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SEDIMENTATION IN THE ANADARKO BASIN

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SEDIMENTATION IN THE ANADARKO BASIN

PURPOSE

The purpose of this investigation was to determine the location and extent of the Anadarko Basin; to determine its structure; to study the physical and mineralogical characteristics of its sediments; and to determine the source of sediments and the conditions under which they were laid down.

LOCATION OF AREA

The Anadarko Basin proper is located in that part of Western Oklahoma which lies north of the Wichita Mountains, and in the northern part of the Texas Panhandle (fig. 1). It is situated principally

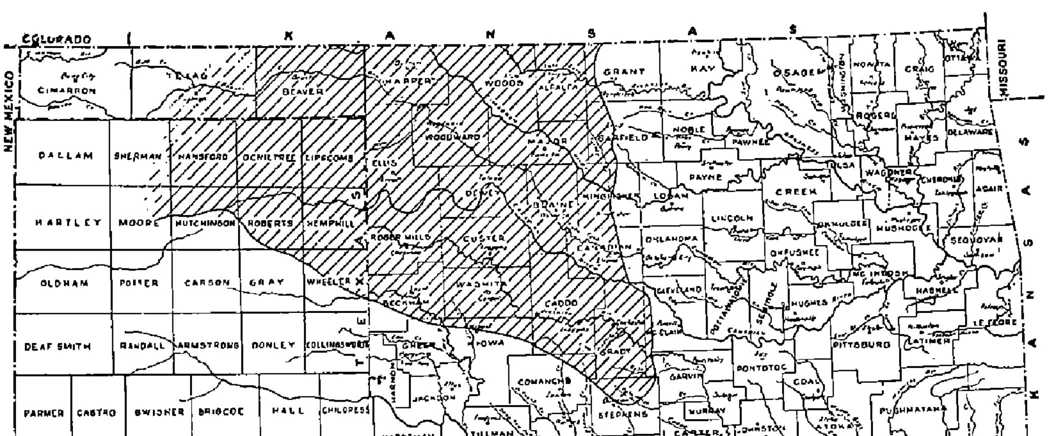


Figure 1. Index map showing location of Anadarko Basin.

within the drainage basin of the Cimarron, Canadian, and Washita River valleys. According to Fenneman[1] it lies within two physiographic provinces, i. e., the Central Lowlands and the Great Plains.

1. Fenneman, Nevin M., Physiographic divisions of the United States: Annals Assoc. American Geog. vol. 18, pp. 309-325, pl. 1, 1928.

METHODS OF INVESTIGATION

Field work was carried on during seven weeks of the summer of 1927 and six weeks of the summer of 1928. The work consisted of studying the lithology and structure and taking detailed sections of the formations. Samples were collected at the surface exposures and from drilling wells for the purpose of making laboratory tests.

The laboratory work consisted of making complete analyses of the samples collected in the field, including determination of their solubility in acid, of their size-grade distribution, of the shapes of the detrital grains, and of the heavy mineral content. The methods used for mechanical analyses were those employed in the sedimentation laboratories of the department of geology of the State University of Iowa.[2] Mineral analysis was accomplished by the use of the usual methods.

ACKNOWLEDGMENTS

The writer is especially indebted to Dr. Chas. N. Gould, Director of the Oklahoma Geological Survey, who made the investigation possible and whose extensive knowledge of the red beds region enabled him to give the writer invaluable assistance in studying the problem and procuring data. To Mr. C. L. Cooper and other members of the geological staff of the Oklahoma Geological Survey credit is due for assistance.

To Professor A. C. Trowbridge of the department of geology of the State University of Iowa, the writer acknowledges his indebtedness for the complete supervision of the problem and the editing of the manuscript. Thanks are also due Prof. A. C. Tester, of the department of geology of the State University of Iowa, for his aid in the petrographical work and many helpful suggestions during the preparation of the paper.

Credit is also due Messrs. R. L. Clifton, Frank Gouin, Clyde M. Becker, C. Don Hughes, C. Max Bauer, A. A. Langworthy, C. L. Nufer, and other petroleum geologists familiar with the problem, for their generous aid in contributing surface and subsurface data and in giving many helpful suggestions.

Acknowledgment is made of the use of the equipment of the sedimentation laboratories of the department of geology at the State University of Iowa.

HISTORICAL SKETCH

For many years geologists working in the Permian red beds of western Oklahoma have known that somewhere in that general region

2. Wentworth, C. K., Methods of mechanical analyses of sediments: Univ. of Iowa Studies, vol. II, no. 11, 1926.

there exists a large synclinal trough, the precise location and extent of which were unknown.

During the first decade of the present century, Gould, who accomplished the preliminary work on the stratigraphy of the red beds of western Oklahoma, had a rather hazy idea regarding this structural trough. He recognized the fact that this region was synclinal, but no definite statement was made to that effect. On the map accompanying Water-Supply Paper 148 of the U. S. Geological Survey, there is shown in the region northeast of the Wichita Mountains the southeastern extension of the Woodward formation, consisting of the Dog Creek shale, the Whitehorse sandstone, and the Day Creek dolomite. The southeastern terminus of the rocks of the Woodward formation was shown extending into the Chickasaw Nation, then a part of Indian Territory, and no work was done to determine the extent of this formation in that region.

In 1917, Aurin[3] published a description of the surface and subsurface geology of western Oklahoma as revealed by well log data. So far as the writer is aware, this was the first attempt to set forth on a large scale the subsurface geology of Oklahoma. In his report Aurin published a map showing the principal geologic divisions of the State and the base of the red beds. On this map he located the larger synclinal trough of the Permian red beds of western Oklahoma as extending along a line nearly east and west, passing near the towns of Chandler, Luther, Edmond, El Reno, Bridgeport, Hydro, Arapaho, and Cheyenne. It is also to be noted that the western end of this syncline coincides very closely with the location of the Anadarko Basin as at present understood.

In 1918, Ohern[4] outlined the southeastern extension of the Whitehorse sandstone in the region northeast of the Wichita Mountains, including parts of Canadian, Caddo, Stephens, and adjacent counties. He appears to have confused the Whitehorse with the Duncan sandstone, but his line of outcrops as traced on the map indicates that he had in mind the general position of the Anadarko Basin as we now understand it. His map is the first graphic presentation of the location of any part of the structure now known as the Anadarko Basin. He demonstrated that the Whitehorse sandstone continues southeast across Grady County into Garvin County, where the escarpment turns sharply to the south, thence west across Stephens County to the vicinity of Duncan. From Duncan the outcrop trends northwest toward Fletcher, Comanche County. In Grady County, he found the rocks dipping to the southwest, but in the vicinity of Duncan they were found to dip strongly to the north or northeast.

In 1922, Howell[5] described the Wichita-Duncan-Arbuckle uplift

3. Aurin, Fritz, Geology of the red beds of Oklahoma: Oklahoma Geol. Survey Bull. 30, 1917.
4. Ohern, D. W., A contribution to the stratigraphy of the red beds: Bull. Am. Assoc. Pet. Geol., vol. 2, 1918.
5. Howell, J. V., Some structural factors in the accumulation of oil in southwestern Oklahoma: Econ. Geology, vol. 17, no. 1, p. 23, 1922.

and the Red River uplift and mentioned three prominent synclines in the southwestern part of the State, namely, the Red River syncline, the Ardmore Basin, and the Washita syncline. This Washita syncline, located in northern Caddo and Grady counties, is now known to be a part of the Anadarko Basin. According to our present interpretations, he placed the axis something like twenty-five miles too far north, for this axis is now believed to cross the southern part of these counties. Howell's description of the Washita syncline is as follows:

> North of the Wichita-Arbuckle axis, and with its trough following, in general, the course of the Washita River, is a broad, deep syncline which is usually referred to as the Washita. This great depression seems to have had no direct contact with the Red River and Ardmore basins during most of the Pennsylvalian, and certainly was separated during all but the latest Permian. Proof of this may be seen in the fact that no gypsum beds are found south of the Duncan arch, though occurring but a short distance to the north. The thick Duncan sandstone occurs close along the north flank of the arch, but never appears to the south, although stratigraphically it might be expected. In general the Permian beds north of the arch carry more sand than those to the south. That part of the Pennsylvanian which immediately underlies the Permian in the Washita area includes almost no limestone, whereas that on the souh side of the arch contains limestone beds in considerable number and sometimes many feet in thickness. This last difference may, however, be due to an unconformity between the Permian and Pennsylvanian, the upper Pennsylvanian being absent south of the arch.

In 1920, Greene[6] called attention to the fact that there is a structural trough running northwest-southeast in the region north of the Wichita Mountains.

After the previously mentioned workers had established the presence of a northwest-southeast syncline, Gould and others familiar with the area were led to believe that the Blaine was probably the same as the Greer of the "western area".

In 1924, Gould called a field conference in this general area in which H. D. Miser, J. W. Beede, J. V. Howell, C. Don Hughes, R. W. Sawyer, and F. W. Floyd participated. The results of the conference as summarized in a paper by Gould[7] are as follows:

> 1. The former classification of the red beds, on the basis of the presence of gypsums, has been abandoned, and the new classification on the basis of unconformities is adopted.
> 2. Two new formations are added, the Duncan sandstone and the Chickasha formation, both of which are the stratigraphic equivalent of the upper part of the Enid.
> 3. The Blaine formation has been mapped as continuing around the southeast end of the Anadarko Basin and has been correlated with the so-called "western area" of the Greer at

6. Greene, Frank C., Oklahoma's stratigraphic problem (the red beds); Oil and Gas Jour., vol. 18, no. 49, p. 54, 1921.
7. Gould, Chas. N., A new classification of the Permian red beds of southwestern Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 8, no. 3 pp. 340-341, 1924.

its type locality at Cedartop Hill and along North Fork of Red River in southern Beckham County.

4. The Dog Creek shales and Whitehorse sandstone are also found to continue around the Anadarko Basin, and may be traced as far as the North Fork of Red River in southern Beckham County, and appear in Harmon County. * * *

5. The name "Woodward," which had formation rank, is abandoned, and the three units, Dog Creek, Whitehorse, and Day Creek, previously considered members of the Woodward, have been advanced to the rank of formations.

6. The name "Greer" is abandoned. For the so-called "eastern area" of the Greer, the name "Cloud Chief" is proposed. It is shown that the rocks in the "western area" of the Greer belong to the Blaine, Dog Creek, Whitehorse, and Cloud Chief formations.

7. A structural trough, known as the Anadarko Basin, is recognized as extending northwest from a point near the west end of the Arbuckle Mountains for a distance of more than 150 miles.

8. Since it has been found that a conglomeratic sandstone, which in Texas occurs at the base of the Double Mountain, as that series of rocks was first described by Cummins in 1901, is the same bed as the Duncan sandstone of Oklahoma, it follows that the formations described in this paper, from the Duncan to the Quartermaster inclusive, are the stratigraphic equivalents of the Double Mountain, the uppermost Permian division of Texas.

Also in 1924, Sawyer[8] discussed, but did not name, the syncline north of the Wichita Mountains. He is quoted as follows:

> A large syncline with a steep south flank and a gentle north flank occurs just north of the Wichita Mountains, the axis of the syncline being parallel to that of the mountains. The Cement oil field and the Chickasha gas field are local anticlines almost in the center of the syncline.

In 1926, Gould[9] attempted a correlation of the Permian beds of Kansas, Oklahoma, and northern Texas, mapped the various formations exposed in this general region, and described the structure as follows:

> The broad syncline known as the Anadarko Basin lies north of the Wichita Mountains, extending from a point near the west end of the Arbuckles an indefinite distance to the northwest. The causes for this structural trough, as well as its limits, are not now definitely understood. It has been suggested that the Anadarko Basin represents the northwest extension of the Mill Creek syncline of the Arbuckle Mountains. On the other hand, some believe that it is the reflex to the north, away from the mountains, being a continuation of the dips on the north side of the Arbuckle and Wichita Mountains, and possibly also along the north side of the buried Amarillo Mountains of the Texas Panhandle.

A subsurface map accompanying an article by Lockwood[10] shows the strata dipping steeply away from the Amarillo Mountains toward the axis of the Anadarko Basin.

8. Sawyer, R. W., Areal geology of part of southwestern Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 8, no. 3. pp. 319-320, 1024.
9. Gould, Chas. N., The correlation of the Permian of Kansas, Oklahoma, and northern Texas: Bull. Am. Assoc. Pet. Geol., vol. 10, no. 2, p. 146, 1926.
10. Lockwood, C. D, Geology of Panhandle (Texas): Oil and Gas Jour., vol. 24, no. 43, p. 30, 1926.

In 1926, Dwyer[11] published an article, accompanied by a map prepared by M. M. Valerius, in which the axis of the syncline of the Panhandle is located along a line extending almost east and west, crossing southern Dallam, Sherman, Hansford, Ochiltree, and Lipscomb counties, Texas and Ellis and Dewey counties, Oklahoma.

In 1926, Clifton[12] published a map showing the outcrops of the Whitehorse sandstone in Kansas, Oklahoma, and Texas, and the general location of the Anadarko Basin in western Oklahoma and another map[13] in which an attempt was made to locate the axis of Anadarko Basin in the Panhandle of Texas.

Greene[14] in 1926 published the results of the study of the logs of several hundred deep wells throughout western Oklahoma and the Texas Panhandle and a map in which the Anadarko Basin is located in that region.

The same year Gould and Lewis[15] presented in some detail the current knowledge of the stratigraphy and structure of the Panhandle of Texas and the western part of Oklahoma. This report was accompanied by a general map outlining the major structural features of the southern part of the Great Plains, and another indicating the location of the axis of the Anadarko Basin and the Amarillo Mountains.

In 1928, Bullard[16] in his studies of the Lower Cretaceous of Oklahoma, presented a subsurface map, contoured on the base of the red beds, showing the deep Anadarko Basin paralleling the north flanks of the Wichita and Amarillo mountains and a shallow syncline extending from Custer County, Oklahoma, northward into southern Kansas. He also found that the "outliers" of the Lower Cretaceous of western Oklahoma were practically limited to these two synclines and that there existed a definite structural relationship between the Cretaceous and the underlying Permian rocks.

At this time the outline and location of the Anadarko Basin have been determined partly by the mapping of surface exposures of Permian formations, and partly by the study of logs of deep wells, and it is now believed to extend from southwestern Garvin County, Oklahoma, thence northwest, the axis crossing successively Stephens, Grady, Comanche, Caddo, Washita, Custer, Beckham, and Roger Mills counties, Oklahoma, into the Panhandle of Texas, crossing Wheeler, Gray,

11. Dwyer, J. S., Texas County, Oklahoma, has good possibilities: Oil and Gas Jour., vol. 25, no. 1, p. 34, 1926.
12. Clifton, R. L., Stratigraphy of the Whitehorse sandstone: Oil and Gas. Jour., vol. 23, no. 2, p. 70, 1926.
13. Clifton, R. L., The geology of Woods, Alfalfa, Harper, Ellis, and Major counties, Oklahoma: Oklahoma Geol. Survey Bull. 40-A, 1926.
14. Greene, Frank C., The subsurface stratigraphy of western Oklahoma: Oklahoma Geol. Survey Bull. 40-D, 1926.
15. Gould, Chas. N., and Lewis, Frank E., The Permian of western Oklahoma and the Panhandle of Texas: Oklahoma Geol. Survey Cir. 13, 1926.
16. Bullard, Fred M., A study of the outlying areas of Lower Cretaceous in Oklahoma and adjacent States: Oklahoma Geol. Survey Bull. 47, 1928.

Roberts, Hutchinson, and Moore counties. The approximate location of this axis is shown on the accompanying map, fig. 12, page 76.

The location of the western end is not definitely known. The Anadarko Basin appears to be much shallower in Sherman County, Texas, than farther east, and probably flattens out and disappears to the west from here.

Neither is the location of the eastern end of the Anadarko Basin known. At this time there are not sufficient data at hand to warrant an opinion. A study of deep wells in Garvin and Murray counties should aid in answering the question.

STRATIGRAPHY

The rocks lying within the red beds region of western Oklahoma are difficult to classify and correlate. All of the formations are lithologically quite similar. Many of them locally contain beds and lenses of gypsum, dolomite, siltstone, sandstone, and clay that grade into one another both vertically and laterally. The rocks at one locality commonly differ from those occurring in another locality, even though they be at the same stratigraphic horizon. Not all of the rocks are consolidated. Some are marine, and others are terrestrial. The scarcity of good outcrops makes it very difficult to trace out formations. In most localities the logs of wells are of little value, and if reliable cuttings are not available, they are useless. Fossils are scarce, being limited to a few beds and a few localities. By noticing the slight lithologic changes, by "walking out" beds, and by laboratory study of samples, differences and similarities can be detected to justify at least some correlation and classification.

The rocks studied in the region belong to the Permian system and include the eight upper formations, i. e., the Duncan, Chickasha, Blaine, Dog Creek, Whitehorse, Day Creek, Cloud Chief, and Quartermaster, in ascending order.

Geologic Classification

AGE	FORMATION
Lower Cretaceous	Morrison
PERMIAN	Quartermaster Cloud Chief Day Creek Whitehorse Dog Creek Blaine Chickasha Clear Fork Wichita
PENNSYLVANIAN	Pontotoc (Cisco in Texas)

Correlation Table of Kansas, Oklahoma, and Texas.

<table>
<tr><th>AGE</th><th>SOUTHERN KANSAS</th><th colspan="2">WESTERN OKLAHOMA</th><th colspan="2">NORTH-CENTRAL TEXAS</th><th>TEXAS PANHANDLE</th></tr>
<tr><td rowspan="8">PERMIAN</td><td>Big Basin</td><td colspan="2">Quartermaster</td><td colspan="2">Quartermaster</td><td>Upper Red Beds</td></tr>
<tr><td>Hackberry
Day Creek
Whitehorse
Dog Creek</td><td colspan="2">Cloud Chief
Day Creek
Whitehorse
Dog Creek</td><td rowspan="4">DOUBLE MOUNTAIN</td><td>Cloud Chief
(Alibates)
Whitehorse
Dog Creek</td><td>Alibates
Whitehorse
Dog Creek</td></tr>
<tr><td>Blaine</td><td colspan="2">Blaine</td><td>Blaine</td><td>Blaine</td></tr>
<tr><td>Flower Pot
Cedar Hills
Salt Plains</td><td rowspan="5">ENID</td><td>Chickasha</td><td>Chickasha</td><td rowspan="3">Salt Series
Red Cave</td></tr>
<tr><td>Upper Harper</td><td>Duncan</td><td>San Angelo</td></tr>
<tr><td>Lower Harper</td><td>Hennessey
Garber</td><td colspan="2">Clear Fork</td></tr>
<tr><td>Wellington</td><td>Wellington</td><td colspan="2">Clear Fork</td><td rowspan="3">Big Lime Series of Panhandle</td></tr>
<tr><td>Marion
Chase
Council Grove</td><td>Stillwater</td><td colspan="2">Wichita-Albany</td></tr>
<tr><td>PENNSYLVANIAN</td><td>Waubaunsee</td><td colspan="2">Eskridge</td><td colspan="2">Cisco</td></tr>
</table>

DUNCAN SANDSTONE

Name and Distribution

The Duncan sandstone derives its name from the city of Duncan, located in northern Stephens County, where the formation appears in a conspicuous escarpment one mile north of the city limits. In 1915, Wegemann[17] described this formation in the vicinity of Duncan but did not name it. In 1924, Gould, when the Oklahoma Geological Survey adopted a new classification for the Permian of Oklahoma, first used the term as a formation name.

It crops out in the form of a large **V**, having its vertex in central Stephens County, with one limb projecting northward and the other westward. The western limb crops out roughly parallel to and within five to fifteen miles north of the north flanks of the Wichita Mountains in Comanche and Caddo counties. In northeastern Kiowa County near the town of Mountain View, two gray, calcareous sandstone scarps are mapped as Duncan by Miser of the U. S. Geological Survey.[18] To the west and south, a gray sandstone occupying practically the same stratigraphic position as the above mentioned rock, and also considered to be Duncan, and correlated with the San Angelo sandstone of Texas,[19] crops out intermittently to the north banks of the Red River.

The north limb, starting at the vertex of the **V** in northern Stephens County, trends nearly straight north, passing through the counties of Garvin, Grady, McClain, Cleveland, Canadian, Kingfisher, Blaine, Garfield, Major, Woods, Alfalfa, and Grant in Oklahoma, and Harper County, Kansas, where it has generally been known as the Harper sandstone. Recent studies by H. L. Griley and others, yet unpublished, would indicate that the Duncan is the equivalent of the Cedar Hills of Kansas rather than the Harper.[20]

Character

The Duncan sandstone varies in color, texture, and bedding with locality. In and near the vertex of the basin it is a coarse, gray, horizontal to cross-bedded sandstone. Out on the north limb its texture becomes finer, its bedding more nearly horizontal, and its color varies from pink to a deep red. On the west limb the sandstone also becomes finer and more calcareous, but retains its gray color and fine cross-bedding.

