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CARL C. BRANSON, DIRECTOR

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GEOLOGY OF NORTHEASTERN OSAGE COUNTY, OKLAHOMA

by

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GEOLOGY OF NORTHEASTERN OSAGE COUNTY, OKLAHOMA

by W. F. Tanner

ABSTRACT

Northeastern Osage County is a belted plain underlain by Missourian and Virgilian shales and sandstones which dip westward 30 to 45 feet per mile. The surface formations considered in this report are, from lowest to highest, the Barnsdall and Tallant, of Missourian age, and the lower part of the Vamoosa, of Virgilian age. Twenty-two members are described; 15 are mapped.

The section is composed chiefly of shale, with large amounts of fine-grained sandstone and siltstone and minor amounts of limestone. The section thickens slightly toward the north.

There is no clear evidence of unconformity within the area studied.

Two distinctive facies occur in the section: (1) sandstones, here assigned to a barrier island and beach environment; and (2) gray-green shales and thin siltstones and limestones, here assigned to a lagoonal and protected shallow sea environment. The barrier facies contains, here and there, red shales which probably indicate proximity to river mouths.

The use of oriented data permits calculation of the shore line direction: approximately N. 20° E., S. 20° W., for most of the area, swinging in the southern part (T. 24 N.) to about N. 20° W., S. 20° E. The land mass lay to the east, and the sea to the west. The procedure for making paleogeographic reconstructions from oriented data is discussed.

Structures within the area—all gentle—include anticlines which trend, in general, N. 35° E., S. 35° W., and faults, downthrown to the east, which trend predominantly N. 30° W., S. 30° E. These structures probably owe their origin to a combination of stratigraphic irregularities and the Permian subsidence of the Anadarko Basin.

Despite its long history of oil exploration, the area still holds promise of extensive future development. Exploration based on structural considerations alone, however, will most likely not be greatly successful.

PREVIOUS INVESTIGATIONS

The outstanding single contribution to an understanding of the geology of Osage County was the joint work of a team of United States Geological Survey geologists, under the field supervision of K. C. Heald, in 1917 and 1918 (White, 1922). The report covering this field work contains detailed maps, scaled at 1:31,250, and printed in three colors: black for culture and drainage, green for stratigraphy, and red for structure.

The mapping for that report was carried out with plane table and alidade. The prime purpose was the delineation of structure. Beds are, in many instances, not mapped continuously from one township to the next. The lack of continuity was partly due to the method of organization of the rather large field party, and partly due to the difficulty with which plane table techniques can be adapted to stratigraphic work where individual beds are not invariably easily seen. For structural work, the maps are excellent.

Beckwith (1928), using the federal report and other information from various commercial sources, reviewed the geology of Osage County for the Oklahoma Geological Survey's study of Oil and Gas in Oklahoma. Beckwith's paper was accompanied by a black-and-white map, scaled at 1:125,000. On this map, the approximate positions of many limestone and sandstone ledges are shown as single black lines. Since this compilation was based largely on the federal survey township maps, it suffered from the same defect: lack of stratigraphic continuity. For a compilation based on existing literature, it was a definite advance over anything previously available.

Perhaps the one person who has done the most work in the region in the last quarter century is Malcolm C. Oakes, of the Oklahoma Geological Survey. His early mapping led to the publication of a report on Washington County and the southeastern part of Osage County (strata up to and including the horizon of the Birch Creek limestone) (Oakes, 1940). In more recent years, he has worked on beds higher than the Birch Creek, naming and defining the Barnsdall and Tallant formations (Oakes, 1951). Much of his work appeared for the first time on the latest Geological Map of Oklahoma (Miser, 1954).

The western and central parts of Osage County have been studied recently by graduate students at the University of Oklahoma. Those whose work extended as low, stratigraphically, as the Oread limestone were Carter (1954), Shannon (1954), and Russell (1955).

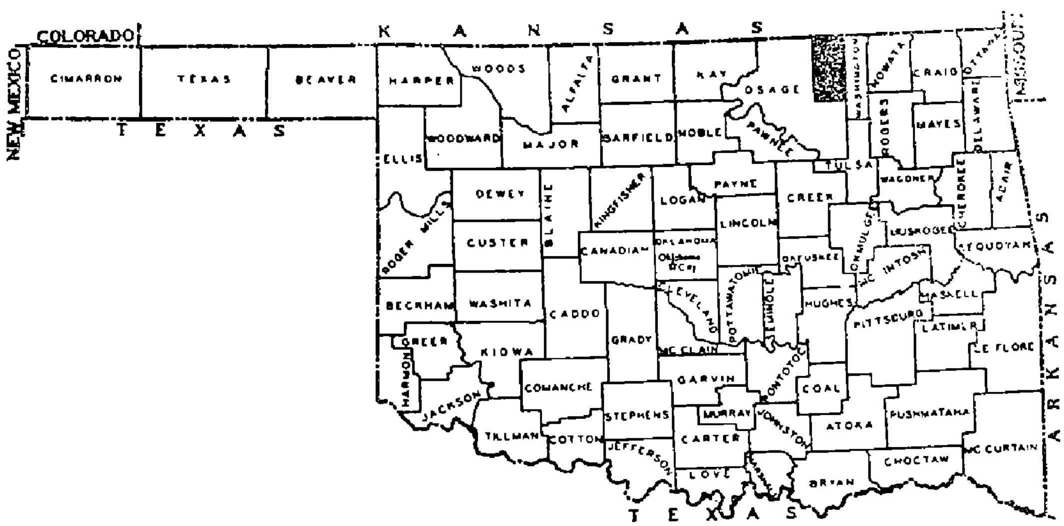
Many shorter contributions, prompted by the interest in oil development, have been published on the subsurface geology of the county.

PRESENT INVESTIGATIONS

Field work for this report was carried out in June and July, 1955, under the general supervision of Carl C. Branson, director of the Oklahoma Geological Survey.

Mapping was done on U. S. Department of Agriculture photographs. For the first half of the project, only the coverage flown in 1937 was available; the photographs of that date are relatively poor in quality. Photographs flown in 1954 became available midway through the field work, and were used for the rest of the project. Townships mapped from the later flights are undoubtedly more accurate, from a cartographic standpoint.

Culture, drainage and geology were transferred from the photographs to township plats scaled 1:19,500. This involved areas of arbitrary adjustment, where individual pictures—especially of the older coverage—varied from the scale. The township plats were reduced and used for the construction of the completed map. The latter project was carried out by draftsmen of the Oklahoma Geological Survey.



The photographs were used for tracing beds, identifying general lithologies, mapping alluvial materials, locating faults, determining the relative movements along many of the faults, and estimating dips. The latter information was useful in making measured sections in the field.

Field work consisted of checking the stratigraphic sequence established on the photographs, measuring and describing detailed sections, examining lithologies, collecting shale samples and fossils, procuring oriented data, and in rare instances, walking of thin beds not clearly shown on the pictures. Although many measured sections were made, both long and short, it was the writer's primary purpose to obtain at least three good composite sections: for the northern, central, and southern parts of the area.

Sections were measured with Brunton compass and eight-foot tape. Unless other information was available, it was assumed that the dip was westerly, between 30 and 45 feet per mile. In some instances local measurements of dip, using the Brunton, were possible. In others, dips were obtained from the U. S. Geological Survey bulletin on Osage County (1922). The maps accompanying the latter are not, however, as complete as might be desired. Hence for certain areas dips were calculated from the air photographs, or measurements were made along the strike or over minimum-length traverses, to reduce as much as possible the error arising from an inaccurate estimate of the dip. It is thought that, in general, the measured sections are correct to within 5 percent.

No effort was made to map dip reversals or closures.

It was found advisable to spend two days on limestones, exposed in Osage County, higher in the section than the Middle Oread, and three days on beds, exposed to the east of the area, lower in the section. These five days were taken from the main mapping project to enlarge the writer's view of late Pennsylvanian history, especially in view of the fact that only two and a half formations crop out within the formal limits of the map area.

The author is particularly indebted to T. E. Weirich and Jack Graves, both of Phillips Petroleum Company, Bartlesville, for assistance in the early stages of the project, and to Carl C. Branson, director of the Oklahoma Geological Survey, for critical examination of the map and manuscript.

GEOGRAPHY

The area covered by this report is located in the eastern part of Osage County, Oklahoma (map). It is bounded on the north by the Kansas State line; on the east by the Washington County line, or the horizon of the Birch Creek member of the Barnsdall formation, whichever is farthest west; and on the west by the outcrop of the Middle Oread limestone member of the Vamoosa formation. Mapping to the south extended to the vicinity of the town of Barnsdall (T. 24 N.). About 500 square miles are covered on the accompanying map.

No city is located within the area. Pawhuska, the county seat of Osage County, is situated about two miles west of the outcrop of the Middle Oread; Bartlesville is just across the line in Washington County, about half-way between the northern and southern limits of the area. Villages within the area include Hulah, Bowring, Herd, Bigheart, Nelagoney, Okesa, Pershing, Barnsdall, Tallant, and Boulangerville.

Four paved highways, and many first-class graded and gravelled roads, form a moderately tight transportation network. Running east-and-west through Bartlesville and Pawhuska is U. S. Highway 60; southeast from Pawhuska, Oklahoma Highway 11; southwest from Bartlesville, Oklahoma Highway 23; and north-and-south along the western edge of the area, State Highway 99. Probably any spot in the area is within three miles of a graded, maintained dirt or gravel road.

Three railroads, the Missouri, Kansas and Texas; the Atchison, Topeka and Santa Fe; and the Midland Valley, provide rail service.

Several lakes have been impounded for either flood control or recreation. The oldest is Sunset Lake (T. 27 N., R. 10 E.) The largest is Lake Hulah, developed by the army engineers for flood control along the Caney River (T. 28 N., R. 11 E.). One of the newest is Lake Hudson, the Bartlesville city water supply (T. 27 N., R. 12 E.). Lake Bar-Dew is located in the same township. At Lake Hulah the army engineers have provided ample facilities for boating, swimming, fishing, picnicking and camping.

The main economic activities are centered about oil and ranching. Osage County is in the heart of the blue-stem grass country. Most tracts are either standing in timber (blackjack oak), or are used for grazing. The emphasis on these two activities results in rather large land holdings. The section-line road grid, so common throughout much of Oklahoma, is missing in this area.

Petroleum development dates from 1897, when the first commercial oil well in Oklahoma was completed in what is now the north edge of downtown Bartlesville.

CLIMATE

Osage County has a sub-humid climate, with hot, dry summers and moderately cold winters. Records for the eastern half of the county are available at two weather stations: a sub-station in Pawhuska, and the Bartlesville municipal airport station, half a mile west of the county line.

The Pawhuska records, for a 36-year period (up to 1941) show maximum and minimum recorded temperatures of 116 and -26 degrees. The average annual rainfall is 36.58 inches, divided as follows:

January	1.37
February	1.46
March	2.54
April	3.79
May	4.84
June	4.97
July	3.51
August	3.48
September	3.77
October	3.21
November	2.23
December	1.41

The average annual temperature is 59.5 degrees, the average for January 36.9 degrees, and the average for July 81.8 degrees. The earliest recorded killing frost occurred on October 26, and the latest recorded killing frost on April 4, The growing season is considered to be 200 days long.

Bartlesville airport records, for a 37-year period (up to January 1, 1955), show an average annual precipitation of 36.05 inches. The highest recorded for a single year was 48.57 inches (1941), the lowest 22.48 (1952). The recent dry years show up clearly in the following figures:

37-year average	36.05
1950 through 1954	33.84
1952 through 1954	30.60

The cumulative rainfall deficit for the last decade (1945-1954) is 20 inches.

GEOMORPHOLOGY

Osage County is the type area of the Pawhuska "rock plain", an erosional feature described by Ham (1940) and Melton and Ham (1939). The Pawhuska "rock plain" extends across east central Oklahoma, northward into Kansas, and eastward into the corners of Missouri and Arkansas. It is generally found at an elevation of 1,000 to 1,050 feet above mean sea level.

In Osage County, from about the meridian of Pawhuska westward, the "rock plain" occurs at the proper elevation, according to the Pawhuska topographic map (U.S.G.S., 1910). In the area of this report, however, the Pawhuska surface is missing. The mean elevation is 860 feet, the mode 875, the median 875, and the maximum 1,053. Only nine percent of the area stands above 1,000 feet.

The average topographic profile (Fig. 2) reveals a rolling plain between 700 and 900 feet, with a few incised valleys to about 650, and a few hilltops to about 1,050 feet. The latter stand along the western edge of the area, and may be east-lying remnants of the Pawhuska erosion surface. The Elgin sandstone member and the Upper Oread limestone member of the Vamoosa formation crop out along the eastern edge of the Pawhuska "rock plain".

The topography is essentially a set of scalloped cuestas, somewhat difficult to recognize because of the low dip and the deep incision by east- and southeast-flowing streams.

The chief streams are, from north to south, Caney River, Sand Creek, and Bird Creek. Throughout most of their lengths, they have gradients measured in feet per mile. They also possess wide

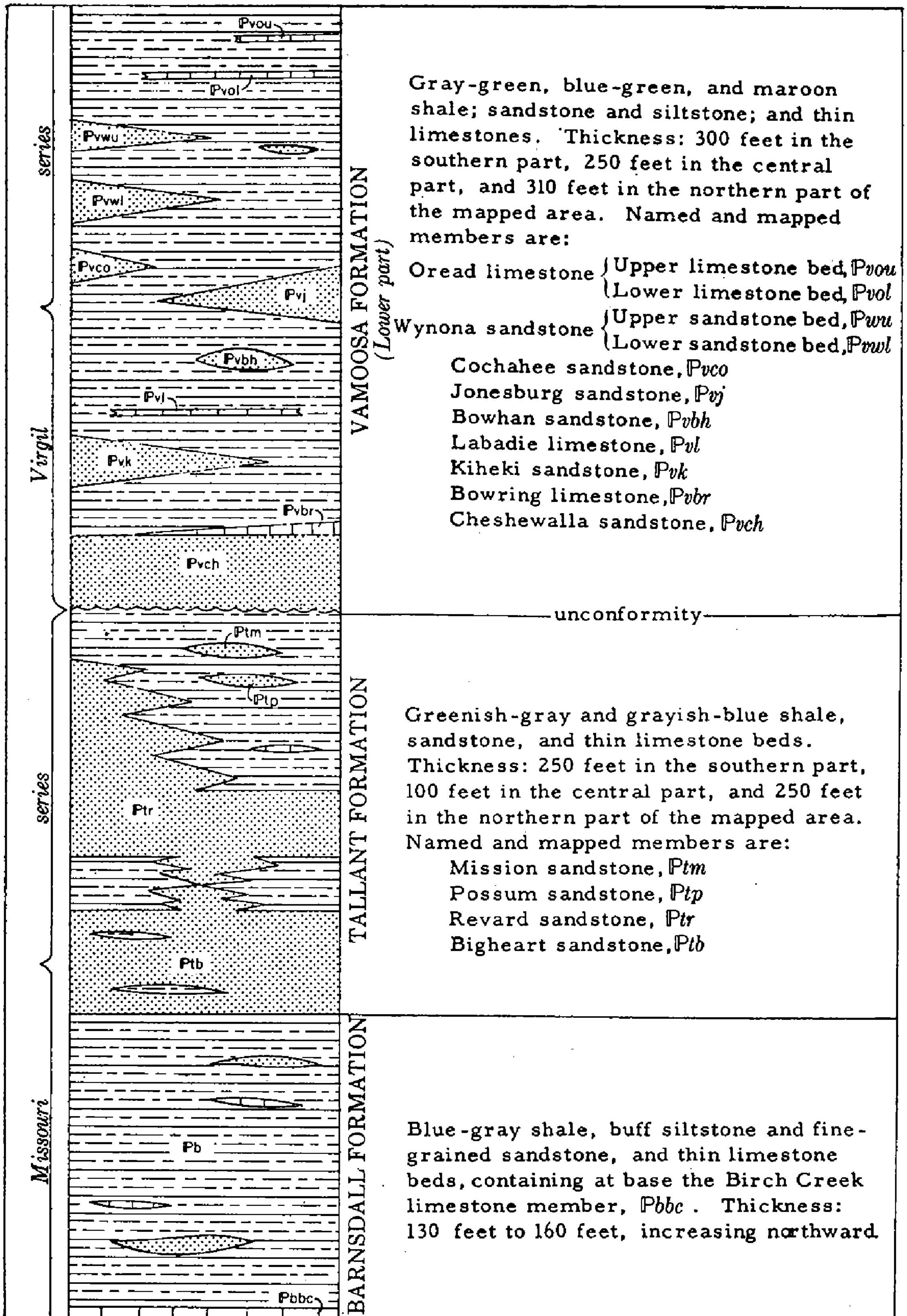


Figure 1. Idealized stratigraphic column of Pennsylvanian rocks cropping out in northeastern Osage County.

flood plains which in many instances pass imperceptibly into low terrace deposits. Because of the lack of elevation differences between terrace and flood plain, no effort has been made to show the two separately on the map. In most places, however, material of alluvial origin is flood plain. The streams which have formed the flood plains are generally flowing across bedrock; hence many rapids and waterfalls appear, even in broadly alluviated valleys.

Although the gradients are low (i.e., three to ten feet per mile), the valley floors are wide, and the supply of sand is ample, the main streams have imperfectly developed meander patterns. This is due largely to the fact that the alluvial material is thin, and that most stream channels are actually cut in bedrock. Further, the meander pattern shows evidence of having been formed at an earlier time, before the streams had cut to their present positions, when perhaps the alluvial fill was thicker than it is now. Such a history apparently post-dates the Pawhuska erosion surface. Suggestions of earlier alluviation include incised meanders, abandoned semi-circular undercut valley walls, and abandoned meander loop cores.

Valley-flats which appear on the Pawhuska quadrangle topographic sheet (U.S.G.S., 1910) are not invariably of alluvial origin. The wide spacing of contour lines on a map having a contour interval of 50 feet does not guarantee either monotonously flat surfaces or extremely gentle slopes. Wide "flat" areas shown on the map are in many instances pediments cut in shale (i. e., on the upper Barnsdall formation, in sections 1 and 2, T. 26 N., R. 11 E.), rather than flood plains or terraces. Slopes on such surfaces are of the order of a half degree. Because the streams of the region have not had a sufficiently long still-stand to permit wide-spread planation, the pediments are narrow, and limited to areas of thick shale. They are also relatively imperfect.

Structural control may be seen in part of the drainage network. Viza Creek, for example (sections 9 and 16, T. 26 N., R. 12 E.), flows for nearly two miles apparently up the slope of the flood plain of Sand Creek, into which it empties. Viza Creek is, in these two sections, flowing around a structurally high outcrop of resistant Dewey limestone, a half mile to the east (not shown on the map).

Linears, commonly less than a mile long, occur in many parts of the area. Some of these are fractures, but probably most of them are faults. The linears are revealed much more clearly on the 1954 air photographs than on the 1937 coverage. Relative movement along the faults is easily discernible, in many instances, on the 1954 photographs. The regional dip is so low that ledges are not readily confused with other linears. Most of the fractures and faults trend north-northwest to south-southwest, or north-northeast to south-southwest.

