

THE ORIGIN AND AGE OF THE BOULDER-BEARING
JOHNS VALLEY SHALE IN THE OUACHITA MOUN-
TAINS OF ARKANSAS AND OKLAHOMA.

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The Johns Valley shale is a dark clayey shale, locally some 1,000 to 1,500 feet in thickness, that occurs in the upper part of the geologic section of the northern and western Ouachita Mountains in west central Arkansas and southeastern Oklahoma. Its most distinctive character is the occurrence of numerous large and small boulders distributed irregularly through the shale. Since the boulders are identifiable as having been derived from fossiliferous Early, Middle and Late Paleozoic formations that are foreign to the Ouachita stratigraphic section and since some of the boulders have a maximum diameter measured in hundreds of feet, the origin of the Johns Valley beds is an exceptionally interesting problem. The age of the boulder-bearing shale is likewise a subject that has given rise to much discussion, for some evidence seems to indicate definitely a Late Mississippian age while other evidence quite as definitely supports the conclusion that the deposit is of Early Pennsylvanian age. Study of the Johns Valley shale has importance, therefore, not only because it is an unusual type of sedimentary deposit but because determination of the origin and age of the formation is believed to have bearing on the location of the Mississippian-Pennsylvanian boundary.

My first field study of the Johns Valley boulders was made in the summer of 1927 in company with H. D. Miser of the U. S. Geological Survey. During part of the time then spent outcrops in Johns Valley, north of Antlers, and Compton Cut, north of Talihina, both in Oklahoma, were visited with H. D. Miser, Sidney Powers, C. W. Tomlinson, C. N. Gould and C. L. Cooper. Papers describing the boulders and discussing their origin had previously been published (as noted in the appended bibliography) by Taff (11, 12), Woodworth (19) and Ulrich (14). Subsequent to 1927, contributions to study of the problem have been written by Miser (8, 9), Powers (10), Van der Gracht (15-17), Harlton (5) and more incidentally by others. In August, 1932, Mr. Miser and I revisited Johns Valley and spent two days studying the numerous scattered boulders and outcrops of boulder-bearing

shale that had recently been discovered near Boles, Scott County, Arkansas. Special acknowledgment and appreciation are due to Mr. Miser for this assistance. On various occasions I have discussed the boulder problem with Miser, Powers, Harlton, Tomlinson, Ulrich, and A. I. Levorsen, and I express thanks to them for aid in the study. Until recently, however, I have not been able to formulate an explanation that seemed to me to fit reasonably with field observations.

THE JOHNS VALLEY SHALE.

The Johns Valley shale was named in 1927 by Ulrich (14, p. 21). The shale in Johns Valley (Ts. 1 N. and 1 S., R. 16 E., Oklahoma) and equivalent outcrops in the Ouachita Mountains area had previously been called Caney and for some time had been regarded as equivalent to the fossil-bearing marine shale of Late Mississippian age, likewise called Caney, on the north and south flanks of the Arbuckle Mountains. Fossils exactly like those of the Arbuckle Caney were known to occur commonly in the Ouachita "Caney" shale. The shale of the Arbuckle area, however, was observed to be entirely lacking in erratic boulders while that of the Ouachita region contains them abundantly. Indeed, "Caney" (now called Johns Valley) with boulders occurs in many places just south of the Ti Valley fault that parallels the northwest front of the Ouachitas, whereas on the other side of this fault only a short distance away are outcrops of boulderless Caney of the Arbuckle type. Evidently, the difference in content of boulders is significant but the identity of marine faunas in the two shales seemed certainly to indicate equivalence in age. Ulrich called attention to actual slight differences in the lithology of the shales and concluded that the Caney fossils of the boulder-bearing "Caney" were all reworked (14, p. 19). Like the boulders which had been derived from various older formations, Ulrich interpreted the fossils as having been transported from their original place of burial in Arbuckle Caney shale and redeposited in the younger Ouachita "Caney" shale. Believing that the two shales were entirely different, it naturally became desirable to rename one of them. Since the term Caney was very well known and commonly applied in the Arbuckle section, the new name Johns Valley shale was proposed for the boulder-bearing shale in the Ouachita Mountains. It was regarded by Ulrich as Early Pennsylvanian in age.

General Character and Distribution.—Because of previous publications it is unnecessary to give here a detailed description of lithologic features of the Johns Valley shale. It is sufficient to say that, although dark-grey to almost black like the Caney, the Johns Valley beds are mostly distinguishable on lithologic characters from the Caney. The latter formation is harder, more distinctly and evenly laminated, less unctuous when wet and a little darker in general tone than the Johns Valley shale. Studies by Harlton (5) of the microfaunas

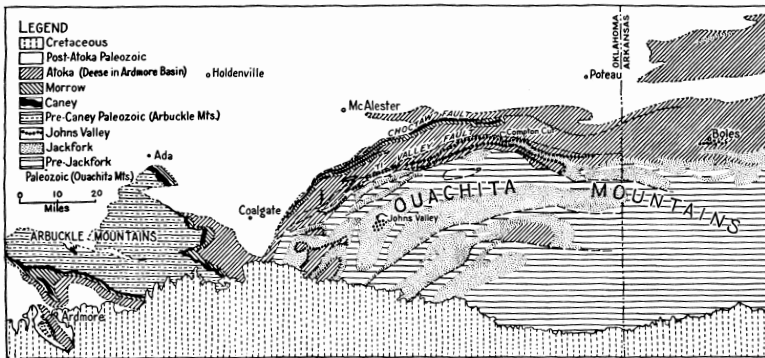


Fig. 1. Map of the Ouachita and Arbuckle region showing distribution of Johns Valley and Caney shales.

from numerous typical Johns Valley outcrops show definite, easily perceptible distinctions in the fossils from this formation and those found in the Caney as restricted. On the other hand, there are exposures of shale in parts of Johns Valley and near Boles, Arkansas, in the Johns Valley outcrop belts, that duplicate in every known feature of lithology and fauna the characters of typical Caney shale of the Arbuckle region. These evidently conflicting observations are responsible for much of the confusion connected with descriptions and interpretations that have been published. The significance of the divergent evidence will be discussed later.

