The Ouachita Mountains of Oklahoma and Arkansas are the central segment of an elongate belt of folded and faulted Paleozoic rocks (table 1) called the Ouachita system that stretches from west Texas to Mississippi. East and southwest of the Ouachita Mountains, the belt of deformed rocks is overlain by Cretaceous, Tertiary, and younger sedimentary rocks (fig. 1). Studies of the Quachita Mountains are therefore of great importance in unraveling the geology and tectonic history of the southern margin of the central United States.

maps (A, B, and C) and line of cross sections (fig. 2).

TABLE 1.—GENERALIZED GEOLOGIC SECTION OF PALEOZOIC ROCKS IN CENTRAL OUACHITA MOUNTAINS AND SOUTHERN ARKOMA BASIN (Modified from Stone and others, 1973; Ham and Wilson, 1967) Atoka Formation Johns Valley Formation

10,000 Stanley Group Arkansas Novaculite Missouri Mountain Shale Blaylock Sandstone Polk Creek Shale Bigfork Chert omble Shale lakely Sandstone azarn Shale stal Mountain Sandstone Collier Shale (base not exposed) 1,000+

tural contrasts, with tightly folded and faulted sedimentary rocks in some areas and broad, relatively simple synclinal folds close by. on field studies, particularly on the examination of rocks in stream and road cuts. This has provided a wealth of knowledge about many parts of the Ouachitas (for example: Cline, 1960; Fellows, 1964; Harlton, 1938, 1966; Hart, 1963; Hendricks and others, 1947; Honess, 1923; Miser and Purdue, 1929; Reinemund and Danilchik, 1957; Seely, 1963; and Shelburne, 1960). In addition, a number of symposia and other major reports have assembled data on the entire region (Cline, 1968; Cline and others, 1959; Flawn and others, 1961; Goldstein and Hendricks, 1962; Ham and Wilson, 1967; Kansas Geological Society, 1966). structural features and tectonic events in the Ouachita Mountains was undertaken in the belief that stereoscopic examination of large-scale aerial photographs of good quality covering the central part of the mountain system might help establish some of the regional trends and relationships that are obscure when studied only on the ground. This discussion relies heavily on the interpretation of these photographs, which are especially useful in recognizing and mapping faults. This in no way belittles or ignores the great amount of important field examination that has been carried out by others; the many stratigraphic and structural maps now available are indispensable in any study of the Ouachita system. This study, however, does emphasize the value of approaching from a different

perspective the geological problems of this fascinating

region that has long challenged geologists.

The accompanying maps (A, B, and C) show the major structural elements distinguished by photograph examination. The cross sections (fig. 2) are part of an interpretation of the tectonic history of the Ouachita Mountains. Most of the study is at a reconnaissance level, based on examination of contact-print mosaics and photo-index mosaics (map A); but the central Ouachitas of Oklahoma (maps B and C) were also studied with stereo-contact prints (scale 1:20,000 or larger) in great detail.

The Ouachita Mountains are a region of abrupt struc-Most investigators of the Ouachitas have relied heavily and Johnson, 1968). ably nearly full of sediments while it was subsiding. This current aerial-photograph interpretation of

photographs, in the preparation of maps and other illusindebted to David C. Bowlby, Oklahoma City, for preparing and near the Quachitas in Cline (1906). In a region of moderate present-day dips, many of these faults were distinct the Quachitas compared to certain other places, such a local control of the Compared to certain other places, such a local control of the Compared to certain other places, such a local control of the Compared to certain other places, such a local control of the cont

PHOTOGEOLOGIC OBSERVATIONS

The early stage of Paleozoic sedimentation (fig. 2a) in the Ouachita Mountain region is represented in outcrops by nearly 12,500 feet (3,800 m) of dark shale, sandstone, chert, and (or) novaculite of Early Ordovician through Devonian age (table 1). In addition, there may be another 10,000 feet (3,050 m) or more of older Early Ordovician and Cambrian clastic sedimentary rocks farther south. A similar thickness of such rocks was penetrated (without reaching basement rock) in the Viersen and Cochran 25-1 Weyerhaeuser well (sec. 25, T. 5 S., R. 23 E.) in the Broken Bow uplift of McCurtain County, Oklahoma. This is believed to represent the beginning of a geosynclinal The second stage of sedimentation (fig. 2) is represented by the thick sequence of Mississippian through Early Pennsylvanian dark shales and turbidites in the Stanley and Jackfork Groups and Johns Valley Formation

