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Structure of the Ouachita Mountains of Oklahoma and Arkansas

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STRUCTURE OF THE OUACHITA MOUNTAINS OF OKLAHOMA AND ARKANSAS[1]

BY HUGH D. MISER

INTRODUCTION

The Ouachita Mountains of Oklahoma and Arkansas constitute a relatively small geologic unit whose surface features, rocks, and geologic structure are all different from those of the adjacent regions. Geologists have long recognized that the type of folding of the rocks is similar to that of the Appalachian region. The suggestion was offered some years ago by Dake[2] that the rocks of the Ouachita Mountain region were thrust northward a long distance over rocks that have the same facies as those of the Arbuckle Mountains, near-by to the west. But it was not until 1927 that the presence of low-angle thrust planes in the Ouachita Mountains was proved by field observations. In that year I discovered a window through an overthrust mass in and near Round Prairie, in the Potato Hills, west of Talihina, Okla. This window, which is described on page 20, not only leads to the conclusion that low-angle thrusts exist in the Ouachita Mountains but supports the suggestion of Powers[3] that the numerous major parallel faults in the mountains bound thin slices of the earth's crust.

PRESENT AND PREVIOUS INVESTIGATIONS

The present paper gives the first published picture of the geologic structure of the entire Ouachita Mountain region. It is based in large measure on field data that I have obtained during all or parts of fourteen field seasons, beginning in 1907. Most of the field seasons were spent in the Arkansas portion of the region. No opportunity came for spending much time in the Oklahoma portion until 1927, when field studies were extended to all the mountain areas that I had not previously visited. Thus it was not until that year that I was able to gain a complete structural picture of the entire region.

My own field results are necessarily combined, to a large extent, with those of other geologists who have made stratigraphic and structural studies of the region. These geologists

1. Published by permission of the Director of the United States Geological Survey. Presented in abstract before the Geological Society of America in Cleveland, Ohio, December, 1927 and before the Geological Society of Washington, in Washington, D. C., March 1928.

2. Dake, C. L., The problem of the St. Peter sandstone: Missouri Univ. School of Mines and Metallurgy Bull., vol. 6, no. 1, p. 55, 1921.

3. Powers, Sidney, Age of folding of Oklahoma Mountains: Geol. Soc. America Bull., vol. 39, pp. 1031-1072, 1928.

include Griswold, Ashley, Drake, Taff, Wallis, Honess, and the late Professor Purdue. In fact, I worked for several years (1907-1911) as an assistant to Purdue, a devoted teacher, to whom I owe much of my training in geology.

The structure of portions of the Ouachita Mountains in Arkansas, especially the DeQueen and Caddo Gap quadrangles and also the area covered by the Geological Survey's map of Hot Springs and vicinity, has been described by Purdue and me in several reports,[4] and all our unpublished and published maps have been used by the Arkansas Geological Survey in the preparation of the new geological map of Arkansas.

The region containing the novaculites in Arkansas was covered by reconnaissance studies by Griswold[6] about 40 years ago, and the region of Paleozoic rocks lying south of the novaculite region in Arkansas was also covered by similar studies by Ashley[7] in 1890 to 1892. Part of these same regions were mapped in detail in 1907 and later years by Purdue and me. Wallis[8] in 1914 mapped a narrow belt along the northwest side of the Ouachita Mountains in Oklahoma. In 1896 Drake[9] mapped a portion of the northwest border of the mountains in Oklahoma. Northern McCurtain County and parts of the adjacent counties to the north have been mapped in detail in recent years by Honess,[10] who has accepted and discussed at length[11] Dake's hypothesis of the northward overthrusting of the Ouachita Mountains already mentioned. The west end of the mountain region has been described by Taff[12] in the Atoka folio, and the portions of the mountains embraced in the McAlester, Windingstair, Tuska-

4. Purdue, A. H., The slates of Arkansas, Arkansas Geol. Survey, 1909.
Miser, H. D., Manganese deposits of the Caddo Gap and DeQueen quadrangles, Arkansas: U. S. Geol. Survey Bull. 660, pp. 59-128, 1917.
Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas, Hot Springs folio (No. 215), 1923.
Miser, H. D., and Purdue, A. H., Geology and mineral resources of the DeQueen and Caddo Gap quadrangles: U. S. Geol. Survey Bull. 808, 1929.

5. Branner, G. C., Geologic map of Arkansas, Arkansas Geol. Survey, 1929.

6. Griswold, L. S., Whetstones and the novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, 1892.

7. Ashley, G. H., Geology of the Paleozoic area of Arkansas south of the novaculite region (with introduction by J. C. Branner): Am. Philos. Soc. Proc., vol. 36, pp. 217-318, 1897.

8. Wallis, B. F., The geology and economic value of the Wapanucka limestone of Oklahoma, with notes on the economic value of adjacent formations: Oklahoma Geol. Survey Bull. 23, 1915.

9. Drake, N. F., A geological reconnaissance of the coal fields of the Indian Territory: Am. Philos. Soc. Proc. vol. 36, pp. 326-419, 1897.

10. Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, 1923; Geology of southern Le Flore and northwestern McCurtain Counties, Oklahoma: Bur. Geology Circ. 3, Norman, Oklahoma, 1924.

11. Honess, C. W., Geology of Atoka, Pushmataha, McCurtain, Bryan, and Choctaw Counties, Oklahoma: Oklahoma Geol. Survey Bull. 40-R, 1927.

12. Taff, J. A., Geol. Survey Geol. Atlas, Atoka folio (No. 79), 1902.

homa, Antlers, and Alikchi quadrangles, Okla., were mapped in detail some 20 years ago by Taff, though his mapping in those quadrangles was first presented in published form on the recently issued geologic map of the State of Oklahoma.[13] Papers discussing not only stratigraphic but structural features of the Ouachita Mountains of Oklahoma have been written recently by Ulrich[14] and Powers.[15]

From the information now available I have been able to compile the two accompanying geologic maps (pls. I and II), which illustrate graphically the structure and areal distribution of the rocks of the entire Ouachita region.

LOCATION AND GENERAL GEOLOGIC FEATURES OF THE OUACHITA MOUNTAINS

The Ouachita Mountains extend westward from Little Rock, in central Arkansas, to Atoka, in southeastern Oklahoma, a total distance of 220 miles. They have an average width of about 50 miles. They are composed of numerous parallel, closely spaced, densely forested ridges that have a general east-west trend and attain an altitude of 2,850 feet above sea level. See fig. 1.

The rocks are mostly shale and sandstone, with some chert, novaculite, limestone, and tuff, and are of many ages —Cambrian, Ordovician, Silurian, Devonian, Mississippian, and early Pennsylvanian (Pottsville). Their aggregate thickness is 25,000 feet. Igneous rocks that range in age from possible Ordovician to Upper Cretaceous are exposed in a few areas of small size. The sedimentary rocks were deposited in what is here called the Ouachita geosyncline. The Carboniferous (Pottsville and Allegheny) rocks of the Arkansas Valley, which adjoins the north side of the Ouachita Mountains, were laid down in the northern portion of the geosyncline, and if we add the thickness of the Alleghgeny rocks of the Arkansas Valley to the thickness of the older strata in the Ouachita Mountains, the total thickness of the strata in the geosyncline is about 30,000 feet

13. Miser, H. D., Geologic map of Oklahoma, U. S. Geol. Survey, 1926.

14. Ulrich, E. O., Fossiliferous boulders in the Ouachita "Caney" shale and the age of the the shale containing them: Oklahoma Geol. Survey Bull. 45, 1927.