Distribution of the boulder-bearing Johns Valley shale and of the Caney shale is shown in the accompanying map (Fig. 1). The known extent of the deposits along the strike of the outcrop belt from the line of concealment by Cretaceous overlaps on the southwest to the farthest known occurrence on the east, is about 130 miles. The maximum distance from the

outermost to the innermost outcrop belt at right angles to the average strike is about 14 miles, but if shortening due to folding and faulting were removed this maximum distance would probably be expanded to upwards of 20 miles. The exposures of boulder-bearing shale are all located southeast of the Ti Valley fault. For reasons subsequently developed, I would restrict application of the name Johns Valley to this region, excluding belts of dark shale north of the Ti Valley fault that were regarded by Ulrich (14, p. 13) as equivalent to Johns Valley shale.

Stratigraphic and Structural Relations.—In each known occurrence the Johns Valley shale rests with parallel structure, so far as known, on Jackfork sandstone. The latter is a very competent formation, 4,000 to 6,000 feet or more in thickness, consisting of massive beds of quartzitic sandstone separated in places by layers of shale a few tens of feet in thickness (Fig. 2). The Jackfork rests with apparent conformity in turn upon the Stanley shale, 6,000 to 10,000 feet in thickness. The Stanley consists mainly of dark, somewhat greenish shale, but contains many layers of dark-greenish sandstone, the latter increasing in numbers and thickness toward the southeast. The Stanley is a relatively incompetent formation. Scanty and poorly preserved marine fossils and plant fossils that have been collected from the Stanley and Jackfork formations indicate definitely their "Carboniferous" age, but whether either or both belong to Late Mississippian or Early Pennsylvanian time has been entirely unsettled, although there has been a growing tendency to regard the Stanley as Late Mississippian (Chester). Some geologists regard the Jackfork also as Late Mississippian, but others think it may be better interpreted as an initial Pennsylvanian deposit resulting from uplift of the hinterland south of the Ouachita geosyncline. The uplift is thus regarded as forming part of the crustal changes that may be inferred to have terminated Mississippian sedimentation and introduced Pennsylvanian conditions (see Ulrich, 14, p. 23). A review of paleontologic and other evidence on the age of the Stanley and Jackfork formations has been published by Miser and Honess (8).

In most exposures the boulder-bearing Johns Valley shale occurs between Jackfork sandstone, which extends continuously beneath it, and sandstone and shale of the Atoka formation, which continuously overlies it. In the eastern and southern parts of the Ouachita Mountains area, Atoka beds rest

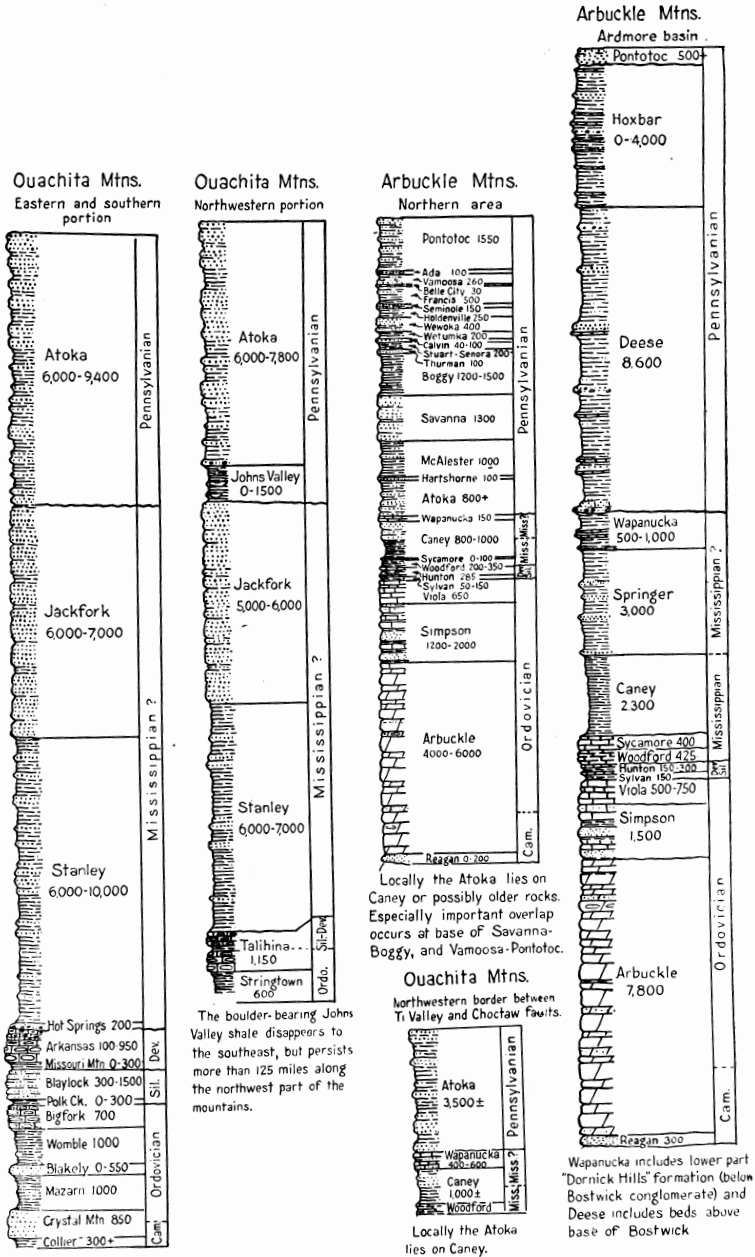


Fig. 2. Generalized sections of rocks in the Ouachita and Arbuckle areas.

directly on Jackfork sandstone, but it is significant that throughout the known area of Johns Valley occurrence along the northwestern margin of the Ouachitas the boulder-bearing shale is found in a constant stratigraphic position between Jackfork and Atoka. This observation is important.