(Cline, 1960; Goldstein and Hendricks, 1962; Seely, 1963). These three units have an aggregate thickness of 21,500 The overlying Atoka Formation is a sequence of shale and irregular sandstones. Its thickness varies markedly northward from near the geosynclinal axis. From sec. 16, . 6 N., R. 27 E. (Oklahoma), to sec. 36, T. 7 N., R. 32 V. (Arkansas), a distance of about 18 miles (29 km), it thins northward from about 16,000 feet (4,900 m) to about 6,600 feet (2,000 m), a reduction of 9,400 feet (2,900 m), or some 520 feet per mile (98.5 m per km; see Buchanan The great thicknesses of the sedimentary units previously listed mark the position of the Ouachita geosyncline. It was an elongate, approximately east-west-trending crustal trough filled with sedimentary rocks and was prob-There exists a large amount of geological and geophysical literature that describes the possible origin and destiny of these deep subsiding troughs. Much of this literature has appeared since 1970 and shows that many troughs are part of the continents and that others lie beneath the oceans and no doubt form some of the greatest ocean deeps.

The author is indebted to Kenneth S. Johnson, Oklahoma Geological Survey, for much help with aerial trations, for critical examination of the manuscript, and in determining field relations in the study area. He is also

and mosaic study of aerial photographs concern (1) early are called growth faults by oil and gas geologists. The voids for important suggestions regarding this process.

bedding faults, (2) other faults, (3) schistosity, (4) major left by sliding were probably accommodated by local 3. Schistosity lineaments, (5) high-angle faults, (6) the big anticlinoria, and (7) the Big Cedar fault. . Early Bedding Faults

A series of faults parallel or nearly parallel to bedding in the upper part of the Stanley and younger rocks was recognized early in the stereoscopic study of photographs near the Oklahoma-Arkansas line. The faults apparently formed when beds above and below the faults slid past each other during the early stages of deformation, possibly by underthrusting. They are herein referred to as early bedding faults. The date of this faulting is unknown. Movement may have begun in or soon after Stanley-Jackfork time; but the culmination of this type of bedding faults was probably long after this, in late Pennsylvanian, perhaps Permian, time. At this time, there was much asymmetrical folding and complicated and repeated folding of the fault slices; this complex folding contrasts with a later and much simpler type of folding (see section 6, following). These faults occur mainly along the contacts between competent and incompetent beds (between sandstones and shales): the sandstones appear undisturbed and form hogbacks, but close stereoscopic study reveals that the bedding of adjacent rocks is commonly at a discordant angle to the fault surface by a few degrees. Early bedding faults are most pronounced in the coves of major synclines and other large folds, and are present in Stanley strata on the east end of the Lynn Mountain and Rich Mountain synclines. The recognition of early bedding faults is externely important in unraveling the structural sequence and geologic history of the Ouachitas. The exposed geologic record does not clearly enlighten us as to the origin of the Ouachita geosyncline. But the nature of faulting and folding visible at the surface, and known from oil- and gas-well records nearby to the north, may point to the correct explanation. Though it has been

the geological custom to explain low-angle faults and overturned folds as having been caused by "overthrusting" or 'overfolding." it now seems best to start with the assumption of underthrusting and to apply all possible tests to this assumption. It seems preferable to use the term underthrusting at present, although geophysical data may later show that this geosyncline lay above a zone of subduction, wherein one crustal plate descended laterally and downward beneath another. The first recognizable major tectonic movement was downward and was the cause of the geosyncline; and it continued, giving place to new subsidence and new sedimentary formations in the geosyncline. If one assumes, as do many geophysicists and geologists, that the crystalline crust ("basement" to some) and upper mantle moved laterally southward beneath the Quachita region to form the crustal trough of the geosyncline he can point, for evidence, to some of the faults formed in Atoka time in the Arkoma basin, north of the Choctaw fault, in the frontal Ouachita folds. These faults are shown guished from underthrusts, are probably not common in by detailed structural and stratigraphic cross sections in and near the Ouachitas in Cline (1968). In a region of are bound to be extremely common. Klippen are a rarity placed downward on the south side, in some cases in Atoka as the Northern Rockies of Canada or the Alps, where time. This is perhaps best explained by southward gravity they are common. sliding of Atoka beds along shaly formations, toward the