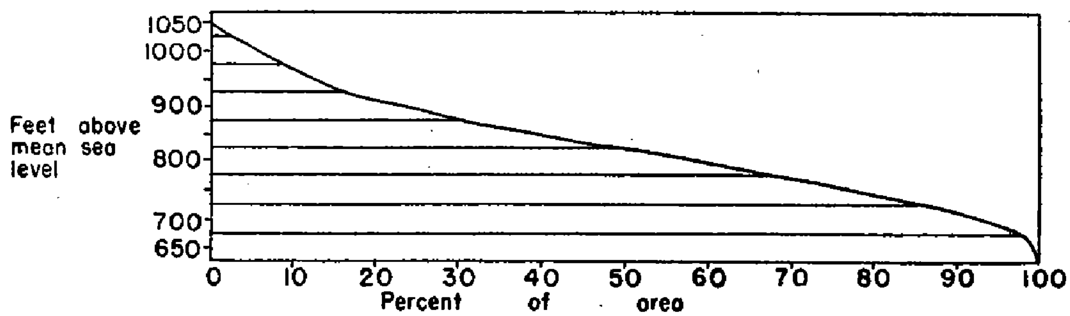


Figure 2 Average topographic profile of eastern Osage County (cumulative percentage curve) (East of 96' 20°)

The three common lithologies—shale, sandstone, limestone—are expressed, physiographically, as is to be expected in a sub-humid climate. The dense Labadie limestone may be recognized from the air or on the photographs because of the checkerboard pattern made by the fracture network. The sandstones are generally found on tree-covered ridges. The shales crop out on grassy benches or lowlands. Siltstones, however, add a complicating factor. Where soft, they form no strong ledges, and therefore may be considered with the shales. Where well-cemented and resistant, they commonly occur under grassed ledges, a situation which normally would lead to an interpretation of limestone. In eastern Osage County, where the limestones are few, thin, and well-known, no difficulty was involved in distinguishing between them and hard siltstones.

FACIES

Two rather distinctive environments are represented by the sediments of eastern Osage County. One, here termed "lagoonal", probably included areas of shallow, calm, open sea. The other, termed "barrier", probably included mainland beach and barrier island, as well as submarine bar, deposits.

Certain terms, used widely in this report, may be defined as follows:

Coarse-grained—about one-half millimeter in diameter.
Medium-grained—about one-quarter millimeter in diameter.
Fine-grained— about one-eighth millimeter in diameter.
Very fine-grained—about one-sixteenth millimeter in diameter.
Coarse crystalline, medium crystalline, etc.—same sizes as given above for sands, but referred to limestones.
Massive—beds more than 24 inches thick.
Thick-bedded—beds eight to 24 inches thick.
Medium-bedded—beds two to eight inches thick.
Thin-bedded—beds one-quarter of an inch to two inches thick.
Laminated—beds less than one-quarter of an inch thick.
Low-angle cross-bedding—inclinations, in general, of less than five degrees.

High-angle cross-bedding—inclinations, in general of more than 10 degrees; where the term, "cross-bedded", is used, the high-angle variety is meant.

The barrier facies consists largely of cross-bedded, contorted sandstones and siltstones. Prints of leaf fragments are rather common, but other fossils are rare. The barrier sandstones grade both east and west (i. e., both landward and seaward) into shales. At one point, for example (measured section No. 19), the Tallant formation is approximately 65 percent sandstone, 35 percent shale. A few miles to the east and slightly north (measured sections No. 9, 10) the Tallant is much thicker, and approximately 22 percent sandstone, 75 percent shale, and 3 percent limestone. Ripple marked sandstones are found here and there in the barrier facies, but are not dominant.

Cross-bedding is both high-angle and low-angle, and the high-angle variety represents both littoral currents and channel currents. Clay pebble conglomerates are fairly common.

The presence of dark red shales in the Tallant formation in the southern part of the area (west of the town of Barnsdall; T. 24 N.) suggests the possibility that the barrier facies there is, in part, continental. It is not here implied that red shales necessarily carry any climatic connotations; their presence does, however, point to two items: (1) There was, in the immediate vicinity, a source of red shales which did not supply recognizable materials to the same formation farther north in the area. (2) The associated sandstones strongly suggest a deltaic environment.

Red shales are relatively common in the lower part of the Vamoosa formation, especially in the central part of the area, where they are closely related to cross-bedded, lenticular, plant-bearing sandstones and clay pebble conglomerates. Again, a deltaic environment may be indicated.

The lagoonal (and open shelf) facies consists chiefly of grayish-green shales containing thin beds (generally one to two inches thick) of limestone, calcareous siltstone, and limonitic siltstone. Locally the limestones are several feet thick. Various horizons are marked by marine invertebrate fossils, limonite concretions, trails, worm (?) burrows, crab burrows, ripple marks and other bottom markings, and leaf prints. The limestones, where more than a few inches thick, are commonly characterized by wavy bedding (Plate II, B) here interpreted to identify the gentle scouring and winnowing found in many shallow calm seas. The lagoonal facies, in several instances, grades seaward (i. e., toward the west) into the thick sandstones referred, above, to the barrier facies.

Locally, channel type sandstones occur within the lagoonal facies.

Oakes (1940, p. 42) suggested a lagoonal environment for the deposition of the Hogshooter limestone in Washington County. The Hogshooter in that area possesses the same wavy bedding and general lithologic characteristics of the Osage County limestones.

In fact, the present writer, after field examination of each of the beds named, would like to add to the lagoonal facies the following: Checkerboard, Dewey, Paola, Avant, Birch Creek, Bowring, Labadie, Oread, Deer Creek, Lecompton, and many unnamed limestones.

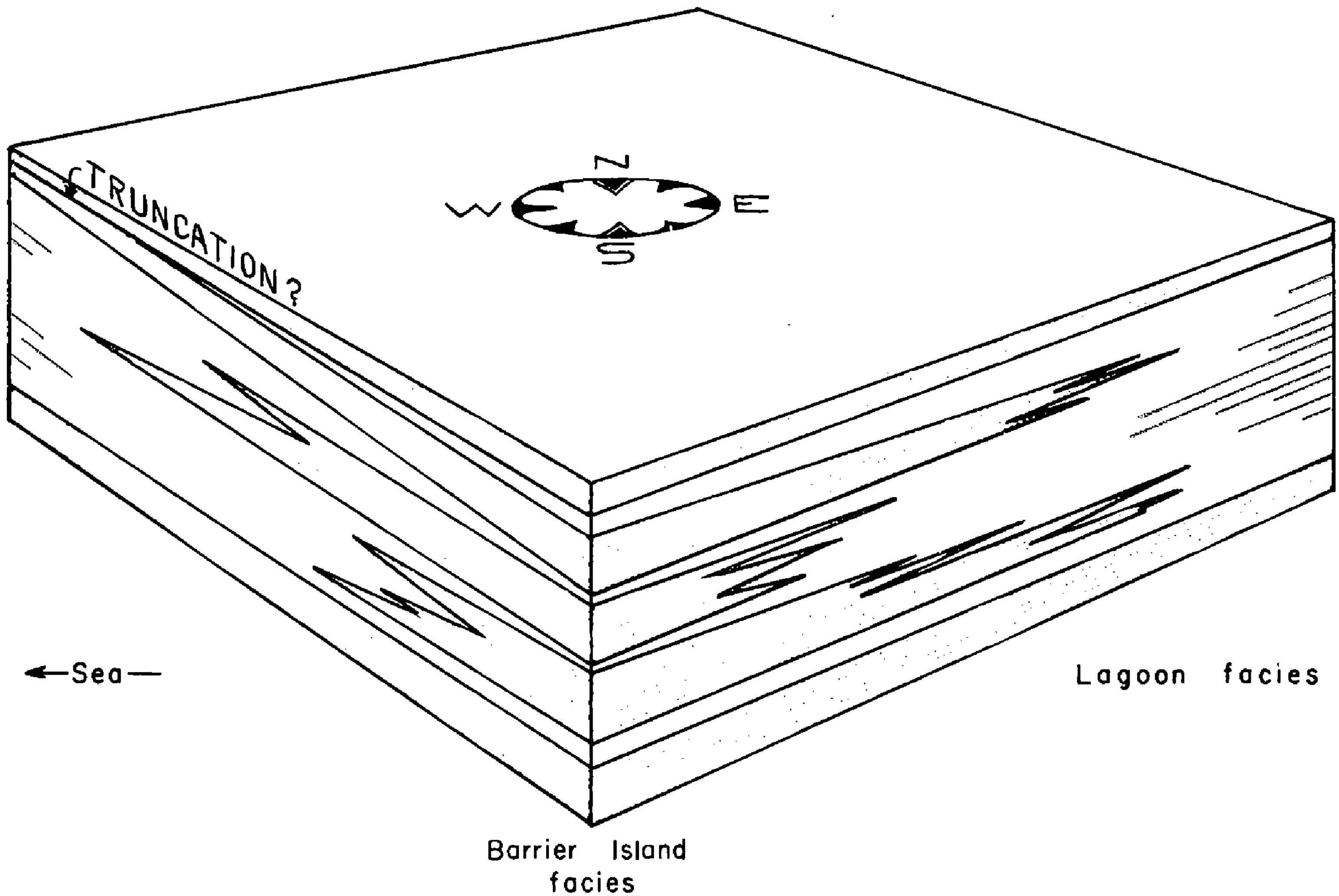


Figure 3

W. F. Tanner '55

The question has been raised whether or not any of these limestones represent reefs, especially where developed to thicknesses of 25 or more feet. The thinness of bedding, the wavy bedding, the lack of a rigid wave-deforming structure, the nature of the invertebrate fossils, and the character of the associated shales indicate lagoonal rather than reef origin.

Lagoonal shore lines are noted for the very gentle slope of the land surface into the sea. The angle of this slope may well be of the order of three or four feet per mile. If this gently sloping plane is supplied largely with mud, the coast will be marshy. If this plane is supplied largely with sand-sized particles, wave action is almost certain to result in barrier islands, behind which lagoons form.

That at least part of the late Pennsylvanian shore line of Oklahoma was suitable for the formation of barrier islands and lagoons, has been shown by field studies in Seminole County, in the east central part of the state (Tanner, 1955). In that area, the late Pennsylvanian land surface sloped into the sea at an angle of a few feet per mile, and plenty of sand was on hand for the construction of beaches and barrier islands. Lagoonal limestones described from that area include the DeNay, Homer, Sasakwa, Belle City, Hart, and many unnamed lenses; and an excellent example of a lagoonal-type shale occurs in the Hilltop formation.

The geometry of barriers and lagoons is not absolutely fixed, but varies with—among other things, such as the size of the sand particles—the slope of the land surface into the sea. Barriers are, however, commonly about a mile wide, while lagoons and their related estuaries may have widths anywhere from about a mile up to perhaps 25 or more miles.

Fluctuations in sea level and in rate of supply and removal of sand, coupled with slight positive or negative movements of the land, result in a landward or seaward shifting of the barrier. This shifting may give rise to barrier facies deposits which are much more than a mile wide, and lagoonal facies deposits which are much more than 25 miles wide.

There is, apparently, no particular limit to the length of either barrier or lagoon. Along the Texas coast, either one exceeds 100 miles in length.

This is partly due to the aridity of the Texas landmass between Brownsville and Corpus Christi, and therefore the absence of well-developed streams emptying into the lagoon. From the standpoint of a meteorologist or climatologist, the Osage County coast, in Missouri and Virgil time, was probably broken by many streams, particularly in view of the fact that the prevailing westerlies had a broad expanse of water across which to move before reaching the shore.

Lagoons may be the sites of accumulation of many different sediments: sand, mud, carbonaceous matter (coal), limestone, gypsum, and others. Gypsum, an indicator of at least semi-aridity, has been recovered from sediments of modern Laguna Madre (Texas Coast), where evaporation exceeds rainfall. No gypsum has been found in the deposits of Osage County. No coal was found in the course and area of this study. Coals do occur, however, lower in the section, in Washington County, to the east, and a coal smut (Russell, 1954) and a coal bed (Shannon, 1954) have been reported from central Osage County.

The chief lithologies found in the lagoonal facies of the area are, first, shale, with a small amount of limestone, representing the undisturbed lagoon or similar open sea; and second, sandstone, due either to the shifting of the beach or barrier, or to influx from stream channels suddenly diverted into the immediate vicinity. A number of examples of the latter have been found.

The most interesting lithology associated with the lagoonal facies is the "crab burrow" sandstone. This may be examined in the field at the following localities: (1) southeast of the dam at Sunset Lake, 12 to 15 feet below the base of the Labadie limestone, and 100 yards or so downstream (NW¼ sec. 33, T. 27 N., R. 10 E.); (2) south of the Caney River, in the extreme northwestern corner of the area, about 15 feet above the Upper Oread limestone, along the gravel road (SW¼ sec. 20, T. 29 N., R. 10 E.); and (3) the Hay Hollow member of the Tallant formation, in a rather inaccessible area (secs. 25 and 36, T. 28 N., R. 11 E.). Each of these is a slabby, hard sandstone, commonly one foot or less in thickness, composed of more or less poorly cemented sandstone, with tubes, about one inch in diameter, of well-cemented sandstone. The tubes coil and intertwine in an intricate pattern below the sandstone slabs. On weathering, the softer sand is washed away, leaving the complex network of hard sandstone tubes. "Crab burrow" sandstone slabs have been utilized in the construction of the store building at Sunset Lake.

The present writer has seen sandstones of this type in the field in South Florida, where they are of late Cenozoic age. It is reasoned, from exposures there, that the burrows were made by small crabs, working in a bottom layer of impure sand a few inches to a foot or so deep. The burrows were gradually filled as coarser, cleaner sand was washed into the area by wave or current action. During lithification, cementation proceeded to a greater degree in the coarser, cleaner sand within the burrows. For a fruitful discussion of some of these ideas, in the field, this writer is indebted to George Grice, a marine biologist. The burrows in Osage County are probably those of organisms of similar habitat, perhaps some primitive crustacean.

Part of the facies interpretation constructed above rests on the analysis of oriented data, discussed elsewhere in this report.

ORIENTED DATA

Paleogeographic reconstructions would be relatively easy if the geologist could always locate with assurance specific geographic features such as river channels and beaches. Unfortunately, river channels of the recognizable type are rare; and beaches, as they advance or retreat across coastal plains, leave, primarily, sand *sheets* rather than the sort of elongate bar-like feature the average geologist pictures when he thinks of barrier islands. Under these conditions, precise location of single features is rarely possible.

The next best bit of information, after location, is orientation or direction. Within a sand sheet of considerable areal magnitude, a beach could have existed in almost any direction. If a reliable orientation can be established, the shore line, for one geological instant, at least, can be drawn, and the directions of advance and retreat can be indicated. Such orientation is available in many sandstones and conglomerates. The main features from which direction may be obtained are cross-bedding, ripple marks, "bar structures" and channels (given in rough order of decreasing frequency of occurrence).

It is obvious that the direction of "dip" of one cross-bedded sand layer is the direction in which the current was flowing at the time of deposition. Cross-bedding, however, "dips" in many directions, and the human mind does not readily make order out of the apparent chaos. For assistance in this problem, the help of statistics may be sought.

First, it should be pointed out that ordinary statistics will not serve. The measurements obtained in the field, with a compass, from cross-bedded sandstones, are directions, to be noted on a circle rather than along a straight line. On a circle there is no genuine zero; the "zero" or "north" of the magnetic compass is arbitrary, and cannot be used in calculations such as the determination of an average (Jizba, 1953). For instance, two directions such as N. 10° E. and N. 10° W., expressed in some form of circular measure as "10" and "350", average out to 180°, which is due south. This is plainly as wrong as possible. In this particular example, the correct answer can be had by averaging "quadrant measure" numbers (i. e., plus 10 for N. 10° E., and minus 10, for N. 10° W.). However, other examples can be set up to show that, in our present state of knowledge, it is not permissible to calculate an average based on an arbitrary zero. Therefore, directions *per se* cannot be averaged.

To get around this difficulty, several manipulations are available. One is to fall back on simple vectors (rather than using an "average" such as the mean). With this procedure, one may adopt the convention of plotting each item, obtained by field measurement, as a line of a certain length (i. e., one cm), drawn in the direction of the "dip" of the cross-bedding. Measurement No. 2 can then be drawn (both direction and length) from the terminus of No. 1; No. 3 can be added to No. 2; and, in time, all of the measurements from a single locality will be plotted as a rather angular spiral. When the initial point of No. 1 is connected with the terminal point of the final measurement, the new line is the vector sum, a direction representing all of the measurements used.

In the Cochahee sandstone member of the Vamoosa formation, about one mile south of the village of Nelagoney, nine cross-bedding directions were obtained. These range from N. 35° E., westward and southward to S. 20° W.—an arc of 195 degrees. An average (i. e., mean) of these nine directions is 208° (S. 28° W.). This is badly in error, and obviously so. The vector sum, however, is 285° (N. 75° W.), a much more plausible and useful result (Fig. 4).

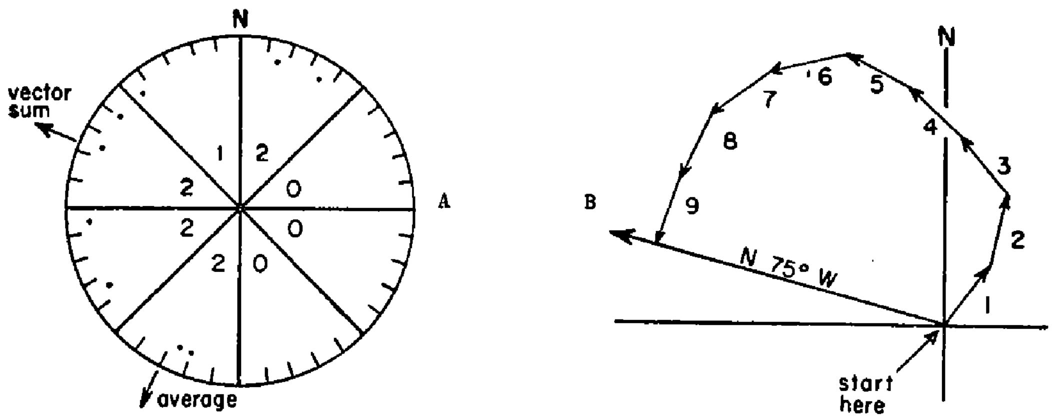
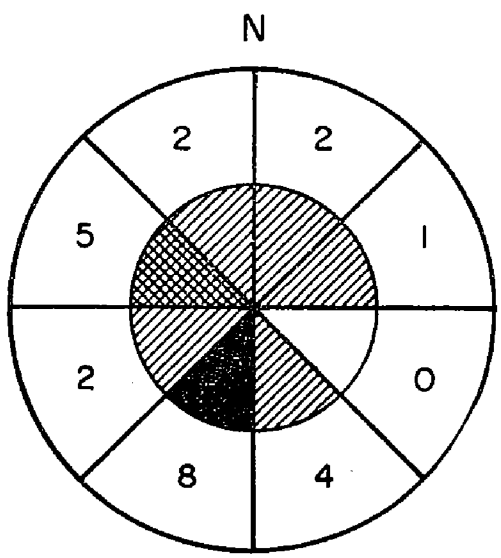


Fig. 4 (A) Nine measurements from the cross-bedded Cochahee sandstone (see text) with average (i.e., mean), and vector sum.

(B) Calculation of the vector sum, same data.

Another possibility is to divide the circle into arbitrary divisions (generally octants, although sixteenths are useful in certain instances), and total the number of measurements for each division. For the Cochahee data, above, the total in each octant is given in the figure. These totals can then be handled statistically, yielding the average (i. e., mean), and any more advanced parameters which may be desirable, such as the standard deviation. The octant having the largest total may be designated as the mode. For the Cochahee data, no mode appears, but for other examples, the mode is a most useful device.

