THE PERMO-CARBONIFEROUS OROGENY IN THE SOUTH-CENTRAL UNITED STATES

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BY

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT

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ERRATA.

Page 70:

E. H. SELLARDS advised the writer that the effect of his paper in the September Bulletin of the American Association of Petroleum Geologists, 1931, p. 1038, and the statement on page 70 in this treatise, is to credit the discovery of overthrusting in the Solitario region to C. L. BAKER, but that this is incorrect, since overthrusting in that region was made known as the result of work by SELLARDS, ADKINS and ARICK, and is shown on maps which these authors have placed in circulation during 1930.

The writer wishes to correct this unintentional oversight.

Page 87, footnote:

SIDNEY POWERS advised the writer that the statement credited to him, that geophysical evidence suggests that the Appalachians continue in the subsurface towards New Orleans, was not based on personal observation, but that this fact had been communicated to him and he has not been in a position to check this information.

ABSTRACT.

This treatise is a synopsis of the late-Paleozoic orogeny in the South-Central States of North-America. Numerous recent papers by American geologists, and personal work of the writer and his collaborators, are coordinated into as complete a picture as our present knowledge of the largely buried late-Paleozoic chains and their foreland, along the south-eastern rim of Laurentia, permits.

Two independent mountain systems are distinguished:

1. The WICHITA-SYSTEM, comprises the Wichita Mountains, the Criner Hills, the Arbuckle Mountains, the buried folds along the Red River, including the Muenster Arch, and the equally buried Amarillo Mountains.

These folds, though belonging to the Permo-Carboniferous cycle, originated within an intra-continental, pre-Mississippian geosyncline, in which the major accumulation of predominantly marine limestone sediments was *pre-Devonian*.

This system strikes generally East-West and WNW-ESE.

It meets nearly at right angles the front of the second complex : the considerably more important Ouachita system.

2. The OUACHITA SYSTEM (in a wider sense), is a large arcuate feature, of which only a small portion of the widely overthrust outer rim of the northernmost loop is exposed in the Ouachita Mountains of southeastern Oklahoma and central Arkansas. Most of this system is buried, but the writer believes that the folds exposed in the Marathon Uplift in Southwest-Texas belong to the southwestern extension of the same system, which in Oklahoma and Arkansas is itself an extension of the southern Appalachians, which disappear in Alabama under the Cretaceous blanket of the Gulf Coast Plain.

Unlike the Wichita complex, the Ouachita ranges originate from an inter-continental Carboniferous geosyncline, with major post-Devonian deposition, *principally in the latest Mississippian and early-Pennsylvanian*. The facies of the pre-Pennsylvanian rocks is also intrinsically different. The exposed portion consists of great overthrust masses, of a type that can best be compared with the northern front of the European Variscan Mountain System in France, Belgium and Westfalia. The principal phases of folding in both the Wichita and Ouachita orogenies are Pennsylvanian, and the final overthrusting of the Ouachitas is possibly Permian. Precursory late-Mississippian movements are in evidence or indicated.

Much recent geological work, based on the extensive drilling campaign for petroleum, has enabled us to trace the rim of the buried Ouachita range conclusively in the sub-surface of East-Central Texas, especially by

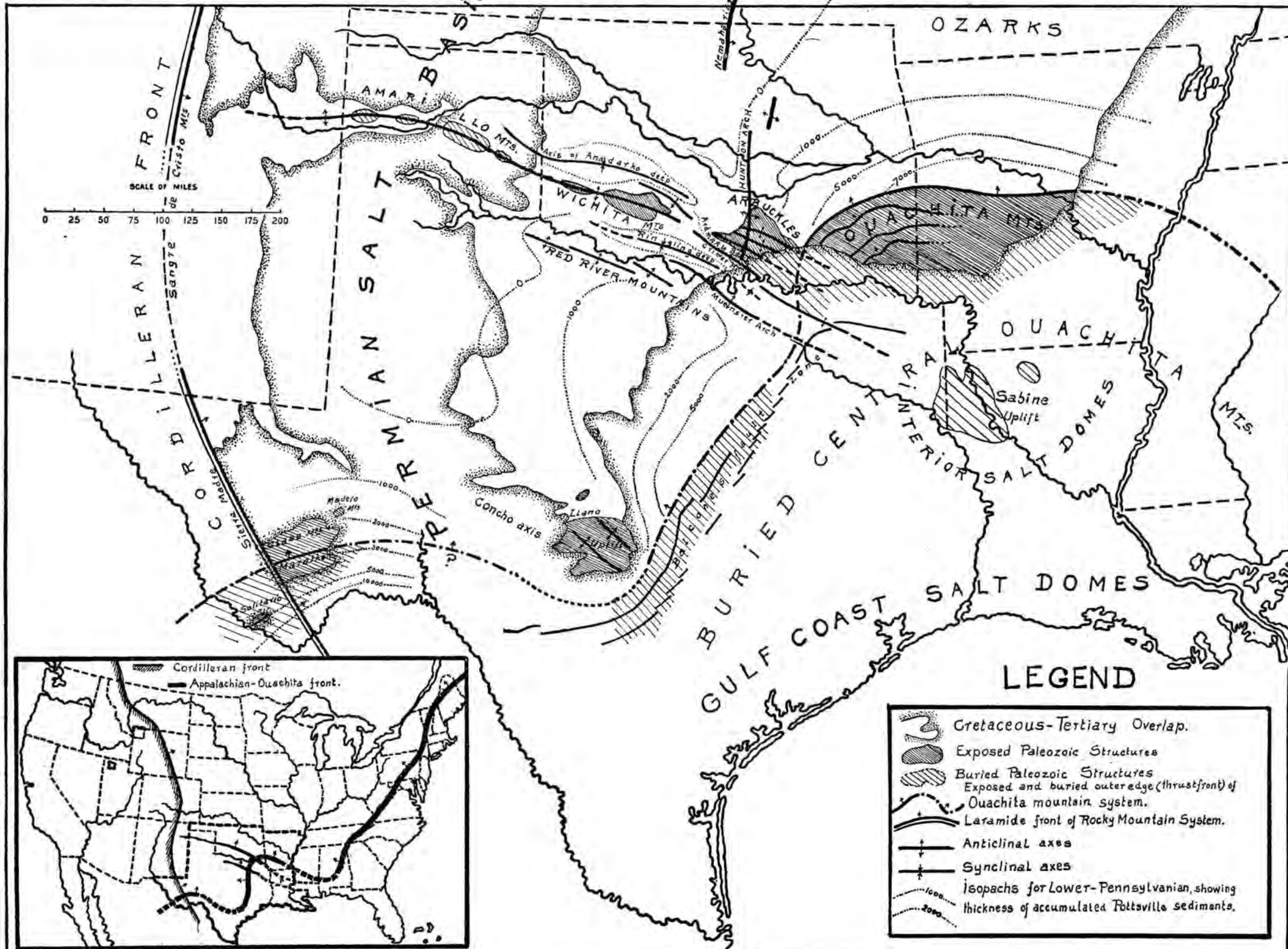
the characteristic depressed early-Pennsylvanian foreland-basin of sedimentation, which exactly reproduces the coalbasin foredeep of southeastern Oklahoma and Arkansas. The present Llano-Burnett Uplift marks the existence of a resistent buttress in the foreland, which causes a salient around which the chain turns, to reassume an East-West to Southwest course in southern and southwestern Texas, where the folds reappear at Marathon and Solitario, after which we lose them underneath the Cordillera in Mexico.

The Hunton Arch is another buttress, causing the uplift of the foreland fault slices of the Arbuckles.

The character of *the nappe-structure of the Ouachita chains* is discussed from the little knowledge we have of the small exposed portion in the Ouachita Mountains, and at Marathon in southwestern Texas, both still imperfectly surveyed, and which, moreover, only represent the outer rim, comparable to the frontal flysch- and molasse zones of the Alps and the Carpathians, and particularly to the similar Paleozoic "flysch" of the great Variscan system of Europe in the coalfields of southern England and Wales, northern France, Belgium, Holland and Westfalia and their immediate hinterland. The mountain structure in the South-Central United States, and the fore- and hinterlands, are discussed in constant comparison to other chains, notably in Europe.

Incidentally, a new explanation is offered for the *"glacial boulders" in the Caney shale (Mississippian) of the Ouachita Mountains.* Their glacial character is emphatically disputed. They are considered as "exotic blocks", comparable in particular to the "klippen" of the Carpathians and the flysch-blocks of the frontal thrustsheets of the Alps.

PLATE 1.


OZARKS
AMARILLO MTS.
PERMIAN SALT BASIN
CORDILLERAN FRONT
Sangre de Cristo Mts
SCALE OF MILES
0 25 50 75 100 125 150 175 200
WICHITA MTS
ARBUCKLES
OUACHITA MTS.
RED RIVER MOUNTAINS
Muenster Arch
Nemaha
Hunton Arch
OUACHITA
Sabine Uplift
INTERIOR SALT DOMES
BURIED CENTRAL ZONE
GULF COAST SALT DOMES
Concho axis
Llano Uplift
Marathon
Solitario
Sierra Madre
Cordilleran front
Appalachian-Ouachita front.
LEGEND
Cretaceous-Tertiary Overlap.
Exposed Paleozoic Structures
Buried Paleozoic Structures
Exposed and buried outer edge (thrustfront) of Ouachita mountain system.
Laramide front of Rocky Mountain System.
Anticlinal axes
Synclinal axes
Isopachs for Lower-Pennsylvanian, showing thickness of accumulated Pottsville sediments.

INTRODUCTION.

The region under discussion in this paper is bordered to the west by the eastern edge of the Rocky Mountain system, to the south by the Rio Grande and the Gulf of Mexico, to the east by the Mississippi River, and to the north by the northern State lines of Kansas and Arkansas.

It comprises the southwestern spur of the Laurentian nucleus of the North-American continent, its covering of Paleozoic plateau-deposits, and its rim of late-Paleozoic mountains. This region is not only of great interest for the regional structure of the continent, but its knowledge is important for all such geological studies as embrace structural problems of the earth's crust as a whole. Up to very recently the region was very imperfectly known, a condition of which many of the European geological textbooks and tectonic studies show evidence. The scanty geological information available was scattered over a great number of mostly disconnected papers, with not infrequently conflicting conclusions. The area is also of considerable importance from a viewpoint of economic geology, since it contains several of the most important accumulations of petroleum in the world, as well as immense deposits of rocksalt and potash.

This treatise contains the results of about twelve years of work of the writer in the southern Midcontinent of the United States. It was presented in abstract at the New Orleans meeting of the American Association of Petroleum Geologists in March 1930; the same subject was shortly introduced at the meeting of the Royal Academy of Sciences in Amsterdam in February 1930 [1]). It is also being published in an abbreviated form in the Bulletin of the American Association of Petroleum Geologists. (1931) [2]).

The writer wishes to express his thanks to the numerous geologists who collaborated with him in the organisations which he has directed, and have assisted him in this research work. He wishes especially to mention: F. L. AURIN, MAX W. BALL, H. L. BALDWIN, J. C. BARTRAM, W. R. BERGER, W. G. BLANCHARD, A. E. BRAINERD, D. D. CHRISTNER, G. C. CLARK, R. A. CONKLING, ALEXANDER DEUSSEN, F. P. GEYER, B. F. HAKE, T. K. HARNSBERGER, C. E. HYDE, J. V. HOWELL, P. B. HUNTER, I. A. KEYTE, G. C. KIRBY, A. W. MCCOY, J. J. MAUCINI, F. B. PLUMMER, G. M. RUBY,

[1]) Verslag van de gewone vergadering der Afdeeling Natuurkunde, Deel XXXIX, N⁰. 2.

[2]) Very similar views as are put forward in this treatise, have been pronounced by Ph. B. KING in Bulletin No. 3038 of the University of Texas, published in the spring of 1931, while this publication was in the press. (cf. **120**, pp. 113—116). The fact that two workers, entirely independent of each other, the one of which has had the benifit of considerable more recent and extensive personal work in the field, have come to such similar conclusions, is considered as a most welcome confirmation by the writer.

J. M. TATUM, E. A. TRAGER, CH. R. VERTREES, C. G. WILLIS, and ROBIN WILLIS. In addition, the writer owes much information and assistance to a large number of geologists, their friendly personal intercourse and subsequent correspondence, and the papers cited in the annexed bibliography. Thanks are expressed in particular to E. H. SELLARDS, F. H. LAHEE, SIDNEY POWERS, BRUCE H. HARLTON, C. L. BAKER, PH. B. KING and H. D. MISER.

The Paleozoic geology and paleo-geography of the region under discussion is entirely controlled by a system of mountains, which derives its origin from the great world-wide Permo-Carboniferous orogenic cycle. These chains evidently control the sedimentation, structure and consequent accumulation of petroleum in the region. This is not merely true for the Paleozoic oilreservoirs, but it is probable that many of the important oilfields of the southern States, which occur in younger strata, from the late-Permian to the younger Tertiary, are structurally as well as genetically influenced by the general plan, and possibly even in some cases bij petroliferous strata of the Paleozoic basement.

Our subject is one of particular difficulty, because to a far greater extent than the Permo-Carboniferous structures of Eurasia, the old mountains are almost completely buried under a great thickness of more recent, chiefly Cretaceous sediments. In the Gulf Coast Plain these grade up into a great mass of Tertiary. Even within the Plateau region a thick blanket of Permian deposits, deposited after the diastrophism, obscures the old foreland folds.

Only in a few, very restricted areas are fragments of the old structures exposed: the Ouachita Mountains of southwestern Arkansas and southeastern Oklahoma, the Arbuckle Mountains and the Wichita Mountains in southwestern Oklahoma. These conspicuous islands of Paleozoic and older rocks, with their intense folding, have attracted the attention of geologists from the very first moment that this region began to be scientifically explored. The general age of the diastrophism and its apparent relation to the great Permo-Carboniferous system of the Appalachians farther east were soon recognised. It was difficult, however, to correlate the isolated outcrops, which presented disconcerting differences in facies of the rocks as well as in structure. The same applied to another isolated exposure of Paleozoic folds, considerably farther to the southwest, in the uplifts of Marathon and Solitario, in the midst of the Cretaceous blanket. We will see that the Llano-Burnett Uplift of Paleozoic and pre-Cambrian rocks in Central-Texas is no part of the mountains but a foreland massif.

Until quite recently the work of geologists had been chiefly confined to local analysis of the exposed features in the individual horsts. It is only through the extensive exploration for petroleum that we have finally obtained sufficient knowledge of the older Paleozoic floor in the adjacent areas to enable us to attempt a more regional analysis of the fundamental structure of the region. Very valuable information has recently been published in a number of papers by various workers, many of them petroleum geologists, who have assembled and discussed the results of the intense drilling campaign of the last ten years. I cite in particular papers by LUTHER H. WHITE (**113**, 1926), C. W. TOMLINSON (**99**, 1927), ROB. H. DOTT (**38**, 1927), C. W. HONESS (**55**, **56**, 1923—1927), SIDNEY POWERS (**83**, 1928), H. D. MISER (**75**, **76**, **77**, 1926—1929), M. G. CHENEY (**27**, **28**, 1929), C. M. BECKER (**13**, 1930), F. A. MELTON (**73**, 1930), PH. B. and R. E. KING (**63**, **64**, **65**, **120**, 1926—1930), and many others cited in the attached bibliography [1]).

In the present treatise the writer will assemble, critically discuss and correlate the available material further, attempting to give a comprehensive picture of the general structure of the mountain chains, encircling this important region, and to offer a theory which has gradually grown in his conviction, and has considerably been strengthened by the valuable data, observations and thoughts of the authors referred to. Much of the latest work cited has brought considerable confirmation of his theory, after it had already been given out in the advance notices referred to on page 3.

His views have been further corroborated by comparison of the results obtained in the great progress which has been made during these last years in the knowledge of the structure of the Alpine and Variscan chains of Europe, which the writer has been able to study after his return from America.

For much detail the reader must be referred to the papers cited.

As a general introduction the following outstanding facts may be brought forward from the mass of information now at our disposal. They will be discussed further in the subsequent chapters.

(The reader is referred to the map *Plate 1.*)

THE KNOWN MOUNTAIN BLOCKS.

In addition to the already mentioned Ouachita, Arbuckle and Wichita Mountains and the exposures at Marathon and Solitario, the drill has revealed a number of other buried structures, which clearly belong to the same system of mountain chains. They constitute similar trunkblocks, which fail to protrude through the covering blanket.

In the northwestern prolongation of the Wichita mountains a row of great buried masses of granite has been outlined by the drilling in northern Texas and eastern New Mexico. These are the Amarillo Mountains, famous for the immense accumulation of helium-bearing gas which overlies them, and the valuable oilfields of the Texas Panhandle on their northern flank.

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[1]) The figures in bold face type refer to the bibliography.

To the south of the exposures of the Wichita-Arbuckle Mountains, a wide zone of echelon folds has been revealed by the drill, all along the Red River in the border region between Oklahoma and northern Texas. The Criner Hills, just south of the Arbuckle Mountains, are a small isolated exposure of these structures, all the others are buried. These anticlines cause a number of well known oilfields. They evidently belong to the same general zone of folding as the exposed portion of the Wichita chain, and contain the same series of sediments in the same facies.

To the south, southeast and east of the Llano-Burnett Uplift of pre-Cambrian rocks, in eastern Texas, wells have reached Paleozoic and some metamorphic, possibly Proterozoic rocks, in Ouachita facies. Old-Paleozoics in Wichita facies have been reached all around the Llano Uplift, and were found productive of oil at Big Lake in the West-Texas Salt Basin.

THE PRE-CAMBRIAN BASEMENT OF THE SOUTHERN REGION OF THE MID-CONTINENT PLATEAU consists of a rather thoroughly baseleveled floor of gneisses, shists, some crystalline limestones and other metamorphic sedimentaries, with intrusions of granite and other plutonic rocks.

Some, possibly very ancient, positive elements are in evidence in this region. These influence the structure as well as later sedimentation in their neighbourhood. Amongst these, the Ozark Dome, the Nemaha Granite Ridge of Kansas, the Hunton Arch of southeastern Oklahoma, and the Concho Divide of South-Central Texas (to which belongs the outcropping Llano-Burnett Uplift), are particularly prominent.

Two general trends are suggested in the old basement: the most prominent one strikes generally North-South, with deflections to NNE and NNW; it is most clearly developed in Oklahoma and Kansas. Another Northwest-Southeast strike is more in evidence in Texas, in the old rocks of the Llano-Burnett Uplift and forming the Concho Divide, but is possibly reflected in similar directions farther to the north in the area of the Salina Basin of western Kansas. These two directions may reflect the old grain of Laurentia, which thereby continues to influence part of the Paleozoic deformation.

The ancient substructure of the Nemaha Granite Range of Kansas appears to the writer as an uplifted tilted faultblock in the old floor, with a downthrow faultscarp on its eastern side, similar in structure to the many long faultblock ranges, (of much more recent date), in the Great Basin Province of the West. The ridge lies to the southeast of a major spur of the Canadian Shield, which it parallels in its general NNE-SSW trend: the Sioux Spur in Minnesota, Colorado, Utah and Nebraska, — which finds extension in the shallow buried granite masses of western Kansas (west of the Salina Basin), in southeastern Colorado and northeastern New-Mexico. Pre-Paleozoic erosion may already have leveled the Nemaha

Granite Ridge. Early in the Pennsylvanian it was a chain of mountains, with numerous culminating peaks and deep cross depressions [1]).

Paralleling the Nemaha Range in Kansas, and beyond its southern end, where it dies out near the Oklahoma state line, a series of similarly shaped and trending minor structures, more or less en echelon, appears. These have, in all probability, an analogous deepseated origin and reflect fault blocks in the basement floor. On these structures many of the oilpools of Kansas, and of the major oilfields of central Oklahoma are located: the Blackwell, Thomas, Newkirk, Ponca, Tonkawa, Billings, Garber, Marschall-Lovell, and Oklahoma City pools. There probably exist others, which are still undiscovered. Nearly all these are more or less north-south trending anticlines, overlying tilted fault blocks, with a fault, or at least a steep flexure, mostly on their eastern side.

Another ancient feature, with the same general meridian trend and almost certainly rooting in the pre-Cambrian, is *the Hunton Arch.* It evidently extends southward through the Arbuckle uplift. This ancient positive element must be considered as ante-dating the geosyncline, from which the Wichita group of mountains originated. It is probably responsible for the fact that the present Arbuckle Mountains, and the Criner Hills to the south of them, now again stand out as uplifts, exposing the old mountain structure, where all surrounding features are buried. Already in Pennsylvanian times it caused the Arbuckle region to stand out from the otherwise submerged foreland, and to remain subject to erosion. The great region of oil accumulation in the Seminole district is also directly influenced by the Hunton Arch. The Cushing structure belongs to a similar feature.

Analogous old axes in the basement might cause the *present* rejuvenated topographic uplift of the Wichitas. Similarly, the present physiographic expression of the Ouachitas seems to be related to another old positive element: the Ozark dome. To the west the region is bordered by the great uplifted front scarp of *the Rocky-Mountains* and *Sangre de Cristo Range.* This seems a true crustal thrust-block in the sense of Argand.

The whole of the ancient „Siouia" mass of SCHUCHERT was subject to much orogenic disturbance in late Paleozoic time. The „Ancestral Rockey Mountains" of this age, are also called the „San Luis Mountain System". The eastern front ranges of this system were initiated at least as early as late-Pennsylvanian time, but they did not assume their present form until between Cretaceous and late-Tertiary time. There is also some evidence of movements at the close of the Ordovician (Caledonide revolution?), and in the Grand Canyon region, as far back as the pre-Cambrian.

[1]) For further details, see: H. W. Mc CLELLAN (117), and also:
E. HAWORTH: Kansas Geol. Survey Bull. 1915.
CHAS. H. TAYLOR: A. A. P. G. Bull. I, (1916—1917).
R. C. MOORE: A. A. P. G. Bull. II, (1918) and Bull. IV, (1920).
HENRY A. LEY: A. A. P. G. Bull. X, (1926).

A pre-Cambrian primary origin of the frontal Rocky Mountains is suggested but not proved.

The pre-Cambrian basement of the Plateau region first received a blanket of sediments, extending from the Cambrian until the close of Hunton time (lower-Devonian). Old-Paleozoic (Caledonide) minor warping is indicated. This was succeeded by a period of emergence, during which the region was slightly tilted in a WSW direction, away from the Ozark doming, and eroded to a peneplain, in which all the formations from the Ordovician to the lower-Devonian inclusive are exposed in very persistent facies, now forming broad belts, with a general WNW strike (**113**). Deposition followed again in the Chattanooga period (lowermost Mississippian), unconformably overlying the old peneplain. This was succeeded by the mass of the "Mississippi limestone" and shales.

All the mentioned structures were considerably folded, faulted and uplifted, and thereafter eroded in post-Mississippian—pre-Cherokee time, indicating an early-Pennsylvanian orogenic phase affecting this entire area. The entire Midcontinent Plateau was domed and emerged in this period. Another submergence covered the landscape by a blanket of late lower-Pennsylvanian (Cherokee) sediments. This period of deposition continued until well into the Permian (**6, 30, 117, 118**).

During the entire Pennsylvanian and much of the Permian, orogeny was active along the southern border of the old Plateau and reverberated more or less in its frame. After middle-Permian time this entire region was still slightly warped, and finally eroded down to sealevel. It was completely flooded by the Coloradoan sea, starting late in the Jurassic in the West, and continuing during Cretaceous time. Much of the here mentioned structure was rejuvenated in Tertiary and probably still more recent times, when the whole of the earth's crust became subject again to drift and warping, culminating in the worldwide Alpine orogeny.

THE TWO PALEOZOIC GEOSYNCLINES.

Two distinct geosynclinal troughs control the paleo-geographic distribution, as well as the facies and structure of the Paleozoic sediments, which were laid down over the pre-Cambrian basement in this region. These are :

I. A minor OLD-PALEOZOIC (PRE-DEVONIAN) GEOSYNCLINE trending WNW-ESE (a pre-Cambrian direction ?) through southern Oklahoma and northern Texas, the belt now occupied by the Wichita-Arbuckle Mountains. We will see that this geosyncline is an intra-continental one, still within the Plateau, at least in its known part in Texas and Oklahoma, since the Plateau-region continues to the south of it in Central-Texas. This trough accumulated a great thickness (9000 feet) of Cambro-Ordovician to lower-Devonian sediments, largely in massive marine limestone facies. This same facies of the old-Paleozoic covers this entire area of the Plateau [1]), but here it represents only an aggregate thickness of some 1000—1500 feet, thinning towards the north and the west, with the exclusion of a thickening in the Salina Basin of Kansas. The massive Arbuckle limestone (Cambro-Ordovician) is the most prominent feature. This member alone reaches a thickness of 4000 to 6000 feet in the Wichita-Arbuckle geosyncline, against 800—1000 feet in the equivalent „Siliceous Limestone" of Oklahoma and Kansas, which thins towards the north. The „Ellenburger Limestone" of Texas, south of the geosyncline, with a thickness of at least 1000 feet, belongs to the same facies, and is of lower-Ordovician age.

This geosynclinal development of the Cambro-Ordovician and Silurian is succeeded by some 1500 feet of Lower-Carboniferous: Woodford Chert, Sycamore Limestone and the lower portion of the Caney Shale, and these, in turn, by lower Pennsylvanian rocks. There is indication that, originally, and at least in part, the Wichita geosyncline also contained a great thickness of Mississippian; much of this is still preserved from erosion in northwestern Oklahoma and parts of southwestern Kansas.

II. A considerably more important CARBONIFEROUS GEOSYNCLINE skirted the Plateau region beyond its southern rim. This has the characteristics of an outer inter-continental geosyncline. It shows an *entirely distinct province of sedimentation*, very different from the development in the Wichita intra-continental trough.

Here no abnormal thickness of pre-Devonian sediments is in evidence and the facies is totally different from that of these strata on the Plateau or in the Wichita geosyncline. The Ordovician-Devonian series is no longer developed as a massive limestone sequence, but as some 3000 feet of graptolite bearing siliceous shales, cherts and some finegrained quartzitic sandstones. It is only in the upper part of the lower-Carboniferous that geosynclinal conditions become very pronounced, causing accumulation of the enormous thickness of 17.000 to 20.000 feet of late-Mississippian to early-Pennsylvanian sediments, not represented in the Arbuckle-Wichita Mountains. This clastic, not limestone, uppermost Mississippian of the Ouachita geosyncline presents a typical "flysch"-facies and must be considered *an orogenic deposit*; the middle and lower limestone zones of the foreland Mississippian are either absent or, possibly, are represented by the upper part of the cherts of the Arkansas Novaculite [2]).

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[1]) On the broad Ozark doming they have been partly eroded off, and a portion of them may never have been deposited. (See L. H. WHITE, **113**).

[2]) The Alpine *Flysch* is a sequence of sediments deposited during the later stages (Cretaceous to Oligocene) of the geosyncline, directly previous to the major paroxysm, when initial diastrophism had already developed interior ridges exposed to erosion. In the locally shallow, but elsewhere probably very deep troughs of this early structure, a very characteristic marine sequence, composed chiefly of poorly fossiliferous clayey muds, with more or less sandy beds intercalated in the shales, were laid down to a great thickness.

DIASTROPHISM: TWO DISTINCT MOUNTAIN SYSTEMS.

The first described pre-Devonian geosyncline was in upper-Carboniferous time compressed into the WNW—ESE folds of the Wichita Mountains, the Criner Hills, the echelon folds of the Red River—Muenster Arch, and finally in a later phase, of the Arbuckle Mountains. The buried Amarillo Mountains belong to the same orogeny.

This complex of chains we will call the WICHITA SYSTEM for the purpose of this treatise.

The second, major geosyncline has been compressed and overthrust into the Ouachita Mountains, quite distinct in facies as well as in structure.

Only a small portion of the outer rim of this certainly very important mountain complex has remained exposed in southeastern Oklahoma and central Arkansas, probably due to the rejuvenating action of the great positive element of the Ozark Dome, of which the present Ouachita Mountains constitute the southern flank in the present topography.

The same Ouachita Mountain complex reappears at the surface far to the southwest in Southwest-Texas, in the erosional inliers in the Cretaceous blanket at Marathon and the Solitario uplift.

The great arcuate chain of the Ouachitas has been strongly pushed to the northwest. The Oklahoma-Arkansas Ouachita Mountains must be considered as lying considerably farther north than the original geosyncline in which these rocks were deposited. They have, in the writers opinion, been pushed far out over their foreland. The geosynclinal region from where they came may have been located to the south of the Sabine Uplift in northern Louisiana, and extended under the region now occupied by the Gulf of Mexico.

For the purposes of this treatise, we will refer to all the mountains issuing from this geosyncline as the OUACHITA MOUNTAIN SYSTEM in its wider sense.

This formation can be conceived as rapidly filling the foredeep, which was being depressed in front of an advancing major crustal thrustblock and migrating with it.

Since this typical flysch is not confined to the Alps and the Carpathians, but is a characteristic deposit found associated with all folded mountain systems of Alpine structure, the term "*flysch*" is used to denote this particular orogenic *facies* anywhere in the world, regardless of its age and the location where it occurs.

The *molasse* in the Alps is a generally much more clastic, very thick sequence, succeeding the flysch; partly marine, partly deltaic, often containing enormous masses of coarse conglomerates. It is the detritus worn from elevated ranges during and immediately posterior to the major diastrophism, deposited in a *later* foredeep, considerably in front of the preceeding flysch geosyncline.

It may be deformed and overthrust by the final last advance of the nappes.

This is also a typical formation common to all large mountain chains, and hence the term "*molasse*" may be applied to all orogenic deposits of a similar genesis.

Consequently, this paper continuously speaks of the flysch and molasse deposits of the Paleozoic American mountains, which we are discussing.

THE PRE-PERMIAN SEQUENCE IN THE WICHITA GEOSYNCLINE AND ARDMORE BASIN.

