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Cover Picture

Current Ripple Marks on Atoka Sandstone

In eastern Oklahoma, the sandstone units in the Atoka Formation (Early Pennsylvanian) contain several types of sedimentary structures, one of which is the current ripple marking shown in the cover photograph. Sole marks, cross- and convolute lamination, graded bedding, and marks on tops of beds are also present and well preserved in Atoka sandstones.

Although the Atoka ranges in thickness from 1,000 to 3,000 feet in most places, 7,000- to 8,000-foot thick sections have been measured along Winding Stair Mountain northeast of Lake Talihina. The formation comprises alternating beds of gray sandstone and shale, some of the massive sandstone beds reaching thicknesses of 10 feet or more. Typically, however, the formation consists of 1- to 3-inch sandstone units alternating with somewhat thicker shales. The sandstone is micaceous and composed predominantly of quartz; plant fragments are abundant near the tops of many of these units. Clay galls are common at tops and bottoms of beds, and a crude sort of graded bedding is not uncommon.

The specimen pictured is from NE¼ SW¼ sec. 27, T. 4 N., R. 21 E., Latimer County, and originally appeared in Oklahoma Geological Survey Circular 65, *Geology of the Western Part of Winding Stair Range, Latimer and Le Flore Counties, Oklahoma*, by L. D. Fellows.

—P. W. W.

GEOLOGY OF OKLAHOMA — A SUMMARY*

LOUISE JORDAN

INTRODUCTION

The following summary of the geology of Oklahoma has been written at the request of the Geophysical Society of Tulsa and is intended mainly as an aid in understanding the major geophysical anomalies shown on the magnetic and gravity maps of the State.† Because much of the geology is too complex for simple treatment, however, the text has been abbreviated, it is mainly descriptive, and the geology of the Oklahoma Panhandle has been omitted.

The principal theme of the paper is regional geology. Accordingly, the discussions are concentrated on major stratigraphic and structural provinces, and these are elucidated by an outcrop map and sections, by a structure contour map on top of the basement rocks, and by pre-Pennsylvanian and pre-Woodford maps.

Most of the sedimentary rocks of Oklahoma are of Paleozoic age, locally 40,000 to as much as 60,000 feet thick. In the southern third of Oklahoma are the three principal fold belts of the State, all originating from orogeny and uplift in Pennsylvanian time. North of the fold belts are two deep basins, and north of these basins are the tectonically stable shelf areas of northern Oklahoma. Petroleum is found in all the provinces and is produced from 72 of the 77 Oklahoma counties. An intensive exploratory program of drilling for oil and gas during the past 50 years has provided most of the subsurface information, which is a critical part of the report.

For valuable assistance in preparing the manuscript the writer is indebted to William E. Ham of the Oklahoma Geological Survey, and to Peter Jacobsen, Jr., and Paul L. Lyons of the Geophysical Society of Tulsa.

ROCKS OF OKLAHOMA

For convenience of discussion, rocks in Oklahoma are divided into ten main units. All these units crop out within some part of the State, but Pennsylvanian and Permian strata crop out over most of the State as shown on the generalized geologic map (fig. 1). The youngest stratigraphic unit consists of Tertiary-Quaternary strata in the western part of the State and in the Panhandle. They occur as a thin blanket of sandstone, siltstone, and caliche and are not further discussed in this report. Tertiary-Quaternary deposits along stream valleys are not

* Reprinted with slight modification from the **Proceedings of the Geophysical Society of Tulsa**, vol. 8, 1961-1964; permission to reprint is gratefully acknowledged.

† The maps referred to are those that accompany papers by Jones (1964) and Lyons (1964) in the **Proceedings** volume cited above. The maps have also appeared as Oklahoma Geological Survey Maps GM-6 (magnetic) and GM-7 (gravity).

shown on the map. The principal units in descending order are (1) Mesozoic, (2) Permian, (3) Pennsylvanian, (4) Mississippian, (5) Devonian-Silurian, (6) Upper and Middle Ordovician, (7) Lower Ordovician and Upper Cambrian, (8) Middle and Lower Cambrian, and (9) Precambrian. The stratigraphic names referred to in this report are given in stratigraphic sequence in figure 2.

Mesozoic Rocks

The Mesozoic is represented mainly by Cretaceous rocks. Strata of this age are present in the Cretaceous Gulf Coastal Plain of south-central and southeastern Oklahoma. The rocks are essentially limestones, clays, and sands, and the sequence unconformably overlies rocks ranging in age from Pennsylvanian to the Precambrian in the southern