The Noxie sandstone member of the Chanute formation, in northern Nowata County, yielded 24 measurements (Fig. 5). The counts, per octant, range from zero to a maximum of eight. Eight is the mode. It indicates currents which flowed toward the south-southwest. Just how significant is this direction? The average (mean) is three, and the standard deviation (see any elementary statistics text) is 2.4. Adding 2.4 to three gives 5.4: any total higher than 5.4 is significantly high. The mode, therefore, is significant, and is inked solid black in the figure. The west-northwest octant contains five measurements, which is close to the sum of the mean and the standard deviation. Since it exceeds its immediate neighbors, it is cross-hatched. This is the secondary mode, not as significant as the mode, but nevertheless indicating a single direction for a considerable number of measurements.



Total: 24

Mean: 3

Standard deviation: 2.4

Significantly high: 5.4 and above.

Significantly low: below 0.6.

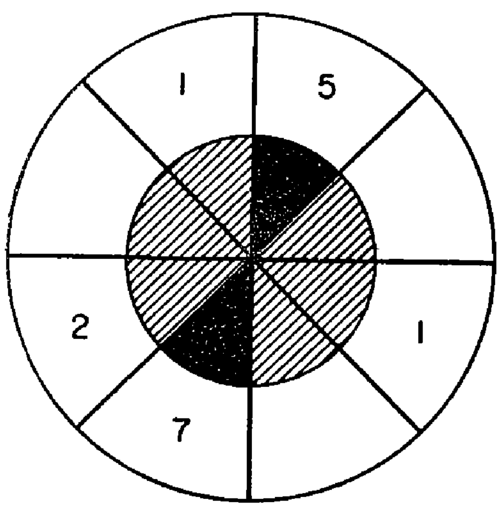
Fig. 5.

Figure 5. Cross-bedding directions from the Noxie sandstone member at the Chanute formation, northern Nowata County. For discussion, see text.

Subtracting the standard deviation from the mean leaves 0.6: any total smaller than this is significantly low. The east-southeast octant, with no measurements at all, is significantly low, and therefore is left white. This octant might be called the minimum arrow, or minimum direction. All other octants, falling as they do well within one standard deviation of the mean, are considered to be without great significance, and are shaded lightly.

The pattern so obtained is quite revealing. An interpretation is given below.

Seventeen measurements from selected localities in the lower part of the Vamoosa formation are given in Fig. 6. The statistical parameters are included in the figure. There are two octants which are significantly high (each one exceeds 4.5), and, although only one is the mode, both are inked solid black to indicate their significance. No octant is significantly low. The most interesting thing about this example is the fact that the two high octants are diametrically opposite each other! Further, one of the "black" octants is the same direction as the Cochahee mode.



Total: 17

Mean: 2.125

Standard deviation: 2.37

Significantly high: 4.5 and above

Significantly low: (none)

Fig. 6.

Figure 6. Cross-bedding directions from selected localities in the lower part of the Vamoosa formation. For discussion, see text.

From the two figures, four significant directions have been obtained; sketched on a map, they form a cross. Two of the directions represent many currents, one direction not quite so many, and the fourth direction, no currents at all. (The other four octants are not significant.)

The interpretation is this: The minimum arrow indicates the direction in which the land mass lay, and from which currents may come, but toward which very few currents flow (for exceptions to this generalization, see Tanner, 1955). The cross-hatched, secondary mode (of the Noxie data) indicates the direction toward the open sea, and the direction in which channel currents, either alluvial or submarine, flowed. The two opposed modes (of the lower Vamoosa formation) indicate littoral currents, and hence the trend

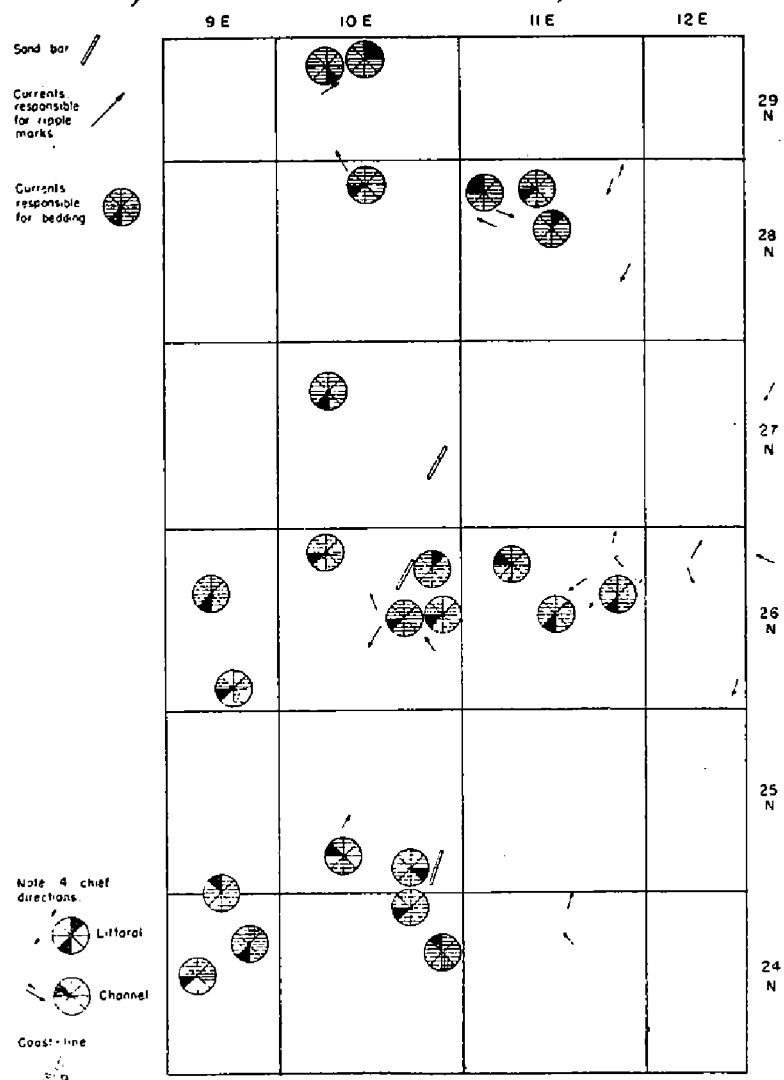
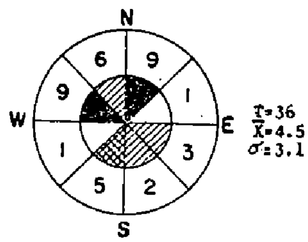
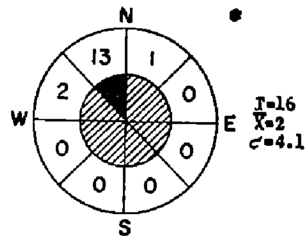


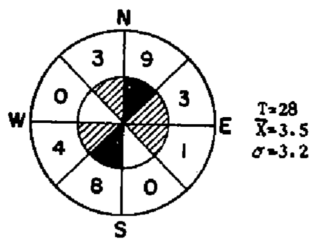
Figure 7



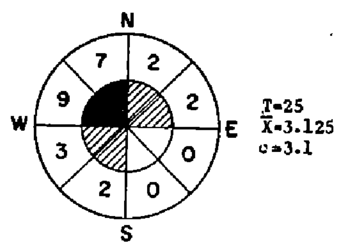
(A) Ripple-marks;
central and northern
townships.



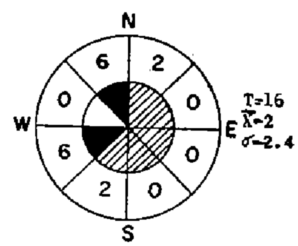
(B) Ripple-marks;
southern townships.



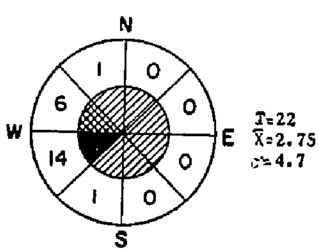
(C) Vamoosa
cross-bedding,
littoral deposits;
central and northern
townships.



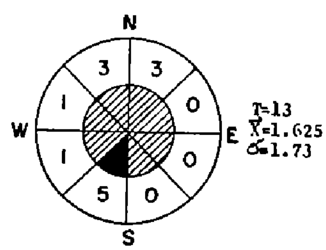
(D) Vamoosa
cross-bedding,
channel deposits;
central and northern
townships.



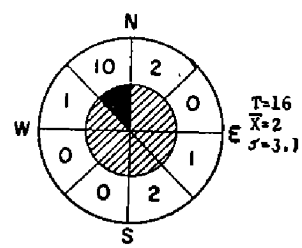
(E) Vamoosa
cross-bedding,
channel and littoral;
southern townships.



(F) Tallant
cross-bedding,
channel deposits;
central and northern
townships.



(G) Tallant
cross-bedding,
littoral deposits;
central and northern
townships.



(H) Tallant
cross-bedding,
littoral deposits;
southern townships.

Fig. 8. Summary of oriented data.

or orientation of the shore line. The agreement of the four is, in these instances at least, excellent.

It will be noted that the vector sum of the Cochahee data agrees in direction with the secondary mode of the Noxie data.

For this study, over 300 readings were taken from cross-bedded sandstones, and 50 directions were recorded for asymmetrical ripple marks. From these, the conclusion is drawn that the shore line lay in a north-northeast south-southwest direction (although its precise location is not specified), and that the sea lay to the west-northwest. Further, it is observed that the various localities visited fit into two categories: (a) those like the lower Vamoosa, indicating a shore line trend, and (b) those like the secondary mode of the Noxie data, indicating a channel current.

The Noxie is interpreted, in the light of the above, as being primarily the product of littoral currents, and secondarily the product of channel currents. It is apparently not a continental deposit, and does not suggest the presence of a single, well-developed channel. The Torpedo sandstone was also, apparently, the product of littoral activity. The true channel sands of eastern Osage County, found particularly in the Tallant and Vamoosa formations, do not differ in general appearance from other sandstones in those formations. The statistical tools described above, however, make the distinction.

In the southern part of the area (T. 24 N.), the shore line trend swings around to a slightly different direction (Fig. 9). Readings from cross-bedded sandstones in the Bigheart and Revard members of the Tallant formation, and the Wynona and Elgin members of the Vamoosa formation, point to littoral currents which flowed along a shore line trending north-northwest south-southeast.

This is the part of the area where the Tallant formation contains dark red shales instead of the more common gray-green and blue-gray shales.

Because of this shift in the shore line trend, totals for the entire area are of little use.

The conclusions reported in this chapter were reached early in the field work. As familiarity with the section increased, no reason was found to change them. Interpretation of much of the section was based on this early regional paleogeographic analysis.

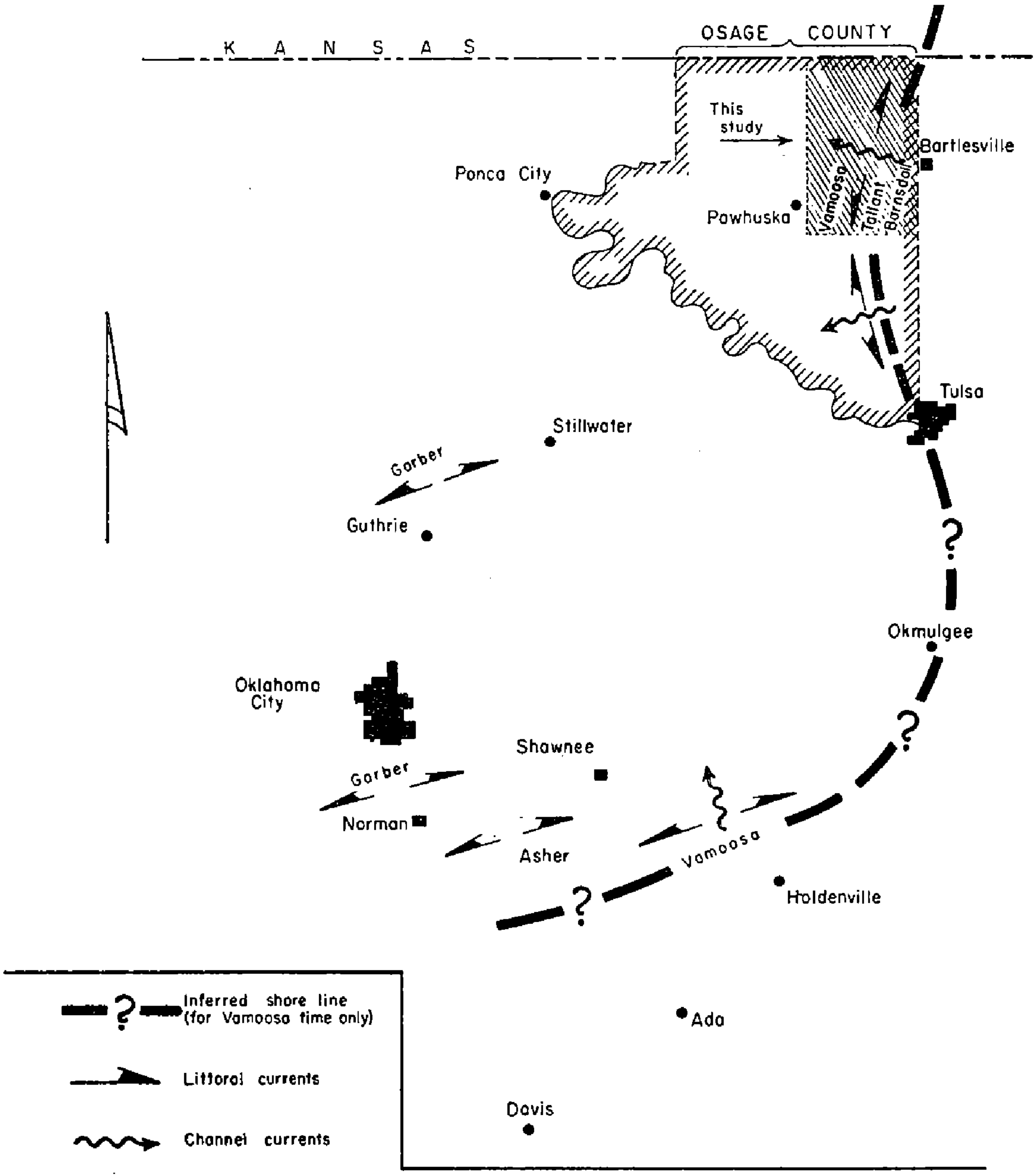


Figure 9 Shore line trends for Missouri and Virgil time

SURFACE STRATIGRAPHY

Pennsylvanian System

Introduction

Surface rocks studied in the preparation of this report belong to three formations: Barnsdall (lowest), Tallant, and Vamoosa (highest). The three formations include a total of about 675 feet of section in the southern part of the area, about 650 feet in the central part of the area, and about 940 feet close to the Kansas line. The uppermost 150 to 220 feet of the Vamoosa formation (that part lying above the Oread limestones) was examined only cursorily, to avoid duplication of recent work by Carter (1954), Shannon (1954), and Russell (1955).

The section is composed of 51 percent, 75 percent and 85 percent shale(figures for southern, central and northern parts of the area); 49 percent, 22 percent and 13 percent sandstone; and zero, 4 percent and 2 percent limestone. Much of the variation, in the center and north, is actually in the shale: limestones average a total thickness of 20 feet, sandstones average a total thickness of 120 feet, but shales vary from 800 feet, near the Kansas line, to only 410 feet, in the central part of the area. In the south, shales thin to about 345 feet, and sandstones thicken to 335 feet.

Locally the section departs quite a bit from the average; it is this fact which leads to part of the facies interpretation given elsewhere in this report. The local variations are in many instances, found along east-west lines, whereas the averages given above have been calculated for changes in a north-south direction.

The Barnsdall and Tallant formations belong to the Missouri series; the Vamoosa formation, to the Virgil series. The chief difference between the two series is this: the Missourian (in this area) is primarily a shale section interrupted regularly by sandstone ledges and irregularly by limestone lenses; the Virgilian is largely a shale section interrupted regularly by limestone ledges and irregularly by sandstone lenses.

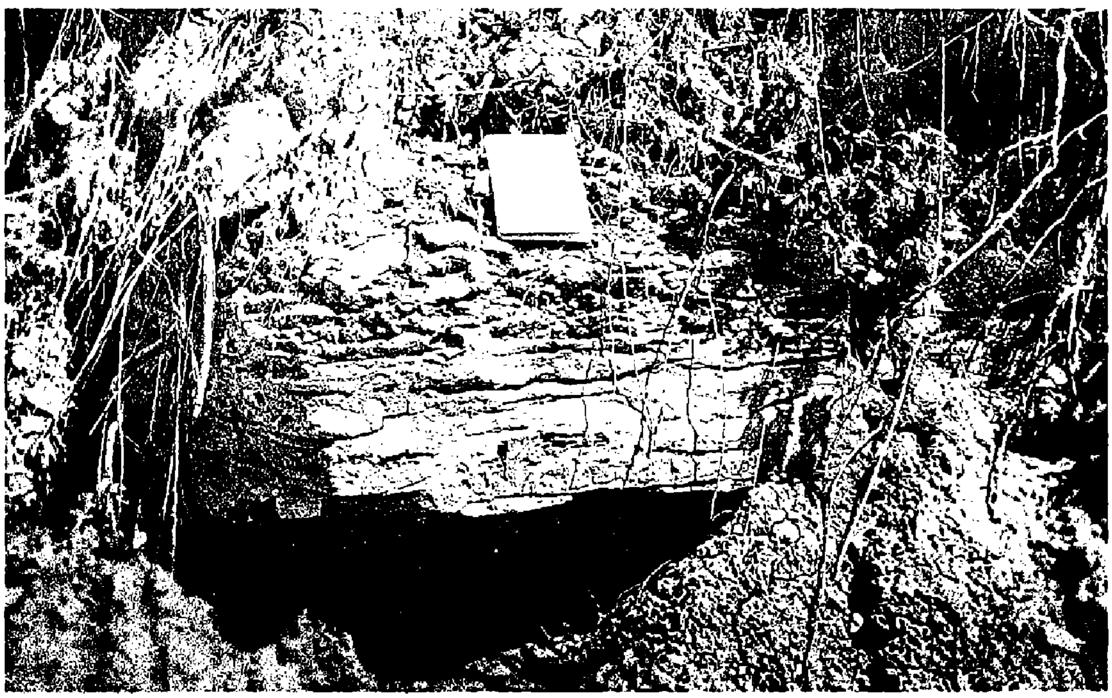
There is no specific evidence for a regional unconformity at any place within the section, although there is little doubt that erosion—at least of a submarine nature—was active at times during the deposition of the various beds.

Barnsdall Formation

The name Barnsdall was first applied by Oakes (1951, p. 119), to a sequence of shales and sandstones cropping out in the vicinity of the village of Barnsdall, and southward. The formation includes two named members, the Birch Creek limestone at the base, and the Okesa sandstones in the middle, with unnamed shales.

The Barnsdall in east central Osage County is 130 to 160 feet thick. It is commonly 80 percent or more shale.

A. Barnsdall formation. Lagoonal shales and thin limestones exposed in spillway of Lake Hudson.



B. Birch Creek limestone member of Barnsdall formation. Exposure on road to Okesa.

Birch Creek limestone member. At the base of the formation is a horizon where may be found, locally, the Birch Creek limestone, named by Bowen (1918, p. 17) from sec. 25, T. 24 N., R. 10 E. At most points the Birch Creek horizon is marked by thin, flaggy siltstones or fine-grained sandstones. At a few places, where the Barnsdall directly overlies the Torpedo sandstone member of the Wann formation, the Birch Creek horizon can be identified as being at the top of the sandstone.

Where sandy, the Birch Creek is like the Okesa sandstones higher in the section. Where limy, it is easily mistaken for any one of a number of limestone lenses. For structural control it is useful only in the Panther Creek vicinity, where it was mapped by the United States Geological Survey (1922) as the Panther Creek limestone.