15. Powers, Sidney, Age of folding of the Oklahoma Mountains: Geol. Soc. America Bull., vol. 39, pp. 1031-1079, 1928.

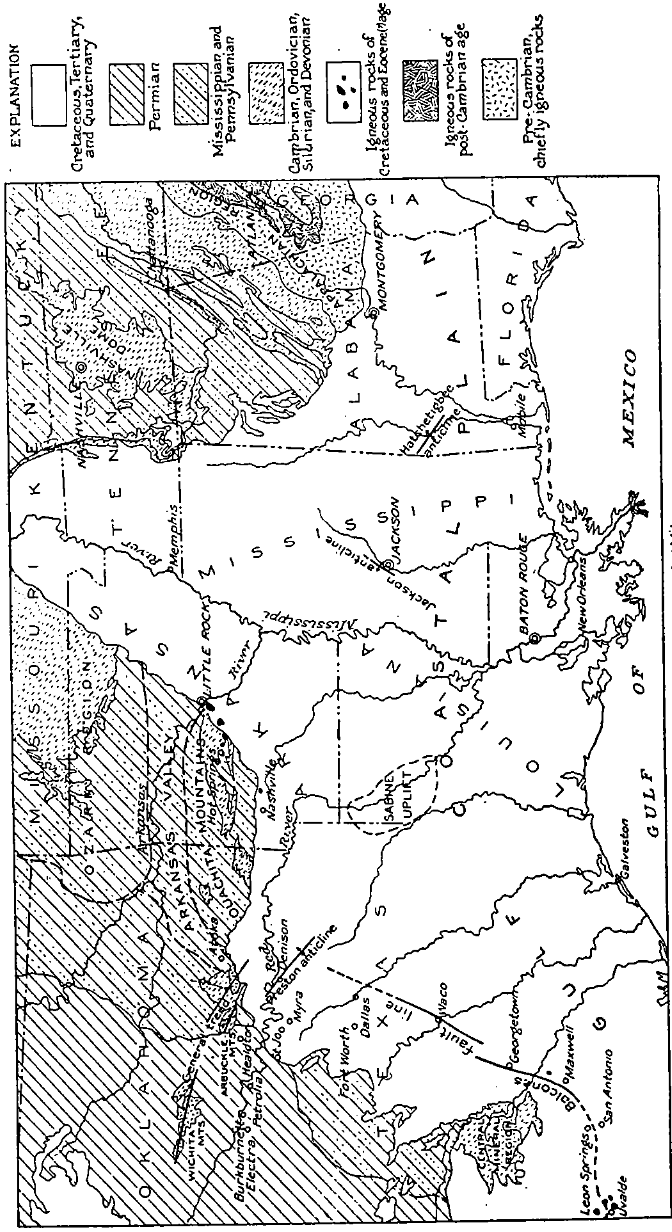


Figure 1.—Geologic map showing relations of Ouachita Mountains to adjacent regions.

The exposed Paleozoic strata of the Ouachita Mountains, having been deposited in a geosyncline, are much thicker than the Paleozoic rocks of the Ozark region, which was a geanticline during the Paleozoic era. The pre-Carboniferous Paleozoic rocks in the Ouachita Mountains also differ widely in character and in faunas from the rocks of this age in both the Ozark and Arbuckle regions. In the Ouachita region they consist of shale and sandstone, with some limestone, chert, and novaculite, whereas in the Ozark and Arbuckle regions they consist of limestone and dolomite, with some shale, sandstone, and chert. Furthermore, the Carboniferous rocks—mostly shale and sandstone—of the Ouachita Mountains differ markedly in character, thickness, and fossil content from the rocks of this age in the Ozark region, but they are somewhat similar in character, thickness, and fossil content to the Carboniferous rocks in and adjacent to the Arbuckle Mountains. Pre-Cambrian crystalline rocks are widely exposed in the Arbuckle and Ozark regions but are nowhere revealed at the surface in the Ouachita Mountains, and they have not been penetrated by deep borings there.

Toward the east and south the rocks of the Ouachita Mountains pass underneath the Cretaceous and Tertiary sediments of the Gulf Coastal Plain (pl. I), and very little is now known of their extent and character in these directions, especially at great distances from the mountains. Several deep wells drilled in the Coastal Plain not far south or southeast of the Ouachita Mountains have penetrated rocks of the same age and character as those in these mountains. These wells are listed below, with their distances from the mountains.

Oklahoma-Colorado Oil & Gas Co., well in SW.¼ SW.¼ NW.¼ sec. 7, T. 6 S., R. 19 E., Choctaw County, Okla.; 9 miles south.

Perpetual Oil & Gas Co., well at Nashville, Howard County, Ark.; 12 miles south.

Johnston Petroleum Syndicate, Lady Alice No. 1 well, Silver City, Red River County, Tex.; Bokhoma well, northwest corner NW.¼ SE.¼ sec. 15, T. 8 S., R. 26 E., 2 miles north of Bokhoma, McCurtain County, Okla.; each 15 miles south.

Gillam & Foster Co., Wade No. 1 well, sec. 13, T. 6 S., R. 14 E., Choctaw County, Okla.; 18 miles south. Information furnished by C. W. Honess, in letter of Feb. 9, 1929.

Dudley et al., Owen No. 1 well, sec. 27, T. 10 S., R. 16 W., Dallas County, Ark.; well in NE.¼ SW.¼ sec. 12, T. 10 S., R. 16 W., Dallas County, Ark.; W. S. Hall, Goodgame No. 1 well, southwest corner sec. 19, T. 11 S., R. 16 W., Ouachita County, Ark., each 30 miles southeast; Newblock et al., Green No. 1 well, NE.¼ NE.¼ sec. 18, T. 10 S., R. 13 W., Dallas County, Ark.; Arkansas Natural Gas Co., Tate No. 1 well, sec. 4, T. 9 S., R. 11 W.; each 40 miles southeast. Information about last three wells furnished by W. C. Spooner, in letter of Feb. 13, 1929.

Most of the clastic sediments for the Paleozoic rocks of the Ouachita Mountains had a southern source. Although the ancient land supplying the sediments is now deeply buried and thus completely concealed underneath the deposits of the Coastal Plain, it is thought by most geologists to have existed in Louisiana and eastern Texas.[16] This ancient land is known by the name Llanoria, or the more recent name Llanoris proposed by Schuchert.[17]

Some geologists have held that the Ouachita Mountains are an outlier of the Appalachian system.[18] J. C. Branner,[19] in a paper issued in 1897, says, "I was at first disposed to think the Ouachita uplift a part of the old Appalachian land system, but this opinion I have been obliged to abandon." In the same paper he gives evidence in support of his conclusions that "the Ouachita anticline (uplift) is the structural equivalent of the Cincinnati-Nashville arch,"[20] and that the "old Appalachian land area crossed what is now the lower Mississippi Valley from northern Alabama to the pre-Cambrian area northwest of Austin, Tex."[21]

Keith[22] discusses the relations of the Appalachian and Ouachita mountains as follows:

> Some geologists consider the Ouachita Mountains of Arkansas and Oklahoma to be the western extension of the Appalachians, in which case the latter would be bent nearly at a right angle. It seems to the author, however, that the Ouachita folds, while developed at the same time, rose on one of the cross-axes which characterized the earth movements at the end of the Paleozoic.

16. Dumble, E. T., The geology of east Texas: Texas Univ. Bull. 1869, pp. 11-13, 1920.
Miser, H. D., Llanoria, the Paleozoic land area in Louisiana and eastern Texas: Am. Jour. Sci., 5th ser., vol. 2, pp. 61-89, 1921.
Schuchert, Charles, Textbook of geology, pt. 2, Historical geology, 1924.
Ulrich, E. O., Fossiliferous boulders in the Ouachita "Caney" shale and the age of the shale containing them: Oklahoma Geol. Survey Bull. 45, 1927.
Powers, Sidney, Age of folding of the Oklahoma Mountains: Geol. Soc. America Bull., vol. 39, pp. 1031-1072, 1928.

17. Schuchert, Charles, op. cit.

18. Winslow, Arthur, The geotectonic and physiographic geology of western Arkansas: Geol. Soc. America Bull., vol. 2, p. 231, 1890.
Griswold, L. S., Whetstones and the novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, pp. 212-213, 1892.

19. Branner, J. C., The former extension of the Appalachians across Mississippi, Louisiana, and Texas: Am. Jour. Sci., 4th ser., vol. 4, p. 367, 1897.

20. Idem, p. 370.

21. Idem, p. 357.

22. Keith, Arthur, Outlines of Appalachian structure: Geol. Soc. America Bull., vol. 34, pp. 311-312, 1923.

Ulrich[23] writes:

> In my opinion the Ouachita Mountains are comparable in genesis to the Alps of Europe and the Himalayas in Asia. Their relation to the Gulf of Mexico is the same as that of the Alps to the Mediterranean and that of the Himalayas to the Indian Ocean. In other words, the rocks of the Ouachitas were deposited in a subsiding basin that lay a hundred or more miles to the south of their present position. To the south of the original Ouachita basin lay an older foreland.

Moore suggests "that the Ouachita trough is a continuation of the Appalachian geosyncline and that eastern Llanoria may have joined southwestern Appalachia."[24]

The Ouachita geosyncline was, in my opinion, a westward extension of the Appalachian geosyncline during at least a part of the Paleozoic era, because some of the rocks of the Ouachita and Appalachian regions are similar in lithologic character and fossil content. Much, possibly conclusive evidence on the subject may be contributed in the future by geophysical exploration and by deep wells adjacent to and between the two regions. Similarly much evidence may be supplied about the relations of Appalachis to Llanoris. The paleogeographic maps so far published suggest that these two ancient lands were connected during only a minor portion of the Paleozoic era.

