exposures farther north, but there seems to be a minor roll, the axis of which lies along the head of this valley in sec. 22.

In the western part of T. 5 S., R. 8 W., the large anticline that is well exposed in the river bluff in sec. 13, T. 5 S., R. 9 W., trends eastward across secs. 17 and 18, T. 5 S., R. 8 W. There is some indication of a slight saddle in the crest just northeast of the center of sec. 18. The crest rises and expands in sec. 17 and the axis of the fold in this section appears to lie approximately north and south, as

if the anticline that extends eastward from the river bluff ends in a north-south fold in sec. 17. The crest of this fold extends northward into the SW. ¼ sec. 8. Its extension to the south is more or less conjectural. There appears to be a pronounced dip to the west in the SE. ¼ sec. 30, which would seem to indicate the presence of the north-south axis east of this locality, but its more definite location is impossible because of the lack of exposures. If the relations of the exposures in sec. 17 to those in secs. 11 and 14 have been correctly determined there is a dip to the east and northeast of about 50 or 60 feet to the mile in the central part of the township. There are, however, no rock exposures in this area and the structure is therefore more or less conjectural.

It is impossible to correlate the sandstone beds of the exposures in the S. ½ sec. 6 and the N. ½ sec. 7, T. 5 S., R. 8 W. There is a suggestion here of the existence of a shallow syncline, but the information at hand is so meager that the structure here has not been represented, the structure contours being drawn to show a general dip to the north, corresponding to the dip in adjoining areas.

In sec. 31, in the southwest corner of the township, the beds are practically horizontal.

T. 6 S., R. 8 W. (FRACTIONAL).

This fractional township is bounded on the west and south by the valley of Red River and on the east by the valley of Beaver Creek. It contains few rock outcrops.

In the NW. ¼ sec. 12 on a grassy slope 8 to 10 feet of sandstone is poorly exposed. The base appears to lie at an elevation of 897 feet. Across the road, to the west, the base is well exposed at an elevation of 898 feet, but the strata above and below are concealed. A quarter of a mile north of the south quarter corner of sec. 2 there is a poor exposure of about 6 feet of thin-bedded, greenish-gray calcareous sandstone, which possibly represents the same bed. The base of the bed lies about 891 feet above sea level. This sandstone can be traced to the west, and in the stream bed near the road on the west side of sec. 2 the following section is exposed:

Section of rocks exposed in W. ½ SW. ¼ sec. 2, T. 6 S., R. 8 W.

	Ft.	in.
Sandstone, light gray, thin bedded	1+	
Shale, red		8
Sandstone, light gray, thin bedded; elevation of base, 888 feet above sea level	2	0

The base of the sandstone is not exposed, but the lowest bed that outcrops lies 888 feet above sea level.

In the north bank of Red River, near the center of sec. 26, the following section was measured:

Section of rocks exposed in north bank of Red River near center of sec. 26, T. 6 S., R. 8 W.

	Ft.	in.
Sandstone, greenish gray	3	0
Shale, drab	4	0
Shale, red; thickness about	4	0
Sandstone, dirty green; when measured but 1 foot was exposed above river level; probable thickness	2+	

The beds of this exposure could not be correlated with those of any other.

Across secs. 19 and 20 runs an outcrop of massive sandstone, which is the source of several springs. The bed is poorly exposed but appears to be practically horizontal along its outcrop. Altitudes taken on the top of the bed range from 847 to 855 feet.

Rock outcrops in T. 6 S., R. 8 W., are so few that they give practically no key to the structure. Along the outcrops in the northeastern and southwestern parts of the township the beds appear to be horizontal.

It is reported that Garret Mayo drilled a well in the SW. ¼ sec. 5, T. 6 S., R. 8 W., to a depth of 419 feet, obtaining a showing of oil at 96 feet, a bucketful of oil at 320 feet, and a strong showing of gas and oil at 419 feet. The report was not verified. The location is in line with the north-south anticlinal axis mapped in secs. 17 and 20, T. 5 S., R. 8 W. (See also p. 100.)

SUGGESTIONS TO PROSPECTORS.