In this assumed southward underthrusting, the crustal basement rocks caused shearing in the less competent overlying thick shales, such as those of the Mazarn, Womble and lower Stanley, and in other shale and sandstone units, thus producing the many early bedding faults. This process took place mainly along formation contacts that separated sharply different lithologies. It was most extreme and had the greatest effect on geosynclinal sediments at and near the bottom of the sedimentary section. It initiated the development of many of the features characteristic of pre-Stanley rocks below (south of) the Mena and Hamilton lineaments: these features include tight isoclinal folds, schistosity and slaty cleavage, low-grade metamorphism, and other features. The underthrusting, as a strictly geological event (distinct from a geophysical event), can probably not be distinguished from overthrusting in the opposite direction and at a higher level. The remarkably detailed structural geologic maps of the literature (especially Hendricks and others, 1947; Cline, 1968) document the structural displacements formed by this deep faulting and other distortions. The time of movement has not been determined exactly; but the writer believes that underthrusting started in early Atoka time, though the culmination of all such

slumping or tilting to fill the voids at the upper end of

in the Gulf Coastal Plain farther south.1

the moved blocks. This is a well-known fault relationship

movement-both southward under thrusting and northward overthrusting-must have been in Late Pennsylvanian to Early Permian time. Certainly the movement occurred before the big anticlinorial uplifts and also before formation of the steep faults and graben mentioned in section This underthrusting probably culminated in some of the most outstanding faulting and folding of the Ouachitas. But there are folds and faults that did not have this origin main structural features and trends north and south of (see section 5, following). The faults shown in cross sections of Hendricks and others (1947) and Cline (1968) above and over the Potato Hills anticlinorium agree well in principle with the early bedding faults of this paper. The writer. however, was not able to map such a fault, or faults, after very careful stereoscopic study of 1:20,000 and larger scale

Two nearly horizontal faults (revealed by klippen) were observed in the area of stereoscipic study: examples are Carver and Harvey Mountains (sec. 6, T. 2 N., R. 25 E., and secs. 22-23, T. 3 N., R. 23 E.), both on the south flank of Winding Stair Range in Oklahoma. Other sites of possible low-angle faults in Arkansas are in Rich Mountain syncline (T. 1 S., R. 31 W.) and Blansett syncline (T. 1 N., R. 30 W.). Outstanding low-angle overthrusts, as distinthe Ouachitas, although bedding overthrusts northward

contact prints. The faults of map C are a fair example places recumbent), schistosity and slaty cleavage, lowof the most detailed faulting that can be mapped with grade metamorphism, hydrothermal quartz veins with

Principal observations made during the stereoscopic center of the subsiding Ouachita geosyncline. These slides 'The author is indebted to M. W. McQuillan, Norman, Oklahoma,

Schistosity and (or) rock cleavage in general increases downward stratigraphically, and it is most pronounced in the beds below the Bigfork Chert-Arkansas Novaculite sequence in the central uplift of Arkansas. It is usually at a low angle to the bedding, judging from reconnaissance field work. The youngest rocks examined on the outcrop in which cleavage is conspicuous are in shales in the lower part of the Stanley Group (Mississippian), mainly eastward from Mena, Arkansas. In special situations, younger rocks are probably affected.

Structural discontinuities or bedding faults separate the tightly folded and locally overturned pre-Stanley rocks in the Benton-Mount Ida uplift from the broad, open folds of the upper Stanley-Jackfork-Atoka rocks to the north in the frontal Ouachitas. One such major feature in the ower Stanley between Smithville, Oklahoma, and the Lake Winona area, Arkansas, is herein named the Mena lineament. Within the zone of this lineament, which is generally 1 to 2 miles (1.6 to 3.2 km) wide, bedding is almost unrecognizable in aerial photographs. On the other hand, cleavage (and/or schistosity) is pronounced where the writer has examined the lineament on the ground. A similar discontinuity, herein referred to as the Hamilton lineament, is en echelon to the Mena lineament; it extends eastward from the area just south of Mount Tabor, Arkansas, thence southeastward in a giant curve into the core area northwest of Benton. The dips of these lineaments are not known, but probably they are northerly, away from the central

The Mena and Hamilton lineaments clearly separate two distinct and contrasting regions of the Ouachitas; the the lineaments do not cross them (exceptions are two unusual northwest-trending faults that do cross the lineaments, which can be seen in Arkansas in T. 1 S., R. 24 W., and T. 2 S., R. 26 W.). Features characteristic of the pre-Mississippian rocks south of the Mena and Hamilton lineaments include tight isoclinal folding of shales (in some associated high-temperature minerals, and elongation and suturing of quartz grains in sandstones (Miser, 1943, 1959; Goldstein, 1959). These features contrast with the following features, which are characteristic of Mississippian-Pennsylvanian rocks in the Ouachita frontal belt, north of the Mena and Hamilton lineaments: broad open folds, little

net result was a complicated series of anticlinoria with It is believed that the Mena and Hamilton lineaments very many small folds combining to make big folds. Vertical are two of the principal north-dipping decollements or dimensions of these early uplifts cannot be measured, as bedding faults across or under which relative movement occurred during underthrusting in the region. Another shear zone is the Mountain Valley lineament, which extends northeastward from the Mountain Pine area T. 2 S., R. 20 W., in Arkansas) through Mountain Valley and intersects the Hamilton lineament just northwest of Rubicon (T. 1 S., R. 17 W.). The direction of dip of the uplifts during Cretaceous time. Part of these uplifts may Mountain Valley lineament is uncertain. (The age relationships of sections 5, 6, and 7, which follow, cannot be stated with certainty. The order of presentation, however, is believed to be correct, and there is some evidence to support the order, as cited in this study.)