Whatever the relations of the Ouachita geosyncline to the Appalachian geosyncline may have been, the Ouachita and Appalachian regions occupy analogous positions. To the north of the Ouachita region lies the positive element, the Ozark region, and to the south the concealed ancient land, Llanoris, the source of most of its sediments. Northwest of the Appalachians is the Cincinnati Arch, including the Nashville dome, and southeast of them the ancient land mass, Appalachis. Llanoris and Appalachis are, as stated by Schuchert, border lands of the Ouachita and Appalachian geosynclines.[25]

23. Ulrich, E. O., Fossiliferous boulders in the Ouachita "Caney" shale and the age of the shale containing them: Oklahoma Geol. Survey Bull., 45 p. 26, 1927.

24. Moore, R. C., Framework of southeastern North America: Geol. Soc. America Bull., vol. 39, pp. 181-182, 1928.

25. Schuchert, Charles, Sites and nature of the North American geosynclines: Geol. Soc. America Bull., vol. 34, pp. 160, 215, 1923; A textbook of geology, pt. 2, Historical geology, pp. 138-140, 1924; Schuchert, Charles, and Le Vene, C. M., The earth and its rhythms, pp. 162-163, 1927.

STRUCTURE OF ROCKS OF THE OUACHITA MOUNTAINS

GENERAL FEATURES

The shortening of the earth's crust in the Ouachita Mountains themselves has been great,—about 50 miles in the Arkansas portion, or approximately half of the original horizontal extent of strata, and perhaps more than 70 miles in the Oklahoma portion. But the deformed strata of Paleozoic age extend an unknown distance toward the south underneath the Cretaceous and Tertiary rocks of the Coastal Plain, as indicated by the wells previously cited. The aggregate minimum crustal shortening in Arkansas thus actually exceeds 50 miles. It is reasonably assumed to be at least 60 miles, because deformed Paleozoic rocks have been penetrated in wells in that State 12 miles south of the southern margin of the mountains. The minimum shortening in Oklahoma also exceeds the 70 miles estimated for the mountains alone. The amount is assumed to be at least 85 miles, because deformed Paleozoic rocks have been penetrated in wells 15 to 18 miles south of the southern margin of the mountains. The shortening in Arkansas is due to close folding, together with a minor amount of thrust faulting, but the shortening in Oklahoma has been brought about by many long parallel thrust faults as well as by folds. The folds in Arkansas are overturned in large areas, but the folds in most of the Oklahoma area are open, though asymmetric.

The competent beds that are involved in most of the overturned folds are the Arkansas novaculite (lower part Middle Devonian, upper part Devonian?) and the Jackfork sandstone (Carboniferous). The Arkansas novaculite, a variety of chert, is massive and thin-bedded and 500 to 900 feet thick in large areas. Wherever it is underlain and also overlain by great thicknesses of shale and of thin-bedded chert and sandstone it has been bent into closely compressed anticlines and synclines. See figs. 2, 3, and 4.

The Jackfork sandstone is massive and some 6,000 feet thick. In spite of these characteristics, it has been bent into closely compressed folds in the southern Ouachita Mountains of Arkansas, and some of the folds are overturned. It is there underlain by the Stanley shale (Carboniferous) and overlain by the Atoka formation (Carboniferous), each of which is 6,000 feet thick and consists predominantly of shale. In Oklahoma the Jackfork sandstone is underlain by the Stanley shale, which is there similar in thickness and character to the Stanley of Arkansas, but the overlying Atoka formation, although some 6,000 feet thick, is a massive sandstone containing very little shale. Thus in Oklahoma the Jackfork and Atoka constitute a body of massive sandstone 12,000 feet thick, though in some areas a thin formation, the Caney shale, perhaps 100 to 1,000 feet thick, intervenes between the two. This great mass of sandstone is broken by many long parallel faults. It was too thick to be bent into folds with parallel sides.

Closely compressed anticlines that have been broken by faults are especially numerous in parts of the region that contain the Arkansas novaculite. See figs. 2, 3, and 4. Both normal fan folds and inverted fan folds are present. Examples of normal fan folds are to be found in both Oklahoma and Arkansas. See figs. 3 and 4. The largest inverted fan fold is the Mazarn synclinorium, 60 miles in length, which extends westward from the vicinity of the city of Hot Springs, Ark., on its north edge. See fig. 5. The synclinorium is underlain at the surface by Carboniferous rocks (Stanley shale and Jackfork sandstone) and is bounded on both its north and south sides by pre-Carboniferous rocks, the folds in which are overturned toward the synclinorium.

Figure 2.—Structure sections through several mountains in western Arkansas, illustrating their complicated structure. (After Miser and Purdue, U. S. Geol. Survey Bull. 808.)

A. Whisky Peak, near Hatton, DeQueen quadrangle.

B. East Hanna Mountain, near Shady, DeQueen quadrangle.

C. Katy Mountain, near Shady, DeQueen quadrangle.

D. Raspberry Peak, near Shady, DeQueen quadrangle.

E. High Point, near Shady, DeQueen quadrangle.

F. Mountain 1 mile northeast of Shady, DeQueen quadrangle.

G. and H. Brier Creek Mountain, near Albert, Caddo Gap quadrangle.

Cs, Stanley shale; **Da**, Arkansas novaculite; **Sm**, Missouri Mountain slate; **Sb**, Blaylock sandstone; **Opc**, Polk Creek shale; **Obf**, Bigfork chert.

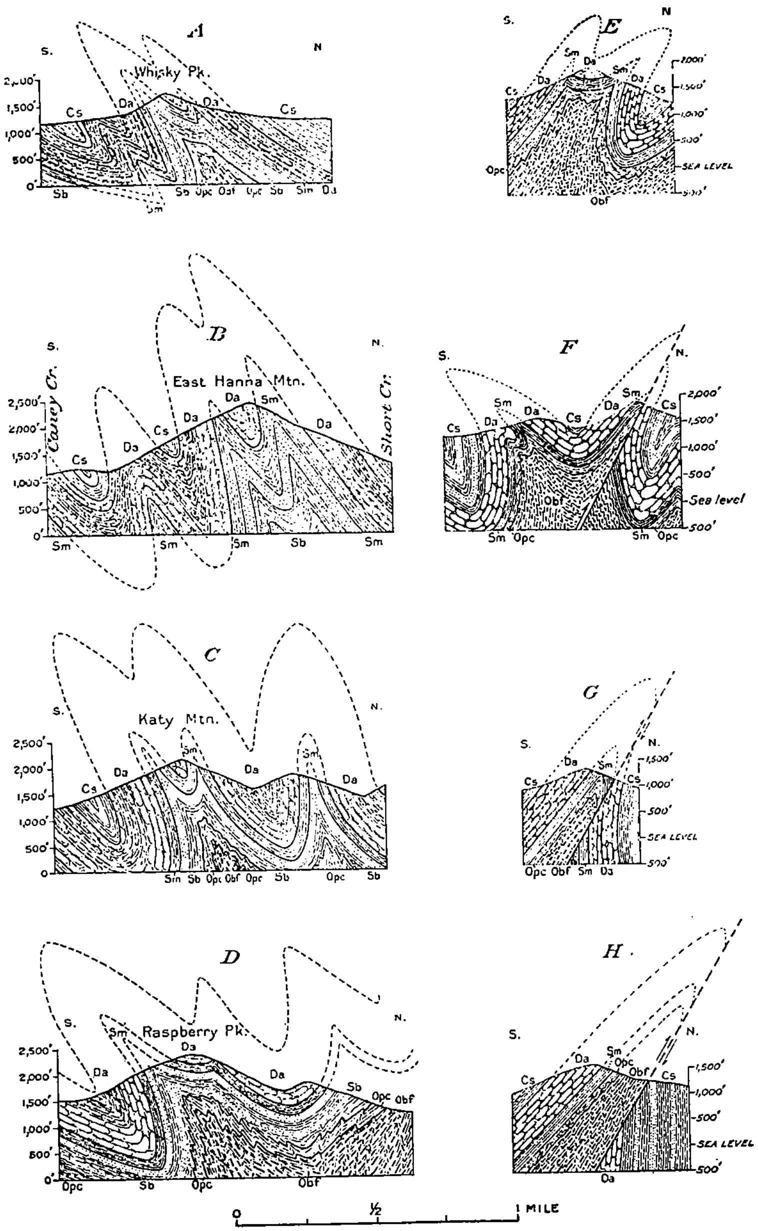


Figure 2
(See explanation, bottom page 13)