The Birch Creek limestone is notable for its variations laterally from lens to lens. On "The Mound", immediately north of U. S. Highway 60, and across the county line from Bartlesville, the Birch Creek is a medium gray fine to medium crystalline limestone which weathers to a yellowish-buff color. Both invertebrate fossils and bottom markings can be seen on the bedding planes. The layers are commonly one to two inches thick, rarely eight inches thick. The total thickness varies between two and four feet. Locally pockets of shell hash—including fragments of bryozoans, pelecypods and crinoids—can be found.

Northwest of Copan, in Washington County (NW¼ sec. 7, T. 28 N., R. 13 E.), the Birch Creek is a lenticular sandy limestone and calcareous siltstone, buff on both fresh and weathered surfaces. It contains, here and there, brachiopod fragments and clay pebbles. Where a more or less pure limestone, the color is gray.

At the Highland School (sec. 24, T. 26 N., R. 11 E.), close to the road intersection, the Birch Creek is a buff very fine sandstone or siltstone, less than one foot thick. Generally it is only one or two inches thick, soft, and poorly exposed. Hard, small lenses of dark brown rubbly limestone, which weather yellow, and soft nodular masses of yellow to gray shell hash limestone occur at various places. All of the lenses are not in precisely the same stratigraphic position.

One half mile west of the intersection, the member is two to three feet thick, largely limestone. About one mile west of the intersection, the limestone grades laterally into a ripple-marked sandstone, with crinoid stems locally present.

Along the road in NE¼ sec. 12, T. 26 N., R. 11 E., the Birch Creek is a steel gray, fine to medium crystalline limestone about one foot thick. It is thin-bedded, non-fossiliferous, locally grayish-brown, and quite compact.

Northeast of the village of Okesa (middle of east line sec. 15, T. 26 N., R. 11 E.), the Birch Creek is a medium gray coarse crystalline limestone and shell hash about three feet thick. Locally it is grayish-green and grayish-blue. It is associated here with a brown, contorted sandstone not generally found at this horizon. The limestone contains crinoid stems, and fragments of Bryozoa, *Composita,* and other invertebrates. The bedding is uneven.

In the southwest quarter of the same section, the limestone is either steel gray or cinnamon brown, weathering yellow. Here it is finely crystalline and marked by wavy bedding.

At the brow of the cuesta about one mile south of the village of Wolco (sec. 25, T. 24 N., R. 11 E.), the Birch Creek is a light gray to buff, medium to coarse crystalline limestone which weathers into brown rounded boulders. Fossils are rare in this area.

At some points the Birch Creek horizon is a thin layer of brachiopods and pelecypods in a thin-bedded, buff, calcareous sandstone.

In general, the Birch Creek occurs at more than one horizon, and represents more than one environment. It is a very unsatisfactory key bed.

The Okesa sandstone was named by Clark (in Hopkins, 1918, p. 76) from exposures east of the village of the same name (T. 26 N., R. 11 E.). The Okesa sandstones come and go in the section. Where present they are silty, thin-bedded, calcareous, and grayish-green to buff. Contortions, on a small scale, ripple marks and bottom markings are common. The Okesa sandstones are typically exposed along U.S. Highway 60, in the road-side cuts south of the U. S. Air Force radar installation (sec. 6, T. 26 N., R. 12 E.).

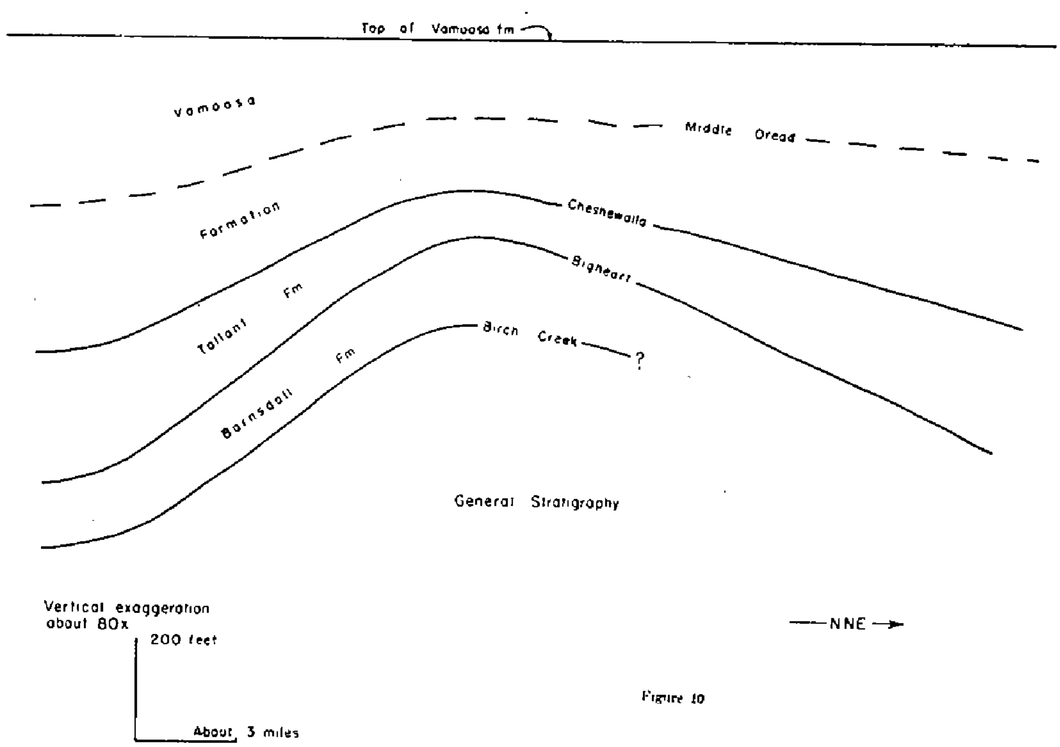


Figure 10

In the vicinity of Buck Point (sec. 11, T. 26 N., R. 11 E.), the Okesa sandstones and siltstones are calcareous, greenish-gray to buff, thin-bedded and flaggy. Contortions, leaf prints, and sandstone lenses up to three feet thick are common. The sandstones are not continuous, however, and are useful for mapping only in restricted localities.

From the radar station to the west (and south) the Barnsdall is sandy: that is, the Okesa sandstones are well developed. To the east (and north), however, the sandstones vanish, the Barnsdall is almost entirely a shale. This facies is well exposed in spillway and road-side cuts near Lake Hudson (sec. 17, T. 27 N., R. 12 E.). It includes blue-gray shales, thin buff siltstones and very fine-grained sandstones, and thin blue-gray medium to fine crystalline limestones. The sandstones are laminated and locally ripple-marked, but are neither cross-bedded nor contorted. Bottom markings, including trails and burrows, occur on bedding planes of both limestones and sandstones. Marine invertebrate fossils can be found here and there in the section.

The Okesa, because of its position to the west, its sandy nature, and its cross-bedding and penecontemporaneous contortion, is interpreted as being barrier facies. The calcareous shales and thin limestones and ripple-marked sandstones are thought to be the product of a lagoonal environment.

Tallant Formation

Oakes (1951, p. 121) first used the name, Tallant, to apply to a sequence of sandstones and shales which crop out in the vicinity of the town of Tallant, and southward.

The Tallant, in the area of this study, includes four fairly persistent members: the Bigheart sandstone at the base, an unnamed shale, the Revard sandstone, and a second unnamed shale. In addition, several named sandstone beds have been assigned, either correctly or incorrectly, to the Tallant. Among them have been the Buck Point, Gap, Hay Hollow, Hulah, Mission, and Possum sandstones.

The Tallant varies in thickness from 100 feet, in the east central part of the area, to 250 feet in the northeastern (T. 28 N., R. 12 E.) and southern parts (T. 24 N., R. 10 E.). Where only about 100 feet thick (measured section No. 19), the Tallant is approximately 65 percent sandstone, 35 percent shale. Where it is about 250 feet thick (measured sections No. 31, 32), it is 27 percent sandstone, 72 percent shale, and 1 percent limestone. In between, where about 200 feet thick (measured sections No. 9, 10), it is 22 percent sandstone, 75 percent shale, and 3 percent limestone. Near the type locality, it is about 245 feet thick: 72 percent sandstone and 28 percent shale.

Shales of the formation are well exposed in the construction cut west of the dam at Lake Hudson (sec. 17, T. 27 N., R. 12 E.). The shales are greenish-gray and grayish-blue. Various horizons within the shales are marked by limonite concretions (up to three inches in diameter), fossiliferous light gray medium crystalline limestone beds one to two inches thick, thin yellow calcareous siltstone beds with profuse bottom markings, and thin beds of *Linoproductus* shell fragments.

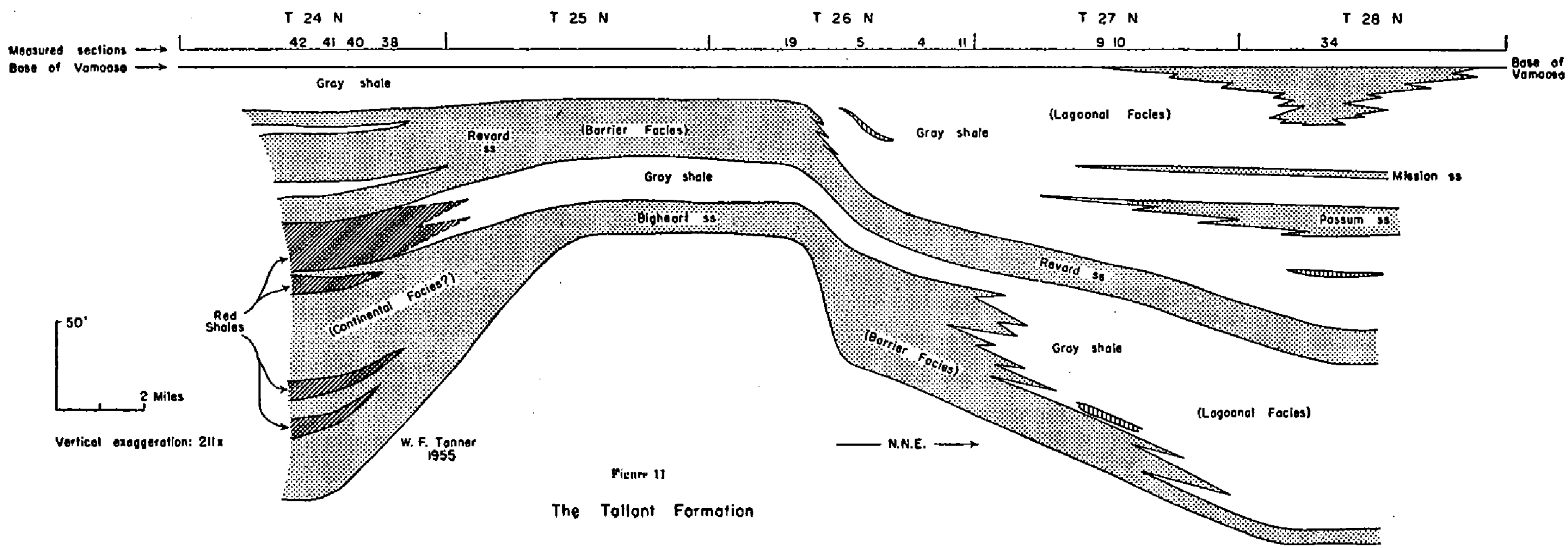


Figure 11

The Tallant Formation

Bigheart sandstone member. The basal member of the Tallant formation is the Bigheart sandstone. It was named by Snider (1911, p. 221) from the town of Bigheart (now the town of Barnsdall). The sandstone is well exposed along U. S. Highway 60, about six miles west of Bartlesville (NE¼ sec. 10, T. 26 N., R. 11 E.). Here it is a thin-bedded to massive buff to brown fine to very fine-grained sandstone of uncertain thickness. Partings of gray-green shale, and secondary limestone lenses can be found in the section. Local pockets of conglomerate consist of pebbles and cobbles of clay (limonite yellow), very fine sandstone (pale green), and sandstone (brown). The largest cobble found is eight inches in diameter.

A few faint contortions occur along with low-angle cross-bedding, gentle scour pockets, current ripple marks, "tadpole nests", and a general lenticularity. Bottom markings and "*Linoproductus*" casts are common.

The difficulty in measuring the thickness at this point lies in the fact that there is no apparent upper limit to the sandstone. Oakes (1954) has commented on the fact that no two geologists seem to agree on the thickness of this member.

In this particular locality, the Tallant is sandstone without a significant break from the bottom of the Bigheart to the top of the Revard (which is almost the top of the formation). This is the general area in which the Tallant is about 65 percent sandstone: this is the barrier facies. A few miles farther north, the Bigheart varies between eight and 25 feet in thickness. Several miles farther south, the member splits into several sandstone tongues, most of which pinch out in relatively short distances. The average thickness of the member is between 10 and 35 feet.

Along the Okesa road, about one mile south of U. S. Highway 60 (sec. 6, T. 26 N., R. 11 E.), the Bigheart is well exposed. The total thickness of the member is about 50 feet. The interval between it and the Revard—about 32 feet—is largely sandstone, and might be included in the Bigheart. In fact, from the base of the Bigheart to the top of the Revard, a total thickness of 105 feet, is largely sandstone. The Bigheart has been restricted here to the lowest 50 feet, on the basis of lateral continuity as observed on the airplane photographs.

In this locality the member is a massive, buff, lenticular, cross-bedded fine-grained sandstone, grading upward into a thin-bedded fine-grained sandstone. Moderate contortion is present, but no conglomerate. The associated shales are gray-green (the common shale color in the area), brown, gray, buff, and yellow. The shales are silty. The contact with the underlying Barnsdall formation is irregular, with about five feet of relief in a lateral distance of 100 feet. This is not necessarily an unconformity, in the sense of requiring sub-aerial erosion.

Along Sand Creek, near the east limits of Osage Hills State Park (sec. 12, T. 26 N., R. 10 E.), the Bigheart is about 50 feet of cross-bedded, ripple marked, buff, thin-bedded to massive sandstone. Plant fragments up to one foot long occur in these beds. Gray-green shales and thin-bedded siltstones alternate with the sandstones. The ripple marks include "tadpole nests" as well as current ripple marks. "Bar structures" have a general trend slightly east of north.

At the west end of the Lake Hudson dam (sec. 17, T. 27 N., R. 12 E.), the Bigheart consists of 28 feet of buff, laminated, fine-grained sandstone which appears to be massive when weathered. The beds are slightly thicker in the lower half. The upper two feet contain a rotten-looking, brown, medium-bedded sandstone and clay pebble conglomerate. The sandstones are neither cross-bedded nor contorted.

In the vicinity of Lake Bar-Dew (sec. 15, T. 27 N., R. 12 E.) the Bigheart is 19 feet thick, a buff, thin-bedded sandstone containing brachiopods at the top of the ledge. No cross-bedding was found in either the Lake Hudson or the Lake Bar-Dew areas. Ripple marks, worm trails, other bottom markings, and plant fragments are fairly common, however.

Along the road in the NW¼ sec. 1, T. 26 N., R. 11 E., the Bigheart is 40 feet of buff, ripple marked, thin-bedded, fine-grained sandstone. The member is not cross-bedded. In the creek bed in sec. 24, T. 27 N., R. 10 E., the Bigheart is a highly contorted and "corrugated" buff sandstone containing plant fragments up to two feet long. "Bar structures" trend slightly east of north. West of the village of Okesa (secs. 19 and 20, T. 26 N., R. 11 E.), the Bigheart is a highly contorted, obscurely cross-bedded, fine-grained sandstone and siltstone.

The Woolaroc museum building is veneered with ripple-marked slabs of Bigheart sandstone. It should be observed from the above that the Bigheart occurs in two facies: a thick, cross-bedded, contorted, plant-bearing sandstone, here interpreted as belonging to a bar or barrier island environment; and a thin-bedded ripple marked sandstone loaded locally with invertebrate fossils and various bottom markings, interpreted as the product of a lagoonal environment. The later facies is typically developed in the areas of Lake Hudson and Lake Bar-Dew; the former, between Okesa and U. S. Highway 60, and in the vicinity of Buck Point. The east-west component of distance between the two areas is about six miles, the north-south component a like amount.

South of Bird Creek, in the vicinity of the town of Barnsdall (T. 24 N.), the Bigheart member includes a sandstone section 114 feet thick. Red shales, in units averaging four feet thick, account for about 21 feet of the total. A few of the thinner beds are composed of siltstone. The sandstones are buff, fine-grained, and cross-bedded. Clay pebble conglomerates occur here and there in the section.

Immediately north of Bird Creek (sec. 10, T. 24 N,. R. 11 E.), the exposed portions of the Bigheart are characterized by many ripple marks, indicating currents which flowed toward the north-northwest (13 out of 16 measurements fell within the north-north-west octant). Farther west, but still north of Bird Creek, the Bigheart is exposed on hill tops, where its full thickness is rarely developed.

Revard sandstone member. The Revard sandstone was named by Winchester and others (1918, p. 61), from Revard Point (sec. 13, T. 26 N., R. 10 E.), south of what is now Osage Hills State Park. The Revard is the higher of the two persistent sandstone ledges in the Tallant formation. The member is in general 18 to 22 feet thick, but locally (i. e., west of Okesa) thickens to between 35 and 40 feet. The base of the Revard commonly falls between two fifths and half of the way from the bottom to the top of the formation.

In the park, overlooking Sand Creek in the immediate vicinity of Revard Point, the member is 19 feet thick, buff, thin-bedded and fine-grained. It is cross-bedded and ripple-marked.

In the Lake Hudson area (sec. 17, T. 27 N., R. 12 E.) the member is contorted on a small scale, buff, thin-bedded and fine-grained. It is approximately 18 feet thick.

Southwest of the lake (sec. 36, T. 27 N., R. 11 E.,), plant prints, bottom markings and faint contortions can be found.

The Revard member provides an excellent example of a lagoonal sandstone in its outcrop immediately below the Lake Hulah spillway (sec. 12, T. 28 N., R. 11 E.). Excellent trails, ripple marks, plant prints, other bottom markings, limonite concretions and clay pebble conglomerates can be seen there. The member is a buff, laminated to massive, very fine-grained sandstone and siltstone, with no cross-bedding. The ripple marks, exclusive of the "tadpole nests", were formed by currents flowing toward the north-northeast.

West of the village of Okesa (sec. 20, T. 26 N., R. 11 E.), the Revard is a buff, thin-bedded, fine-grained sandstone or pale green siltstone which has a massive appearance when weathered. It is 35 feet thick.

A clay pebble conglomerate occurs in the Revard west of Panther Creek (sec. 24, T. 26 N., R. 11 E.). Plant fragments up to 15 inches long, contortions and "tadpole nests" also occur there.

In T. 24 N., the Revard member is a gray green or buff very fine-grained sandstone or siltstone, five to 15 feet thick, more easily traced on the airplane photographs than on the ground.

Hulah sandstone member. The Hulah sandstone member was named by Goldman and Robinson (1920, p. 365) from an outcrop east of the village of the same name (sec. 5, R. 28 N., R. 12 E.). It is particularly well exposed north of the Caney River, where it is a fossiliferous yellow or orange sandstone about four feet thick. South of the Caney River, the Hulah appears in the upper part of the Revard sandstone member, and would therefore seem to be an equivalent of the latter. However, the Hulah mapped at the type locality by the nomenclators (SE¼ sec. 5, T. 28 N., R. 12 E.) is in the present writer's opinion the Bigheart, and elsewhere in the same township the bed named Hulah appears as a lens between the Bigheart and Revard members.