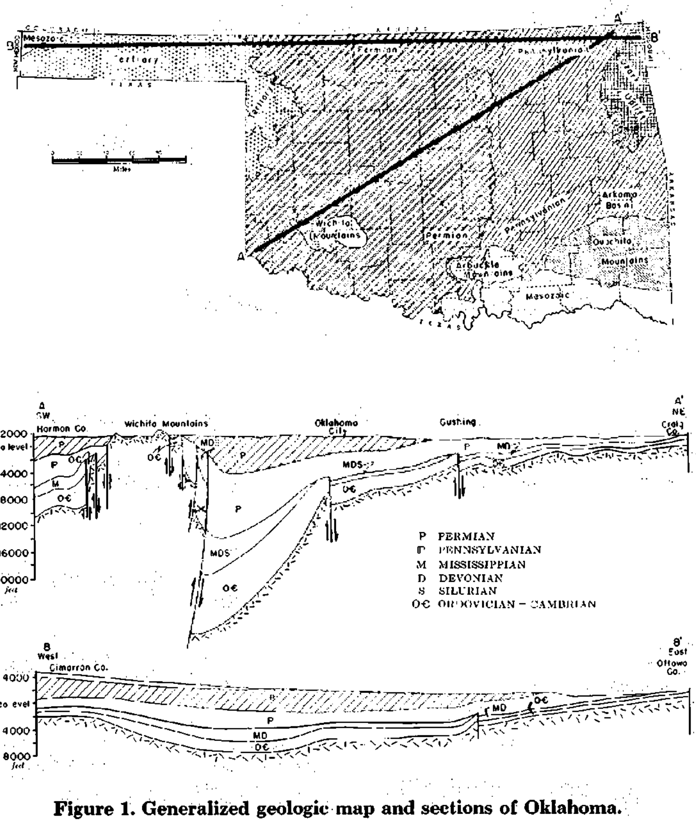

Figure 1. Generalized geologic map and sections of Oklahoma.

parts of the Marietta basin, Ardmore basin, Tishomingo-Belton segment, and the Ouachita province (figs. 1, 3). This section containing rocks of Gulfian and Comanchean age thickens from a featheredge along the northern margin to more than 3,500 feet in the southeastern corner of Oklahoma. A few Cretaceous outliers are present in northwestern Oklahoma and are significant only in that they indicate previous cover and erosion.

Permian Rocks

Permian rocks are present in the western two-thirds of Oklahoma (fig. 1). North of the Wichita province the sequence consists of basal marine carbonates and shale overlain by four evaporite sequences separated by red shale, siltstone, or sandstone. Only the uppermost sequences, Blaine and Cloud Chief, crop out. The lower three evaporite units consist of halite, anhydrite, dolomite, and shale. Halite clearly

Cretaceous	Gulf	
	Comanche	
Permian		
Pennsylvanian	Virgil	Arbuckle orogeny
	Missouri	
	Des Moines	
	Atoka	Wichita orogeny
	Morrow	
?	Springer	
Mississippian	Chester, Goddard	
	Meramec, Jackfork, Stanley	
	Osage	
	Kinderhook	
Devonian and Silurian	Woodford, Chattanooga Arkansas Novaculite	
	Hunton, Missouri Mountain, Blaylock	
U. and M. Ordovician	Sylvan, Polk Creek	
	Fernvale-Viola, Bigfork Chert	
	Simpson, Womble	
L. Ordovician and U. Cambrian	Arbuckle	
	Timbered Hills (Reagan Sandstone at base)	
M. and L. Cambrian	Rhyolite, granite, gabbro, spilitic basalt, metasediments	
Precambrian	Granite, rhyolite	

Figure 2. Stratigraphic succession and equivalent terms used in this report. Major regional unconformities shown by wavy lines. Vertical bars show range of hiatus associated with Wichita orogeny and pre-Woodford unconformity.

predominates in part of the section and occurs in as much as 2,000 feet of strata, some of it almost pure rock salt 1,000 feet thick. Maximum salt thickness for one stratigraphic unit does not coincide structurally or geographically with maximum thicknesses of other evaporite units. In the southeastern part of the Anadarko basin and in the Ardmore basin, evaporite strata are absent and the rocks are mainly sandstone, shale, and conglomerate.

Thickness of Permian rocks in western Oklahoma increases from 3,000 feet at the north to more than 6,500 feet in the deeper part of the Anadarko basin. In parts of the Wichita Mountains province these rocks rest directly upon basement. Southward in the eastern Palo Duro basin, the rocks are mainly red shale with some evaporites, carbonates, and granite wash.

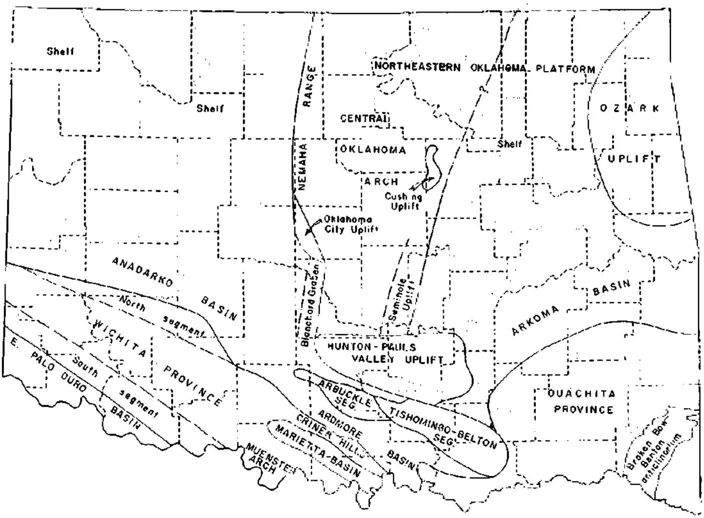

Figure 3. Major structural features and provinces of Oklahoma (exclusive of Panhandle).

Pennsylvanian Rocks

The generalized geologic map (fig. 1) shows the area of outcropping Pennsylvanian rocks in the eastern part of Oklahoma where the homoclinal sequence has been beveled by erosion. Pennsylvanian strata are divided into five series (descending): Virgil, Missouri, Des Moines, Atoka, and Morrow. Some geologists also place Springer in the Pennsylvanian. The rocks are primarily shale, but contain beds of sandstone, limestone, coal, and conglomerate. Along the northern and southern flanks of the Wichita uplift, coarse clastic sediments (granite wash) grade basinward into sandstone, siltstone, and shale. Coarse clastics are present near major uplifts such as the Arbuckle segment and the Criner uplift.