TABLE I

System	Series	Formations		Thickness in feet	Description of sediments
UPPER-CARBONIFEROUS	CONEMAUGH	UPPER-CISCO	Redbeds (Permian?) Konawa / Stratford; Pontotoc: Van Oss	250—1500	arkosic red sandstones, conglomerates, shales, (and thin limestones), deposited around Arbuckle Mts, Wichita Mts, and Red River chains, merging into undifferentiated redbeds to N and NW.
UPPER-CARBONIFEROUS	CONEMAUGH	Break and hiatus in Middle-Cisco in NE. Texas			Ada formation, Vamoosa formation: not yet arkosic conglomerates and sandstones in Pontotoc and Seminole counties, Okla. ∼∼∼ large angular unconformity: ARBUCKLE PHASE.
UPPER-CARBONIFEROUS	CONEMAUGH	LOWER-CISCO	ARDMORE BASIN GLENN Fm.[1]: Hoxbar formation	4000	chiefly shales, limestones, non-arkosic sandstones.
UPPER-CARBONIFEROUS	ALLEGHENY	CANYON	ARDMORE BASIN GLENN Fm.[1]: Hoxbar formation		
UPPER-CARBONIFEROUS	ALLEGHENY	STRAWN	ARDMORE BASIN GLENN Fm.[1]: Deese fm.	6000—7000	sandstones and chert conglomerates, separated by shales, with minor limestone shells.
UPPER-CARBONIFEROUS	POTTSVILLE	MORROW (Upper-Pottsville)	ARDMORE BASIN GLENN Fm.[1]: Dornick Hills fm.	2500—4000	shales, limestones and sandstones, limestone conglomerates. ∼∼∼ unconformity: WICHITA PHASE.
UPPER-CARBONIFEROUS	POTTSVILLE	MORROW (Upper-Pottsville)	ARDMORE BASIN GLENN Fm.[1]: Wapanucka lm.	100	limestone, represented in Arbuckle region.
UPPER-CARBONIFEROUS	POTTSVILLE	MORROW (Upper-Pottsville)	ARDMORE BASIN GLENN Fm.[1]: Springer formation	3000—3500	black bituminous shales with several sandstones: only known in Ardmore Basin, where it may represent upper portion of Arbuckle Caney (circa 1600 feet).
UPPER-CARBONIFEROUS	POTTSVILLE	Middle- and Lower-Pottsville. ?	Ardmore Basin Caney	up to 2500	black shales. *Probable hiatus in series increasing in extent to NW.*
LOWER-CARBONIFEROUS	MISSISSIPPIAN		Sycamore	200	limestone, Boone age.
LOWER-CARBONIFEROUS	MISSISSIPPIAN		Woodford	250—600	chert. < break in the sedimentation.
DEVONIAN (Lower) / SILURIAN			Hunton	150—300	Frisco limestone (± 20 ft); Bois d'Arc limestone (± 60 ft), Oriskany. Harragan shale (± 100 ft), Helderbergian. Henry House shale (± 90 ft), Niagaran fauna. Chimney Hill limestone (± 35 ft), Alexandrian fauna.
SILURIAN			Sylvan	300	greenish shale, Richmond fauna. ∼∼∼ unconformity at base of Fernvale horizon ∼∼∼
ORDOVICIAN			Viola	500—700	limestone, Cincinnatian.
ORDOVICIAN			Simpson	1200—2400	limestones, sandstones, shales, in thin alternating beds; bituminous, Trenton to Chazy. ∼∼∼ *slight warping* ∼∼∼
ORDOVICIAN			Arbuckle	5000—8000	massive marine limestone, largely dolomitic in lower portion. Fossils represent from upper-Cambrian to Beekmantown ages.
CAMBRIAN			Reagan	300—500	arkosic sandstones; glauconitic in part.

∼∼∼ major unconformity ∼∼∼

PRE-CAMBRIAN: Basement rocks: gneisses, shists, granite and other igneous rocks.

REMARKS

These sediments, being detritus from the mountains of the Arbuckle-Wichita chains, decrease rapidly in thickness toward the north, the lower members failing entirely. The Ouachitas are no source region for these deposits.

Equivalent sequence in northern Oklahoma and Kansas:

Wabaunsee, Shawnee, Douglas	Cisco	less than 2000 feet
Lansing, Kansas City	(Canyon)	
Marmaton, Cherokee	Strawn)	

No lower Pennsylvanian is represented in Kansas, northern and western Oklahoma, and northwestern Texas.

The *Arbuckle phase* occurred near the end of Lansing time and previous to most of the Douglas deposition. There is no break, however, and still less unconformity in northern Oklahoma and Kansas.

In the Ardmore Basin, the sediments above the Bostwick horizon of the Dornick Hills originate predominantly from the Ouachita region. Below the Bostwick horizon the principial source is from the Criner Hills (Wichita system).

The *Wichita phase* is not represented in the true Arbuckle Mountains and the Ardmore Basin, but confined to the central-Wichita chains. Epeirogenic uplift in northern Arbuckle region and on Hunton Arch.

The lower-Pottsville and uppermost-Mississippian formations are detritus from the earlier pulsation of the Wichita orogenic phase, which seems confined to the Ouachita system: these deposits are restricted to the region adjacent to their source in the Ouachitas: the Ardmore Basin (cf. Table II). Outside of the Ouachita province they thin away to the NW; they seem absent in the Anadarko Basin. The 1600 feet of "Caney" north of the Arbuckle Mountains, in all probability, comprise both Springer and Caney of the Ardmore Basin.

With the exception of the Wichita geosyncline, and also of the Salina Basin in Kansas, the pre-Carboniferous sequence on the Plateau measures only 1000—2500 ft. in Texas, and ± 1500 ft. in Oklahoma. The facies, however, remains everywhere the same as in the Wichita geosyncline, and is intrinsically different from the Ouachita facies of the corresponding formations, as represented in Table II. [2])

[1]) The Glenn sequence (Springer to Hoxbar) is confined to the Ardmore Basin; the Deese and the Hoxbar are also present in the Waurika Basin; whether lower Glenn horizons are present there is not known.
The correlation of the Glenn sequence of the Ardmore Basin is still somewhat uncertain. Here the views are followed of BRUCE H. HARLTON, R. C. MOORE and C. O. DUNBAR, which seem to represent the most reliable consensus of opinion after recent research work.

[2]) Mississippian in great thickness (1500—1800 ft.) has recently been found to underlie the Pennsylvanian in northwestern Oklahoma and southwestern Kansas. It is youngest Chester, overlying the equivalent of the "Mississippi lime" (Boone). It begins near Oklahoma City and extends in the direction of Kingfisher, Okla. It may be possible that this Mississippian basin is part of the pre-Carboniferous Wichita geosyncline, and extends under the Anadarko Basin; it may once have been present in the region of the Wichita chains, before Pennsylvanian uplift and erosion obliterated all traces of it.

THE PRE-PERMIAN SEQUENCE IN THE OUACHITA GEOSYNCLINE.

TABLE II

FORMATIONS				THICKNESS IN FEET	DESCRIPTION OF SEDIMENTS	REMARKS	
UPPER CARBONIFEROUS	Allegheny	CANYON	Seminole cgl.	15–350	Shales and sandstones, conglomerate in top, predominantly but not exclusively erosion products of the Ouachita Mountains to the south ("molasse"). The thickness decreases away from the mountains to the northward; maximum in Coal Basin, dwindles to 1200–1500 feet at Tahlequah and near Muskogee.	OUACHITA "MOLASSE"	Down to the Hartshorne sandstone these formations are only represented in the foreland trough, not in the thrusted sheets of the Ouachita Mountains. The lower members are only represented in the foredeep, not farther out on the Plateau.
			Holdenville sh.	180–260			
			Wewoka fm.	50–700			
			Wetumka sh.	80–120			
			Calvin ss.	0–240			
			Senora fm.	50–500			
			Stuart sh.	90–280			
			Thurman ss. & cgl.	80–280			
			Boggy sh.	2000–3000			
			Savanna ss.	750–2000			
		STRAWN	Mc Alester fm.	1150–2500 (Total max. ± 9000 ft.)			The Wetumka correlates with the Fort Scott limestone.
			Hartshorne ss.	100–200			
	Pottsville		Atoka fm.	3000 to 9500	interbedded sandstones and shales; varies considerably locally. Occurs both in foreland and on the thrustsheets of Ouachitas. Sandstones predominate in northeastern section.		The foreland Atoka is of Pottsville age. The base of the Pennsylvanian ("Atoka") on the thrustsheets is of Morrow age, and represents the Wapanucka = „upper-Jackfork" of Honess. The pronounced influence of the Ouachitas as a source region for the Ardmore Basin Glenn sediments begins above the Bostwick horizon of the Dornick Hills formation. The lower Dornick Hills is derived from the Criner Hills. (cf. Tables I and III).
					unconformity (upper-WICHITA PHASE)		
		MORROW	Wapanucka	0–100	cherty fossiliferous limestone.	OUACHITA "FLYSCH"	
		?	Ouachita "Caney" sh.	up to 2000	Blue-back shales; with certainty only developed on foreland and in autochtonous Ouachita belt north of Ti Valley shearplane. Within the Ouachita nappes the Caney, of the frontzone is included in the Jackfork.		The Wapanucka is not represented as limestone south of the Ti Valley shear, but seems included partly in the "Atoka", partly in the Jackfork of the thrustsheets. The Caney north of the Arbuckles (1600 feet) probably represents the entire Jackfork-Stanley sequence on the thrustsheets (17000 feet), and also the Springer-Caney sequence (5000 feet) of the Ardmore Basin. According to MISER, the Jackfork-Stanley are all upper Mississippian. The writer adopts the opinion of ULRICH, that the Jackfork is lowermost Pennsylvanian (lowest Pottsville), and only the Stanley is uppermost Mississippian and equivalent to the Parkwood formation of Alabama. The Jackfork-Stanley sequence is strictly confined to the flysch geosyncline, and represented by a hiatus on the foreland.
?	?	lowermost Pennsylvanian ?	Jackfork ss.	max. 6600	mostly sandstone in massive beds, with minor intercalations of blue and black shales, which disappear southward.		
LOW. CARBONIFEROUS	MISSISSIPPIAN	Parkwood	Stanley sh. ?	6000 to 10000	mostly blue shales, indurated into slates in places; intercalations of thinbedded finegrained dark-colored sandstones, increasing southward.		
		Chester to Osage	Hiatus ?		unconformity (lower-WICHITA PHASE)	According to ULRICH (**103**), the upper Novaculite may also represent the Keokuk and Kinderhook divisions of the Plateau Mississippian, thus replacing the predominant limestone facies by cherts. The lower Novaculite would represent the middle-Devonian of Tennessee. (MISER disputes this correlation). Lower Devonian is absent.	
		Kinderhook	Arkansas Novaculite	250–950	black and white cherts. *Break:* lower Devonian and upper Silurian missing.		
upper- and middle DEVONIAN							According to MISER (**75**), the Talihina chert, and underlying Stringtown shale, represent this entire sequence down to the Womble. Formations below the Stringtown shale are not exposed there.
SILURIAN			Missouri mountain slate	600–1500	shales and slates, basal conglomerate. (Niagaran ?)		
					unconformity		
			Blaylock ss.		thin sandstones with shales (Richmond fauna)		
ORDOVICIAN			Polk Creek shale Bigfork chert Womble shale Blakely sandstone Mazarn shale	1600–3500	Graptolite bearing shales, slates, cherts, with some sandstone and limestone members. Identifiable fossils range from middle Ordovician to Beekmantown.	Only known from southern part of the Ouachita Mountains, in Mc Curtain county, Oklahoma, and Montgomery county, Arkansas	
Lowest Ordovician?			Crystal Mountain ss.	500–850	massive grey eolian? sandstone, conglomerate at base.		
					unconformity		
CAMBRIAN			Collier slate	only 500 ft. exposed	metamorphosed shales, limestones with sandstone members; base not exposed; no lower formations are exposed or known from wells.		

Both the Wichita- and Ouachita mountain systems, regardless of the different age of their geosynclines, belong essentially to the Permo-Carboniferous cycle; both are the result of a push principally to the north. In the Ouachita chains, being strongly arcuate, the movement is directed to the northwest, and diverges to the west in those parts of the loop which trend more or less north-south in eastern Texas. It will be discussed later that the writer believes these chains to continue all through eastern Texas, to sweep around the Llano-Burnett Uplift, and to reappear at Marathon, from where we lose them under the folds of the Cordillera in the largely unexplored mountain wilderness of Chihuahua in Mexico.

Thus the Ouachita ranges are thought to encircle the entire southeastern spur of the Laurentian mass.

The writer's idea regarding *the relation between the Wichita- and Ouachita mountain systems* is the following:

The Wichita system crosses the western wing of the Ouachita loop practically at right angles in Atoka and Bryan counties, Oklahoma, and, to the writer's conviction, *passes underneath it*. The far more important Ouachita Mountains have been thrust to the west and northwest in a series of overthrust sheets, over the ante-dating Wichita system, which continues in the autochtone for an unknown distance to the southeast. Possibly, though sofar we have no means of knowing, the positive element of the Sabine Uplift of Louisiana, which lies exactly in the trend of the Wichitas, may be connected with these latter.

This will be discussed in detail in later chapters.

SEDIMENTAL SEQUENCE IN THE TWO GEOSYNCLINES.

The dissimilarity between the two sedimentary provinces is best illustrated by the two abbreviated *Tables I and II*.

In the WICHITA GEOSYNCLINE the pre-Permian sequence is briefly as represented in *Table I*, (this is the combined sequence in the Arbuckle Mountains and of the immediately adjacent Ardmore Basin).

In the OUACHITA GEOSYNCLINE we have the intrinsically different condition, devoid of any similarity with the Wichita sequence previous to the Pennsylvanian, which is condensed in *Table II*.

Therefore, we have in the WICHITA GEOSYNCLINE:

Upper-Carboniferous (Pennsylvanian):
foreland-"molasse": . . . . maximum thickness 20.000 feet;
(particularly developed in the foredeep-trough of the eastern section: the Ardmore Basin)

Lower-Carboniferous (Mississippian), known north of the Anadarko Basin:
limestone, shales and chert (quiet conditions) . . . . . ± 2.000 feet;

Cambro-Ordovician-Silurian:
largely massive marine limestones (marked basin) . . . 9.000 feet.
This we may call the *Wichita- or foreland facies.*

In the OUACHITA GEOSYNCLINE, on the contrary:
Upper-Carboniferous: foreland "molasse" (same development as in front of the eastern Wichitas) maximum 17.000 feet;
Lower-Carboniferous: shales and massive sandstones, in lowermost Pennsylvanian to upper-Mississippian orogenic "flysch"-facies; only uppermost Mississippian is present: maximum 17.000 feet;
Cambro-Ordovician-Silurian-Devonian, and possibly some lower Mississippian: graptolite bearing shales, siliceous limestones, locally predominant cherts, (presumably quiet deepwater conditions off shore): . . . . . 3.000 feet.
This we may call the *Ouachita facies.*

Though the Pennsylvanian erosion detritus is very similar for both mountain ranges, the pre-Pennsylvanian development is utterly distinct. We shall also see that in Permian time development was also different. The Wichitas yielded practically no more material late in the Permian, but the Ouachitas continued to disperse a large amount of sediment over their entire foreland. Early in the Permian and in the latest Pennsylvanian, conditions were to a considerable extent reversed.

Regardless of the utterly different facies, the full development of the Ouachita series is now found only 12 miles east of the outcropping Arbuckle sequence in Atoka county, Oklahoma. A well encountered Arbuckle rocks still 8 miles farther to the southeast of the outcrops. This is an irrefutable proof that great overthrusts must separate these two facies, and that we do not deal with mere overthrusting, but with shearplanes at the base of true frontal nappes, which have glided to the west and northwest over very considerable distances, introducing rocks in an exotic facies, deposited in an entirely different and originally remote province of sedimentation. The underlying autochtone must be in Wichita-Arbuckle (foreland) facies. This will be discussed in more detail farther down in the subsequent chapters.

Entirely unlike the Ouachita facies, the pre-Carboniferous sediments in the Wichita geosyncline are merely a local thickening of the same rocks, which have been laid down in the same facies over the entire Plateau in this area, both north and south of the geosyncline. The Cambro-Ordovician Arbuckle limestone, the most prominent member, is found as the 1500 to 1000 feet thick "Siliceous limestone" all over Oklahoma and in Kansas, where it gradually dwindles from 800 feet in northern Cowley county to only around 100 feet in eastern Clay county.

South of the Wichita geosyncline we find a practically equivalent

Cambro-Ordovician limestone of about 1500 feet, dwindling to 600 feet farther south, the "Ellenburger limestone".

Similar conditions apply to the Mississippian in the Wichita geosyncline, and both north and south of it on the Plateau. In Kansas and Oklahoma the Mississippian has emerged and been considerably eroded, notably on the structural highs, in pre-Cherokee time. In southwest Kansas and northwest Oklahoma, however, a very thick limestone series has been preserved in the Mississippian. Nowhere else, however, is there a considerable thickness. West of the Nemaha Ridge 300—400 feet of Mississippian still overlie the Chattanooga. In Central Texas the Mississippian, known at the surface to the eastward of Brown county, comprises the Boone limestone and overlying Barnett limestone and shale. In Hamilton and Coryell counties it measures only 100 to 125 feet. Mississippian is also present in Lampasas, Coleman, Brown and Taylor counties, but seems to disappear farther to the southwest, approaching the buried extension of the Ouachita mountains (**27**, **28**). The Woodford chert is questionably reported in north-central Texas. To what extent the Mississippian is developed throughout Texas as a whole, is still poorly determined and will require further coredrilling [1]).

As regards the Mississippian of the Ouachita geosyncline, it must be noted that *the flysch seems to comprise only uppermost Mississippian*. The age of the Jackfork is still somewhat in dispute. E. O. ULRICH (**103**) considers the Jackfork as basal Pennsylvanian, and bases his opinion in part on plantremains (loc. cit. pp. 47—48). HONESS obtained a fauna from a 6000 feet thick succession of sandstone in eastern Pushmataha and northern McCurtain counties, lithologically identical with Jackfork, which proved to be of Morrow age, and which he differentiated as "Upper-Jackfork" (**76**, p. 21). With HONESS' approval, these sandstones are now included in the Atoka on MISER'S new geologic map of Oklahoma. (**75**). H. D. MISER and C. W. HONESS bring paleontological evidence to bear, including an opinion by DAVID WHITE on Jackfork and Stanley plant remains, that both these formations are upper-Mississippian. The flora, however, is of an indistinct transitional character between Pennsylvanian and Mississippian. ULRICH (**103**, p. 21) considers the Stanley equivalent to the Parkwood formation of Alabama, which is uppermost Mississippian, younger than the Pitkin horizon of northeastern Oklahoma, and constitutes a series which is only developed in the Appalachian geosyncline, but is absent on the foreland: an orogenic deposit. All this, to the writer's opinion, proves that both lowermost-Pennsylvanian and uppermost-Mississippian sandstones and shales, in orogenic facies, occur in the overthrust nappes of the Ouachita Mountains. The very involved structure of these mountains, which is still far from unraveled in details, will always make it easily possible that these very similar sandstones and shales are locally confused.

[1]) E. H. SELLARDS: News letter from the Bureau of Economic Geology. January 1931.

It also seems evident, however, that no middle- and certainly no lower-Mississippian is contained in the Ouachita flysch. ULRICH believes that the Arkansas Novaculite-Talihina chert series of the nappes comprises lower-Mississippian (Osage and Kinderhook divisions) as well as Devonian, not in limestone, but in cherty facies, (**54**).

In the Marathon region the pre-Carboniferous rocks occur again in a facies which is much more related to that of the Ouachita geosyncline than to the limestone facies of the Wichita trough and of the Plateau. At Marathon we have a known sequence of some 1500 to 2000 feet of siliceous shales, sandstones and thin limestones, overlain by some 600 feet of upper Ordovician and Devonian cherts. We have to go all the way to the Van Horn region and El Paso before we again find outcropping Ordovician and Silurian in a massive limestone facies : El Paso and Montoya limestones, 1250 feet (Ordovician), overlain by 1000 feet of Fusselman dolomite (Silurian). Here again we are well out on the Ouachita foreland.

At Marathon we again find a great thickness of lower-Pennsylvanian to upper-Mississippian flysch, similar in lithology as well as, very probably, in age, to the same kind of sediments in the Ouachita Mountain region.

It is to be noted, therefor, that cherts and siliceous shales, next to limestones, form a notable constituent of the pre-Carboniferous series of this entire region, but limestones, though often cherty and siliceous, characterise the Plateau province and the intra-continental geosyncline of the Wichitas. In the major outer geosyncline of the Ouachitas the limestones recede very much in importance and cherts and siliceous shales predominate, indicating increased deposition of gelatinous silicate. Graptolites characterize these oozes. This facies proves more or less quiet conditions throughout the whole of the pre-Carboniferous, previous to the diastrophism, which only begins in Carboniferous times. The slight pre-Devonian (Caledonide) movements that are indicated, are only insignificant warpings. The southern province of the Plateau, in Central-Texas, already suggests that the limestone facies may be changing towards conditions as we find them in the outer Ouachita geosyncline. The massive Ellenburger limestone is not equivalent to all of the Arbuckle limestone. The lower portion of the massive limestone seems represented in Texas by the more shaly, cherty and sandy Wilbern and Cap Mountain formations (upper-Cambrian), which underlie the Ellenburger. More extensive deep drilling in Texas, to explore the petroleum possibilities of these formations, will define the section more accurately.

A considerable layer of chert, Woodford, extends into the area of the Plateau facies ; it overlies the Hunton, in the Arbuckle region, and is known underground in north-central Texas. CHENEY mentions a bed of similar chert 5 miles southwest of Lampasas, on the northeastern edge of the Llano-Burnett uplift.

TABLE III

CARBONIFEROUS SEQUENCE IN THE ARDMORE BASIN AND ADJACENT AREAS

LATEST VIEWS, PRINCIPALLY AFTER C. W. TOMLINSON (99, 1929) AND B. H. HARLTON.

	FORMATIONS THICKNESS IN FEET	CORRELATIONS	DESCRIPTION AND REMARKS	
PERMIAN	POST-PONTOTOC REDBEDS circa 1000 in most complete exposures	Permian	WICHITA FORMATION: equivalent of Asher formation of Pottawatomie county, Okla. Brilliant red and vermillion shales, with white and grey streaks, and dark red to blackish, hard, slabby sandstones.	
PENNSYLVANIAN			PENNSYLVANIAN (?) REDBEDS (Stratford-Konawa fms): Dark brown and varicolored shales and reddish-buff and white, crossbedded sandstones. Local, lenticular, *arkosic* sandstones and conglomerates (of chert, granite, and quartz pebbles) occur, notably in lower strata, in southeastern Jefferson county, Okla. and Montague county, Texas. Scanty remains of landplants and land vertebrates suggest non-marine facies. Away from Wichita axis, both to the north in Oklahoma, and to the south in Texas, these beds grade into marine strata.	
PENNSYLVANIAN	PONTOTOC very variable thickness: 0—1000 ca.	*Upper-Cisco* in Texas = Wabaunsee and possibly part of Shawnee-Douglas groups in Kansas	VAN OSS FORMATION. *Arkosic* red sandstones, grits and conglomerates; several hundred feet of coarse limestone conglomerates near Sulphur, Okla., originating from Arbuckles; in Ardmore Basin, only 0—200 feet of deep red shales with coarse *arkose* grit: in Ringling Basin, up to 1000 feet of *arkose* sandstones, grits and conglomerates (chert, limestone, quartz, felspars and hard shale fragments), thinning to only a few hundred feet over Nocona and Waurika anticlines; locally absent over Healdton axis. Conglomerates markedly coarser nearer to major uplifts; notably developed over and around Nocona ridge.	
PENNSYLVANIAN		*Hiatus* in Middle Cisco	*Hiatus*: includes only partly arkosic conglomerates of Ada and Vamoosa formations north of Arbuckle Mountains = part of Shawnee-Douglas groups of Kansas.	
			ARBUCKLE OROGENIC PHASE Large angular unconformity *The Hoxbar series totally lacks arkosic materials.*	
PENNSYLVANIAN	HOXBAR 4000	*Lower Cisco* (Graham) *Canyon* *Upper-Strawn* (Mineral wells above Mingus sh.) = Francis north of Arbuckles = Belle City to middle-Holdenville = Kansas City formation	Brownish, yellow, reddish and tan shales, with some few fossiliferous limestone ledges and rare sandstones; a few limestone conglomerates, *pointing to Arbuckles as their source.* About 1000 feet below top a 4 feet *coalseam* (at Daube). Detailed section by TOMLINSON (**99**, pp. 39—47). *Confederate Limestone* at base: 60 feet grey to buff limestone ledges, with conglomerate (Brazos River conglomerate in Texas).	
PENNSYLVANIAN	DEESE 6000—7000	*Lower Strawn* (Mingus shale and upper-Millsap) in Texas = middle of Holdenville to Savanna north of Arbuckles = Marmaton and most of Cherokee group in Kansas	„Glenn"-series of Goldston (1922) — Source region predominantly in Ouachita facies: Succession of often massive, crossbedded sandstone beds and chert conglomerates, separated by bluish, tan and red shales, with minor and relatively inconspicuous limestone members. *Devil's Kitchen sandstone* (100—200), 800 feet above base, grading southeastward, *toward Ouachitas*, into coarse chert conglomerates, without limestones (this excludes Criner Hills but indicates Ouachitas as a source). The Deese sandstones are extensively saturated with asphalt; were quarried for this purpose. *Pumpkin Creek limestone*: 70 feet of fossiliferous limestone ledges.	Non-arkosic Franks conglomerate, north of Arbuckles, equivalent to these horizons: ± middle-Dornick Hills to lower-Hoxbar.
PENNSYLVANIAN	DORNICK HILLS 1500—4000 thinning to northwest	*Lowermost Strawn* (lower Millsap in Texas) = Mc Allester ss. to Atoka form. north of Arbuckles = Cherokee group (in part) in north-central Oklahoma and Kansas	The Dornick Hills is a series of bluish, tan, and rarer reddish and brown shales, with limestone ledges, limestone conglomerates and sandstone beds. The series increases considerably in thickness and clastic character to southward: 4000 feet, very conglomeratic, on northern border of Love county, and less than 1500 feet near Glenn, against southern edge of Arbuckle Mountains, where conglomerates lack entirely. Farther west, around Graham, and more toward northwest, in NW-Carter county, the ever thinning sequence developes more limestone. After this time *source of sediments from Ouachitas* more than from Criner Hills (**99**, p. 28). Source in Wichita facies: 1200—1500 feet above base: *Bostwick limestone conglomerate* and limestones (300 feet). In this horizon, and below same, *sediments originate from Criner Hills*, and thin out to northward.	
PENNSYLVANIAN		Bend (Morrow) in Texas; Smithwick shale?	*Otterville limestone* carries already a Wapanucka-Marble Falls fauna (Girty; cf. **99**, p. 30). *Jolliff conglomerate and limestone* constitute base of Dornick Hills series.	
			WICHITA OROGENIC PHASE [1]) Great angular unconformity in Criner Hills and other ridges; *not in Ardmore Basin.*	
	SPRINGER 3000—3500	Marble Falls in Texas = Wapanucka and upper portion of Caney in S. Oklahoma: absent in N.-Oklahoma and Kansas	Black bituminous shales, with ferruginous and calcareous concretions, with which are interspersed four persistent continuous sandstone members, forming prominent topographic ridges. Poor fossils from middle of Springer are said to be earliest Morrow in age (Ch. E. DECKER).	Equivalent to upper part of Caney shale east of Arbuckle Mountains = Jackfork ss. in Ouachita Mountains. ? Mississippian lower part of Caney shale east of Arbuckle Mountains
MISSISSIPPIAN	CANEY 2000—2500 along southern edge of Arbuckles	Uppermost Mississippian	Dark shales, mostly black and bituminous, with thin ferruginous and other concretionary layers, without substantial sandstones or limestone members.	
MISSISSIPPIAN	SYCAMORE Limestone WOODFORD Chert	Middle- to Lower-Mississippian	In conformable sequence, without any conspicuous angular unconformities: only a small conglomerate occurs at base of the Simpson, and still less important conglomerate beds are reported at two or three levels in the Arbuckle limestone. (See for this sequence Table I).	
OLDER PALAEOZOICS	HUNTON Frm. SYLVAN Sh.	Dev. & Silurian		
OLDER PALAEOZOICS	VIOLA SIMPSON ARBUCKLE Limestone	Cambro-Odovician		

[1]) The Wichita chains were raised by this diastrophism. The Criner Hills become a source of clastic sediments for the first time. The Dornick Hills formation overlaps unconformably Viola and Simpson. Erosion during and after the uplift, but prior to Bostwick time, had abraded more than 5000 feet of sediments, mostly soft shales, from the northern edge of the Criner Hills: above the Bostwick horizon, higher pebblebeds originate more from the Ouachitas than from the Criner Hills. Yet, about the north end of the Hills, uppermost Deese and lower Hoxbar rest unconformably upon older rocks, clear down to the Arbuckle limestone. West of the Criner Hills, in the Brock field, wells show peaks of Ordovician rocks rising up into the base of the Hoxbar formation (99, p. 21). The same is the case for the Healdton and Hewitt ridges, the Duncan anticline in Stephens county, Okl., and the Nocona, Bulcher and Muenster anticlines in Montague and Cooke counties, Texas (J. R. BUNN, 24 1930). In these southern ridges upper Deese rests immediately on pre-Cambrian granite, bared by erosion. (Yet, the granite yielded no arkosic material).

The Talihina chert of the Black Ridge, east of Atoka, Oklahoma, is something different; it already belongs to the thrusted mass of the Ouachitas, and represents the sequence of the Ordovician, Silurian and Devonian (cf. the legend of MISER's map of Oklahoma, **75**). According to ULRICH, the cherts of the Arkansas Novaculite of the Ouachita province comprise from middle-Mississippian to middle-Devonian (**103**).

Chert conglomerates in the upper-Pennsylvanian and lower-Permian sediments of Oklahoma and Texas, decreasing northward and westward, away from the Ouachita ranges, again emphasize that *the chert facies was largely characteristic of the latter.*

THE STRUCTURE OF THE WICHITA MOUNTAIN SYSTEM.

The surface expression of *the Wichita Mountains*, at this present time, is a long range of disconnected hills and knobs, mostly of granite, which pierces the Permian redbeds over a distance of some 70 miles in Comanche, Kiowa and Greer counties, Oklahoma. The larger coherent mass in the Wichita National Forest, in Comanche county, forms the Wichita Mountains proper. These massifs are only the emerging summits of an important chain, buried under the latest Paleozoic blanket. The general trend has the same WNW strike as *the Criner Hills* and *Arbuckle Mountains*, which, after an interruption of some 60 miles, emerge farther to the ESE in Carter, Murray, Johnston and Pontotoc counties. Buried extensions belonging to the same mountain system are *the Amarillo mountains*, and the buried ranges along the Red River : *the Red River Mountains*.

As was mentioned before, we will, for the purpose of this treatise, call this entire 400 miles long complex of mountain chains: THE WICHITA SYSTEM.