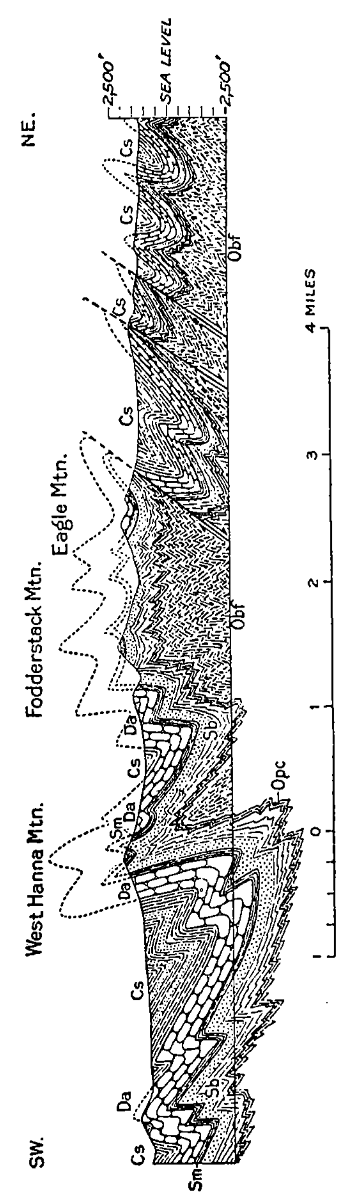


Figure 3.—Structure section through several mountain ridges near Shady, DeQueen quadrangle, Arkansas. Shows a fan-shaped arrangement of folds. (After Miser and Purdue, U. S. Geol. Survey Bull. 808.) **Cs**, Stanley shale; **Da**, Arkansas novaculite; **Sm**, Missouri Mountain slate; **Sb**, Blaylock sandstone; **Opc**, Polk Creek shale; **Obf**, Bigfork chert.

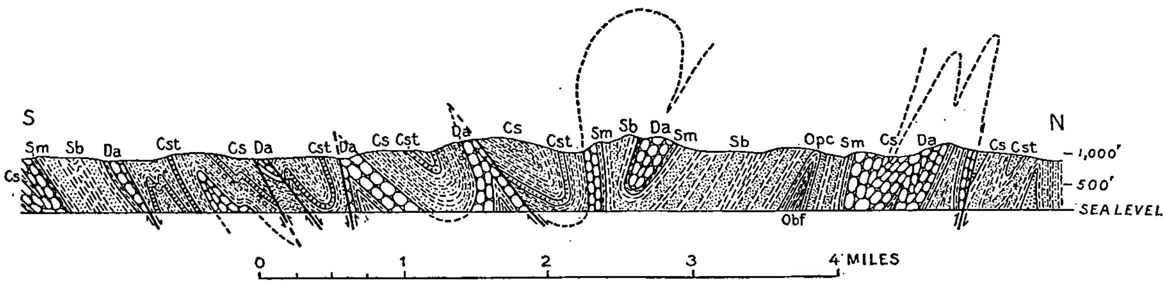


Figure 4.—Structure section across several mountain ridges in northern McCurtain County, Okla. Shows fan-shaped arrangement of folds. (After Honess, Oklahoma Geol. Survey Bull. 32.)

Cs, Stanley shale; **Cst,** Tuff near base of Stanley shale; **Da,** Arkansas novaculite; **Sm,** Missouri Mountain shale; **Sb,** Blaylock sandstone; **Opc,** Polk Creek shale; **Obf,** Bigfork chert.

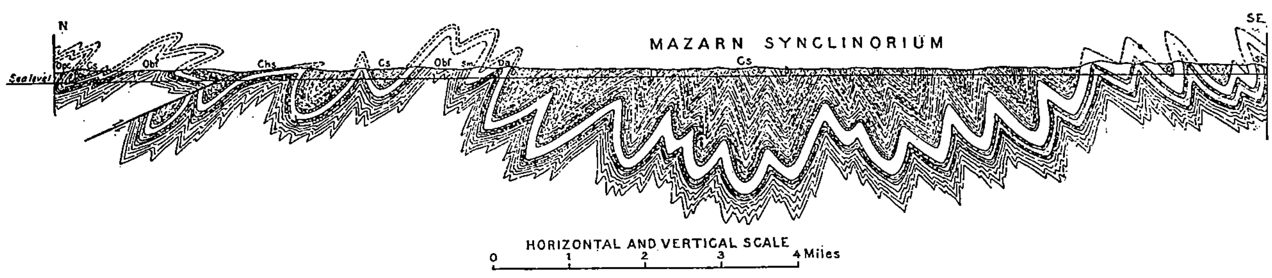


Figure 5.—Structure section across part of the Hot Springs district, Ark., showing the overturning of the folds of two anticlinoria toward the Mazarn synclinorium. [After Purdue and Miser, U. S. Geol. Survey Geol. Altas, Hot Springs foilo (No. 215).]

Cs, Stanley shale; **Chs,** Hot Springs sandstone; **Da,** Arkansas novaculite; **Sm,** Missouri Mountain shale; **Sb,** Blaylock sandstone; **Opc,** Polk Creek shale; **Obf,** Bigfork chert.

FAULTS

The comparatively few faults in Arkansas are all of the thrust type. Most of them have been produced by the breaking of strata in closely compressed anticlines. The planes of some faults dip toward the north and of others toward the south, in conformity with the dip of the axial plane of each anticline that has been broken.

In Oklahoma there are many long parallel thrust faults. They break all the strata from Cambrian to Carboniferous, but most of them involve for long distances at the surface only the Carboniferous rocks—the Stanley shale, Jackfork sandstone, Caney shale, Wapanucka limestone, and Atoka formation. The longest faults are named on the structural and geologic maps (pls. I and II). The Choctaw fault, along the northwest margin of the Ouachita Mountains, has a length of 125 miles and extends a short distance into Arkansas. The Windingstair fault, 110 miles in length, also extends a short distance into Arkansas. The Windingstair and Ti Valley faults may merge with the Choctaw fault near the west end of the Ouachita Mountain region, as suggested by their westward convergence near the west end of the Ouachita Mountains. See pls. I and II.

The Choctaw fault and several others pass out of sight where they reach the edge of the Coastal Plain in Oklahoma. Their full length is therefore not known, but they surely extend southwestward many miles underneath the Cretaceous strata. The possible position of the Choctaw fault underneath the Coastal Plain for a distance of 10 miles southwest of Atoka, Oklahoma, is shown on Plate II. This position is apparently determined from the log of the Hansen, et al., well,[26] in the SE.¼ NW.¼ sec. 17, T. 4 S., R. 11 E., which did not penetrate rocks of the Ouachita Mountain facies but instead encountered rocks of the Arbuckle Mountain facies from comparatively shallow depths to the bottom of the hole.

The usually accepted idea is that the planes of the major faults of the Ouachita Mountains have steep dips—say between 30° and 90°. But low-angle thrust planes are present, as shown by the window in the Potato Hills, near Talihina, Okla., discovered in the course of field work in 1927. Rocks of Ordovician, Silurian, and Devonian age have there been thrust northward over the Stanley shale (Carboniferous) as well as over older rocks. See fig. 6. I interpret this fault as

26. Honess, C. W., Geology of Atoka, Pushmataha, McCurtain, Bryan, and Choctaw counties, Oklahoma: Oklahoma Geol. Survey Bull. 40-B, p. 28, 1927.