In a large proportion of the oil fields of the world the accumulation of the oil is controlled principally by the structure of the rocks in which it is contained. In northern Texas and Oklahoma the structure is unquestionably one of the controlling factors, the oil in all the fields explored having accumulated along the axes or on the flanks of anticlines, domes, or monoclines. Even the accumulations that apparently lie in synclines, such as that in part of the Glenn pool,[1] are probably controlled by the monoclinal structure on which the shallow synclines are superimposed.

That other important factors enter into the problem there is no doubt. The presence of water in the same stratum that contains the oil, the direction of movement of this water, the size of the grains of the containing rock, the thickness and continuity of the bed, the nature of the overlying and underlying strata—all these things and probably many more are factors in oil accumulation; but they are

[1] Smith, C. D., The Glenn oil and gas pool and vicinity, Okla.: U. S. Geol. Survey Bull. 541, pp. 34-48, 1914.

in general effective only in the presence of favorable structure. In geologic work in oil fields structure is the most readily determined of the factors involved in the accumulation of oil and in many fields is the only factor that can be determined.

From what has just been stated, the scope and limitations of geologic work in discovering oil pools are apparent. In most fields a study of the rocks may determine localities at which the structure is most favorable to the accumulation of oil; but only the drill can determine whether oil is present at these localities, for the absence of other unknown factors may have prevented its accumulation. If in any field it is not present at localities where the structure is favorable, there is small probability of finding it at places in that field where the structure is unfavorable.

In testing an anticline for oil it is generally conceded that the first hole should be put down on the axis, or as near to it as practicable. If oil is encountered, the extent of the pool may be determined by properly spaced holes bored along the axis and at right angles to it. If gas is encountered along the axis, a fuel supply is thus obtained for further drilling and oil may be sought on the limbs (the sloping sides) of the fold, for oil and gas are generally, although not invariably, associated.

Salt water is usually found in the oil-bearing "sand" on the flanks of the anticline below the oil zone. Not infrequently several "sands" lie at intervals one above another. One "sand" may contain salt water, whereas a lower "sand," separated entirely from the upper by intervening shale, may bear gas or oil.

In considering the possibility of obtaining oil in an area that has not been tested by the drill the amount of dip of the rocks necessary to produce an accumulation of oil is a factor in the problem which it is difficult to estimate. In the area under discussion there is one anticline which, with reference to the syncline of Beaver Creek valley, on its east, is at least 160 feet high, the strata on its flanks having a dip of 60 or 70 feet to the mile, and in certain small areas considerably more than that amount. There are also several minor anticlines or domes, some of which are but 30 or 40 feet high. Which, if any, of these anticlines has been sufficient to effect an accumulation of oil is a problem whose answer can be surmised only by comparing the conditions here with those in adjoining fields.

In the Petrolia field, which lies about 10 miles south of the area under consideration, the structure is reported by Udden and Phillips [1] "to be an irregular, elongated dome some 200 feet high and having an area of 6 or 7 square miles." The dip of the rocks is represented on Plate II of the same report as about 200 feet to the mile. Of the

[1] Udden, J. H., and Phillips, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, p. 102, 1912.

Electra field the same authors[1] write: "It is situated either on the crest of a very wide and flat anticline or else close to the south edge of a structural terrace where flat-lying beds soon begin to dip to the south." This southerly dip is said to be about 15 feet to the mile, which is very low in comparison to the structure in the Petrolia field.

In the Healdton field, which lies 25 miles east of the area under discussion, the producing structure is a broad dome or anticline bearing on its surface several minor domes, the whole being 4 miles long by $1\frac{3}{4}$ miles broad. The dip on the steepest flank of the fold is about 250 feet in half a mile, a dip much greater than any reported from other fields in this general region.

In the Cushing field[2] in northern Oklahoma outside the "Red Beds" area the dip of the rocks exceeds 150 feet to the mile.

The dip in the Glenn pool[3] does not exceed 100 feet to the mile, and in many productive areas in northern Oklahoma is 50 feet to the mile, or even less.

In the area covered by the present report the anticline that is exposed in the east-central part of T. 5 S., R. 9 W., and extends into T. 5 S., R. 8 W., affords by far the most promising location for drilling. It is not so pronounced as the Healdton anticline, being rather comparable in the degree of dip of its slopes to the Petrolia dome. Its dip exceeds that found in most of the fields in the northern part of the State, but it is smaller in areal extent.