The Wichita system as a whole forms an important orogenic unit, but the folding is moderate and no overthrusting on a larger scale is anywhere in evidence in the visible ranges. As was lately emphasized by F. A. MELTON (**73**), faulting seems to have been the chief mode of deformation of the strata in the Wichita Mountains, though folding also plays a considerable part, notably in the east, gradually disappearing westward. The abrupt slopes on the north side of the main Arbuckle- and Wichita Mountain arches constitute faultline scarps. They seem to a very considerable extent block mountains, notably the western units.

The importance of the uplift is shown by the great extent over which the otherwise deeply buried pre-Cambrian basement rocks have been elevated to the surface and bared of their at least 8500 feet thick mantle of pre-Carboniferous sediments. The enormous quantity of Pennsylvanian and early-Permian detritus originating from these mountains and collected in a marked foredeep, may also be cited in evidence.

In this general complex there are *two distinct elements*, which differ in character as well as in the time of diastrophism: the *Wichita Ranges proper* (including the buried Red River chains), and *the Arbuckle Mountains*.

They both originate within the same intra-continental geosyncline, and contain the same stratigraphic elements in the same facies, but the Wichita- and Red River Mountains apparently form the true chains (the Wichita's proper), while the Arbuckles are a piece of the uplifted, elsewhere little affected foreland in front of the Wichitas, where it is traversed by the ancient resistant Hunton Arch. This foreland zone was only affected by a later phase of the Wichita orogeny; the Arbuckles are separated from the main chains by a deep foreland trough, *the Ardmore Basin*, which was originally very much wider than it is now [1]).

The Wichita Mountains (we now mean the hills designated under this name on the geographical map) form a large complex anticlinorium. The present surface exposures are chiefly igneous rocks. The mantle of old-Paleozoic sediments is only preserved on the flanks, and is but poorly exposed and mostly buried under the redbeds. It consists of Ordovician limestones, in the same development and facies as in the Arbuckles. CLYDE M. BECKER (**13**, 1930) has published the most recent study of these mountains [2]).

The uplift is expressed in three en echelon ridges of pre-Cambrian quartzite and granite (granophyres), with gabbro and porphyry. They strike WNW—ESE. The northwestern one is a faulted anticline with a granite core, exposed all along the axis, flanked on the north side by the full section of the Arbuckle limestone. Farther to the northwest, in Kiowa county, Viola limestone, Simpson and probably Arbuckle limestone have been reached in deep wells. On the south flank, however, we find a strike fault with a downthrow of about 2000 feet to the south, making that only the upper 4000 feet of the Arbuckle limestone are exposed. A very deep syncline, now compressed into a very narrow, but 8000 feet deep trough, separates this northeast ridge from the central ridge, equally composed of granite. Only along its southeastern extremity, and for approximately 20 miles on the northeastern flank, contact with the pre-Carboniferous limestones is indicated. On the southwestern ridge this contact is nowhere visible.

Compressive stresses are comparatively little in evidence in these ridges, so little that BECKER is inclined to explain these mountains as a mere vertical uplift, caused by slow ascension of three batholiths early in the Pennsylvanian, instead of by folding. Some indications of contact metamorphism against the Cambrian Reagan sandstone are stated to support this theory, but do not appear very conclusive. Metamorphism is only mentioned on the contact with *the porphyry* in the northeast ridge (loc. cit. p. 43). This porphyry may be a later intrusion.

1) A peculiarity of this foreland zone is, that it still lies within the old Ordovician geosyncline. This may be explained by the fact that this pre-Devonian trough is so very much older than the diastrophism. This is an exceptional characteristic of the Wichita system.

2) Whilst this treatise was in the press, M. G. HOFFMAN has published another geologic description of the Wichita Mountains (Oklahoma Geological Survey, Bulletin N⁰. 52, 1930). It contains a detailed petrographic description of the Wichita rocks, excellent photographs of the region, and an exhaustive bibliography.

The interpretation may be correct as to the block mountain character and, possibly, some action of intrusives, but yet the general origin of the Wichita System, including the Arbuckle Mountains, the Red River Ranges, and the Amarillo Mountains, in their perfectly maintained strike and en echelon alinement, rising out of a marked geosyncline, is clearly the effect of compressive crustal forces on a larger scale. Evidently these ridges were pressed together later, and the intervening deep and narrow synclines can only be understood as the result of considerable *compression* [1]).

The pressure origin of the Wichita Mountains is also demonstrated by a marked foreland depression: *the Anadarko Basin* (A. J. FREIE: **41**, 1930). A foredeep of this nature, following the general strike exactly, is a compressive feature. The axis of this trough is traceable as far west as southern Sherman county, Texas. This basin is characterized by an enormous thickening of the Permian material filling the depression. These sediments attain over 4500 feet near Chanute, only 25 miles from the nearest surface outcrop of granite. The development of the underlying Pennsylvanian in the heart of the basin, is unknown but it may also be great in the eastern part. BECKER, assuming no particularly great thickness for this Pennsylvanian, (only 1500—2000 feet), nevertheless calculates that the highest part of the Wichita Mountains anticlinorium was elevated structurally approximately 19.000 feet above the axis of the Anadarko foredeep ! This trough is an asymmetric syncline, steeply dipping on the southwestern limb, and more gently on the opposite northeastern side.

The already mentioned basin, filled with a great thickness of late-Mississippian (1500—1800 feet of youngest Chester, overlying an equivalent of the Boone limestone), known to occur in the subsurface of northwestern Oklahoma and southwestern Kansas, may also be related to the Anadarko Basin, which is adjacent to the south of these wells (cf. A. I. LEVORSEN, **118**, Plate I and fig. 18). The fact that these beds are not known in the Anadarko Basin, as usually conceived, may partly be due to excessive depth, partly to pre-Permian erosion nearer to the arch of the Wichitas. It would seem probable that this Mississippian does not indicate another parallel basin to the north of the Anadarko through. The writer is inclined to believe that it indicates the northern edge of the original older-Paleozoic geosyncline, and that these upper-Mississippian strata were preserved here from erosion, because neither the arching of

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1) M. G. HOFFMAN, in the just mentioned Okla. Geol. Survey Bulletin N⁰. 52 (October 1930), contends that the igneous rocks of the Wichita Mountains are *not batholiths*, but have been injected as very thick sills (several thousands of feet) into Proterozoic quartzites. The intrusion occurred in pre-Cambrian time. Upper-Cambrian rests unconformably on the eroded surface of these igneous rocks (igneous pebbles in the base of the Reagan sandstone). No metamorphism is mentioned.

Consequently, it would seem that the Wichita Mountains are *not the result of batholithic uplift*, but that these igneous intrusions merely happen to be present in the pre-Cambrian basement exposed in the core of the anticlines.

the Wichitas nor of the Hunton Arch affected this area, but, on the contrary, the depression of the Anadarko Basin gave increased protection.

Foothill folds are also indicated, particularly by the anticlinal structures of the Cement, Knox and Chickasha oil and gas fields, to the northeast of the Wichita front, on the edge of the Anadarko deep. These folds still affect the Permian, although part of this latter effect may be due to compaction over the older buried ridges.

Western extension of the Wichita geosyncline.

It is not known precisely how far west limestone sedimentation of the old-Paleozoics continued in the original geosyncline. As far as facts are at the writer's disposal, nothing is known about the extension of the Arbuckle limestone on the flanks of the buried granite masses, which we call *the Amarillo Mountains.* None of the wells, of which he has records, have pierced older strata than upper-Cisco, which overlaps on the granite. This may be an effect of early Pennsylvanian erosion. A marked foredeep is no longer in evidence here (**41**, p. 76). It would appear as if the Wichita geosyncline dies out rapidly to the westward of the Wichita Mountains, and that the Amarillo Mountains are, still more than the Wichitas, caused by block faulting of the basement. Clearly, however, all this must ultimately have been the result of the same pressure which uplifted the Wichitas. The rigidly maintained strike, slightly convex to the north, is a convincing evidence.

The buried outcrop of the flanking pre-Carboniferous limestones seems to take a northerly course into Kansas west of Harper county. This is the influence of the uplift of *the Ancestral Rocky Mountains.*

The old floor is brought to the surface again in the Sangre de Cristo Range of southern Colorado and New Mexico, and the Manzano, Sacramento and San Andres Mountains, forming the front of the Rocky Mountain system in this region. These ranges are mostly block fault uplifts of the basement.

In the Sangre de Cristo Range of Colorado we find some 350 feet of older Paleozoics (Buelah to Manitou formations) between the Mississippian and the pre-Cambrian, at the extreme northern end of the mountains, and along the Arkansas River a few miles below Salida. A siliceous limestone of Silurian age is also reported on the western side of the range near San Luis, in Costello county, Colorado. (**57**, 1929).

In the southern extension of the Sangre de Cristo Range, in New Mexico, the upper-Pennsylvanian Magdalena Limestone immediately rests on the pre-Cambrian. This is also the case in the Manzano and Oscura Mountains. Farther north, the buried eastern portion of the Ancestral Rocky Mountains presents only Pennsylvanian beds deposited over an uneven granitic basement (**83**). In the Pedernales Hills, an island of older rocks east of the Manzano Range, no Carboniferous is exposed and the Permian immediately butts against the pre-Cambrian.

Only at the southern end of the Oscura Mountains, and all along the eastern scarp of the San Andres Mountains, and also in the western scarp of the Sacramento Mountains, south of Alamogordo, a small thickness of Ordovician and Silurian: Fusselman limestone (Silurian), Montoya- and El Paso Limestone (Ordovician), and Bliss Sandstone (Cambrian), begins to intercalate itself between the lower-Carboniferous and the pre-Cambrian. There is also a little Devonian (Percha shale). These rocks increase in importance toward the south and southwest, and seem to be part of a new basin extending in that direction.

In Colorado and northern New Mexico the pre-Cambrian is overlain by a great clastic development of upper-Pennsylvanian and Permian, an enormous thickness of mostly very coarsely clastic granitic detritus (10.000 to 13.000 feet). The lowermost of these beds grade into the Magdalena limestone in New Mexico. There is an unconformity above this partly marine lower portion. Evidently, these mountain blocks already consisted largely of bared granite at that time, subsequent to much earlier uplifts. They were again highly elevated by the movements within the late Pennsylvanian and the Permian, and became subject to renewed very active, often violent erosion.

It seems, therefor, that this entire western region, now constituting the frontal province of the Rocky Mountain system, was outside the Wichita province of large deposition during the early Paleozoic, which characterizes the geosyncline. The uplifts, though more or less contemporaneous with the orogeny in the Wichita ranges, were no part of the Wichita system. *The Wichita geosyncline dies out in western Texas.*

TIME AND CHARACTER OF THE WICHITA AND ARBUCKLE OROGENIES.

1. *The Wichita phase of orogeny.*

The principal folding of *the Wichita Mountains* occurred in the early upper-Carboniferous (Pennsylvanian). This is a very widespread orogenic phase, which does not merely affect this mountain system, but is greatly in evidence over the entire Plateau region: all Oklahoma, Kansas and Texas, as far south as the Llano-Burnett region and Marathon. The entire Mid-continent region, and most, if not all the structural features on the Plateau, show considerable uplift, emergence and erosion between the deposition of the Mississippian and the advance of the younger-Pennsylvanian (Cherokee) sea.

According to H. A. LEY[1]), the Nemaha Mountains of Kansas were elevated for a thousand feet or more above the surrounding country, and similar, though less pronounced uplift took place in the structures of north-

[1]) Bulletin Am. Assoc. Petrol. geologists, 1926, p. 96.

central Oklahoma and on the Hunton Arch; it is in evidence through all Colorado and New Mexico. Evidently, the entire Southwest of the continental block of North-America came under considerable stress at this period, regionally doming the entire Plateau, and causing the old major positive elements, and also the minor fault blocks, to become vertically displaced, rejuvenating the older faults and, possibly, originating new ones. (**117, 118**). In the Wichita Mountains and the related chains of the Wichita geosyncline (excepting the Arbuckles), this diastrophism reached a maximum of very much greater importance than on the Plateau area to the north and south.

In southeastern Oklahoma we can more accurately date the maximum movement as falling, in two phases, between latest Mississippian and Atoka time.

The Arbuckle Mountains are a massif of truncated folds and blocks. The present exposed mass is only a fragment, though the most important one, of the original structure. The pre-Cambrian basement is exposed over a considerable area and, in addition, the entire series of pre-Pennsylvanian rocks.

Folding is fairly intense in the southern part, but the northern half of the exposed mountains seems less sharply folded and rather more broken and faulted. There are indications that the mass of Ordovician limestone in the northern Arbuckles may, in part, have been thrust on the less broken northern portion of the Hunton Arch, which crosses this entire area.

In order to discuss the Arbuckle structure properly, we have also to consider the next fold to the south, exposed in the small outcrop of the *Criner Hills*, a complexly folded and faulted horst, consisting largely of Ordovician limestones, like those in the Arbuckle Mountains.

A narrow, very deep depression, *the Ardmore Basin*, separates the Criner Hills from the Arbuckle Mountains. It is now only 14 miles wide, but the synclinal folds were depressed to a depth of 10 miles (**99**, cross section on Plate XVII). Overlying the older Paleozoics, it is filled with a some 17.000 feet thick sequence of Pennsylvanian detritus, clearly derived mostly from a southern and southeastern source. Most of this belongs to the so called Glenn formation (Dornick Hills plus Deese formations), and is a typical detrital "molasse". C. W. TOMLINSON's map is here reproduced, with the kind permission of the Oklahoma Geological Survey and of the author, as our *Plate 2*. Also compare our *Plate 8* for the following discussion.

The Carboniferous sequence in the Ardmore Basin and the adjacent area is condensed in *Table III*.

The Criner Hills must be consedered as a direct continuation of the anticlinorium of the Wichita Mountains. *The Arbuckles, however, are an entirely different feature*. They were not folded simultaneously with the Wichitas (including the Criner Hills), but considerably later.

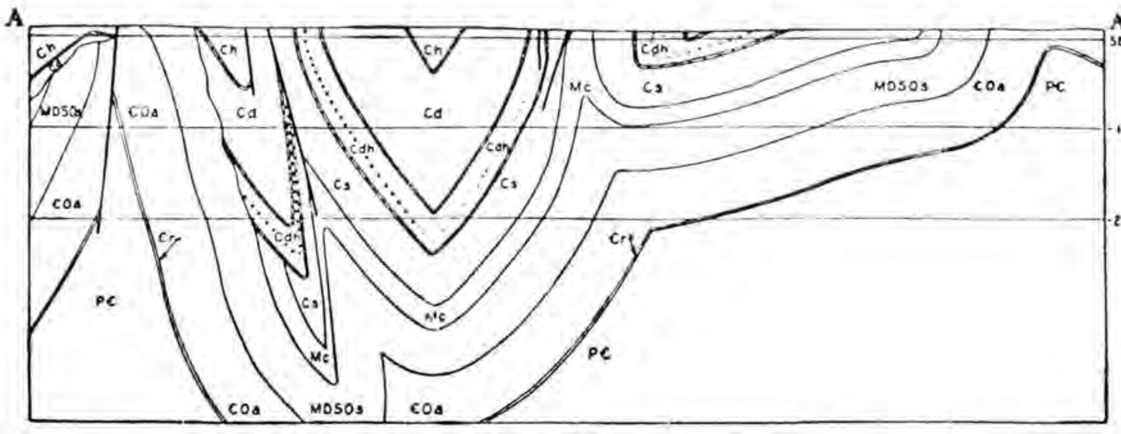
The Ardmore Basin is a southeastern equivalent of the Anadarko Basin. Both are part of the foredeep which skirts the entire Wichita system, which, furthermore, intermingles at its eastern end with the foredeep of the Ouachita system. This relation to the Ouachita foredeep is demonstrated by the basal deposits of the Carboniferous. The 3000 to 3500 feet of Springer formation, which antedates the principal phase of the Wichita orogeny, are decidedly an orogenic deposit. The basal members of the Springer may extend into the Mississippian. The lowest sofar found fossils occur near the middle of the series. They suggest Morrow. At least 2000 feet of strata, from which no fossils have yet been discovered, intervene between that horizon and the fossiliferous Ardmore Caney, which is certainly Mississippian. The top of the Springer marks the beginning of the second Wichita-phase of folding. The Springer-Caney complex, therefor, may be compared to the Jackfork-Stanley sequence of the Ouachita system [1]). The Springer, in particular, may be an equivalent of much of the Ouachita Jackfork sandstone, and the Ardmore Caney represent the Stanley shale, comprising the uppermost portion of the Mississippian, which seems confined to the Ouachita geosyncline, including the Appalachians in Alabama (Parkwood formation). This uppermost Mississippian is younger than the Pitkin limestone of the Ozarks and the general Plateau, and is replaced by a break in the stratigraphy and erosion on the entire foreland outside of the Ouachita flysch geosyncline, of which the Ardmore Basin forms a western embayment into the Wichita geosyncline. (**88**, **118**). We will revert to this later when discussing the orogeny of the Ouachita system. This orogenic lower-Carboniferous may indicate that the movements of the Wichita phase originated in the region to the south or southeast of the Criner Hills, some time before the climax of folding was reached in the frontal Wichita chains.

C. W. TOMLINSON was the first to analyse clearly the confusing outcrops in the Ardmore Basin. Interpretating correctly the structure of the Overbrook anticline, he proved that the basal conglomerate of the Dornick Hills formation unconformably overlaps over the Viola, Simpson, Caney and Springer formations. This anticline is a great overturned and thrustfaulted fold between Ardmore and the Criner Hills, with a structural height of at least 10.000 feet (it is, in part, a post-Wichita Arbuckle-phase feature). (See *Plate 2*).

The orogeny which raised the Criner Hills (the frontal chain of the eastern Wichitas) was, therefor, post-Springer. It created for the first time, in this region, a source of coarsely clastic sediments.

If the Wichita chains were at all affected by the earlier, late-Mississippian phase of the Wichita orogeny, this must have been confined to the more southern Red River ranges (cf. page 28). This phase may, however,

[1]) The 1600 feet of Caney north of the Arbuckle Mountains, in all probability, comprise both Springer and Caney of the Ardmore Basin. We will revert to this on pages 43 and 51.



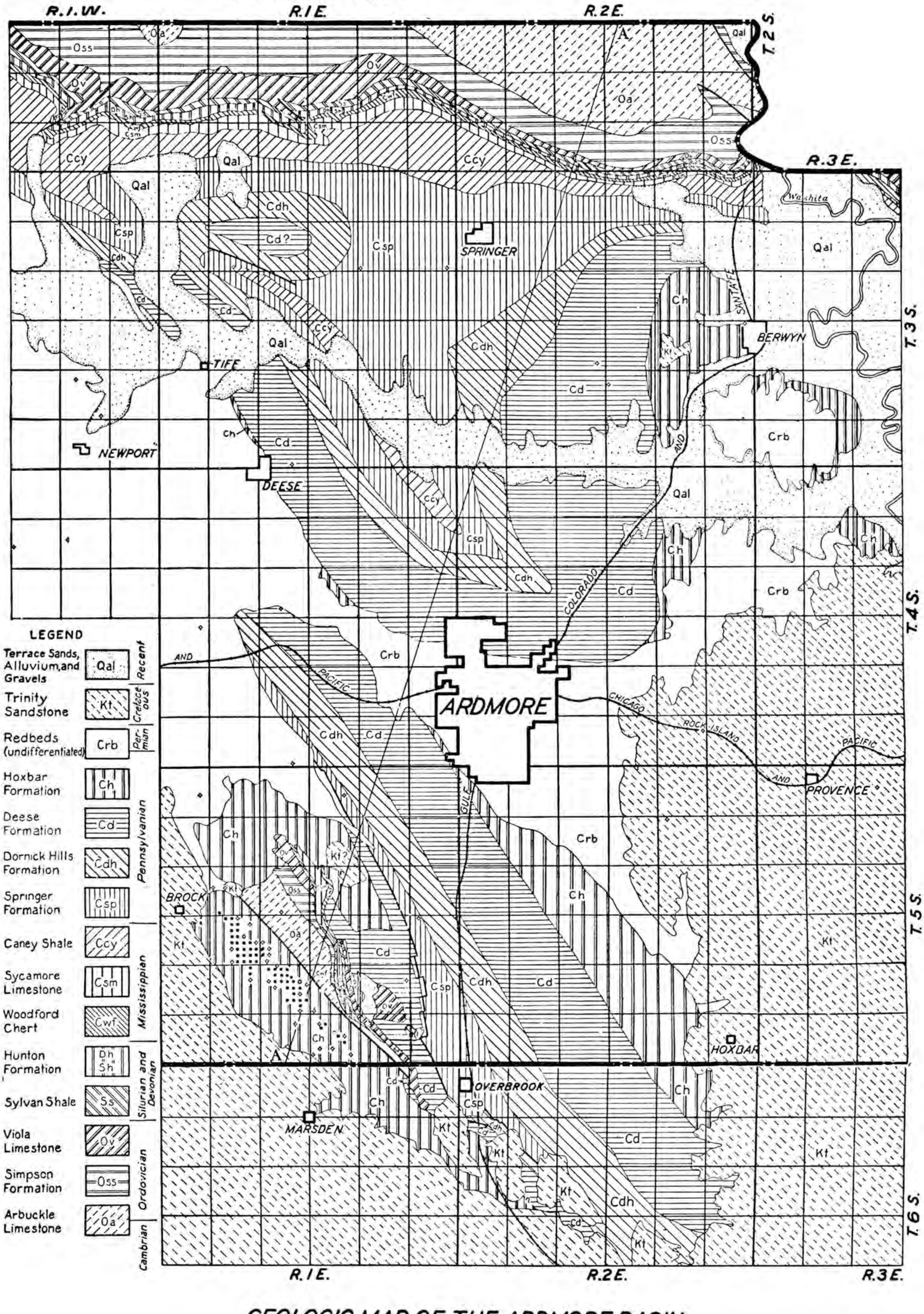
LEGEND FOR CROSS-SECTION

Ch- Hoxbar Formation
Cd- Deese Formation
Cdh- Dornick Hills Formation
Cs- Springer Formation
Mc- Caney Shale
MDSOs- Sycamore Limestone, Woodford Chert, Hunton Formation, Viola Limestone and Simpson Formation
COa- Arbuckle Limestone
Cr - Reagan Sandstone
PC - Pre-Cambrian

Scale 2500 FT 5000 FT 10,000 FT 20,000 FT 30,000 FT

Horizontal Scale same as Vertical

OKLAHOMA GEOLOGICAL SURVEY
CHAS. N. GOULD, DIRECTOR
NORMAN, OKLA
1928



GEOLOGIC MAP OF THE ARDMORE BASIN

CARTER AND LOVE COUNTIES, OKLAHOMA
BY
C.W. TOMLINSON

(Reproduced by permission of the Oklahoma Geological Survey from Bulletin No. 46.)

be limited to the Ouachita System, where we will discuss it hereafter. The Springer sediments may have originated exclusively from the Ouachitas in the southeast (cf. page 41). (**99**, p. 21).

The Criner Hills remained emerged and continued to yield detritus from the close of Springer time until the end of the Deese period at least. They became finally submerged and buried only in Hoxbar (upper-Strawn) time. However, it was only in the lower part of the Dornick Hills division, inclusive of the Bostwick conglomerate, that the Criner Hills were the principal source of the deposits. After Bostwick time, the Glenn sediments seem derived more from a Ouachita facies source in the southeast than from Wichita ranges (cf. *Table III*).

The middle-Carboniferous Wichita diastrophism, therefor, was of considerable duration in the Wichita province: from uppermost-Mississippian to early-Pennsylvanian. *It shows two marked pulsations: one in the uppermost Mississippian* probably just after Pitkin time (and very possibly confined exclusively to the Ouachita system), causing the deposition of the Ouachita flysch and the equivalent Ardmore Caney-Springer sequence; *the second phase, at the end of the Morrow*, causes the folding of the Wichita system proper (anyhow of the frontal chains), and the deposition of the Pottsville molasse of the Ouachitas and the Glenn detritus of the Wichitas (Ardmore Basin, etc.). To which of these two phases the movements of the structures on the Plateau, between the middle-Mississippian and the Cherokee submergences, must be referred, cannot be ascertained: they are just general Wichita-phase movements.

2. *The Arbuckle phase of orogeny.*

The Criner Hills were folded simultaneously with the Wichita Mountains at the close of Springer time. *This Wichita folding did not affect the main part of the Ardmore Basin.* Here, and in the entire area west of the Wichita River, including the Arbuckle Mountains, there is no evidence, either stratigraphic or structural, that any movement started before Deese time (lower-Strawn) at the earliest. No angular unconformity interrupts the essential parallelism of the strata from the Cambrian Reagan sandstone to the top of the Hoxbar formation (lower-Cisco). Then, at the beginning of middle-Cisco time, about at the end of the Thrifty period of Central-Texas, therefor very late in the Pennsylvanian, a tremendous break occurs. Northwest of Ardmore the red base of the upper-Cisco Pontotoc conglomerates overlaps the upturned and truncated edges of the entire series of formations, down to the pre-Cambrian, transgressing over some 25.000 feet of sediments. (See *Plate 2*.)

This diastrophism, which we call *the Arbuckle phase*, is the effect of a renewed push to the NNE. It strongly reaffected the Criner Hills, compressed the originally much wider Ardmore Basin into the present very narrow trough, and now strongly folded and even crumpled the southern end of the Hunton Arch, thereby *creating the Arbuckle Mountains.*

The *Wichita Mountains* were also intensily reelevated at this time, and the three original ranges compressed closely together. The *Anadarko* deep was depressed, and began to be filled with its great thickness of upper-Pennsylvanian and lower-Permian sediment, largely originating from the Wichita Mountains. The *Ringling-Waurika Basin* was also depressed, and possibly originated only at this time.

The Amarillo Mountains were also considerably lifted and now yielded the erosional detritus of "the granite wash", so important in petroleum geology.

Farther out on the foreland, the Arbuckle orogeny is not indicated by a very pronounced major unconformity, but rather by a change in the process and character of sedimentation, influenced by the expanse of lands emerged by the Arbuckle phase (cf. pages 29—31). There exists a rather widespread break and erosion period, however, coupled with minor unconformities, which can be traced, and permit to time the Arbuckle phase, relative to the Kansas section, as occurring principally near the end of Lansing time and, anyhow, previous to most of the Douglas deposition. Disturbance, however, begins since the end of the Marmaton division.

At the time of the earlier Wichita diastrophism, there probably was no *folding* in the Arbuckles, but nevertheless there occurred a general upbulging of the Hunton Arch. SIDNEY POWERS (**83**, pp. 1052—1053) describes a conglomerate at the base of the equivalent of the upper part of the Dornick Hills series of the Ardmore Basin, in the Mill Creek syncline, just north of the truly folded chains of the Arbuckle Mountains, containing an assortment of pebbles proving that the sedimentaries of the Arbuckle sequence, with the exclusion of the granite, had been uplifted and truncated at that time in the region. This conglomerate is not found to the north of Ardmore, only ten miles farther to the south. This disturbance is perceptible as far north as Seminole county, where a pronounced unconformity separates the Wapanucka limestone (overlying the "Cromwell oilsand") from the succeeding Pennsylvanian beds (Boggy formation). That regional emergence and active erosion occurred already at this time in the Arbuckle region, depositing *non-arkosic* limestone conglomerate, is also proven by the Franks conglomerate, which farther to the north grades into the Hartshorne, Mc. Alester, Savanna and Boggy formations. Evidently, erosion had not yet cut down to the pre-Cambrian. Certain movements in the foreland continued till after Atoka time, since the Hartshorne sandstone overlaps the offlapped Atoka series, and again the Savanna the Mc. Alester. Disturbance is renewed in Thurman time (**80**).

North of the Wichita Mountains the upper-Pennsylvanian, beginning with the "Glenn series", unconformably overlaps the older Pennsylvanian on the southern edge of *the Anadarko Basin*. This is the repercussion of the Wichita orogeny. The upper-Pennsylvanian Glenn period is a relatively quiet one here, depositing blue and brown shales, with thin limestones, as in the Ardmore Basin, but much thinner, proving entirely similar conditions in the entire length of the Wichita foredeep. The Pontotoc, upper-Cisco, however, is also a thick granite wash (1600 feet), grading into redbeds farther northward. *This proves that the Arbuckle phase also affected the Wichita Mountains.*

In Wichita-Albany time erosion had apparently finished in the Wichita Mountains: for the Stillwater beds of this age consist of blue shales and limestones, layers of anhydrite and dolomite. The upper-Permian Redbeds, however, give evidence of renewed erosion, *but these materials came not from the Wichitas in the south, but from the Ouachitas in the east.* The Wichita mountains must have been practically completely buried by this time. These Permian strata overlie Wichita rocks with a dip of only 20 to 40 feet to the mile, but along the edge of the uplift, they are tilted three to seven degrees. Possibly the Wichita mass, though remaining buried, was slightly elevated in later Permian time. The Permian beds on the Cement, Knox and Chickasha anticlines are also "folded". Probably however, much of this may be the effect of compaction (**13**).

The principal *folds* of the Arbuckle Mountains are *the Timbered Hills* and *Tishomingo-Dougherty Ranges*, folded *only* by the just described Arbuckle orogenic phase. It is not improbable that at this time a moderate amount of thrusting took place in the northern Arbuckles. A rather major overthrust seems to be suspected by R. H. DOTT (**38**, p. 17). His argument is the sudden absence of the enormous detrital Glenn series on the Hunton Arch, within only a few miles of the Arbuckle Mountains. The equivalent of the Glenn is only very thin and unconformable on older beds, as is generally the case in north-central Oklahoma. There are at least 15.000 feet of Glenn sediments in Township 3 South, and practically none in Township 2 North. DOTT suspects the thrustplane in the Wichita River gorge between Berwyn and Dougherty, in the "Mill-creek syncline". In this region there is a structural relief of some 10.000 feet. Within the northern Arbuckle Mountains the Hunton Arch is much crumpled and faulted by Arbuckle trends crossing it.

It does not seem necessary, however, to resort to wide overthrusting to explain this difference in sediments. The great thickness of Glenn material, that DOTT refers to, lies in the Ardmore Basin, the old foredeep, and to the south of the later Arbuckle Mountains. The shortening of this originally much greater distance and the compression of the formerly far wider Ardmore Basin occurred during this same Arbuckle phase (Cisco). The region north of the Arbuckles, where the Glenn sequence is practically absent, *was always outside of this foredeep*, and moreover on the already bulging Hunton Arch, already uplifted by the Wichita diastrophism, and therefor less apt to receive these molasse deposits. The shortness of the present distance is only the result of the violent compression of the strata by the Arbuckle phase, which greatly narrowed the Ardmore Basin. This may have caused fractured slices, slightly thrust over each other on the Hunton Arch, within the Arbuckle Mountains, but this is very different from the true nappe-structure of the neighbouring Ouachita Mountains.