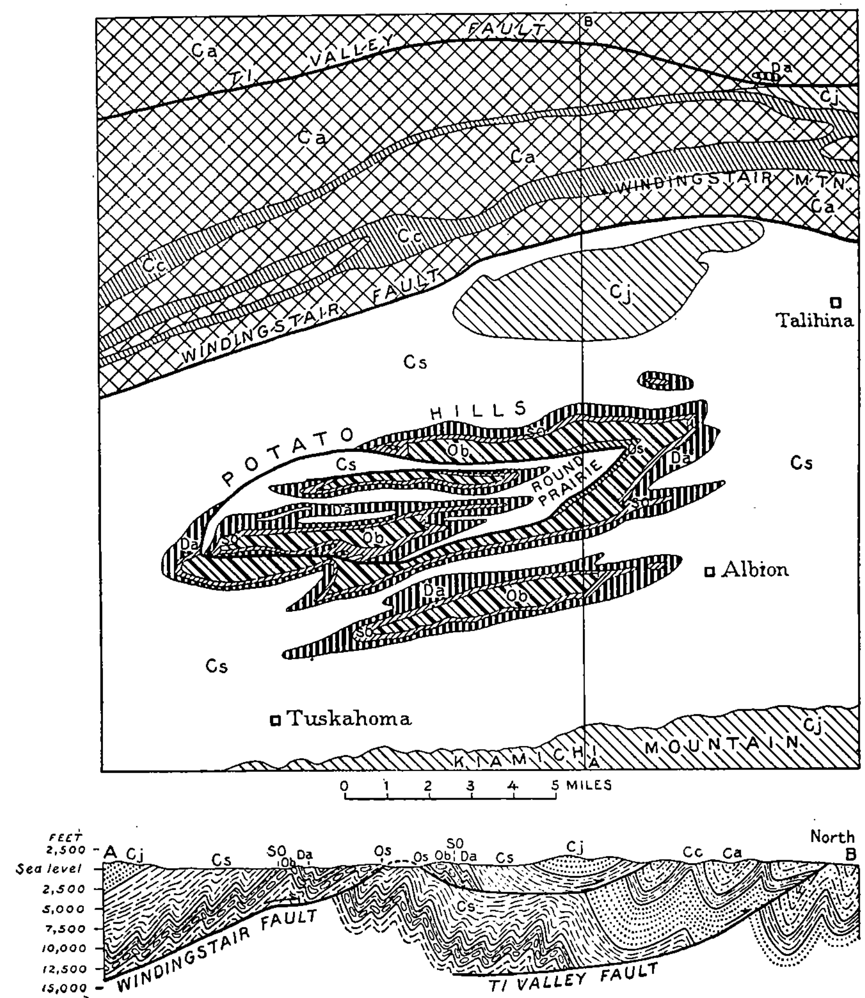


Figure 6.—Geologic map and structure section of the Potato Hills and adjacent areas in southeastern Oklahoma. Section illustrates the folded character of the Windingstair fault.

Horizontal scale of section is same as scale of map.

Ca, Atoka formation (Carboniferous); **Cc,** Caney shale (Carboniferous); **Cj,** Jackfork sandstone (Carboniferous); **Cs,** Stanley shale (Carboniferous); **Da,** Arkansas novaculite (Devonian and Devonian?); **SO,** Missouri Mountain shale (Silurian) and Polk Creek shale (Ordovician); **Ob,** Bigfork chert (Ordovician); **Os,** Stringtown shale (Ordovician).

an outcropping edge of the Windingstair fault plane which finally comes to the surface at the south base of Windingstair Mountain, 3 miles north of the Potato Hills. The actual horizontal displacement by the fault is therefore at least 3 miles. The total apparent known extent of the fault plane from Windingstair Mountain into the Potato Hills is 6 miles. The fault plane in the Potato Hills is somewhat folded and eroded, as represented in the section (fig. 6). The discovery of this window not only leads to the obvious conclusion that low-angle thrusts exist in the Ouachita Mountains, but it establishes as a fact the suggestion of Powers[27] that the major parallel faults in the region bound thin slices of the earth's crust. Such a slice is represented in the section (fig. 6); it is bounded above by the Windingstair fault and below by the Ti Valley fault.

The Boktukola fault, also in Oklahoma, cuts across a syncline. The horizontal displacement, as shown by the strike of the beds in the syncline, is at least five miles and may be as much as 8 miles. See fig. 7. The synclinal axis designated as *B* in figure 7 may be an offset portion of the synclinal axis *A*. The distance between the axis *B* and the westward projection of *A* is 5 miles. On the other hand, the Jackfork sandstone on the south side of the synclinal axis *A* may be thrust northward beyond the point *C* on the Boktukola fault. The distance from *C* to point *D*, which is on the southern boundary of the westward projection of the belt of Jackfork sandstone south of the axis *A*, is 8 miles.

27. Powers, Sidney, Age of Folding of the Oklahoma Mountains: Geol. Soc. America Bull., vol. 39, pp. 1031-1072, 1929.

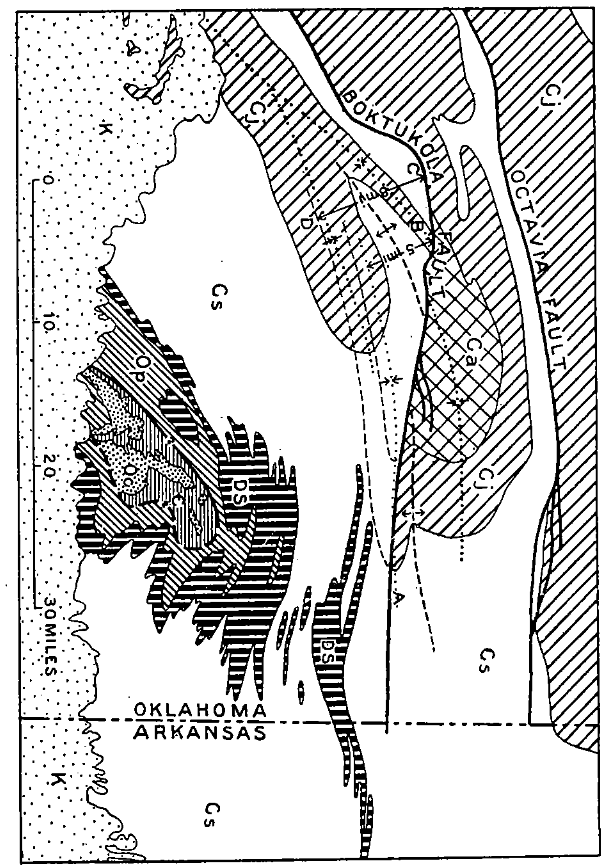


Figure 7.—Geologic map of part of southeastern Oklahoma, showing possible window in the pre-Carboniferous rocks. The apparent window is surrounded by a fault that may be a southward continuation of the plane of the Boktukola fault.

K, Cretaceous; **Ca,** Atoka formation (Carboniferous); **Cj,** Jackfork sandstone (Carboniferous); **Cs,** Stanley shale (Carboniferous); **DS,** Arkansas novaculite (Devonian), Missouri Mountain shale and Blaylock sandstone (Silurian); **Op,** Polk Creek shale, Bigfork chert, Womble schistose sandstone, Blakely sandstone, and Mazarn shale (Ordovician); **Oc,** Crystal Mountain sandstone (Ordovician?); **C,** Collier shale (Cambrian).

Recent mapping by Honess[28] in McCurtain County, Okla., southeast of the Boktukola fault has revealed some puzzling stratigraphic relations. He not only shows faults around much of the central portion of the pre-Carboniferous area, but also shows that the Cambrian and Ordovician strata in the central area do not partake of the folds of the rocks that surround the central area.

When we keep in mind the fact that the Windingstair fault has a slightly folded low-angle plane, may we not conclude that the Boktukola fault has such a plane? At any rate, the peculiar structural relations of the central core of old rocks in McCurtain County can apparently be explained by the assumption that the core area is a window through the overthrust mass of the Boktukola fault. If such an explanation is adopted, then the origin of the numerous normal faults in this part of Oklahoma described by Honess can be readily explained. Normal faults do not occur elsewhere in the Ouachita Mountains. All the normal faults that are described by Honess occur in the apparent overthrust mass of the Boktukola fault. The overthrust mass is a relatively thin slice of the earth's crust, and the breaking of the slice during its thrusting and flexing would have produced normal faults, as well as thrust faults.

STRUCTURE SECTIONS ACROSS ARKANSAS AND OKLAHOMA, AND DIRECTION OF COMPRESSIVE FORCES

Two parallel sections, 65 miles apart, that run northward from the Coastal Plain across the Ouachita Mountains and Arkansas Valley to the Boston Mountains of the Ozark region are given in Plate III to illustrate the structural relations of the Ouachita Mountains. Each section is about 125 miles long. Section *A* crosses eastern Oklahoma, and section *B* western Arkansas. In the southern Ozark region the strata lie nearly horizontal and are underlain at shallow depths by pre-Cambrian igneous rocks, as is indicated by drill holes 2,000 to 2,500 feet in depth[29] and by an exposure on Spavinaw Creek, Okla.[30] South of the Ozark region folds in the strata appear, and across the Arkansas Valley and

28. Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32. 1923.
29. Gould, C. N., Crystalline rocks of the plains: Geol. Soc. America Bull., vol. 34, p. 556, 1923.
Greene, F. C., Granite wells in the northern Mid-Continent region: Am. Assoc. Petroleum Geologists Bull., vol. 9, pp. 351-352, 1925.
Miser, H. D., and Ross, C. S., Pre-Cambrian rhyolite discovered in well in northwestern Arkansas: Am. Assoc. Petroleum Geologists Bull., vol. 9, p. 1115, 1925.
Croneis, Carey, Oil and gas possibilities of the Arkansas Ozarks: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 283, 287-288, 1927.
30. Miser, H. D., Geologic map of Oklahoma, U. S. Geol. Survey, 1926.