Thickness

The Duncan sandstone is believed to be thickest in Stephens, Garvin, and Grady counties, where a total of 180 feet was measured. In

17. Wegemann, C. H., The Duncan gas field, Oklahoma, and the Loco gas field, Oklahoma: U. S. Geol. Survey Bull. 621, pt. 2, 1915.
18. Misner, H. D., Geologic map of Oklahoma, U. S. Geol. Survey, 1926.
19. Gould, Chas. N., and Lewis, Frank E., The Permian of western Oklahoma and the Panhandle of Texas: Oklahoma Geol. Survey Cir. 13, 1926.
20. Gould, Chas. N., personal communication.

the well of the Malernee Oil Company, sec. 8, T. 3 N., R. 7 W., the thickness is about 120 feet. South of the town of Fletcher, in northeast Comanche County, the Duncan is only 20 feet thick, according to Becker.[21] Northeast of El Reno, in Canadian County, it is approximately 60 feet thick. In Beckham County, along the north bank of the North Fork of the Red River, in T. 8 N., R. 23 W., it is about 100 feet thick, according to Gouin.[22]

Relations to Adjacent Formations

Because no detailed work was done by the writer on the Wichita-Clear Fork formation, which underlies the Duncan sandstone, he can contribute nothing on the stratigraphic relations beneath the formation. Gouin[23] reports a discordance in dips between two formations and concludes that they are unconformable. The relations of the Duncan to the overlying Chickasha formation are not definitely understood. The writer is inclined to believe that the change is of a transitional nature, the one grading into the other in a lenticular fashion. The contrast is greatest in Stephens County, where the lithological differences of the two formations are quite pronounced, but to the north the lithological differences are not so obvious; in fact, they can hardly be distinguished by mineralogical and textural characteristics.

Detailed Sections and Analyses

Section at Table Mountain, sec. 14, *T.* 2 *N., R.* 3*W.*

		Feet
CHICKASHA		
11.	Mudstone, coarse, purple, massively bedded, sandy	10
10a.	Concealed	60
DUNCAN		
10.	Massive, coarse, friable, gray-red sandstone	5
9.	Massive crossed-bedded, lavender, soft sandstone interbedded with gray shale	9
8.	Gray-red shaly sandstone	15
7.	Finely cross-bedded gray sandstone	6
6.	Finley cross-bedded purple muddy sandstone	6
5a.	Concealed	15
5.	Friable, yellow, iron-streaked sandstone	3
4.	Gray, shaly, cross-bedded, fine sandstone	15
3.	Very fine, evenly bedded, purple shaly sandstone	6
2.	Gray, shaly siltstone	2
1a.	Concealed	30
1.	Fine, gray sandstone	8

Mechanical Analyses

Figure 2 *A*, p. 17, shows the results of mechanical analyses. In this figure and similar ones to follow, the figures in the left hand

21. Becker, Clyde M., verbal communication.
22. Gouin, Frank, Geology of Beckham County, Oklahoma: Oklahoma Geol. Survey Bull. 40-M, p. 8, 1927.
23. Gouin, Frank, The geology of the oil and gas fields of Stephens County, Oklahoma: Oklahoma Geol. Survey Bull. 40-E, 1926.

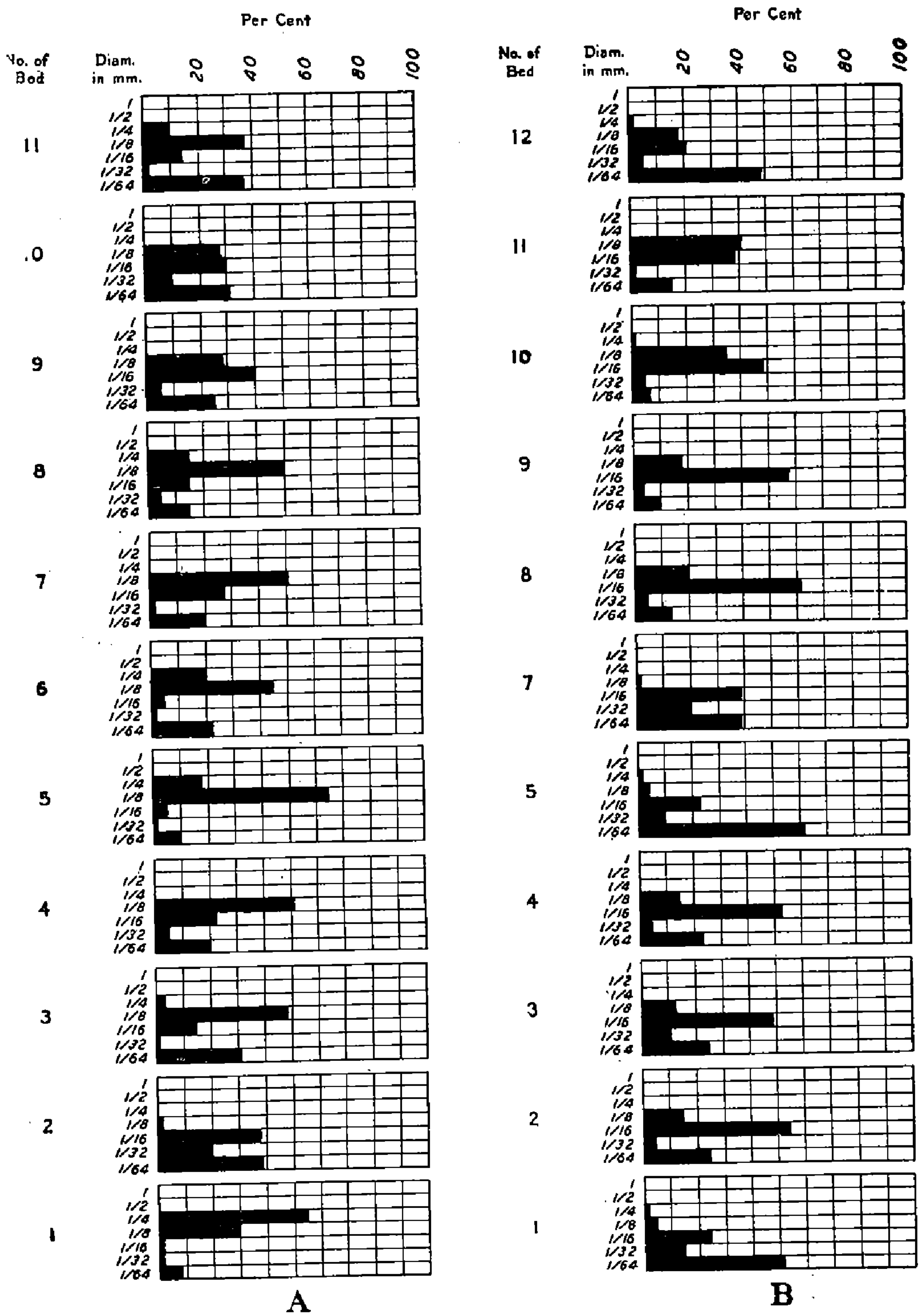

Per Cent
No. of Bed
Diam. in mm.
20
40
60
80
100
1
1/2
1/4
1/8
1/16
1/32
1/64
11
10
9
8
7
6
5
4
3
2
1
12
A
B

Figure 2.

column correspond to the numbers of the beds in the section, and the graphs indicate the percentage of distribution of the size-grades.

Bed 1 is at or near the base of the Duncan in this locality. Mechanical analysis shows it to be a fine sandstone with but little clay.

The Duncan-Chickasha contact is somewhere in 10a. Bed 11 is commonly called a "mudstone", but mechanical analyses show it to be a fine sandstone with a high percentage of clay.

The intermediate beds are similar and lack sorting, indicating fluvial or current deposition.

Solubility in acid

	Per cent
Beds, 1, 2, 3, and 4	12
Beds 5, 6, and 7	17
Beds 8, 9, and 10	15
Bed 11	32

Shapes of Grains

SHAPE	BED NUMBER		
	1	2-5, 7, 9-10	11
	Per cent	Per cent	Per cent
Round	2	0	3
Subround	8	5	5
Subangular	20	25	25
Angular	70	70	67

Mineral Content

MINERAL	BED NUMBER		
	1	2-5	6-11
	Per cent	Per cent	Per cent
Leucoxene	50	12	25
Tourmaline	40	10	45
Ilmenite	8	----	----
Garnet	2	2	18
Pyrite	----	75	----
Zircon	----	1	10
Apatite	----	----	1
Black opaque	----	----	1

Light minerals,* 99.8 per cent of samples; heavy minerals, 0.20 per cent. Quartz is the most abundant mineral. Fresh feldspar is always present as an accessory mineral.

*The term, light minerals, as used throughout this report, includes all minerals below 2.90 specific gravity. Heavy minerals are those above 2.90 specific gravity.

The high percentages of leucoxene, feldspar, and tourmaline in beds 1 and 6-11, and of pyrite in beds 2-5 are noteworthy.

Section in center of sec. 17, T. 8 N., R. 3 W.

	Ft.	in.
CHICKASHA		
12. Mudstone, slabby, thinly bedded, sandy, red	8	0
DUNCAN		
11. Cross-bedded, massive, red siltstone	4	0
10. Cross-bedded, sandy red siltstone	4	0
9. Cross-bedded, red, shaly, lenticular siltstone	5	0
8. Cross-bedded, massive, red, sandy siltstone	5	0
7. Evenly bedded, red, shaly siltstone	15	0
6. Sandy, gray, slabby dolomite		3
5. Massive, red, sandy shale	8	0
4. Finely bedded gray, dolomitic sandstone		3
3. Fine, red, shaly, cross-bedded, sandy siltstone	10	0
2. Mottled red and gray, cross-bedded, lenticular, sandy siltstone	8	0
1. Sandy, gray shale	12	0

Bed 12 is believed to be near or at the base of the Chickasha because of its characteristic red, mudstone lithology.

Mechanical Analyses

Figure 2 *B*, p. 17, shows the results of mechanical analyses. The silt and clay grades predominate, and no single sample has more than 3 per cent in the ¼-⅛ mm. or fine sand grade. In these samples also the sorting is poor.

Solubility in acid

	Per cent
Beds 1-11 (average)	17
Bed 12	60

Shapes of Grains

SHAPE	BED NUMBER 1, 2, 5, 12	3, 4, 8, 9, 11	7, 10
	Per cent	Per cent	Per cent
Round	1	0	0
Subround	4	1	0
Subangular	15	10	15
Angular	80	89	85

Mineral Content

MINERAL	BED NUMBER			
	1-3	4-8	9-11	12
	Per cent	Per cent	Per cent	Per cent
Yellow Tourmaline	35	33	----	----
Black opaque	25	28	35	6
Garnet	18	23	18	25
Zircon	12	5	10	20
Leucoxene	10	1	7	9
Graphite	tr.	tr.	----	----
Mica	tr.	----	----	----
Ugrandite	----	10	----	10
Tourmaline (green)	----	----	30	----
Tourmaline	----	----	----	30

Light minerals, 99.84 per cent of samples; heavy minerals, 0.16 per cent. Quartz is the most abundant mineral. Fresh feldspar is always present as an accessory mineral.

Tourmaline and the black opaque minerals are the most abundant in all samples excepting in 12 where the black opaque minerals drop down to 6 per cent. It is to be noted that in beds 4 and 8 and in bed 12, ugrandite (a variety of garnet) makes its appearance. In beds 9-11 green tourmaline takes the place of the yellow.

Section northeast of El Reno, NW. ¼ sec. 21, T. 14 N., R. 6 W.

		Feet
5.	Chert conglomerate	2
4.	Lenticular, purplish sandstone	5
3.	Massive, cross-beeded, red sandstone	15
2.	Red, lenticular shale	2
1.	Massive, cross-bedded sandstone at base	—

Mechanical Analyses

Figure 3 *A*, p. 21, shows the percentages of distribution of the materials in the different size-grades.

Beds 1, 2, 3, and 4 are quite similar in having most of the material distributed in the clay and silt grades and in having large secondary maxima. Bed 5 differs from all the others in that the secondary maxima is in the 16-8 mm. size-grade. The chert material in these grades consists of angular to rounded pebbles which were probably let down from post-Permian formations that may have overlain this area at one time, rather than by contemporaneous Permian deposition.

Solubility in acid

	Per cent
Beds 1, 2, and 3	12
Beds 4 and 5	40

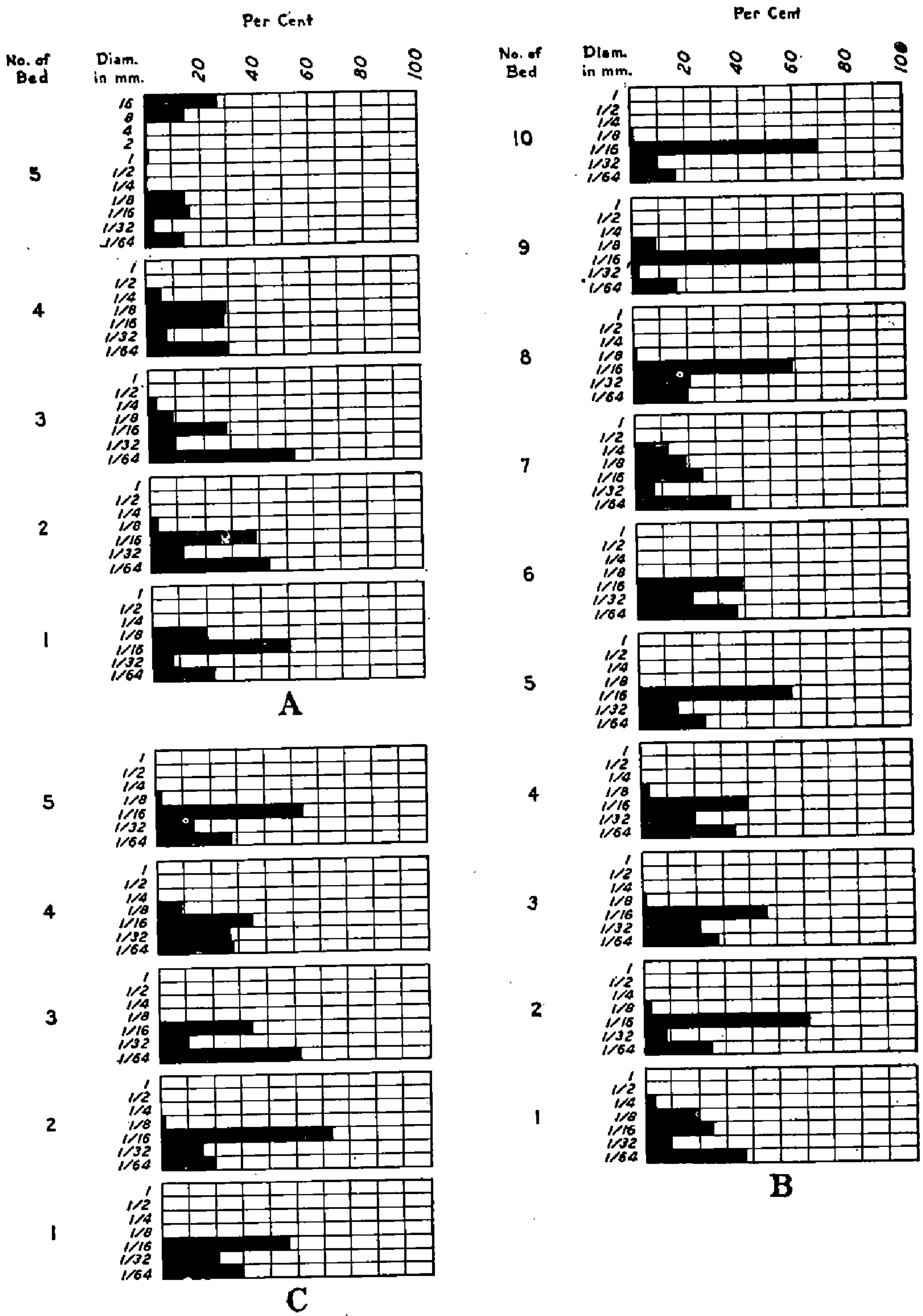

Per Cent
No. of Bed
Diam. in mm.
20
40
60
80
100
16
8
4
2
1
1/2
1/4
1/8
1/16
1/32
1/64
5
4
3
2
1
A
B
C
10
9
8
7
6

Figure 3.

Shapes of Grains

SHAPE	BED NUMBER		
	1	2, 3, 4	5
	Per cent	Per cent	Per cent
Round	0	2	2
Subround	0	4	21
Subangular	15	10	25
Angular	85	84	52

Mineral Content

MINERAL	BED NUMBER	
	1-3	4, 5
	Per cent	Per cent
Black opaque	30	25
Yellow tourmaline	25	20
Green tourmaline	20	35
Zircon	15	----
Garnet (weathered)	8	10
Leucoxene	2	8
Ugrandite	----	2

Light minerals, 99.8 per cent of samples; heavy minerals, 0.20 per cent. Quartz is the most abundant mineral. Feldspar is rarely present as an accessory mineral.

Section about 7 miles south of Kingfisher
sec. 8, T. 15 N., R. 7 W.

	Ft.	in.
DUNCAN		
5. Massive, red, gypsiferous scarp-forming sandstone	7	0
4. Massive, medium-grained, gray, friable, cross-bedded sandstone	5	0
3. Cross-bedded, lenticular, shaly sandstone	1	6
2. Cross-bedded, gray, fine, shaly, hard sandstone	2	0
HENNESSEY		
1. Blocky, brown-red shale	5	0

The Hennessey-Duncan contact is between beds 1 and 2. The shale of bed 1 is characteristic of the Hennessey shale.

About 6 miles north of the city of Enid and 2 miles west and 2 miles north of Hellum Lake, in sec. 35, T. 24 N., R. 7 W., the Duncan sandstone forms quite a conspicuous escarpment over an area of about one square mile. The Hennessey shale is found at the base of the Duncan in this locality. The section is as follows:

Section of Duncan sandstone, sec. 35, T. 24 N., R. 7 W.

		Ft	in.
DUNCAN			
10.	Thinly bedded red-gray siltstone	25	0
9.	Shale and red siltstone, more shaly near top than near bottom	25	0
8.	Horizontally bedded red shaly siltstone	4	0
7.	Dark red, fine, blocky shale	1	2
6.	Thin, cross-bedded, fine, red-gray, shaly siltstone	20	0
5.	Horizontally and massively bedded fine, shaly siltstone	4	0
4.	Persistent bed of wavy-bedded, deep red silty shale	1	0
3.	Thinly bedded, red, gypsiferous, shaly siltstone	7	0
2.	Horizontally bedded, slabby, fine, light gray, shaly siltstone	1	6
HENNESSEY			
1.	Gray-red shaly, horizonally bedded sandstone	2	0

Mechanical Analyses

Figure 3 *B*, p. 21, shows the mechanical analyses of the samples from the several beds. The silt and clay grades predominate throughout the section.

Solubility in acid

	Per cent
Bed 1 (Hennessey)	24
Beds 2-10	17

Shapes of Grains

SHAPES	BED NUMBER		
	1 (Hennes-sey)	2-6, 8-10 (Duncan)	7 (Duncan)
	Per cent	Per cent	Per cent
Round	0	0	3
Subround	5	0	9
Subangular	15	20	35
Angular	80	80	53

Mineral Content

MINERAL	BED NUMBER	
	1	2-10
	Per cent	Per cent
Iron oxide	70	----
Garnet (weathered)	30	----
Black opaque	----	48
Yellow tourmaline	----	2[illegible]
Green tourmaline	----	16
Zircon	----	5
Garnet	----	3
Leucoxene	----	2

Light minerals, 99.83 per cent of samples; heavy minerals, 0.17 per cent. Nearly all quartz. No feldspar found.

In the analyses of the previous section the differences between bed 1 (Hennessey) and beds 2-10 (Duncan) are brought out.

The first difference is brought out by the graphs showing the distribution of the size-grades of the materials, fig. 3 *B*, p. 21. Bed 1 (Hennessey) differs from beds 2-10 (Duncan) in having a high clay grade and a high secondary maximum in the silt and fine sand grades; whereas in the Duncan analyses the silt grade predominates and a high secondary maxima is absent.

A second difference between the two formations is that the Hennessey is more soluble in acid by 7 per cent than is the Duncan.

The shapes of the detrital grains of the two formations are not so obvious. In the Hennessey, 5 per cent of the grains are classified as subround, while no subround grains are found in the Duncan.

The most striking difference between the two formations is found in the mineral analyses which furnish a basis for separation. In bed 1 (Hennessey), iron oxide and weathered garnet make up the list. In beds 2-10 (Duncan), the black opaque minerals, yellow tourmaline, green tourmaline, zircon, garnet, and leucoxene occur in their order of abundance as listed.