The most promising locations for test wells lie along the anticlinal axis indicated on the map (Pl. V) in sec. 13, T. 5 S., R. 9 W., and sec. 18, T. 5 S., R. 8 W. Practically all of sec. 17 offers promising territory. Probably the E. $\frac{1}{2}$ sec. 20 and possibly the E. $\frac{1}{2}$ sec. 29 are crossed by the axis, but exposures are so few that exact determinations are impossible. In the south-central part of sec. 8 there is some indication of the extension of the axis to the north, which, however, is lost in secs. 6 and 7. A small subsidiary dome, the axis of which lies near the line between secs. 31 and 32, T. 4 S., R. 8 W. and is continued northward across the E. $\frac{1}{2}$ sec. 30, is in line with the north-south fold in T. 5 S., R. 8 W., and may be considered a continuation of it. Its crest represents fair territory for testing, although probably not so good as that near the top of the large fold. Such minor structures on the flanks of large folds are believed to interrupt the course of the oil as it rises up the dip toward the major crest and tend to collect it. The flanks of the small dome here, however, are very short in comparison with the flanks of the major fold and hence the "gathering ground" from which the oil is collected

[1] Udden, J. H., and Phillips, D. McN., op. cit., pp. 103-104.

[2] Structural map of the Cushing oil field, published by the Oklahoma Geol. Survey, 1914.

[3] Smith, C. D., The Glenn oil and gas pool and vicinity, Okla.: U. S. Geol. Survey Bull. 541, pl. 3, 1914.

toward the small dome is much smaller than that tributary to the major structure. For this reason the possibilities of finding oil or gas are much better in the major structure than in the subsidiary folds. The small fold in the NW. ¼ sec. 3 and the NE. ¼ sec. 4 is probably of only minor importance, and should not be tested unless oil is found in the dome northwest of it, just described.

The constant rise of the beds toward the south in the south half of T. 4 S., R. 11 W., and the existence of the same structure in the north tier of sections in T. 5 S., R. 11 W., indicate the probable presence of an anticlinal axis somewhere to the south. The axis noted in sec. 12 of this township may possibly be this principal axis, but the exposures are not sufficient to establish this fact. It may be merely a subsidiary structure on the side of the major anticline. It seems more probable that the anticlinal crest toward which the beds in Tps. 4 and 5 S., R. 11 W., rise is situated somewhere south of Red River, in Texas. Munn's map of T. 5 S., R. 12 W.,[1] shows a pronounced dip to the northwest in secs. 9, 16, 30, 31, and 32, and there is no indication of a large fold crossing T. 5 S., R. 12 W., from east to west. Therefore the fold that appears to lie south of Red River opposite T. 5 S., R. 11 W., is probably a dome or a plunging anticline that dies out to the west. It is possible, however, that the axis bends to the southwest, in the general direction of the Burkburnett oil field.

No data could be obtained from surface exposures as to the relation of the probable structure just described to the anticline exposed in sec. 13, T. 5 S., R. 9 W., but the land on the Texas side of Red River directly west of the middle of sec. 13, T. 5 S., R. 9 W., and in line with the anticlinal axis exposed in that section should be good territory for at least half a mile west of the river.

In T. 4 S., R. 10 W., the dips to the northeast in sec. 12 and to the southwest in sec. 27 indicate the presence of an arch between them in the east-central part of the township, but outcrops in this area are so few that it is impossible to tell whether the structure is a single broad arch or a series of small, ineffective folds. The structure appears to extend northward into sec. 32, T. 3 S., R. 10 W.

In the northwestern part of T. 4 S., R. 9 W., there appears to be a gradual rise of the beds toward the NE. ¼ sec. 9, but the structure is so poorly exhibited in the outcrops that statements can be made only with great reserve. The possibility of finding oil in such minor structures as the two last named appears doubtful. They should not be tested unless the exploration of the more promising folds is successful.

[1] Munn, M. J., op. cit.

DEEP WELLS DRILLED IN AND NEAR THE AREA COVERED BY THIS REPORT.