Early Pennsylvanian rocks, Morrowan and Atokan, are absent over the Central Oklahoma arch (fig. 3), over anticlines in the Ardmore basin, and in the shelf areas of the Arkoma and Anadarko basins, delineated for the most part by the northern edge of Morrow rocks as shown by the dotted lines on figure 4. In western Oklahoma, thickness of Pennsylvanian strata ranges from 2,000 feet near the Kansas boundary, southward to more than 16,000 feet in the deeper part of the Anadarko basin. Here approximately 9,000 feet of the section is assigned to the Morrow and Atoka Series, which are absent in the north. In the eastern Palo Duro basin in southwest Oklahoma, the sequence attains a thickness of about 4,000 feet and reportedly contains all units of the Pennsylvanian.

In the Ardmore basin, thicknesses of Pennsylvanian strata (Virgil to Morrow inclusive) range up to 15,000 feet, but here 5,000 to 8,000 feet of the section is assigned to the Des Moines. In the southeastern deeper part of the Marietta basin, the base of the Pennsylvanian is reached at a depth below 14,000 feet. Cretaceous rocks less than 1,000 feet thick overlie Late Pennsylvanian strata. Atokan, and possibly Morrowan, rocks are confined to the deeper part of the basin.

In the Arkoma basin, the strata are mainly shale with some sandstone. They attain a thickness of at least 15,000 feet north of the Choctaw fault of the Ouachita province. At the surface, Des Moines rocks, locally absent, range from 1,000 to 3,500 feet in thickness. Most of the section is assigned to the Atoka, the Morrow unit being less than 1,000 feet thick.

Mississippian Rocks

Figure 4, a generalized geologic map of pre-Pennsylvanian rocks, shows the area where Mississippian rocks are present at the surface and in the subsurface. The greatest thickness of Mississippian strata is in the Ouachita province where alternating strata of sandstone and shale, primarily of the Stanley and Jackfork Groups (Meramec), attain a thickness of more than 20,000 feet. Westward in the Ardmore basin the Late Mississippian Goddard and Springer, approximately 4,500 feet thick, are mainly shale and sandstone. They are underlain by a sequence of Mississippian shale and silty carbonate 500 to 700 feet thick. Chiefly of Meramec age, they contain about 100 feet of strata which may be assignable to the Osage and Kinderhook. In the Marietta basin the Goddard and Springer are absent.

In western Oklahoma both north and south of the Wichita uplift, the Mississippian strata are primarily carbonate rocks 1,500 to more than 3,500 feet thick. Within the Anadarko syncline and on its flanks, equivalent strata are overlain by Springer shales and sandstones. In the Elk City field, the Springer is 1,450 feet thick, but the base of the Mississippian has not been reached at a total depth of 24,003 feet. Southeastward toward the Ardmore basin (Cement field), a well drilled 6,861 feet of steeply dipping Mississippian beds without reaching the base of the Mississippian.

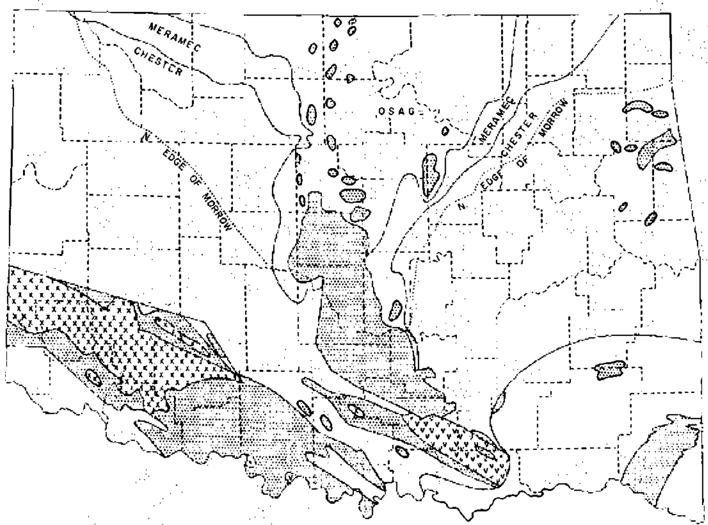

Figure 4. Generalized geologic map of pre-Pennsylvanian rocks in Oklahoma (exclusive of Panhandle) showing surface and subsurface distribution. Blank areas indicate Mississippian strata. In north-central Oklahoma, Mississippian rocks are subdivided into Chester, Meramec, and Osage. Stippled areas indicate Devonian, Silurian, Ordovician, and Upper Cambrian strata. Middle and Lower Cambrian igneous rocks are indicated by X's and Precambrian igneous rocks are shown by V's.

In northern Oklahoma where the Chester and/or Meramec units (fig. 4) have been removed by pre-Pennsylvanian erosion, the remaining Meramec or Osage rocks are principally cherty carbonates ranging in thickness from 200 to 600 feet.

In northeastern Oklahoma, the Mississippian is represented by carbonates about 400 feet thick in the lower part of the system, whereas in the Arkoma basin to the south Upper Mississippian shales predominate. North of the Choctaw fault, at the south edge of the Ardmore basin, the strata are 1,300 feet thick.