At the type locality in Johns Valley, the boulder-bearing shale occurs in a comparatively broad gentle syncline of elliptical form underlain by Jackfork sandstone which forms a rim surrounding the valley. A small area of Atoka beds in the central part of the syncline is shown on the state geological map of Oklahoma compiled by Miser (1926), but subsequent studies by Miser indicate that the sandstones here found are upper Jackfork which is brought to the surface by minor anticlinal folds in the syncline. Farther south there are similar broad synclinal folds involving Jackfork, Johns Valley and Atoka beds which, however, are intersected by thrust faults that cut across the axes of the synclines. Along the northwestern and northern Ouachita front the Johns Valley and associated rocks are steeply inclined, the outcrops being variously repeated as a result of folds and thrust faults.

Erratic Boulders.—The erratic rock fragments in the Johns Valley shale range in size from small pebbles to masses 369 feet¹ or more in greatest diameter (Miser, 9, p. 28). Most common are boulders of various sorts of limestone, but there are also masses of chert, sandstone and, according to Harlton's (5, p. 5) view and mine, of shale. Some of the limestone and chert boulders are peculiarly scratched, grooved or gouged.

Many of the boulders contain fossils, and it is possible by means of these and by observation of distinctive lithologic features to identify the geologic formations that supplied the boulder material. Ulrich (14, pp. 9-21) has demonstrated that the source beds of the boulders range in age from Cambro-Ordovician (Arbuckle) to so-called Early Pennsylvanian (Wapanucka or Morrow).² Especially common are boulders of Arbuckle and Simpson limestone. These and many other of the boulders correspond so closely to well-known formations of the Arbuckle Mountains area that Ulrich (14, pp. 13, 44) concludes that this region was undoubtedly their source. It is

¹ The record by Powers (10, p. 1043) of a boulder 550 feet in diameter is based on erroneous field determinations by Charles Miller and is not to be credited.

² Miser notes that the Wapanucka-like rocks seen by him in the Ouachitas are in the form of beds or broken beds. This has important bearing on the age of the Johns Valley shale and calls for further study.

certainly significant that the formations represented by the boulders are entirely foreign to the Ouachita geosynclinal area, in which the formations corresponding in age to that of the boulders are entirely different. That the boulders were not actually derived from the existing Arbuckle Mountains area is, however, indicated by absence of Johns Valley type of boulder-bearing shale in any part of the Arbuckle Mountains region, and by the occurrence among the boulders of fos-

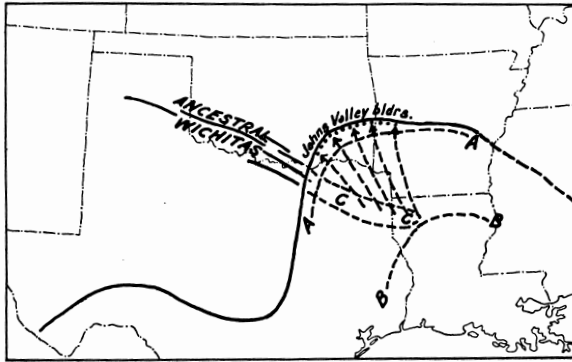


Fig. 3. Sketch map showing relation of the Ouachita geosyncline to the Ancestral Wichita Uplift. The sinuous line extending across the map marks the present front of northwestwardly thrust Ouachita geosynclinal rocks. A-A marks the original northwest border of part of the geosyncline if crustal shortening due to the Ouachita orogeny amounts to about 50-75 miles. B-B marks this original border if the Johns Valley boulders were derived from an overridden southeastward extension of the Ancestral Wichita Mountains, C-C. The arrows indicate assumed movement of the boulders from this source according to the tectonic hypothesis.

siliferous Devonian chert closely resembling the Camden chert of Tennessee, but absent in the Arbuckle Mountains district. As noted by Ulrich (14, p. 19), however, a small outcrop of cherty beds containing this fauna occurs at one locality at the northwest margin of the Ouachita Mountains, just north of the Ti Valley fault. Many of the boulders observed near Boles, Arkansas, resemble units known in the Ozarks more closely than any formations in the Arbuckle Mountains. Among these Ozark-type boulders, Miser has discovered a fossiliferous fragment of Boone (Middle Mississippian) limestone containing fossils. The Boone is entirely unknown in the Arbuckles, but extends an unknown distance southward from the Ozarks toward the Ouachitas.