The Hulah was given a name because of, and traced out in view of, the fact that it is so distinctive in appearance in the area north of the Caney River. In the eastern half of Osage County, however, only continuity and stratigraphic position are reliable bases for correlation; appearance is extremely deceitful because of the many facies variations within single beds.

Goldman and Robinson (1920, p. 366) state that ". . . as the names in use in these reports and in others on northeastern Oklahoma were generally applied to thick series of beds, while the mapping of structure was based on single benches, and different geologists working in adjacent townships did not always use the same benches, the tracing is not entirely continuous." Continuity and stratigraphic position were not prime aims of the early United States Geological Survey mapping of Osage County; and if they had been, the lack of the best modern tool for the purpose—airplane photograph analysis—would have seriously handicapped the work.

Gap sandstone member. The Gap sandstone member was named by Goldman (1920, p. 333) from Gap Ridge (T. 29 N., R. 12 E.) in Osage and Washington Counties, where the Santa Fe railway passes through a deep cut. The nomenclator correlated this lenticular member with the Revard sandstone, but the present writer believes that it is the northward continuation of the Bigheart, except south of the Caney River, where it undoubtedly falls at the top of or above the Revard.

Possum sandstone member. The Possum sandstone member is a typical more-or-less massive sandstone, about 10 feet thick, named by Goldman (1920, p. 332) from outcrops along Opossum Creek (SE corner, T. 29 N., R. 11 E.). He identified it correctly as probably a tongue of the Revard member.

Mission sandstone member. The Mission sandstone member was named by Goldman and Robinson (1920, p. 364) from prominent occurrences along Mission Creek (T. 28 N., R. 11 E.), where it is a slabby sandstone, about four feet thick, characterized by shell imprints on the upper surface. It is not continuous, farther south, with any bed now known, but probably belongs to the Revard sequence.

The Mission sandstone is well exposed along the south bank of Lake Hulah, between the dam and the main boat docks, a distance of approximately a mile. On the hills along this stretch of the shore, only three beds appear; the Mission, at the water's edge, the Cheshewalla sandstone on the hilltops, and a few patches of Bowring limestone above the Cheshewalla.

The Mission member is a buff to light brown, thin-bedded to massive, very fine-grained sandstone. It is contorted, locally shows bottom markings, and possesses cross-bedding with a pronounced due-west orientation (11 of 12 measurements were within 22.5° of west). It is here interpreted as a channel deposit, possibly fluvial, but probably shallow marine.

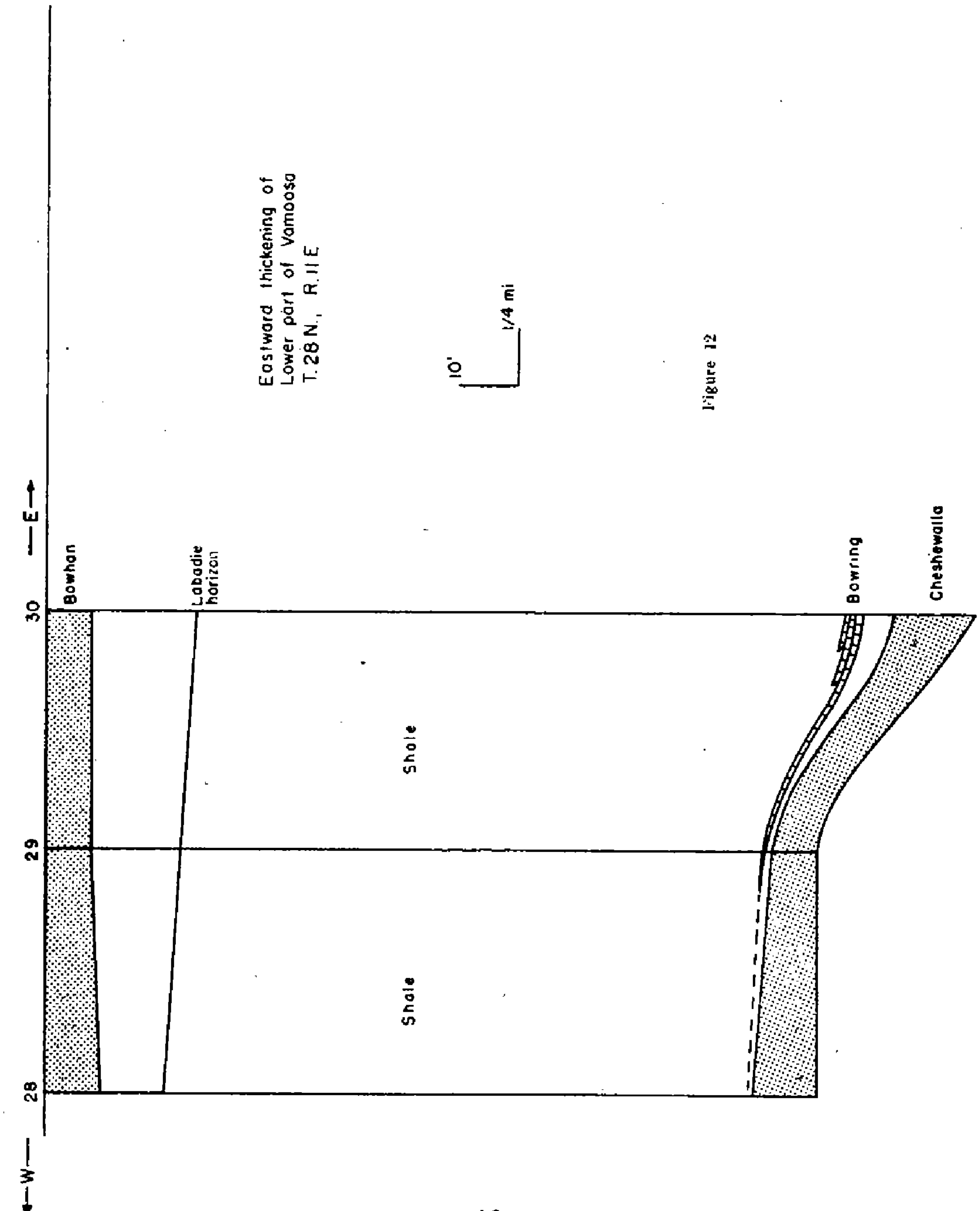
Hay Hollow sandstone member. A distinctive "crab-burrow" deposit is the Hay Hollow member, named by Goldman and Robinson (1920, p. 363) from Hay Hollow (secs. 25 and 36, T. 28 N., R. 11 E.), where it is a slabby, yellow, fine-grained sandstone slightly less than a foot thick. "At many places it contains peculiar winding, cylindrical sandstone casts half an inch in diameter, closely interwoven, which cover the surfaces of slabs," (Goldman and Robinson, 1920, p. 363). The Hay Hollow is a lens with little lateral extent, like other "crab-burrow" sandstones examined in the same region by the present writer.

Vamoosa Formation

The Vamoosa formation was named by Morgan (1924, p. 125), after the townsite of the same name, in Seminole County. There the formation contains several continuous ledges of sandstone and chert conglomerate, for which it is noted, but is primarily a shale (Tanner, 1955). Ries (1955) restricted the usage of the term Vamoosa, to exclude the dark shale section at its base, which Tanner (1953, p. 2046) named the Hilltop and correlated with the Tallant and Barnsdall and perhaps lower formations.

The Vamoosa formation in eastern Osage County consists of red and green shales alternating with thin limestones and thin to thick sandstones. It is about 300 feet thick in the central part of the area studied, 540 feet thick near the Kansas line, and over 630 feet thick near Wynona (T. 24 N.).

Detailed field work for this report was not carried above the Oread limestone member of the Vamoosa formation. The upper part of the formation (above the Middle Oread limestone) is 150 feet thick in the central part of the area (Shannon, 1954) 220 feet thick near the Kansas line (Carter, 1954), and 330 feet thick south of Pawhuska (Russell, 1955). The lower part of the formation (below the Middle Oread limestone) varies from about 250 feet in the central part of the area to 300 to 310 feet in the north and south.



In the vicinity of the Caney River, near the northern edge of the area, the lower Vamoosa is about 82 percent shale and siltstone, 17 percent sandstone, and only 1 percent limestone. In the central part of the area, the limestone percentage varies from 5 to 35 (as the Labadie member thickens and thins), the sandstone percentage is 12 to 25, and shales and siltstones make up about 68 percent to 78 percent of the lower part of the formation. South of Bird Creek (T. 24 N.) the ratio is 56 percent shale, 44 percent sandstone.

In general, the proportion of shale increases northward.

The Vamoosa is the lowest formation in the Virgil series. In Seminole and Okfuskee Counties (Tanner, 1955; Ries, 1955), the base of the Vamoosa is marked by a pronounced unconformity. In the course of field work for the present report, no evidence was found to suggest that the base of the Vamoosa is, in Osage County, marked by an unconformity. Farther south, the best evidence for an erosion interval may be found in the truncation of many older ledges. In the area of this study, no truncations were found. The uppermost 25 feet of the underlying Tallant formation contains no continuous sandstone ledges.

Cheshewalla sandstone member. The basal member of the Vamoosa formation in Osage County is the Cheshewalla sandstone. This ledge was named by Winchester et al (1918, p. 61), from exposures along Cheshewalla and Nelagoney Creeks (SE¼ sec. 10, T. 25 N., R.10 E.), in the east central part of the county. The member is generally about 15 feet thick, although it varies between seven and 20 feet.

Lithologic characteristics alone are not sufficient for an identification of the Cheshewalla. In the northeastern part of the county, the bed is closely overlain by a thin, discontinuous limestone, the Bowring. Here and there the upper surface of the member is fossiliferous. The Bowring is commonly absent, however, and the fossils in the sandstone are not diagnostic. The best criterion for identifying the Cheshewalla is position: 60 to 100 feet below the top of the Labadie limestone member. Beyond the northern limit of the Labadie, the Bowring is at many places present five to 15 feet above the top of the Cheshewalla.

The member is commonly a buff, thin-bedded to massive, cross-bedded, fine to very fine-grained sandstone or siltstone. The topographic expression is not as pronounced as that of the Bigheart or Revard members below, nor that of the Elgin sandstone member above. The continuity, however, is excellent.

Where U. S. Highway 60 crosses the Cheshewalla outcrop (sec. 8, T. 26 N., R. 11 E.), the member is a buff, cross-bedded, contorted, lenticular sandstone about 12 feet thick. Micro-cross-bedding (cross-bedded units one inch high) and bottom markings of various kinds occur in this locality. The abundant cross-bedding indicates currents which flowed toward the west-northwest. The bottom markings, however, preclude the notion that the sandstone is entirely or even predominantly of fluvial origin.

In the railway cut north of Bowring (SW¼ sec. 15, T. 28 N., R. 11 E.), the Cheshewalla is a buff, cross-bedded and contorted, lenticular, thin-bedded to massive, fine-grained sandstone. The cross-bedding in this locality indicates currents which flowed toward the north-northeast.

Immediately southwest of the Lake Hulah dam, where the Cheshewalla member and Bowring limestone cap several small hills, the Cheshewalla is a buff, laminated to thin-bedded, locally contorted, fine-grained sandstone.

Where Oklahoma Highway 99 crosses Pond Creek (NW¼ sec. 2, T. 28 N., R. 10 E.), the member is a buff to faintly greenish-gray siltstone, thin- to medium-bedded, and contorted. Locally it is a buff very fine-grained sandstone with partings of gray-green shale in it. Bottom markings are common. Ripple marks indicate currents which flowed toward the northwest; cross-bedding indicates currents which flowed toward the southwest. Clay pebble conglomerates occur in small pockets, and limonite concretions occur here and there. The member is between 10 and 20 feet thick at this locality.

In T. 24 N., south of Bird Creek, the Cheshewalla is a good ledge of buff massive sandstone possessing much low angle cross-bedding. It is approximately 17 feet thick.

Other exposures of the Cheshewalla are much like those described above. The cross-bedding directions, however, permit nearly every exposure to be placed in one of two categories: (a) littoral cross-bedding, due to currents flowing toward the north-northeast and toward the south-southwest (diametrically opposed); and (b) channel cross-bedding, due to currents flowing northwest or west-northwest. The Cheshewalla, like much of the rest of the Vamoosa, appears to have been the product of two different agencies, each of which operated in different places at different times.

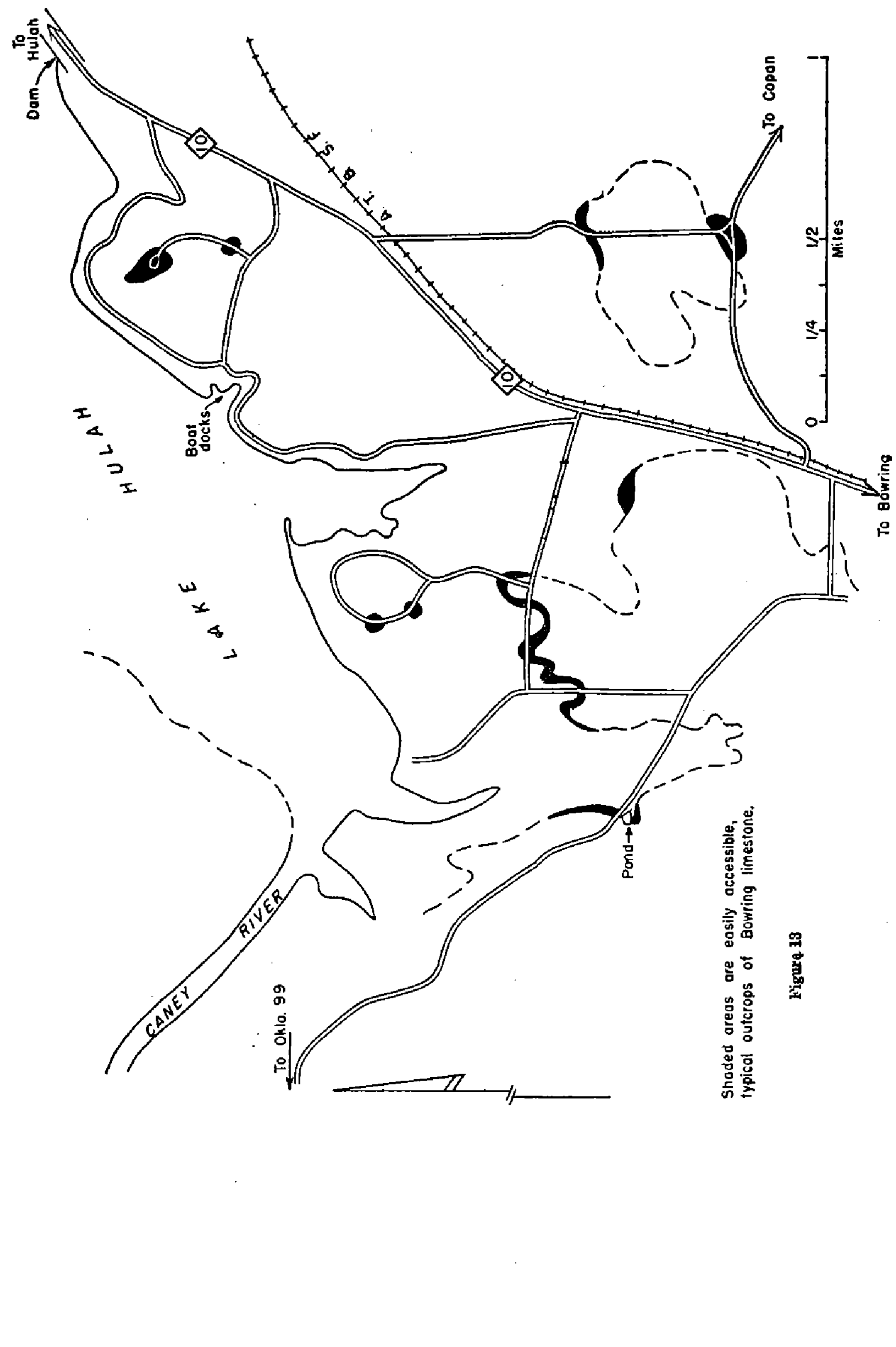
Apparently only one generalization may be made about the two categories of sandstone: bottom markings (especially trails, tracks and casts) are more common in sandstone (b).

Bowring limestone member (*new name*). A limestone member is found in the Lake Hulah area, north of Bowring (T. 28 N., R. 11 E., T. 29 N., R. 11 E.), above the Cheshewalla sandstone. This member was first questionably identified as the Iatan. The Iatan, however is definitely placed in the Pedee group of the Missouri series, below the unconformity marked by the Tanganoxie sandstone, believed to be equivalent to the Cheshewalla sandstone. The limestone member is here named Bowring limestone after the village of Bowring (see T. 28 N., R. 11 E.). The section measured in NE¼ sec. 16, T. 28 N., R. 11 E., is designated the type section. The first syllable of the name is pronounced to rhyme with "cow".

The southernmost exposure of Bowring found during the course of this study occurs about a mile and a half northeast of Bowring (SE¼ sec. 15, T. 28 N., R. 11 E.). At this locality the member is two or more feet thick, and five to 10 feet above the Cheshewalla sandstone, which crops out to the east and south. Crystalline gray limestone, fossiliferous gray limestone, secondary brownish-gray contorted limestone (calcarenite ?), and brown sandstone occur in the Bowring here. There are few macro-fossils, but fusulinids are locally abundant. Clay pebble conglomerates contain clay balls to one inch in diameter.

The Bowring may also be seen on top of the hill half a mile southwest of the Lake Hulah dam (NE¼ sec. 10, T. 28 N., R. 11 E.), where it occurs as patches of thin, wavy bedded, light gray limestone above the Cheshewalla sandstone. It is sparingly fossiliferous.

Another convenient exposure occurs on the east-west road south of Pond Creek (NW¼ sec. 12, T. 28 N., R. 10 E.), where the Bowring is a one-foot greenish-gray limestone at the top of a thin,



Shaded areas are easily accessible, typical outcrops of Bowring limestone.

Figure 13

silty Cheshewalla. At this locality bottom markings are prominent in the Bowring, and the wavy bedding found elsewhere is not conspicuous.

A pale yellow, vuggy aspect of the Bowring occurs along the road and in the fields in the NE¼ sec. 16, T. 28 N., R. 11 E., where the member is two to three feet thick. Many fossil fragments can be found there.

Kiheki sandstone member (*new name*). A single, more-or-less continuous sandstone ledge, five to 25 feet thick, occurs in the shale interval between the Cheshewalla and the Labadie members. It extends as far north as sec. 24, T. 27 N., R. 10 E., where it vanishes in a shale section below the thickening Labadie. It generally occurs within 30 feet below the latter; or, within 50 to 75 feet above the Cheshewalla sandstone. The unit is here named Kiheki for the siding and cattle loading platform on the Missouri, Kansas and Texas Railroad in sec. 3, T. 25 N., R. 10 E. The type section is that measured along the road in sec. 25, T. 26 N., R. 10 E.

In the Osage Hills State Park area (sec. 13, T. 26 N., R. 10 E.), this bed is a buff, thin-bedded to massive, fine-grained sandstone, 24 feet thick.

At one place on U.S. Highway 60 (NE¼ sec. 7, T. 26 N., R. 11 E.), the sandstone is badly slumped, with local "dips" up to 45°. In this locality the bed is a very fine-grained sandstone or siltstone bearing plant fragments up to 15 inches long.

South of Bird Creek (T. 24 N.), this ledge consists of an upper sandstone, about eight feet thick, and a lower sandstone, about 11 feet thick, separated by a six-foot shale interval. The sandstones are very fine-grained or locally siltstones, and locally contorted. The color is buff or, where siltstone, gray-green. About 35 feet of dark gray-green shale separate this sandstone from the Cheshewalla member.