Devonian-Silurian Rocks

Except for the area of the Ouachita province, the Devonian-Silurian sequence consists of carbonate rocks of the Hunton Group, together with the unconformably overlying Woodford Formation or Chattanooga Shale (locally including a basal sandstone called the Misener). Figure 5 shows the formations which underlie the Woodford or equivalent formations, or underlie Mississippian rocks where the Woodford is absent. The Hunton has been removed from the area of the Chautauqua arch and from much of northeastern and northern

Oklahoma; farther south, on the east-trending Guthrie-Holdenville arch (Tarr, 1955), the Woodford rests upon Sylvan. Locally in the Ardmore basin, the Woodford rests upon Sylvan and Viola. The thickest recorded normal section (800 feet) is in a well in the Anadarko basin area of northeastern Caddo County. Southwest of this well, in central Caddo County, approximately 700 feet of the Hunton was encountered. Within the complex folded and faulted area of the North Wichita segment, much greater apparent thicknesses have been drilled.

In the Ouachita province a section of sandstone and shale respectively named the Blaylock and Missouri Mountain (Silurian), ranging in thickness from 800 to 1,000 feet, is overlain by the Arkansas Novaculite. The novaculite is considered for the most part to be equivalent to the Woodford Formation.

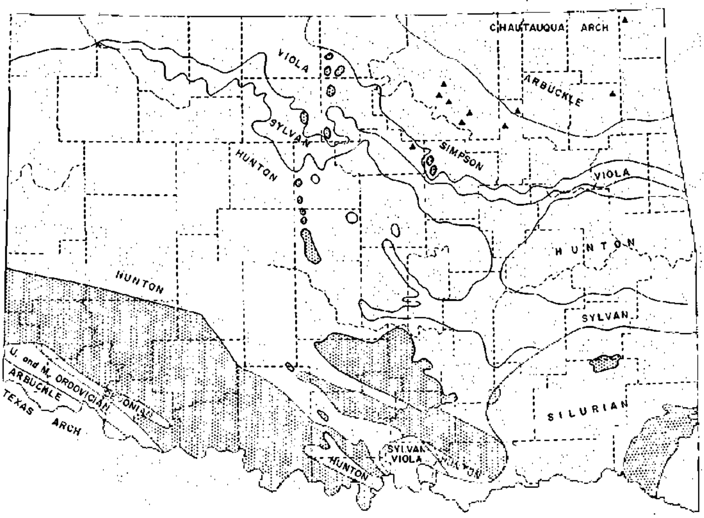

Figure 5. Map showing distribution of rock units at post-Hunton unconformity and sub-Woodford or sub-Mississippian surface (exclusive of Panhandle). Stippled areas are those from which Woodford and Mississippian strata have been removed by Pennsylvanian uplift and erosion. Triangles represent sharp local topographic highs on basement surface.

The Woodford is thickest in southern Oklahoma but is absent at places in the normal sequence in northeastern Oklahoma (parts of Osage, Rogers, and Wagoner Counties), in extreme northwestern Oklahoma (Harper County), and in the eastern Palo Duro basin. It is normally less than 50 feet thick in northern Oklahoma and is 300 to 500 feet thick in the Arbuckle Mountains and the Wichita province.

Upper and Middle Ordovician Rocks

Upper and Middle Ordovician rocks consist of the Simpson Group and overlying Viola-Fernvale limestones and Sylvan Shale.

The Simpson Group is divided into six formations which consist of sandstone, limestone, and shale. Well-known oil- and gas-producing sandstones are in the Bromide, Tulip Creek, McLish, and Oil Creek Formations (descending order). Informal names, such as Marshall zone and Wilcox sand, are applied to productive sandstones of Simpson age in northern Oklahoma. The areal distribution of each of these units is not everywhere the same in the State. For instance, the Tulip Creek Formation is limited generally to the basinal area or southern part of the State, whereas the Bromide, McLish, and Oil Creek Formations are more widely distributed. The group thins northward and southwestward, away from the area of greatest subsidence in the Anadarko-Ardmore depositional basin. Those units which extend toward the Chautauqua arch have been truncated by pre-Woodford erosion in northeastern Oklahoma as shown in figure 5. The group is thickest in southern Oklahoma and decreases to less than 300 feet in northern Oklahoma where it is overlain by Viola-Fernvale limestones. Thickness at the outcrop in the Arbuckle segment is about 2,300 feet and may be as much as 2,500 feet in this vicinity. In the Ouachita province most of the Womble shale section is equivalent to the Simpson Group and is about 600 feet thick.

The Viola-Fernvale limestones, which overlie the Simpson Group in all areas except where eroded by pre-Woodford or later erosion, attain a maximum thickness of not more than 1,000 feet in the Ardmore basin of southern Oklahoma. Just north of the Ouachita province the thickest section recorded is less than 200 feet. In the northwestern shelf area where overlain by Sylvan Shale the carbonate section is normally not more than 200 feet thick, and locally may be less than 100 feet thick. In the Ouachita province equivalent strata, the Bigfork Chert, are from 600 to 700 feet thick and consist of chert and limestone or cherty limestone with interbedded shale.

The Sylvan Shale, highest named unit in the Ordovician in Oklahoma and equivalent to the Polk Creek Shale in the Ouachita province, attains a maximum thickness of probably less than 350 feet. The areas of greater thickness are probably in the Ardmore basin and in the Arbuckle segment. The unit is absent in northeastern Oklahoma and near the Kansas border in northwestern Oklahoma because of pre-Woodford erosion. The shale unit is not recognized in most of Harper County, and may be absent because of nondeposition or pre-Hunton erosion. It thins to extinction westward from Frederick in the eastern Palo Duro basin, perhaps because of pre-Devonian erosion.