Ouachita Mountains they become higher and higher and also more and more closely compressed. The increasing intensity of the folding in this direction indicates clearly that the compressive movements that deformed the rocks in the Ouachita Mountains and Arkansas Valley came from the south. This direction of the compressive movements is also indicated by the southerly dip of the major overthrusts of the Ouachita Monutains. The compressive movements thus came from the direction of Llanoris, the ancient Paleozoic land mass of Louisiana and eastern Texas.

The belts of rock outcrop, the faults, and also the axes of the folds in the Oklahoma portion of the Ouachita Mountains reveal an arcuate arrangement. See pls. I and II. Such an arrangement suggests to me that the source of the compressive forces was not due south of the Ouachita region, but more nearly south-southeast of it. The Stanley shale, 6,000 to 10,000 feet thick, apparently derived its clastic sediments from a land mass to the southeast or south-southeast of the Ouachita region. Thick beds of sandstone appear in the shale in this direction. From the present evidence the clastic sediment of the other rock formations of the Ouachita Mountains had simply a southerly source—whether due south, southeast, or southwest I do not know.

Normal faults occur in the Boston Mountains and in the adjoining part of the Arkansas Valley, but thrust faults break the strata farther south in some areas of intense folding. The thrust faults of Oklahoma, as they are represented in section *A* of Plate III, appear to bound thin slices of the earth's crust. The long folded fault plane in the section is the plane of the Boktukola fault.

STRUCTURAL SALIENT IN OKLAHOMA

A structural salient with an arcuate north front occurs in the Ouachita Mountains in Oklahoma and projects northward beyond the westward projection of the frontal axial trends in Arkansas. A portion of the salient reaches into western Arkansas There is not only an arcuate arrangement of the belts of rock exposures, of the faults, and of axes of folds along the frontal margin of the salient, but there is also such an arrangement farther south in the salient. The presence of the salient is brought out clearly by both the structure and geologic maps of the Ouachita Mountains (pls. I and II). Its presence leads to the following conclusions:

1. The earth's crust in the Oklahoma portion of the mountains has been shortened more than in the Arkansas portion. The amount of crustal shortening in Arkansas was about 50 miles; in Oklahoma it was perhaps at least 20 miles greater.

2. The forces producing the shortening were so intense that the rocks broke along numerous parallel faults. Many of the faults involve rocks that are no more competent or resistant than those in Arkansas, where faults are relatively few. But some of the faults involve as much as 12,000 feet of massive sandstone in a continuous succession. It is almost inconceivable that so thick a succession of competent rocks could be deformed without faulting.

3. The rocks of the Ouachita Mountains have been moved in a northerly direction past the east end of the Arbuckle Mountains. The massive competent rocks of the Arbuckle Mountains probably acted as a buttress past which the Ouachita rocks moved northward during the profound deformation of the rocks and the consequent shortening of the earth's crust. The east end of the Arbuckle Mountains is, in fact, only about 12 miles from the west end of the Ouachita Mountains. The rock facies of the two mountain regions, so close to one another, are strikingly diverse. This fact, when considered in connection with the structural salient in the Oklahoma part of the Ouachita Mountains, suggests, as has been pointed out by Dake.[31] that the Ouachita rock section has been thrust a long distance over rocks of the Arbuckle Mountain facies. How great the distance of thrusting is we do not know. A measure of the northward thrusting in the salient may possibly be obtained by determining the distance from the front of the salient to a projected line that represents a west-southwesterly continuation of the structural axes which pass through the region immediately north of Mount Ida, Ark. Such a continuation of these axes would pass through or near the village of Eubanks, Okla. The distance from the front of the salient to Eubanks is about 20 miles.

This supposed amount of thrusting of the Ouachita Mountain facies over the Arbuckle Mountain facies is borne out by the distribution of the asphalt deposits of the Ouachita Mountains of Oklahoma. The oil yielding these deposits apparently did not come from the Ouachita Mountain facies.

31. Dake, C. L., The problem of the St. Peter sandstone: Missouri Univ. School of Mines and Metallurgy Bull., vol. 6, no. 1, p. 55, 1921.

It is believed by Honess[32] and me, as well as by other geologists, to have originated in deeply concealed rocks of the Arbuckle Mountain facies and to have migrated up toward the surface to form the asphalt. The asphalt deposits are found as far as 20 miles southeast of the boundary of the Ouachita Mountain facies.

Oklahoma salient, in its form and in the extensive faulting of the rocks, resembles strikingly the four salients of the Appalachian region described by Keith[33] as lying adjacent to and northwest of a large group of granite batholiths. This resemblence suggests the hypothesis that an area of concealed batholiths lies underneath the Coastal Plain, in a southerly direction from the Oklahoma salient. The intrusion of the batholiths adjacent to the Appalachian salients is placed in Carboniferous time by Keith and is held by him to have produced the salients. The Carboniferous age assignment of some of the batholiths opposite salients in the Appalachian region, however, as well as the manner of the formation of the salients, has been questioned by A. I. Jonas.[34] But nevertheless it appears to me that a significant relation of some kind exists between the Appalachian salients and their associated batholiths.

BOUNDARY BETWEEN OUACHITA AND ARBUCKLE MOUNTAIN FACIES OF ROCKS

The Choctaw fault is usually designated as the northwest boundary of the Ouachita Mountains, but a fault that runs through Ti Valley appears, as noted by Ulrich[35] and Powers,[36] to mark the northwest boundary of the Ouachita Mountain facies of rocks. On its north side the exposed rock strata are more nearly like those of the Arbuckle Mountains, whereas on the south side the exposed rocks are different in both lithology and fossil content. Only three rock formations are common to the two facies, the Woodford chert (Devonian?), Caney shale (Mississippian and Pennsylvanian), and Atoka formation (Pennsylvanian). In the Ouachita area the Woodford is represented in the upper part of the Arkansas novaculite.

32. Honess, C. W., Geology of Atoka, Pushmataha, McCurtain, Bryan, and Choctaw Counties, Oklahoma: Oklahoma Geol. Survey Bull. 40-R, pp. 26-27, 1927.

33. Keith, Arthur, Outlines of Appalachian structure: Geol. Soc. America Bull., vol. 34, pp. 309-380, 1923. Also, Structural symmetry in North America: Geol. Soc. America Bull., vol. 39, pp. 321-386, 1928.

34. Paper read before Geological Society of Washington, January, 1929.

35. Ulrich, E. O., Fossiliferous boulders in the Ouachita "Caney" shale and the age of the shale containing them: Oklahoma Geol. Survey Bull. 45, p. 26, 1927.

36. Powers, Sidney, Age of folding of the Oklahoma Mountains: Geol. Soc. America Bull., vol. 39, pp. 1031-1072, 1928.

TIME OF DEFORMATION

The 25,000 feet of exposed strata of Paleozoic age in the Ouachita Mountains were subjected to great compressive movements during the middle or later part of the Pennsylvanian epoch. They were, however, warped at earlier times during the Paleozoic era. Erosion, together with this warping, has produced angular unconformities in the sequence. The most conspicuous unconformity of this kind occurs at places in Arkansas at the base of the Stanley shale (Carboniferous) or at the base of the subjacent Hot Springs sandstone (Carboniferous) wherever that is present. There is not only a basal conglomerate as much as 30 feet thick, but all the Devonian, Silurian, and Ordovician rocks down to the Bigfork chert (Middle Ordovician) are absent because of erosion.

The Hot Springs sandstone and Stanley shale are regarded by most if not all geologists as of Mississippian age. The deposition of these two formations was accompanied by a more or less gradual sinking of the area of accumulation, and this sinking continued with perhaps minor intervals of erosion until some time in the Pennsylvanian epoch. While this subsidence was going on the sediments for the Stanley, Jackfork, and Atoka formations, aggregating about 18,000 feet in thickness, were laid down in the region of the present Ouachita Mountains. Thinner formations were deposited here and there, but the three formations just named were uniformly spread over most of the region. I conjecture that deposition was rapid, because so great a thickness of sediments was accumulated. However that may be, the Ouachita geosyncline and its pre-Carboniferous rocks were downwarped more than 3½ miles during the Mississippian and Pennsylvanian epochs.

The youngest rocks (Atoka formation) in the Ouachita Mountains are of Pottsville age. There are succeeded northward in the Arkansas Valley by other Pottsville rocks (Hartshorne sandstone), and these in turn by rocks of Allegheny age (McAlester shale, Savanna sandstone, and Boggy shale, the oldest named first). So far as determined, the Hartshorne and McAlester formations contain no unconformities, and the Hartshorne is conformable with the underlying Atoka formation. The oldest rocks exposed south of the Ouachita Mountains are of Lower Cretaceous age. They have a low southerly dip and rest upon the smoothly truncated edges of the Paleozoic strata along the full length of the south side of the Ouachita Mountains.