Section in Grant County, Oklahoma, T. 29 N., R 8 W., north of Manchester

LOWER DUNCAN	Ft.	in.
5. A series of finely laminated gray-red horizontally bedded shaly siltstone	15	0
4. Hard light-gray horizontally bedded sandy siltstone	2	0
3. Deep red shaly siltstone	2	6
2. Red mottled-gray shaly horizontally bedded siltstone	10	0
1. Gray-red shaly horizontally bedded siltstone	2	0

The above section is near the base of the Duncan, but its contact with the Hennessey was not found. Between the Oklahoma-Kansas boundary and Anthony, Kansas, the Duncan of Oklahoma (the Harper of Kansas) is more shaly than it is in Oklahoma, although the other characteristics, such as the red color and horizontal bedding, are the same as in Oklahoma.

Mechanical Analyses

Figure 3 *C*, p. 21, shows the results of mechanical analyses. The fact that these samples contain no grains larger than 1/8 mm. in diameter indicates that the Duncan formation becomes finer toward the north.

Solubility in acid

	Per cent
Bed 1 (Hennessey)	24
Beds 2-10	17

Shapes of Grains

SHAPES	BED NUMBER	
	1-5	3-5
	Per cent	Per cent
Round	0	0
Subround	0	0
Subangular	5	15
Angular	95	85

Mineral Content

MINERAL	BED NUMBER 1-5
	Per cent
Black opaque	35
Tourmaline	30
Zircon	25
Garnet (weathered)	5
Leucoxene	4
Apatite	tr.
Graphite	tr.

Light minerals, 99.9 per cent of samples; heavy minerals, 0.1 per cent. Nearly all quartz.

Section one mile north and one mile east of McWillie, Alfalfa County, Oklahoma, in the NE. cor. sec. 23, T. 24 N., R. 11 W.

	Feet
CHICKASHA	
5. Fine gray-red shaly sandstone interbedded with thin layers of gypsum	15
4. Gypsiferous red shale with streaks of gray	4
3. Red-gray shaly sandstone	5
2. Gray sandy gypsiferous shale	3
DUNCAN	
1. Dark red, blocky shale	3

Section west of Alva, in sec. 22, T. 27 N., R. 14 W.

		Ft.	in.
CHICKASHA			
11.	Silty shale, red with gray streaks	12	0
10.	Gray sandy siltstone		6
9.	Red shaly siltstone	6	0
8.	Red shaly siltstone interbedded with thin layers and nodules of gypsum	15	0
7.	Red, sandy, bedded, gypsiferous siltstone	8	0
6.	Persistent bed of light-gray sandy siltstone; stands out conspicuously between the red siltstones above and below		10
DUNCAN			
5.	Alternately red and gray shaly sandstone	2	0
4.	Massive gray-red shaly siltstone with specks of gray. In fresh exposures the massive bedding is prominent	24	0
3.	Yellowish-red shaly siltstone		4
2.	Shaly siltstone red with streaks of gray	2	0
1.	Red-gray, gypsiferous, silty shale. Secondary layers of thin gypsum interbedded with the shale	10	0

Mechanical Analyses

Figure 4 *A*, p. 27, shows that the entire section, including both the Duncan and the Chickasha, is made up of fine material which contains no grains larger than ⅛ mm. in diameter.

Solubility in acid

	Per cent
Bed 1 (Duncan)	25
Beds 2-5 (Duncan)	7
Beds 6-11 (Chickasha)	7

Shapes of grains

SHAPES	BED NUMBER	
	1, 2, 3, 4	6-11
	Per cent	Per cent
Round	0	0
Subround	0	0
Subangular	4	8
Angular	96	92

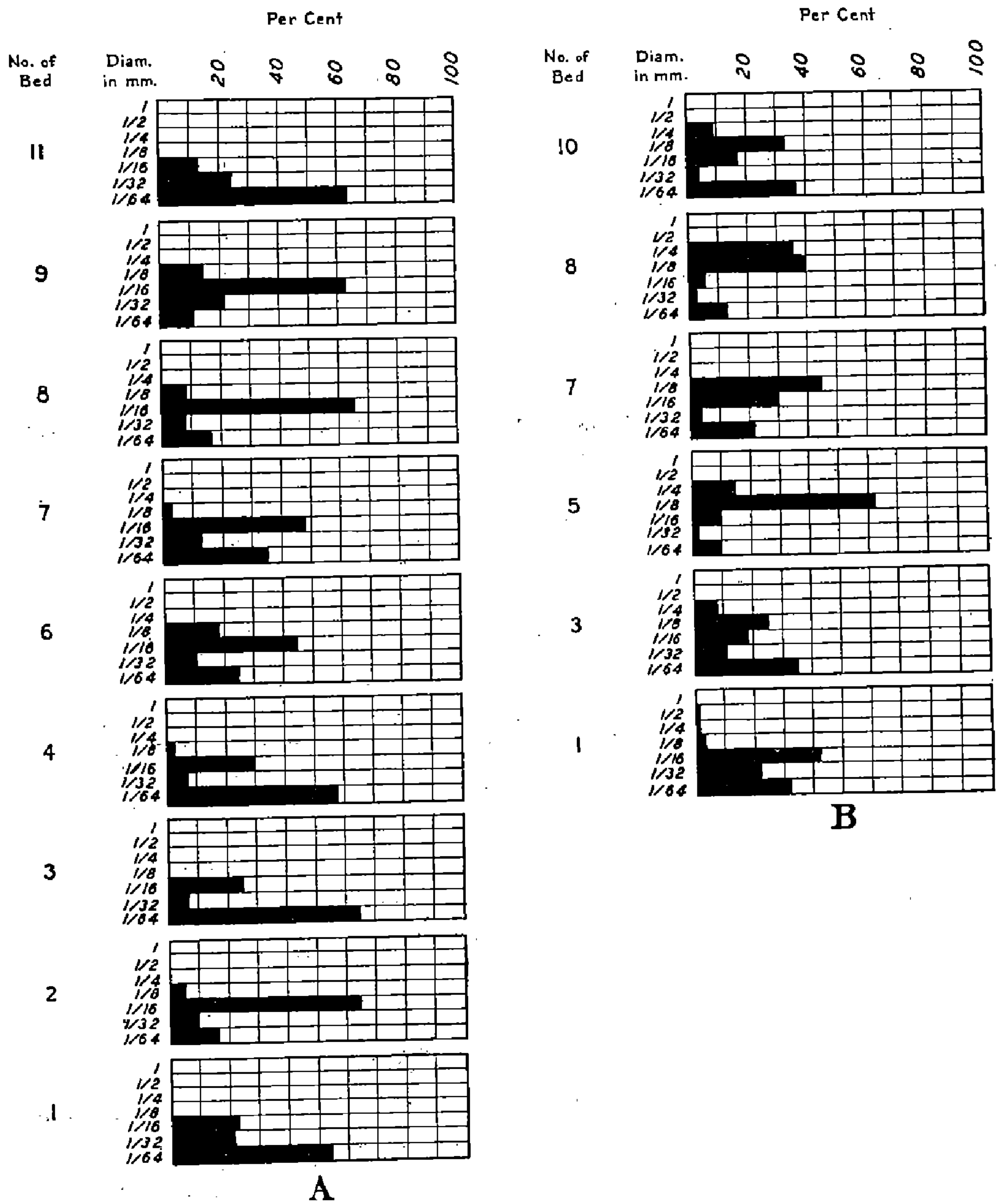

Per Cent
No. of Bed
Diam. in mm.
20
40
60
80
100
1
1/2
1/4
1/8
1/16
1/32
1/64
11
10
9
8
7
6
5
4
3
2
1
A
B

Figure 4.

Mineral Content

MINERAL	BED NUMBER 1-5 (Duncan)	BED NUMBER 6-11 (Chickasha)
	Per cent	Per cent
Black opaque	40	37
Yellow tourmaline	25	27
Zircon	20	16
Garnet (weathered)	10	5
Green tourmaline	5	10
Leucoxene	tr.	5
Hematite	tr.	----

Light minerals make up most of samples; heavy minerals, small per cent. Nearly all quartz.

The foregoing descriptions and analyses show that in northwestern Oklahoma the Duncan and the Chickasha formations are similar in texture and mineral content. In the vertex of the Anadarko Basin the two formations are also similar in texture and mineral content.

Section five miles east of Duncan, Stephens County, sec. 6, T. 1 S., R. 6 W.

		Feet
10.	Cross-bedded, lavender, shaly, sandstone	25
9.	Red mudstone	1
8.	Gray and red shaly sandstone	8
7.	Gray, cross-bedded, hard sandstone	12
6.	Red and gray shale	11
5.	Massive, gray, shaly sandstone	6
4.	Hard, lavender mudstone	3
3.	Red and gray, interbedded, sandy shale	6
2.	Finely bedded, gray, sandy shale	6
1.	Fine, gray-red, shaly siltstone	2

Mechanical Analyses

Figure 4 *B*, p. 27, shows the size-grade distribution and the contrast between series *A* and series *B*. On this figure is the measure of one of the points of contrast between the Duncan of the southeastern portion and of the northwestern portion of the Anadarko Basin.

Solubility in acid

	Per cent
Beds, 1, 3, and 5	13
Beds, 7, 8, and 10	25

Shapes of grains

SHAPES	BED NUMBER	
	1, 3, 5	7, 8, 10
	Per cent	Per cent
Round	0	0
Subround	2	0
Subangular	10	15
Angular	88	85

Mineral Content

MINERAL	BED NUMBER	
	1, 3, 5	7, 8, 10
	Per cent	Per cent
Tourmaline	50	40
Leucoxene	32	35
Garnet	10	10
Zircon	8	....
Rutile	tr.	....
Mica	tr.	....
Ugrandite	....	15

Light minerals make up most of the samples; heavy minerals, small per cent. Nearly all quartz.

The outstanding feature of the minerals in this section is the abundance and freshness of the feldspar. Most of the feldspar is orthoclase. It increases in proportion toward the top of the section.

About one and one-half miles southeast of the town of Elgin, Comanche County, Highway 7 crosses the Duncan scarp which trends northwest-southeast and which here is only a low ridge not noticeable from a distance.

Section in the NE. ¼, sec. 33, T. 4 N., R. 10 W.

		Ft.	in.
7.	Shaly, red sandstone	2	0
6.	Concealed	3	0
5.	Gray, coarse mudstone, with specks of gypsum	5	0
4.	Cross-bedded, coarse, red mudstone dipping to the northeast	15	0
3.	Red-gray, fine sandstone		8
2.	Red, friable, cross-bedded silty sandstone	1	0
1.	Gray silty shale	20	0

Mechanical Analyses

Figure 5 *A*, p. 30, shows the results of mechanical analyses.

Solubility in acid

	Per cent
Beds 3 and 7	14
Beds 1 and 2	64
Beds 4 and 5	36

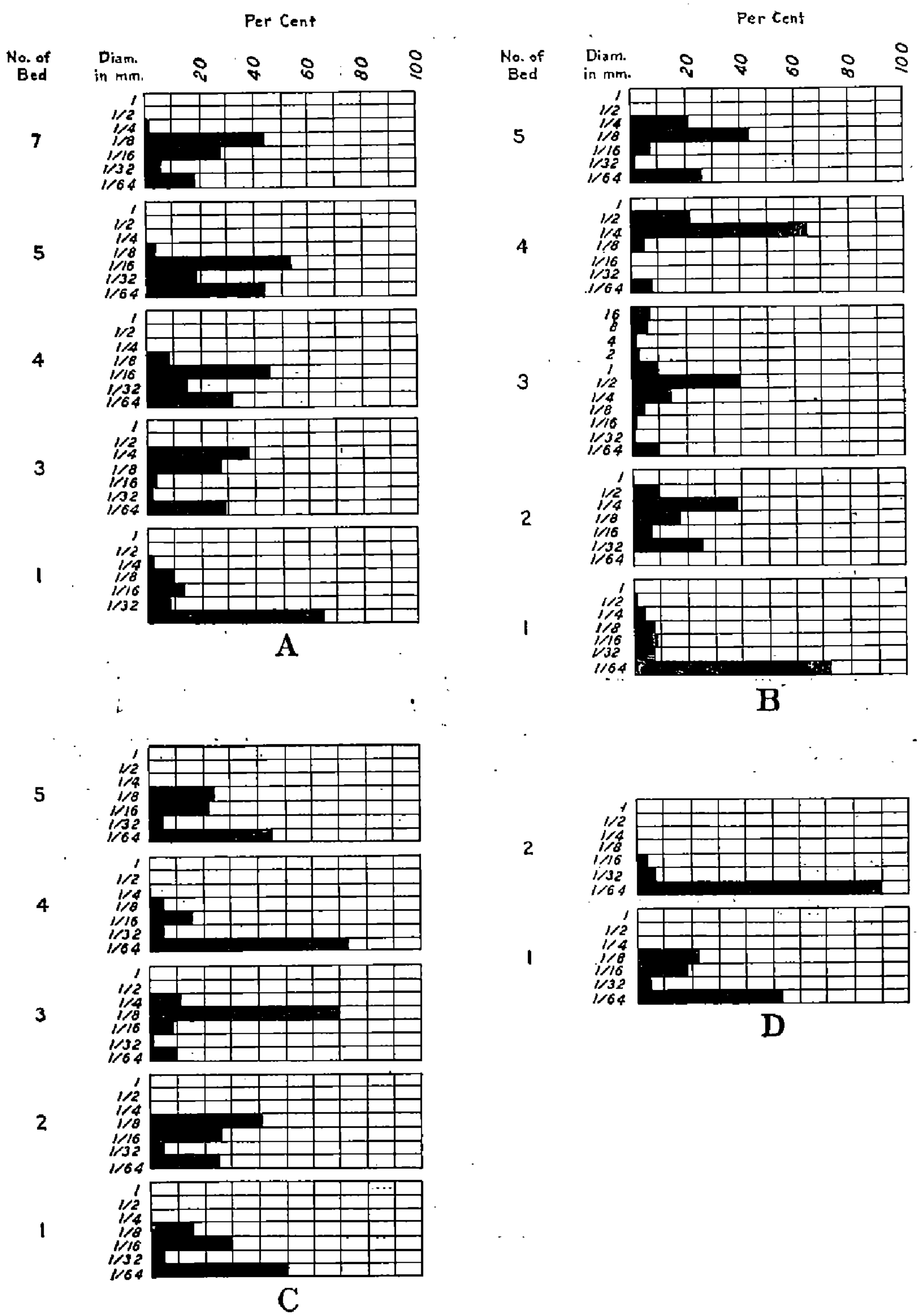


Figure 5.

Shapes of Grains

SHAPES	BED NUMBER	
	1, 2, 3, 4, 5	7
	Per cent	Per cent
Round	0	0
Subround	6	0
Subangular	10	5
Angular	84	95

Mineral content

MINERAL	BED NUMBER	
	1, 3	4, 5, 7
	Per cent	Per cent
Tourmaline	45	14
Garnet	30	22
Leucoxene	20	10
Black opaque	3	3
Pyrite	2	----
Ugrandite	----	31
Zircon	----	8
Sphalerite	----	6
Apatite	----	4
Pyroxene	----	1
Rutile	----	1

Light minerals make up most of the samples; heavy minerals, small per cent. Nearly all quartz. Fresh feldspar abundant as an accessory mineral.

A great variety of heavy minerals in beds 4, 5, and 7 is noteworthy. Ugrandite is conspicuously abundant.

Section of upper Duncan or lower Chickasha on north side of St. Louis and San Francisco Railroad in Comanche County, sec. 20, T. 4 N., R. 10 W.

	Feet
5. Dark, maroon-lavender sand	6
4. Gray shaly sandstone	2
3. Chert conglomerate zone	1
2. Cross-bedded, gray-lavender, friable sandstone	5
1. Lenses of red shale	3

Mechanical Analyses

Figure 5 *B*, p. 30, shows mechanical analyses.

Solubility in acid

	Per cent
Beds, 1, 2, and 3 (each sample)	30
Beds 4 and 5 (each sample)	9

Shapes of grains

SHAPES	BED NUMBER		
	1, 2	3	4, 5 (each)
	Per cent.	Per cent.	Per cent
Round	0	3	0
Subround	2	6	4
Subangular	25	23	10
Angular	73	68	86

Mineral Content

MINERAL	BED NUMBER			
	1	2	3	4, 5
	Per cent	Per cent	Per cent	Per cent
Tourmaline	45	45	40	35
Leucoxene	30	35	20	35
Garnet	20	5	----	5
Ugrandite	5	15	8	----
Black opaque	----	----	32	25

Light minerals make up most of the samples; heavy minerals, small per cent. Nearly all quartz. Fresh feldspar abundant as an accessory mineral.

Section southeast of the town of Mountain View sec. 24, T. 7 N., R. 15 W.

		Ft.	in.
5.	Gray mudstone	6	0
4.	Gray shale, mostly concealed	75	0
3.	Gray, cross-bedded, very fine sandstone	1	6
2.	Gray, friable, very fine sandstone	4	0
1.	Gray, sandy shale	8	0

Mechanical Analyses

Figure 5 *C*, p. 30, shows mechanical analyses.

Solubility in acid

	Per cent
Beds 1, 2, and 3 (each sample)	11
Beds 4 and 5 (each sample)	62

Shapes of grains

SHAPES	BED NUMBER	
	1, 2, 3, 4 (each)	5
	Per cent	Per cent
Round	0	0
Subround	0	8
Subangular	15	20
Angular	85	72

Mineral Content

MINERAL	BED NUMBER	
	1-3	4, 5
	Per cent	Per cent
Tourmaline	35	42
Garnet	31	32
Zircon	15	18
Leucoxene	10	6
Ugrandite	8	4
Black opaque	1	2

Light minerals make up most of the samples; heavy minerals, small per cent. Nearly all quartz. Feldspar rare as an accessory mineral.

Section in western Caddo County NE. 1/4 sec. 31, T. 7 N. R. 13 W.

	Feet
2. Blue-gray mudstone interbedded with red shale	2
1. Gray-red sandy shale	3

Mechanical Analyses

For mechanical analyses, see fig 5 *D*, p. 30.

Solubility in acid

	Per cent
Bed 1	64
Bed 2	18

Shapes of grains

SHAPES	BED NUMBER 1	BED NUMBER 2
	Per cent	Per cent
Round	0	0
Subround	0	0
Subangular	5	5
Angular	95	95

Mineral Content

MINERAL	BED NUMBER 1	BED NUMBER 2
	Per cent	Per cent
Tourmaline	41	48
Zircon	31	36
Leucoxene	14	3
Garnet	12	10
Black opaque	2	1
Ugrandite	----	2
Mica	----	tr.
Pyrite	----	tr.

Light minerals make up most of the samples; heavy minerals, small per cent. Quartz is by far the most abundant mineral. Feldspar rare accessory mineral.

Section northeast of Gotebo in the NW. 1/4 sec. 11, T. 7 N., R. 16 W.

		Feet
3.	Finely cross-bedded gray calcareous sandstone forming the upper scarp	1-2
2.	Gray-buff silty shale	10
1.	Gray calcareous sandstone forming the lower scarp	1+

Mechanical Analyses

Figure 6 *D*, p. 35, shows the mechanical analyses.

Solubility in acid

	Per cent
Bed 1	49
Bed 2	45
Bed 3	18

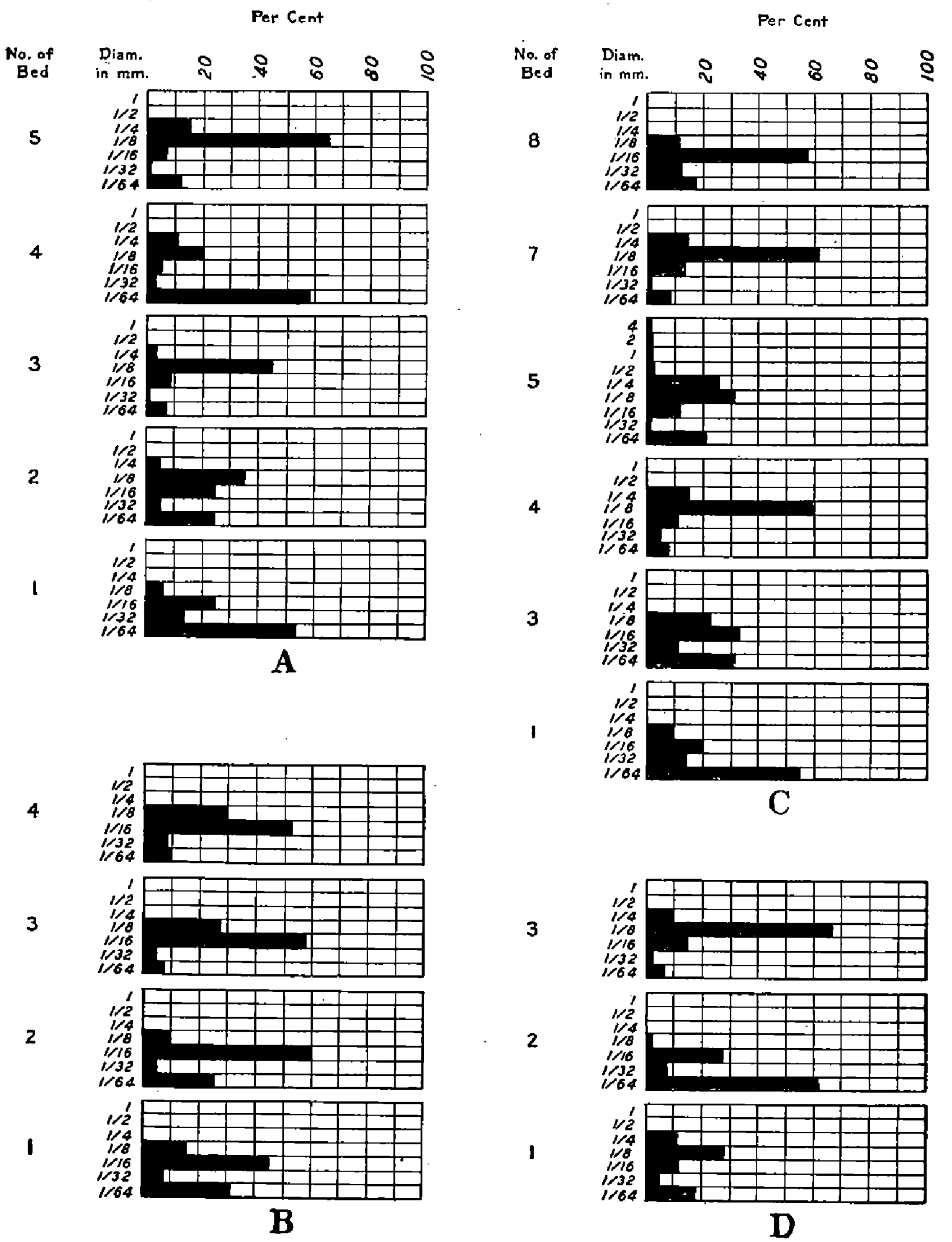

Per Cent
No. of Bed
Diam. in mm.
20
40
60
80
100
5
4
3
2
1
1
1/2
1/4
1/8
1/16
1/32
1/64
A
B
8
7
5
4
3
2
1
4
2
C
D

Figure 6.