Lower Ordovician and Upper Cambrian Rocks

Rocks of this age in Oklahoma consist of the Timbered Hills Group and part of the overlying Arbuckle Group. Other names are applied in northwestern Oklahoma, but the general section is equivalent and in this report is referred to as the Arbuckle dolomite. Except for the basal

Reagan Sandstone, most of the rocks in this sequence are carbonates. They are widely distributed in all parts of Oklahoma except in the Ouachita Mountains, where the known equivalent Ordovician beds are black shale and sandstone. Maximum thickness of the strata is in the Anadarko-Ardmore depositional basin of southern Oklahoma, ranging in this area between 6,000 and 8,000 feet. In south-central (Pauls Valley-Hunton uplift) and central Oklahoma, they are 3,000 to 4,000 feet thick, whereas in northern Oklahoma the section is 1,000 to 1,500 feet thick. South of the Wichita uplift in the Palo Duro basin, the same strata generally are 1,500 to 3,000 feet thick. The basement surface in northeastern Oklahoma is characterized by many small peaks of igneous rock (fig. 6) which are referred to collectively as the "Tulsa Mountains." The hills, many with relief of 1,000 feet or more, were mostly buried by Arbuckle dolomite, but some were not completely covered until Mississippian time. Erosion subsequent to Woodford or Mississippian deposition may have removed some of the Arbuckle section. Some of the peaks, indicated by triangles on figure 5, protrude a few feet to more than a hundred feet above the Arbuckle surface. Thickness of the Arbuckle near these peaks is directly related to the relief of the hills, and the lower part of the Arbuckle is found only in the valleys between the hills.

Middle and Lower Cambrian Rocks

Rhyolite, granite, gabbro, basalt-spilite, and metasediments make up the basement rocks of the Wichita province. They have an isotopic age range of 500 to 550 million years. Igneous rocks of this age also crop out in the Arbuckle segment (fig. 4), and underlie the Anadarko, Marietta, and Ardmore basins.

Metamorphosed sediments of this age and perhaps younger are referred to as basement in the core area of the Ouachita province in southeastern Oklahoma (fig. 6).

Precambrian Rocks

Ages of Precambrian igneous rocks, mainly granite and rhyolite, have been isotopically dated from 1,050 to 1,350 million years in northeastern Oklahoma and in the areas of the Central Oklahoma arch, the Hunton-Pauls Valley uplift, the Tishomingo-Belton segment of the Arbuckle Mountains, and the Muenster arch. The granites are distinct petrographically, petrologically, and chemically from the Wichita granites of Cambrian age.

MAJOR UNCONFORMITIES AND STRUCTURE

Surfaces of erosion subsequent to regional tectonic disturbance are keys to an understanding of the distribution of rocks and their thicknesses at interfaces of major unconformities.

The two major orogenies involving Paleozoic strata of Oklahoma are those that are easily recognized in the tectonic provinces in the southern one-third of the State. The orogenies were mostly confined to Pennsylvanian time, and occurred as strong pulses that extended

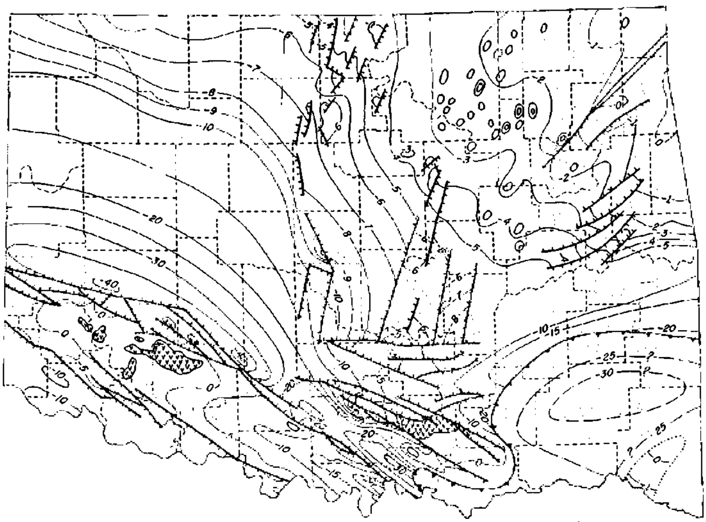

Figure 6. Generalized contour map of basement rocks in Oklahoma (exclusive of Panhandle). Patterned areas are basement-rock outcrops. Contour interval: 1,000 to 5,000 feet.

from early Middle Pennsylvanian time up to the close of the Pennsylvanian period. Different areas were affected to different degrees by these deforming stresses.

The earlier pulse, commonly called the Wichita orogeny, is characterized by strong folding and the uplift of pre-Atoka strata. Many of the upfolded structures that now contain vast amounts of oil were first formed during this period of unrest. The arkosic sediments which surround and largely conceal the Wichita Mountains indicate that highlands of igneous rock survived for a longer time here than in the Arbuckle Mountains area.

The latest orogenic pulse is called the Arbuckle orogeny. The Arbuckle segment was strongly uplifted in post-Missouri (Hoxbar) and pre-Vanoss time, culminating in great uplift in the Arbuckle segment and intense compression of the Ardmore basin. Close folding accompanied by major faulting occurred at this time, and structures formed previously by the Wichita orogeny were modified.

The time of folding of the great Ouachita fold belt cannot be precisely determined, but it is believed by some to have taken place in Oklahoma near the end of Atoka time. The Ouachita orogeny intensely compressed the Ouachita geosyncline, raising the Ouachita Mountains into high relief so that great wedges of chert conglomerates, sands, and deltaic sediments extended northwestward into the Ardmore basin. Later pulses possibly extended into Permian time.