The deep wells indicated below were drilled in the area considered in this bulletin:

NE. ¼ NE. ¼ sec. 25, T. 4 S., R. 13 W. Indian meridian, Okla., 2 miles northwest of Randlett and 6 miles west of the area here described, Green River Oil Co., No. 1. Well begun December 28, 1913; completed June 1, 1914. For complete log see pages 28–29.

SW. ¼ sec. 1, T. 4 S., R. 9 W. Indian meridian, Okla., northeast of Hastings, West Virginia Petroleum Co. J. H. Marley No. 1 well. Well begun February 16, 1914; completed in June, 1914. For complete log see page 29.

SE. ¼ SE. ¼ sec. 30, T. 4 S., R. 11 W. Indian meridian, Okla., Riverside Oil Co., 1912. Total depth of well reported as 400 to 500 feet. Altitude of top of casing, 1,013 feet.

In Texas, one-third of a mile south of Red River and 1½ miles southwest of the mouth of Cache Creek, Riverside Oil Co. Well begun December 7, 1912. For complete log see page 30. Altitude of top of casing, 982 feet.

NW. ¼ sec. 6, T. 5 S., R. 8 W. Indian meridian, Okla. Flow of gas reported at 1,300 feet. No other information obtained. Altitude of top of casing, 940 feet.

SW. ¼ sec. 5, T. 6 S., R. 8 W. Indian meridian, Okla. Shallow well drilled by Garret Mayo. Not located on map. Record reported as follows:

Shale, red and blue, down to 95 feet.
Showing of oil at 96 feet.
Bailed out one bucketful of oil at 320 feet.
Stronger showing of gas and oil at 419 feet.
Drilled 6 to 8 feet in sand.
108 feet, 6-inch casing.
400 feet, 4-inch casing.

SE. ¼ SE. ¼ sec. 34, T. 5 S., R. 8 W. Indian meridian, Okla. Two wells drilled by the Ryan Oil Co. Drilling begun July, 1911; completed in spring of 1912. No records obtained.

COAL.

Small deposits of bituminous coal of no economic value were found at several places in the area here considered. They occur as small "pockets" only a few inches thick and apparently represent the remains of single logs rather than masses of bedded material. The coal is black and "slacks" or crumbles on exposure to air and sunlight. It is at many places associated with deposits of copper and is probably the agent which, by deoxidation, precipitated copper from ground water. Coal was noted in the NE. ¼ NW. ¼ sec. 3, T. 5 S., R. 11 W. (see p. 52), and in the NE. ¼ NE. ¼ sec. 8, T. 5 S., R. 10 W. (see p. 66), and is reported to have been struck in digging a cellar at Taylor in the SE. ¼ SE. ¼ sec. 27, T. 4 S., R. 11 W.

MANGANESE.

Manganese oxide in an amorphous form, probably an impure hydrous oxide, is found in many of the sandstone beds of the Wichita formation. It appears principally as small specks in the sandstone, which in some specimens coalesce into dendritic forms. The oxide is probably precipitated from ground water around particles of some substance which acts as a precipitating agent, and the precipitation occurs principally along bedding planes in the sandstone. At some places the manganese oxide produces small, round concretions like buckshot. At other places it is disseminated through the sandstone, apparently replacing the calcite cement, and the sandstones in which such replacement occurs are extremely soft and friable. In calcite concretions in sandstone and in clay-limestone concretions in shale the manganese oxide appears as dendritic penetrations, which extend from the surface into the concretions. It is deposited also in the calcium carbonate and shale pebbles of the conglomerate that is characteristic of the Wichita.

One of the localities in the field at which a deposit of manganese oxide was noted is in the east-west road about a quarter of a mile east of the southwest corner of sec. 5, T. 5 S., R. 8 W., where a small ledge of black and yellowish-gray sandstone is rather poorly exposed. Part of the sandstone is black, extremely friable, and appears to be cemented entirely by manganese, the concentration of which at this place is greater than at most places in the field, but is nevertheless too low to be of any economic value. The deposit is probably only local.

Most of the sandstones in which the manganese oxide occurs are of the normal type, which are cemented by calcite. The fine-grained type of sandstone, in which the cement is silica, carries relatively small amounts of manganese oxide. The dendritic deposits of manganese oxide in the calcareous sandstone and clay-limestone concretions are probably forming at the present time by deposition from ground water.