Shapes of grains

SHAPE	BED NUMBER	
	1, 3	2
	Per cent	Per cent
Round	0	0
Subround	4	0
Subangular	12	10
Angular	84	90

Mineral Content

MINERAL	BED NUMBER
	1, 2, 3 each
	Per cent
Tourmaline	38
Garnet	25
Zircon	20
Leucoxene	10
Ugrandite	5
Black opaque	2
Mica	tr.
Rutile	tr.

Light minerals make up most of the samples; heavy minerals, small per cent. Quartz by far the most abundant mineral. Feldspar rare accessory mineral.

Section along North Fork of Red River, sec. 24, T. 7 N. R. 21 W.

	Feet
4. Gray silty sandstone	2+
3. Massive bed, gray, cross-bedded sandstone	8
2 Thinly bedded silty sandstone	2
1a. Concealed	25
1. Fine, cross-bedded, gray sandstone	2+

Mechanical Analyses

Figure 6 *B*, p. 35, shows the distribution of the size-grades.

Solubility in acid

	Per cent
Beds 1 and 2	28
Beds 3 and 4	62

Shapes of Grains

SHAPE	BED NUMBER 1-4
	Per cent
Round	0
Subround	0
Subangular	15
Angular	85

Mineral Content

MINERAL	BED NUMBER 1-4
	Per cent
Yellow Tourmaline	60
Garnet	25
Zircon	10
Leucoxene	5
Rutile	tr.
Pyrite	tr.
Mica	tr.

Light minerals make up most of the samples; heavy minerals make up small per cent. Quartz most abundant mineral. Feldspar absent.

Origin

The following origin and history of the Duncan sandstone have been worked out as a result of several weeks of field study of this formation, together with detailed laboratory work on the physical and mineral characteristics of samples collected in the field. In addition, various geologists familiar with the sediments of the Anadarko Basin have been consulted. However, the writer does not feel competent to make dogmatic statements as to the origin of this formation, source of materials, and so on, but wishes to state rather briefly his tentative conclusions.

In the southeast end of the Anadarko Basin the Duncan sandstone attains its maximum thickness, coarseness, and variability (fig. 2, p. 17; fig. 3 *A*, p. 21; fig. 4 *B*, p. 27; fig. 5 *A* and *B*, p. 30.) Traced to the northwest, along the north limb of the *V*-shaped outcrop, the sands change to silts and clays; and on the average the material becomes finer (fig. 3 *B* and *C*, p. 21; fig. 4 *A*, p. 27; fig. 5 *C*, p. 30 and fig. 6, p. 35.)

The mechanical analyses of samples from the Duncan sandstone along the north flanks of the Wichita Mountains do not differ very greatly from those to the southeast end of the Anadarko Basin (fig. 5 *A*, *C*, and *D*). The material is finer on the average, and large percentages fall into the very fine sand grades.

There is considerable variation in mineral content with locality. In the southeast end of the Anadarko Basin and along the north flanks of the Wichita Mountains, considerable quantities of feldspar are present, but out along the northeast limb feldspar is rare or entirely absent. Furthermore, the mineral content of this formation along the southwest limb is quite constant, while along the north limb there is a marked change.

With these facts in mind, it is concluded that much of the material making up the Duncan sandstone came from a southeasterly and southerly direction and from not far distant sources. As the Arbuckle and Wichita mountains are the closest positive areas in this direction from the Anadarko Basin, they no doubt furnished a large portion of the sediments. However, the Arbuckle and Wichita mountains may not have been of sufficient extent vertically and horizontally to supply all of the material, and it may be necessary to look for another source. As has been pointed out by Wilson,[24] Miser,[25] and others, there were positive areas to the east, southeast, south, and west that supplied material for the drainage into the Anadarko Basin during the time of Duncan deposition.

Mechanical analyses of the formation along the north flanks of the Wichita Mountains show uniformity of texture and of heavy mineral content. If the Wichita Mountains furnished considerable material, it would be expected to find coarse clastics in the Duncan in this area. Tourmaline, zircon, garnet, and leucoxene usually occur in the order named. Feldspar is abundant northeast of the mountains but is more rare to the west, suggesting that its main source may have been the Arbuckle Mountains. The hornblendes, pyroxenes, and magnetites are rare, but some were observed in the numerous samples studied. That the ferro-magnesian minerals are rare also suggests that the granitic cores of the Wichita Mountains were probably covered by older Paleozoic rocks during Duncan deposition. It is also a noteworthy fact that the minerals found in this formation are of the kind that undergo a great deal of transportation without decomposing or disintegrating. This fact also indicates that the source of the sediments was probably from secondary rocks, such as the limestones, shales, and sandstones of the Arbuckle and Wichita mountains. Therefore, the conclusions that have been advocated indicate that the Arbuckle Mountains and other remote positive areas, probably to the east, south, and

24. Wilson, Roy A., The upper Paleozoic rocks of Oklahoma: Oklahoma Geol. Survey Bull. 41, 1927.
25. Miser, H. D., Llanoria, the Palezoic land area in Louisiana and eastern Texas: Amer. Jour. Sci., 5th ser., vol. 2, pp. 61-84, 1921.

west, furnished most of the material and that the Wichita Mountains furnished very little.

CHICKASHA FORMATION

Name And Distribution

The Chickasha formation was named by Gould[26] after the town of Chickasha in Grady County, where the formation attains its maximum development. In contrast with the underlying Duncan, which contains two or three scarp-forming sandstones, the Chickasha is composed of soft, friable, loosely cemented sands that have little topographic expression and few exposures. The Chickasha lies immediately above the Duncan, and therefore its outcrops are distributed within the boundaries of the large *V* which has already been described for the Duncan. The belt of outcrop is only two or three miles wide along the west limb and from five to twenty miles wide near the extreme end of the north limb of the Anadarko Basin. The formation has been traced from Harper County, Kansas, southward around the head of the Anadarko Basin and westward along the north flanks of the Wichita Mountains, where it is hard to distinguish from the Duncan.

Character

In respect to lithology, color, and bedding, the Chickasha formation exhibits even greater variations than does the Duncan. In the southeast end of the basin, it is commonly referred to as the "purple sandstone".[27] Practically the entire formation consists of lenses of uncemented sands, cemented sands, shales, siltstones, and mudstones, no one of which can be traced for long distances. Northward along the north limb of the basin, the lenses give place to horizontal beds, and the purple sands and mudstone conglomerates change to brick-red, gypsiferous, shaly, siltstones and fine sandstones. In the northern part of the State the formation has no cross-bedding but uniformly horizontal bedding with no great lithologic changes. In the the west limb of the basin, as has been pointed out by Sawyer,[28] there is a similar change in lithology, color, and bedding, as in the vertex of the basin, Northwest of the town of Fletcher the characteristic Chickasha purple sand lenses and mudstone conglomerates have changed into red shale and siltstone and some gray, fine sandstones. West of Mountain View, because the outcrops are scarce, it is difficult to find even suggestions of a distinguishing characteristic by which to separate the Chickasha from the underlying Duncan.

26. Gould, Chas. N., A new classification of the Permian red beds: Bull. Am. Assoc. Pet. Geol. vol. 8, no. 3, p. 329, 1924.
27. Becker, Clyde M., Oil and gas geology of Caddo and Grady counties: Oklahoma Geol. Survey Bull. 40-I, p. 12, 1927.
28. Sawyer, R. W., Areal geology of a part of southwest Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 8, no. 3, 1924.

Thickness

The Chickasha formation has considerable variation in thickness. In the southeast end of the basin, south of Rush Springs, a thickness of 160 feet was measured. In northwestern Comanche County, Becker[29] reports a thickness of 90 feet. In Woods County it thickens to about 275 feet.[30]

Relations To Adjacent Formations

Because of variations in thickness and lenticular bedding, the relations of the Chickasha formation to the underlying Duncan are not well understood. In some localities the two formations are unconformable, but in general they are conformable to each other.

Detailed Sections and Analyses

To obtain good continuous sections of the Chickasha is quite difficult because of the non-resistant nature of the rock, especially in the southeast end of the Basin where the soft sands and mudstones are prevalent. Only where erosion is quite rapid is it possible to obtain fairly good sections, and even these are not thick. Most of the sections taken for field description and laboratory analyses occur in localities where fairly fresh contacts were available. Many of the sections have been described with the Duncan, pp. 16, 19, 25; figs. 3, p. 21, and 4, p. 27.

Section in the SE.¼ sec. 36, T. 4 N. R. 6 W.

		Ft.	in.
5.	Greenish-lavender shale and cross-bedded purplish mudstone	3	6
4.	Abrupt change to a lense of purplish-red horizontally bedded mudstone	3	0
3.	Fine, purplish-gray sandstone, with uniform bedding and texture	4	6
2.	Lense of gray, sandy, finely bedded shale	1	6
1.	Cross-bedded, hard, purple, finely laminated, sandy shale	2	0

Mechanical Analyses

Figure 5 *B*, p. 30, shows the results of mechanical analyses.

Solubility in acid

	Per cent
Beds 1 and 2 (each)	14
Bed 3	9
Beds 4 and 5 (each)	28

29. Becker, Clyde M., oral communication.
30. Longmeyer, J. L., oral communication.

Shapes of Grains

SHAPES	BED NUMBER	
	1, 2, 4, 5	3
	Per cent	Per cent
Round	0	2
Subround	3	6
Subangular	12	15
Angular	85	77

Mineral Content

MINERAL	BED NUMBER	
	1-3	4, 5
	Per cent	Per cent
Tourmaline	40	36
Leucoxene	30	39
Garnet	16	12
Zircon	11	10
Black opaque	2	2
Apatite	1	1

Light minerals make up most of the samples; heavy minerals, small per cent. Quartz is by far the most abundant mineral. Feldspar is an abundant accessory mineral.

Section in Grady County, sec. 11, *T.* 3 *N., R.* 6 *W.*

	Ft.	in.
BLAINE		
8. Thinly bedded, red sandy siltstone, interbedded with thin zones of gypsum and streaks of gray sand	15	0
7. Thinly bedded, gypsiferous sandy shales	5	0
6. Red shaly sandstone containing specks of gray shale and interbedded gypsum	2	0
5. Horizontally bedded red sandstone containing grains of chert about 1 mm. in diameter	1	0
CHICKASHA		
4. Lenticular zone, very fine, friable sandstone	2	6
3. Lenticular zone of pink-lavender mudstone		3
2. Lenticular, fine, lavender sandstone	1	0
1. Cross-bedded, lenticular, sandy lavender shale	2	6

Sandstone concretions up to 4 inches long and irregular in shape occur in beds 1-4.

Mechanical Analyses

Figure 5, *C*, p. 30.

Solubility in acid

	Per cent
Bed 1	13
Beds 2 and 4 (each)	9
Bed 3	28
Beds 5 and 6	14
Beds 7 and 8 (each)	11

Shapes of grains

SHAPES	BED NUMBER	
	1, 3	4, 5, 7, 8
	Per cent	Per cent
Round	0	0
Subround	0	8
Subangular	11	18
Angular	89	74

Mineral Content

MINERAL	BED NUMBER	
	1-4	5-8
	Per cent	Per cent
Tourmaline	35	30
Garnet	23	2
Ugrandite	18	8
Zircon	8	7
Leucoxene	7	18
Black opaque	4	35
Apatite	3	----
Rutile	2	----

Light minerals make up most of the samples; heavy minerals, small per cent. Beds 1-4. Quartz most abundant mineral. Fresh feldspar abundant accessory mineral. Beds 5-8. Quartz most abundant mineral. Feldspar rare accessory mineral.

Sections of the Chickasha on the north and east limbs of the basin are included on pages 16, 19, and 25. Section of the Chickasha in the southeast end of the basin are included with subsurface data, fig. 10, p. 72.

Origin

That the source of the Chickasha formation is closely related to that of the Duncan sandstone is strongly suggested by comparing the field aspects and the results of analyses of the two formations.

In the field the Chickasha, in and near the vertex of the basin, appears as a series of interbedded pink sandstones, shales, and lavender mudstones. Out on both flanks of the basin the formation changes from interbedded, lenticular shales, sandstones, and mudstones into horizontally bedded, fine, shaly red sandstones. Along the north flank, in the general region of Alfalfa and Woods counties, numerous bands of gypsum are interbedded with the shaly red sandstones and siltstones. Along the west limb, although no good outcrops were seen, the formation also becomes shaly, and the lenticular structure gives place to horizontal bedding.

Mechanical analyses show that the sediments become finer away from the vertex of the Basin. Most of the grains at the vertex of the Basin are in the ½-¼ or ¼-⅛ mm. grades (subsurface data, fig 10 p. 72); whereas in Woods County they are in the 1/16-1/32 mm. grades (fig. 4 *A*, p. 27).

The minerals at the vertex (subsurface data, p. 71,) and away from it (p. 28) differ in variety and in order of abundance.

During Chickasha deposition deltaic or shallow water conditions existed in the vertex of the basin. Into this depositional basin flowed rivers, subject to changes in volume and velocity, from the south and east. Toward the north and west the basin was deeper and marine conditions prevailed.

Because the size-grade distribution of the materials, the sorting, and the heavy mineral content of the Chickasha are very similar to those of the Duncan in the same localities, it is likely that the contributing sources were the same. The texture, the lack of sorting, and the presence of relatively fresh feldspars in the southeast end of the basin suggest that the material came from the south, southeast, and east. The nearby Arbuckle and Wichita mountains no doubt contributed some material toward the Chickasha in this locality, as they did in the case of the Duncan. Because the material out on the flanks of the basin becomes very fine and the mineral content changes, another and probably more remote source, perhaps the ancestral Rocky Mountains to the west, is indicated.

BLAINE FORMATION

Name and Distribution

The Blaine gypsum was first described by Gould in 1902[31] and with some modifications again in 1905.[32] It is one of the most easily

31. Gould, Chas. N., General geology of Oklahoma: 2d Bien. Rept., Dept. Geology and Nat. History, Territory of Oklahoma, pp. 17-74, 1902.
32. Gould, Chas. N., Geology and water resources of Oklahoma: U. S. Geol. Survey Water-Supply Paper 148, 1905.

recognized formations in the Anadarko Basin and has great longitudinal extent. According to Gould and Lewis,[33] it has been traced from northwestern Barber County, Kansas, southward around the head of the Anadarko Basin, thence to the Colorado River, Texas. It can be detected in a large number of well logs in the Panhandle of Texas and Oklahoma, but its exact top and base are not readily determined. In the Texas Panhandle, in Potter and Moore Counties, it outcrops along the South Canadian River.

Character

Along the northeast limb of the basin the Blaine consists of three massive gypsum beds, beds of red and gray shales, and thin dolomitic sandstones that contain marine fossils. In the vertex of the basin the massive gypsum beds are less conspicuous in the red shales, but distinct beds of red, gypsiferous, sandy shales are present. In the region of Greer County as many as five gypsum beds occur in the red shales of the Blaine, together with thin beds of dolomite.

Thickness

The thickness of the Blaine varies with locality. In Blaine County, near the head of Salt Creek, a total thickness of about 230 feet was measured. Toward the southeast its thickness decreases to about 43 feet[34] in Grady County. In sec. 7, T. 2 N., R. 5 W., a thickness of about 85 feet was measured. In Beckham County the Blaine averages about 200 feet in thickness.[35] Well logs in Beckham and Washita counties show a thickness of 110-250 feet.

Relations To Adjacent Formations

The exact relations to the underlying Chickasha, though not well understood, are regarded as being generally conformable but with local unconformities. The overlying Dog Creek shale is conformable.

Fossils

Fossils have been collected from the Blaine dolomites for many years. They consist of poorly preserved pelecypods reported by Beede[36] and others to be a species of *Pleurophorus*, a distinctly marine form. In the dolomite beds exposed in Salt Creek Canyon and in the vicinity of Watonga and Okarche, they are abundant in some zones. Along the southeast flank of the basin pelecypods in this formation may be found in the following localities: (1) NW. ¼, sec. 20, T. 7 N., R. 13 W., in a small creek bed, (2) in the vicinity of Mountain View, and (3) in the SW¼, sec. 20, T. 7 N., R. 13 W.

33. Gould, Chas. N., and Lewis, Frank E., The Permian of western Oklahoma and the Panhandle of Texas: Oklahoma Geol. Survey Cir. 13, 1926.
34. Becker, Clyde M., Oil and gas geology of Caddo and Grady counties, Oklahoma: Oklahoma Geol. Survey Bull. 40-I, 1927.
35. Gouin, Frank, Oil and gas geology of Beckham County, Oklahoma: Oklahoma Geol. Survey Bull. 40-M, 1927.
36. Beede, J. W., Invertebrate paleontology of the red beds (Oklahoma): 1st Bien. Rept., Dept. Geology and Nat. History, Territory of Oklahoma, 1902.

Mechanical Analyses

Figure 7 *A,* shows the size-grade distribution in the several beds.

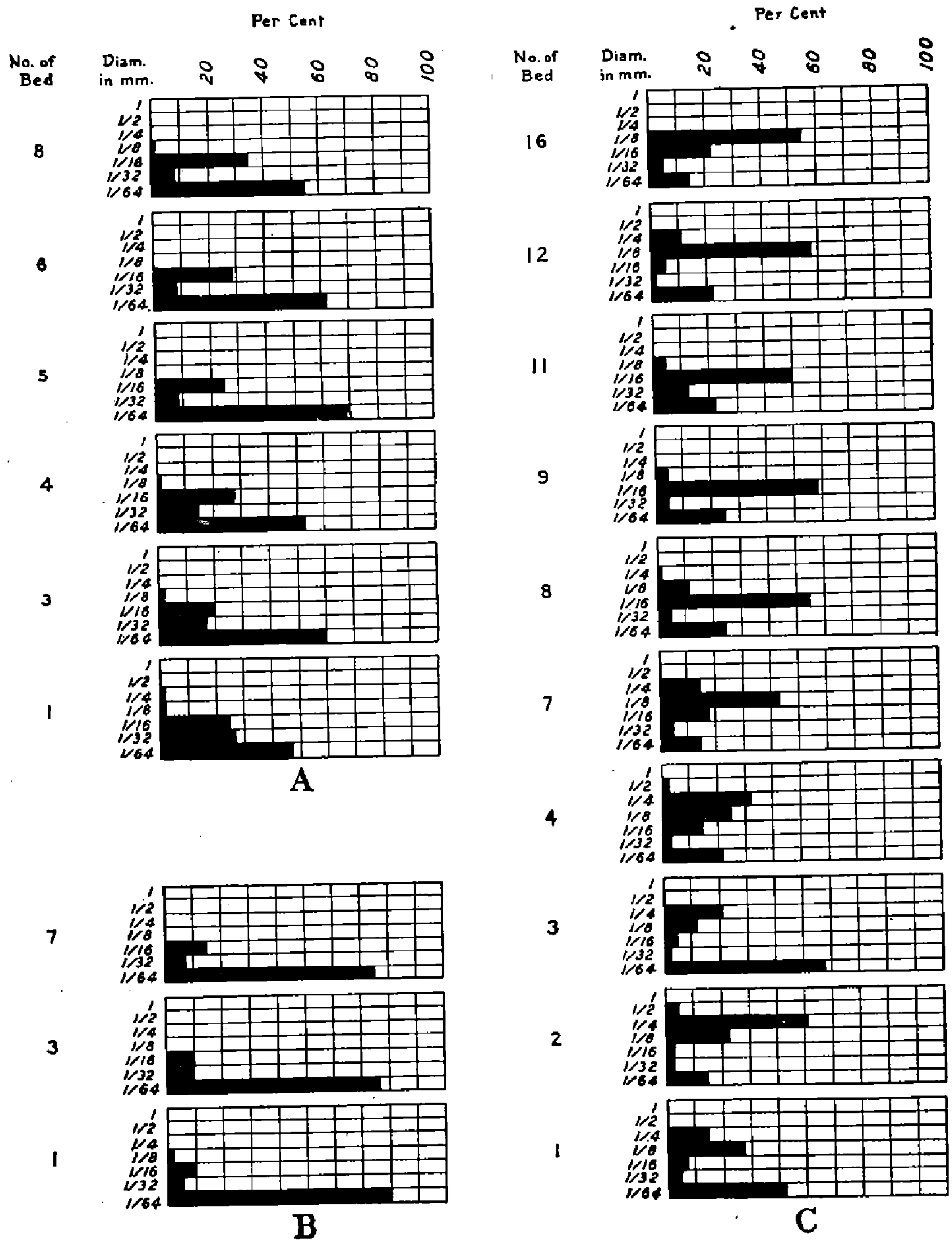


Figure 7.