Basement Surface and Pre-Upper Cambrian Unconformities

The present relief of the basement surface of the State is speculatively presented in figure 6. Control is limited to some 600 wells in northeastern Oklahoma and in the southern part of the State west of the Ouachita province. No wells have penetrated basement in the Anadarko basin and shelf area, in most of central Oklahoma, in the deeper part of the Arkoma basin, or in the Ouachita province. Basement rocks crop out in the Wichita and Arbuckle Mountains and on the Ozark uplift. If the metasedimentary rocks of Early Paleozoic age are accepted as basement in the Ouachita province, as proposed by some, the basement crops out in the Broken Bow-Benton anticlinorium; figure 6 is so contoured. Late Cambrian and Ordovician sediments accumulated upon the basement surface. The unconformity between Precambrian rocks and sedimentary rocks is a major one, as for example in the "Tulsa Mountains," in other parts of northeastern Oklahoma, and in the Tishomingo-Belton segment of the Arbuckles. However, the Reagan Sandstone, the lowermost formation of Late Cambrian age, is structurally conformable to the layered igneous basement rocks of Early and Middle Cambrian age, and the unconformity is relatively minor in the Wichita province, the Anadarko, Marietta, and Ardmore basins, and the Arbuckle segment.

Late Cambrian-Devonian deposition was interrupted many times, and on three occasions major unconformities were developed when older rocks were regionally tilted at low angles and beveled. These unconformities are those developed before Simpson deposition, at the end of Sylvan deposition, and between the time of accumulation of the Silurian and Devonian parts of the Hunton Group.

Post-Hunton Unconformity and Sub-Woodford (Chattanooga) Surface

Figure 5 is a generalized map showing distribution of rocks below the Woodford (Chattanooga) Shale, or where it is absent, below Mississippian rocks. Areas of major post-Mississippian erosion are shown by stipple pattern, and it is assumed that most of these areas were once covered by Upper Cambrian-Devonian rocks. Omitting the Ouachita province, parts of three major structural provinces are shown: (1) northwestward-trending Southern Oklahoma geosyncline (an extension of the Colorado sag of Eardley), (2) flank of the Ellis-Chautauqua-Ozark dome to the north, and (3) flank of the Texas arch to the southwest. Several areas of upwarp are shown where Hunton is absent and Woodford rests upon Sylvan or Viola. Mississippian, Pennsylvanian, and Permian tectonic disturbances mask pre-Woodford structures and make interpretation difficult. However, thickness maps of individual units of the pre-Woodford sedimentary sequence reveal many other areas where faulting, uplift, and erosion occurred previous to Woodford deposition. Many prominent anticlines in southern Oklahoma, such as at Apache and Carter-Knox, and along the axes of the Caddo, Overbrook-Enville, and Mannsville-Madill-Aylesworth anticlines, give evidence of pre-Woodford movements. Evidence is also present at the surface in the Arbuckle Mountains area.

Sub-Pennsylvanian Surface and Post-Mississippian Unconformity

Figure 4 is a simplified map showing the present distribution of rocks older than Pennsylvanian in the surface and subsurface. Tectonic activity and erosion during Pennsylvanian and Permian time and in later periods have affected the distribution of pre-Pennsylvanian rocks in most of southern Oklahoma and on the Ozark uplift. The Central Oklahoma arch and most of northern Oklahoma, the Pauls Valley-Hunton uplift, the northwestward-trending faulted anticlines lying en echelon between the Arbuckle and Wichita Mountains, the Muenster arch, and the Criner Hills uplift were positive elements developed prior to Atoka deposition and were finally buried by upper Des Moines strata of the Pennsylvanian. The Central Oklahoma arch is bounded on the west and east by northward-trending zones of normal faults. Eastward-trending faults are also present. Complexly faulted uplifts appear to be more abundant along the western boundary, called the Nemaha Range. This southward-trending arch was a barrier between the Anadarko and Arkoma shelves and part of the basin areas at least during Atokan time, and probably during Morrowan time. Atoka and Des Moines strata onlap the flanks of the arch and some parts were not covered until late Desmoinesian time.

In parts of southern Oklahoma, such as in the Marietta basin, the unconformity is considered to be pre-Atokan in age. Many geologists state that, in the Anadarko basin, where Springer strata are present, sedimentation was continuous from Mississippian into Pennsylvanian time, but in the Ardmore basin, the Springer beds over many structures are unconformable with the overlying Pennsylvanian formations. Study of oil-productive anticlines, such as Carter-Knox and Cement in the southeastern Anadarko basin area, where many thousands of feet of Pennsylvanian-Springer-Goddard rocks are present, indicates that thrust faults and normal faults are confined to these rocks. Pre-Chester formations may have been folded at the time of faulting, or the first evident structural movement may have been post-Hunton and pre-Woodford.

In the Wichita province, the central core area of basement rock is partly covered by a thin veneer of dominantly Permian rocks and is flanked to the north and south by complex horst-and-graben blocks formed during uplift of the structural element in Pennsylvanian time. The prominent west-northwest fault pattern is transected by northeastward striking cross faults in the entire province. This basin area of Upper Cambrian through Chester deposition was uplifted sufficiently so that Early Paleozoic igneous and sedimentary rocks contributed significantly to the Des Moines-Missouri-Virgil and Early Permian sequence of the surrounding area.