Labadie limestone member. The Labadie limestone member was named by Bowen (1918, p. 45) from exposures at and near Labadie Point (sec. 9, T. 26 N., R. 10 E.). Its best development, however, occurs about six miles farther north.

The member is a gray to white limestone, commonly six to eight feet thick. It is characterized by wavy bedding. Recognizable outcrops occur from about three miles north of Nelagoney to a point about one mile west of Bowring. The horizon of the Labadie has been carried northward beyond Bowring to the alluvium associated with Lake Hulah, where it is only a calcareous zone in the shales and soft siltstones. In the southern half of its outcrop, the limestone weathers to a distinctive dark brown which, coupled with its wavy bedding, make it easy to identify. In the northern half of its outcrop it is generally an off-white on weathered surfaces.

For airplane photograph analysis, the Labadie is characterized by a checkerboard pattern due to a fine mesh of fractures. These fracture zones can be seen in the field, despite the presence of a veneer of soil; the weeds grow slightly taller, and do not turn brown as readily in the hot, dry summer months, over the fractures. On the photographs, the fracture network is readily recognized. The squares are five to 10 feet on each side. The Upper Oread limestone, along the northwestern boundary of the area, exhibits the same pattern. The great stratigraphic and geographic intervals between the two, however, reduce the chance for confusion.

The limestone is not highly fossiliferous. The underlying shale yields a fauna noteworthy for its small individual horn corals.

In section 17, T. 27 N., R. 10 E., the Labadie is exposed in an abandoned quarry. Limestone and interbedded thin calcareous shales were measured to be 25 feet thick, down to the water level. From the position of the quarry on the outcrop, it was estimated that perhaps 10 additional feet of limestone occur below the water level, making a total thickness (measured and estimated) of about 35 feet. This is the maximum thickness for the member. The limestone is light gray on fresh surfaces, dirty white on weathered surfaces, and highly fractured. The wavy bedding (Plate III, B) is prominent. At this position, the Labadie is approximately 170 feet below the Middle Oread limestone.

Along the road in section 13, T. 27 N., R. 10 E., the Labadie member is 23 feet thick. At this exposure, the limestone is primarily light gray, with a two-foot bed of brown sandy limestone near the center, and thin calcareous shale beds here and there. Individual limestone beds are one to five inches thick; the wavy bedding is well-developed. The limestone is fine crystalline, with local occurrences of coarse recrystallized calcite. Fossil fragments are relatively

A. Labadie limestone exposed on U. S. Highway 60 west of entrance to Osage Hills State Park.

B. Labadie limestone with wavy bedding. Wall of quarry.

common. A thick gray-green shale occurs above the member, and another similar shale below.

A striking example of solution weathering may be seen in the Labadie limestone where exposed in the spillway adjacent to the dam, at Sunset Lake (sec. 28, T. 27 N., R. 10 E.). The limestone is about eight feet thick, including six feet of brown or reddish-brown Labadie overlying one to two feet of white or light gray Labadie. Underneath the limestone is a 10-foot section of blue-gray shale. Overflow from the lake has attacked the joint system in the limestone, dissolving channels about two feet wide, and leaving natural bridges, tunnels, caverns and pot-holes. The extensive solution work has taken place since the dam was constructed, less than 30 years ago.

At Midway Store, on U. S. Highway 60 (sec. 3, T. 26 N., R. 10 E.), the Labadie is a wavy-bedded light gray limestone weathering dark brown. It is sandy, locally being calcareous sandstone. Thickness is seven feet.

On the Okesa-Pawhuska road (sec. 25, T. 26 N., R. 10 E.), the Labadie is only four feet thick. The wavy bedding is typical. The fresh limestone is greenish-gray, the weathered surfaces yellow to yellowish-brown. Locally the bed is nodular and not resistant to weathering. Fossil fragments are common.

Along the south line of the same township, the Labadie becomes thin and difficult to follow. In T. 25 N., it is primarily a highly calcareous sandstone, without the distinctive appearance of the limestone farther north.

Cochahee sandstone member. The Cochahee sandstone member was named by Winchester et al (1918, p. 60), from outcrops along the creek of the same name in the east central part of Osage County (SW part T. 25 N., R. 10 E.).

In the vicinity of the village of Nelagoney, near the type locality, the Cochahee is a buff, thin- to medium-bedded, fine-grained sandstone, exhibiting "bar structure", ripple marks, and cross-bedding. The ripple marks indicate a current flowing north-northeast. Cross-bedding directions range from N. 35° E., westward and southward to S. 22° W. The vector sum for nine readings was N. 75° W., the mode N. 56° W. (arithmetic averages are practically useless for circular or oriented data). The cross-bedding apparently was formed by channel currents flowing toward the northwest or west-northwest.

In T. 24 N., the Cochahee consists of at least 10 feet of buff sandstone, and may include a 12-foot contorted sandstone, separated from the lower bed by 20 feet of shale.

There does not seem to be any difference in either lithology or stratigraphic position between the Cochahee and Four Mile sandstone members.

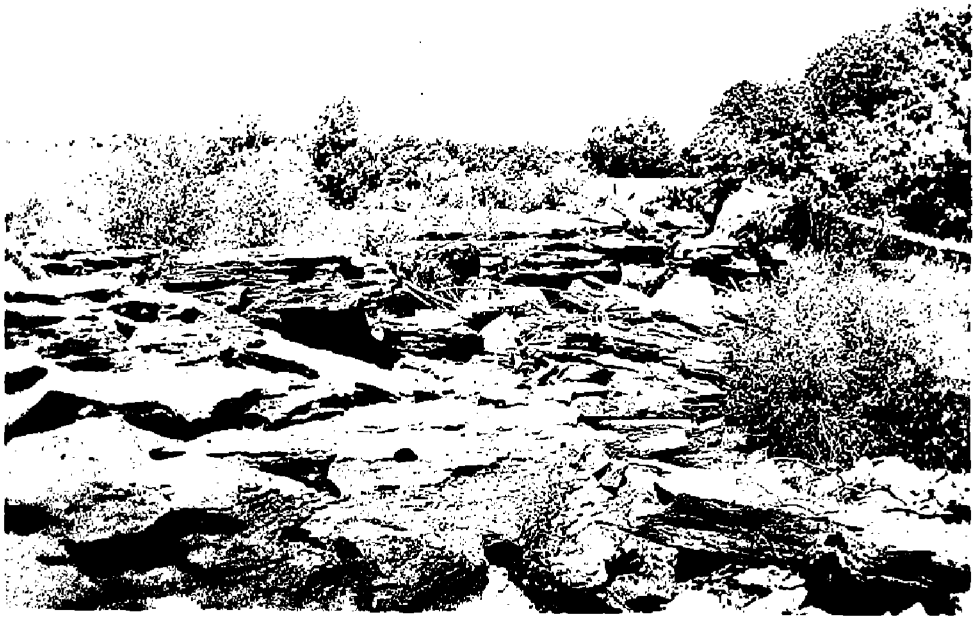
Bowhan sandstone member. The Bowhan sandstone member was named by Goldman and Robinson (1920, p. 361), from exposures at Bowhan Point (sec. 16, T. 28 N., R. 11 E.). Together with the Jonesburg sandstone member immediately above it, the Bowhan extends from the vicinity of Sunset Lake, northward across the state line into Kansas. The Bowhan is well developed south of the Caney River; as it thins northward toward the bank of Pond Creek, the Jonesburg thickens.

The Bowhan is a fine- to very fine-grained buff sandstone which is thin-bedded but weathers massive. It is commonly eight to 10 feet thick. Ripple marks are beautifully preserved at the outcrop on the point in sec. 7, T. 28 N., R. 11 E. Of current origin, the ripple marks indicate a channel trending toward the west-northwest. At the same locality, the Bowhan is 110 to 140 feet above the Cheshewalla.

Locally the Bowhan is contorted and cross-bedded.

In the vicinity of Sunset Lake, the member is a distinct sandstone, buff and fine-grained, with cross-bedding and contortions here and there. South of the lake, the Bowhan passes into a sequence of discontinuous sandstone lenses.

Jonesburg sandstone member. The Jonesburg sandstone member, named by Marcus Goldman (1920, p. 329) from exposures on top of the ridge west of the town of the same name in Chautauqua County, Kansas, is well developed in Oklahoma as far south as sec. 22, T. 28 N., R. 10 E. Although it appears to lie 20 or more feet above the Bowhan, the relative behavior of the two leads the present author to believe that they are more nearly at the same horizon. Perhaps the thin southern edge of the Jonesburg was deposited topographically a few feet higher than the thicker more northerly portion.



A. Labadie limestone member of Tallant formation. Exposure in creek bed below dam at lower end of Sunset Lake.

B. "Crab burrows" in sandstone below the Labadie limestone. Spillway at Sunset Lake.

The member is well exposed on the hill north of Boulangerville (secs. 27 and 28, T. 29 N., R. 10 E.), where it is 54 feet thick. The upper part, about 23 feet thick, consists of buff fine-grained sandstone, exposed at the top of the hill. The lower part, 11 feet thick, is a contorted buff sandstone and greenish-gray siltstone. Thin flaggy siltstones alternating with shale make up the middle part. The lower ledge must not be far from the stratigraphic position of the Bowhan. The Middle Oread limestone lies about 100 feet above the top of the Jonesburg.

Close to the Kansas line, the Jonesburg is only 38 to 40 feet thick, but is highly cross-bedded. Ripple marks, micro-cross-bedding, and both micro- and macro-contortions occur in the exposure along Oklahoma Highway 99, about a half mile south of the state line. The cross-bedding indicates currents which flowed toward the north-northeast or northeast. Much of this exposure is made up of siltstone.

The 100-foot interval from the Jonesburg sandstone member to the Middle Oread limestone member is primarily shale, with many lenses of sandstone and a few lenses of limestone. South of the southern limit of the Jonesburg, this lenticular zone extends from the Labadie limestone to the Middle Oread member, a thickness of about 170 feet. In other words, the Jonesburg and Bowhan sandstones are named members in the lower part of an otherwise unsystematized sequence of lenses.

The shales below the Middle Oread are distinctive because of the color change which occurs here and there. Although in many outcrops the color is the same pale gray-green typical of all the shales farther east in the county, lenses of red and maroon shale are fairly common. This is the approximate stratigraphic position of the color "line" which has been interpreted by many (i. e., Anderson, 1941) as the division between marine deposits (to the east) and continental deposits (to the west). Because of the regressive nature of the Vamoosa sea, the relationships given above do not mean that the land lay to the west and the sea to the east; quite the contrary. The notion, held by some, that red shales indicate continental environments, however, implies a rapid, if temporary, westward retreat of the sea.

The sandstone lenses in this multicolored shale section contain clay pebble conglomerates, plant fragments, leached sandstones and siltstones, and coarse, angular to sub-angular quartz grains. It would be a mistake, however, to conclude that the red shale, the leached sandstone, the leaf fragments, and the coarser sand grains prove continental deposition.

A typical sandstone lens, as described above, is exposed in the road cut on Oklahoma Highway 99, 6.5 miles north of the junction with U. S. Highway 60 (west of the Labadie quarry; in the SW¼ sec. 8, T. 27 N., R. 10 E.). The cross-bedding at this locality is strongly indicative of currents flowing toward the south-southwest. In line with the evidence adduced in many other places in this report, this sandstone is clearly the product of littoral environment. It is quite possible, of course, that exposure to continental conditions preceded the deposition of the littoral sandstone and clay pebble conglomerate.

An unnamed limestone lens, in the shale interval described above, occurs on U.S. Highway 60, about 1.2 miles east of the Santa Fe Railway underpass (NW¼ sec. 7, T. 26 N., R. 10 E.). The limestone is two to three feet thick, light gray, medium crystalline, and thick-bedded. The weathered surface is a dark brown, but the bedding planes are not wavy and discontinuous. The lower surface of the limestone is characterized by abundant bottom markings, with scattered fossil fragments. A white, leached siltstone, about two feet thick, occurs about four feet below the limestone. Red and maroon shales are present in the vicinity.

Many other thick, extensive sandstone lenses, and a few thin, patchy limestones occur in the shale interval between the Labadie and the Middle Oread members.

Wynona sandstone member. The Wynona sandstone is a sequence of beds up to about 70 feet thick, named after the town of Wynona in T. 24 N., R. 9 E. It was first described by Heald (Bowen, 1918, p. 17).

The member consists of at least two sandstones, each about 25 feet thick, separated by about 20 feet of shale and sandy shale. The beds are buff in color, very fine- to coarse-grained, thin-bedded to massive. Both penecontemporaneous contortions and high angle cross-bedding are common.

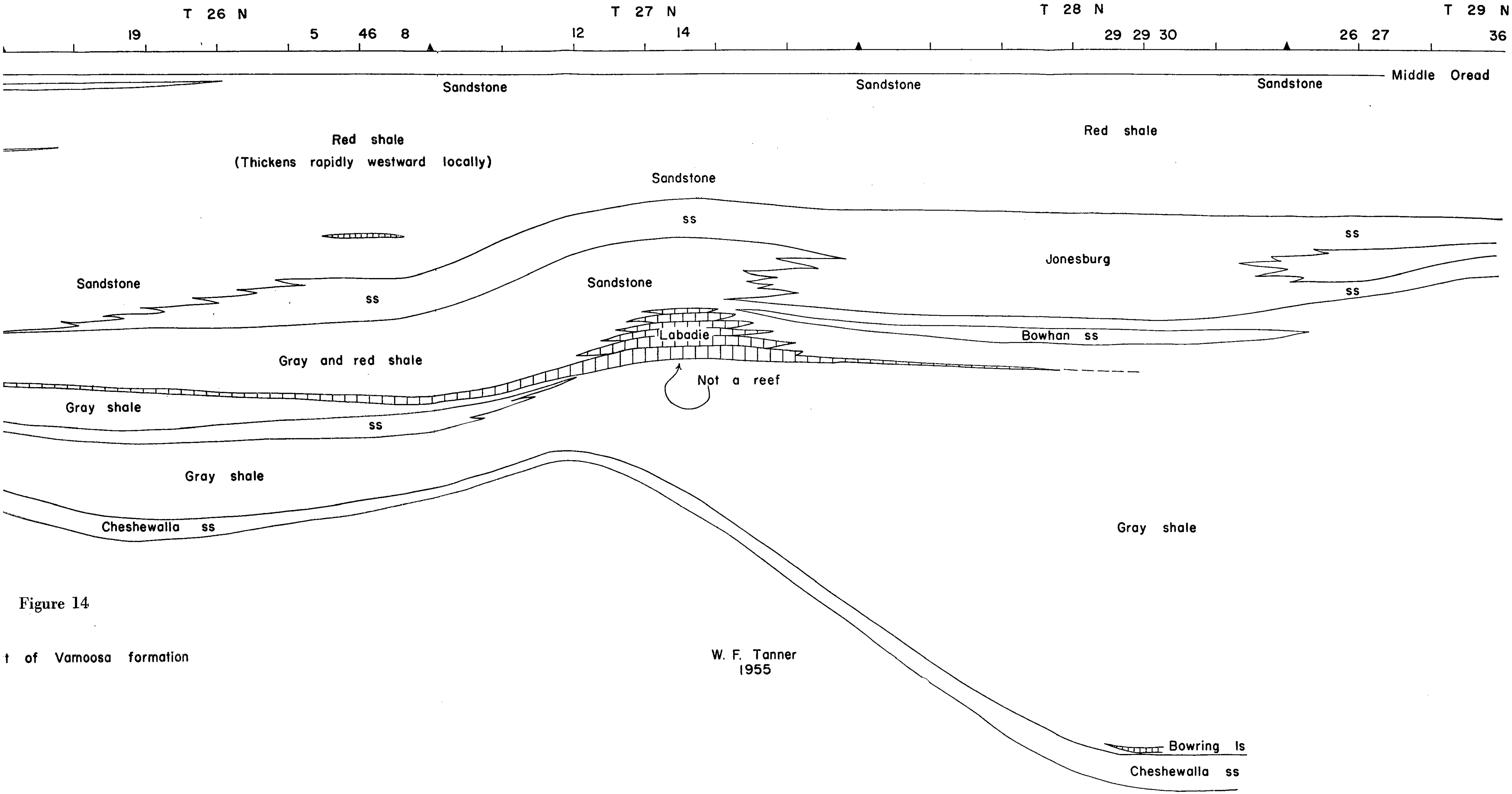


Figure 14

t of Vamoosa formation

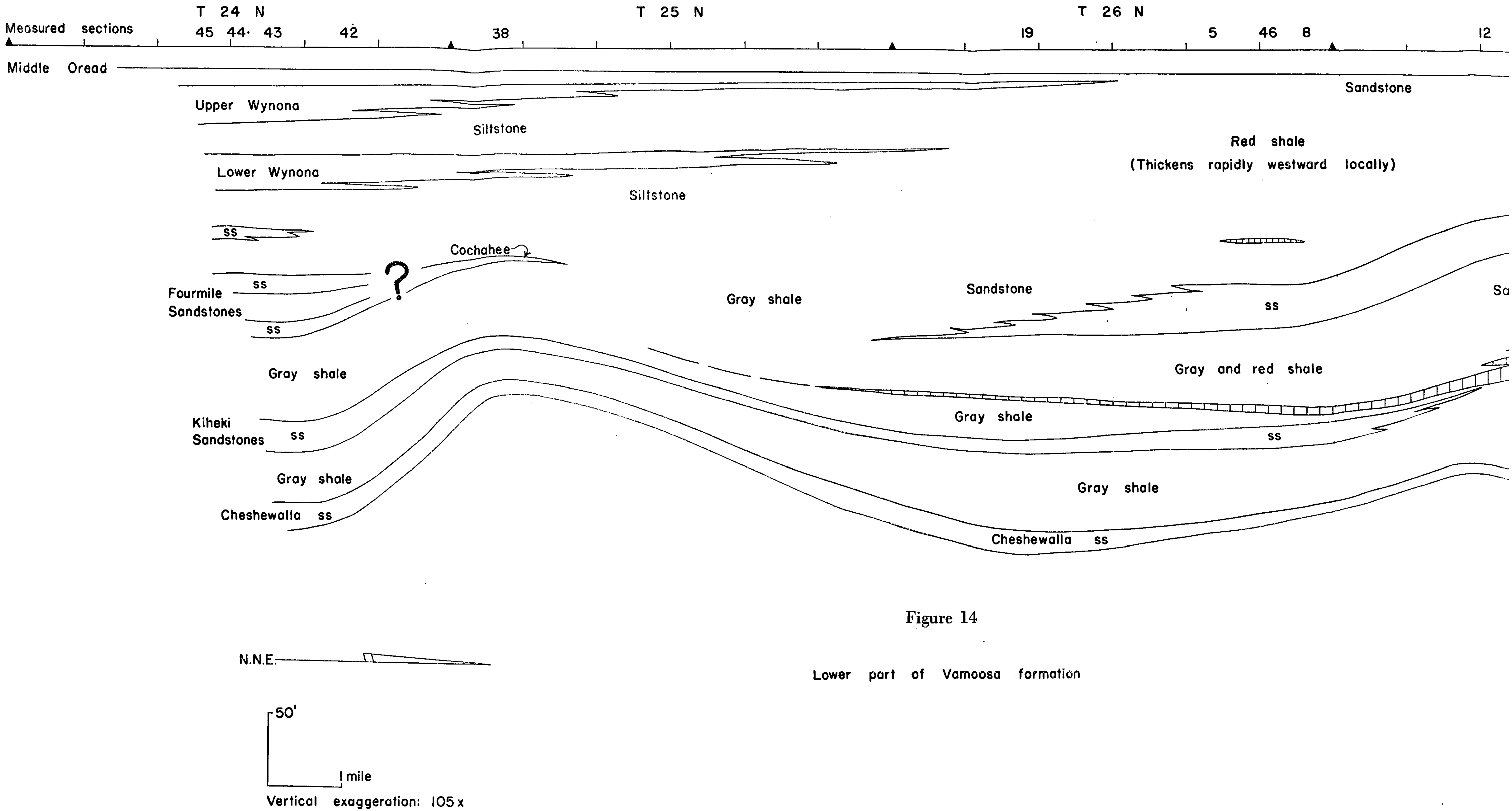


Figure 14

Lower part of Vamoosa formation

The cross-bedding does not present a simple picture for the member as a whole. When taken by localities, however, and especially interpreted in conjunction with cross-bedding from the Elgin sandstone, about a mile west of the town of Wynona, and lower sandstones to the east, the pattern becomes clear. Cross-bedding in T. 24 N., in general, is not aligned like that farther north. At this latitude, the littoral trend is north-northwest south-southeast, and channel currents apparently flowed toward the west-southwest. For the Elgin sandstone west of the town of Wynona, all measurements fell in the west-southwest quadrant. Twenty-four measurements from three localities of Upper Wynona sandstone showed two sets of preferred directions; in the northern part of T. 24 N., during Wynona time, conditions were alternating between those prevailing farther north, and those prevailing farther south. Sixteen upper Wynona measurements indicate north-northeast south-southwest littoral currents; eight show north-northwest littoral currents.