From such unconformable relations it is obvious that the close folding and faulting of the rocks of the mountain region took place prior to Cretaceous time. There is thus no structural or stratigraphic evidence in the Ouachita Mountains for dating the period of profound deformation of the rock strata more closely than the interval between Allegheny and lower Cretaceous time.

The uplift, folding, and faulting in the Ouachita Mountain and Arkansas Valley regions were, however, probably contemporaneous, at least in part, with extensive movements of a like nature in the Arbuckle Mountains, in southern Oklahoma, which according to Morgan,[37] took place at four different times during the Pennsylvanian epoch—namely, near the end of the Atoka time (late Pottsville), near the end of the Savanna time (Allegheny), a little before the end of Wewoka time (middle Pennsylvanian), and near the end of Vamoosa time (late Pennsylvanian). I am inclined to agree with Honess[38] that the close folding and extensive faulting of the rocks of the Ouachita Mountains occurred near the middle of the Pennsylvanian epoch. Since there is a probability that the massive competent rocks of the Arbuckle Mountains acted as a buttress past which the Ouachita rocks moved northward, it appears that some mountain building movements took place in the Arbuckles prior to the profound deformation in the Ouachitas.

ERRATIC BOULDERS IN CANEY SHALE

Erratic boulders that occur in the Caney shale (Carboniferous) of the Ouachita Mountains present puzzling problems with reference to the paleogeography of the Ouachita and adjoining regions, and they also suggest interesting speculations with reference to the structural history of the Ouachita Mountains. The boulder deposits have been briefly described by Taff,[39] Woodworth,[40] and me[41] and more fully by

37. Morgan, G. D., Geology of the Stonewall quadrangle, Oklahohma: Bur. Geology Bull. 2, pp. 19-21, Norman, Okla., 1924.
38. Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, p. 259, 1923.
39. Taff, J. A., Some erratic boulders in middle Carboniferous shale in Indian Territory [abstract]: Science, new ser., vol. 21, p. 225, 1905; Ice-borne boulder deposits in mid-Carboniferous marine shales [abstract]: Science, new ser., vol. 29, p. 637, 1909; Geol. Soc. America Bull., vol. 20, pp. 701-702, 1910.
40. Woodworth, J. B., Boulder beds of the Caney shale at Talihina, Okla.: Geol. Soc. America Bull., vol. 23, pp. 457-462, 1912; abstract, Science, new ser., vol. 35, p. 319, 1912.
41. Miser, H. D., in Miser, H. D., and Honess, C. W., Age relations of the Carboniferous rocks of the Ouachita Mountains of Oklahoma and Arkansas: Oklahoma Geol. Survey Bull. 44, footnote on pp. 22 and 23, 1927.

Ulrich[42] and Powers.[43]

It is not my purpose to describe fully at this time the boulder deposits nor to set forth their origin at length, though I shall discuss certain ideas of their origin that have a bearing on the structural history of the Ouachita Mountains.

The boulders do not occur in ordinary gravel or boulder beds, such as coarse conglomerate, but they are irregularly scattered through a marine Carboniferous shale (Caney shale) like plums in a pudding. Most of the boulders are thus separated from one another by shale. They are of many sizes; some are pebbles a fraction of an inch in diameter; many measure 10 feet in their longest dimension; several observed blocks measure 30 feet in length; some measure as much as 200 feet; and one 369 feet.[44] Also there are different kinds of rock—a little flint, some sandstone, and many kinds of limestone—but boulders and blocks of limestone are most numerous. Each boulder that contains fossils has a distinctive fauna. The many faunas that are represented by collections from boulders at numerous localities have been demonstrated by Ulrich[45] to range in age from Ordovician to Carboniferous. The faunas are also shown by Ulrich to be the same or similar to the faunas of the exposed rocks of the Arbuckle Mountains.

In my opinion the boulders were transported by floating ice. To be sure, the transportation of a mass of rock whose revealed dimensions are 369 feet in length and 50 feet in thickness would require a large iceberg many hundreds of feet in its several dimensions. Furthermore, the large size of the icebergs and their acquisition of such huge masses of rock suggest valley glaciation in a region of tilted rocks with valleys perhaps several thousand feet in depth. Taff[46] has expressed the opinion that the boulders were transported by ice from "a range or group of mountains in the region now occupied by southern Indian Territory [Okahoma] and northern Texas." Woodworth[47] agreed with Taff's conclusion that the boulders were transported by ice. Ulrich[48] has attributed the origin of the boulders "to occasional transportation and indiscriminate droppings of loose surface rock embedded in drifting and melting land or shore ice" has expressed the opinion that the source of most of them was the Arbuckle Mountains. Powers[49] suggests they may have come from mountains that he postulates as having once occupied the present west end of the Ouachita region. The rocks of this mountain area are supposed by him to be similar in lithology and fossil content to the rocks of the Arbuckle Mountains. He discusses the pros and cons of their transportation by ice and also the suggestion that the boulders may be small remnants of thin sheets that were overthrust from the north. He, like me, finds apparently fatal objections to the overthrust idea.

42. Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, p. 352, footnote, 1911; Fossiliferous boulders in the Ouachita "Caney" shale and the age of the shale containing them: Oklahoma Geol. Survey Bull. 45, 1927.

43. Powers, Sidney, Age of folding of the Oklahoma Mountains: Geol. Soc. America Bull. vol. 39, pp. 1031-1072, 1928.

44. These measurements were obtained by me as the result of four separate visits to Johns Valley. During the last visit in March, 1929, I reviewed all my own measurements and also those reported by Charles Miller of the Oklahoma Geological Survey. There may be larger limstone masses than are indicated by the above dimensions but their presence is not indicated to me, because of poor and discontinuous exposures.

45. Ulrich, E. O., Fossiliferous boulders in the Ouachita "Caney" shale and the age of the shall containing them: Oklahoma Geol. Survey Bull. 45, 1927.

46. Taff, J. A., Science, new ser., vol. 21, p. 225, 1905.

The boulders are all confined to the Caney shale and are present in both the Mississippian and Pennsylvanian portions of the formation. They thus occur at definite stratigraphic horizons. Furthermore, they are present only where the Caney lies between the Jackfork sandstone and Atoka formation, each 6,000 feet in thickness. If the boulders are remnants of overthrust sheets of massive limestone the Caney shale would have provided a good gliding plane for the overthrust sheets. The thrust faulting must have taken place in the Carboniferous period before Atoka time in order to permit erosion to remove the thrust sheets almost completely before that time. Surely such extensive erosion would have spread thick beds of limestone conglomerate in the Atoka in some other parts of the Ouachita region. As a matter of fact, very little conglomerate is found anywhere in the Atoka.

The postulated faults that would be required to overthrust one or more sheets of limestone during the Carboniferous would of necessity have had to cut through the Stanley shale and Jackfork sandstone if they came from the south. There is, however, no evidence that such thrusting took place. If there were such thrusts there should be some areas of limestone that cut across the Stanley shale and Jackfolk sandstone, but no such areas are revealed anywhere in the Ouachita Mountains. Furthermore, rocks of the Arbuckle Mountain facies could not have been thrust from the south, because