Detailed Sections and Analyses

Section in Blaine County, sec. 23, T. 18 N., R. 12 W. near the head of Salt Creek

		Ft.	in.
10.	Bed of pure white gypsum	20	0
9.	Dolomite containing pelecypods		8
8.	Red and gray gypsiferous shale	25	0
7.	Bed of massive white gypsum	10	0
6.	Red and gray gypsiferous shale	20	0
5.	Massive bed of gypsum and shale	10	1
4.	Gray, sandy dolomite with pelecypods		8
3.	Gray, sandy shale	2	0
2.	Red shale with streaks of gypsum	140	0
1.	Very small exposure of gray gypsiferous, sandy shale that looks somewhat like the Chickasha at the head of the basin	2	0

Solubility in acid

	Per cent
Bed 1	30
Beds 3, 4, 5, 6, and 8 (each)	26

Shapes of grains

SHAPES	BED NUMBER	
	1	3, 4, 5, 6, 8
	Per cent	Per cent
Round	0	0
Subround	5	0
Subangular	20	10
Angular	75	90

Mineral content

MINERAL	BED NUMBER	
	1	2-8
	Per cent	Per cent
Zircon	36	24
Garnet	32	46
Black opaque	30	14
Tourmaline	2	8
Sphalerite	----	4
Apatite	----	4

Light minerals make up most of samples; heavy minerals, small per cent. Quartz abundant mineral. Feldspar absent.

The Blaine gypsum can be followed southeastward to a point north-
st of Watonga where the two pelecypod-bearing dolomites can be
n in a nearly continuous section. The red gypsiferous shales between

the two massive gypsum ledges have thinned to about 30 feet, but the sandy dolomites bearing the pelecypods have about the same thickness. The shales show a slight decrease in the amount of gypsum present.

Section northeast of Watonga

		Ft.	in.
7.	Massive ledge of white gypsum	12	0
6.	Gray sandy dolomite with pelecypods	1	0
5.	Gray shale		5
4.	Red gypsiferous shale	30	0
3.	Massive bed of white gypsum	15	0
2.	Gray, calcareous sandstone with pelecypods	2	0
1.	Red shale, thickness unknown.		

South of El Reno the red massive gypsum beds grade into red gypsiferous shales that have been traced around the southeast end of the Anadarko Basin and westward to the area north of Gotebo and Hobart, where the gypsum and pelecypod-bearing strata are again in

In southeastern Beckham County, in T. 7 N., R. 21 W., the Blaine gypsum forms prominent escarpments very similar in appearance to those found in Blaine and Major counties on the opposite side of the Anadarko Basin. As is the case with most of the red beds in Oklahoma, it is nowhere possible to obtain very thick sections of the Blaine, but it is believed to have an average thickness of about 200 feet.[38] The heavy gypsum members are the upper part. The following section is by Gouin.

Section of Blaine Formation

	Feet
Dolomite, honeycombed	3
Shale, red and blue	20
Gypsum, massive white	18
Shale red	5
Gypsum, massive, white	15

Section in sec. 14, T. 7 N., R. 21 W.

		Feet
9.	Massive bed of white gypsum	15
8.	Gray shale	2
7.	Gray to red gypsiferous shale	25
6.	Massive, impure, shaly gypsum	2
5.	Red, gypsiferous shale	12
4.	Hard gray gypsiferous shale	2
3.	Red gypsiferous shale, badly slumped	30
2.	Gray shale and gypsum	1
1.	Red gypsiferous shale	5

Mechanical Analyses

Solubility in acid

	Per cent
Bed 1	18
Beds 3 and 7 (each)	12

37. Gould, Chas. N., and Lewis, Frank E., The Permian of western Oklahoma and the Panhandle of Texas: Oklahoma Geol. Survey Cir. 13, 1926.
38. Gouin, Frank, Oil and gas geology of Beckham County, Oklahoma: Oklahoma Geol. Survey Bull. 40-M, 1927.

Shapes of Grains

SHAPES	BED NUMBER 1,3,7 (each)
	Per cent
Round	0
Subround	0
Subangular	5
Angular	95

Mineral Content

MINERAL	BED NUMBER 1	3, 7
	Per cent	Per cent
Black opaque	50	35
Tourmaline	30	20
Zircon	15	3
Garnet	3	30
Leucoxene	2	12

Light minerals make up most of the samples; heavy minerals, small per cent. Quartz most abundant mineral. Feldspar absent.

Section in the southwestern area, after Gould[39]

	Feet
Dolomite, honeycombed	3
Red Clay	20
Massive White gypsum (Collingsworth)	12
Red and blue clay	6
Massive white gypsum (Cedartop)	18
White and green and red clay	6
Massive white gypsum (Haystack)	20
Red and greenish clay	15
Greenish selenitic gypsum (Kiser)	12
Red Clay	12
Hard stratified gypsum (Chaney)	4
Bluish and red clay	5
Hard gypsum	2
Red and bluish shale banded	75

Section in the SW. 1/4, sec. 5, T. 7 N., R. 17 W.

	Feet
3. Buff-gray dolomite with pelecypods	1
2. Gray shale	5
1. Red shale	14

39. Gould, Chas. N., U. S. Geol. Survey Water-Supply Paper 148, 1905.

Section in the NE. corner, sec. 9, T. 7 N., R. 17 W.

		Feet
4.	Buff-gray dolomite	1
3.	Red shale	25
2.	Gray shale	35
1.	Red shale	40

Near the town of Mountain View the heavy gypsum ledges have disappeared almost entirely and the two dolomites have become thinner. The pelecypod-bearing dolomite, believed to be the same as the one found in the Blaine west of Mountain View, was traced southeast to the SW. ¼ sec. 20, T. 7 N., R. 13 W.

Section in SW. ¼, sec. 20, T. 7 N., R. 13 W.

3.	Surface		
2.	Buff-gray dolomite with pelecypods		3
1.	Red shale	4	0

Elevation of dolomite, 1,381 feet.

Section in northern Stephens County, SW. ¼, sec. 7, T. 2 N., R. 5 W.

		Ft.	in.
BLAINE			
17.	Horizontally bedded, silty shale with disseminated selenite; very hard and resistant. Near the top is a scarp-forming layer composed of thin horizontal beds	5	0
16.	Gray silty shale and a little gypsum	1	0
15.	Series of fine, deep-red shales and a little gypsum	16	0
14.	Red shale overlain by 8 inches of sandy gray gypsum	3	0
13.	Red silty shale with streaks of gray sand	10	0
12.	Red thinly bedded gypsiferous shale with stringers of satinspar that have a thickness of a fraction of an inch to 1 inch	8	0
11.	Gray gypsiferous shaly fine sand in horizontal beds 8 inches thick	3	0
10.	Red gypsiferous silty shale with gray lenses; thinly bedded	2	0
9.	Hard brown gypsiferous shale	30	0
8.	Massive beds of gypsiferous shale with gray specks	4	0
7.	Massive bed of red and gray shaly gypsum with gray specks that give it a mottled appearance, and thin lenses of gypsum	4	0
6	Gypsiferous silty shale, very resistant		6
CHICKASHA			
5.	Gray shale	1	0
4.	Gray calcareous shale		2
3.	Purple mudstone lens; highest mudstone in the Chickasha	3	0
2.	Lens of purplish-gray fine sandstone	1	0
1.	Mudstone lens, thinning out to the northwest	2	0

Mechanical Analyses

For mechanical analyses, see fig. 7 *C*, p. 45.

Solubility in acid

	Per cent
Beds 2 and 5 (each)	15
Beds 1, 3, and 4 (each)	51
Beds 7, 8, and 9 (each)	20
Beds 10-14 (each)	20
Beds 15-17 (each)	20

Shapes of grains

SHAPES	BED NUMBER	
	1-4	7-16
	Per cent	Per cent
Round	0	0
Subround	5	0
Subangular	15	20
Angular	80	80

Mineral Content

MINERAL	BED NUMBER			
	1-5	7-8	9-11	12-17
	Per cent	Per cent	Per cent	Per cent
Tourmaline	40	24	15	30
Ungrandite	30	17	----	10
Garnet	15	----	----	----
Leucoxene	14	44	----	5
Black opaque	1	10	75	55
Garnet (weathered)	----	5	8	----
Zircon	----	----	2	----
Sphalerite	----	----	tr.	----

Light minerals make up most of the samples; heavy minerals, small per cent. Quartz most abundant mineral. Feldspar in 1-5, rare in 7-8, absent in 9-17.

Mechanical analyses of the previous section show certain differences between the Chickasha and Blaine formations. Figure 7 *C*, p. 45, shows that the detrital grains of the Chickasha are coarser than the Blaine, and not so well sorted, indicating a change in sedimentation probably from deltaic in the Chickasha to deltaic-shallow marine in the Blaine.

The solubility in acid (p. 50) of the Chickasha exceeds that of the Blaine by about 30 per cent.

The shapes of grains (p. 50) of the Chickasha are slightly less angular than of the Blaine.

Origin

The clastic beds. Along the north flank of the Anadarko Basin, in Blaine County, nearly all of the detrital material falls into the clay and silt grades (fig. 7 *A*, page 45). On the opposite side of the basin, in Beckham County, nearly all of the detrital material falls into the clay grade and in no sample more than 15 per cent into the 1/16-1/32 mm. size-grade (fig. 7 *B*, page 45). At the most eastern outcrop of the Blaine, in Stephens County, the material is much coarser than out on the flanks of the basin. The predominating size-grades are in the 1/8-1/16 mm. and 1/16-1/32 mm. divisions, and the clay grades are subordinate to the silt and sand grades (fig. 7 *C*, page 45).

The heavy mineral content of the Blaine is quite uniform throughout its entire area of outcrop. However, there is some difference in the order of abundance as between the extreme north flank of the basin and the vertex, and along the west flank, but the kinds of heavy minerals are essentially the same.

It appears, therefore, that the clastic sediments constituting the Blaine formation had two distinct sources. Because in and near the head of the basin the strata are distinctly sandy and grade into shales toward the west, it is believed that the source was somewhere to the east and south, probably from the Arbuckle Mountains or even farther away. In the western area, where the thickness is greatest, where the massive gypsum beds and thin dolomites occur, where the detrital material is about the same texturally, where the detrital material is about the same out to the extreme ends of the two flanks, and where the heavy minerals are very nearly the same as those found in the underlying Duncan and Chickasha formations, the source was probably very nearly the same as for those older formations, somewhere to the west, perhaps the ancestral Rocky Mountains.

At the southeastern end of the basin the water must have been very shallow, and perhaps dry land existed temporarily and locally. Farther west, however, the basin was probably deeper.

The gypsum. The early workers on the origin of gypsum, particularly of the gypsum of New York, believed that the action of sulphurous waters on limestones caused the formation of gypsum, the sulphurous waters being derived from the oxidation of pyrite and other sulphides.

In 1877, Ochsenius published the results of his work on the composition of sea waters, which resulted in the formulation of the idea that gypsum is precipitated directly from the concentration of the saline contents of sea water by evaporation.

In 1913, Grabau[40] pointed out certain difficulties with the direct

40. Grabau, A. W., Paleozoic delta deposits of North America: Bull. Geol. Soc. America, vol. 24, pp. 496-498, 1913.

evaporation theory, the main objection being the large amount of water necessary to furnish the gypsum. Wilder[41] has estimated that a fifteen-foot bed of gypsum requires the evaporation of a basin of normal sea water having a depth of 34,987 feet and vertical sides. It is not generally believed that any such great depth of water existed where the present day gypsum deposits are located.

Branson[42] proposed a "modified bar hypotheses" to account for the thick deposits of gypsum free from salt, his idea being that the evaporating basin receives highly concentrated solutions instead of normal sea water. He says:

> In the drying up of a large interior sea the waters might come to lie in separate basins if the bottom were uneven. Evaporation over the full expanse of the interior sea might be rapid enough to decrease the depth and area in spite of the inflow of some stream, but when considerable areas of bottom had become exposed, the total evaporation would have become less and the inflow nearer to the amount of evaporation. Assuming that isolated basins would be formed separated by low barriers and that the main streams would empty into the marginal basins the inflow might be sufficient to cause these basins to overflow and supply the inner basins that had no direct stream connections with highly charged waters as fast as their own waters evaporated. As beds of gypsum 10 feet in thickness are widespread a depth of water great enough to contain the salt of sea water evaporated to deposit them must be assumed and the evaporation must not be carried beyond nine-tenths of the original amount if the salt is to remain in solution. The depth of a basin for 10 feet of gypsum would have to be at least 1,400 feet and possibly 1,500.

He also supposes that where very great thicknesses occur currents shifted unconsolidated gypsum about, probably into deeper and more quiet basins. Furthermore, he proposes that after gypsum has been precipitated in a basin, water inflows from a stream-fed border basin, which causes the basin to overflow into another basin, where further evaporation brings the water to the salt-depositing stage. Such conditions must be somewhat ideal; it is doubtful that they would frequently occur, and, at the present time, no such places are known to exist on the surface of the earth. However, there are a few places where some gypsum is deposited today, such as in Karabugas Gulf, the Nile delta, and the Red Sea salinas. The gypsum deposited in these places is very impure, consisting of thin bands or individual crystals scattered throughout the silt.[43]

The lime carbonate associated with the gypsum must be accounted for by precipitation from sea water. The order of precipitation is inversely as the solubility of the salts;[44] that is, the least soluble salts are deposited first. Wilder states that there should be at least one foot

41. Wilder, Frank A., Gypsum; its occurrence, origin, technology, and uses: Iowa Geol. Survey, vol. 28, 1917-1918.
42. Branson, E. B., Bull. Geol. Soc. America, vol. 26, p. 236, 1915.
43. Wilder, Frank A., op. cit., p. 117.
44. Clarke, G. W., Data of Geochemistry: U. S. Geol. Survey Bull. 770, p. 218, 1924.

of limestone below a fifteen-foot bed of gypsum. Laboratory experiments show that lime carbonate is first partly deposited and also later partly deposited with the gypsum. Branson[45] points out that the waters might have been more widespread in the beginning, thereby precipitating the calcium carbonate over a wide area before further concentration of the water in a more restricted basin to precipitate the gypsum. In spite of this, there should be some calcium carbonate contamination of the gypsum.

Steiglitz[46] calls attention to the importance of the carbon dioxide in the atmosphere influencing the solubility of calcium carbonate, a fact which must be considered in accounting for the direct precipitation of calcium sulphate from sea water. He assumes an ideal situation, in which the natural waters of the earth contain only lime salts, that is, the sulphate, carbonate, and bicarbonate, in equilibrium with the atmosphere; then by evaporation calcium carbonate would be deposited first, as is now the case until the saturation point for gypsum is reached, when even still some calcium carbonate contamination is evident, the degree of which depends partially on the pressure of the carbon dioxide in the atmosphere. Conclusions based on Stieglitz's work indicate that gypsum deposits containing less than 0.9 per cent of calcium carbonate were unlikely to have formed under salt pan conditions.

Wilder[47] states that there is no calcium carbonate present in the Medicine Lodge or Blaine gypsums.

Grabau[48] has suggested that the connate waters, or sea waters imprisoned during the laying down of sediments have been the chief sources of saline deposits. Wilder[49] says that along ocean shorelines of today the beach sands contain considerable gypsum and salt formed by the evaporation of brines forced up onto the shore by wave action. The salts, of course, are leached out quite readily, and the gypsum remains.

Wilder[50] says that the shales in nearly every geological horizon in many localities contain crystals of selenite produced by the action of iron sulphate derived from the oxidation of pyrites on lime carbonate. He believes that the gypsum beds at Fort Dodge, Iowa, were formed by the concentration of gypsum by streams flowing over and through the St. Louis limestones and the shales of the "Coal Measures." These limestones and shales contain as high as 2.95 per cent of gypsum, and since gypsum is quite soluble, the streams easily took it into solution and later deposited it.

45. Branson, E. B., Bull. Geol. Survey America, vol. 26, no. 2, p. 235, 1915.
46. Stieglitz, Julius, Contribution to cosmogony and the fundamental problems of geology: Carnegie Inst., pub. 107, p. 236, 1909.
47. Op. cit., p. 120.
48. Grabau, A. W., Textbook of Geology.
49. Op. cit, p. 121.
50. Op. cit., p. 121.

Rogers[51] concludes that most of the important gypsum deposits have been formed by the hydration of sedimentary anyhydrite.

Because of the fact that the Blaine gypsums are interbedded with a sedimentary series of shales and sandy dolomites that contain marine fossils, it is likely that the gypsum was deposited in partially isolated basins that were fed by sea waters and by land streams, in probably semi-arid climatic environments conducive to rapid evaporation of water.

DOG CREEK SHALE

Name And Distribution

The Dog Creek shale was named and first described in Clark County, Kansas, by Cragin.[52] It consists of a series of red clay shales lying immediately above the gypsum ledges of the Blaine formation in the Gypsum Hills region and can be traced southward around the southeast end of the Anadarko Basin. In northwestern Grady County the shales stand out conspicuously in some of the hills near the town of Minco. In the vicinity of Chickasha and Rush Springs they can be picked up at intervals, though with considerable uncertainty because of striking resemblance in color, lithology, and texture to the underlying Blaine and overlying Whitehorse. Along the southwest limb of the Anadarko Basin, the Dog Creek becomes more obscure, and it is easy to confuse it with the underlying and overlying formations. Up to the present time the Dog Creek has been traced westward as far as Beckham County.

Character

The Dog Creek, like all the other formations, is variable in character. In the western part of the area shales and siltstones are prevalent, but in the eastern end of the Anadarko Basin, the Dog Creek changes to gypsiferous, shaly, very fine sand.

Thickness

The thickness of the Dog Creek varies with locality. In Kansas it is only 30 feet thick, but shows gradual thickening to the south until in Woodward County its thickness is 225 feet.[53] Still farther south in Blaine County, it is 400 feet thick. Becker[54] reports a thickness of 90-115 feet in Caddo and Grady counties. In the southwestern area of the basin, in Beckham County[55] its thickness is about 90 feet. The logs of wells in Kiowa County give the Dog Creek a thickness of about 400 feet.

51. Rogers, A. J., School of Mines Quarterly, Columbia Univ., vol. 36, p. 141, Jan. 1915.
52. Cragin, F. W., The Cimarron series of Kansas: Colorado Coll. Studies, vol. 6, 1896.
53. Gould, Chas. N., A new classification of the Permian red beds: Bull. Am. Assoc. Pet. Geol., vol. 8, p. 334, 1924.
54. Becker, Clyde M., Oil and gas geology of Caddo and Grady counties: Oklahoma Geol. Survey Bull. 40-I, 1927.
55. Gouin, Frank, Oil and gas geology of Beckham County: Oklahoma Geol. Survey Bull. 40-M, 1927.

Relations To Adjacent Formations

The Dog Creek lies conformably above the Blaine gypsum ledges in the western part of the Anadarko Basin and is also believed to be conformable with the gypsiferous Blaine shales and siltstones in the eastern area. It is probably unconformable under the Whitehorse sandstone throughout the basin.

Detailed Sections and Analyses

Thick surface exposures are not plentiful, and the best sections are to be had from well cuttings.

Dog Creek in contact with the Whitehorse, sec. 25, T. 13 N., R. 10 W.

	Feet
WHITEHORSE	
6. Thinly bedded red shaly fine sandstone	11
5. Shaly red sandstone beds 4 in. thick and some dolomite	3
DOG CREEK	
4. Shaly sandstones interbedded with ½ in. layers of coarser sands	5
3. Ledge of massive shaly sandstone, bedding obscure	4
2. Resistant shaly massive sandstone beds	10
1. Shaly fine red sandstone in massive beds	15

Mechanical Analyses

Figure 8 *A*, p. 56.