Under the head of erratic boulders I may now refer to certain outcrops of black shale which are well shown in Johns Valley and near Boles, Arkansas. These outcrops of shale, which appear along small streams, have maximum linear extent of some hundreds of feet, and in one case an exposed height

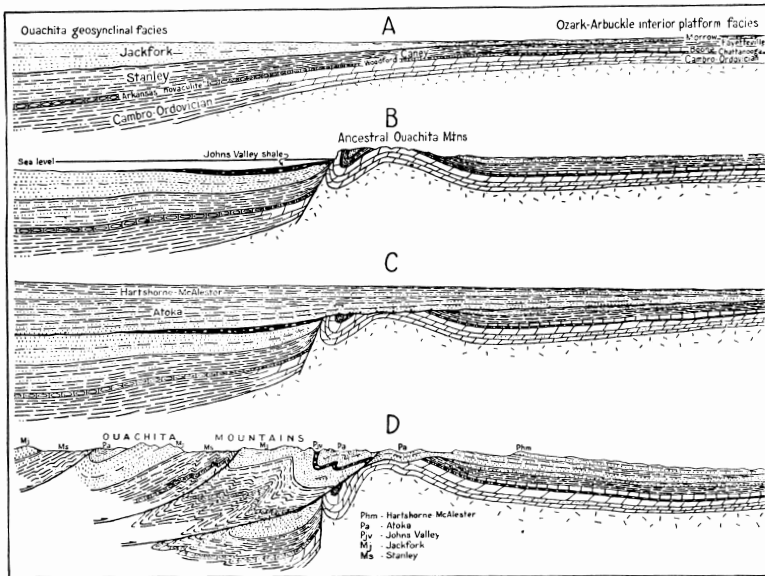


Fig. 4. Diagram showing inferred development of the Ancestral Ouachita Mountains along the northwest border of the Ouachita geosyncline. A. Section of the geosyncline and neighboring foreland near close of Morrow time. B. Same in Johns Valley time, showing hypothetical Ancestral Ouachitas and formation of the boulder-bearing Johns Valley shale which is here classed as basal Pennsylvanian. C. Same in post-McAlester time. The Ancestral Ouachita Uplift is represented as beveled by pre-Atoka and early Atoka erosion and buried by Atoka and younger Pennsylvanian sediments derived from the hinterland south of the geosyncline. D. Diagrammatic representation of present conditions showing formations of the geosynclinal area overthrust on the Ancestral Ouachitas and the foreland.

above the creek of more than 50 feet. The outcrops have commonly been interpreted as part of the Johns Valley shale matrix, which, despite the fact that these particular shale bodies lack any erratic boulders, has been presumed to be the same as the boulder-bearing shale elsewhere. As a matter of fact, the boulderless black shale masses are typical Caney shale of the Arbuckle type. The lithology of this true Caney shale

can be distinguished readily from adjacent outcrops of Johns Valley shale containing boulders. At the Johns Valley locality I found and was able to trace for several feet the sharp contact between Caney shale and contiguous boulder-bearing shale. As already noted, the typical Caney contains no erratic boulders and it yields abundant Caney fossils. The fossils occur in small phosphatic nodules, in large subelliptical limestone concretions, and between bedding planes of the shale. The fossils between bedding planes are in places very abundant, and include many perfectly preserved delicate thin shells of brachiopods, pelecypods and other forms. In every respect the observed features of lithology and occurrence of fossils duplicate characters observed in Caney outcrops of the Arbuckle Mountains area, and accordingly there is no reasonable room for doubt as to actual identity of these outcrops with typical Caney.

The statement has been made by Ulrich (14, p. 19) that slightly waterworn reworked Caney fossils occur in the boulder-bearing Johns Valley shale. This is undoubtedly true, for I, also, have seen reworked Caney fossils in undoubted Johns Valley shale. Ulrich has advanced the view, however, that all of the Caney fossils from Johns Valley outcrop areas are reworked, that they may not be considered as having "lived, died, and been buried in the shale" where they are now found. With this interpretation in mind, Miser (8, pp. 22, 23) and I examined the fossil-bearing shale outcrop in Johns Valley. This is an outcrop which I now identify as true Caney shale, no erratic boulders being associated with the fossil-bearing strata. That the fossils found in this shale did live, die, and become buried in the shale containing them can be affirmed most emphatically. Miser is right in his published statements on this point, but neither Miser's nor Ulrich's statements as to the indigenous character of the Caney fossils in the locality containing shale applies to all of the Caney fossils in the Johns Valley shale outcrop areas. In other words, I conclude that the Caney shale masses with their contained indigenous fossils are themselves erratic boulders. Harlton (5, p. 5) has also noted that these shale masses are entirely typical "Mississippian Caney" and he regards them as "boulders" transported bodily from some part of the previously formed "Arbuckle Caney." Because it is harder to imagine the occurrence of large shale masses transported an unknown distance into new surroundings and because the Caney shale, though somewhat more

indurated, lithologically resembles the surrounding Johns Valley shale, it is not surprising that the Caney shale bodies in the Ouachita area should have been regarded as occurring in place.

There remains to be specially mentioned the occurrence in the Johns Valley shale of erratic material derived from Wapanucka or other Morrow beds. Identification of the Morrow rocks rests both on lithologic and paleontologic grounds, some of which have been described by Ulrich (14, p. 21). I have found *Marginifera* and bryozoans regarded as typical of the Morrow in erratic materials at Compton Cut north of Talihina, Oklahoma. The reworked Morrow and Caney fossil-bearing rocks in the Johns Valley shale support Ulrich's main contention that the Johns Valley formation is younger than Morrow and Caney. Miser regards the Wapanucka boulders, especially at Compton Cut, as portions of ledges which have been broken during folding and faulting.³ If this interpretation is correct, at least part of the Johns Valley beds under discussion must be of Morrow age.

ORIGIN OF THE JOHNS VALLEY SHALE.

Previous Hypotheses.

Attempts to explain the Johns Valley boulders may be classed in two groups: (1) those that assign the origin of the shale and its contained "erratics" to agencies of sedimentation, and (2) those that call on tectonic forces as the primary cause of observed conditions.