47. Woodworth, J. B., Science, new ser., vol. 35, p. 319, 1912.

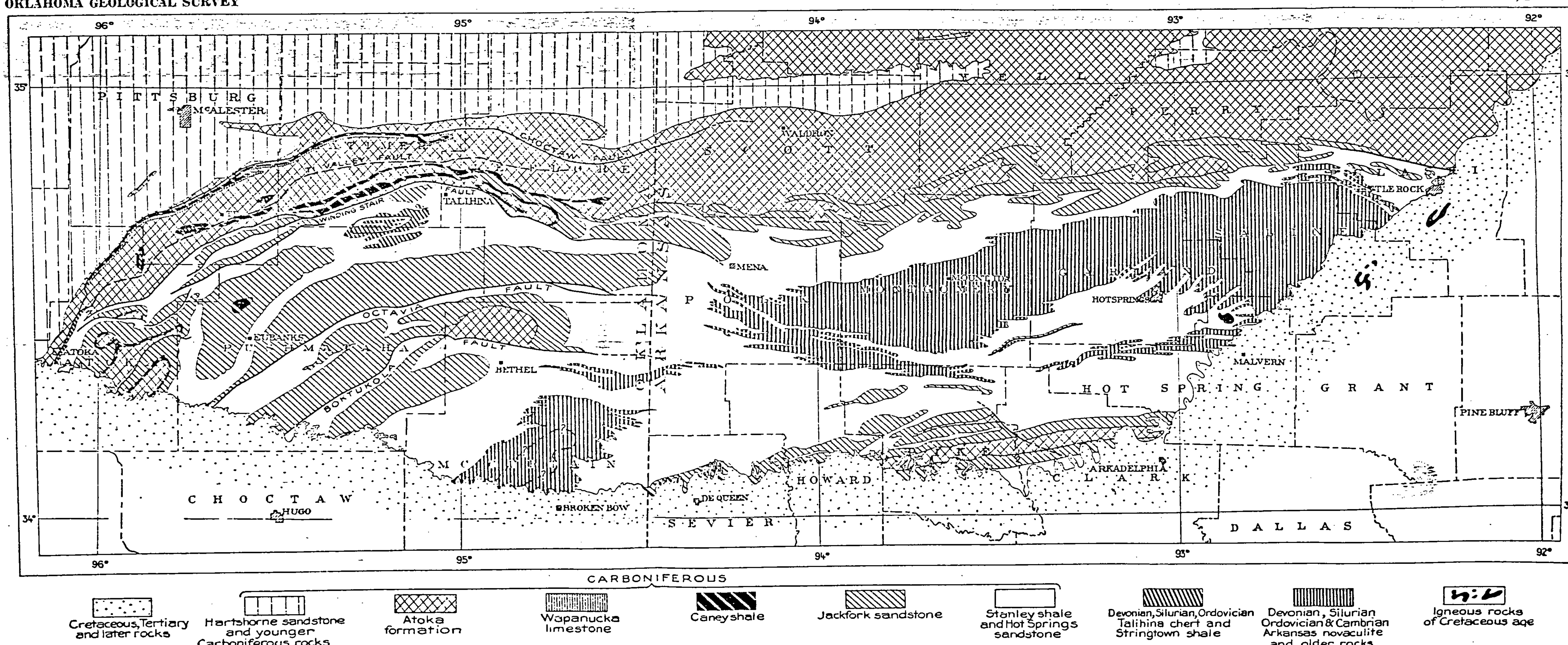
48. Ulrich, E. O., Oklahoma Geol. Survey Bull. 45, 1927.

49. Powers, Sidney, Age of folding of the Oklahoma Mountains: Geol. Soc. America Bull., vol. 39, pp. 1031-1072, 1928.

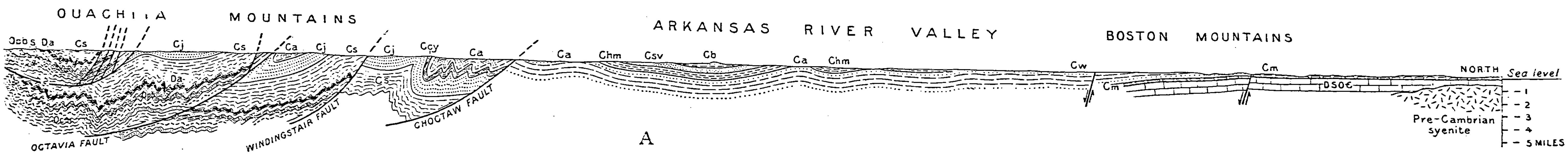
(1) the ancient land Llanoris, the source of the clastic sediments for the entire Paleozoic succession of the Ouachita Mountains, lay in that direction, and because (2) the Ouachita Mountain facies of rocks would have extended continuously from the present Ouachita region to Llanoris.

The only direction from which rocks of the Arbuckle Mountain facies could have been thrust during Carboniferous time is from the north. There is, however, no evidence of such thrust sheets from this direction unless it consists in the boulders themselves. I am at present unable to comprehend any mechanics of mountain building that would produce great thrusts from the interior of the North American continent toward its southern margin and later produce similarly great thrusts overriding toward the interior of the continent.

My present opinion is that the erratic boulders in the Caney were transported by icebergs from some mountainous area that was undergoing alpine glaciation. I believe also that the mountainous area lay south of the present Arbuckle Mountains and that it occupied parts of southern Oklahoma and northern Texas. The relations of the Carboniferous and pre-Carboniferous rocks of the Arbuckle Mountains, as they have been worked out in the field in recent years by Morgan and other geologists, are such as to indicate that Paleozoic mountain building did not take place there until after Caney time. The first such movement there took place near the end of Atoka time, which was after Caney time. Perhaps further study will demonstrate that the boulders are not ice-borne, but the preponderance of present evidence is in favor of ice transportation.

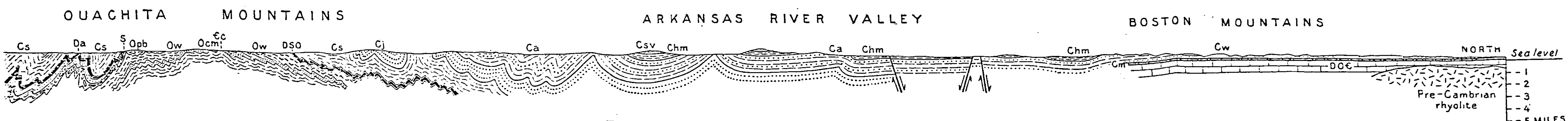


Geologic Map of the Ouachita Mountains of Oklahoma and Arkansas



A

SECTION ACROSS EASTERN OKLAHOMA



B

SECTION ACROSS WESTERN ARKANSAS

VERTICAL AND HORIZONTAL SCALES

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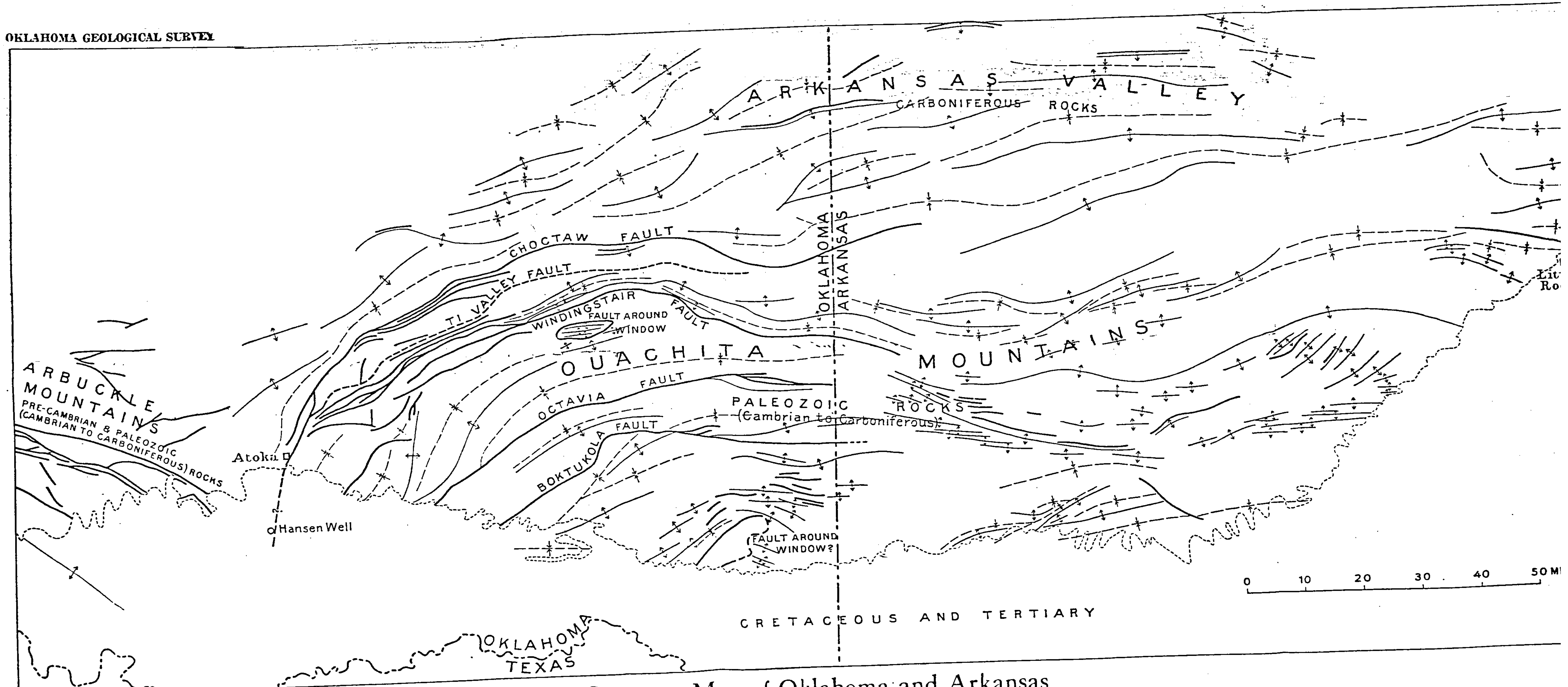

Structure Map of Oklahoma and Arkansas