The Arbuckle Mountains, therefor, must be chiefly considered as a piece of the foreland, made specially resistent by the presence of the ancient Hunton Arch, which was first bulged by the Wichita phase, and afterwards folded, faulted and possibly moderately overthrust by a posterior push in the late-Pennsylvanian, the Arbuckle phase. This later push lifted the Arch considerably more and drove the Pennsylvanian sea far to the north. The sea only readvanced again in Shawnee (Vamoosa) time, at the very end of the Pennsylvanian epoch.

The buried ranges of the Wichita System.

The features sofar described are the only exposed portions of the Wichita mountain system. The extensive drilling in this region has given us a fair idea as to how these structures are connected in the subsurface.

Buried en echelon folds, belonging to the general anticlinorium represented by the Criner Hills, connect these latter, across the intervening depression (80 miles), with the exposed eastern end of the Wichita Mountains. Several of these folds cause accumulations of petroleum in the overlying younger sediments, domed largely by compaction. The best known of these structures are at *Hewitt, Healdton, Loco, Woolsey* (Township 2 North, Range 6 West), and *Nellie* (Township 1 North, Range 9 West). That *the Criner Hills,* which formally were also buried beneath the Deese formation, are now exposed at the surface, just south of the Arbuckle Mountains, whilst all the rest of the anticlinorium is buried. is most probably due again to the rejuvenating influence of the Hunton Arch, that caused the uplift and exposure of the Arbuckles, and almost certainly extends under the Criner Hills in their basement. The prominence of the buried uplifts in the *Nocona* and *Bulcher* folds, still farther to the south in Montague and Cooke counties, Texas, may even be due to the selfsame influence.

The underground continuation of the Arbuckle fold of the Tishomingo granite range has probably been encountered 10 miles north of Durant on the Blue River in a well in Sect. 1, Township 5 South, Range 9 East. Even the *Knox* and *Cement* foothills folds may be related to this trend. Sidney Powers believes that the swell of the northern Arbuckles can be traced to the west as far as Pauls Valley (83, p. 1050).

The trough of the Ardmore Basin can also be traced farther to the northwest and southeast under the blanket of Redbeds and Cretaceous.

It appears to widen where it was less subject to compression against the buttress of the Hunton Arch. The folds at *Velma*, (in Stephens county, Oklahoma), *Graham*, *Caddo* and *Overbrook* (in Carter county, Oklahoma), and at *Madill* (in Marshal county, Oklahoma), are evidently situated within this basin. They are typical Arbuckle phase structures, consisting of steeply compressed Pennsylvanian, unconformably overlain by upper-Cisco Pontotoc and Redbeds. *The Preston anticline* in the Cretaceous (in Grayson county, Texas) may indicate a buried extension of these same conditions. Here the Cretaceous is folded in the same trend and in direct continuation of the Ardmore Basin folds. Ordovician rocks, in Ouachita facies, were reached here in several wells directly underlying the Cretaceous. The presence of this facies makes its relation to Ardmore Basin folds a little doubtful. This anticline lies in the center of a deep trough. Other minor anticlines with the same trend occur in this Cretaceous depression (SIDNEY POWERS, **83**, p. 1058). It is probable that this Mesozoic trough is a posthumous reflection of the continuation of the underlying Wichita-foreland basin, under the overriding Ouachita nappes.

All the foredeep folds here described, seem true *foothills folds in front of the Wichitas, comparable to the open folds in front of the Ouachitas in the Coal Basin of Oklahoma and the Arkansas Valley* (**99**, fig. 2).

The Wichita-Criner Hills Range, though apparently the most important, is only the frontal range of the Wichita system. Farther to the south, separated from the frontal chain by another deep trough, filled with Pennsylvanian and Permian detritus, the drill has again revealed a number of anticlinal structures, overlying buried pre-Pennsylvanian ridges. They occur all along the Red River, particularly in northern Texas, in an en echelon alinement, following the same Wichita strike.

The deep intervening *Waurika-Ringling-Marietta Basin* (see *Plate 8*) is indicated by several wells, which have penetrated near to 5000 feet of Permian and upper-Pennsylvanian, down to the Deese, without reaching any older strata, although to the north, in the *Duncan fold*, Ordovician is reached at 3500 feet, and at *Loco*, still higher up on the Wichita Mountains doming, Ordovician already occurs at 1500 feet. In parts of this basin, notably in its southeastern portion, more of the enormous sequence of the Ardmore Basin Glenn series may possibly be represented, although this synclinorium seems mostly caused by compression through the Arbuckle phase. Even as in the Ardmore Basin, minor folds, always following the same trend, occur in this depression. To the south of this synclinorium, at *Oscar*, the Deese (Strawn) again rests on Ordovician limestone and pre-Cambrian. Whether pre-Deese Pennsylvanian is present or not in the basin, cannot be affirmed. [1]) The same condition exists south of the Red

[1]) In 31—4 S—9 W and in 28—5 S—8 W, Cambrian sediments were encountered below the Deese. These are thought to be equivalent to the Honey Creek limestone of the Arbuckles and Williams formation of Texas. (Communicated by F. H. LAHEE).

River in *the Nocona fold* in Montague county, Texas, and still farther to the southeast, in *the Bulcher anticline* in Cooke county, Texas. (J. R. BUNN, **24**, 1930, cross section).

All these pre-carboniferous rocks are in Wichita (foreland) facies.

The southern system of buried ranges is known in the literature as *the Red River Arch,* because they express themselves as a broad arching in the younger formations at the surface, overlaying the real truncated buried ranges. The northern chain begins in northeastern Denton county, Texas, where wells encountered Ellenburger limestone at 1400 feet. Wells in Cooke county have drilled more then 1500 feet in such limestones, indicating that geosynclinal development persists in the pre-Mississippian. A zone of granite uplifts and „granite wash" with old-Paleozoic limestones on their flanks, extends in the subsurface from Denton and Cooke counties, across northeastern Montague county, Texas, into southern Jèfferson county, Oklahoma. A second southern chain extends from northern Clay county, westward through Wichita and Wilbarger, into Foard county (See *Plate 8)*. Several wells encountered diorite, granite and granite wash (probably middle-Cisco) on the ridges, whereas, along the flanks, the wells remained in Ordovician limestones. The structure is asymmetric, more steepsided to the north, proving that the pressure came from the south.

This is, apparently, a more complex system of ranges than the buried en echelon chains between the Criner Hills and the Wichita Mountains (the front range). Several more or less parallel lines of en echelon structures seem included in these central chains. The wells encounter granite more frequently than Ordovician limestones, possibly because only the highest culminations are sought and drilled by the petroleum geologist, who looks for accumulations of petroleum in the overlying upper-Pennsylvanian strata. (Prolific oil and gas fields are located on these folds, the most important of which are the *Petrolea, Burkburnett* and *Electra* fields. The area is also noted for its occurrence of helium in the natural gas). The Pennsylvanian comprises Canyon and Cisco, in a facies similar to the Ardmore Basin series. The Canyon, however, begins already to assume the more limy facies of central Texas, whilst the Cisco begins to lose the coarse conglomeratic Pontotoc character and to develop bituminous shales and intercalated oilsands, though streaks of coarse grits and conglomerates are still present, notably on the ridges.

The Bend lies unconformably on the Ordovician of the southern flank of the Arch, indicating *the Wichita orogeny* (S. POWERS, **83**, 1929, p. 1062). The Pennsylvanian series seems confined largely to Cisco and Canyon. The Strawn formation of central Texas extends from the Llano-Burnett uplift northward to Wichita and Clay counties, where according to POWERS (**83**, p. 1061), it is overlapped unconformably by upper-Canyon. This points to *the precursory movements of the Arbuckle orogeny in the Ardmore Basin and the Criner Hills,* as it is indicated there in the Hoxbar sediments. A strong folding is again in evidence late in the Cisco, when the Permian unconformably overlies the folded and eroded Pennsylvanian. This is *the Arbuckle phase*. (See also F. E. KENDRICK and H. C. MCLAUGHLIN, **61**, 1929).

Therefor, it would seem as if these, possibly also somewhat older ranges were more deeply buried under Pennsylvanian sediments than the frontal chain. Only the highest ridges, which are also best explored, seem to emerge. There is no Strawn on these, but only Canyon, and often only the Cisco, rest on the pre-Carboniferous limestone.

It does not seem improbable that, as in many other mountain systems, the more central and southern chains of the Wichita system had begun to break down already at the time of the final orogeny in the frontal range.

Local, lenticular, coarse, arkosic sandstones and conglomerates in the upper Cisco redbeds in Cooke, Montague, and Jefferson counties, however, indicate the effects of the Arbuckle phase, and that erosion remained active at several places, where the ridges were emerged. (TOMLINSON, **99**, pp. 47 and 58).

THE PERIOD OF EROSION.

A great mantle of detritus is spread over the entire foreland region, originating from the Wichita Mountains and the adjacent Ouachitas. A considerable unconformity, representing the Arbuckle orogenic phase, divides these sediments in a lower and an upper series. Only this upper part is arkosic, in the region north of the Wichita-Arbuckle Mountains, showing that it was the Arbuckle phase, that finally caused the pre-Cambrian in the Wichita system to be elevated sufficiently to become bared by erosion.

It were not only the Wichita ranges that, before the close of Pennsylvanian time, had been eroded down to the granite core. The same applies to the Arbuckle Mountains. The Franks conglomerate, north of the Arbuckles, which is equivalent to the Bend and most of the Strawn, is still non-arkosic. The same applies to the limestone Bostwick conglomerate in the Dornick Hills formation (lower-Millsap) of the Ardmore Basin and the Mill Creek Conglomerate of the Arbuckle Mountains. After the Arbuckle phase, however, which, as we saw, began at the end of the Canyon and culminated in middle-Cisco time, the Pontotoc conglomerate contains much granitic material, mixed with pre-Carboniferous limestones.

The erosion detritus of the older Pennsylvanian, deposited previous to the Arbuckle phase, seems to have originated to a far greater extent from the then more important Ouachita Mountains, than out of the Wichita ranges. These deposits seem well developed only in the more eastern basins. These fell within the great foredeep belt of the Ouachita Mountains, which we will discuss hereafter. These mountains, however, did not then occupy their present location, but were situated considerably farther south. On both sides of the Wichita Mountains proper, west of the Ardmore

Basin, only a thin layer of non-arkosic, shaly and limy older Pennsylvanian is known to rest on the Mississippian. It is particularly the upper-Cisco "granite wash" that is such an important feature on the flanks of all the Wichita chains, (equivalent to the Pontotoc). It must be born in mind, however, that we know next to nothing about a possible development of the Glenn sequence in the Anadarko Basin, where most of such material, if it ever originated from the Wichita Mountains, should have collected. Farther from its source the older Pennsylvanian material becomes ever finer and more decomposed, so that in the end it cannot be differentiated from normal redbeds in the well logs.

It seems clear, therefor, that in the Wichita system the main topographic elevation and consequent active erosion of the mountains occurred through the Arbuckle (Cisco) orogenic phase, and that *before this time the Ouachitas were already the more important mountains.* The Wichita orogenic phase, though causing important folding and affecting almost the entire foreland, must principally have occurred at greater depth in the subsurface, and at least for the frontal Wichita ranges, it cannot have caused important elevation of the surface[1]).

The relative importance of the Arbuckle (Cisco) phase in the Wichita system is further indicated by *the influence of these ranges on the redbed facies of the sediments* in their entire surrounding area. The upper-Permian, above the San Angelo—Duncan horizon, is everywhere developed as redbeds, but this latter facies begins to descend ever deeper in the lower-Permian in central Kansas as well as in northern Texas. In southeastern Oklahoma and northeastern Texas the red facies encroaches well down into the upper-Pennsylvanian Cisco, but *not lower.* The transition is not merely in color, but at the same time that the blue shales turn red, the limestone ledges in the series disappear and turn into red sandstones. First the shales turn red, somewhat farther the sandstones also become red. Some few limestones still persist for several miles into the area of the red facies, thereby making excellent key horizons for purposes of correlation, but these also disappear eventually. On the geologic map the redbed facies cuts diagonally across the strike both in Oklahoma and in Texas, reaching farther to the east, meaning farthest down into the Pennsylvanian, in the Arbuckle-Wichita belt. Marine fossils are absent; some few landplants and remains of land vertebrates indicate complete emergence. (CH. N. GOULD, **46**). These significant facts clearly indicate that *this condition is connected with the Wichita mountains.*

1) It may be emphasized here that work in the Alps brings out ever clearer that the major topographic uplift of a mountain chain need by no means be contemporaneous with the major orogenic phase. The higher elevations of the Eastern Alps, where a complete sequence of upper-Tertiary sediments permits a more correct timing of the physiography, began their major present uplift late in the Miocene, if not in the Pliocene, and bulged only into relatively lower ridges at the time of the major orogenic phase in the Oligocene. Probably the Alps are higher now than at any previous time in their history. Much of them was submerged under Miocene seas.

The red facies does not reach below the Cisco, in other words, *not below the Arbuckle orogenic phase*. Here again it is this latter phase which mostly influences the character of the sediments.

Farther west, in the Amarillo Mountains, the ranges do not seem to have exercised this influence on the color of the sediments. The beds are already non-red and non-arkosic on the southern flank of the western Wichita Mountains. On the southern flank of the Amarillo Mountains the sequence is probably quite thick, but non-red. The red facies of the Albany in Texas seems confined to the north-eastern region, outside of the area where later the Permian salt basin formed.

This also indicates that *the Ouachita complex had little, if any to do with the development of the red facies in Texas.* (We will see later that these mountains continue in the subsurface of all eastern Texas). It seems influenced exclusively by the Wichita system, and *notably by its eastern end, and the Arbuckle Mountains*, and to have originated only after the Cisco orogenic phase, when the granites became bared.

By the close of Cisco time, most of the Wichita ranges must practically have been peneplained. In Vamoosa-Wabaunsee time (uppermost-Cisco) sea covered much of the region, as far west as Harmon county, in the southwest corner of Oklahoma. The Wichita Mountains may have emerged longer, constituting an island, but the southern ranges certainly did no longer contribute any coarse clastic material to the lower Permian (Albany). How long the Wichita Mountains persisted as a surface elevation and remained emerged is uncertain. The Amarillo Mountains did not become covered until well in the Permian. The western peaks may have remained emerged longest ; these are already under the influence of the uplift of the Ancestral Rockies.

In the Anadarko Basin the Permian Duncan sandstone still originated from the south and southeast. Felspar is still abundant northeast of the Wichita Mountains, but becomes ever rarer toward the west, suggesting that the source may have been more from the direction of the Arbuckle Mountains than from the Wichitas. In the northern and western portion of the Anadarko Basin, the Permian sediments are derived from the west and northwest, out of the Ancestral Rocky Mountains region. (A. J. FREIE, **41**, pp. 37—38).

Younger folding also begins to make its appearance in the lower Permian. Farther south, in central Texas, there are sharp folds affecting the San Angelo formation in Stephens and Comanche counties, and gentle folds in the Wichita and Clearfork formations. The San Angelo sandstone seems to repose unconformably over the entire Permian basin of southwestern Texas. According to F. GOUIN (**28**, p. 19), late Permian folding is in evidence all over southern Oklahoma. These folds would indicate the presence, or at least a reflection of a Permian orogeny (Appalachian phase?) in this region. We will discuss later that the final overthrusting of the Ouachita Mountains may possibly have occurred in the Permian, about at the time of the San Angelo unconformity.

Not all slightly bulging anticlines in Permian beds, however, indicate true folding. In quite a number of structures, notably within the belt of older sharp Wichita folds, it may in part be due to compaction over buried ridges. Part of this pre-Cretaceous warping affects the Triassic.

SUMMARY.

We may now summarize the structure of the Wichita System as follows:

The ranges are caused by the compression of a pre-Mississippian intracontinental geosyncline. The eastern end of this geosyncline disappears under the Ouachita overthrusts; in the west it fades out before reaching the front of the Rocky Mountain System.

The diastrophism is spread over two distinct phases:

1. The early-Pennsylvanian *Wichita phase*;
2. The late-Pennsylvanian *Arbuckle phase*.

The first really folded only the Wichita chains proper, south of the Anadarko-Ardmore foredeeps, but farther north, caused considerable warping and epeirogenic uplift. The two sub-phases, which are so well distinguished in the Ouachita system, are not so indicated for the Wichitas. It is the second, post-Morrow sub-phase that raised the Wichita System.

The Arbuckle phase was very marked, and strongly affected the topography; it not only rejuvenated the Wichita chains, including the Red River ranges, but compressed the entire system, shoved the Anadarko-Ardmore foredeep together, depressed the intra-mountainous Ringling Basin, and folded and thrust the southern end of the Hunton Arch into the great foreland massif of the Arbuckle Mountains.

Previous to the Arbuckle orogeny, the Wichita chains had become largely peneplained and submerged under upper-Pennsylvanian (Hoxbar) sediments.

After the Arbuckle orogeny, the Arbuckles and the rejuvenated Wichita ranges had become peneplained again by the close of the Pennsylvanian epoch, but the Wichita, and notably the Amarillo Mountains, persisted more or less into the Permian.

TABLE IV.

STRATIGRAPHY WITHIN THE OUACHITA MOUNTAINS.

System	Formation. Thickness, in ft.	Correlations	Description	
PENNSYLVANIAN	ATOKA 3100 to more than 9400	Lower Strawn	Blue and black shales, with dark brown sandstones; occurs also in autochtone W and NW of Choctaw fault, on Hunton Arch, and in Boston Mountains (Winslow). On thrustmass, largely sandstone in Oklahoma section, grading into predominant shales in Arkansas, except in southern zone; a few impure cherty limestone lentils. In general, clastic character increasingly pronounced towards the east; in many places in the southern exposures it is essentially shale.	
PENNSYLVANIAN	WAPANUCKA 100	Bend (Morrow)	Cherty fossiliferous limestone. Occurs in foreland and in Arbuckles, also in outer thrustzone back of Choctaw fault. Not present between Atoka and Caney in eastern Atoka county, Okla. Not present back of Ti Valley thrustplane. Not present as limestone in Arkansas: included in Atoka.	
PENNSYLVANIAN	"CANEY" SHALE of Ouachita Mts: up to 800 in Atoka county, ("Johns Valley shale")	Lowermost Pottsville?	Blue and black shales. Does not appear in its typical facies within overthrust mass, and not at all back of Winding Stair thrust fault. A Mississippian (?) shale, "Johns Valley shale", also called "Caney", carries large erratic boulders and blocks of Arbuckle facies rocks in frontal thrustsheets of Oklahoma section [1]).	
MISSISSIPPIAN?	JACKFORK SANDSTONE 5000—6600	(Missing in foreland)	Fine to medium grey sandstone, in massive beds, interbedded with minor blue and black, carbonaceous shales. Typical of overthrust mass of Ouachitas; does not occur on foreland and in Arbuckles; only occurs south and east of Winding Stair thrust. Clastic character increases toward the south [1]).	
MISSISSIPPIAN?	STANLEY SHALE 6000—10000	Uppermost-Mississippian [1]) (Missing in foreland) ...... ?	Dark, often graphitic shales, partly indurated, with thin beds of hard greenish grey sandstones and quartzites, which increase in number and thickness to southeast. Occurs exclusively within Winding Stair thrustplane; absent to northwest of same. Hatton tuff lentils near base in Arkansas section (up to 100—200 feet). Hot Springs sandstone at base in Arkansas, (200 feet), with chert conglomerates in southern exposures. ∿∿∿∿∿ Unconformity indicated in frontal zone. — Lower phase of WICHITA OROGENY — [2])	
? / DEV	ARKANSAS NOVACULITE 250—950	Mississippian ? Upper & middle Devonian	Thin bedded, white and black chert, with layers of thin black shale. According to ULRICH: Upper portion: probably Keokuk (middle-Mississippian). Middle part: Kinderhook-Chattanooga (lower-Mississippian). Lower part: Lower-middle Devonian of Tennessee. Lower-Devonian is absent.	
		<BREAK>	∿∿∿∿∿∿∿∿∿∿	
			Sequence in central area to south and southeast of Octavia thrustplane in Oklahoma and Arkansas	**Equivalents to NW of Octavia fault**
SILURIAN	MISSOURI MOUNTAIN SLATE 60—300	Silurian	Green and red shales and slates, conglomerate at base. ∿∿∿∿∿	Equivalent to middle part of Talahina Chert of northwestern portion of Oklahoma section, NW of Octavia fault.
SILURIAN	BALYLOCK SANDSTONE 600—1500	Silurian	Hard quartzite and hard green slates. *(Richmond fauna).*	
ORDOVICIAN	POLK CREEK SHALE 0—200	Upper Ordovician	Jet black graphitic or carbonaceous soft graphitic shale. *(Fernvale fauna?)*	Talahina Chert in northwest portion of Oklahoma section, to NW of Octavia fault is equivalent to this horizon.
ORDOVICIAN	BIGFORK CHERT 700—800	Middle Ordovician	Black chert and limestones, interbedded with black slaty shales. *(Trenton fauna).*	
ORDOVICIAN	WOMBLE SHALE 250—1000		Soft green sandstones and shales, notably developed in Arkansas section; locally limestones near top.	Stringtown shale of northwestern portion of Oklahoma section. (Base not exposed).
ORDOVICIAN	BLAKELY SANDSTONE 0—500	Lower Ordovician	grey siliceous sandstone, with beds of black and green shales. Conglomerate. —<small hiatus ?>—	
ORDOVICIAN	MAZARN SHALE 1000		black and green banded carbonaceous shales; thin beds and layers of sandstone and limestone. *(Beekmantown fauna)*	
ORDOVICIAN	CRYSTALL MOUNTAIN SANDSTONE 500—850	Lower Ordovician?	Massive, coarse grained, white sandstone and quartzite; limestone conglomerates at base. *(No fossils known).* ∿∿∿∿∿	
	COLLIER SLATE 300, base not exposed.	Cambrian?	Bluish black metamorphic slate, graphitic, with minor conglomerates and some limestones. *(No fossils known).*	

[1]) There is controversy about the real age of the members of the Atoka-Caney-Jackfork-Stanley sequence within the thrustmasses of the Ouachitas. Fossils are few and rather indefinite; this applies as well to the few marine invertebrates, as to plant remains. In addition, the structure is so involved, that it is not by any means certain that the various members have been properly named for each of the localities in this great mass of flysch. The lowest member, the Stanley has been assigned to lower-Pennsylvanian as well as to Mississipian. The best review is by HONESS and MISER (**76**), and MISER and PURDUE (**78**). They conclude that the Arbuckle "Caney" contains Pennsylvanian as well as Mississippian strata, and that the Jackfork-Stanley are definitely Mississippian. ULRICH assigns the Jackfork to the lowest Pennsylvanian. It seems to the writer, that we may be assured that lowermost Pottsville as well as uppermost Mississippian are represented in this flysch. These particular horizons are represented by a widespread hiatus over the entire foreland (**118**). This is the point of major interest for our purpose. The correlation of ULRICH has been used in this table.

[2]) Confer our Table III for the influence of the Ouachita facies as source region for sediments of the Ardmore Basin.

THE STRUCTURE OF THE OUACHITA SYSTEM.

The at present exposed Ouachita Mountains occupy a belt 50 to 60 miles broad, from Atoka county Oklahoma, eastward into Pulaski, Saline and Hotsprings counties, Arkansas, or a length of 215 miles. This is only a minor portion of the entire chain: all along the southern and eastern border of the present exposure, the mountains disappear below the Cretaceous blanket of the Gulf Coast Plain, or the Tertiary of the Mississippi Embayment. Only on the western and northern sides of the Ouachita Mountains is the edge exposed, in the form of large overthrust faults.

Wells have encountered the Ouachita rocks within a belt of about 40 miles width to the south and southeast of the outcrops, all along a line from Boswell in Choctaw county, to Bokhoma in McCurtain county, Oklahoma, and beyond the Arkansas line, up to near Fordyce in Dallas county, and west of Rison in Cleveland county, Arkansas. Then again a number of wells in northeastern Texas reached Paleozoics of the Ouachita facies in Grayson, Fannin and Red River counties, Texas.

The stratigraphy of the Ouachita Mountains is described in a condensed manner in *Table IV*.

Recently a good synopsis of the structure of these mountains has been published by H. D. MISER (**77**, 1929), from which publication the writer is liberally quoting. Another important recent paper by F. A. MELTON (**73**) has appeared in 1930. We may also refer to the recent Bulletin No. 3 of the Arkansas Geological Survey, by C. CRONEIS (**115**), and E. O. ULRICH'S stratigraphical studies (**103**). Other literature is mentioned in the bibliography.

MISER (**77**) gives interesting geological and structural maps in his Plates I and II, which are here reproduced, with the kind permission of the Oklahoma Geological Survey and of the author, in our *Plates 3 and 4*. These maps give all such information as is sofar known. The recent geological maps of the States of Oklahoma (**75**, 1926) and of Arkansas (**20**, 1929) are also referred to. The structure, however, is very complicated and the often rather inaccessible or poorly exposed region has not yet been worked in sufficient detail to permit us to consider these maps as by any means final and complete. Notably the great thrustplanes, which are so conspicuous in the Oklahoma section, fail almost completely on the map of Arkansas. As we will discuss later, this must be erroneous.

Nappe structure of the Ouachita Mountains.

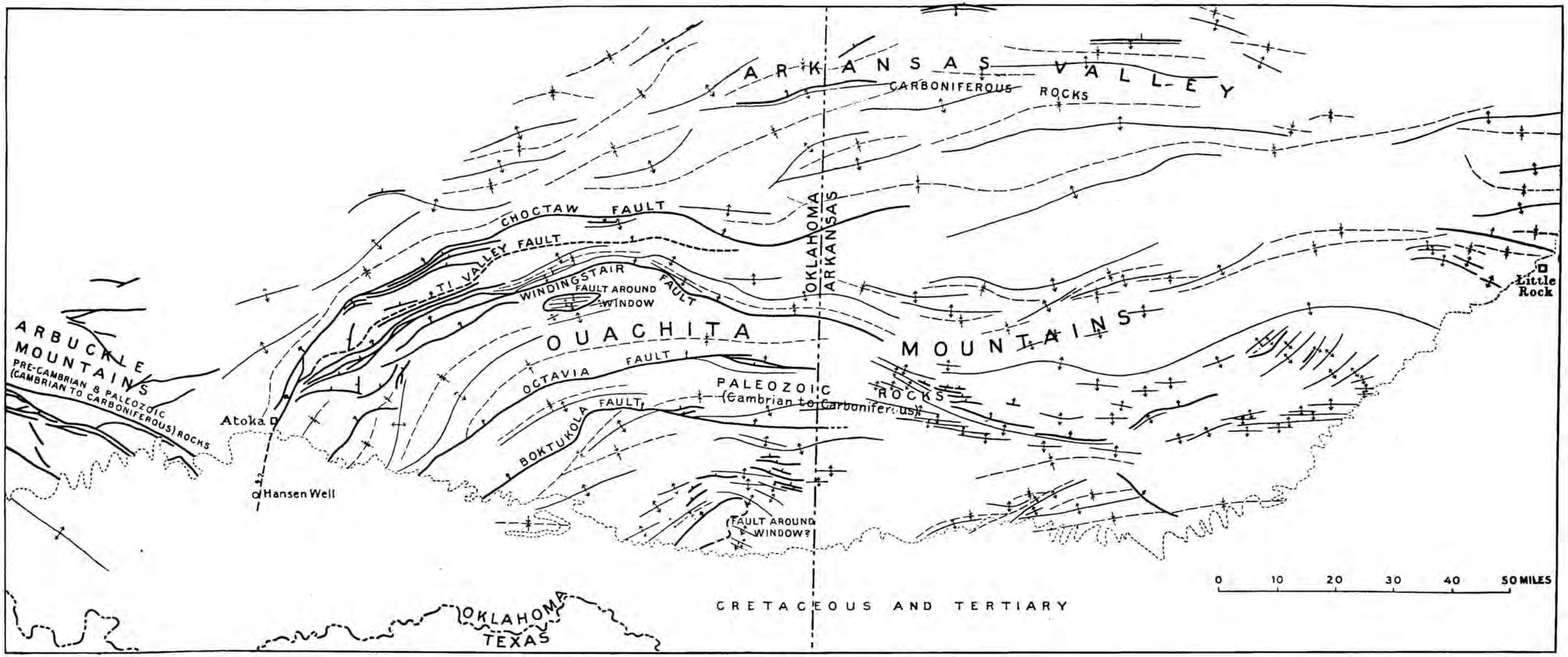
The Ouachita Mountain structure is composed of a number of folded thrustsheets, which have glided on and over each other. In general, it closely resembles the structure of the southern section of the Appalachian Mountains. In front of the overthrusts lies a zone of open folds in the foreland, which gradually decreases in intensity toward the north. This also is in analogy with the Appalachians.

To the west the Ouachita Mountains butt almost against the eastern end of the Arbuckle Mountains. The outcrops at the surface are only 12 miles distant, across the Boggy Creek valley in Atoka county, Oklahoma. As we have seen, the faults in the Arbuckle Mountains are not large thrustplanes as in the Ouachita Mountains, and it is very doubtful whether overthrusting has occurred in the Arbuckles to any notable extent. *The strikes in the two mountain systems cross each other almost at right angles.*

As we have already discussed, the rocks in the Ouachita Mountains are of an entirely exotic character, as compared to the sediments deposited in the Wichita geosyncline and all over the Plateau region. Apart from this suggestion, the structure itself also clearly points to thrustsheets, pushed far to the north and northwest from some southern source, now buried beneath the Cretaceous. The complex is tremendously contorted and broken, not only by several distinct large shearplanes, but by an infinite number of smaller shearfaults and joints, and the rocks are distinctly metamorphosed and show cleavage in several places. The Stanley shales are metamorphosed over the entire region and partly turned into brittle stony slates. But few of the flysch sandstones are quartzitic, but most of them have a chloritic and sericitic cement. The formations are often cut by innumerable quartz veins in all directions.

The crushed structure of the thrust blocks is explained by the fact that the moving mass is a pack of rather incompetent shales and shaly sediments, containing many sandstones, including some very massive members. The whole involved series, to the top of the Cambrian, insofar as it is known, measures close to 30.000 feet in thickness.

The Choctaw thrustfault forms the northwestern edge of the Ouachita structure, but another indistinct shear, that apparently runs through the shale area of the Ti Valley, with poor, and consequently indefinitely worked exposures, appears to mark the northwestern boundary of the thrustsheet which contains the Ouachita-facies of rocks. This was already remarked by ULRICH (**103**, pp. 26—27) and POWERS. Better marked is the Winding Stair fault, a little farther to the south. On the northern side of the Ti Valley fault, the exposed rocks are more nearly like those of the general foreland region, including the Arbuckle Mountains, whereas on the south side they are altogether different in lithology. Only two formations seem to be common to the two areas in a more or less similar facies : the Woodford chert (lowermost Mississippian), and the Atoka formation (lower-Pennsylvanian). (**76**, pp. 21—22). In the sequence of the Ouachita facies the Woodford is possibly represented in the middle part of the



Structure Map of Oklahoma and Arkansas

(Reproduced by permission of the Oklahoma Geological Survey from Bulletin 50, Plate II.)