Solubility in acid

	Per cent
Beds 1 and 2 (each)	8
Beds 3 and 4 (each)	6
Beds 5 and 6 (each)	4

Shapes of Grains

SHAPES	BED NUMBER	
	1, 2, 3, 4 (each)	5, 6 (each)
	Per cent	Per cent
Round	0	1
Subround	5	3
Subangular	15	25
Angular	80	71

Mineral Content

MINERAL	BED NUMBER	
	1,2,3,4	5,6
	Per cent	Per cent
Tourmaline	45	50
Black opaque	35	30
Leucoxene	12	10
Garnet	7	6
Zircon	1	4

Light minerals make up most of samples; heavy minerals small per cent. Quartz most abundant mineral. Feldspar rare or absent.

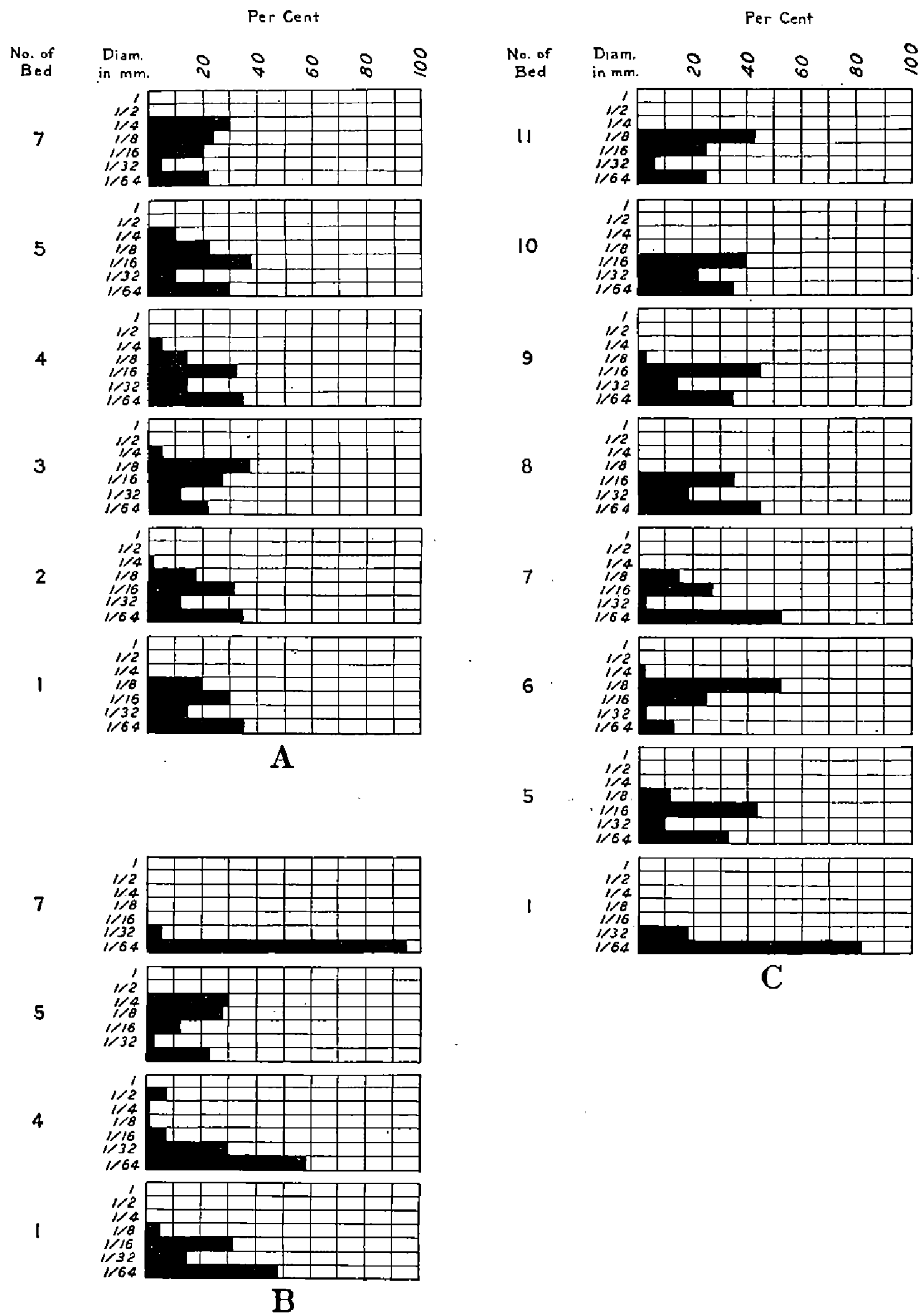


Figure 8.

Mechanical analyses of this section show that there is a large percentage of material in the ¼-⅛ mm. grades in beds 5-6 (Whitehorse) than in beds 1-4 (Dog Creek). Lack of sorting is a characteristic of the entire section. (See fig. 8 *A*, p. 46).

There is practically no difference in the percentage of soluble material throughout the section.

The detrital grains in beds 5-6 (Whitehorse) are less angular than in beds 1-4 (Dog Creek).

Heavy mineral analyses show insufficient variation in kind and order of abundance to warrant a separation of the two formations on this basis.

Upper part of Dog Creek, sec. 25, T. 13 N., R. 10 W.

	Feet
WHITEHORSE	
5. Fine light-red sandstone	2
4. Thinly bedded fine red sandstone containing flakes of gypsum and dolomite	2
DOG CREEK	
3. Hard gypsiferous shaly fine sandstone	2
2. Red gypsiferous shaly sandstone containing specks of blue-gray shale	3
1. Fine red shaly siltstone	3

Figure 8 *B*, p. 56, gives the results of mechanical analyses of the several beds. In fig. 8 *C*, bed 7 represents analyses of bed 1 in the previously described section.

Solubility in acid

	Per cent
Bed 1	8
Beds 2, 4, and 5 (each)	13

Shapes of grains

SHAPES	BED NUMBER 1	BED NUMBER 2, 4, 5 (each)
	Per cent	Per cent
Round	0	0
Subround	0	3
Subangular	2	12
Angular	98	85

Mineral Content

MINERAL	BED NUMBER 1-5
	Per cent
Tourmaline	42
Black opaque	35
Leucoxene	15
Garnet	5
Zircon	3

Light minerals make up most of the samples. Quartz most abundant. Feldspar rare or absent.

Subsurface section.—(See subsurface data, fig. 10, p. 72, and p. 71; and fig. 11, p. 74, and p. 73.)

Origin

Mechanical analyses of the samples analyzed from the various localities of the Dog Creek shale do not show any marked variations in the size-grade distribution, sorting, and heavy mineral content of the materials. However, in the southeast end of the basin, analyses show (fig. 10 p. 72) that there the detrital grains are a little coarser than farther to the west and north, as is shown by fig. 11, p. 74, and fig. 8 *A* and *B*, p. 56. These facts indicate that in the head of the basin material came from the east.

The heavy minerals found in the southeastern and western areas are nearly of the same kind and occur in about the same order of abundance, suggesting a single source. The minerals also resemble those found in the Duncan, Chickasha, and Blaine formations, which, in the western area of the Anadarko Basin, derived their sediments from the west; it is therefore apparent that the main source of the Dog Creek shale was to the west.

The Dog Creek shale is a shallow marine deposit in the western area and probably a terrestrial deposit in the southeastern area.

WHITEHORSE SANDSTONE

Name And Distribution

The Whitehorse sandstone was first named by Cragin[56] the "Red Bluff sandstone." The type locality is at Red Bluffs, on Bluff Creek, northwest of Protection, Comanche County, Kansas. In 1905, when Gould submitted his Water-Supply Paper 148, the committee on geolo-

56. Cragin, F. W., The Permian system in Kansas: Colorado Coll. Studies, vol. 6, p. 40, 1896.

gic names ruled that the name "Red Bluff" was in use elsewhere, and the name "Whitehorse" was substituted.

The Whitehorse outcrops over a wide area and crosses the axis of the Anadarko Basin toward its southern extremity. West of the town of Mountain View, where the dips are steep, the belt of outcrop is limited to a band only two or three miles wide. Along the northeast limb of the basin, where the dips are not so steep, the belt of outcrop averages about fifteen miles wide. Clifton[57] has mapped the formation from Comanche County, Kansas, southward around the head of the Anadarko Basin, westward along the north flanks of the Wichita Mountains to Collingsworth County, Texas; thence southward to and along the Red River in Hall County, and from Hall County southward to the exposures along the Colorado River in Coke County, Texas.

Character

The formation consists of fine and very fine sandstone, siltstone, and shale throughout its entire area of exposure. In general, the section contains less clay near and at the top, while near and at the base clay, silt, and very fine sand predominate. The color throughout is red, generally dark red, except in the region of the Cement oil field, where it is light gray. The individual grains are coated with iron oxide and calcareous matter, both of which make up the cemented material; but many of the beds are friable and free from any cementing material. Where the beds are exposed, weathering is rapid, producing a characteristic loose surface.

The stratification varies from horizontal beds to pronounced cross-bedding. Individual horizontal beds and cross-bedded members vary from a few inches to 25 feet in thickness. In some localities the cross-bedded and horizontal members overlie each other and the general appearance of the horizontal beds lying upon the cross-bedded members resembles an unconformity, as has already been fully described by Reeves[58] in the area of the Cement oil field, in Caddo County. He describes two distinct types of cross-bedding, (1) the regular type, and (2) the irregular type. He says:

> In the regular type of cross-bedding the oblique lamination planes are plane surfaces, and the dips at any one outcrop are all in one direction and all of approximately the same amount. The direction of these dips vary in different outcrops, but in the whole area mapped they are southward, with a range of 45° to the east or the west of south but usually a few degrees west of south. The angles of these dips range from 10° to 30°; as a rule they are more than 20°. Toward the base of a cross-bedded stratum the dip of the oblique laminae decreases and the layers thin and merge into the underlying horizontally bedded layers.
>
> In the irregular type of cross-bedding the layers dip in every direction at angles ranging from a few degrees to 15° but

57. Clifton, R. L., Unpublished thesis, Univ. of Oklahoma, Norman.
58. Reeves, Frank, Geology of the Cement oil field, Caddo County, Oklahoma: U. S. Geol. Survey Bull. 726-b, pp. 53-54, and 59-60, 1922.

> rarely more than 10°. They comprise cencentric and nonparallel layers, which are commonly less than an inch thick. The vertical extent of such cross-bedded material is usually less than 20 feet and its length not more than a few hundred feet. This type of cross-bedding is about as common as the regular type, and the two are found throughout the thickness of the Whitehorse sandstone.

He believes that the regular type of cross-bedding was developed on a delta built out into an inland body of water rather than by stream channels on the flood plain of a river. His reasons for this statement are:

> ***it is inconceivable that cross-bedding with foreset slopes so long dipping at angles so high and so uniformly in one direction, could have been formed in stream channels or on the flood plain of a river. That this type of cross-bedding is not that of the foreset beds of a marine delta is indicated by the facts that these beds are not continuous horizontally for more than a few hundred feet and that they are confined to no definite bed but may occur at several horizons in a single outcrop lying between horizontally bedded strata. Such delta foreset beds indicate a fluctuation in the level of the body of water that received the sediments. * * * and the cross-bedding of the irregular type being produced by the wind drifting the material about on the subaerial portion of the delta.

Southeast of the Cement region, in the vicinity of Rush Springs, as far as the writer is aware, only the regular type of cross-bedding occurs. The direction of dip of the foreset beds was observed to be to the south, the southeast, and the west-northwest.

Northwest of the Cement region, in the vicinity of Fort Cobb, the only type of cross-bedding observed was the regular type with the exception of a few exposures displaying the irregular type. Here all of the foreset beds dip to the west and the southwest.

In the extreme northeast flank of the basin, in Woods County, the Whitehorse is chiefly horizontally bedded, with some zones of regular cross-bedding. None of the irregular type was observed.

Thickness

The thickness of the Whitehorse differs considerably in different localities. In the southern end of the Anadarko Basin, in the Malernee Oil Company well, in sec. 8, T. 3 N., R. 7 W., the Whitehorse sandstone has a thickness of 212 feet. In Washita and Custer counties the logs of wells indicate a thickness of 425 feet. North of Whitehorse Springs, Woods County, Clifton described a continuous section of 280 feet from the top of the Dog Creek shale to the Day Creek dolomite.

Fossils

Gould[59] reported the first fossils in the Whitehorse sandstone in 1901, collected at Whitehorse Springs, Oklahoma, and at Dozier Mounds, Texas. Since that time a few collectors have found fossils in localized areas, chiefly in Woods County, Oklahoma. Beede[60] has described a number of species of brachiopods, pelecypods, and gastropods collected from the above mentioned localities as being strictly marine forms.

Relations To Adjacent Formations

Practically all of the geologists who have studied the Whitehorse agree that it rests unconformably upon the Dog Creek shale, although the contacts of the two formations are not plentiful. Clifton[61] has found that the unconformity is discontinuous and apparently limited to the border areas of the Dog Creek shale. The nature of the unconformity may be well seen in Woods County, where there are great inequalities in the surfaces of the underlying formations. Clifton reports a locality near Wildcat Mounds, in Woods County, where the entire Dog Creek and Blaine formations were removed prior to Whitehorse deposition. Farther toward the south the evidences of an unconformity are more obscure, and there seems to be more of a gradation between the Dog Creek and Whitehorse sediments.

VERDEN CHANNEL SANDSTONE

At the base of the Whitehorse sandstone there occurs a long channel-like deposit extending from a point several miles east of the town of Marlow, in northern Stephens County, northwestward to within several miles southwest of the town of Greenfield in southern Blaine County. Its distribution, lithology, and paleontology have been described by Reed and Meland,[62] Reeves,[63] Gould,[64] and Stephenson [65] and so only a brief mention will be made here. This formation differs strikingly from the adjacent ones because of its coarse texture, cross-bedding, well-rounded quartz grains, angular white chert fragments, and marine fossils. Gould describes the deposit as, "resembling a railroad grade extending across the country." The ledge is in only a few places more than 10 feet thick or more than 1,200 feet wide.

The origin of this peculiar formation is more or less speculative. Reeves[66] suggested a strong tidal current up a southeastward-flow-

59. Gould, Chas. N., Notes on the fossils from the Kansas-Oklahoma red beds: Jour. of Geol., vol. 9, pp. 337-340, 1901.
60. Beede, J. W., Invertebrate paleontology of the upper Permian red beds of Oklahoma and the Panhandle of Texas: Kansas Univ. Sci. Bull., vol.4, no. 3, 1907.
61. Clifton, R. L., Unpublished thesis, Univ. of Oklahoma, Norman.
62. Reed, R. D., and Meland, N., the Verden sandstone: Jour. Geol., vol. 32, pp. 150-158, 1927.
63. Reeves, Frank, U. S. Geol. Surv. Bull. 726-b, 1922.
64. Gould, Chas. N., A new classification of the Permian red beds: Bull. Am. Assoc. Pet. Geol., vol. 8, no. 3, p. 335, 1924.
65. Stephenson, C. D., Observations on the Verden sandstone of southwestern Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 9, no. 3, pp. 626-631, 1925.
66. Reeves, Frank, op. cit,

ing river, and Reed and Meland[67] suggested a northwesterly-flowing stream originating in the Arbuckle Mountains. They show by means of a table the close similarity that exists between the heavy minerals of the Simpson formation and the Verden sandstone. The similarity of the minerals found in the two formations favors the idea of a northwesterly-flowing stream having its headwaters in the Arbuckle Mountains, in the vicinity of which the Simpson outcrops.

Detailed Sections and Analyses

Section 7 miles north of Whitehorse Springs, Woods County, By Clifton[68]

	Feet
DAY CREEK	
7. Dolomite	2
WHITEHORSE	
6. Fine sandstone, poorly cemented	40
5. Highly cemented sandstone	10
4. Fine sandstone, sands, and sandy shales	100
3. Indurated sandstone, thin bed	5
2. Sandstones, sands and sandy shales	125
Unconformity	
DOG CREEK	
1. Shales	

Section in T. 28 N., R. 19 W.

	Feet
DAY CREEK	
Dolomite	2
WHITEHORSE	
15. Gray sandy shale	1
14a. Concealed and slumped	22
14. Finely laminated red and gray shaly sand	15
13. Red and gray sandy dolomitic shale	4
12. Very hard dolomitic shale	4
11. Red gypsiferous shale	2
10. Massively bedded shaly sand	13
9. Massive bed of red friable sandstone	10
8. Concealed and slumped	60
7. Massive red sandstone finely cross-bedded	70
6. Red sandstone, horizontally bedded	25
5. Red fine sandy shale	15
4. Gray dolomitic shale	1
3. Gray shale	2
DOG CREEK	
2. Red gypsiferous shale	20
1. Red gypsiferous shale	30

Mechanical Analyses

Figure 8 *C*, p. 56, shows the size-grade distribution of the materials.

67 Reed, R. D., and Meland, N., op. cit.
68. Clifton, R. L., Unpublished thesis, Univ. of Oklahoma, Norman.

Solubility in acid

	Per cent
Bed 1	18
Beds 5-9 (each)	24
Beds 10-14 (each)	34

Shapes of grains

SHAPES	BED NUMBER		
	1	5-9	10-14
	Per cent	Per cent	Per cent
Round	0	0	0
Subround	0	2	0
Subangular	5	10	20
Angular	95	88	80

Mineral Content

MINERAL	BED NUMBER		
	1	5-9	10-14
	Per cent	Per cent	Per cent
Black opaque	62	72	43
Garnet	15	8	----
Zircon	12	9	----
Rutile	5	6	7
Tourmaline	4	3	12
Leucoxene	2	2	----
Red Weathered Garnet	----	----	36
Ugrandite	----	----	2

Light minerals make up most of samples; heavy minerals, small per cent. Quartz most abundant; feldspar rare or absent.

In the previous section, bed 1 is Dog Creek shale having nearly all of its material in the shale grades (fig. 8 *C*, p. 56) and can thereby be distinguished from the overlying Whitehorse sandstone. It is also less soluble in acid by several per cent than the overlying Whitehorse beds. The heavy minerals in bed 1 and in beds 5-14 are so nearly alike in respect to kind and order of abundance that this criteria cannot be used in distinguishing the two formations in this locality.

Subsurface sections of the Whitehorse and mechanical analyses are given under subsurface data, pp. 71 and 73.

Origin

Mechanical analyses of the Whitehorse sandstone show differences in the size-grade distribution and mineral content in the head of the Anadarko Basin and out along the north flank. In the vertex of the basin the material is coarser and more highly sorted, as is shown by fig. 8 *C*, p. 56. Nearly the same kinds of minerals occur in the Whitehorse, and in nearly the same order of abundance, as in the Dog Creek, Blaine, Chickasha, and Duncan formations in the eastern and in the western area of the basin. Since it has been demonstrated that these older formations derived their material from two sources, i. e., from the east and from the west, it is likely that the Whitehorse sediments also came from the east and from the west.

In the vertex of the basin the Whitehorse sandstone is of terrestrial origin, as is shown by its cross-bedding, sorting, and absence of marine fossils. Much of the material was no doubt worked over by the wind as is suggested by the irregular type of cross-bedding and glazed surfaces of the sand grains.

In the western area there were incursions of the sea into more or less isolated basins as is shown by the localized distribution of the marine fossils.

DAY CREEK DOLOMITE

In the upper part, or directly on top of the Whitehorse sandstone, there occurs commonly a bed of hard, pinkish, white dolomite less than 5 feet in thickness, named by Cragin[69] the "Day Creek dolomite." The formation, being much more resistant than the loose sands of the Whitehorse, weathers into scarps and buttes that produce a rugged topography within the area of the Whitehorse outcrops in the northwestern portion of the basin. The conspicuous buttes in Woods, Blaine, and Caddo counties are of the resistant Day Creek dolomite. However, Evans[70] believes that much of the dolomite called "Day Creek" in Caddo County is in reality dolomite of Quartermaster age. He bases his conclusions on the conditions found near Weatherford, where the Quartermaster dolomite was found to lie directly on the Cloud Chief, partly on the Day Creek, and in some places on the Whitehorse sandstone.

CLOUD CHIEF GYPSUM

Name And Distribution

The Cloud Chief gypsum was named from the town of Cloud Chief, located in eastern Washita County, where the formation is typically developed. The earlier workers in Oklahoma spoke of this formation as the "eastern area" of the Greer.[71] Since that time the formation has been somewhat confusing to geologists, and its exact strati-

69. Cragin, F. W., The Cimarron series of Kansas: Colorado Coll. Studies, vol. 6, 1896.
70. Evans, Noel, Stratigraphy of the Weatherford area, Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 12, no. 7, 1928.
71. Gould, Chas. N., Geology and water resources of Oklahoma: U. S. Geol. Survey Water Supply Paper 148, 1905.

graphic position has been in doubt. Clapp,[72] in his work on the Cement area, considered the gypsum as the equivalent of the Blaine and gave it the name "Cyril." In the field conference of January, 1924, headed by Gould,[73] it was decided, in order to eliminate confusion that existed through usage of the former name, to assign a new name to the formation and the name "Cloud Chief" was selected.