COPPER.

At many localities in the region under discussion the presence of copper is indicated by the green and blue colors of its carbonate minerals, malachite and azurite, which appear in several forms. They occur as stains on the surfaces of sandstone outcrops; as small nodules in the sandstone; as larger nodules, the largest as big as a hickory nut, embedded in shale; and as fossil wood. A critical examination of the different forms reveals the fact that the green malachite and the blue azurite of the nodules and the fossil wood are alteration products of the copper sulphide mineral chalcocite, which occurs in the interior of the deposits. The chalcocite replaced a preexisting iron

sulphide mineral, probably marcasite, small remnants of which are embedded in the encroaching chalcocite.

The evidence for the replacement of the iron sulphide by chalcocite is of several kinds. The nodules, which are concretionary growths, were doubtless originally accretions of but one mineral, for it is unlikely that nodules are formed by simultaneous growths of two minerals in irregular arrangement. The wood also was probably at first fossilized by but one mineral, as it is not likely that during fossilization the organic matter caused marcasite to be precipitated in some parts of the material and chalcocite in others. Chalcocite veinlets occur in the marcasite, the inclosing walls of the marcasite showing corrosion due to the replacement of marcasite by chalcocite. Aside from the above evidence, observation in other fields has shown that marcasite is a primary mineral and that chalcocite is of a secondary origin.

The copper stains found on some of the outcrops of sandstone are altered residues left by the evaporation of ground water. Malachite forms part of the cement of some of the sandstone beds, but the green color due to the presence of that mineral can usually be seen only on freshly broken surfaces of the rock.

The deposits enumerated above belong to a type which is of almost world-wide distribution in "Red Beds," particularly in the Permian "Red Beds." In America the largest of these deposits are found in the "Red Beds" area of the Plateau region of New Mexico, Colorado, and Utah. Several attempts have been made to utilize these deposits, but they have not been very successful because of the great competition offered by the so-called porphyry copper deposits in the West.

The "Red Beds" copper deposits of America are all of low grade, only a few of the richest showing a copper content of more than 2 per cent. As deposits of this type occur in sedimentary rocks, it is doubtful whether the content of copper in the rock at the surface differs materially from that found below the surface. In southern Oklahoma such deposits of copper, although they occur at many places, contain amounts of the ore so small that they are probably much less valuable than the larger and richer deposits of the "Red Beds" type in New Mexico, Colorado, and Utah, and it seems probable that any attempt to utilize the copper of this region under present conditions will prove a failure.

The presence of copper in the area was noted in the NE. ¼ NW. ¼ sec. 3, T. 5 S., R. 11 W. (p. 52); NE. ¼ sec. 8, T. 5 S., R. 10 W. (p. 66); SE. ¼ NW. ¼ sec. 7, T. 5 S., R. 8 W.; SW. ¼ SE. ¼ sec. 35, T. 4 S., R. 10 W.; and NW. ¼ sec. 31, T. 4 S., R. 9 W. It doubtless occurs at many other places.

BIBLIOGRAPHY.

A partial list of the more important works bearing on the geology and oil resources of Oklahoma is given below.

ADAMS, G. I., Oil and gas fields of the western interior and northern Texas coal measures and of the Upper Cretaceous and Tertiary of the western Gulf coast: U. S. Geol. Survey Bull. 184, 1901.

——— Stratigraphic relations of the "Red Beds" to the Carboniferous and Permian in northern Texas: Geol. Soc. America Bull., vol. 14, pp. 191–200, 1903.

——— Stratigraphy and paleontology of the Upper Carboniferous rocks of the Kansas section: U. S. Geol. Survey Bull. 211, 1903.

BARRELL, JOSEPH, Relative geological importance of continental, littoral, and marine sedimentation: Jour. Geology, vol. 14, pp. 316–356, 430–457, 524–568, 1906.

——— Some distinctions between marine and terrestrial conglomerates: Abstract Geol. Soc. America Bull., vol. 20, p. 620, 1909.

——— Criteria for the recognition of ancient delta deposits: Geol. Soc. America Bull. 23, pp. 377–446, 1912.