Arkansas Novaculite (**103**, pp. 24—25). Between the Ti Valley and Choctaw faults the sequence laks both the Jackfork and the Stanley formations (upper-Mississippian and possibly some lowest Morrow), which reach 15.000 feet in the Ouachita nappe, immediately south of the Ti Valley and Winding Stair thrustplanes. North of the Ti Valley shear, the Caney shale rests immediately on the Woodford chert, with an apparently broken contact (**103**, p. 27). The Caney member is not represented at all on the more southerly thrust masses ; here Atoka directly overlies the Jackfork. Whether the "Caney" in eastern Atoka county, east of the Black Knob chert ridge, within the thrust nappes, is real Caney, is a matter on which there is disagreement among geologists. ULRICH proposes a different name: Johns Valley shale (**103**) [1]).

C. L. DAKE (**35**) was the first who, to the writer's knowledge, suggested in 1921 that the exotic rocks of the Ouachita Mountain region were thrust northward a long distance over strata, that have the same facies as those of the Arbuckle Mountains, nearby to the west. That wide overthrusting must be accepted to explain the abrupt change of facies has later been recognised by other geologists: R. H. DOTT (**38**, 1927), E. O. ULRICH (**103**, 1927), S. POWERS (**83**, 1928), M. G. CHENEY (**27—28**, 1929), and H. D. MISER (**77**, 1929). Since a number of years the writer has often expressed the view in correspondence, and to various colleagues on excursions in the region, that the Ouachita Mountains had an Alpine thrustsheet structure, (cf. also **83**, p. 1042). ULRICH expressed the belief in 1927 (**103**), that the Ouachita rocks originated in an other geosyncline altogether than the Arbuckle facies, separated by another foreland, and that "probably during early Mesozoic time", the deposits of the Ouachita basin were "thrust into the middle and eastern parts of the geosyncline, in the western part of which the Arbuckle sequence of almost entirely different deposits was laid down". Except for the Mesozoic age of the final overthrusting, his and DAKE's interpretation probably approach the truth closer than any other views which have sofar been expressed in print [2]).

That the Winding Stair shear, and also certainly the Ti Valley shearplane, are true low angle thrustplanes, is proven by the Potatoe Hills window, north of the Kiamichi river (cut by the county line between Latimer and Pushmataha counties). This was discovered and described by MISER (**77**, pp.

[1]) There is considerable confusion regarding the formations described under the name Caney. We have mentioned already on page 22, that the Caney north and east of the Arbuckles should comprise both Caney and Springer of the Ardmore Basin. The Caney of the foreland and the Ouachita nappes is another instance of confusion. We will revert to this problem when discussing the exotic boulders of the Ouachita "Caney".

[2]) Not all the geologists cited seem equally convinced of the great distances these overthrust masses may have travelled. MISER suggests about 20 miles, DAKE "scores of miles", ULRICH "a hundred or more miles". The latter also compares them to the Alps and the Himalaya.

18—19 and fig. 6). The Carboniferous, as well as older rocks (Talihina series) appear in a window of overthrust rocks of Ordovician, Silurian, Devonian and Mississippian age. The thrustplane nature of the indistinct Ti Valley faultzone is clearly indicated by three similar, smaller, window-like areas in the shale lowlands of the Ti valley, near Wesley, and along the branches of the Brushy creek, on either side of the town of Ti (see **75**). These exposures show Caney shale overlying Woodford chert (Talihina) with a broken contact, suggesting a tectonic juxtaposition. Under the chert lies some highly siliceous limestone, the fossils of which indicate lower-Devonian (**103**, p. 27).

The Boktukola and Octavia faults are also decided low angle thrust-planes. Mapping in 1923 by HONESS in McCurtain county, southeast of the Boktukola fault in the area of pre-Carboniferous rocks, seems to have revealed this. He not only shows faults around much of the central portion of the pre-Carboniferous area, but also that the Cambrian and lower-Ordovician strata there do not partake of the folds in the rocks that surround them (MISER, **77**, p. 21—22, and fig. 7). This indicates either another window or an outlier of another nappe. The fault surrounding the McCurtain window, may be a southward continuation of the winding, warped Boktukola fault.

In order to understand the difficulty of mapping the thrustfaults in the eastern Arkansas section of the mountains, we must bear in mind, that the Atoka formation changes locally from sandstones into shales and vice versa; only in the northeasternmost exposures it, seemingly, consists very largely of sandstone. At many places in the southern exposures, the formation consists predominantly of shales. At the contact with massive sandstones, thrustplanes are clearly in evidence. They are mostly mapped on the contact of the Jackfork sandstone with shales.

In Arkansas we still have the massive Jackfork sandstone of some 6000 feet, but here the outcropping rocks happen to consist far more of Stanley shales than in Oklahoma. The Jackfork member is seen to be bent into closely compressed and broken folds in the southern part of the mountains, some of which are overturned. Thrustplanes are little in evidence in a shaly topography of this character and could only be located through a very detailed survey and paleontological work in the poorly exposed and almost unfossiliferous shales.

On the geologic map, the major thrustplanes of the Oklahoma section all seem to pass eastward into shale areas and become lost (cf. *Plate 3*). The question is whether the nappes are not really present. In this connection it is also interesting to draw attention to the Ti Valley shear in Oklahoma, almost the most important feature in these mountains, since it divides the autochtone facies of the foreland from the Ouachita facies. Yet on the recent map of Oklahoma only small disconnected parts of it have been traced.

The geologic map of Arkansas makes it look very possible that the overriding mass has been preserved much farther north in Sebastian and Logan counties, Arkansas, at least in outliers. Even some patches of "Jackfork" have been mapped there, a formation conspicuously absent anywhere else in the foreland. These patches are marked between Washburn and Chismville, and just south of Waveland. The relation seems insufficiently cleared. If this is true Jackfork, it suggests northern "klippen"-outliers of southern nappes.

If there is so much overthrusting in the Oklahoma section, a similar structure should certainly be expected to an increased degree in Arkansas, directly south of the great Ozark buttress, which should have caused increased compression. That the compressive forces have not decreased, is shown by the continuation of strong open foothills-folding in the Pennsylvanian foreland, to no less degree than in Oklahoma. (**20**, **115**).

The general arcuate structure, which after a slight concavity to the north in Polk and Montgomery counties, Arkansas, again turns convex in a pronounced manner in Garland and Saline counties, is an additional indication for a powerful northward push. The foreland folds again indicate a more eastern convex loop in Faulkner, Cleburn and White counties, north of where the mountains themselves are already buried under the Tertiary.

The Arkansas sections drawn by PURDUE and MISER and published by the latter (**77**), recall very strongly similar sections as were constructed for the Alps before the nappes-structure of these mountains was generally recognised. There these sections have been changed materially. They are now interpreted as superimposed slices, to which the frontal part of the nappes has been reduced; they have been refolded together, or are interpenetrating each other. Special reference can be made to the frontal portion of the High Calcareous Alps in Glarnerland or the Median Pre-Alps of the Haute Savoye and Freiburg (L. W. COLLET, **31**). In the Variscan mountain massifs of Central-Europe the nappe-structure has only very recently been recognised to its complete and enormous extent (**66**, **89**, **96**).

The writer feels convinced that further detail work in the Arkansas section of the mountains will reveal a structure of thrust nappes of no less, but rather greater importance than in Oklahoma. The mechanics of the entire region demand it, as well as the pronounced foreign character of the Ouachita sequence.

A further strong proof for the nappe-structure of the Ouachita Mountains in Oklahoma, are *the exotic boulders of the Caney shale*, presumably a "tectonic moraine" occurring as far east as the town of Stapp, on the Arkansas State line. This problem will be discussed hereafter. (See page 50).

The striking fact that *none of the Ouachita folds show a crystalline core*, and that the pre-Cambrian rocks are nowhere revealed at the surface or reached by wells, also strongly suggests a nappe-structure. These mountains have this feature in common with the *frontal* zone of all major thrust-chains, including the Appalachians, the Variscan Mountains of Europe, the Alps, the Carpathians and many others. This contrasts strongly with such foreland ranges as are less or not all overthrust, as the Arbuckle- and Wichita chains, which all show a pronounced uplift and baring of pre-Cambrian basement rocks. The also strongly thrust Marathon Mountains again show the Ouachita type, with absence of the crystalline core, to the north of the Solitario.

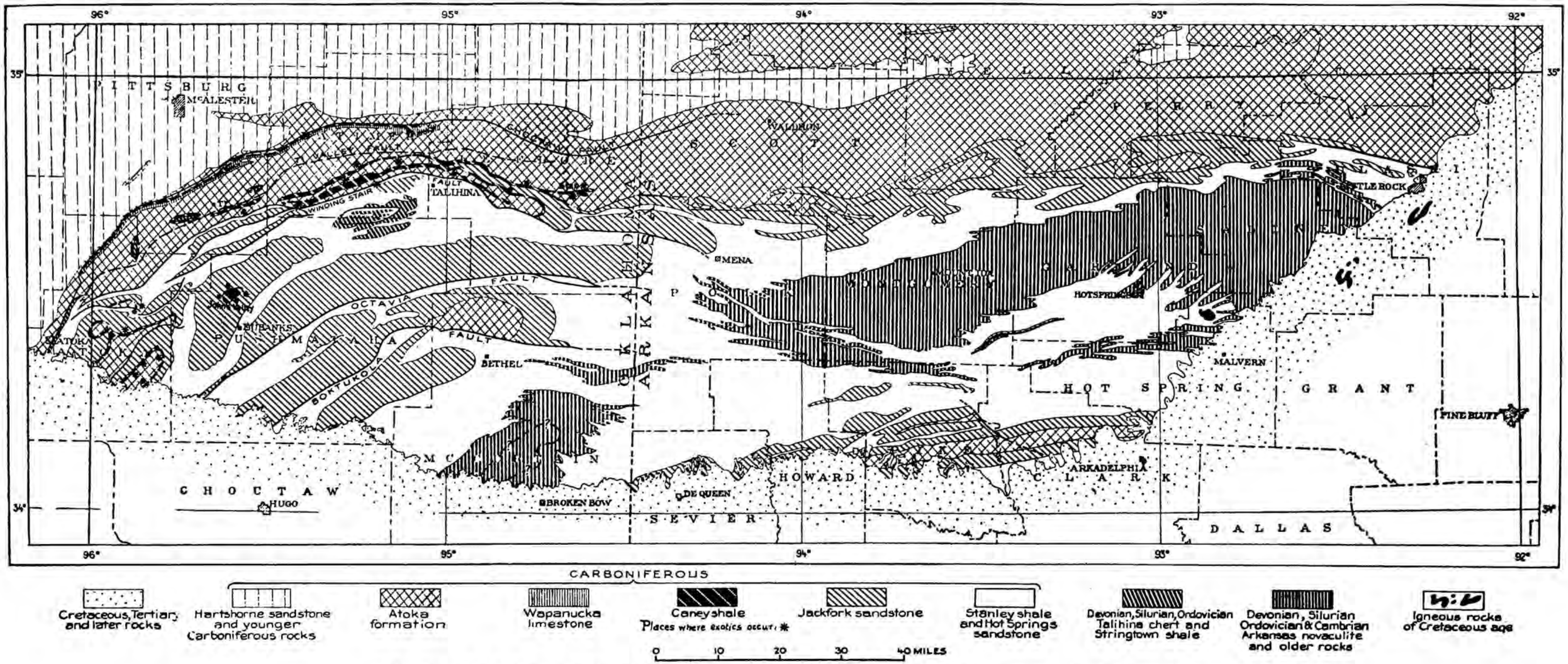
Normal foreland structure and facies are found in the Boston Mountains and in the adjoining part of the Arkansas Valley. Here the strata lie horizontal, are cut only by normal faults, and the Magnesian limestone series of the Ordovician, now approximately 1000 feet thick, in the normal Plateau limestone facies and development, rests on pre-Cambrian rocks, as proven by borings in Arkansas, and an outcrop at Spavinaw Creek in Oklahoma.

The Arbuckle-Wichita chains pass under the Ouachita thrustsheets.

The manner in which the eastern end of the Arbuckle Mountains butts against the Ouachita thrustmasses, shows that the first must pass underneath the latter. Already in 1921 DAKE (**35**, p. 55) suggested this, and HONESS and MISER supported his theory. The Hansen well in Township 4 South, Range 11 West, in southern Atoka County, Oklahoma (see *Plate 4*), encountered Arbuckle-facies rocks over the entire section (MISER, **77**, p. 18). This proves not only that the overthrust rim of the Ouachitas must continue in an almost due southerly course, since this well must be west of it, but it also proves that the Arbuckle facies continues to the southeast and, therefore, *must be* overridden by the Ouachita rocks [1]).

MISER, HONESS and others believe, that the many remarkable *asphalt deposits of the Ouachita Mountains* of Oklahoma and Arkansas supply another proof that Wichita-facies rocks underlie the Ouachitas. These asphalt deposits could scarcely have originated from the markedly metamorphosed Ouachita rocks, but we know that the Simpson and other Ordovician strata are highly petroliferous and a notable source of petroleum, in the facies represented in the Arbuckles, the Wichitas and all over the Plateau. This condition continues in Texas in the hinterland of the Wichita

[1]) Recently this was again proven by several wells on the Preston anticline, in Grayson and Fannin counties, Texas, entering Ordovician rocks, *in Ouachita facies*, directly below the Cretaceous; this is about 40 miles to the S and SSW of the Hansen well. (cf. "Map of the Paleozoic of Ouachita Facies", by E. H. SELLARDS; advance notice from "Handbook of the Stratigraphy of Texas" in preparation, kindly sent to the writer whilst this treatise was in the press). *Graptolites* obtained from one of these wells were identified by E. O. ULRICH as of a type found in the Stringtown and Womble shales of the Ouachita Mountains (E. H. SELLARDS: News letter from the Bureau of Economic Geology, January 1931)).



Geologic Map of the Ouachita Mountains of Oklahoma and Arkansas

(Reproduced by permission of the Oklahoma Geological Survey from Bulletin 50, Plate I.)

chains. The Arbuckle Mountains and the adjacent ridges also show remarkable impregnations of asphalt. On buried ridges, containing these same formations, prolific oilfields have been found in overlying Pennsylvanian beds (Healdton field, and many others) [1]).

In the Ouachita series only the Stanley shale could be considered as a possible source rock of petroleum, but, as HONESS remarks, it seems too much metamorphosed to be very promising in this respect. Consequently, it is rather probable that these oil and asphalt showings originate from other rocks than occur in the Ouachitas, in other words: the underlying Wichita facies.

The asphalt is found in joints of the Talihina chert and in the Stanley and Jackfork formations, as fissure veins and impregnations in sandstones. This occurs as far east as Leflore county, Oklahoma, and all through Arkansas. (C. W. HONESS, **56**). At Redden, in northeastern Atoka county, Oklahoma, sandstone ledges in the Stanley shale are saturated with heavy liquid petroleum at the small depth of 600 feet. The grahamite veins also turn soft in depth. Oil in the basal Cretaceous Trinity formation near Idabel, in McCurtain county, must also have its source in the underlying formations; the same must apply to impregnations in the Trinity at Madill, in Marshall county, Oklahoma, and in Sevier and Pike counties in Arkansas. It may even apply to Cretaceous oil accumulations on the Preston anticline (see footnote on page 38) and still farther south in East Texas and southern Arkansas, although in this case we also have appropriate source rocks in the Cretaceous.

We see, therefor, that the theoretical probability that the chains of the Wichita system pass under the Ouachita Mountains and continue in the underlying autochtone, is supported by considerable proof.

The fact that wells on the Preston anticline have found Ouachita facies rocks underneath the Cretaceous, does not conflict with this opinion. The Wichita trend of this anticline may well be due to the structure of the underlying autochtone, and yet be overlain by Ouachita nappes, which the wells, of course, have not pierced.

THE TIME OF THE OROGENY IN THE OUACHITA MOUNTAINS.

Previous writers have not been very distinct as to the age of the principal diastrophism in the Ouachita Mountains, which gave these chains their present structure. It was generally placed "somewhere in the Pennsylvanian"; many preferred "late-Pennsylvanian" (MISER); lately, however,

[1]) Recently wells in northwestern Cooke county, Texas, notably the Hymans B—6 well, penetrated pre-Mississippian limestone at the shallow depth of 1450 feet and obtained a flow of petroleum of as much as 4370 barrels initial. This is on the Muenster Arch, overlying one of the Central Wichita ranges, directly south of the Arbuckle Mountains.

F. A. MELTON (**73**, 1930) advanced arguments in favor of an important orogeny after early Permian time.

Much argument for a pre-Atoka phase has been based on chert conglomerates in the Atoka and succeeding lower-Pennsylvanian formations in the Lehigh Basin, just north of the town of Atoka, Oklahoma, on the western rim of the Ouachitas. These were supposed to have originated from the Black Knob ridge, just east of Atoka, composed of Talihina chert, which here forms the edge of the major Ouachita thrust mass, which, in this part of the loop, pushed westward over the southwestern extension of the Ti-Valley fault. Hence, this event should have antedated the deposition of the Pottsville Atoka formation. MELTON advanced rather convincing arguments, based on considerable field work, that this assumption is incorrect; that these chert pebbles could not have been derived from the Black Knob ridge, and moreover, that it does not seem to be the same chert. He believes that these chert conglomerates in the Lehigh Valley autochtone entirely antedate the Ouachita overthrusting, and orginated from rocks in the Wichita chains, exposed to erosion after the Wichita diastrophism, shortly previous to Atoka time, and *entirely previous to the Ouachita overthrust*. Other Atoka conglomerates give evidence that ridges in Wichita-Arbuckle facies yielded detritus to lower Pennsylvanian formations in this region. SIDNEY POWERS (**83**, p. 1041) mentions a conglomerate of chert and Ordovician limestone pebbles in basal Atoka a mile south of Stapp in Le Flore county-Oklahoma. This is 10 miles west of the Arkansas line [1]).

I. *The Wichita orogeny in the Ouachita Mountains.*

Though the foregoing remarks support the view that certain chert conglomerates in Pottsville strata had nothing to do with the Ouachita *overthrusting*, it also indicates that there did occur movements and uplift of the Wichita orogenic phase in this region, either in the Ouachita chains or in their autochtone. Such movements would be more than probable anyhow, in view of the very widespread character of this early Pennsylvanian phase in the entire Texas, Oklahoma and Kansas region, and the intensity of its action in the entire Wichita system. This can only be explained as the result of an intense push from somewhere against the southern rim of the Plateau.

When we discussed the structure of the Wichita System, we have already come to the conclusion (cf. page 20 a.f.) that the orogeny of the early-Pennsylvanian Wichita phase was of considerable duration and extended, with two distinct pulsations, from uppermost Mississippian to Pottsville time. We find this clearly confirmed in the Ouachita System.

A. The enormous development of the asymmetric upper-Pottsville to

[1]) This conglomerate is not to be confused with the very much larger exotic Ordovician erratics in "Caney shale", both east and west of Stapp, which we will discuss later.

lower-Allegheny foredeep, and the supply of clastic material to keep this trough filled practically to sea level, or above, are ample proof that somewhere, back in the Ouachita mountains, uplifting and subsequent erosion occurred on a major scale.

This Ouachita molasse, beginning with the Atoka, marks the early-Pennsylvanian, second pulsation of the Wichita phase.

It does not seem probable that the lower-Pennsylvanian detritus originated exclusively from Wichita-Arbuckle rocks in the southeastern continuation of the Wichita chains underneath the Ouachitas in their present, later location. The Woodford and the cherty Ordovician limestones would certainly countribute much chert residue, and that these formations yielded material is proven by limestone pebbles. Ouachita rocks, however, would yield most easily the conspicuous prevalence of chert, mixed with very little, if any limestone fragments, because some limestone also occurs in these sediments. We will see that the same applies to the Strawn-Milsap formations of eastern Texas, originating from an eastern source, in a foredeep, which is the equivalent to the Coal Basin and Ardmore Basin (Brazos River or Garner sandstone : F. B. PLUMMER and R. C. MOORE ; **84**, p. 76). This indicates that Ouachita rocks were subject to erosion in lower-Pennsylvanian time, so much farther south of their present outcrops, and also south of the assumed southeastern extension of the Wichita chains in their autochtone.

We also find molasse deposits of Atoka age within the thrust masses of the Ouachita Mountains, proving that erosion of ridges within the geosyncline filled intra-mountainous basins with detritus at that period (cf. page 43).

We mentioned already that the lower- and middle-Pennsylvanian Glenn series of the Ardmore Basin was not only derived from Wichita chains to the south, but also to a very considerable extent from the southeast. Consequently, highlands must have existed in this direction at that earlier phase of the Ouachitas. Even before the initial phase of the frontal Wichita Mountains, an orogenic deposit, the 3000 to 3500 feet thick Springer formation, was laid down in this embayment. This deposit also clearly originated from the southeast (cf. page 22).

There occurred, in fact, a remarkable interchange of sedimentation in the Ardmore Basin. Some material was clearly derived from the Wichita chains, notably from the adjoining Criner Hills ridge, and is in Wichita facies ; other sediments seem as clearly to have originated from Ouachita-facies rocks, and to have their source farther in the southeast (TOMLINSON, **99**).

The lower member of the Ardmore Basin series above the Springer ; the *Dornick Hills division*, (lowermost Strawn, up to 4000 feet thick, laid down posterior to the Wichita orogenic phase), begon to be derived from the Criner Hills, but later it had its chief source to the southeast. The thinning of the formation and the diminution of the size of the clastic material farther to the northwest is particularly evident in the Graham and Sholom Alechem anticlines (See *Plate 8*). Limestone ledges also increase considerably in that direction (TOMLINSON, **99**, p. 28). The Bostwick conglomerate in the lower part of the Dornick Hills formation and the 1200 to 1500 feet of strata underlying it, are derived from the Criner Hills: the conglomerate is thickest and coarsest in the adjoining belt, with Wichita facies limestones boulders over six inches in diameter. The pebbles decrease in size and finally disappear to the northward, grading into grits with chert grains.

The middle member, *the Deese formation,* (Strawn, 6000 to 7000 feet thick), consists largely of crossbedded sandstones and chert conglomerates, separated by bluish, tan and red shales, with minor and inconspicuous limestone members. *In the Deese the southeastern Ouachita source of the material is most pronounced:* it becomes much coarser in this direction, with increasingly abundant coarse angular and sub-angular chert pebbles. The source is evidently in the Ouachita facies and not in the Wichita facies of the Criner Hills and more southeastern Wichita chains. There is complete absence of Wichita-facies limestone pebbles in the Devils Kitchen conglomerate in the basal Deese. The same is repeated in less conspicuous conglomerates higher up in the Deese sequence (**99**, p. 35). Sedimentation seems too rapid in the very thick clastic Deese to explain this absence of Ordovician limestone material by solution of the limestone elements before deposition of the conglomerates.

The upper member, *the Hoxbar division,* (upper-Strawn, Canyon, and lower-Cisco, about 4000 feet thick), consists chiefly of blue, yellow, reddish and brownish shales with a far greater development of thick limestone ledges and fewer sandstones. A limestone conglomerate occurs at the base in conjunction with the Confederate Limestone member. Other conglomerates contain pre-Carboniferous, as well as older Pennsylvanian limestones and also chert. These Wichita facies rocks originate from the Criner Hills, but notably from the Arbuckle area : they thin out to the southwest (**99**, p. 43). The few conglomerates are probably the indication of earlier precursory uplift of the Arbuckle orogenic phase, but the series still totally lacks arkosic materials.

The Hoxbar apparently buried a considerable portion of the more southern Wichita chains before their rejuvenation by the Arbuckle phase. Together with even some upper Deese, it covers the southern flank of the Criner Hills, unconformably overlapping Caney, Silurian and Ordovician (**99**, Pl. XVII, our *Plate 2*). This means that much of the foreland facies Hoxbar material must have been derived from another source than the frontal Wichita chains. The Arbuckles were beginning to emerge. The Ouachita Mountains, however, must have been peneplained to a very notable extent before Cisco time.

There is, therefor, considerable evidence that, all over lower-Pennsylvanian time, from Bend to late in the Strawn, and possibly as late as the Canyon, uplifted areas subject to erosion prevailed, *notably in the Ouachita facies.* However, we find no mention in the literature of any unconformity between the Atoka and the underlying Jackfork sandstone, on the thrust masses within the mountains south of the Ti Valley fault. It is claimed that the Jackfork-Caney-Atoka sequence is conformable, and that only the "Caney" disappears as such to the east and southeast. Only in the foreland there are unconformities, indicating this phase; first at the base of the Atoka, and then again both at the base of the Savanna and of the Thurman sandstone, indicating movement through most of the Strawn. [1])

We must note again that confusion exists as to what is Jackfork, and what is Atoka. The Atoka formation (Pottsville) rests upon the Wapanucka limestone along the northern autochtone border of the Ouachita Mountains in Oklahoma; farther to the southeast, within the overthrust masses, it rests upon the Ouachita Caney, and beyond the margin where "Caney" it at all represented, it rests on the still older Jackfork. The latter is everywhere the case in Arkansas, both in the frontal thrust zone and farther back in the mountains. The Atoka thickens from about 3000 feet in the Coal Basin in the foreland, to 6000 and even 9400 feet, at least, farther to the east and southeast in the mountains (**115**).

Here HONESS had distinguished an upper- and a lower-Jackfork sandstone, entirely similar in lithology, in eastern Pushmataha and northern McCurtain counties. MISER (**76**, p. 21) proved that HONESS' "upper-Jackfork" (6000 feet thick) is equivalent to the Atoka: it has a Morrow fauna at the base. This basal zone may be equivalent to the Wapanucka limestone farther north, here replaced by sandstone. On the geologic map of Oklahoma this intra-mountainous "upper-Jackfork" is now represented as Atoka, with the approval of HONESS.

The Caney shale north and east of the Arbuckle Mountains (1600—2000 feet thick) seems the equivalent of the entire Jackfork-Stanley sequence of the Ouachita thrustsheets. In that case it would represent the outer edge of this mass of flysch, in a fine shale facies and devoid of clastic material, at this distance from the source in the Ouachita hinterland. This contrast is another indication of the distance which the thrust masses of the Ouachitas may have traveled. The Ardmore Basin affords an opportunity to study the development of the outer edge of this flysch in a locality farther to the south, where it is still in situ, although the Ardmore Basin has been severely shortened by compression. This basin is a kind of embayment of the flysch geosyncline, where the latter extends into the geosyncline of the Wichita system. The Arbuckle Mountains are on the outside edge of this embayment.

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[1]) We will see in the chapter describing the Marathon Mountains (p. 61), that in this westernmost exposure of the Ouachita System, a similar conformity is in evidence between the flysch (Tesnus-Dimple) and the molasse (Haymond-Gaptank) deposits in the exposed part of the structure.

In the Ardmore Basin the Arbuckle Caney of the region to the north of the Arbuckles, seems replaced by a sequence, of a thickness which already attains 5000 feet, is less exclusively shaly, and now contains both the Ardmore Caney and the more clastic Springer formation. This is apparently a transition to the 17.000 to 20.000 feet of Jackfork-Stanley flysch in the Ouachita Mountains. TOMLINSON remarks that the hard greenish sandstones in the base of the Springer formation resemble sandstones which occur in the Stanley shale series. (**99**, p. 16). (See also our page 51).

Another theory holds that the Caney in the Ouachitas progressively overlaps the Jackfork and Stanley formations to the westward, where it finally comes into contact with the Woodford chert in the Arbuckle Mountains. This would then mean a break and unconformity.

The writer believes that the first theory is correct, and that the Caney of the Arbuckles (divided into two parts by a considerable hiatus) represents the entire Jackfork-Stanley sequence. He suspects, however, that much of the intra-Ouachita Atoka is widely thrust over some of the Jackfork and Stanley, and that these formations may have occasionally become mixed in a very involved manner, and that the "Caney" of the northwestern Ouachitas in Oklahoma, which carries the exotic boulders, is some tongue of late-Mississippian shale, intercalated, and perhaps rolled out between sandstone masses, and that still farther to the south, the structural relationship between the Pennsylvanian and the older Carboniferous is still very obscure. We will refer to all this later, when discussing the erratic boulders and blocks in the Ouachita "Caney".

B. Farther to the south an earlier important uplifting must necessarily have occurred, antedating the movement which, at the close of Morrow time, initiated the deposition of the molasse sediments of the Atoka and higher Pennsylvanian beds in the Coal Basin and Ardmore foredeeps.

The sudden development of sedimentation in the uppermost Mississippian and lowest Pottsville, depositing more than 17.000 feet (20.000 feet in McCurtain county, according to HONESS) of orogenic flysch, seems ample evidence, particularly if we note the absence of any very active sedimentation during the preceeding earlier Paleozoic periods in the Ouachita province. We have only 3000 feet of aggregate thickness of sediments, deposited during the entire Cambrian, Ordovician, Silurian and Devonian. It is very doubtful whether there was any sedimentation at all here in the lower- and middle-Mississippian : if there was, it was only gelatinous silica in extremely quiet, possibly rather deep water, resulting in cherts.

This great flysch deposit announces the earlier, late-Mississippian pulsation of the Wichita orogeny.

This flysch came from a southern source. Thick beds of sandstone appear in the shale section in this direction. Many small pebbles in the Jackfork sandstone of the southern outcrops become ever less abundant toward the north. All this indicates highlands to the south, yielding an enormous amount of erosional detritus, so much in fact, that *only a very active orogeny in the hinterland could explain it.* A mere uplifting of an old "borderland" would seem entirely inadequate. *A flysch mass of this character and in such quantity requires actively rising mountain chains, and a genetically related, sinking geosyncline.*

These southern mountains consisted in a large measure of acid igneous and metamorphic rocks. All sandstones contain bits of fresh plagioclase, and many of the coarser layers contain fragments of black shale, slate, chert, micaceous shist, porphyritic basic rocks, granitic quartz, muscovite, biotite, tourmaline, garnets, etcetera. The rarity of orthoclase and microcline may be explained by reason of its relatively easy destruction by decomposition. The large amount of chlorite, present with sericite as a binding material in practically all the sandstones, indicates that the original cement must have been ferruginous. Considerable carbonaceous matter and bits of carbonized wood prove that vegetation must have existed on the emerged hinterland. (**55**, p. 196).