The structural pattern of the Ouachita province consists primarily of long linear folds, many of which were ruptured to produce thrust faults directed toward the north and northwest. Strike-slip movement of the mass is postulated along transverse faults bordering the Arbuckle buttress, and this type of movement extended into the Arbuckle Mountains area. The Broken Bow-Benton anticlinorium forms the central part of the range where pre-Stanley rocks (Devonian and older) with incipient to low-grade metamorphism crop out in the southeasternmost county of the State. Major tectonic deformation and uplift occurred during Middle Pennsylvanian time, and the core of the Ouachitas was exposed, probably in Early Permian time, before deposition of Cretaceous strata.

The Ozark uplift, a southwestward extension of the Ozark dome, was a broad, stable, positive element during much of geologic time. Northeastward-trending folds and normal faults are roughly parallel to the axis of the feature. These are mapped southwestward into the subsurface. On the southern part of the uplift, the trends of the faults are more easterly and roughly parallel the folds and faults of the Arkoma basin, indicating a genetic relationship to Ouachita deformation.

Principal deformation of the Arbuckle and Tishomingo-Belton segments, occurring in Late Pennsylvanian time, caused the formation of overturned folds and normal and thrust faults in these segments as well as in the Ardmore basin, Criner Hills, and Marietta basin. Strike-slip movement is postulated along the northwestward-trending, through-going faults, which are both normal and reverse faults.

PRESENT LAND SURFACE

Regional movements, with the resultant downwarping and development of extensive seas to the west of Oklahoma during Late Permian through Jurassic time and the partial submergence of Oklahoma during Cretaceous time, introduced a general westward and southwestward tilting of rock strata in much of the area. This is revealed at the surface by the northward-trending bands of Pennsylvanian outcrops in the areas where the strata have not been affected by the major orogenies of southern Oklahoma or by the Ozark uplift. The outcrop bands of Early Permian rocks indicate the position of the Anadarko basin, but are interrupted in the southern part of the State by the Wichita Mountains.

The Cretaceous and Early Tertiary uplifts that produced the Rocky Mountains also imparted a slight eastward tilt to all the rocks in Oklahoma and gave the present eastward slope of the land surface, with elevations ranging from 5,000 feet at the northwestern tip of the Oklahoma Panhandle to 300 feet along the Red River in the southeast corner of the State.

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List of Mineral Producers Compiled

A list of mineral producers in Oklahoma has been compiled by the Oklahoma Geological Survey for the Oklahoma Economic Development Foundation, Inc. The project was carried out with the assistance of the Foundation and chambers of commerce, county assessors, and producing companies throughout the State.

The list comprises two parts. The first part lists producers according to 18 categories of mineral products: bentonite, cement, chat, clay, coal, copper, dimension stone, dolomite, glass sand, granite, gypsum, lead and zinc, lime, limestone, salt, sand and gravel, tripoli, and volcanic ash. The second part lists producers by counties.

The list has been reproduced by multilith from the readout of data-processing cards. Copies may be obtained from the Survey for fifteen cents per copy.

Bulletin on Henryhouse Trilobites Issued

Bulletin 115, *Trilobites of the Henryhouse Formation (Silurian) in Oklahoma*, by K. S. W. Campbell, was issued November 16, 1967, by the Oklahoma Geological Survey. In this bulletin, Campbell describes the trilobite fauna of the Henryhouse and erects three new genera and ten new species. The abstract of this book is reprinted below.

ABSTRACT

A small fauna of trilobites from the Henryhouse Formation of Oklahoma consists of eleven species referred to ten genera. Among the genera, the cheirurid *Anasobella* (type species *A. asper*, new species) and the phacopid *Ananaspis* (type species *Phacops fecundus communis* Barrande) are new. Ten of the species are new. The fauna is peculiar in that it lacks illaenids and lichids.

Certain representatives of the subfamilies Phacopinae and Phacopidellinae are discussed, and *Phacops* Emmrich, *Reedops* Richter and Richter, and *Eophacops* Delo are redefined. *Eophacops* is transferred from the Phacopinae to the Phacopidellinae, and *Phacops musheni* Salter and *P. trapeziceps* Barrande are referred to it rather than to *Phacopidella*. A new genus, *Acernaspis*, with type species *Phacops orestes* Billings, is erected. A suggested phylogeny for the Silurian to Middle Devonian phacopinids and phacopidellinids is outlined.

The Henryhouse material is well preserved, and morphological detail is available for almost all species. Attention is drawn to the systematic value of fine surface structures.

The age of the fauna, as indicated by the trilobites, is late Wenlockian to early Ludlovian. Elements of the faunas of Bohemia, Great Britain, and northeastern United States are recognized. It is noteworthy that the fauna lacks the strong Bohemian affinities of the one of similar age from the Gazelle Formation of California.

This publication contains 68 pages, 19 plates, and 7 text-figures; the price of the cloth-bound edition is $5.00, that of the paper-bound edition, $4.00.

New Theses Added to O. U. Geology Library

The following Master of Science thesis was added to the University of Oklahoma Geology Library in October 1967:

Areal geology of the Cheyenne area, Roger Mills County, Oklahoma, by John R. Bowers.

—*L. F.*

Scolecodont Carriers from the Lower Permian of Kansas

Edward L. Gafford, Jr.

Scolecodont carriers were retrieved from the Fort Riley Limestone (Lower Permian) in southeastern Kansas. These carriers are the attachments to the fossil pharyngeal jaws of annelid worms. Stude (1961) extended the upper limit of the range of the Paleozoic scolecodonts from the Lower Mississippian to the Lower Permian but did not report the occurrence of the worm-jaw carriers in his study.