Hypotheses of Sedimentary Origin.—The geographic distribution of the boulders, their occurrence promiscuously scattered about in marine shale and the presence on some of them of striae and gouges, led Taff (11, 12) to conclude that they were transported by ice from "mountains in the region now occupied by southern Indian Territory [Oklahoma] and northern Texas." He mentions the rounding of some of the boulders, implying action of glacial ice but ascribes the striations to work of shore ice and in part to slickensiding due to differential movement and abrasion of one boulder on another during the much later Ouachita orogeny. Woodworth (19) emphasizes the nonglacial origin of the scratches on boulders seen by him north of Talihina but accepts the hypothesis of

³ Personal communication.

shore-ice work to account for transportation of the boulders. Ulrich (see 19, pp. 458-460) concludes that shore-ice work offers the only satisfactory explanation of the peculiarities of some of the striae and regards transportation by large icebergs as necessary to account for distribution of the boulders, including strongly striated large rock masses, in such areas of gentle structure as Johns Valley. He thinks (14, pp. 13, 44) that the source of most of the boulders was in the eastern part of the Arbuckle Mountains area, which necessitates the conclusion that currents floated the boulder-laden bergs at least 100 miles eastward in some cases. Ulrich (19, p. 460) agrees that the scratches on many of the boulders in places of steep folding, as at Compton Cut, are the result of movement during folding. Miser (8, p. 22; 9, pp. 28, 29) believes that the boulders are ice-transported and says that "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." After discussion of the "Caney" boulder problem at some length, Tomlinson (13, pp. 25-27) also concludes that transportation of the erratic blocks by ice is the most plausible hypothesis, but he offers evidence to show that the source of the boulders could not have been located in the Arbuckle Mountains area. Powers (10, pp. 1045, 1046) finds "no theory as to the source of the boulders fully satisfactory." After analysis and rejection of tectonic hypotheses, he is driven to accept tentatively the idea of floating or shore ice even though he recognizes nearly insuperable difficulties.

Dixon (3, p. 344) notes the possibility of origin of the boulders in a long, high fault scarp containing a variety of Paleozoic rocks of Arbuckle type, the boulders being broken loose and transported to their resting place by "successive landslips from this scarp [that] slid out over the Caney shale collecting at its foot."

The evidence in favor of glacial hypotheses appears to consist (a) of striations and gouged markings on some of the boulders and (b) of the lack of known transporting agency other than ice to account for distribution of the erratic masses, especially the larger ones. Woodworth (19) submits convincing evidence, however, to show that the supposed glacial scratches are not glacial. This is particularly indicated by slickensiding and flowage that extend inward a short distance from the surface of the grooves and it is also strongly marked

by the appearance of plastic yielding and by peculiarities of form of the scratches as may be seen in Ulrich's photographs (14, pls. 3-6). I agree with Van der Gracht (17, p. 705) that "these quite irregular scratches and deep short gouges are anything but glacial." As for the assumed transportation by ice, the difficulties of loading large rock masses upon or embedding them in the ice that is to raft them seem insuperable. No evidence of glaciation or even of cold climate at this time is known except that supposedly furnished by the boulders. If, therefore, the markings on the boulders cannot be accepted as glacial and if some adequate means of transportation other than by ice can be suggested, little is left to support the glacial hypothesis.

The hypothesis of derivation of the boulders from a fault scarp and distribution through the agency of creep or sliding is supported by several considerations discussed later. It is opposed chiefly by the considerable horizontal shifting of the erratics that must be assigned to creep.

Hypothesis of Tectonic Origin.—The tectonic hypothesis of the origin of the Johns Valley boulders has been developed chiefly by Van der Gracht (17), who regards the Ouachita structure as duplicating in essential respects the profoundly overthrust nappes of the Alps. Parts of the shale have a complex structure and appear to be mylonitized. This implies strong differential movement and it must be acknowledged that fine dark shale several hundreds of feet thick would form a ready yield zone along which thick competent formations might slide when compressed by mountain-building forces. The exotic blocks of Arbuckle-type rocks that are distributed through the Johns Valley shale are thought to have been dragged from ridges in the southeastern prolongation of the Wichita and Red River mountains (consisting of Arbuckle-type rocks) that were overridden by the Ouachita thrusts. Harlton (5, p. 6) accepts this view. The scratches and slickensides on hard rock boulders and the locally contorted structure in shale, as seen in such exposures as that at Compton Cut, are generally accepted as due to folding, but this is regarded as an altogether local matter that is probably quite unrelated to conditions of forming the boulder-bearing shale.

Chief objections to tectonic hypotheses of the origin of the Johns Valley shale lie in the apparent lack of agreement between postulated and actual geologic structures in the Ouachita Mountains area and in the occurrence of the boulder-

bearing shale at a constant stratigraphic horizon instead of various different horizons.

The comparatively gentle structure of the rocks in Johns Valley and the simple open folds of certain other parts of the Ouachita area where the boulder-bearing shale occurs, seem to preclude the possibility that the Johns Valley shale was formed by overthrusting of any conceivable sort. It seems very doubtful to me if any of the boulder-shale can be explained as derived by faulting from rocks beneath the Ouachita thrusts. This hypothesis of a "tectonic moraine" dragged along in a shale-lubricated shear plane is especially inharmonious with structural conditions observed in the Johns Valley area. No one has published any diagrams attempting to illustrate the derivation and transportation of the boulders by faulting. I have tried several times to construct such graphic representation of the conjectured tectonic origin of the boulders, but have been quite unable to formulate a remotely plausible picture according with observed structural and stratigraphic relations of the Johns Valley shale. Until this can be done, the tectonic hypothesis is not very convincing. The observed uniformity of stratigraphic position of the Johns Valley shale above Jackfork and beneath Atoka is very important, for when account is also taken of the considerable area of distribution of the Johns Valley shale, constancy of stratigraphic relations serves in itself virtually to deny the possibility of Van der Gracht's hypothesis. If the mechanics of the latter is accepted, it is hardly conceivable that other shales of the Ouachita Mountains sequence should not also contain boulders in some places, or that occurrence of "Johns Valley shale" at stratigraphic horizons other than between Jackfork and Atoka should not be found. We may, therefore, dismiss the suggestion of purely tectonic origin of the boulder-bearing shale because it is not accordant with observed structural and stratigraphic relations.