The Wynona sandstones become thinner and finer-grained northward, and splits up into many tongues. The two best ledge-makers have been shown on the accompanying map, where they have been traced as far as about the middle of T. 26 N.

Oread limestone member. The Oread formation was named in Kansas by Haworth (1894, p. 123), and later extended southward into Oklahoma. At the type locality near Lawrence, Kansas, the formation is 45 feet thick, and is composed of four limestones and three shales. The Leavenworth member (No. 2 limestone, counting from the bottom) is the Middle Oread of this report; the Upper Oread is the Plattsmouth member (No. 3 limestone). The bottom limestone does not crop out in Oklahoma.

The Middle Oread is a thin limestone, decreasing from about four feet near the Kansas line, to about four inches in sec. 15, T. 26 N., R. 9 E. South of this point it is a calcareous zone, approximately 15 feet above the top of the Upper Wynona sandstone, and perhaps 30 feet below the overlying Elgin sandstone. Near the Kansas line, where the member is well developed and easily traced, it lies between 15 and 90 feet below the Upper Oread limestone, and approximately 100 feet above the top of the Jonesburg sandstone.

The Middle Oread is a blue-gray, medium to coarse crystalline limestone, which weathers yellow. The presence of many fusulinids lends the weathered surface the appearance of a coarse calcarenite; fragments of apparently inorganic limestone, up to about six millimeters in diameter, are also present. Pink barite is found in the limestone, along with coarsely recrystallized calcite, at many outcrops. At many places the member possesses the wavy-bedding so common in limestones of the area.

The shales associated with the Middle Oread, both above and below, are gray-green or blue-gray, and include thin siltstone and limestone beds having many bottom markings, including trails and plant prints. Limonite concretions are fairly common. Sandstones, contorted and cross-bedded, appear close to both middle and upper limestones, here and there. The currents indicated by the cross-bedding were littoral.

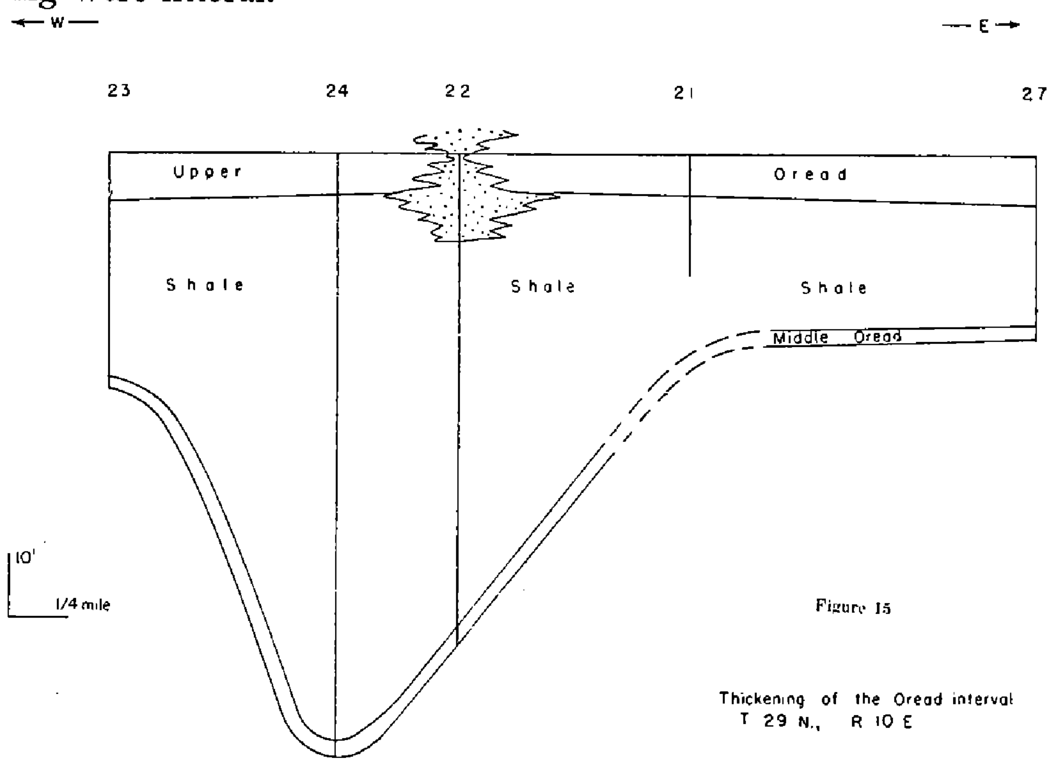


Figure 15

Thickening of the Oread interval
T 29 N., R 10 E

The rapid changes in the thickness of the shale interval between the two limestones necessitates some extra care in mapping in T. 29 N., R. 9 E., especially as the two members are quite similar. The upper limestone, however, extends only about six miles into Oklahoma; south of the north edge of T. 28 N., there is no opportunity for confusion.

The calcareous shale zone thought to represent the Middle Oread in the southern part of the area has been mapped more on stratigraphic position than on field recognition. For example, several geologists (Beckwith, 1928; Shannon, 1954) have drawn the Middle Oread through the railroad cut in sections 20 and 29, T. 26 N., R. 9 E. No doubt, the horizon is present there; it is easily traced from identified exposures only a mile or less away. However, no limestone is present, other than the many thin silty limestones which occur practically everywhere that the "lagoonal" gray shale facies of this report occurs. Farther south the Middle Oread is poorly exposed, at most places appearing as a strip of limy nodules in the soil, probably representing a string of small, thin, soft calcareous lenses.

STRUCTURE

It was not the purpose of this study to map individual structures within the area. Certain remarks about the structure, in general, are appropriate. The strike is slightly east of north, and the regional dip is westerly, about 30 to 40 feet per mile. Locally, however, the beds are flat, or the dip is reversed, or greatly steepened. Structures having dip reversals or dip changes of about half a degree are common within the area.

The average dip increases rather sharply toward the south (about T. 24 N.), and becomes almost perfectly flat toward the north (about T. 28 N.). Consequently, the outcrop pattern thins toward the south, and widens toward the north. A detailed study of thicknesses in connection with outcrop widths should prove of economic value; it is suspected that wide, gentle structures are responsible, at least in part, for a correlation between the two.

Individual folds are shown in detail on the structure contour maps prepared by the U. S. Geological Survey (White, 1922) of Osage County. Many of the faults of the area also appear on the U. S. Geological Survey maps. The faults, however, generally represent movements of only a few feet or at the most a few tens of feet. And where the displaced beds are poorly exposed—which is common—the location and interpretation of faults is extremely difficult. Small faults are easily overlooked in the course of actual field work. These same features show up well on certain types of airplane photographs, specifically those flown, for Osage County, in 1954.

Fault orientation is approximately as follows: 67 percent, northwest-southeast; 30 percent, northeast-southwest; 3 percent, east-west. The northwest-southeast faults are, as a general rule, oriented about 30 degrees west of north and east of south. Nearly three quarters (72 percent) of the faults represent down-motion to the east; the other quarter, down motion to the west. The dominant fault pattern emerges as a small, nearly vertical offset, up to three miles long, trending north 30° west, south 30° east, down to the east.

The two main concentrations of faults within the area occur in the northwestern corner of T. 26 N., R. 12 E., and adjacent townships; and near the center of T. 27 N., R. 10 E. The former concentration is perhaps associated with a thickening of the Okesa sandstones and siltstones of the Barnsdall formation, and perhaps with a structure in the Dewey limestone, a few miles to the east; the latter concentration is definitely located over a pronounced thickening of the Labadie limestone member of the Vamoosa formation. An additional area of considerable faulting is north of Caney River and Lake Hulah, in T. 29 N., Rs. 11 and 12 E. Other faults do not exhibit as much throw, are not as long, or are not as closely spaced.

The relationship between the faulting in T. 27 N., R. 10 E., and the abrupt thickening of the Labadie limestone, suggests that many of the structures in the area are the result of breaking during torsion across locally thick masses of resistant materials (i. e., limestone and sandstone), in an otherwise plastic shale section.

Two-dimensional explanations (involving what has been termed the "strain ellipse") account for the fault orientation better than for the relative movement. The two-dimensional reconstruction calls for a horizontal couple (Fig. 16, A, B, C), which should have resulted in more slip than apparently took place. Of the four possibilities, only one (A) is plausible, and it should have produced a type of movement not yet observed.

Three-dimensional explanations depend on whether one is trying to explain the local forces, which led directly to the breaking, or the regional forces, which were ultimately responsible for the faulting. For the former, a strain ellipsoid, with the maximum axis vertical, may be set up; the results, however, are not particularly useful.

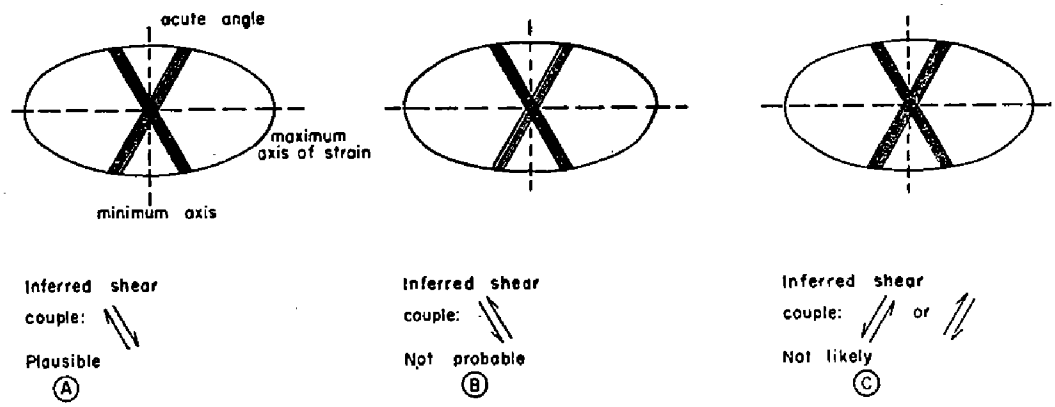


Figure 16

For the latter, a torsion model may be employed to good advantage. An ordinary square rubber eraser serves this purpose very well. To duplicate the conditions in eastern Osage County, place a few grains of fine sand on the eraser; then add a small sheet of moist tissue paper, pressed down firmly. Place the square so that one side is oriented North 20° East. Then depress the southwest corner (the Anadarko basin), raise the southeast corner (the Ouachita Mountains), and hold the other two corners steady (Fig. 17). The same result can be achieved by depressing southwest and northeast corners, by raising northwest and southeast corners, and by a combination of the two. The motions given in the diagram, however, were obviously designed to fit the geological circumstances.

Anticlines in the area trend northeast-southwest.

Fath (1920), Foley (1926), Ickes (1926), Kramer (1939), Link (1929), Powers (1931), Nevin and Sherrill (1929) and Sherrill (1929) have discussed this problem at greater length.

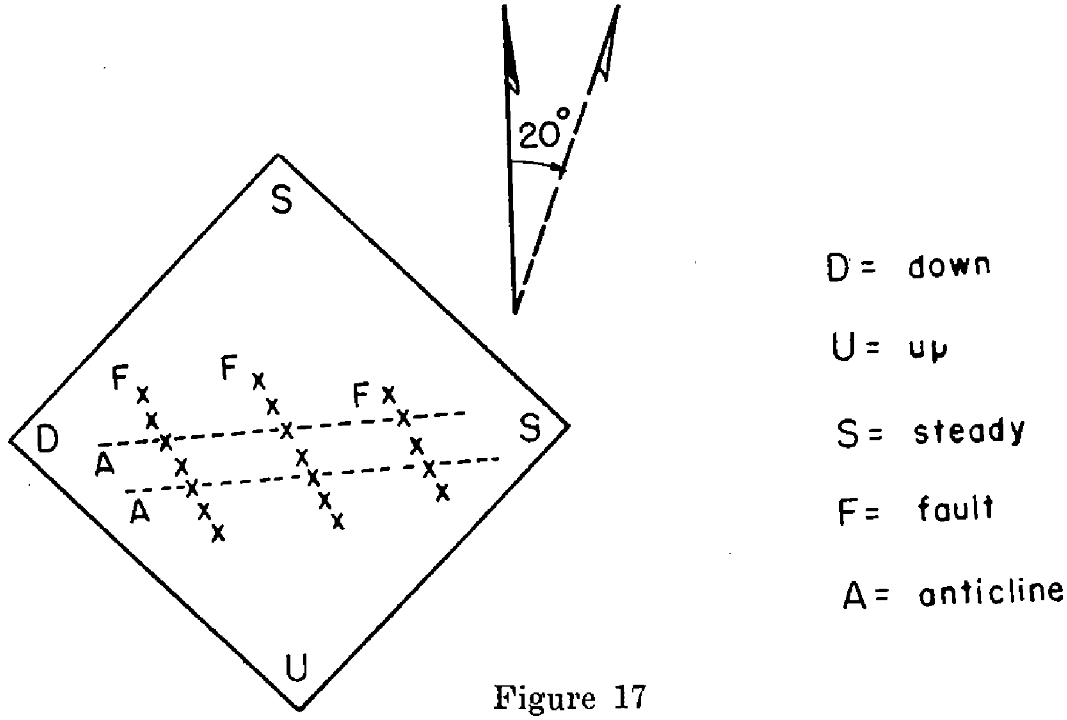


Figure 17

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Selected Measured Sections

North

21. *Part of the Oread, and related beds.* SW¼ sec. 20, T. 29 N., R. 10 E. Along east-west road, to top of Artillery Mountain.

18.0	Siltstone; buff, laminated, ripple marked; contorted near top; locally, very fine-grained sandstone; weathers massive. Measured to top of hill
6.0	Shale; light gray-green
1.0	Siltstone; buff, calcareous; bottom markings; "crab burrows"
3.0	Shale; light gray-green
2.0	Limestone; gray to buff; impure; bottom markings; leaf prints
5.0	Shale; light gray-green; few fossils
4.0	Limestone and secondary limestone; irregular upper surface; contorted
7.0	Upper Oread. Limestone; gray, blue-gray, green, brown; medium to coarse crystalline; bedding planes are wavy locally; locally recrystallized; pink barite; good joint network
----	Shale; gray; with thin buff siltstones

(For lower beds, see section No. 26)

22. *Oread limestones and associated beds.* SW¼ sec. 19, T. 29 N., R. 10 E. Along east-west road

8.0	Sandstones; buff; partly covered; measured to top of hill
30.0	Sandstone and siltstone; buff; thin-bedded to medium-bedded; sandstone is very fine-grained; bottom markings; clay pebble conglomerate here and there near top of bed
....	Horizon of the Upper Oread limestone; locally missing
14.0	Siltstone; buff; soft, thin-bedded, flaggy; alternating with thin, light gray shales; plant prints
3.0	Limestone; yellow; thin-bedded; wavy-bedded; many fusulinids (Fossil collection No. 3)
60.0	Shale; gray-green; with thin, buff siltstones; limonite concretions, to one inch in diameter; bottom markings, including trails; plant remains
3.0	Middle Oread limestone; dark blue-gray and brown, weathers yellow; medium-bedded; crinoid and other fossil fragments. Vertical weathered surfaces or horizontally corrugated; corrugations two to eight inches apart, vertically
33.0	Shale; maroon, purple, buff, yellow, gray-green; few siltstones up to one foot thick
	(For lower beds, see section No. 26)

23. *Oread limestones.* NE¼ sec. 14, T. 29 N., R. 9 E. Along road

8.0	Upper Oread limestone; light gray, weathers yellow; thin-bedded, wavy-bedded; fossiliferous
29.0	Shale; gray-green
2.0	Middle Oread limestone; blue-gray, weathers yellow; medium crystalline, medium-bedded
	(For lower beds, see section No. 26)

24. *Oread limestones.* NW¼ sec. 30, T. 29 N., R. 10 E. Along road

7.0	Upper Oread limestone; nearly white; thin-bedded, wavy-bedded; fossiliferous
3.0	Shale; gray-green
21.0	Sandstone; buff; fine-grained, highly contorted; contortions extend down into low spots in underlying shale
65.0	Shale; gray-green

2.0 Middle Oread limestone; dark blue-gray and brown, weathers yellow; medium-bedded; medium crystalline; crinoid and other fragments; vertical surfaces weather with horizontal corrugations two to six inches apart vertically

(For lower beds, see section No. 26)

25. *Parts of Tallant and Vamoosa formations.* At west end of dam, Lake Hulah

(For higher beds, see sections No. 26, 28, 29, 30)

12.0 Cheshewalla sandstone (basal member of Vamoosa formation)

129.0 Interval not measured in detail; includes Mission sandstone in lower part

20.0 Revard sandstone member of Tallant formation

(For lower beds, see section No. 31)

26. *Vamoosa formation, in part.* Secs. 27 and 28, T. 29 N., R. 10 E. Along north-south road through Boulangerville.

(For higher beds, see sections No. 21, 22, 23, 24)

23.0 Upper Jonesburg sandstone; buff; fine-grained, weathers massive. Measured to top of hill

22.0 Siltstones; buff to gray-green; flaggy; alternating with thin shales

11.0 Lower Jonesburg sandstone; buff to greenish gray; locally siltstone, sandstone is fine- to very fine-grained; contorted

85.0 Shale; gray-green; partly covered

15.0 Cheshewalla sandstone; buff; thin- to medium-bedded; fine- to very fine-grained, locally siltstone

(For lower beds, see sections No. 25, 32, 34)

27. *Oread limestones and associated beds.* Sec. 21, T. 29 N., R. 10 E., Artillery Mountain

8.0 Upper Oread limestone (see section No. 21)

20.0 Shale; mostly covered

2.0 Middle Oread limestone

100.0 Shale; mostly covered

23.0 Upper Jonesburg sandstone

(For lower beds see section No. 26)

28. *Vamoosa formation in part.* Sec. 7, T. 28 N., R. 11 E. Along lake drive on south side of Lake Hulah, about three miles east of Oklahoma Highway 99

(For higher beds, see section No. 26)

10.0	Bowhan sandstone; buff; fine- to very fine-grained, thin- to medium-bedded, weathers massive; ripple marked
10.0	Shale; covered
1.0	Horizon of the Labadie limestone; siltstone; gray-green; calcareous
100.0	Shale; gray-green; siltstones to one foot thick here and there
10.0	Cheshewalla sandstone; buff; laminated; weak ledge

(For lower beds, see sections No. 25, 32, 34)

29. *Vamoosa formation in part.* Sec. 8, T. 28 N., R. 11 E. Along lake drive on south side of Lake Hulah, about four miles east of Oklahoma Highway 99

(For higher beds, see section No. 26)

8.0	Bowhan sandstone; buff; laminated to thin-bedded, weathers massive, fine-grained; locally contorted
15.0	Shale; covered
3.0	Horizon of Labadie limestone; yellow to buff siltstone; laminated, calcareous
100.0	Shale; gray-green; thin buff siltstones here and there
8.0	Cheshewalla sandstone; buff; fine-grained

(For lower beds, see sections No. 25, 32, 34)

30. *Vamoosa formation in part.* NE¼ sec. 16, T. 28 N., R. 11 E.