In all, 20 specimens were recovered from the insoluble residue of this limestone; however, many were not joined pairs (pl. I, figs. 1, 5-8). The carriers range from 30 microns to 55 microns in length and are in the collection at Wichita State University.

As the scolecodonts and carriers are composed of a chitinlike material that is resistant to acid attack, each sample was treated with hydrochloric or muriatic acid. The residues were washed in a 230-mesh

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Explanation of Plate I

Figure 1. **A complete scolecodont carrier, 30 microns long; slide Fort Riley 14′ I (14 feet above base of formation).**

Figure 2. **An assemblage of the genus** Arabellites. **The left jaw became disarticulated during mounting; the assemblage was apparently held together by the carrier. The jaws, with carrier, are 75 microns long; slide Fort Riley 16′ II (16 feet above base of formation).**

Figures 3, 4. **A scolecodont of the genus** Nereidavus **with carrier attached. Figure 3 shows the fossa of the jaw; figure 4 is the same specimen photographed from the other side. Note that the carrier is inserted into a depression or slot in the posterior end of the jaw. Separation of the carrier halves is noticeably different from that of the other specimens figured. The full specimen is 58 microns long; slide Fort Riley 16′ III (16 feet above base of formation).**

Figure 5. **A complete scolecodont carrier. Note the acute angle at the attachment end of the specimen (bottom of figure). Maximum length is 30 microns; slide Fort Riley 9′ IV (9 feet above base of formation).**

Figure 6. **A complete scolecodont carrier. Note the fine-textured membrane joining the two halves of the carrier. The specimen is 55 microns long; slide Fort Riley 10′ V (10 feet above base of formation).**

Figure 7. **A complete scolecodont carrier, 55 microns long; slide Fort Riley 19′ VI (19 feet above base of formation).**

Figure 8. **Complete scolecodont carrier, 47 microns long; slide Fort Riley 9′ VII (9 feet above the base of the formation).**

All photography was done with reflected light, and none of the figures has been retouched.

Plate I

sieve to eliminate the clay-sized particles, and the fossils were handled with a micropipette.

The samples from which the scolecodont carriers were recovered came from the southeast corner of the Augusta quarry in NE¼ sec. 9, T. 28 S., R. 4 E., Butler County, Kansas. This is section 3 of Stude (1961). The Fort Riley Limestone is the prominent upper member of the Barneston Formation and crops out in a nearly continuous band from southeastern Nebraska, across central Kansas, and well into north-central Oklahoma. The Fort Riley in Butler County, Kansas, and in Kay County, Oklahoma, is a highly fossiliferous blue and buff marine limestone approximately 40 feet thick, deposited under relatively quiet, shallow-water conditions.

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Recent Delta Growth in the Butcher Pen, Lake Texoma, Oklahoma

Robert W. Ganser

A large delta has been built up recently in the northern part of the Washita arm of Lake Texoma (secs. 5-8, T. 5 S., R. 7 E.). The Washita River empties into part of Lake Texoma known as the Butcher Pen, which lies on the boundary of Marshall and Johnston Counties, Oklahoma. Bedrock in the area belongs to the Comanchean Series of the Cretaceous and consists of the Caddo and Kiamichi Formations. A comparison of aerial photographs of Marshall County taken in 1956 (fig. 1) with those of Johnston County taken in 1963 (fig. 2) shows a series of changes in the seven years.

The delta first built northward about 1¾ miles. The river then abandoned its northward-trending main channel in favor of a more easterly course and continued building the delta for ⅔ mile, until it abutted the opposite shore. The main channel was deflected southward and deposited another 1½ miles of delta.

In the seven years, the Washita River increased the exposed surface area of the delta by about 1.8 square miles, or nearly 1,200 acres. It must be mentioned that the lake level was higher when the 1963 photographs were taken, and that if the water were at the same level as in 1956, the exposed area of the delta would be even greater.

Figure 1. 1956 aerial photograph of the northern part of the Washita arm of Lake Texoma, on the Marshall-Johnston county line.
Approximate scale: 1 inch = 1 mile.

Figure 2. 1963 aerial photograph of the same area shown in figure 1 (same scale), showing the 1.8-square-mile increase in the surface area of the delta during a seven-year period.

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The Mineral Industry of Oklahoma

The Mineral Industry of Oklahoma, which is a chapter from the forthcoming U. S. Bureau of Mines *Minerals Yearbook* for the year 1966, is now available in preprint form. The chapter, authored by Robert B. McDougal and William E. Ham, gives final statistics for production and value of the mineral products of the State and trends and developments during 1966. A section is devoted to each mineral commodity and to each county.

The booklet comprises 21 pages and contains 23 tables and 1 graph. It may be obtained upon request from the Oklahoma Geological Survey.

Oklahoma Geology Notes to be Issued Bimonthly

To effect certain improvements in the editorial operation of the Survey, *Oklahoma Geology Notes* will be published bimonthly hereafter, beginning with the first number of volume 28. The six numbers of a volume will appear in February, April, June, August, October, and December.

Few immediate changes in format or content are planned. However, the thoughtful suggestions of our readers will receive continuing attention and will be the basis for future changes designed to make the *Notes* a more varied and more useful periodical.

The subscription rate will remain unchanged; the number of pages per volume will not be reduced sufficiently to warrant a lower rate.

The next issue of the *Notes* will appear in February 1968.

Publication Dates, Oklahoma Geology Notes, Volume 27

The twelve numbers of this volume of the Notes were issued on the following dates during 1967:

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