or no schistosity, a lack of obvious low-grade metamor- in the Broken Bow uplift of McCurtain County, Oklahoma,

Some major faults in the central Ouachitas extend for many miles, with a nearly east-west alignment along most of their length. They show up as relatively straight or gently curved fault traces in the valleys and lowlands parallel to the prominent synclinal-graben uplands that are usually capped by thick sandstone units. The strike of the faults is commonly parallel or subparallel to the Many of these faults are zones of closely spaced multiple faults, and fault wedges or slices can be seen locally within the zones. These major faults and fault zones appear to be steep at the surface: their trace is straight or only gently curved, and they are not traceable into the nearby topographic uplands. The fault planes may be curved with depth, but this is not indicated at the surface. They have a structural resemblance to the ranges involving Triassic rocks in the Appalachian and Piedmont provinces in eastern North America. Many of the major faults have been mapped previously (for example: Reinemund and Danilchik, 1957; Seely, 1963; Miser, 1959; Walthall, 1967), and it is clear that further intensive field studies combined with aerial-photograph examination are likely to bring to light many more major faults than have been recognized thus far. 6. The Big Anticlinoria

phism, and a general absence of quartz veins and high-tem-

there have been several later uplifts probably of the same

Late Pennsylvanian and younger strata in the foreland regions, each accompanied and followed by relatively deep Part of the uplift in these anticlinoria definitely took place in Early and Late Cretaceous time. Work by Speer and Melton (1971) describes some of the aspects of these have even preceded the steep faults of the big synclinal graben (section 5, preceding). Thus these uplifts may have been long lasting and frequently repeated. The uplifts may have begun in latest Pennsylvanian or Early Permian time. The evidence for this is found in 7. Big Cedar Fault Pennsylvanian and Permian sedimentary rocks northwest and west of the Ouachitas. The coarse, cherty channel conglomerates in the Middle and Upper Pennsylvanian of central Oklahoma and north-central Texas, cited for decades as proof of Ouachita orogenic episodes and uplift during the Pennsylvanian (Ham and Wilson, 1967; Tomlinson and McBee, 1959; Weaver, 1954), do not appear to constitute a complete, normal suite of tectonic or orogenic conglomerates of the type that should result from sharp uplift of this large regional system. These sedimentary rocks lack the vast flood of coarse erosional debris (hard quartzose sandstone clasts of Atoka and Jackfork sandstone) that would have had to be eroded from a rising Ouachita land area before the pre-Stanley cherty beds in the central uplifts could be exposed. Some 20,000 to 30,000 feet (6,100 to 9,150 m) of sandstones and shales would have had to be eroded before the pre-Stanley cherts were uncovered! Once exposed, chert and novaculite could have formed only a small part of the detritus. Even today, their outcrops are only about 5 percent of the total area of the Ouachita Mountains in Oklahoma and Arkansas. A flood of such coarse-grained quartzose clasts that should have been deposited is not present in the Middle and Late Pennsylvanian sedimentary rocks that are preserved in the vicinity of the Ouachitas. They may have existed close to the Ouachitas in an eastern facies of Early Permian rocks-perhaps of Garber, Duncan-San Angelo, or Whitehorse age. This coarse-grained eastern facies, if it existed, was subsequently eroded, probably during Triassic or Jurassic time. The existing Middle and Upper Pennsylvanian cherty stream conglomerates were probably

and possibly also in the Potato Hills of Oklahoma. The

usually aligned at a noticeable angle (10° to 30°) to the trend of the fault, whereas erratics in the other fault zones discussed are much more nearly parallel 2. The Big Cedar fault touches or borders the following major geologic features in Oklahoma and Arkansas: (1) Potato Hills complex, Oklahoma (south side and east end); (2) east end of Winding Stair Range and west end of Rich Mountain through Big Cedar Gap;