We have already remarked that these highlands must have been situated far to the south, before the flysch geosyncline became violently compressed and overthrust, thereby greatly shortening their distance.

The age of this early pulsation of the Wichita phase must be very late in the Mississippian, in the transition period toward the lowest-Pennsylvanian (Pottsville). In ULRICH's opinion (**103**, pp. 23—24), the Stanley is equivalent to the Parkwood formation of Alabama and Tennessee. It agrees in position as well as in lithologic character. ULRICH thinks that the Jackfork may already represent lowermost-Pottsville, a part not deposited outside of the foredeep. The Parkwood is younger than the Pitkin limestone, which lies at the top of the eroded Plateau Mississippian in northeastern Oklahoma. Here, and in most other areas within the American continent, the Parkwood stage is represented by part of a considerable break: the remarkably widespread unconformable contact of the Pennsylvanian and Mississippian. Only in the Appalachian and Ouachita geosynclines, therefor, the orogenic flysch, deposited in a foredeep fronting the earlier ranges, would fill this gap. This forms another link connecting the Ouachitas with the Appalachians [1]). Exactly the same condition exists probably at Marathon.

[1]) In northwestern Alabama the foreland coalmeasures are separated from the underlying Mississippian strata by a hiatus of great magnitude, which is in part represented by the Parkwood formation of the Birmingham and Shades Valleys. Parkwood still occurs in the subsurface of the Warrior syncline, as proven by borings. The Alabama Parkwood is an unfossiliferous sequence of grey and greenish sandy shales, with some thinbedded sandstones, known to a tickness of 3000 feet. In several respects it is extremely similar to the Ouachita flysch, in medium distance from the source.

Pre-Wichita orogenic movements.

a. In the frontal zone of the Ouachita province still older minor movements of Mississippian time are suggested by an apparent unconformity, separating the Arkansas Novaculite (which may, possibly, extend into middle-Mississippian) and the upper-Mississippian flysch sediments, indicating uplift and emergence before the forming of the flysch geosyncline. Chert conglomerates rest on the Novaculite in the Potatoe Hills; they are also found at the base of the Stanley shale in the southern outcrops. North of the Ti Valley shearplane, the autochtonous Caney appears to rest on different members of the Woodford at different exposures (**83**, p. 1039). Jackfork and Stanley are not yet represented there.

This movement may indicate the beginning of the first (flysch) pulsation, of the Wichita-phase.

b. The widespread unconformity on the top of the Hunton, under overlapping lower-Mississippian (Chattanooga-Woodford) in the Ozark region and on the Hunton Arch, and all over the Midcontinent Plateau, seems to reflect a still earlier phase, which, though faint in the foreland zone, could be conceived as a reflexion of more important movements in the hinterland, the first precursory warpings of the late-Paleozoic orogenic cycle. Similar precursory folding of considerable importance occurred in the northern Appalachians (Acadian phase of Blackwelder, **18**). In the Llano-Burnett uplift, in the foreland of the East-Texas front of the Ouachita system, the chert underlying the Mississippian Barnett shale, which possibly represents the Woodford, also reposes unconformably on the eroded surface of the Ellenburger limestone.

SCHUCHERT, PLUMMER and GOUIN also claim early-Mississippian movements for the Wichita chains.

c. Unconformities are reported overlying the Blaylock, of about Richmond age (**115**, Plate XXV, and also **103**). *This would indicate a Caledonide phase.*

Summary of the early-Carboniferous orogeny in the Ouachita Mountains.

The earliest, largely epeirogenic movements seem to originate in the lowermost-Mississippian *(Acadian phase?)*.

The principal orogeny, of great magnitude, THE WICHITA PHASE, occurs in two pulsations, and lasted from the uppermost-Mississippian well into Pottsville, and possibly into Allegheny time.

The earlier pulsation creates a great flysch deposit: 17.000 to 20.000 feet of Stanley-Jackfork in a wide foredeep, the outer edge of which may have extended as far to the northwest as the Arbuckle region (Arbuckle Caney). It also extended in an embayment into the Wichita geosyncline in the Ardmore region. These sediments originated from ranges of crystalline and metamorphic rocks.

The later pulsation set in towards the end of Morrow time (Wapanucka). It is indicated by considerable unconformities (for instance on top of the Springer). It is contemporaneous with the principal folding in the Wichita geosyncline. We have no clear indications *how* this folding affected the Ouachita chains, but that it did affect them is clear. A new foredeep originated, considerably in front of the original flysch geosyncline and became filled with some 17.000 feet of molasse, derived from a southern source, where important uplift and active orogeny *must* have occurred, creating chains composed of old-Paleozoics as well as flysch facies rocks. Intra-mountainous molasse basins were also formed.

The two pulsations, which were practically continuous, since they followed each other without perceptible break in the mountains, together constitute the *Wichita orogeny* in the Ouachita Mountains.

Later, gentler movements continued in Bostwick, Savanna and Thurman time. These may pertain either to the Ouachita mountain system, or to their Wichita facies autochtone.

II. *The Arbuckle Orogeny in the Ouachita Mountains?*

We have no indication in the Ouachita Mountains of the important orogenetic Arbuckle phase of middle-Cisco time. Within the Ouachitas no strata of this age exist. This does not prove, however, that the earlier sequence was not again affected. It would be possible that this had occurred, since this phase is so very much in evidence in the Marathon Mountains, which we consider as the southwestern extension of the Ouachita system. However, the fact that the upper-Cisco Pontotoc and the general red facies in southeastern Oklohoma and northeastern Texas seem exclusively controlled by the Wichita chains, is an argument against an important Arbuckle phase in the Ouachitas. Already in the Hoxbar (lower-Cisco) the Ouachita Mountains seem to have ceased to be an important source of sediments (cf. page 42).

III. *Final overthrusting of the Ouachita nappes.*

When the great forward movement of the thrustsheets in the Ouachitas occurred is, uncertain: *it may, possibly, have happened fairly late in the Permian.*

Already the analogy with the Appalachians in Alabama suggests this as a possibility. Arguments by F. A. MELTON (**73**) in favor of this view seem rather persuasive. They are based on the assumption that the violent push, resulting in an overthrusting of such magnitude, should have left visible effects in the foreland, which should have been subject at that time to much pressure in the same northwesterly to northerly direction[1]).

[1]) This assumes that overthrusting of this kind is principally the result of a lateral push and not, to a certain extent, of gravitational gliding of masses from an elevated hinterland toward a depressed foredeep, in accordance with theories as expressed by R. A. DALY, E. HAARMANN, and others.

MELTON describes a prominent system of joints radiating fanwise from the convex front of the Ouachita Mountains into the flat laying rocks of central and western Oklahoma, as far north as southern Kansas. Strata as high up as the middle of the Permian section of Oklahoma (Garber sandstone) are cut by these joints. There seems to be a gradation from the smooth high-constraint joints nearer the mountains to the rough low-pressure fractures in central and northern Oklahoma. MELTON develops the theory that the joints in the open folds, skirting the front of the Ouachita Mountains, were formed at the same time that the originally flatter beds of these structures were being tilted in the later process of folding, in other words that these open folds should be considered as largely contemporaneous with the regional jointing and should also have been considerably deformed in Permian time.

There is no comparable system of radiating joints in the exposed strata of central Oklahoma, associated in origin with structures of the Cisco stage of the Wichita-Arbuckle orogeny (**73**, pp. 68—69).

The writer does not think that any known facts seriously conflict with MELTON's theory, that considerable overthrusting of the Ouachitas may have happened that late in the Permian. The apparent sudden termination of the McAlester and Savanna anticlines of the open fold zone, near the middle of the Boggy shale deposition, is, however, a grave difficulty. It has been considered an indication that these folds were formed exclusively in or previous to middle Boggy time by W. W. CLAWSON (**29**, 1928). These folds do not involve beds from the Thurman sandstone upwards, and decided erosional unconformity underlies the Savanna sandstone. MELTON believes that the thick Boggy shale formation (2000—2600 feet), through its plasticity, may well have, to a certain extent, compensated the folding and protected the overlying more competent sandstones from participating, but this does not explain erosional unconformities. There is, therefor, conclusive evidence, that the lower part of the sedimentary section of the foredeep was deformed considerably more than the upper portion. *These folded structures could not possibly date only from Permian time.* They point to slow sinking and compressive movements in the foredeep during the proces of sedimentation.

The phenomenon of increasing intensity of folding with depth in the series is very general and widespread in all the synclinal open fold belts, in front of the world's major orogenies ("Trogfaltung"). We may refer here to the so minutely known open fold zone in front of the thrustsheets of the Variscan mountains of Europe, in northern France, Belgium, Holland and Westfalia. This belt of coalmeasure deposits, so very similar to those in America, presents exactly the same structural picture. The sediments also antedate the final overthrusting of the Variscan front: cf. K. LEHMANN (**68**, **69**), and notably H. BÖTTCHER (**23**).

That a Permian orogenic phase revived the Ouachita system, is certain.

We have already mentioned the evidence for the belief that the Ouachitas must have been considerably peneplained in the intermediate period before the middle Permian, when these mountains again became an active topographic feature in southern Oklahoma and northeastern Texas. Only the chains elevated by the Arbuckle phase *in the Wichita system* influenced the development of the redbed facies in the upper-Cisco and lower-Permian of these regions. Later in the Permian, a change in this condition is indicated in the San Angelo-Duncan sandstones, which are clastics originating from *a new eastern source*. The later Permian beds have intrinsically the same character, though they become finer in texture, even the heavy minerals remain the same. In the eastern portion of the Permian Basin, all these beds point to a new eastern and southeastern source, in the Ouachita chains, though of constantly diminishing topographic importance. (CHENEY. **27**, **28**). See our *Table VII*.

If, therefor, there is no evidence that the Arbuckle phase itself was expressed by considerable diastrophism in the Ouachita Mountains, the overthrusting must have occurred either earlier, or it must have happened later.

If the present Ouachita nappes had been in place before the Arbuckle phase, overriding the chains of the Wichita system, the very strong compression, which is so conspicuous in the immediately adjoining Ardmore Basin, should have strongly remodelled them; it would have caused very much more conspicuous refolding of the thrustplanes than is anywhere indicated. There is no doubt that the Arbuckle phase must have affected the Wichita folds in the autochtone of the Ouachitas as strongly as it acted only 12 miles farther to the west. The Preston anticline proves that even a much less important phase in the Cretaceous reaffected the Ouachita structure along Wichita lines, and wells have demonstrated that here the pre-Cretaceous bedrock is in Ouachita facies. Hence the nappes of Ouachita rocks must have been shoved over the Wichita chains *later* than the Arbuckle orogeny. Although the Arbuckle phase must have elevated the Wichita chains considerably, they must have been peneplained to a considerable extent before the overthrusting could have occurred. That some relief still remained, however, is shown by the "Caney" exotics of Wichita facies rocks.

The conclusion seems permissible, therefor, that *an important orogeny, which created the Ouachita Mountain structure, as we now know it,* was, probably completed only *in Permian time, some time posterior to the Garber sandstone of Oklahoma (Clear Fork of Texas), possibly in San Angelo-Duncan time*. Very much coarser Permian detritus has probably originated from this phase than we now find in the remaining exposures. No Permian deposits remain in existence in the immediate vicinity of the Ouachita front. This is another instance of the similarity between the American chains and the contemporaneous Variscan Mountains of Europe.

SUMMARY.

We may now summarize the structure of the Ouachita Mountains as follows:

At least two earlier phases occurred: early Mississippian and late-Mississippian — early-Pennsylvanian; the latter probably also in two sub-phases. Most of these diastrophisms can only be indirectly inferred from the development of the sediments and the general geologic history of the region. *The late Pennsylvanian Arbuckle phase is at least problematical,* if not improbable. Only the first of the earlier phases is expressed by any, sofar known structural proofs within the Ouachitas. All the direct information we have is predominantly controlled by *the culminating paroxysm of overthrusting, possibly in the Permian.* Probably more detailed work in these mountains will gradually reveal clearer proofs of the previous phases. This was the experience in the Alps [1]).

THE PRE-CARBONIFEROUS EXOTIC BOULDERS IN THE SO CALLED "CANEY SHALE" IN THE NORTHWESTERN FRONT OF THE OUACHITA MOUNTAINS.

In the frontal zone of the Ouachita Mountains of Oklahoma (not of Arkansas), between the Ti Valley thrustplane and the Winding Stair fault, and farther south in the western portion, but never south of the

[1]) In the southern Alps of Austria, as well as in the Dinarides, important movements are in evidence, preceding the final diastrophism, which created the present structure. The oldest movements are always confined to the more central zones, and only gradually orogeny proceeds towards the outer zones. In the interior belts of the Southern Alps A. WINKLER (**110**, **112**) describes Middle-Jurassic folding in the high (central) Julian Alps. Traces of the Cretaceous phase are clearly preserved in the entire eastern province of the Southern Alps. In the Julian and Steiner Alps, and their eastern prolongations, folding now spreads into the more outer zones. In the Dinarides, the frontal zones, exposed in Croatia and Slavonia, were not yet affected by Cretaceous deformation and remained geosynclinal, but these movements affected already the now largely buried inner ophiolitic zone and adjacent still more central zones, which are now only exposed far to the southeast, and are not visible in the plains of Slavonia, adjacent to the Southern Alps.

In the Southern Alps, these Cretaceous movements were restricted to folding, but in the central chains of the Austrian Alps Cretaceous overthrusting takes place on a wide scale (as already indicated in the Drau chains and even in the northern belt of the Karawanken range).

In the early Eocene another orogeny again affects the Southern Alps.

The major Tertiary diastrophism of this entire complex, however, is post-Eocene, pre-middle-Oligocene. This phase created the now so conspicuous structure and largely obliterated and obscured the traces of the earlier orogenies, which were only revealed through painstaking detailed fieldwork.

The final phase was followed by a series of gradually less important after-phases: in the older Miocene, the middle-Miocene and in a series of Pliocene warpings. The present great elevation of the major massifs dates probable from the Pliocene.

A similar series of phases has gradually been revealed, as detailed work progressed, in the Paleozoic (Variscan) chains of West-Central Europe.

Octavia fault, narrow outcrops of a locally macerated black shale occur, some few hundred feet thick, intercalated between masses of Atoka formation, and Jackfork sandstone, which are some 4000 to 6000 feet thick each. This shale is generally called "Caney" in the literature and on the geologic map of Oklahoma. Its real stratigraphic meaning and correlation are in dispute.

On page 43 we have already discussed the conditions pertaining to the foreland Caney in the Arbuckle region and the Ardmore Basin. Recapitulating this shortly: the foreland Caney overlies the Sycamore limestone, which latter, according to ULRICH, represents the upper part of Kinderhook horizon, the lower division of the Mississippian. This Caney comprises lowermost Pennsylvanian as well as Mississippian; the lower portion is, according to ULRICH, separated from the upper part by a break (**103**, p. 25). This upper Caney would be Morrow, and may only be a shaly equivalent of the Wapanucka limestone; ULRICH places the basal portion in the middle-Mississippian (Meramec). This may be too low. In the writer's opinion, this outer foreland-Caney is probably representative of the complete Jackfork-Stanley flysch sequence of the Ouachitas. In the Ardmore Basin we have a transition development: the 5000 feet thick Springer-Caney sequence.

There is no Wapanucka, at least no Wapanucka *limestone*, in Oklahoma south of the Ti Valley shearplane; also there is none farther to the east in Arkansas.

In the Arkansas section there is no "Caney shale" intercalation between the Atoka formation and the Jackfork. South of the Octavia fault it is also absent in the Oklahoma section, and the Atoka formation overlaps directly over older rocks. A fauna of Morrow age, however, continues in the base of this Ouachita intra-mountainous Atoka.

The lithologic characteristics of the "Caney shale" are the same in all Ouachita locations: a black, locally much crushed shale, filled with small, round, marblelike phosphatic nodules, and occasional larger limestone concretions. G. H. GIRTY (cited by MISER: **76**, p. 27) states, that the fauna of all the exposures is also similar, indicates Mississippian, and presents only regional differences with the Mississippian part of the foreland Caney. SIDNEY POWERS states that the shale contains many micro- and some macro-fossils.

The southern exposures of the certainly uppermost Mississippian Stanley shale show that sandstone ledges, increasing in thickness and clasticity toward the south, finger out toward the north. Thus the "Caney" of the Ouachita nappe could not possibly be the equivalent of the foreland Caney as such. It can only represent a comparatively thin tongue of a more persistent shale, of general lower-Caney age, in a part of the flysch-section, which has already become largely arenaceous; this shale is now intercalated between the massive Jackfork sandstone and the Atoka formation. Overlapping is also suspected.

In this relatively thin bed of shale (never in the autochtonous Caney. north of the Ti Valley shear) numerous boulders and also far greater blocks of foreign rocks occur. They are found in a zone of about a hundred miles long in the northwestern section of the mountains, in Oklahoma; they have never been mentioned from Arkansas, where this "Caney" shale intercalation is not represented. *The boulders and blocks represent samples of the complete section of pre-Carboniferous sedimentary rocks of the Arbuckle sequence, a series which, as we have seen, is entirely foreign to the Ouachita section.* They consist mostly of compact limestones, but sandstones and even arenaceous and calcareous shales, (these mostly in small pieces) are observed. Pre-Cambrian does not occur.

The erratics are found embedded in the shale, but are mostly seen weathered out and strewn over many of the bare outcrops of the lower part of the shale band (ULRICH, **103**, p. 7). By the fossils contained in the pieces, the following formations have been identified: *Cambro-Ordovician* Arbuckle limestone (very frequent), *Ordovician* Simpson and Viola limestone, *Silurian* Sylvan shale and Chimney Hill oolite, *Devonian* cherts, some shales of Sycamore (*lower-Mississippian*) age, a light grey calcareous shale with *Morrow* fossils, and a crinoidial limestone, equally with a *Wapanucka* (Morrow) fauna. As said, granite or other crystalline or metamorphic basement rocks do not occur.

All these fragments, with the possible exception of some of the Devonian cherts, could only have originated from formations which are wholly absent in this facies in the Ouachita system, but *they represent the complete sequence of the Arbuckle province*, excepting only the granite and the basal Cambrian Reagan sandstone. As ULRICH points out (**103**, p. 9), many of the rocks are *typically Arbuckle*, different from contemporaneous formations represented anywhere in this entire region.

MISER describes the boulders and pebbles as irregularly scattered through the shale "like plums in a pudding", not at all alike to an ordinary boulder bed or conglomerate (**77**, p. 28). The fragments are of many sizes: some are mere pebbles a fraction of an inch in diameter, very many blocks measure ten feet in their longest dimension, but others as much as 200 feet: one was measured by MISER as 50 by 369 feet. SIDNEY POWERS mentions a Viola limestone block measuring 60 by 550 feet (**83**, p. 1043). All the largest blocks occur in the Johns Valley exposure. The larger blocks may be even greater, being not fully exposed.

The pieces are subangular or rounded, and most of them appear weathered or corroded by solution. In some of the outcrops, smaller pieces have been squeezed out and elongated into lenticular shapes, apparently by pressure; many boulders are slickensided and not infrequently gouged.

These exotics appear in streaks in a partly mylonitized shale, thus giving the appearance of boulder "beds". SIDNEY POWERS drew the writers attention to the fact that by no means all this "Caney" shale appears highly crushed. He has studied localities where the shale "enclosing the famous boulders" is neither macerated nor mylonitized [1]). MISER describes shale beds from Johns Valley, which are in every way lithologically similar to foreland Caney, and show no signs of mylonitization or mixture with other material ; such shale overlies the boulder horizon, which is confined to the lower 50 to 100 feet of the shale. (**76**, pp. 22—23). At other localities there are three or four boulder-bearing horizons; elsewhere again, there are no boulders in the lower black shale, but in an overlying grey shale. Caney micro-fossils occur in shales below the most abundant boulder-zones (**83**, p. 1043).

It seems evident, therefor, that the entire mass of the Ouchita-"Caney" is not a thrustplane-mylonite, but that considerable masses of a sedimentary, more or less undisturbed shale are present. The streaks of exotics do not occur in some regular "bed", but vary their place in the shale.

Although the Johns Valley locality has been best described in the literature, similar blocks occur and are mentioned along the entire belt of "Caney" outcrops, as far east as Stapp in Le Flore county, near the Arkansas line. They have never been described from Arkansas localities.

Concurrence of opinion gives the matrix Mississippian age, except ULRICH. POWERS cites macro- and micro-fossils; the latter occurring both above and below the most abundant boulder bearing horizon. These micro-fossils are post-Chester and pre-Pottsville in age, according to HARLTON (**83**, p. 1040). MISER and GIRTY (**76**, pp. 25—26) cite Mississippian macro-fossils in evidence, chiefly from calcareous concretions; ULRICH, however, considers these latter as much remanié as the exotic fragments (this could scarcely apply to the micro-fauna). Consequently, ULRICH wishes to place the shale in the lower-Pennsylvanian, higher than the youngest boulders identified in it (Morrow). He considers the blocks and boulders sedimentary erratics, transported by shore ice, and hence the matrix must not be older than any of the boulders. He, therefor, proposes to change the name "Caney" into "Johns Valley shale". The writer also thinks that it would seem highly adequate not to call this shale "Caney", regardless of its age.

The exotics occur *only* in such localities where the shale matrix is intercalated between Atoka and the great Jackfork sandstone, and *never in the autochtone true Caney, resting normally on Sycamore limestone.*

Even within the Ouachita Mountains, these erratics do not occur in the autochtonous belt south of the Choctaw fault. They do not occur in the Brushy Creek inlier, in sections 4 and 5, Township 2 North, Range 15 East. They only set in abruptly and in great abundance in the bands of shale on the flanks of Winding Stair Mountain, that is south of the Ti Valley shear plane. The first of these occur about 3 miles south of the Brushy Creek exposures (**103**, p. 42). The principal localities where the exotics occur are

[1]) Written communication of December 8, 1930.

marked on ULRICH'S map (**103**, fig. 1, p. 13). They are marked by a * on the map of our *Plate 3*.

In addition to these "*Caney*" zones of blocks, other layers with erratics occur. Some of these appear to be more or less normal conglomerates; others perhaps not. G. D. MORGAN and B. F. WALLIS (**103**, p. 10, cited by ULRICH) mentioned occurrences of erratic boulders in shales and limestones, referred by them to a Morrow (Wapanucka) horizon. POWERS also mentions such. They occur a considerable distance to the northwest of the Brushy Creek exposure, therefor apparently in the autochtone, and they are not associated with large blocks. They also occur farther east in LeFlore county. POWERS describes a conglomerate in basal Atoka near Stapp, containing rounded boulders of black chert and Ordovician *limestone*, tightly cemented in a sandy matrix. They measure up to 4 or 6 inches; the largest are a foot long. (**83**, p. 1041). Similar boulder beds occur in basal Atoka near Compton (Township 4 North, Range 22 East). MISER (**77**) and TOMLINSON (**99**) also mention Wapanucka-horizon conglomerates.

Perusing the literature, however, it strikes one that the stratigraphic correlations of these exposures seem still unsatisfactory as to what is Jackfork, Atoka, or Wapanucka, and that the structural relations of these strata are not well cleared. Anyhow, it seems that there occur conglomerates, containing no very great blocks, in horizons that are regarded as of Wapanucka age, and these lie to the northwest of the true "Johns Valley shale" exposures. These also contain Ordovician *limestones*, seemingly therefor Arbuckle-facies rocks. They only seem to occur in the immediate vicinty of boulder bearing "Johns Valley shale" outcrops, not farther out in the foreland, and also not in Arkansas. They seem, therefor, somewhat related.

We may, therefor, summarize the description of the Ouachita-exotics as follows. They only occur in the Ouachita-flysch of Oklahoma; not in Arkansas. The large blocks are confined to a relatively thin layer of not infrequently, but not always, mylonitized black shale of upper-Mississippian age, intercalated between the sandstones and shales of the Atoka and the massive Jackfork sandstone, the latter several thousand feet thick. The occurrence seems confined to this association in a zone of about 100 miles long, exclusively within the frontal zone of the overthrust sheets. The exotics constitute a practically complete assemblage of the sedimentary rocks of the Arbuckle-Wichita sequence, in fragments up to the size of a large building. These rocks are utterly foreign to the sequence of formations represented in the Ouachita Mountains, but they must be assumed to occur in the autochtonous basement buried beneath the thrust masses. [1])

[1]) Through a recent communication from E. H. SELLARDS (News Letter from the Bureau of Economic Geology, January 1931) the writer was advised that rather similar exotic boulders have been found at Marathon, in the upper part of the equivalent flysch-

Origin and genesis of the Ouachita exotics.

All American geologists (ULRICH, MISER, TOMLINSON, POWERS, WOODWORTH, TAFF), who have discussed these "boulders", seem to have come to the conclusion that these blocks are *sedimentary*, and must have been carried from outcrops in the Arbuckle province *by floating ice or icebergs*, and that they were dropped on the seabottom in uppermost Mississippian or earliest Pennsylvanian time. ULRICH emphasizes again and again that they must have been deposited at the same time as the matrix enclosing them. ULRICH believes that the ice came from the Arbuckle Mountains. TOMLINSON, POWERS and MISER think that the source is in some region east or southeast of the Arbuckles or adjacent ranges, from a location now buried beneath the Gulf Coast Plain, or under some of the present overthrusts of the Ouachita Mountains, which did not yet exist at the time that the matrix was deposited. That many of the boulders appear scratched or gouged has been adduced as evidence of their glacial origin. ULRICH gives some good photographs of scratched fragments (**103**), but he comes to the conclusion (p. 35), "that it appears physically impossible that these phenomena can have been produced as slickensiding by movements in place or in a fault breccia. Neither could they have been made by the steady flowage of glacial ice". He believes, however, that they could be explained if boulders of varying hardness were imbedded in the base of floating masses of shore ice. A study of ULRICH'S photographs, and of Caney boulders which the writer has personally observed, convinces him that these quite irregular scratches and deep short gouges are anything but glacial. He refers to a paper by K. KREJCI-GRAF (**67**), dealing with the many erroneous conclusions based on supposedly glacial scratches on boulders.

The writer has further objections against a glacial or floating shore ice theory for Carboniferous erratics in this region. They are the following:

1. Who has ever seen or heard of blocks of such enormous size, up to several hundred feet across, transported by floating ice, even of the magnitude of Antarctic icebergs? Their size far exceeds that of any ice-born rocks known. The only glacial erratics approaching such dimensions are sheared off pieces of a substratum, over which a very large glacier or land-ice moved, and similar masses were never transported very far, and are always associated with extensive basal moraine deposits and occasionally with scratched rock floors.

2. The faunal and floral character of the Mississippian and lower-Pennsylvanian of the Ouachita and Arbuckle provinces certainly does not suggest glacial climatic conditions. The writer refers to the paleontological lists, including the plant fossils, given by ULRICH, MISER and HONESS

molasse sequence of the Permo-Carboniferous chains in Southwest-Texas. Some blocks of Caballos Novaculite measure up to 100 feet in their largest diameter; other, much smaller fragments are composed of rocks ranging in age from the pre-Cambrian to the Dimple. (Pottsville, probably Morrow; cf. Table V). They are in Ouachita facies (see pag. 72).

(**103, 77**). These are self-explanatory, even if we take into account that our conclusions as to climatic conditions under which Paleozoic organisms may have lived, must be drawn cautiously.

3. If these blocks had been transported by ice, or any other floating agency, where should they have come from to be deposited as a sedimentary product in a Mississippian shale? They comprise the whole sequence of pre-Pennsylvanian Paleozoics *of the Arbuckle province*. Granted that the "Caney" of these Ouachita thrustsheets was deposited long before the major overthrusting of these mountains, *it requires a Mississippian folding in the Arbuckle province of sufficient magnitude to create outcrops of this complete sequence, of an aggregate thickness of* 15.000 *feet, within a comparatively restricted area*, from which these boulders could have reached the equally *restricted* area, within which we now find them in this Ouachita "Caney". And, even assuming that such an orogeny had taken place, from where came the Morrow boulders in this Mississippian shale? (This is ULRICH'S difficulty and the cause of his controversy with MISER regarding the age of the Ouachita "Caney"). However, there is no trace of any s e r i o u s diastrophism in the Arbuckle Mountains and the Ardmore Basin before *late* Pennsylvanian (Cisco). The earliest proven i n t e n s e folding in the frontal Wichita System, south of the Anadarko-Ardmore foredeep, is post-Morrow. We must look to the central Red River folds, before encountering any, even remote possibility for an orogenic phase, that could have folded any Wichita facies rocks, and uplifted them sufficiently to make it possible for *Mississippian* erosion to cut deep enough into the folds, to bare a considerable expanse of strata far down into the Cambro-Ordovician. There is no indication of any such orogeny in the entire Wichita-Arbuckle system.

In the writer's opinion, these boulders and blocks are not glacial, and, at least in the case of the large blocks, not sedimentary. He believes that they are TECTONIC BLOCKS, similar to such as we find in the frontal thrustsheets of many other mountain chains with a nappe structure.

In the mountain ranges of Europe exotic blocks of an entirely similar nature are well known. They have attracted attention and were mentioned in literature as early as the beginning of the 19th century. We know them from the entire front of the Alpide chains, from the Carpathians as well as from the Alps, even from the Apennines. They also occur in the Caucasus. They will no doubt be found in many other similarly built mountains. The extensive literature occupies itself mostly with Alpine localities. The reader can be particularly referred to treatises by ARNOLD HEIM (**54**, 1907), G. GEYER (**42**, 1904), and H. P. CORNELIUS (**32**, 1924). The two last mentioned papers contain an extensive bibliography on the subject.

The origin of the very large blocks, which also occur amongst these European exotics, has always been more or less a riddle; the problem was complicated by considerable confusion, since there exist many different kinds of these boulder beds and breccias, which are by no means of the same origin. It was the merit of ARNOLD HEIM to have brought order in the confusion.

There are three kinds of boulders, blocks, and gigantic masses in the Alpine flysch zone, as distinguished by HEIM:

1. Blocks belonging to the sedimentary sequence in which they are now found, originating from harder ledges in the same formation, which have been broken, rolled out, scattered and displaced over more or less greater distances ("einheimische flyschblöcke");

2. "Klippen", wich are larger or smaller remnants of higher nappes, which have been bodily eroded ; large or smaller outliers, now resting as exotics on entirely different strata. The Mythen peaks of Switzerland (**31**, pp. 264—266) are a classic example; we know similar klippen from numerous other chains, also from the frontzone of the northern Rocky Mountains. Often these are huge masses, which could not be confused with erratic blocks, but not infrequently, smaller remnants have become much broken and scattered, and now appear as exotic blocks strewn over the surface. We could even imagine that such blocks were afterwards covered by new sediment, and would appear as incorporated in such a layer.