The Cloud Chief gypsum is best developed along the axis of the Anadarko Basin, from southeastern Caddo County northwestward to the vicinity of Cloud Chief and Colony, in eastern Washita County. The formation outcrops intermittently along this line to eastern Washita County where the exposures diverge along the northeastern and southwestern limbs of the basin. The belt of outcrop is narrow along the southwest limb and wide along the northeast limb, as are the outcrops of the underlying formations. The southwest belt has been mapped across southern Washita County and into southern Beckham County as far west as the North Fork of Red River, southwest of Sayre. The northwest belt outcrops over a wide area over Washita, Custer, and Dewey counties and into Roger Mills, Woodward, Harper, Beaver, and Texas counties, Oklahoma.

Character

The formation consists of heavy gypsum ledges interbedded with red shale. In the vicinity of Cement there are two massive gypsum beds; the upper one has a thickness of 85 feet, and the lower, separated from the upper by 15-20 feet of red gypsiferous sandy shale, has a thickness of 1-40 feet. In Washita County well logs show from 2 to 4 gypsum beds interbedded with red shale.

Thickness

In its type locality, near Colony and Cloud Chief, this formation has a thickness of about 100 feet, and well log data in Washita County show even a greater thickness. In the Cement area, Reeves[74] finds this formation to have a thickness of 85 feet.

Relations to Adjacent Formations

The Cloud Chief lies unconformably upon the Whitehorse sandstone. To the west, near the Texas-Oklahoma line, the Cloud Chief is believed by some geologists to be missing, so that the Quartermaster formation lies directly on the Whitehorse. Evans[75] has shown, by detailed work in the Weatherford area, unconformable relations of the Cloud Chief with the overlying Quartermaster.

72. Clapp, Frederick G., Geology of the Cement oil field: Trans. Amer. Inst. Min. Met. Eng., vol. 65, 1921.
73. Gould, Chas. N., A new classification of the Permian red beds: Bull. Am. Assoc. Pet. Geol., vol. 8, no. 3, 1924.
74. Reeves, Frank, op. cit.
75. Evans, Noel, op. cit.

QUARTERMASTER FORMATION

Name And Distribution

The rocks of this formation are typically exposed along the banks of Quartermaster Creek in Custer County, Oklahoma; hence the name. It is the youngest Permian formation in western Oklahoma and the Texas Panhandle. It outcrops in western Washita, Custer, Beckham, and Roger Mills counties, Oklahoma, and in some of the stream valleys in the Panhandle of Texas.

Character

The formation consists of red shale, siltstone, sandstone, and dolomite that locally contains small quantities of gypsum. One of the outstanding characteristics of the Quartermaster is the white sandy streaks interbedded with the shale, siltstone, and sandstone. The formation is further characterized by its irregular dips that are almost always present. In some localities, where the formation is quite sandy, cross-bedding is highly developed.

Thickness

The thickness of the Quartermaster formation is variable. Evans,[76] who has done detailed work in the vicinity of Weatherford, Oklahoma, reports a thickness of 150 feet. Gould[77] assigns a thickness of 250-300 feet in the Texas Panhandle. Studies of the few well logs available in the area of outcrop suggests thicknesses that vary from 60 to 250 feet.

Relations to Adjacent Formations

The Quartermaster formation is unconformable with the subjacent Cloud Chief gypsum and the superjacent post-Permian formations. In sec. 5, T. 9 N., R. 13 W., in the vicinity of Weatherford, Evans[78] reports this formation to rest unconformably upon the Whitehorse sandstone. This unconformity represents, then, the erosional period during which much of the Cloud Chief gypsum, some of the Day Creek dolomite, and a part of the Whitehorse sandstone were removed.

Detailed Sections and Analyses

Section 6 miles southwest of Elk City in Headwaters of Elk Creek, northwest Beckham County

		Ft.	in.
7.	Ledge of very fine shaly, red-gray sandstone, bedding 1-6 inches	4	6
6.	Red sandy shale thinly bedded	11	0
5.	Gray-red shaly sandstone thinly bedded	2	0
4.	Red sandy shale thinly bedded (Bed of gray shale separates beds 4 and 5)	8	0
3.	Red shale thinly bedded	12	0
2.	Gray and red sandy shale alternating 3-inch beds	1	6
1.	Yellowish-red shaly sandstone	4	0

76. Evans, Noel, op. cit., p. 709.
77. Gould, Chas. N., U. S. Geol. Survey Water-Supply Paper 154, p. 21, 1906.
78. Evans, Noel, op. cit., pp. 705-714.

Mineral Content

MINERALS	BED NUMBER	
	1-4	5, 6, 7
	Per cent	Per cent
Black opaque	64	51
Garnet	17	34
Zircon	8	10
Apatite	6	----
Tourmaline	4	3
Rutile	1	----
Ugrandite	----	2

Light minerals make up most of samples; heavy minerals, small per cent. Quartz most abundant mineral. Feldspar rare or absent.

Section three miles east of Clinton, Custer County, Oklahoma

		Feet
3.	Red, shaly, uniformly and horizontally bedded very fine sandstone	60
2.	Red, shaly, horizontally bedded very fine sandstone	75
1.	Red, hard, firmly cemented massive beds of shaly siltstone	50

Mechanical Analyses

See fig. 9 *B*, p. 68, for mechanical analyses.

Solubility in acid

	Per cent
Beds 1, 2, and 3 (each)	19

Shapes of grains

SHAPES	BED NUMBER
	1, 2, 3 (each)
	Per cent
Round	0
Subround	4
Subangular	20
Angular	76

Mineral Content

MINERAL	BED NUMBER 1, 2, 3
	Per cent
Black opaque	79
Garnet (weathered)	11
Leucoxene	5
Tourmaline	5

Light minerals make up most of samples; heavy minerals make up small per cent. Quartz abundant. Feldspar (weathered) rare accessory.

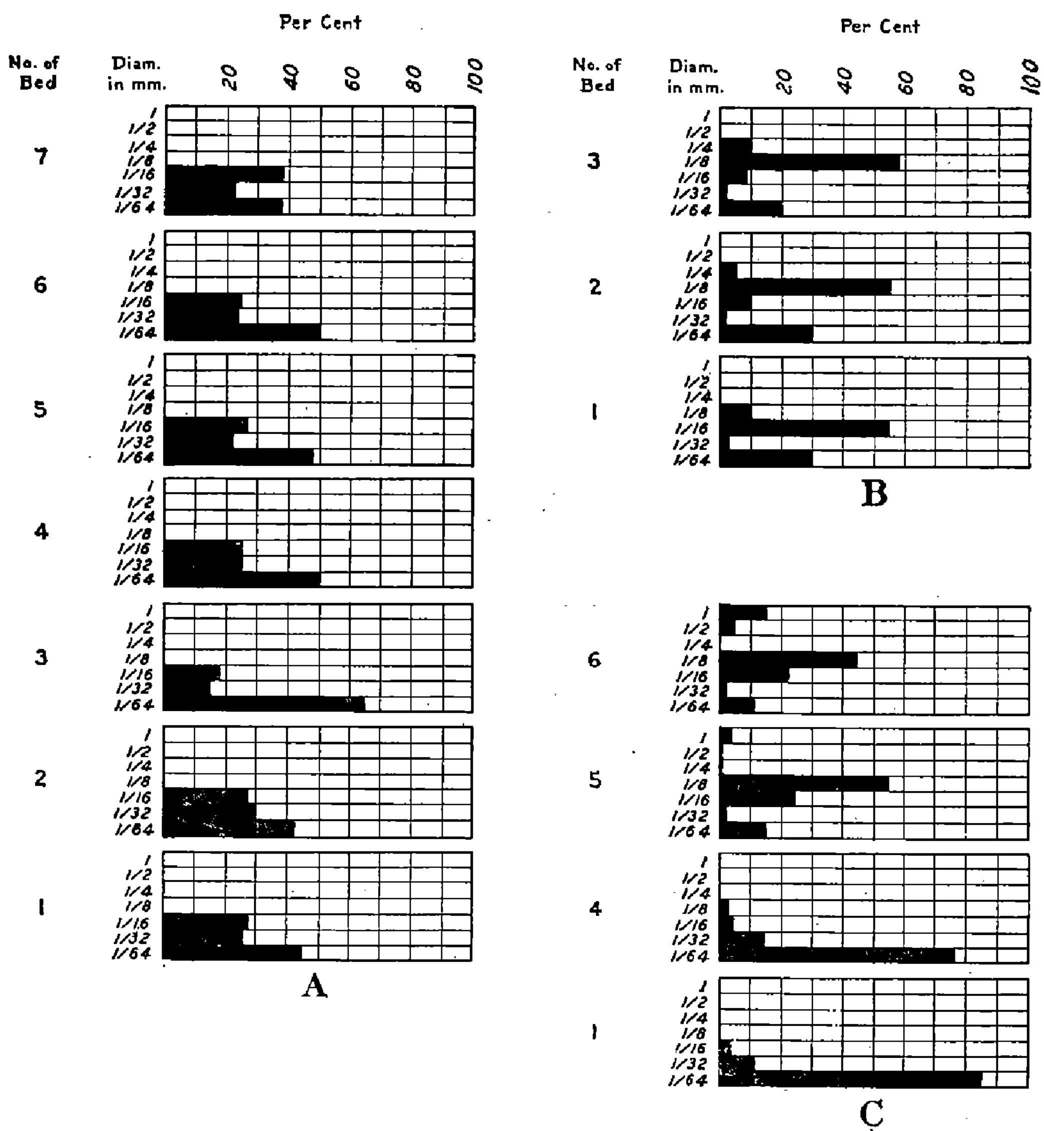


Figure 9.

Section in southern Washita County three miles east of No. 41 Gin

		Ft.	in.
6.	Red cross-bedded sandstone	10	0
5.	Red irregularly cross-bedded sandstone containing streaks of coarse sand	5	6
4.	Gray sandy shale horizontally bedded		1
3.	Fine red sandy shale	10	0
2.	Red finely cross-bedded shale	4	0
1.	Red gypsiferous sandy shale with the gray sandy streaks characteristic of the Quartermaster	5	0

Mechanical Analyses

Figure 9 *C*, p. 68, shows size-grade distribution of materials.

Solubility in acid

	Per cent
Beds 1-4 (each)	13
Beds 5-6 (each)	20

Shapes of grains

SHAPES	BED NUMBER	
	3, 4 (each)	5, 6 (each)
	Per cent	Per cent
Round	0	2
Subround	0	10
Subangular	10	15
Angular	90	73

Mineral Content

MINERAL	BED NUMBER	
	3, 4	5, 6
	Per cent	Per cent
Black opaque	45	28
Tourmaline	33	20
Zircon	13	5
Garnet	9	33
Bronzite	tr.	....
Leucoxene	tr.	12

Light minerals make up most of the samples. Quartz most abundant. Feldspar rare or absent.

The lower part of the Quartermaster formation consists of thinly bedded silty red shales showing little vertical or horizontal variation in texture and sorting. (See fig. 9 *A* and *B*.) This phase of the Quartermaster is probably a marine deposit. In about the middle of the Quartermaster section there is a sudden change toward a coarse texture and irregular cross-bedding. This abrupt change in texture and lack of sorting is illustrated by fig. 9 *C*, p. 68.

Since most of the Quartermaster formation occurs in the center of the Anadarko Basin and the lower part is uniform in texture and bedding and has little horizontal variation, it was probably deposited in a restricted marine basin. In later Quartermaster time the sea retreated from the basin, and fluvial environments prevailed when the coarse, poorly sorted, highly cross-bedded sandstones were deposited.

Log of Redbank Oil Co.'s No. 1 Shanklin, C. NW. 1/4, sec. 15, T. 12 N., R. 11 W.

(Elevation 1,562 feet)

Formation	Top-Bottom
Red shale	0- 15
Red sand	15- 35
Red shale	35- 47
Lime	47- 50
Sand	50- 84
Shells	84- 85
Sand	85- 100
Sand and shale	100- 110
Sand and gyp	110- 117
Sand	117- 138
Sand and gyp	138- 143
Red shale	143- 281
Shells	281- 286
Red shale	286- 359
Gyp	359- 365
Blue shale	365- 385
Gyp	385- 395
Shale	395- 420
Gyp	420- 428
Shale and shells	428- 465
Gyp	465- 475
Shale and shells	475- 505
Red rock	505- 623
Sandy shale	623- 725
Broken lime and shale	725- 800
Broken lime	800- 925
Shale and lime shells	925- 976
Sandy shale	976-1050
Red rock	1050-1075
Red rock	1075-1089
Red rock	1089-1100
Shale	1100-1170
Gyp	1170-1172
Shale	1172-1200
Red rock	1200-1220
Sandy shale	1220-1260
Red rock	1290-1305
Red shale	1305-1375
Shale and lime shells	1375-1450
Red shale	1450-1495
Shale and lime shells	1495-1525
Shale	1525-1561
Red shale	1561-1600
Red rock	1600-1650
Lime	1650-1655
Red shale	1655-1700
Broken lime	1700-1750
Red rock	1750-1800
Shale	1800-1815
Brown shale	1815-2005
Shale and boulders	2005-2060
Brown shale	2060-2120
Shells and boulders	2120-2173
Brown shale	2173-2272
Hard shale	2272-2300
Sandy shale	2300-2350
Shale and boulders	2350-2365
Brown shale	2365-2434
Lime shells	2434-2435
Brown shale	2435-2475
Hard lime and brown shale	2475-2476
Brown shale	2476-2509
Shale	2509-2520
Broken lime	2520-2525
Blue slate	2525-2570
Blue Shale	2570-2639
Lime	2639-2643
Broken lime & shale	2643-2673
Blue shale	2673-2700
Blue shale	2700-2712
Broken lime and blue shale	2739-2751
Lime	2729-2739
Broken lime and blue shale	2639-2751
Blue shale	2751-2773
Broken lime and blue shale	2773-2800
Blue shale	2800-2830
Lime	2830-2840

The heavy minerals present in the samples examined from the three localities were very nearly the same and occur in about the same proportion. It is to be noted that the kinds and order of abundance of the minerals are about the same as those found in the underlying formations out on the flanks of the basin. Therefore, it is suggested that the sediments making up this formation were derived from the same source which was probably an area to the west.

Mechanical Analyses

See fig. 10 p. 72, for size-grade distribution.

Solubility in acid

Feet	Per cent
0-100	30
100-240	22
240-340	20
340-470	15

Shapes of grains

SHAPES	DEPTH (FEET)			
	0-100	100-240	240-340	340-470
	Per cent	Per cent	Per cent	Per cent
Round	0	0	0	0
Subround	10	3	0	0
Subangular	20	15	10	12
Angular	70	82	90	88

Mineral content

MINERAL	DEPTH (FEET)			
	0-100	100-240	240-340	340-470
	Per cent	Per cent	Per cent	Per cent
Black opaque	73	55	43	60
Zircon	10	3	12	4
Garnet	8	30*	32	10
Rutile	4	----	----	----
Leucoxene	3	2	2	1
Tourmaline	2	10	11	25

*Weathered.

Light minerals make up most of samples; heavy minerals, small per cent. Quartz most abundant; feldspar rare or absent.

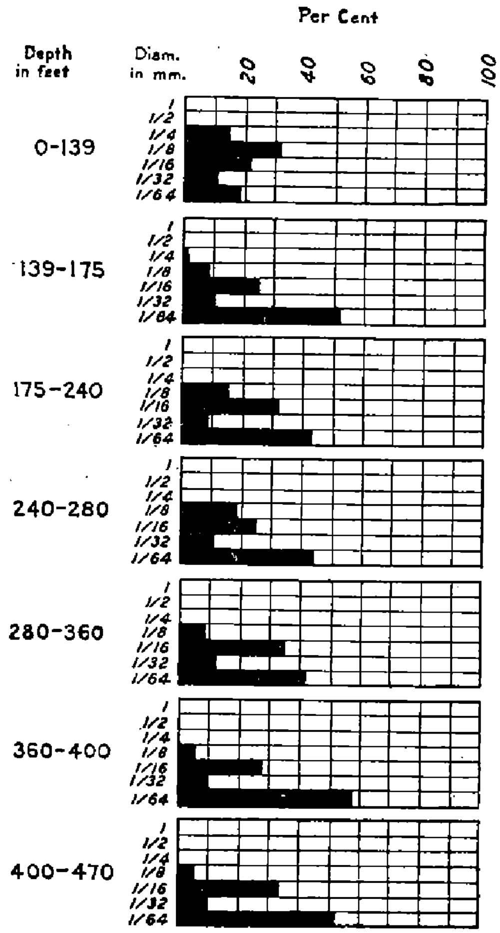


Figure 10.

Log of Malernee Oil Co., sec. 8, T. 3 N., R. 7 W.

(Elevation 1335)

Formation	Top Bottom
Red sand	0- 50
Red sand	50-100
Red shaly sand	100-200
Red shaly sand	200-212
Hard sandy shale	212-250
Red sandy shale	250-300
Red hard sand	300-334
Lavender sand	334-350
Gray lavender sand	350-400
Red shale	400-410
Lavender sand	410-436
Hard gray sandstone	436-485
Shale and sand	485-550
Red and gray sand	550-600
Hard gray sand	600-670

Mechanical and Mineral Analyses of Samples from Malernee Oil Company's well.

DEPTH (Feet)	GEOLOGIC FORMATION	SOLUBILITY IN ACID Per cent	SHAPES OF GRAINS (Per cent)				MINERAL CONTENT																
							Light Minerals		Heavy Minerals[1] (Per cent)														
			ROUND	SUBROUND	SUBANGULAR	ANGULAR	QUARTZ	FELDSPAR	TOURMALINE	LEUCOXENE	ILLMENITE	MAGNETITE	GRAPHITE	GARNET	PYRITE	BL. OPAQUE	HEMATITE	ZIRCON	APATITE	CORUNDUM	UGRANDITE	RUTILE	SPHALERITE
0-59	Whitehorse	3	2	10	25	63	a	b	50	21	13	13	3										
59-112	Whitehorse	9	0	10	20	70	a	b	52	18				5	3	22							
112-166	Whitehorse	18	0	5	25	70	a	c	56	20				10	2	18							
166-212	Whitehorse	28	0	3	20	77	a	c						14	4	70	2	2					
212-234	Dog Creek-Blaine	32	0	1	15	84	a	b		1				13		77		7	2	tr.			
234-284	do.	25	0	0	35	65	a	b-c	14	4			2			64	2				14		
284-334	do.	34	0	0	30	70	a	c	8	2				13		56		16				4	1
334-360	Chickasha	39	5	8	30	57	a	d	38	3				25		6		10	3		15		
360-436	Chickasha	5	2	6	35	57	a	d	40	1				30		2		12			15		
436-577	Duncan-Chickasha	15	2	8	40	50	a	d	46	30				17		3		4					
577-670	Duncan	9	3	5	35	57	a	d	60	20				18				2					
670-773	Duncan	3	2	10	25	63	a	b	42	28	15					15							

a—Most abundant; b—rare; c—absent; and d—abundant.

[1]—Heavy minerals make up only small per cent of sample.

Mechanical Analyses

(See fig. 11 for size-grade distribution.)