Hypothesis Here Proposed.

Source of the Boulders.—It is evident from study of the erratics in the Johns Valley shale that these were derived from rocks of Arbuckle or Ozark facies, the source of which can be assigned definitely to territory lying west, northwest, or north of the original geosynclinal area of Ouachita sedimentation. Deposits consisting largely of limestone, such as are now

exposed in the Arbuckle and Ozark areas, form the normal Paleozoic geologic column of the interior continental platform or foreland area. With some variation, but no essential interruption, this type of column borders all of the western side of the Appalachian geosyncline and occurs along the interior border of the Ouachita-Marathon geosyncline to West Texas. A geosynclinal belt, in which clastic sedimentation was dominant, existed during Paleozoic time in the Appalachian, Ouachita, and Marathon districts, and it is probable that this was all a single continuous belt. Beyond the geosyncline to the east and southeast lay the extensive borderland (or hinterland) that supplied most of the geosynclinal sediments. This regional picture, supported by many geologic evidences, is now recognized, but with Miser and others I hold that the original site of the Ouachita geosyncline was by no means so far south as postulated by Van der Gracht (15, p. 999), that is, in the region of the present Gulf Coastal Plain south of the Sabine Uplift in Louisiana. In any case it is clear that the source of the Johns Valley boulders is some part of the rock succession that bordered the Ouachita geosyncline on the side toward the continental interior.

In the effort to locate the geographic source of the boulders more exactly, I agree with Miser, Powers, Van der Gracht and Tomlinson that the present Arbuckle area may be eliminated. The essential reasons for this conclusion rest on evidence that important folding in this area did not occur until much later (post-Hoxbar or post-Missouri) in Pennsylvanian time and on the absence of any boulder-bearing shale on the flanks of the Arbuckle Uplift. Folding or faulting with several thousands of feet vertical displacement was certainly necessary in the source area of the boulders in order to expose Early Paleozoic formations that are abundantly represented in the Johns Valley erratics. No movement of this sort in the Arbuckle area in post-Wapanucka pre-Atoka time is known. At the northeast margin of the Arbuckles, however, it has been shown that there was some pre-Atoka uplift, for the Atoka and McAlester formations overlap Wapanucka onto Caney and there is locally conglomerate containing limestone pebbles apparently derived from Viola and Arbuckle limestone (Morgan). It is possible, therefore, that an eastward extension of the Arbuckles, now concealed beneath part of the Coalgate Basin and the northwestward overriding front of the Ouachitas, may have supplied some of the Johns Valley erratics.

A source suggested by Van der Gracht (17) is the assumed southeastward extension of the Wichita-Criner Hills mountain uplift. This suggestion is supported by definite evidence that the Wichita chain was strongly uplifted in post-Morrow (post-Otterville, post-Bend) pre-Atoka (pre-Deese, pre-Strawn) time. Van der Gracht (15, p. 1010) has appropriately designated the crustal movements of this time in the central and southern Mid-Continent as the Wichita orogeny. The age of this deformation corresponds to that which must have given rise to the Johns Valley boulders (if they are a sedimentary deposit), and the type of rocks involved, probably including southeastward extensions under the overthrust front of the Oklahoma portion of the Ouachitas, is of the required sort. Opposing evidence, however, is found in the fact that the boulder-bearing beds are now known to extend well into Arkansas, and this fact, together with the westward and north-westward movement of the Ouachita rocks in subsequent folding and thrusting, requires either that the interior continental platform type of sediments along the Wichita axis must extend much farther southeastward under the Ouachita cover than seems reasonable, or that the boulder masses in Arkansas must have been transported an unbelievable distance eastward as well as northward from their supposed source. In this connection it must be recalled that the interior platform or foreland type of geologic section extended southeastward in the southern Oklahoma-northern Texas region only to the here south-trending border of the geosyncline, and rocks of the Arbuckle type cannot have extended southeastward along an extension of the Wichita-Criner axis farther than the border of this geosyncline. A further reason for rejecting Van der Gracht's hypothesis as to source region of the erratics is the very great horizontal thrusting of the geosynclinal sediments which is necessitated and which he believes has occurred. Miser (9, p. 27) estimates that crustal shortening in the Arkansas part of the Ouachita Mountains, in which little thrust faulting is recognized, is about 50 miles and that the shortening in the Oklahoma part is perhaps 70 miles. Van der Gracht (15, p. 999), on the other hand, considers that the horizontal shortening was probably more than 200 miles.

The Ancestral Ouachita Mountains.—The suggestion may now be advanced that the required area of post-Morrow pre-Atoka uplift involving a foreland limestone section was located along that portion of the geosynclinal border most closely

adjacent to the area of Johns Valley shale distribution. This signifies an area approximately parallel to the present northwest front of the Ouachita Mountains but somewhat south and southeast of the present front, for the post-Atoka Ouachita orogeny has involved an unknown amount of northward and northwestward thrusting of the geosynclinal sediments. The indicated site of this uplift, which I suggest may appropriately be termed the Ancestral Ouachita Mountains, essentially coincides with Powers' (10, p. 1044) "pre-Ouachita uplift." It seems to provide all of the necessary conditions as regards type of rocks involved and offers a source nearest to the areas where the boulders were deposited. It may be noted incidentally that the border zone between foreland and geosyncline is a belt of anticlinal tendencies that is likely to yield by upfolding or faulting to crustal stresses. Evidence from the erratic materials in the Johns Valley shale indicates that the postulated Ancestral Ouachita uplift occurred in post-Wapanucka time. Subsequently it may have been beveled by erosion and concealed by Atoka sedimentation, but in any case the site of the uplift has been overridden by the northwestward thrusts of the Ouachita orogeny in the Oklahoma structural salient. The occurrence in the Arkansas area of erratics that most closely resemble Ozark formations agrees with the inferred location of the Ancestral Ouachita uplift.