advance and sedimentary onlap of marine formations. The A Late Pennsylvanian or Early Permian age for this Pliocene or even Pleistocene time, although such late uplift of the anticlinoria seems most reasonable. Shale of the Boggy Formation (Pennsylvanian, Desmoinesian) is sea in this region (see Speer and Melton, 1971). folded and faulted within the frontal zone of the Quachita Mountains and also in the Arkoma basin. It is only the and well removed from the mountains-that are not deformed by orogeny in the present-day eroded Ouachitas, and the writer (Melton, 1930) found that Late Pennsylvanian and some Early Permian sedimentary rocks contain joint patterns that may be genetically related to the Qua chita crustal movements. In addition, adularia from quartz veins in the Ouachita Mountains gives isotopic ages showing that the last stage of low-grade metamorphism occurred during the Permian (Bass and Ferrara, 1969).

0 1 2 3 4 5 6 7 8 KILOMETERS

but of course long after Stanley time. In general, the surface rocks are of different tectonic aspects stratigraphi-The longest fault observed in the study region appears cally below and above the Mena (lineament) zone. to extend some 200 miles (322 km) from the east end of the Potato Hills in Oklahoma to Jacksonville in T. 3 N., a phase of the near-surface effects of continued and deeper R. 10 W., Arkansas. The significance of this fault was first subduction of a crustal plate in the later stages of its recognized at Big Cedar Gap, where it passes between activity. Examples of similar grabens containing Triassic Vinding Stair Mountain on the northwest and Rich rocks are well known in the eastern Appalachian-Piedmont Mountain on the southeast (T. 2 N., R. 25 E., Oklahoma). It is herein called the Big Cedar fault (maps B and C). This remarkable fault cuts across or touches a number f different structures in Oklahoma and Arkansas. In Oklahoma, at Big Cedar Gap, it truncates at a sharp angle nd apparently postdates other major faults of the area. Big Cedar fault is a fault zone along part of its length: slices and wedges such as Honess Mountain (secs. 28-30, 7.3 N., R. 26 E., Oklahoma) are incorporated within the fault zone, and a swarm of faults makes up the zone just southwest of Big Cedar Gap. It has been referred to as the "Y" City fault over much of its length in Arkansas. The fault appears to show left-lateral movement in the vicinity of Big Cedar Gap. A description of this fault in writing would be fruitless except to point out: 1. Fault erratics large enough to be seen in stereoscopic aerial photographs at a scale of 1:20,000 or larger are

largest structural features.

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The great contrast in rocks below and above the Mena lineament points to a separation of the stratigraphic section along a weak shale zone, below which there may have been underthrusting southward and above which there may have been overthrusting predominantly northward. Many diagrams illustrating subduction in the geophysical literature cause the reader to speculate on the possibility SEPM Annual Meeting Field Trip, p. 104-108. of separation of the section into an underthrust portion and an overthrust portion. If this has happened in the Ouachitas, it may have occurred above the lower Stanley, The large synclinal-graben upland ranges may also be MELTON, F. A., 1930, Age of the Ouachita orogeny and its tectonic MISER, H. D., 1943, Quartz veins in the Ouachita Mountains of

Finally, the reader should keep in mind that this contribution, together with the associated maps, is not a complete presentation of the geology of the Ouachita Mountain system. This study does emphasize the types of faulting, folding, and erosional remnants and the relative age relationships of structural features. The missing element, which would make a more complete contribution, would be detailed stratigraphic and structural mapping of the areas under discussion. The previously available stratigraphic and structural maps are undoubtedly the best possible that dedicated geologists could have produced at that time. The author feels that the time has come for a detailed structural study to be made, using the best available aerial photographs as well as the published stratigraphic-structural maps. The photographic scale should be larger than 2 inches per mile (1:31,680). Satellite and SEELY, D. R., 1963, Structure and stratigraphy of the Rich Mounsimilar imagery should be used, but it shows only the

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Post-Jackfork sediments (P-J; Pennsylvanian and Permian?)

Figure 2. Schematic cross sections through Ouachita Mountains in western Arkansas, showing progressive development. Vertical exaggeration, 2:1. Line of sections shown in figure 1.

The next stage may have been extensive broad antiderived from some area other than the central uplifts of clinal arching of the Benton-Mount Ida uplift of Arkansas the Ouachitas (possibly from the eastern Arbuckles) and (fig. 2d). Similar uplift probably occurred at the same time should not be used to date an uplift of the Ouachitas. STEREOSCOPIC AND MOSAIC AERIAL-PHOTOGRAPH STUDY OF THE STRUCTURE OF THE CENTRAL OUACHITA MOUNTAINS

IN OKLAHOMA AND ARKANSAS

Frank A. Melton 1976