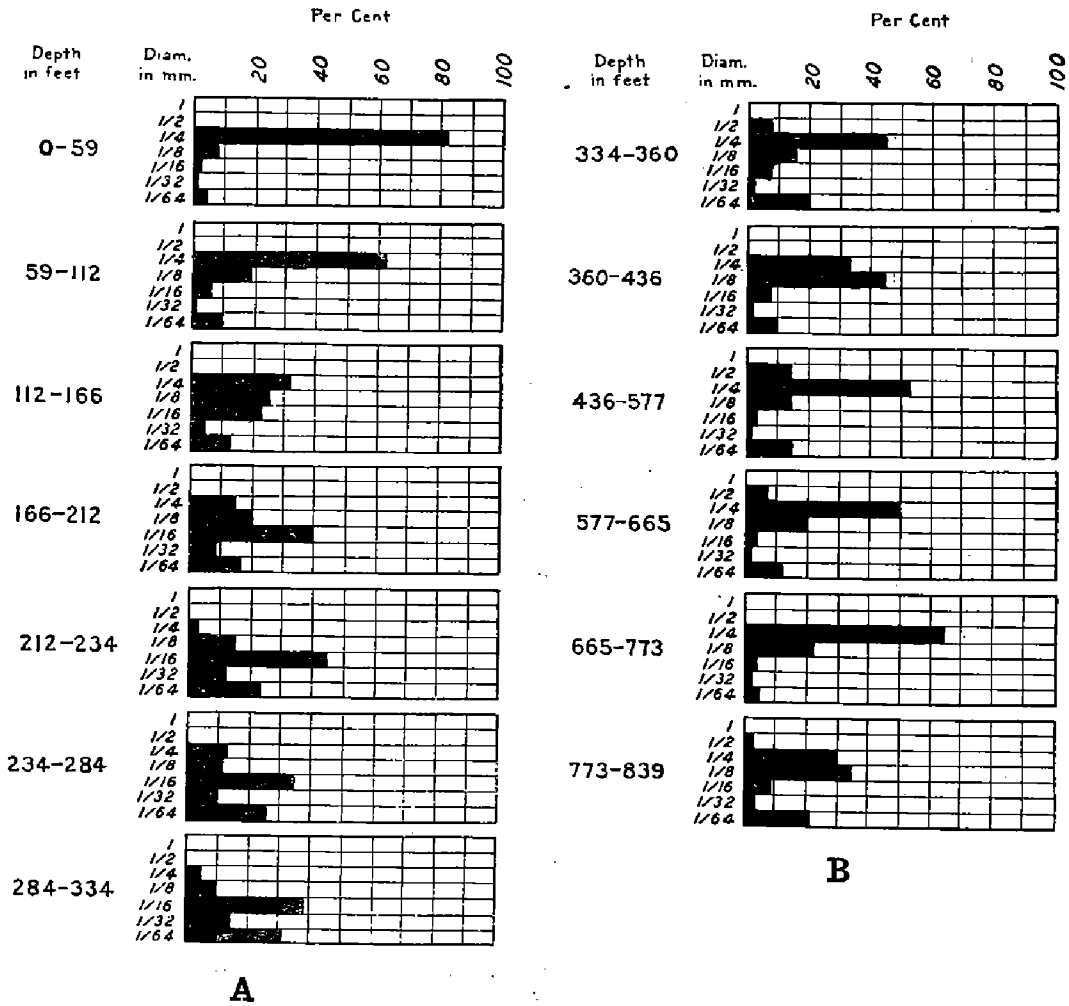


Figure 11.

STRUCTURE

The major structural features in western Oklahoma and the Texas Panhandle are the Wichita-Amarillo Mountains and the large asymmetrical syncline paralleling the north flanks of these mountains, known as the Anadarko Basin.[79]

The Amarillo Mountains are buried ridges of granite flanked by "granite wash" and overlain by a thick bed of limestone known as the "Big Lime". These mountains are believed to represent the northwestward extension of the Arbuckle-Wichita mountains of Oklahoma.

All along the north flanks of the Wichita Mountains the strata dip to the north and northeast at an average rate of about 250 feet to the mile. In the southeast end of the basin, in western Garvin County, the dips are almost straight west at the rate of about 50 feet to the mile. Out along the north flank of the basin the dips gradually become less steep. In the vicinity of Blanchard the dip of the Duncan sandstone is about 35 feet[80] to the mile to the southwest. Along the extreme north flank of the basin the dips average approximately 10 feet[81] to the mile to the southwest. With the steep north dips along the north flanks of the Wichita Mountains and the gentle south dip on the north flank of the basin, it is obvious that the axis must be near the Wichita Mountains. (See fig. 12, p. 76).

It is difficult to determine the exact structural features of the basin because of the scarcity of well logs in western Oklahoma and the futility of attempting to correlate the red beds by this method.

The best marker in wells in western Oklahoma is at the base of the Enid formation, where there occurs a thick zone of blue shale that can be picked out of well logs. It is on this formation that the structure of the Anadarko Basin is determined and illustrated by the map, figure 12.

Within the Anadarko Basin there is a shallow syncline starting in the vicinity of northern Custer County and trending northward into southern Kansas. Along the main axis of the basin there are three anticlinal folds, the Duncan anticline, the Cement anticline, and the Sayre dome.

The Duncan[82] anticline is located in the southeast end of the Anadarko Basin in southern Stephen County. The structure is about two miles wide and five miles long. The axis trends a few degrees west of north. According to Wegemann's map it has a closure of about 350 feet.

The Cement[83] anticline is located in southeastern Caddo County about 40 miles northwest of the Duncan anticline. It is an anticlinal

79. Gould, Chas. N., Bull. Am. Assoc. Pet. Geol., vol. 5, no. 5, pp. 605-608, 1921.
80. Latimer, Frank, Oral communication.
81. Longmeyer, J. L., Oral communication.
82. Wegemann, Carrol H., The Duncan gas field, Stephens County, Okla: U. S. Geol. Survey Bull. 621-d, 1915.
83. Reeves, Frank, op. cit.

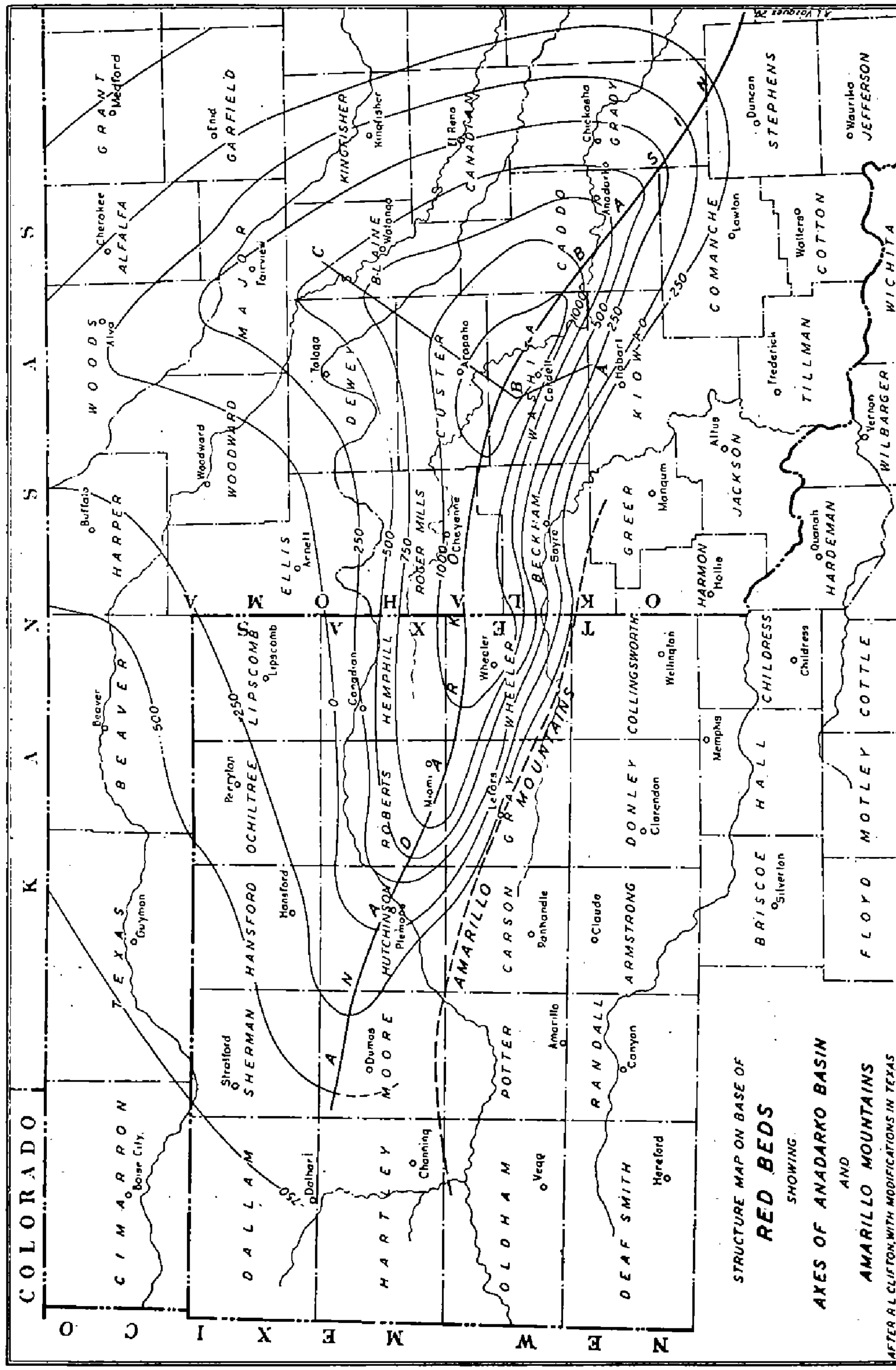


Figure 12.—Structure map showing axes of the Anadarko Basin and Amarillo Mountains.

fold about 11 miles long and 2 miles wide, trending N. 70° W. The structure has a closure of approximately 60 feet.

The Sayre[84] dome is located in Beckham County, T. 9 N., R. 23 W. Contours based on well logs show an elongated dome trending N. 30° E. This structure has a closure of about 100 feet.

In Beckham County, Oklahoma, and southern Wheeler County, Texas, there is a long normal fault trending northwest-southeast, having a displacement of about 1,000 feet. The downthrow side is to the northeast. Bauer[85] is of the opinion that this fault explains in a large measure the westward extension of the Anadarko Basin.

GEOLOGIC HISTORY

In discussing the geologic history of the Anadarko Basin all of western Oklahoma and the Panhandle of Texas is involved, the salient points of which have already been fully discussed by Gould and Lewis.[86]

The Anadarko Basin came into existence with the Wichita Mountain uplift, which, in the opinion of Schuchert,[87] Plummer and Moore,[88] and Gouin,[89] began in early Mississippian time. The second uplift of the Wichita Mountains occurred at the time of the folding and elevation of the Arbuckle Mountains, which, according to Moore,[90] occurred in late Pennsylvanian time. Gould and Lewis[91] believed that the Amarillo Mountains and the ancestral Rocky Mountains were also uplifted at this time. They are quoted as follows:

> These two mountain masses, the Ancestral Rocky Mountains and the Amarillo Mountains, were probably elevated at somewhere near the same time, and had arrived at their full height during late Pennsylvanian time. It is, of course, quite probable that erosion was contemporaneous with elevation, but it is also logical to believe that, in general, elevation proceeded faster than erosion, and that at the period of greatest elevation these mountains stood possibly several thousand feet above the surrounding plains. During late Pennsylvanian time the Amarillo Mountains were surrounded by seas, as is shown by granite wash in limestones on their flanks. There was apparently a struggle between the agents of elevation and of erosion, so that instead of being high mountains, the region consisted of a series of low islands or an archipelago.

Most of the sediments making up the Permian beds in the Anadarko Basin were derived from the uplifted areas to the east, south, and

84. Birk, R. A., The Sayre field, Beckham County, Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 8, no. 3, 1924.
85. Bauer, C. Max., Oil and gas fields of the Texas Panhandle: Bull. Am. Assoc. Pet. Geol., vol. 10, no. 8, p. 741, 1926.
86. Gould, Chas. N., and Lewis, Frank E., op. cit., pp. 25-29.
87. Schuchert, Chas., Textbook of Geology, pt. 2, p. 343, 1924.
88. Plummer, F. B., and Moore, R. C., Stratigraphy of the Pennsylvanian formations of north-central Texas: Univ. of Texas Bull. 2132, 1921.
89. Gouin, Frank, Geology of the oil and gas fields of Stephens County, Oklahoma: Oklahoma Geol. Survey Bull. 40-E, 1926.
90. Moore, R. C., The relation of mountain folding to the oil and gas fields of southern Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 5, no. 1, p. 32, 1921.
91. Gould, Chas. N., and Lewis, Frank E., op. cit., pp. 27-29.

west. In the southeastern end of the basin some of the sediments were derived from the Arbuckle and Wichita mountains and a more distant area to the east and south. In the western area of the basin the sediments were probably derived from the ancestral Rockies to the west.

The thick and numerous beds of gypsum and salt are evidence that enclosed basins existed in the region, in which saturated solutions evaporated. The presence of marine fossils in the Blaine and Whitehorse formations is evidence of oceanic invasions.

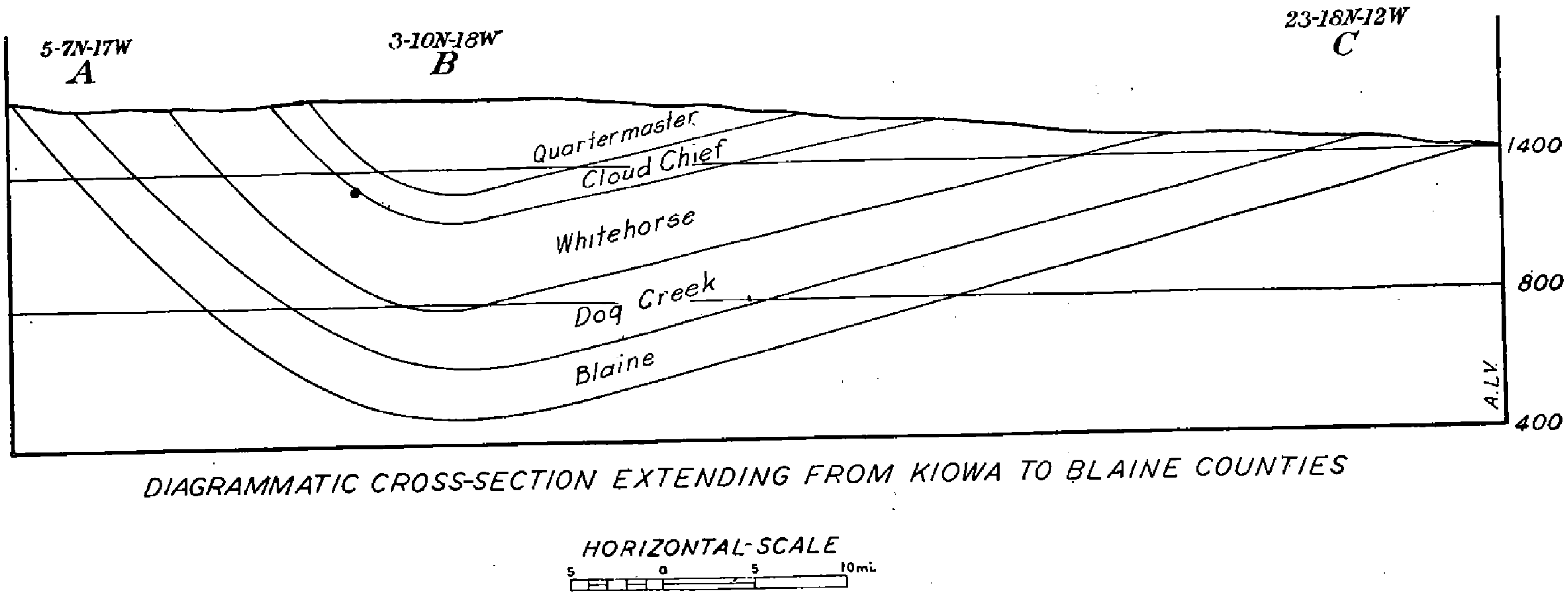
Throughout the entire period of Permian sedimentation the basin was gradually filled in with clastic material brought in by rivers, and subjected to shiftings of the strand line, together with the southwestward withdrawal of the sea, bringing about the intercalation of marine and nonmarine sediments.

Following the deposition of Permian beds, orogenic movements again took place in the Arbuckle-Wichita region as is evidenced by the minor folds in the Permian strata in the Cement and Duncan anticlines.

During most of the Mesozoic the region stood above the water and erosion was active. During Cretaceous times a great sea invasion occurred that covered the entire area. At the close of Mesozoic time the Arbuckle-Wichita-Amarillo mountains were again uplifted as has been shown by Bullard,[92] who found that the Createaceous outliers conform structurally with the underlying Permian beds.

In connection with the history of the development of the Anadarko Basin, the process known as the compaction of sediments should not be overlooked. It has been known for a long time that the volume of sediments decreases because of compaction due to their own weight. That certain structures are produced by this process has been suggested by Blackwelder.[93] The Permian strata in the Anadarko Basin show a definite thickening toward the axis of the Basin. This in itself is a suggestion that during the entire period of Permian sedimentation there was some settling, which caused the thickening of the sediments along the axis of the basin. It is not believed that the compaction of the sediments was the main cause in developing the Anadarko Basin, but no doubt was a process worthy of consideration.

92. Bullard, Fred M., Lower Cretaceous of western Oklahoma: Oklahoma Geol. Survey Bull. 47, 1928.
93. Blackwelder, Elliot, The origin of central Kansas oil domes: Bull. Am. Assoc. Pet. Geol., vol. 4, pp. 89-94, 1920.



DIAGRAMMATIC CROSS-SECTION EXTENDING FROM KIOWA TO BLAINE COUNTIES

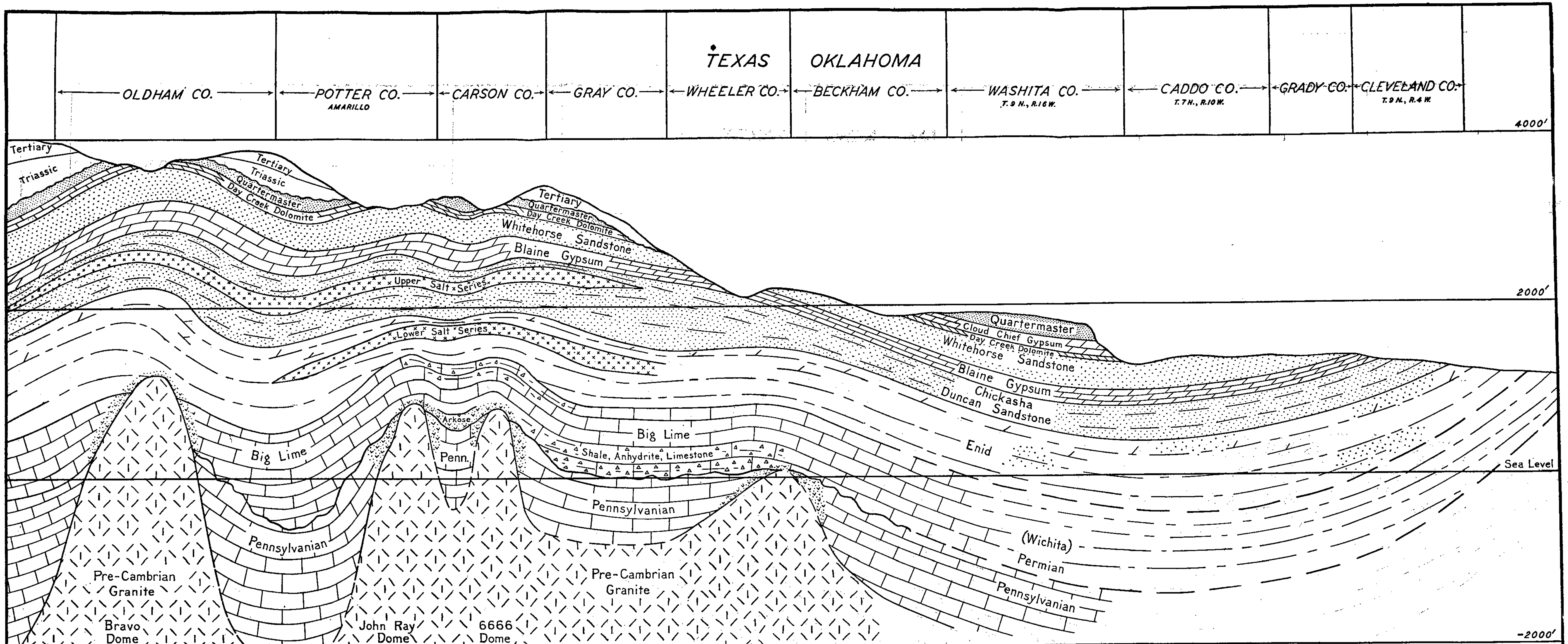
(See figure 12 for line of cross-section)

Figure 13.

SUMMARY

As determined by a study of surface and subsurface geology, the Anadarko Basin was found to parallel the north side of the Wichita Mountains in Oklahoma and the buried Amarillo Mountains in the Texas Panhandle. Structurally the basin is an asymmetric syncline having a steeply dipping southwest limb and a gently dipping northeast limb. Its axis extends from a locality a short distance northwest of the western end of the Arbuckle Mountains, northwestward through northern Stephens, Grady, Comanche, Caddo, Washita, Custer, Beckham, and Roger Mills counties, Oklahoma; enters the Texas Panhandle through Wheeler County, Texas, continues northwestward through Gray, Roberts, Hutchinson, and Moore counties, and probably ends in southern Sherman County, Texas.

The field and laboratory studies of the sediments in the basin indicate that there were two contributing sources. In and near the southeastern end of the basin the materials were derived from the east, southeast, and south; the materials making up the formations in the northern and western parts of the basin were derived from the west and northwest.



GENERALIZED EAST-WEST CROSS-SECTION THROUGH ANADARKO BASIN
FROM
CLEVELAND CO., OKLAHOMA THROUGH AMARILLO, TEXAS
TO
OLDHAM CO., TEXAS
TEXAS PANHANDLE SECTION AFTER C. DON HUGHES

OKLAHOMA GEOLOGICAL SURVEY
CHAS. N. GOULD, DIRECTOR
NORMAN, OKLA.