BEEDE, J. W., Invertebrate paleontology of the Upper Permian "Red Beds" of Oklahoma and the Panhandle of Texas: Kansas Univ. Sci. Bull., vol. 4, pp. 113–171, 1907.

——— Formations of the marine stage of the Kansas Permian: Kansas Acad. Sci. Trans., vol. 22, pp. 248–256, 1909.

——— The bearing of the stratigraphic history and invertebrate fossils on the age of the anthracolithic rocks of Kansas and Oklahoma: Jour. Geology, vol. 7, pp. 710–729, 1909.

——— Relationships of the Pennsylvanian and Permian faunas of Kansas and their correlation with similar faunas of the Urals: Abstract Geol. Soc. America Bull., vol. 20, p. 702, 1909.

——— The correlation of the Guadalupian and Kansas sections: Am. Jour. Sci., 4th ser., vol. 30, pp. 131–140, August, 1910.

——— Origin of sediments and coloring matter of "Red Beds" of Oklahoma: Science, new ser., vol. 35, pp. 348–350, Mar. 1, 1912; Geol. Soc. America Bull., vol. 23, No. 4, pp. 723–724, Dec. 17, 1912.

BOWMAN, ISAIAH, Well-drilling methods: U. S. Geol. Survey Water-Supply Paper 257, 1911.

CAMPBELL, M. R., Historical review of theories advanced by American geologists to account for the origin and accumulation of oil: Econ. Geology, vol. 6, No. 4, June, 1911.

CASE, E. C., Restoration of Diadectes: Jour. Geology, vol. 15, pp. 556–559, 1907.

——— The character of the Wichita and Clear Fork divisions of the Permian "Red Beds" of Texas: Am. Mus. Nat. Hist. Bull., vol. 23, pp. 659–664, 1907.

——— Revision of the Pelycosauria of North America: Carnegie Inst. Washington Pub. 55, 1907.

——— Notes on a collecting trip in the Permian of Texas: Science, new ser., vol. 29, p. 195, 1909.

——— Revision of the Amphibia and Pisces of the Permian of North America: Carnegie Inst. Washington Pub. 146, 1911.

COPE, E. D., Systematic catalogue of the Permian vertebrate fauna of North America: Am. Philos. Soc. Trans., vol. 16, pp. 285–288, 1888.

CUMMINS, W. F., The Permian of Texas and its overlying beds: Texas Geol. Survey First Ann. Rept., pp. 183–197, 1890.

——— Geology of northwest Texas: Texas Geol. Survey Second Ann. Rept., Austin, 1890.

CUMMINS, W. F., Transactions of the Texas Academy of Science (1897), vol. 2, pp. 93–97.

——— The localities and horizons of Permian vertebrate fossils in Texas: Jour. Geology, vol. 16, No. 8, pp. 737–745, 1908.

DAY, D. T., The petroleum resources of the United States: U. S. Geol. Survey Bull. 394, pp. 30–50, 1909.

——— Natural-gas resources of the United States: U. S. Geol. Survey Bull. 394, pp. 51–61, 1909.

——— Analyses of crude petroleum from Oklahoma and Kansas: U. S. Geol. Survey Bull. 381, pp. 494–503, 1910.

——— The production of petroleum, issued annually as a chapter of U. S. Geol. Survey's Mineral Resources of the United States.

ELDRIDGE, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, pp. 219–452, 1901.

FURMAN, J. H., The geology of the copper region of northern Texas and Indian Territory: New York Acad. Sci. Trans., vol. 1, pp. 15–20, 1882.

GILPIN, J. E., and BRANSKY, O. E., The diffusion of crude petroleum through fuller's earth, with notes on its geologic significance: U. S. Geol. Survey Bull. 475, 1911.

GORDON, C. H., Geology and underground waters of northeastern Texas: U. S. Geol. Survey Water-Supply Paper 276, 1911.

——— Geology and underground waters of the Wichita region, north-central Texas: U. S. Geol. Survey Water-Supply Paper 317, 1913.

GORDON, C. H., GIRTY, G. H., and WHITE, DAVID, The Wichita formation of northern Texas, with discussions of the fauna and flora by George H. Girty and David White: Jour. Geology, vol. 19, No. 2, pp. 110-134, 1911.