3. True "exotic blocks": foreign rocks *embedded* in the Alpine flysch (notably in the Wildflysch), or other similar formations of orogenic origin. These are larger or smaller boulders and blocks of rocks, which form no part of the sequence in which they are now enclosed, but have been derived from some foreign series. They range in size from ordinary coarse breccias, to blocks several hundred feet across. In the Alpine flysch they happen to be predominantly crystalline rocks, though sedimentaries also occur. This is accidental.

These truly exotic blocks can again be subdivided in two kinds:

a. Blocks which have been enclosed in the matrix in which they are now found by *processes of sedimentation*. Such boulder beds may be fans of ancient torrents, (or could even be old glacial moraines in suitable localities) ; on former coasts they may have been caused by the action of the surf on beach cliffs. If climatic conditions would permit such an interpretation, there is no objection to conceive some as carried by floating ice, derived from coastal, or piedmont glaciers. Notably the *very* large blocks of this class may have been deposited at the base of former cliffs, from which they were dislocated by landslides and transported a short distance by mudstreams. In this case the interpretation postulates a considerable, at least erosional break in the sedimentation, in conjunction with the formation of a topographic relief of considerable magnitude.

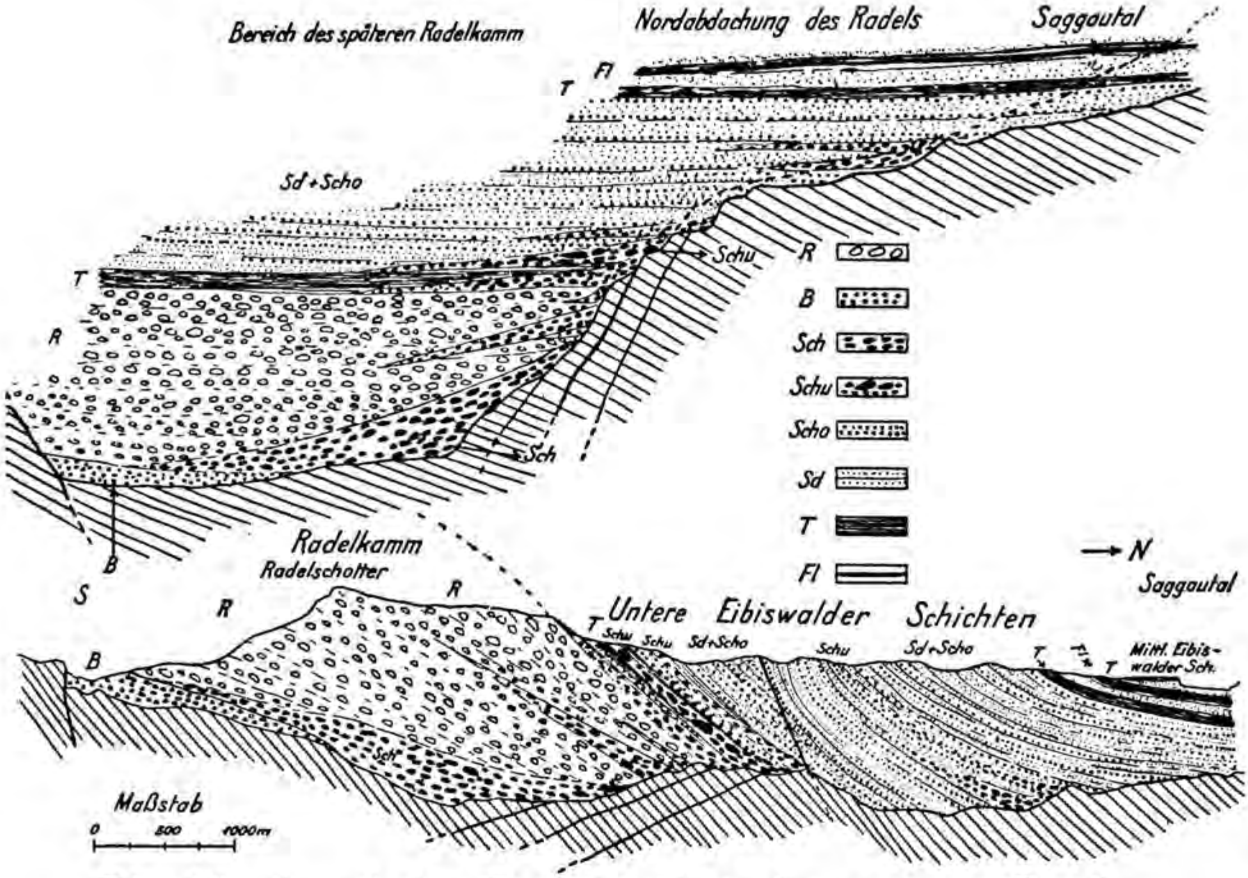
Examples of blocks of this class exist in the Cretaceous Gosau formation of the eastern Alps (AMPFERER, **1**, 1909), and also in the blocks in the Miocene of eastern Styria, in the Radelgebirge (A. WINKLER, **111**, 1929). In both cases these are blocks, which can be traced as derived from steep slopes in an ancient relief. Several of the large flysch blocks may have originated in the same manner. It is evident, that at the present time, such blocks need no longer lay at a lower elevation relative to the place of their origin, but that, through posterior tilting, folding or even overthrusting, their present location may seem at a higher altitude than their source. This is, for instance, evidently the case in the Radelgebirge (cf. *Plate 5*, reproduced by permission of A. WINKLER). These Radel blocks have also been explained as glacial before their true origin was recognized. The original source of such blocks in other localities may have been so displaced and obscured by subsequent structure, as to have become utterly irrecognisable. If the block bearing formation became later embodied in a thrustsheet, the boulder beds may now occur very far from the source region. An instance that the genesis can be clearly traced, is probably rather exceptional.

b. Another kind of exotics, finally, are *blocks which have been sheared off* from their original outcrops, or otherwise picked up, and are now *tectonically embodied in other structural elements*. The writer may add another variation of a related kind, namely *fragments pulled off from the frontal edge of a nappe*, overrun and rolled out under another overriding mass. Both kinds are, in part, what AMPFERER has very adequately called "*tectonic moraines*". They occur notably at the base (in "the sole") of overthrust masses.

The first named would have been sheared off from the substratum, particularly when the thrust was pushed over a surface showing a previous topographic relief. They were sheared off from ridges, rolled, worn, slickensided, gouged, and carried along in the thrustplane, or in underlying slices in the sole. Many of the larger and smaller exotic blocks of the Alpine or Carpathian flyschfront, embedded in often, but not always, crushed and macerated shaly beds, apparently belong to this class. These are confined to certain quite restricted zones and belts. This is easily understood, because they can only be present tectonically "downstream" relative to the motion of the overriding mass, that scattered a certain ridge. It is not necessary that all such material is a breccia, actually pried lose from the solid outcrops by the overthrusting. If an old surface was covered by wash, containing larger and smaller blocks of lose rock, more or less waterworn or corroded, these will equally become embodied in the overriding mass. The effect of a thrustsheet on its substratum and the mechanics of such a process are very similar to what happens under a large glacier, only on a much magnified scale. This fact was demonstrated by AMPFERER from numerous sections studied in detail in the eastern Alps. (**1**, **2**, **3**, **4**: "Relief-Überschiebungen") [1]).

It is clear that, as the thrustmasses move along, breaking up into smaller slices, which slide and pile upon each other, or even become involuted, the

[1]) BAILLY WILLIS also believes that some of the Appalachian thrusts overrode an older relief: "erosion-thrusts".



Blockbeds of the Radelgebirge in eastern Styria.

Upper figure: original deposition
Lower figure: present position of tilted and folded strata.

LEGEND

R	= Torrential gravels of Radel conglomerate.	RADEL CONGLOMERATE (basal Miocene)
B	= basal, more sandy beds of R.	
Sch	= angular block facies: landslide material at the base of the ancestral Radel cliff.	
Schu	= angular blocks in Lower-Eibiswalder series.	LOWER-EIBISWALDER SERIES (lowermost Miocene)
Scho	= gravel beds.	
Sd	= sands.	
T	= clays.	
Fl	= coal seam.	

The bedrock of the Miocene and the ancestral Radel cliff consist of crystalline rocks, probably highly metamorphosed old-Paleozoics.

(Reproduced by permission of the Geologische Bundesanstalt in Vienna from Jahrbuch 1929.)

original basal plane, carrying the exotic blocks picked up from the substratum, may finally become intercalated between quite different elements, in such a complicated manner, that it becomes next to impossible to unravel the problem, unless exceptionally well exposed detailed sections are available, as is very occasionally the case in the high Alps, but can scarcely ever be expected in less abruptly dissected mountains. This makes that, in Europe as well as in America, the majority of these orogenic exotics remain a grave problem. In many cases they have every appearance of having been deposited in the beds, which now contain them, by a process of sedimentation, though it remains impossible to devise plausible means for the transportation of the often huge blocks over any considerable distance. The hypothesis of drifting ice has also been repeatedly advanced in Europe (Geyer, **42**, p. 380; also A. Favre, H. Schardt, E. Renevier, Ch. Sarasin, Arnold Heim, H. P. Cornelius, and others), though it remains utterly inexplicable how the required *extremely heavy* ice could have occurred in the Cretaceous and Eocene seas of the Alpine region, associated with the prevailing fauna and flora, an assemblage which is much easier to collate with climatic conditions than is the case for Paleozoic forms. *This assemblage certainly does not suggest a remotely appropriate climate.* Even the well known and often mentioned conditions on the southwestern coast of Chili (known to the writer from personal observation) would not by any means be sufficient, and, moreover, could not occur in a mediterranean sea as the Mesozoic Tethys, in a period when, generally, the world's climate was apparently considerably milder than in the present era.

The most conspicuous blocks of this nature in the flysch front have been more plausibly explained by the assumption of old ridges in the substratum of the overthrust masses. This is the case in the Carpathians as well as in the Alps. In part these overridden ridges are hypothetical, but not completely so, since both for the Alps and the Carpathians a few outcrops have been discovered, which are generally (though not unanimously) considered as autochtone rocks and would constitute actual bared portions of such ancient ridges (cf. Geyer, **42**, pp. 373, 376, and 382). This is notably the case for the famous block bed in the Eocene flysch of the Bolgenberg in the Allgäu Alps, on the border of western Austria and Bavaria (**32**).

These ridges, mostly of crystalline rocks, have been named the Vindelician range by C. Gümbel; it is supposed to be traceable, with interruptions, from the western Alps as far east as the east-Carpathian front. This ridge would, to a certain extend, mark the northern shoreline of the earlier Alpine flysch geosyncline in late Mesozoic-early Tertiary time, since overridden by the thrustmasses. (In this conception there would be a certain parallelism between this Vindelician ridge and such uplifts as the Arbuckle Mountains of the American Midcontinent.)

Only a careful study, not only of the exotic blocks themselves and their matrix, but of the structure of the entire region, may lead to a conclusion whether certain blocks, in a certain location, should be explained as sedimentary, or as a purely tectonic product. In many cases the known facts do not yet permit a definite conclusion for the exotic Alpine flysch blocks. The fact, however, that conspicuously large and even unwieldy exotics of this nature are always so typically associated with the frontal zones of large "flysch"-nappes in overthrust mountain chains, suggests, that *in very many cases it must be this particular kind of structure that causes them.* We cannot yet, indeed, explain the mechanics in detail, and still less trace the exact track of the majority of these swarms of exotic fragments. It appears to the writer, that the explanation must be sought in this direction. Most of such aggregates, which contain very large blocks, and particularly such of which no nearby source region can be conceived, are very difficult to understand as having been placed where we now find them by any sedimentary means; they can only be a product of a tectonic process. They must be blocks taken up from the autochtonous substratum, or other sources, by overriding thrustmasses; they were carried along in shearplanes and somehow incorporated, notably in softer, crushed layers between more competent beds, which have acted as a gliding plane of masses moving relatively to each other. AMPFERER has described in detail the mechanics of complex thrustmasses moving over an autochtone relief, and how secondary shearplanes and slices are formed within the sheet through the obstruction caused by obstacles in the substratum (2, 1924). Entirely similar things can be seen to happen on a miniature scale in glacier ice.

It appears to the writer that, in the frontal zone of the Ouachita Mountains, and the location where the "Caney" boulders are found, the very conditions are present for the occurrence of tectonic exotics.

We have a structure composed of thrustsheets, which by their totally different facies postulate lateral displacement over considerable distances. We have a typical flysch, with great competent masses of sandstone (containing the Jackfork member, 4000—7000 feet thick) and intercalated incompetent shales. In the autochtone substratum the presence of the various rocks of the Paleozoic Arbuckle series must be assumed for numerous reasons. This substratum has been intensily folded and elevated by at least two major orogenic phases: the Wichita (late-Mississippian to early-Pennsylvanian), and the Arbuckle (late-Pennsylvanian) diastrophisms. The last of these does not antedate the final overthrusting of the Ouachitas so far, that considerable relief may not have persisted at the time when the Ouachita thrustsheets advanced over, what may have been an old topography, as the Alpine thrustsheets did when they overrode an old relief. Consequently very similar phenomena may have occurred as are so well in evidence at numerous localities in the European Alpides.

When, therefor, we find the entire Paleozoic sequence of the autochtone substratum represented in boulders and huge blocks, in a comparatively thin layer of shale, locally traversed by mylonitized zones, at the base of several thousand feet of Atoka molasse, and resting immediately on a some 6000 feet thick mass of Jackfork sandstone, belonging to the flysch-sequence, in the outer front the Ouachita thrustsheets, it seems that *the conclusion should be, that these blocks are not only true exotics, but should be considered a tectonic product.*

The boulder bearing streaks in this "Caney" shale are probably no "beds" at all, and much of the "Caney" shale may be a mass of out-rolled and sliced uppermost-Mississippian or lowest-Pottsville shale (which normally may have been very much thicker), over which the overlying mass of Atoka molasse has glided relatively to the underlying Jackfork; in other words, the contact is, very possibly, only tectonic.

This explanation would do away with the difficulty that early-Pennsylvanian Morrow boulders are embedded in a shale, which, judging from micro-fossils, must once have been an upper-Mississippian or, anyhow, pre-Morrow sediment. The overthrusting occurred later: this is the main requisite.

We must however point to some puzzling facts, which remain to be explained:

Some of the shale enclosing the boulders does not appear mylonitized or crushed. In a not much indurated shale this is not always easy to determine with certitude. In a shear-zone of this kind, great, individually little deformed slices are apt to occur, dragged along in the sole.

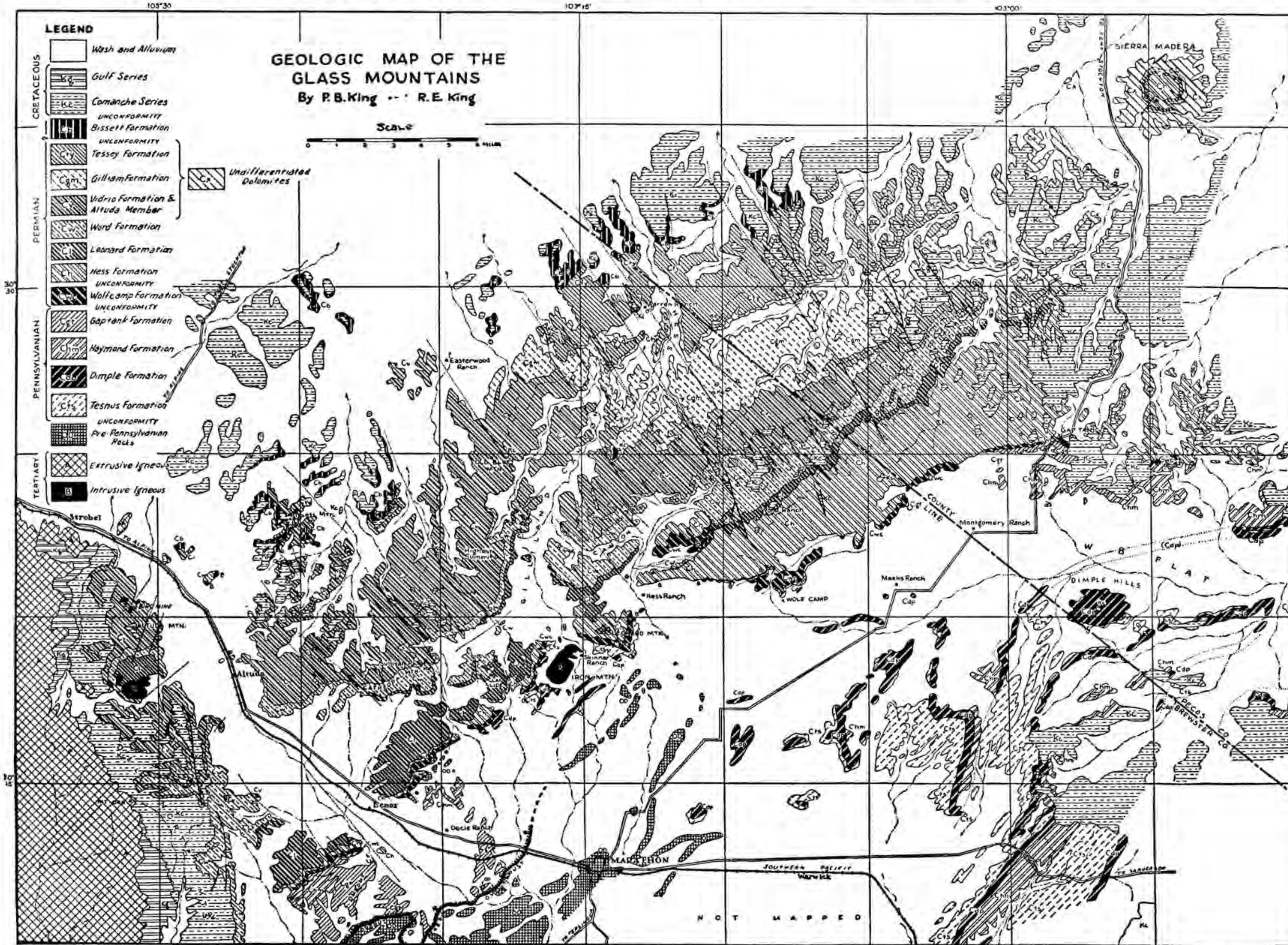
No granite or other basement rocks occur among these exotic blocks, although after the Arbuckle orogenic phase, in the visible chains, the pre-Cambrian had become considerably bared on the ridges by erosion. The final overthrusting of the Ouachita nappes was probably posterior to the Arbuckle orogeny (cf. page 47). It is possible, however, that the special ridge, which yielded the exotics, occurring in this restricted area, happened to contain no exposed pre-Cambrian.

The writer's conclusion is, therefore, that the "Caney" boulders of the Ouachita Mountains in Oklahoma are *by no means glacial;* he is inclined to think, that, very probably, most of them are not even sedimentary, but *exotic blocks of a purely tectonic origin,* a true "tectonic moraine" in the sense of AMPFERER, displaced a considerable distance toward the north.

Some of the fragments may have been pried lose from solid outcrops, others may have been in an ancient surface wash and been picked up by the overriding thrustmass.

The source are ridges in the buried southeastern prolongation of the Arbuckles, or more southerly chains of the Wichita system, which antedated the final overthrusting of the Ouachita Mountains. Elements of the nappes, gliding over each other, have carried these fragments along in an intervening shearplane. When a some 15.000 feet thick thrustmass, consisting of massive sandstone members separated by shale beds, moved over a rough relief, it is self-evident that the sandstones must have become displaced relative to each other, with shale beds as lubricants. Probably the entire mass broke up in an infinite number of also thrust minor slices, and it is therefor hopeless to attempt to trace the track of these boulders through this probably very complicated maze of shearplanes. Without extremely detailed mapping (provided the outcrops permit such), any attempt of this kind would be worthless speculation.

Before the structure is known in minute detail, it will also be impossible to decide definitely whether these exotics are *exclusively* of tectonic origin, or whether they may in part have been derived from exposed ridges by sedimentary processes, as described sub 3a, on page 57. Even in that case, they would have been carried a long distance north of their place of origin by the overthrusting, and probably have become associated with strata in no way connected with their original environment. It would remain next to impossible to conceive the origin of such Wichita ridges in pre-Morrow time, able to yield blocks to a flysch deposit by sedimentary processes.



Geologic map of the Glass Mountains.

(Reproduced by permission of the University of Texas from Bulletin No. 2801, Plate I.)

THE MARATHON MOUNTAINS.

In the extreme southwestern corner of Texas, on the boundary line between Brewster and Pecos counties, a most interesting area of highly folded and partly overthrust Paleozoic rocks appears as an inlier in the Cretaceous, bared by post-Cretaceous erosion, after a regional doming of the basement: *the Marathon Uplift.*

The general strike of the Paleozoic folds is SW-NE. This trend also determines the general exposure, which extends about 54 miles in a SW-NE direction. Excepting some small outlying spots, the general width of the inlier in a SE-NW direction is 27 miles, for the Carboniferous and pre-Carboniferous exposures. These rocks form a hilly plain, the Marathon Basin, within a wall of high rim rocks, which consist mostly of unconformable Cretaceous, except in the north, where the high limestone scarp of the Permian Glass Mountains (also called Comanche Mountains on some maps) borders the Marathon Plain. This Permian is still a portion of the Marathon doming, its rocks follow the same general northeast strike and are unconformably overlain by the Cretaceous. The upper horizons of this Permian sequence belong already to the southern edge of the saline series of the great Permian Salt Basin of southwest Texas.

The southwestern boundary of the Marathon Basin is formed by the Mount Ord and Santiago Mountains. These constitute the front range of the Cordillera: Cretaceous, folded and thrust to the east, with a NNW strike. They are capped by later outpourings of rhyolitic, trachitic and phonolitic lavas, and contain syenite and basalt intrusions.

40 Miles to the southwest, along the road from Marfa to Terlingua, another smaller exposure of Paleozoic rocks occurs in the *Solitario Uplift.* It is cut by the Presidio-Brewster county line.

This is an almost circular exposure, on the apex of a topographic dome, in which the Paleozoic is bared within a circular arena with a diameter of approximately 4½ miles, surrounded by a rim of lower-Cretaceous, and Tertiary to recent igneous rocks: felsite, rhyolite and basalt. On the western side the rim culminates in Solitario and Fresno Peaks. The igneous rocks also cover portions of the Paleozoic area. Patches of lower-Cretaceous are also left within the arena.

The Paleozoic formations are exposed in overthrust faultblocks, which contain closely compressed and broken folds. The strike of these latter is NNE in the eastern portion of the area; in the western part they strike more E-W to ENE. In the northern end a fault separates a block, in which the formations strike NW-SE, at variance with the general northeasterly direction. The divergences, apparently, are largely due to the thrusting and shuffling of faultblocks, and the normal strike is NNE-SSW. The formations are very much disturbed and the folds closely pressed [1]).

Sedimentary sequence.

The older Paleozoics at Marathon and the Permian Glass Mountains, which interest us at present, have notably been described by UDDEN, BAKER and BÖSE (**101**, 1916), UDDEN, BAKER and BOWMAN (**8**, 1917), PH. & R. KING (**63**, **64**, **65**, 1926, 1928 and 1929), SCHUCHERT (**87**, 1927), KEYTE, BLANCHARD and BALDWIN (**62**, 1927), and PH. B. KING (**120**, 1931). [2])

The sequence is condensed in the *Tables V. a., b. and c.,* giving the principal correlations, according to the cited papers, supplemented by personal work of the writer, who also spent considerable time in the region, at times with some of the authors referred to.

The Permian sequence in the Glass Mountains is the thickest and most fossiliferous of any in North-America, and being open-sea marine, represents the key sequence for the correlation of the American Permian with that elsewhere developed in the world [3]).

In the *Solitario uplift* the sofar identified Paleozoics comprise the following formations:

Carboniferous: Tesnus.

Devonian: Caballos Novaculite.

Ordovician: Maravillas formation and older strata, down to the upper-Cambrian; there also occur metamorphic rocks, that are possibly pre-Cambrian.

The section of the older-Pennsylvanian and pre-Pennsylvanian formations of these uplifts has not yet been completely unraveled. Intricate folding, thrustfaulting and flat overthrusting, combined with an extensive covering by surface wash, not only make measurements very difficult, but

1) Communication and map received from E. H. SELLARDS, as advance notice of a report in preparation (Oct. 1, 1930).

2) While this treatise was in the press, this last cited new important work by PH. B. KING was published by the University of Texas (**120**. 1931). It gives a great deal of new detail for the stratigraphy, as well as for the structure of the Marathon region. Through kind advance communications from the author and from E. H. SELLARDS, the writer has been enabled to make use of such of the results as pertain to our present problems.

3) BÖSE correlates the Word formation with the Fusulina Limestone of the Sosio valley of Sicily, regarded as post-Artinsk, and equivalent to the Kungur of the Russian sequence. This would make the Vidrio-Tessey salt series of the Texas Salt Basin equivalent to the typical upper-Permian: the Kazan-Tartarian series of Russia and the Zechstein of Germany. To this same division belong the Capitan-Carlsbad-Apache limestones of the western rim of the Salt Basin. The Hess-Leonard ammonites correlate with the Artinsk divisiou. (SCHUCHERT, **87**, p. 398).

TABLE Va.

PERMIAN SEQUENCE IN THE GLASS MOUNTAINS (MARATHON REGION) IN SOUTHWEST TEXAS.

CORRELATIONS			THICKNESS IN FEET	DESCRIPTION OF FORMATIONS MARATHON REGION
CRETACEOUS				Lower Cretaceous (deposited after tilting)
				~~ *Unconformity, peneplaination*
TARTARIAN—KAZAN SERIES; higher zones of Productus Limestone of Indian Salt Range	UPPER PERMIAN	DOUBLE MOUNTAIN SERIES	0—720	BISSET CONGLOMERATE: subangular to rounded boulders, predominantly Glass Mountain dolomites, with a few cherts, quartz and quartzites from the Word and older Marathon rocks, partly interbedded with red shales and thin yellow limestones or sandstone beds, containing Permian ostracods, poor casts of gastropods and late-Permian plant remains.
				~~ *unconformity*, overlaps over some 1800 feet of eroded upper-Permian strata.
TARTARIAN—KAZAN SERIES; higher zones of Productus Limestone of Indian Salt Range	UPPER PERMIAN	DOUBLE MOUNTAIN SERIES	circa 2800	CAPITAN SERIES (Tessey-Gilleam-Vidrio): Generally very massive, locally more platy, partly unstratified, partly crossbedded, dolomitic limestones and dolomites, generally light grey; intergrading and passing toward the east into beds of brown, moderately coarse grained sandstone, interbedded with red shales and gypsum; sandstone finally makes up 40 % of middle (Gilliam) division. Represents southern edge, partly algal barrier reef, of great Salt Basin, grading within not exceeding 25 miles toward north, in anhydrite and rocksalt, and basal dolomites and sandstones (wells in Pecos county). *Macrofossils* are very scarce: *Fusulina elongata* through entire series in places; other forms point to similar fauna as in Carlsbad-Capitan limestones of Sacramento-Guadalupe Mountains.
				~~ *slicht unconformity indicated.* ~~
KUNGUR DIVISION Lower Productus Limestone of Indian Salt Range		DOUBLE MOUNTAIN SERIES	1500—300	WORD FORMATION: dense cherty limestones, partly bituminous and siliceous (radiolarian), partly sandy shales; thickening toward south and grading into sandstones with conglomerates (Del Norte Mountains). Toward northeast the formation thins to 300 feet of cherty dolomite in Sierra Madera, sandstones and shales lensing out; finally grading into basal dolomites and sandstones of saline sequence of Salt Basin. *Fossils: Waagenoceras* zone, also other ammonoids. *Tegulifera, Lyttonia* and other Permian brachiopods. *Fusulina elongata* large and common. Fauna in top of Word equals that in uppermost dark limestone of Delaware Mountain fm.
ARTINSK DIVISION	LOWER PERMIAN	CLEAR FORK SERIES	1800—300	LEONARD FORMATION: very variable: *in West:* 1800 ft. of brown, platy, flinty radiolarian shales, with thin layers of limestone, partly bituminous; pebblebeds and gritty pebbly limestones, notably in southwestern section; *toward northeast:* shales and marls lense out and limestones change into dolomites: 300 feet or less of featureless sandy and pebbly dolomite in Sierra Madera; finally grades into basal dolomites of main Salt Basin. In the southwestern section the limestones are full of pebbles of chert, quartz and limestone. *Fossils* abundant: large *Crinoids* frequent: zone of *Perrinites vidriensis* and other ammonoids; *Teguliferas, Lyttonias* and other Permian brachiopods.
				~~ ? *slight unconformity* ? ~~~~~~
ARTINSK DIVISION	LOWER PERMIAN	WICHITA-ALBANY SERIES	• 50—2100	HESS FORMATION: Predominantly dark limestones, thinbedded and non-dolomitic in the west, becoming dolomitic toward the east; to the eastward the dolomites interfinger in their lower part with vari-colored marls, sandstones and shales, some of which are red. The base is in all localities conglomeratic, coarse and thick in the west, thin and finer in the east. Sediments thicken southwestward, but the actual thickness of the formation decreases in that direction through successive overlapping against a probably contemporaneous uplift of Wolfcamp beds in the south. As a result, the easternmost section measures 2100 feet; northeast of Lennox, in the west, only 50 feet. A bed of massive pure limestone persists here. *Fossils* only in certain layers: zone of *Perrinites compressus; Fusulina* cf. *elongata, Lyttonia.* (Fauna of Bonespring Limestone of Guadalupe Mountains).
				~~ *angular unconformity* ~~~~~~
ARTINSK DIVISION	LOWER PERMIAN	WICHITA-ALBANY SERIES	475—700	WOLFCAMP FORMATION: dominantly shales, some few limestones and conglomerates. Overlaps on folded Pennsylvanian in southwest, thickening there to 600 feet, of which 400 feet are conglomerate. In the western part of the Glass Mountains the Wolfcamp is folded into broad arches, not shared by the overlying Hess fm. *Fossils:* fairly common: *Schwagerina, Tegulifera* and *Lyttonia* in upper 500 feet of formation; in base: zone of *Uddenites* and other ammonoids. (B. H. HARLTON, and others, consider this lower-Wolfcamp upper-Cisco: PH. B. KING and many others basal Permian.)
				~~ *erosional unconformity and important break,* decreasing in importance towards northeast:
PENNSYLVANIAN				equivalent of *ARBUCKLE OROGENIC PHASE.*

PENNSYLVANIAN AND OLDER SERIES.
(See Table V*b*.)

TABLE Vc.