(For higher beds, see section No. 26)

----	Bowhan sandstone, not measured; at top of hill
18.0	Shale; covered
3.0	Horizon of the Labadie limestone; siltstone
110.0	Shale; partly covered; thin siltstones here and there
3.0	Bowring limestone; white to pale yellow, weathers pale yellow; thin-bedded, wavy-bedded; slightly vuggy; many fossil fragments
10.0	Covered; shale or soft sandstone
15.0	Cheshewalla sandstone; buff

(For lower beds, see sections No. 25, 32, 34)

31. *Tallant formation in part.* NW¼ sec. 29, T. 28 N., R. 12 E. (For higher beds see section No. 25)

----	Revard sandstone; buff; thick-bedded to massive; contorted; not measured
95.0	Covered with much float; interval not certain
8.0	Bigheart sandstone; buff; poorly exposed

32. *Tallant formation and part of Vamoosa formation.* SE corner sec. 18, T. 28 N., R. 12 E. Sundown Hill

(For higher beds, see sections No. 26, 28, 29, 30)

----	Bowring limestone
6.0	Cheshewalla sandstone
2.0	Sandstone; "crab burrows"
27.0	Shale; gray-green; thin limestone and calcareous siltstone lenses
4.0	Mission sandstone
10.0	Shale
10.0	Possum sandstone
25.0	Shale and soft sandstone
5.0	Hulah sandstone equivalent within the Revard sandstone
16.0	Revard sandstone; buff, soft, lenticular
86.0	Shale; few sandstone beds
1.0	Limestone or calcareous sandstone
15.0	Bigheart sandstone

34. *Tallant and Vamoosa formations, in part.* Secs. 23, 24, 25, T. 28 N., R. 11 E. Along east-west road and in gullies crossing road

(For higher beds, see sections 26, 28, 29, 30)

1.5	Bowring limestone and secondary limestone; light gray and buff; thin-bedded, wavy-bedded; contorted; fusulinids
7.0	Cheshewalla sandstone; buff to brown; medium-bedded
32.0	Probably Cheshewalla sandstone; buff and gray-green; thin- to medium-bedded; fine-grained; lenticular; siltstone and shale lenses
26.0	Shale; gray-green
3.0	Siltstone; white, leached; "tadpole nests"; equivalent to the Mission
16.0	Shale; gray-green

18.0 Possum sandstone; buff; medium-bedded to massive; "tadpole nests"; contains pale green siltstone and gray-green shales one to two feet thick; white gastropod fragments at base

20.0 Shale; gray-green; includes thin, ripple-marked siltstones

2.0 Limestone; very light gray; silty or locally calcareous siltstone; highly lenticular and contorted; bottom markings; brachiopods

28.0 Shale; gray-green

20.0 Revard sandstone; buff; thin-bedded, soft, poor ledge

(For lower beds, see sections No. 31, 32)

South

37. *Barnsdall formation.* Sec. 10, T. 24 N., R. 11 E.

(For higher beds see sections No. 40, 41, 42)

11.0 Bigheart sandstone (basal member of the Tallant formation); buff, weathers brown or reddish brown; thin- to thick-bedded; many ripple marks and other bottom markings

82.0 Shale; partly covered; considerable float

5.0 Siltstone; gray-green; thin-bedded to laminated; calcareous; bottom markings

22.0 Shale; gray-green; few thin siltstones

3.0 Siltstone; as above

4.0 Shale; gray-green

9.0 Siltstone; as above

5.0 Sandstone; buff; thick-bedded; fine- to very fine-grained

---- Horizon of the Birch Creek limestone

38. *Part of Tallant and Vamoosa formations.* Sec. 35, T. 25 N., R. 10 E.

10.0 Sandstone; buff; thin- to medium-bedded, weathers massive; cross-bedded; sandstone is fine- to very fine-grained, locally siltstone

20.0 Shale; red and gray

11.0 Cheshewalla sandstone; buff; cross-bedded

30.0 Covered; probably shale

8.0 Revard sandstone; buff; fine-grained sandstone; medium-bedded; weak ledge

50.0 Revard sandstone and siltstone; pale gray-green; soft, no ledge

5.0 Revard sandstone; buff, weathers brown; thin- to thick-bedded; fine-grained; cross-bedded; locally siltstone with "tadpole nests"

40, 41, 42. *Tallant formation.* Along east-west road through secs. 10, 11, 12 and 13, T. 24 N., R. 10 E.

(For higher beds see sections No. 42, 43, 44, 45)

---- Cheshewalla sandstone (basal member of the Vamoosa formation)

25.0 Shale; covered

8.0 Sandstone; buff, soft, thin-bedded

5.0 Shale; gray-green

5.0 Sandstone; buff, medium-bedded

12.0 Sandstone; brown, very fine-grained; locally siltstone; contorted and cross-bedded

10.0 Sandstone; buff

8.0 Shale and silt

15.0 Revard siltstone and very fine-grained sandstone; shale lenses; buff and gray-green

12.0 Shale; maroon

15.0 Shale; white, maroon, gray-green

14.0 Siltstone and shale; alternating; siltstone thin-bedded and cross-bedded

45.0 Top ledge of Bigheart sandstone; buff; thin to massive; locally siltstone; locally clay pebble conglomerate; cross-bedded

3.0 Shale and silt; red

8.0 Shale; red and gray-green

11.0 Sandstones, siltstones and shales; soft, thin-bedded

5.0 Shale; red

2.0 Siltstone and sandstone; buff and gray-green

4.0 Shale; red and gray-green

12.0 Siltstone and shales; alternating; gray-green; lenses of sandstone

12.0 Sandstone; buff, weathers pinkish; shale lenses to one foot thick

3.0 Shale; red and gray-green
9.0 Basal ledge of Bigheart sandstone buff, fine-grained, thin-bedded to massive; low angle cross-bedding common; locally siltstone; locally laminated
---- Barnsdall formation; gray shale
(For lower beds see section 37)

42, 43, 44, 45. *Lower Vamoosa formation.* Taken in east-west direction along road through secs. 10, 17, 20 and 23, T. 24 N., R. 10 E.

15.0 Shale; interval to horizon of Middle Oread limestone
24.0 Upper Wynona sandstone; buff; thin- to thick-bedded
20.0 Shale; covered
26.0 Lower Wynona sandstone; buff; very fine-grained, or siltstone; shale lenses locally; laminated to massive; low angle cross-bedding
18.0 Shale and soft silt
8.0 Sandstone; soft
6.0 Sandstone; buff, very fine-grained; ledge
10.0 Shale
2.0 Sandstone; buff, very fine-grained; siltstone
14.0 Shale; covered
12.0 Sandstone; buff, soft, contorted
20.0 Shale; covered
10.0 Cochahee sandstone; buff. Fourmile sandstone
55.0 Shale; khaki-colored; few siltstone and sandstone ledges up to one foot thick
8.0 Sandstone and siltstone; buff, very fine-grained; locally contorted
6.0 Shale
11.0 Sandstone, siltstone, and some shale, alternating; buff and gray-green; sandstone very fine-grained
35.0 Shale; light and dark gray-green
17.0 Cheshewalla sandstone; buff, massive; low angle cross-bedding
---- Tallant shale
(For lower beds see section No. 40, 41, 42)

Central

4. *Tallant formation in part.* Sec. 16, T. 26 N., R. 11 E. Along north-south road between Okesa and U. S. Highway 60. Interval measured below includes both the Bigheart and the Revard sandstone members of the Tallant formation

9.0	Sandstone; buff; cross-bedded	
2.0	Shale; gray-green	
12.0	Sandstone; buff to gray; very fine-grained, locally siltstone. Poor ledge	
4.0	Shale; gray-green; thin siltstones here and there	
5.0	Shale; maroon, dark gray, light gray; sandstone lenses	
11.0	Sandstone; buff; thin to massive; cross-bedded; fingers into gray-green shale	
6.0	Sandstone; buff; lens or scour pocket in underlying shale	Total thickness: 14 feet
8.0	Shale; gray-green; 14 feet where sandstone is absent	
24.0	Top of Bigheart sandstone; buff; thin-bedded to massive; fine-grained	
8.0	Siltstone; gray-green; thin-bedded; soft	
6.0	Sandstone; buff; thick-bedded to massive; cross-bedded, lenticular, contorted	
6.0	Shale; brown, gray, buff, yellow; silty, fissile	
5.0	Base of Bigheart sandstone; buff; massive, fine-grained; lenticular	
	Uneven contact; about 5 feet of relief in 100 feet of distance	
----	Barnsdall shales and thin siltstones; not measured	
	(For lower beds see sections No. 17, 18)	

5. *Tallant and Vamoosa formations, in part.* Osage Hills State Park, sec. 13, T. 26 N., R. 10 E.

	(For higher beds, see section No. 8)
----	Labadie limestone, not measured
5.0	Covered
24.0	Sandstone; buff, thin-bedded to massive, fine-grained
22.0	Shale; gray-green

3.0 Sandstone; buff to brown; rubbly, calcareous; locally a light gray sandy limestone; many small poorly preserved fossils
2.0 Shale
3.0 Sandstone; buff; coarse-grained, limy; contorted
3.0 Shale
4.0 Limestone; brown, weathers yellow; fine to medium crystalline; thin-bedded, in three distinct beds separated by thin shales; no fossils
12.0 Shale; gray-green; sandstone and siltstone lenses locally
13.0 Cheshewalla sandstone (basal member of the Vamoosa formation); buff; fine- to very fine-grained; cross-bedded
30.0 Shale; gray-green; few sandstone and siltstone lenses
1.0 Limestone; dark brown, weathers yellow; fine to medium crystalline; no fossils
36.0 Shale, gray-green; sandstone and siltstone lenses
18.0 Revard sandstone; buff; fine-grained, thin-bedded
22.0 Shale; gray-green
4.0 Sandstone; buff; thin-bedded
7.0 Shale; gray-green; alternating with thin, thin-bedded siltstones
10.0 Sandstone; buff; thin-bedded, fine-grained
9.0 Covered
19.0 Bigheart sandstone; buff; irregularly bedded, cross-bedded; not fully exposed
10.0 Estimated to base of Bigheart sandstone
(For lower beds, see sections No. 17, 18)

8. *Lower part of Vamoosa formation, partial.* Along U. S. Highway 60, sec. 5, T. 26 N., R. 10 E.
(For beds above, see section No. 46)
26.0 Sandstone; buff to brown; fine-grained, thin-bedded to massive; locally clay pebble conglomerate
22.0 Covered; shale
2.0 Limestone; brown, weathers dark brown; somewhat like Labadie in general appearance, contains more sand, wavy-bedding not so well developed
30.0 Shale; maroon, locally bleached; few thin siltstone lenses
27.0 Covered; shale

38.0 Sandstone; buff; very fine-grained, thin-bedded, locally massive; low angle cross-bedding; locally siltstone
26.0 Covered; shale
3.0 Sandstone; buff; fine- to very fine-grained; mostly thin-bedded; low angle cross-bedding; locally clay pebble conglomerate
8.0 Shale; maroon, bleached in upper foot
22.0 Covered
1.0 Sandstone; buff, weathers brown
6.0 Labadie limestone; light gray, weathers buff to brown; medium crystalline; thin-bedded, wavy-bedded
(For beds below, see sections No. 5, 12, 19)

9. *Tallant formation, in part.* At west end of dam, Lake Hudson, sec. 20, T. 27 N., R. 12 E.
(For higher beds, see section No. 5)
10.0 Revard sandstone; buff; fine-grained, thin- to medium-bedded; highly contorted; incompletely exposed
10.0 Covered; sandstone?
40.0 Shale; green to gray-green; contains thin limy beds, locally, with bottom markings, and thin zones of *Linoproductus* molds and casts
Limonite concretions, to three inches in diameter
27.0 Shale; green to gray-green; contains thin limy siltstone beds with mud cracks and other bottom markings
4.0 Limestone; light gray; medium crystalline; fossiliferous; grading laterally into fossiliferous buff to brown contorted fine-grained sandstone
2.0 Shale; green
2.0 Bigheart sandstone; brown; medium-bedded; clay pebble conglomerate; "rotten" looking
12.0 Bigheart sandstone; buff; fine-grained, laminated, weathers massive
14.0 Bigheart sandstone; buff; fine-grained; medium-bedded; few thin shales
(For lower beds, see section No. 10)

10. *Barnsdall formation, in part.* At east end of dam, Lake Hudson, sec. 20, T. 27 N., R. 12 E.

(For higher beds, see section No. 9)

28.0	Bigheart sandstone; buff; thin-bedded, not cross-bedded
1.0	Sandstone; buff; laminated, weathers thick-bedded
14.0	Shale; blue gray; few thin buff siltstone and limestone beds
5.0	Limestone; blue gray, weathers yellow or buff; thin-bedded alternating with thin shales; locally siltstones; bottom markings
15.0	Shale; blue gray; contains thin beds of blue gray limestone and siltstone, with bottom markings
10.0	Covered; to flood plain

(For lower beds, see sections No. 17, 18)

11. *Barnsdall and Tallant formations in part.* Along road in sec. 1, T. 26 N., R. 11 E.

(For higher beds, see section No. 5)

----	Revard sandstone, not measured
10.0	Covered
40.0	Bigheart sandstone; buff; fine-grained, thin-bedded to massive; ripple-marked
8.0	Shale; blue gray
3.0	Sandstone; buff; lenticular, contorted
90.0	Shale; blue-gray or gray-green; contains thin yellow limestone beds with bottom markings; limonite concretions; crinoids
20.0	Covered; to valley floor

(For lower beds, see sections No. 17, 18)

12. *Upper part of Tallant and Lower part of Vamoosa formations.* Secs. 24 and 25, T. 27 N., R. 10 E.

(For higher beds, see sections No. 8, 14)

3.0	Labadie limestone; dark brown; fine to medium crystalline; thin-bedded
5.0	Covered; shale ?
4.0	Kiheki sandstone; buff; fine- to very fine-grained; thin- to medium-bedded

33.0 Shale; gray-green
2.0 Sandstone; buff; fine-grained; massive
5.0 Shale; gray-green
7.0 Cheshewalla sandstone; buff; fine-grained; thin- to medium-bedded
27.0 Shale; gray-green
5.0 Covered; partly sandstone
5.0 Sandstone; buff; very fine-grained; thin-bedded, contorted; weak ledge
21.0 Shale; gray-green; thin siltstone beds here and there
18.0 Revard sandstone; buff; fine-grained, thin-bedded; bottom markings
6.0 Shale; gray-green
8.0 Sandstone; buff; thin-bedded; weak ledge
8.0 Covered
---- Top of Bigheart sandstone; buff; thin-bedded but weathers massive; contorted; plant fragments to two feet long
(For lower beds, see sections No. 17, 18)

14. *Upper part of lower part of Vamoosa formation.* Along east-west road, through secs. 17 and 18, T. 27 N., R. 10 E.
---- Elgin sandstone; buff, laminated to thin-bedded, weathers massive; shale stringers a few inches thick; contorted
28.0 Shale; green
2.0 Middle Oread limestone; blue-gray; coarse crystalline; thin-bedded; weathers canary yellow to dull yellow; weathered surface looks like calcarenite conglomerate, with fragments to one quarter inch; many fusulinids; pink barite seams
33.0 Shale; green and maroon
3.0 Sandstone; buff
50.0 Covered; mostly shale
19.0 Sandstone; buff; partly thin-bedded, weathers massive; contorted
8.0 Sandstone; buff to brown; medium- to coarse-grained subangular; clay pebble conglomerate concentrated in lowest foot; NOT a channel deposit; cross-bedded; many plant fragments, some up to 2 feet long

50.0 Shale, maroon to purple; contains few thin white siltstone beds

35.0 Labadie limestone and argillaceous limestone; light gray to white; medium crystalline; wavy-bedded, thin-bedded. Exposed in quarry; includes 25 feet measured, 10 feet (at base) estimated

(For lower beds, see section No. 12)

17, 18. *Barnsdall formation.* Along road from Buck Point toward Okesa, sec. 11, T. 26 N., R. 11 E.

(For higher beds, see sections No. 4, 5, 9, 10, 11, 12, 19)

---- Bigheart sandstone (basal member of Tallant formation)

20.0 Heavy float; probably part of Bigheart sandstone

45.0 Covered; probably shale

22.0 Shale; gray-green

28.0 Okesa sandstone; buff; fine- to very fine-grained; laminated to thick-bedded; shale partings to two inches thick; many leaf prints; bottom 10 feet: greenish, calcareous, contorted. Total ledge thickens eastward to 45 feet, at expense of adjacent shales; probably chiefly those underlying the Okesa

45.0 Shale; gray-green; contains thin calcareous siltstone beds characterized by bottom markings, and limonite concretion horizons

3.0 Horizon of the Birch Creek limestone (basal member of the Barnsdall formation); buff sandstone; calcareous, thin-bedded; many braciopods, few pectinoids

---- Shale

19. *Tallant and part of Vamoosa formations.* Along Okesa-Pawhuska road, through secs. 19 and 20, T. 26 N., R. 11 E., and sec. 25, T. 26 N., R. 10 E.

(For higher beds, see section No. 8)

---- Shale; gray-green

4.0 Labadie limestone; greenish-gray, weathers yellow; thin-bedded wavy-bedded; medium crystalline; nodular; fossil fragments

27.0 Shale; dark greenish-brown

8.0 Kiheki sandstone; buff, very fine-grained; weathers massive

28.0	Shale; olive-green and gray-green
18.0	Shale and silt; maroon and gray-green
2.0	Siltstone; gray-green; calcareous; laminated
9.0	Shale; gray-green
14.0	Cheshewalla sandstone (basal member of the Vamoosa formation); buff; fine-grained, thin-bedded; local bottom markings, locally low angle cross-bedding
5.0	Shale; covered
12.0	Shale; gray-green
12.0	Revard sandstone; fine-grained, thin-bedded
10.0	Revard sandstone; shale and silt; gray-green
13.0	Revard sandstone; buff; fine-grained; weathers massive
22.0	Sandstone; poorly lithified; no ledge
8.0	Bigheart sandstone; buff; fine-grained, thin-bedded; obscure cross-bedding
5.0	Bigheart sandstone; covered
5.0	Bigheart sandstone; buff, very fine-grained; highly contorted
----	Barnsdall shale
	(For lower beds, see sections No. 17, 18)

46. *Lower part of Vamoosa formation.* Along U. S. Highway 60. Secs. 5, 6, and 7, T. 26 N., R. 10 E.

----	Middle Oread limestone
110.0	Shale, and thin siltstones
2.0	Limestone; gray-green, weathers buff, brown, pink; massive; medium crystalline
4.0	Shale; maroon
2.0	Siltstone; lavender
20.0	Covered; probably shale
	(For beds below, see section No. 8)

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