HAWORTH, ERASMUS, Oil and gas: Kansas Univ. Geol. Survey, vol. 9, 1908.

HILL, R. T., Geography and geology of the Black and Grand prairies, Tex.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, 1901.

HUTCHINSON, L. L., Preliminary report on the rock asphalt, asphaltite, petroleum, and natural gas in Oklahoma: Oklahoma Geol. Survey Bull. 2, 1911.

MATTHEW, W. D., The oldest land reptiles of North America: Am. Mus. Jour., vol. 9, No. 9, pp. 91–95, April, 1909.

——— Fossil vertebrates—what they teach: Am. Mus. Jour., vol. 11, No. 7, pp. 246–247, November, 1911.

——— Amphibians of the great coal swamps: Am. Mus. Jour., vol. 11, No. 6, pp. 197–200, October, 1911.

MUNN, M. J., The anticlinal and hydraulic theories of oil and gas accumulation: Econ. Geology, vol. 4, No. 6, September–October, 1909.

——— Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, 1914.

PROSSER, C. S., The classification of the upper Paleozoic rocks of central Kansas: Jour. Geology, vol. 3, No. 7, 1895.

——— Revised classification of upper Paleozoic formations of Kansas: Jour. Geology, vol. 10, No. 7, 1902.

REDWOOD, BOVERTON, A treatise on petroleum, 3d ed., 3 vols., London, Charles Griffin & Co., 1913.

RUSSELL, I. C., Subaerial decay of rocks and origin of the red color of certain formations: U. S. Geol. Survey Bull. 52, 1889.

SMITH, C. D., Structure of the Fort Smith–Poteau gas field, Ark.–Okla.; The Glenn oil and gas pool and vicinity, Okla.: U. S. Geol. Survey Bull. 541, pp. 23–48, 1914.

SMITH, G. O., and others, The classification of the public lands: U. S. Geol. Survey Bull. 537, 1913. (Contains chapters on oil and gas accumulation and methods of geologic field work.)

SNIDER, L. C., Petroleum and natural gas in Oklahoma, The Harlow-Ratcliff Co., Oklahoma City, 1913.

TAFF, J. A., Preliminary report on the geology of the Arbuckle and Wichita mountains in Indian Territory and Oklahoma: U. S. Geol: Survey Prof. Paper 31, 1904.

——— U. S. Geol. Survey Geol. Atlas folios 74, Coalgate, Okla.; 79, Atoka, Okla.; 98, Tishomingo, Okla.; 122, Tahlequah, Okla.; 132, Muscogee, Okla.

TAFF, J. A., and REED, W. J., The Madill oil pool, Okla.: U. S. Geol. Survey Bull. 381, pp. 504–513, 1910.

TODD, J. E., Concretions and their geologic effects: Geol. Soc. America Bull., vol. 14, pp. 353–368, 1903.

UDDEN, J. A., assisted by PHILLIPS, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, 1912.

WHITE, C. A., On the fauna of the Permian in Baylor, Archer, and Wichita counties, Tex.: Am. Naturalist, vol. 22, p. 926, 1888.

——— The Texas Permian and its Mesozoic types of fossils: U. S. Geol. Survey Bull. 77, 1891.

WHITE, DAVID, The upper Paleozoic floras, their succession and range: Jour. Geology, vol. 17, No. 4, pp. 320–341, 1909.

——— Permian floras in the western "Red Beds": Science, new ser., vol. 32, p. 223, 1910.

——— The characters of the fossil plant Gigantopteris Schenk and its occurrence in North America: U. S. Nat. Mus. Proc., vol. 41, pp. 493–516, 1912.

WILLIS, BAILEY, Mountain growths of the Great Plains: Science, new ser., vol. 16, p. 1028, 1902.

WILLISTON, S. W., American Permian vertebrates, 145 pp., 39 pls., Univ. Chicago Press, 1911.

WILLISTON, S. W., and CASE, E. C., The Permo-Carboniferous of northern New Mexico: Jour. Geology, vol. 20, No. 1, pp. 1–12, 1912.

WOOD, R. H., Oil and gas development in north-central Oklahoma: U. S. Geol. Survey Bull. 531, pp. 27–53, 1913.

INDEX.