Deposition of the Boulders.—Assuming the validity of the inferences that have been made concerning the existence, general location and age of the Ancestral Ouachita Mountains, it is appropriate to consider how the Johns Valley shale was formed and how the boulders were transported from their postulated source in the Ancestral Ouachitas to their resting place in the shale. I favor the idea that as an accompaniment to the Ancestral Ouachita deformation, a part of the geosyncline south of the mountain front was depressed and submerged by moderately deep waters. This would seemingly provide conditions most suitable for deposition of fine dark muds. The indigenous fauna of the Johns Valley shale, comprised mainly of marine microfossils and essentially lacking bottom-dwelling larger invertebrates, agrees with this suggestion. We may preferably picture a steep mountain front, possibly a fault scarp, facing this sea, and we may imagine that large and small fragments of the uplifted rocks, loosened by weathering, by erosion of steep-dropping streams or of undercutting waves, or conceivably but improbably by work of ice, were dropped from the uplift into the bordering basin. Per-

haps earthquake shocks incident to recurrent movements along a border fault zone helped to dislodge large rock masses. However separated from their mooring, when the "boulders" slid into the oozy mud of the basin it is probable that they found conditions very favorable for lateral creep. Bailey, Collet and Field (1, pp. 604-611) have called attention to examples of large exotic rock masses derived from fault cliffs, some of them probably by submarine landslips, and they note evidence of the extremely small gradient necessary to permit considerable lateral movement of the masses embedded in soft muds. We do not know from actual observation how far large boulders resting on or partly embedded in soft mud may be transported through agency of mud flow or creep, nor what minimum gradient is necessary. The fact that some of the rock masses in the Johns Valley shale would have to have been carried some 20 miles may be urged as opposing this hypothesis, but movement due to creep is deemed more plausible than transportation by floating ice.

The absence of thick conglomerates, so far as known, in the vicinity of the Ancestral Ouachita uplift is suggested as possible opposing evidence of existence of the uplift. Conditions did not favor the spreading of conglomerates in the area of Johns Valley sedimentation but this does not mean that conglomerates are lacking on other flanks of the uplift. Conglomerates occur in places at the base of the Atoka in southeastern Oklahoma and may be present in quantity in the concealed area of the deep Arkansas River trough.

Dixon (3, pp. 342-343; 4, pp. 91, 92) notes striking similarity of limestone boulders in the mid-Carboniferous Bowland shale in north central England to the Johns Valley boulders of the Ouachita region and interprets the Bowland boulders as derived by landslips from scarps along active faults of the Cravens system. The geologic relationships are more clearly defined in the area studied by Dixon, for the location of the fault system and proof of mid-Carboniferous movements along it are known. In the Ouachita region, subsequent folding and faulting have concealed the assumed source region of the Johns Valley boulders. After formulating the conclusions as to origin and age of the Johns Valley deposits as presented here, and after completing part of the writing, it is interesting to discover that Dixon, whose knowledge of the Ouachita area is drawn entirely from the literature, offers explanation of Johns

Valley conditions and history that is practically identical with mine.

Markings on the Boulders.—The striations, gouges and other described markings on the Johns Valley boulders are apparently not satisfactorily explainable as the work of ice. They show distortion effects such as incipient cleavage and slickensiding that extend beneath the surface. There is appearance in some cases of plastic flow. All of these features may possibly be explained as effects of movement along the border faults of the Ancestral Ouachitas, which it has been suggested were formed by uplift totaling thousands of feet. If the scratches were made in the course of fault movements, there would have been nothing to obliterate them after they slid into the soft bed of accumulating Johns Valley muds. Some additional striation and slickensiding were almost certainly occasioned in places by the abrasion of one boulder on another during the Ouachita orogeny (Late Pennsylvanian or Permian).

AGE OF THE JOHNS VALLEY SHALE.

From the evidence that has been reviewed, we may conclude that the Johns Valley shale was deposited on the Jackfork sandstone and not carried there by faulting. Accordingly, the Johns Valley is younger than Jackfork sandstone. The occurrence of Atoka sandstone above the Johns Valley in every unbroken succession proves that the Johns Valley is older than Atoka.

The apparently conflicting evidence of the Caney fossils in the Johns Valley outcrop areas has been explained and we may now class all of the Caney fossils, both the loose reworked ones and those in the Caney shale masses, as erratic elements in the Johns Valley shale. This of course means that the Johns Valley is younger than Caney. Finally, the recognition of erratics of Morrow age shows that the Johns Valley formation is younger than at least part of the Morrow beds. Therefore, the Johns Valley is post-early Morrow and pre-Atoka. If the fossil-bearing rocks of Morrow age that occur in the Johns Valley shale are portions of beds deposited along with the shale, as believed by Miser, the Johns Valley formation is at least in part of Morrow age.

On the southwest flanks of the Ozarks the basal Atoka rests unconformably on Morrow beds. On the northeast flanks of the Arbuckles it likewise rests unconformably on Morrow (Wapanucka) and there is evidence of overlap. In the Ouachita Mountains outside the area of Johns Valley distribution the Atoka lies parallel, but very probably with discontinuity, on Jackfork sandstone. Taking into account the known Late Mississippian or Early Pennsylvanian age of Jackfork and considering paleogeographic probabilities, the stratigraphic relations just noted suggest the possibility that the Jackfork sandstone is of Morrow age. The lower Morrow of northwestern Arkansas is notably sandy although also distinctly calcareous. It rests disconformably on Upper Mississippian dark shales, thin limestones and sandstones. The Jackfork is a thick sandstone which was deposited much nearer the source of sediments in lands to the south. It rests on thick dark shales and sandy beds that are apparently not older than Late Mississippian. Jackfork beneath Atoka is identified in Sebastian, Logan, and Yale counties, Arkansas, some 25 miles north of the Ouachita Mountain front and only a little more than 25 miles from the nearest outcrops of the Morrow beds overlain by Atoka in Crawford County farther north. The probable equivalence of Morrow and Jackfork is shown on sections published by Croneis (2).

In this connection the large fauna of Morrow species obtained by C. W. Honess (6) from a thick succession of sandstone which he called Jackfork, in the northwest corner of McCurtain County, Oklahoma, may be noted. The beds above the horizon containing this fauna have been subsequently classed as Atoka but it is possible that the fossiliferous horizon is really a bed in the upper Jackfork, corresponding, as was supposed by Honess, to the Wapanucka limestone of areas farther north.⁴ The occurrence of this fauna may be regarded as supporting the inferred Morrow age of the Jackfork.

Mississippian-Pennsylvanian Boundary.—On the north and south flanks of the Arbuckle Mountains the Late Mississippian Caney shale is followed conformably or with apparently slight break by sandy beds called "Pennsylvanian Caney" or Springer, and this is conformably overlain, in turn, by limestone and shale containing a Morrow fauna. Following deposition of

⁴ See Moore, R. C., The Mississippian-Pennsylvanian boundary in the Mid-Continent region: *Am. Assoc. Petroleum Geologists, Bull.*, to appear.

these beds, however, the important Wichita orogeny occurred, involving uplift of the Criner Hills and several other axes toward the west and south and there was at least some uplift of the northeastern Arbuckles. This uplift is marked in the Ardmore Basin by the Bostwick conglomerate in the middle of the Dornick Hills formation of Tomlinson (13), which I regard as more appropriately constituting the basal unit of the Deese. The Bostwick and succeeding Deese beds overlap on the pre-Carboniferous rocks of the Criner Hills. North of the Arbuckles, the Atoka and higher Pennsylvanian beds overlap on Caney and older rocks.

The uplift of the Ancestral Ouachita Mountains, as inferred from study of the Johns Valley shale, is a crustal movement that coincides in time with the movements noted in the Arbuckle area. Regional study of the unconformity at the base of the Atoka in the Mid-Continent region, and comparison with geologic relations in the Appalachian and other districts, lead me to conclude that much the most important break in sedimentation in this part of the geologic column is that at the base of the Atoka and equivalent beds. The Morrow deposits are paleontologically distinct from the Chester, but they resemble them lithologically much more than they do the overlying Pennsylvanian rocks, and they lie structurally conformable on Chester. The Morrow group has been classed as Pennsylvanian essentially because of the correlation of the flora above the Bloyd shale coal with a middle Pottsville (18, p. 316) flora in the central Appalachian district. The invertebrate marine fauna also contains a number of genera of Pennsylvanian type mingled with typical Mississippian forms (7). A Morrow marine invertebrate fauna occurs in the Parkwood formation of Alabama, which unconformably underlies the base of the Pottsville, just as the Morrow occurs unconformably below the similar Atoka formation. Clearly the Morrow cannot be equivalent to the Parkwood and at the same time equivalent in age to the mid-Pottsville.

After consideration of evidence much more extensive than can be presented here, I am led to conclude that the unconformity at the base of the Pottsville in the Appalachian region, at the base of the Atoka and Cherokee in most of the Mid-Continent area, at the base of the Deese formation (defined to include the Bostwick conglomerate at the base) in the Ardmore Basin, and the base of the Strawn in north central Texas may

be considered as marking the base of the Pennsylvanian system. In the Ouachita Mountains area the Pennsylvanian-Mississippian boundary should be drawn at the base of the Johns Valley shale, or where that formation is absent at the base of the Atoka formation.⁵

SUMMARY.

The Johns Valley shale, with maximum thickness of 1,500-2,000 feet, occurs along the northwestern border of the Ouachita Mountains in west central Arkansas and southeastern Oklahoma. It lies with parallel structure on Jackfork sandstone below and is succeeded with apparent conformity of structure by the Atoka formation.

The Johns Valley shale contains many pebbles, cobbles and boulders, the latter up to a few hundred feet in diameter, all of which are derived from formations of the Arbuckle-Ozark type which are foreign to the geologic section of the Ouachita geosyncline. The erratic constituents range in age from Arbuckle (Cambro-Ordovician) to Morrow? (tentatively classed by me as latest Mississippian).⁵ To be included among the erratics are large masses of Late Mississippian Caney shale. It is these masses that mainly have led to confusion in determining the age of the Johns Valley formation.

Evidence is presented to show that in post-Morrow time an important uplift of Ozark-Arbuckle type rocks occurred along the region now occupied by the northwestern front of the Ouachita Mountains. This uplift, termed the Ancestral Ouachita Mountains, is presumed to have supplied "erratic materials" to a marine area of dark mud sedimentation lying to the south. After removal from the mountain uplift through agency of wave cutting, stream erosion or other agencies, probably including chiefly landslips along faults, it is suggested that the boulders were distributed through action of flowage or creep in the soft mud of the gently sloping sea-bottom.

⁵ Study carried on since the completion of this paper leads to the conclusion that preponderance of evidence favors classification of the Morrow and equivalent beds as Pennsylvanian. At present this is certainly the more conservative judgment. If additional investigations that are planned corroborate the Pottsville age of the Morrow beds, significant evidence bearing on diastrophic criteria as a basis of inter-regional correlation will be supplied.

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