PRE-CARBONIFEROUS SEQUENCE IN THE SOLITARIO UPLIFT IN SOUTHWEST TEXAS.

(Communicated by C. L. BAKER).

GENERAL AGE	DESCRIPTION	CORRELATION WITH OLD PALEOZOICS OF MARATHON REGION
UPPERMOST MISSISSIPPIAN ?	ROUGH- REEK SHALE:	Tesnus
BREAK	~~~~~~ *erosional unconformity* ~~	WICHITA PHASE
DEVONIAN ?	CABALLOS NOVACULITE: similar to Marathon development.	Caballos Novaculite
?	"SOLITARIO FORMATION": 15—50 feet of bright green siliceous and clay shales.	?
UPPER ORDOVICIAN	MARAVILLAS CHERT: similar development as at Marathon, but with relatively more chert and less limestone *(Richmond-Fernvale age).*	Maravillas chert
	~~ *unconformity and break* ~~~~	~~~~~~
MIDDLE AND LOWER ORDOVICIAN	MARATHON SERIES: *Trenton, Black River, Lowville, Chazy and Beekmantown age:* cherts, shales, limestones, some sandstones and conglomerates, corresponding with similar formations in the Marathon region [1]).	MARATHON SERIES: Woods Hollow shale, Fort Peña formation, Alsate shale, Marathon limestone.
UPPER CAMBRIAN	Marine, fossiliferous, buff, etc. sandstones, drab shales and some thin interbeds of impure limestones; in considerable part arkosic.	Dagger Flat sandstone?
PRE-CAMBRIAN ?	*a.* Much contorted marbles, with very narrow bands of chert, similar and possibly equivalent to marbles with chert bands in the region north of Eagle Flat and Allamore, and north-west of Van Horn, at the southern margin of the Diablo Plateau (in the Millican formation). *b.* Quartzites, resembling somewhat the pre-Cambrian quartzite of the Franklin Mountains [2]).	not represented

[1]) Represented in a very complex anticlinorium, on the nappe in the northern half of the Paleozoic area of the Solitario. This nappe is folded: erosion exposes windows of Rough Creek-Tesnus in the substratum, surrounded by Ordovician rocks.

[2]) These metamorphic rocks are contained in another nappe, overthrust over the Cambro-Ordovician complex.

TABLE Vb.

PENNSYLVANIAN AND OLDER PALEOZOIC SEQUENCE IN THE MARATHON MOUNTAINS

General Age	Thickness in feet	Description	Principal Correlations: New Mexico	Principal Correlations: Southern Oklahoma
BASAL PERMIAN (Upper-Cisco absent)		*Uddenites*-zone of lower-Wolfcamp.	present in Hueco, Diablo and Franklin Mountains in foreland.	
BREAK		*large erosional unconformity and break* ~~~ *ARBUCKLE OROGENIC PHASE* ~~~		
"M O L A S S E" (generally less clastic and more marine than in Ouachita region) — LOWER-CISCO	up to 525	UPPER-GAPTANK FORMATION: mainly thick beds of limestone (10—40 feet), intercalations of shales and some sandstones. *Fossils*, locally abundant: a lower-Cisco assemblage, confirmed by *Fusulinids*.	upper-Cisco missing. limestones, POW-WOW REDBEDS: conglomerates. (circa 200 feet) Cisco *Fusulinids* (65, p. 911)	upper-Cisco missing. VAMOOSA FORMATION Gaptank fusulinids range up into Shawnee formation, but not into Wabaunsee.
CANYON / STRAWN	more than 1000	LOWER-GAPTANK FORMATION: UPPER PART: mainly shales, with interbedded limestones; LOWER PART: limestone conglomerates (25 %), alternating with limestones, heavy sandstones and shales. Conglomerates contain angular blocks (up to 2 feet across) derived prominently from Dimple and Caballos formations and, though less abundant, of entire sequence of older-Paleozoic sedimentaries. (64, p. 143.) Gaetetes-limestone at base. *Fossils:* indicate Pennsylvanian assemblage, including Canyon and upper-Strawn.	Massive and thinner bedded, grey limestones, with lower-Cisco and Canyon fossils. (550 feet) lower dark limestones in Hueco Mountains, with plentiful *Chaetetes* and general Strawn fauna. (900 feet)	HOXBAR FORM. in Ardmore region. (4000 feet) According to PH. B. KING, fossils at the base of Gaptank are decidedly Strawn (= Marmaton). ~~~ *unconformity* at base of Hoxbar in Criner Hills. DEESE FORM. in Ardmore region. (6000—7000 feet) DORNICK HILLS in Ardmore region. Millsap in Texas. (4000 feet)
STRAWN	2500	HAYMOND FORMATION: [1] upper part; thick arkose beds and conglomerates; lower part: sandstones, interbedded with some dark siliceous shales. Exotic blocks reported in upper portion. Several layers with plant remains indicate "Pottsville" (D. WHITE). *No unconformity apparent in Marathon region.*	*unconformity*	*unconformity*
"F L Y S C H" — MORROW	circa 800	DIMPLE FORMATION: [1] thin and massive, very poorly fossiliferous limestones, interbedded with shale. *Foraminifera* indicate lowermost-Pennsylvanian: Morrow, Bend or Lower-Pottsville; a few goniatites and brachiopods of Pottsville age.	*upper-pulsation of WICHITA PHASE.* lowermost limestones of Hueco Mountains, with Morrow fauna (75—150 feet)	SPRINGER FORMATION in Ardmore region. (3000—3500 feet) and JACKFORK FORMATION in Ouachita Mountains (5000—6000 feet)
.....?..... UPPER MISSISSIPPIAN in part?	up to 7000	TESNUS FORMATION: [1] in its greatest development in the southeast: a vast series of greenish quartzitic sandstones, often in massive beds, intercalated with some green chert, and blue, greenish, black and often siliceous shales; predominantly shales at base. Clastics are derived from crystalline and metamorphic rocks (65, p. 908). Thins to a few hundred feet, all shaly, to the N.W. Poorly preserved uncertain *plantremains*, indicating Pennsylvanian-Mississippian transition zone.	HELMS FORMATION of Hueco Mountains: sandy limestones and sandstones, thickening toward southeast. Upper-Mississippian fauna.	STANLEY FORM. of Ouachita Mountains (6000—10.000 feet) According to ULRICH, the Jackfork reaches up into upper-Pottsville (Morrow), including the Springer of Ardmore Basin.
		~~ *general unconformity* ~~~ *marking lower-pulsation of WICHITA OROGENIC PHASE. (unconformity also in Solitario region).*		
BREAK		< HIATUS > *representing most of Mississippian.*	*LAKE VALLEY* limestone: flaggy cherty limestones, thinning toward southeast, (also named middle-Helms).	SYCAMORE limestone in Arbuckle region.
DEVONIAN?	400	CABALLOS NOVACULITE: white, vari-colored and black chert. Few fossils, age uncertain; regarded as of lower-Devonian, Oriskany age by ULRICH (103). *important unconformity.*	cherts in Franklin and Hueco Mountains: PERCHA FORMATION	ARKANSAS NOVACULITE in part.
BREAK			ARBUCKLE MOUNTAINS	OUACHITA MOUNTAINS
Lower Silurian?	350	MARAVILLAS SERIES: [2] Predominantly black alternating thinbedded cherts above, and limestones below; basal conglomerate: large boulders of chert, limestone, sandstone, as old as Cambrian. *Fossiliferous:* Richmond and Upper-Trenton graptalites, brachiopods, bryozoa, etc. *unconformity*	Fernvale-Richmond zone of VIOLA LIMESTONE	BLAYLOCK FORMATION to
O R D O V I C I A N	500	MARATHON SERIES: [2] WOODS HOLLOW SHALE: clay shale, with thin limestone and sandstone beds. Fossiliferous: middle-Ordovician (Trenton) graptolites, bryozoa, brachiopods.	(total Viola 500—700 feet) LOWEST VIOLA	BIGFORK CHERT
	150	FORT PEÑA FORMATION: massive sandy limestone, bedded reddish chert, with conglomerate in lower part; Fossiliferous: middle-Ordovician (?) (Black River or Chazy) graptolites.	SIMPSON FORMATION? (1200—2400 feet in Wichita geosyncline)	WOMBLE FORMATION
	50	ALSATE SHALE: green shale, with some limestone beds in south. Fossiliferous: Lower-Ordovician (Deep Kill) graptolites.	ARBUCKLE LIMESTONE (5000—8000 feet in Wichita geosyncline)	BLAKELY SANDSTONE, MAZARN SHALE (± 2500 feet)
	800	MARATHON LIMESTONE: flaggy limestones, with shale partings; many beds of conglomerate. Deep Kill graptolites; Beekmantown fauna near middle.		CRYSTAL Mt. SANDSTONE?
BREAK or unknown		*Hiatus? top undetermined.*		BREAK
C A M B R I A N	only 250 ft. exposed	DAGGER FLAT SANDSTONE flaggy and thick bedded saccharoidal, brown sandstones, interbedded with dark green shales in upper part. Fossiliferous: upper-Cambrian trilobites. *Base not exposed; no deeper formations are known.*	Hiatus. underlain by Cambrian REAGAN sandstone.	underlain by COLLIER shale. Base not exposed. (Age uncertain).

[1] Similarly as for the Ouachita Mountains (cf. Table IV), the exact age of the subdivisions of the flysch is still undecided, but it is certain that these orogenic sediments at Marathon also represent the transition zone between Mississippian and Pennsylvanian; this interval is represented by a conspicuous gap in the sedimentary sequence over the foreland, outside of the flysch geosyncline (c.f. 118). The Marathon flysch is a geosynclinal orogenic deposit, laid down at a time that the entire Plateau foreland was emerged.

[2] Stratigraphy and correlations after PH. B. KING. There is controversy, whether or not Cambrium is represented at Marathon. The above version is contested by B. H. HARLTON and F. A. BUSH, who advised the writer that the type locality yielded a profusive microfauna of Black River age. (Communications by letters.)

probably cut out portions of the sequence, which appear as absent, but may simply be obscured by overthrusts, or not be exposed. For the same reason it is often difficult to ascertain whether certain angular discrepancies are due to erosional unconformities, or merely to thrustfaults and shearing. The general character and facies of the series, however, are now well known. The older Paleozoic section is of particular importance for the purpose of correlation of these exposures with the general Paleozoic orogeny of North America.

This chapter is a synopsis of the latest views. With the kind permission of the University of Texas and of the authors, a map by PH. B. and R. E. KING is reproduced. (*Plate 6*). [1])

TIME AND CHARACTER OF THE MARATHON OROGENY.

M. G. CHENEY, following C. L. BAKER, suggests (**27**, p. 570) that the Marathon outcrops of Paleozoics are connected with a southwesterly extension of the Ouachita system, and draws attention to the similarity of deposition and structural history. The writer has repeatedly expressed the same views in unpublished reports known to his collaborators. The problem is how these elements are connected. Here lately SELLARDS, CHENEY and Ph. & R. KING, have performed and published valuable work.

The pre-Carboniferous old-Paleozoics exposed in the Marathon region were laid down in an ancient geosyncline, in every way similar to the one we have described for the corresponding sediments in the Ouachita Mountain area. The facies in characterized by a thick succession of dark limestones, shales and bedded chert, in which graptolites are the most abundant fossils, whilst on the foreland these same formations are developed nearly entirely as limestone, and are generally thinner than the geosynclinal sequence. The source of all the Marathon old-Paleozoic sediments is in the southeast, and its shales and limestones are replaced by beds of sandstone in that direction. The Caballos novaculite formation likewise thins out from 700 feet in its southeastern exposures to less than 200 feet in the northwest. Evidence indicates that this is the result of original differences in thickness of the deposits, and not of mere overlap.

I. *The pre-Carboniferous orogenic phases.*

The older Paleozoic sequence in the Marathon region, older than the Carboniferous, has been so very severely folded and overthrust by later diastrophism, that it is difficult to unravel the earlier tectonic history. We will not discuss these pre-Carboniferous phases further: they are more or less outside the scope of this treatise. We will only mention that the best indicated older unconformity is one underlying the probably Devonian

[1]) A more detailed new map of the major part of the area is contained in the already mentioned publication by PH. B. KING (**120**).

Caballos novaculite, involving a break in the series down to the Richmond zone of the lower-Silurian. Another, possibly still more important orogenic break is indicated between the Maravillas and Marathon (Trenton) series. This hiatus, which has also been established at Solitario, should correlate more or less with the "Taconic" orogeny of the northeast of the North-American continent.

This disturbance should be classed as a Caledonian phase.

Not much is known about this interesting tectonic break in the Ouachita Mountains, except that, apparently, both the Arkansas novaculite and the Missouri Mountain slate are unconformable on the Blaylock, also of about Richmond to Trenton in age (**115**, Plate XXV, and also 103).

II. *The Wichita orogeny.*

The Tesnus overlies the pre-Carboniferous unconformably, with a basal conglomerate, indicating a pre-Tesnus erosion of the Novaculite (**64**, p. 111). Unhappily, fossils are almost absent, and the exposures are often so poor and so complicated by structural disturbance, that the extent of the break is not well known. The Tesnus is a typical flysch-type deposit, and probably more than 4000 feet thick in the southeastern angle of the Marathon Basin, whereas to the northwest it is found to thin progressively, dwindling to a thickness of only 225 feet in the region of the Roberts Ranch, southwest of the town of Marathon. This thinning is partly the result of overlap of the Tesnus on the Caballos formation, and the contact is nearly everywhere marked by a conglomerate in this region. There is, however, also a real thinning of the entire Tesnus formation to the northwest, and the sediments, very certainly had their source in the southeast. In the southeastern part of the Basin, the Tesnus is nearly all sandstone, including thick ledges of white quartzite, and other layers of arkose and graywacke, with a chloritic matrix. In the northern part of the Marathon Basin the formation consists for more than half of blackish shales, and its sandstone beds are all of fine grain (cf. **120**, pp. 31—36, and **114**). The Tesnus has also been identified at Solitario in the (upper-Tesnus) Rough Creek shale, resting with an erosional unconformity on the Caballos novaculite [1]).

We do not know the exact age of the entire mass of either the Caballos novaculite or of the Tesnus formation, notably how far the latter may reach down into the Carboniferous. It may only represent the Strawn, but it is very much more probable that a portion of this thick orogenic sequence also includes both Morrow and uppermost-Mississippian horizons. DAVID WHITE has stated that some of the scarce and poor plant remains, collected from near the top of the Tesnus, suggest lowermost-Pennsylvanian, meaning that this is the same transition flora between Mississippian and Pennsylvanian as we find in the Ouachita Stanley-Jackfork flysch (**8**, pp

1) Communication from C. L. BAKER.

103—105). PH. & R. KING also state that foraminifera, also collected from near the top of the Tesnus, according to B. H. HARLTON, suggest lowermost-Pennsylvanian (**64**, p. 111). Thousands of feet of strata, whose age has never been established, underlie these fossiliferous horizons. PH. KING expressed the opinion, that, not impossibly, the base of the Tesnus may correlate with the upper portion of the Helms formation, exposed in the Hueco Mountains, and that, therefor, at least in part, it could be uppermost-Mississippian, and might well occupy a similar position on the foreland as we have discussed for the Arbuckle Caney (cf. pages 43 and 51). (**87**, **62**, **64**, **118**). The upper-Helms is also separated from the underlying lower-Mississippian, and might well occupy a similar position on the foreland, as it also thickens and becomes more clastic toward the south (**120**, p. 36). Mississippian, and might well occupy a similar position on the foreland, as the Ouachita Stanley, and the Parkwood of Alabama, and may also include most or all of the Jackfork. The Dimple, according to PH. KING, is most probably Morrow, and according to DAVID WHITE, plant fossils from the Haymond formation belong to "some part of the Pottsville". The break at the base of the Tesnus might represent the same orogenic phase in the uppermost Mississippian, which we described for the Ouachita Mountains. We called this *the older pulsation of the Wichita phase. This would make the Tesnus, and perhaps a part of the overlying older-Pennsylvanian, the equivalent of the Caney-Springer sequence of the Ardmore Basin, deposits which we have called the "flysch" of the Ouachita Mountains.*

Even as the Ouachita Stanley, the Marathon Tesnus and Haymond sediments are, in part, derived from crystalline and metamorphic rocks (**120**, p.p. 34 and 34). *The Gaptank and uppermost-Haymond conglomerates, on the contrary, are derived from the complete sequence of the older-Paleozoics exposed in the Marathon Mountains, including, notably, the post-Tesnus Dimple, in addition to the Caballos and Maravillas formations* (**65**, p. 908). This makes these two groups of strata markedly different; evidently an important tectonic event separates them.

When discussing the Ouachita Mountains, we noted the absence of a marked break between the flysch and molasse groups in those mountains.

Though there exist irregularities, possibly pointing to a tectonic contact, there is no sign of an important angular unconformity between the Jackfork-Stanley flysch and the Atoka molasse formations in any of the exposures within the Ouachita Mountains. The second pulsation of the Wichita orogenic phase, which caused the change in the sediments, must have been located farther to the south [1]).

Exactly the same seems to have been the case in the Marathon Mountains. No break can be seen in the lower part of the Carboniferous

[1]) A similar local distribution can be noted in the Wichita system. We have seen on page 28, that the late-Mississippian, at least pre-Morrow, pulsation is indicated only in the southern part of this system. On the southern flank of the Red River Arch the Bend lies unconformably on the eroded Ordovician.

sequence, though unconformity has been claimed for the base of the Dimple (Bend). According to PH. KING, the contact between the Dimple and the Haymond (Strawn) is gradational and apparently conformable. The transition is well exposed in several places about 15 miles east of Marathon. The Gaptank also overlies the Haymond conformably. The basal member, the Chaetetes-limestone [1]), rests directly upon thinbedded Haymond sandstone (**64**, p. 114). The outcrop at Solitario gives us no additional information, since no younger Pennsylvanian than upper-Tesnus is represented here.

Although there is no unconformity in the sequence at Marathon, the facies seems to indicate the two pulsations of the Wichita orogeny more or less clearly. The clastic deltaic Tesnus formation is followed by the quiet period of limestone deposition represented by the Dimple (more or less equivalent to the Wapanucka), and this, in turn, is succeeded by a new thick series of clastic sediments, entirely similar to the Tesnus, the Haymond, indicating the resumption of vigorous erosion. There even occurs in the highest Haymond a widespread layer of chert conglomerate. Apparently, most of the Haymond must be considered as upper-Pottsville and Strawn, and would, therefor, correlate with the Atoka-Thurman sequence of the Ouachita Mountain region, and the Dornick Hills-Deese series of the Ardmore Basin. The lowest Gaptank beds may represent uppermost Strawn, whilst the entire Gaptank sequence extends into middle-Cisco, possibly as high as Kansas City-Lansing time. Fossiliferous representatives of the Wetumka (Fort Scott) and Wewoka horizons of the Canyon are well marked, but the upper-Cisco is absent. This would make the Gaptank formation equivalent to most of the Hoxbar of the Ardmore Basin. All this fits in exceedingly well with our views that the Marathon and Ouachita Mountains are members of the same Ouachita System.

In the Marathon foreland, however, the dividing unconformity is in evidence, and we have seen the same thing to happen in front of the Ouachitas, in particular in the Ardmore Basin; there it comes in at the end of Morrow time, overlying the Springer formation. Here in the West, we find in the Hueco Mountains, as well as in the Llano-Burnett exposures,

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[1]) *Chaetetes milleporaceus* is a coral, restricted in central-Texas to the Brownwood shale of the Canyon, and then again reappearing in the much lower zone of the Marble Falls limestone (Bend = Morrow). This, however, indicates that the species has a wide zonal distribution. In the northern Midcontinent this form also ranges from Morrow to approximately Lansing (middle-Cisco), but it is particularly characteristic of the Fort Scott and Pawnee limestones, a horizon approximately equivalent to the Brownwood (**64**, p. 118). The most prolific fossil horizon of the lower-Gaptank, 700 feet above the base, contains a regular Pennsylvanian assemblage, but of widely ranging forms, appearing closest related to the Wewoka of Oklahoma (= Canyon of Texas). (**87**, p. 388). All the various fossil zones, found sofar in the Gaptank formation, seem to define its age as ranging from Fort Scott to Kansas City time of Oklahoma = from Canyon to middle-Cisco in Texas. Representatives of the upper-Cisco Wabaunsee group are absent. (cf. **120**, pp. 46—49).

this same unconformity between beds of Morrow and of Strawn age (**65**, fig. 2, p. 909).

Consequently, we see that *both pulsations of the Wichita phase are in evidence in the Marathon region*: the older late-Mississippian pulsation is expressed by marked unconformity. The later post-Morrow pulsation is only expressed, within the mountains, by a marked change in the character and source of the sediments; in the foreland, however, it is expressed by actual unconformity. All this is exactly similar to conditions in the Ouachita Mountains region.

III. *The Arbuckle orogenic phase.*

The late-Pennsylvanian and Permian orogenic movements are far more clearly indicated in this western region, than in any of the more easterly chains of the Ouachita System. The Arbuckle phase was very intense in these mountains, and affects strata, which are better known in detail. Even as in the Wichita system, it considerably obscures the earlier phases. It seems to begin in Cisco time. The most important break underlies the Permian Wolfcamp formation, and the hiatus comprises all the uppermost Cisco, and possibly some of the lowermost Permian. BAKER places the more important orogenic unconformity at the base of the upper-Gaptank. PH. B. KING does not agree with this opinion, but points to other evidence that the first disturbances began already in Canyon time, entirely similar to what we have described before for the Ardmore region. The Wolfcamp and Hess formations, and perhaps the Leonard, overlap to the southwest over a land-surface uplifted by the Arbuckle phase. Disturbance and reactivated erosion still continued during much of the lower Permian. There is a general unconformity at the base of the Hess, with signs of nearby active denudation and the formation of coarse conglomerate. Deposition of clastics continues in the Leonard. *These are posterior pulsations of the Arbuckle orogeny.* Their prominence and duration emphasize the intensity of this phase in the south-western region of the Midcontinent.

C. L. BAKER discovered the very significant fact that, in the Marathon Basin, the pre-Pennsylvanian formations constitute a nappe, which has overridden the upper-Pennsylvanian beds from the south in a widespread flat overthrust: *the Dugout Creek, or Peña Colorado thrust.* (**64**, pp. 117 and 121 and fig. 8). The thrust is a horizontal, afterwards warped shear. The folds within the overthrust mass are cut off flat, and have no relation to the structure in the autochtone. Posterior warping and erosion have caused a wide window in the northwestern part of the Marathon Basin. East of the longitude of the town of Marathon, we have no clear indications of the edge of the nappe. Several overthrusts have been mapped by KING in the region between the Gap Tank locality and Tesnus railway station, but these seem more related to broken and overthrust anticlines and not to a true nappe.

Since this thrust is seen to override upper-Gaptank (Cisco) beds, it *cannot be older than the Arbuckle phase, but it may be a little younger.* Recently C. L. BAKER has advised the writer that this same overthrust is in evidence at the Solitario Uplift. Here we find Ordovician rocks in a nappe, which has also been warped and eroded, exposing the autochtonous substratum in erosional windows. The autochtone consists here of Rough Creek-Tesnus. In this more southern exposure, another very significant fact has recently been established, not known before, either at Marathon or in the Ouachita Mountains. At Solitario a highly metamorphic quartzite and contorted cherty marbles (resembling somewhat the quartzites of the Franklin Mountains and the Millican formation of the Diablo Plateau), have been found in another nappe, overriding the Cambro-Ordovician thrustsheet [1]). BAKER considers these rocks pre-Cambrian. The writer points to the possibility that these rocks may all or in part be metamorphosed Paleozoics. The discovery of this metamorphic interior nappe, is in accordance with what we know from the structure of the southern Appalachians, and is additional proof for the great importance of the Marathon Mountain chain.

When discussing the Ouachita Mountains structure (cf. page 47), we pointed to the evidence that the final overthrusting of the Ouachita nappes was posterior to the Arbuckle phase in that region, and that the final paroxysm must have occurred after the highlands raised by the Arbuckle orogeny had been considerably peneplained, possibly as late as mid-Permian time. It will be remembered that we came to the conclusion that the Arbuckle phase did not affect the Ouachita Mountains. In the Glass Mountains, on the contrary, we have conclusive evidence that *the Dugout Creek overthrust was pre-Wolfcamp*, in other words that the thrusting was closely related to the Arbuckle phase, though it may have been its concluding stage. The oldest rocks exposed below the thrustplane are referred by KING (**120**, 45) to the upper-Haymond; they are overlain by the Chaetetes-limestone of the basal Gaptank formation. The highest beds in the autochtonous substratum are upper-Gaptank with Cisco fossils. The youngest beds exposed on the nappe, back of the thrustplane, are Haymond. Gaptank, sofar, has not been identified on the overriding mass, which contains the complete section of the pre-Gaptank Carboniferous and old-Paleozoics, as represented in this region. In this the Marathon structure is again similar to the Ouachita Mountains, where the youngest formation in the nappe is Atoka. The Haymond, however, is probably younger than the highest beds included in the intra-Ouachita Atoka. Since no older beds than uppermost Haymond are exposed in the Marathon autochtone, we know nothing of their facies and development, and how far this differs from that on the nappe. It is possible that a well, drilled at the southern base of Dugout Mountain, in the autochtone, has reached the Dimple, after having pierced 1700 feet of black and grey sandy shales of the Haymond (**120**, p. 42). At the Solitario the

[1]) Communication from C. L. BAKER.

autochtone underlying this nappe is upper-Tesnus. Consequently this overthrust overrides the entire Pennsylvanian (and probably some uppermost Mississippian flysch), including beds as high as the Cisco.

The first precursory movements of the Arbuckle disturbance are indicated in highest Haymond time (upper-Strawn) by a thin layer of chert conglomerate. Deposition of coralline limestone followed again in the lower Gaptank, but anticlines now soon began to rise in the geosyncline. Their erosion contributed boulders of Dimple limestone to the Gaptank conglomerates of the southern exposures. Here again there is similarity with southeastern Oklahoma. In the Ardmore Basin, the Hoxbar also contains some conglomerate, pointing to the Arbuckle Mountains as their source (**99**, p. 43). Although the Oklahoma Ouachita Mountains indicate no disturbance at this time, the upper-Strawn (Lower-Hoxbar) Brazos River conglomerate of East-Texas suggests activity farther south in these chains. The folding must have advanced progressively northward in the Marathon region, for it was not until early upper-Gaptank time that the folds had risen sufficiently in the extreme northwestern part of the present Marathon Basin to contribute any sediments to that area. At this time fragments of Caballos and Maravillas chert appear also in these later conglomerates. The finer clastics of the Gaptank formation are considered as reworked erosional products of the Tesnus and Haymond shales and sandstones by KING. During the earlier phases of the disturbance the folding was essentially local, creating differentiated basins of deposition in the general geosyncline, as is shown by the variability in character of the Gaptank deposits in various parts of the Marathon Basin and, in general, the deformation increases in intensity toward the south (cf. PH. B. KING, **120**, p. 51).

The basal Permian Wolfcamp formation extends unconformably over all the structures created by the Arbuckle orogeny. At the west end of the Glass Mountains, fossiliferous upper-Wolfcamp, with 350—400 feet of coarse basal conglomerate, overlies the nappe of the Dugout Creek overthrust, after it had been sufficiently warped and thereafter eroded, to cause a window to be created in the pre-Carboniferous rocks of the nappe in which the Gaptank autochtone was laid bare. In consequence, the Permian now rests indiscriminately on Maravillas, Caballos, and Gaptank rocks (**120**, p. 113). It is here, at a point 4½ miles S. 15° E of Lenox siding, that ammonoids of Cisco age were collected from Gaptank beds, directly beneath the Dugout Creek thrustplane. The lower (Uddenites) member of the Wolfcamp is not present in this western part of the Glass Mountains. Consequently, we can only place the advancing of the Dugout Creek nappe somewhere between middle-Cisco and upper-Wolfcamp for this region. The lower-Wolfcamp of the eastern Glass Mountains rests with apparent conformity on Gaptank, but KING advices that, at other localities in this same region, it rests once on Tesnus and elsewhere on Haymond, with the intervening beds missing (**120**, p. 49). As mentioned before, the presence of the nappe and the amount of overthrusting have not yet been determined for this eastern region.

The known minimum displacement of the Dugout Creek thrust is over six miles, but, particularly in view of its presence farther south at Solitario, it must have been very considerably greater.

Somehow connected with the orogenic phase creating these overthrusts, seems the recently reported occurrence of exotic blocks in the Haymond. Further work will be required before these interesting erratics can be properly interpretated. It would be extremely interesting if these blocks proved to be true Marathon flysch exotics, similar to those we have described from the flysch of the Ouachita Mountains [1]).

IV. *Permian disturbance.*

A Permian embayment from the Tethys extended inland into western Texas, where it divided into two branches, one of which reached to the northeast into the Midcontinent beyond Nebraska, and the other penetrated in the Rocky Mountain region of New Mexico, Arizona and Utah. The Midcontinent extension retreated gradually southward during lower-Permian time; in the Cordilleran branch, on the other hand, the sea spread progressively inland until, in middle-Permian time, it became connected with another seaway extending down from the northern Pacific. Toward the close of the Permian the North-American continent had become wholly a land area, with the exception of only western Texas, where the upper-Permian Capitan formation was deposited in the last remnant of the dwindling embayment. In the north this sea became landlocked and turned highly saline in the Great Salt Basin. The edge formation of these evaporates is well exposed in the Glass Mountains and the Sierra Madera, as the Vidrio-Gilleam-Tessey dolomites. These are similar to the equivalent deposits in the Guadalupe Mountains of New Mexico.

[1]) In December 1930 Ph. B. KING observed a horizon in the Haymond formation, containing pebbles, cobbles and large boulders of extraneous origin. Later work by C. L. BAKER and E. H. SELLARDS traced this horizon farther, and blocks were discovered up to 100 feet in length and 25 feet or more in thickness. The boulders are from various formations older than the Haymond, and include Dimple, Tesnus, Caballos, and smaller erratics from the Marravillas and even from pre-Cambrian sources (Bureau of Economic Geology News Letter, January 1931). A brief paper on these blocks was given by PH. B KING, C. L. BAKER and E. H. SELLARDS at the December 1930 meeting of the Geological Society of America.

SIDNEY POWERS wrote to the writer in March 1931, that the very large blocks are all of Novaculite, scattered along an upturned outcrop. Fairly large blocks, up to 3 feet or more, occur of other formations, together with fine cherty conglomerates. The pre-Cambrian pebbles are rounded and squeezed, and may not belong to the same stratum as the large boulders. Some of the blocks are reported to be "glacially" scratched. In POWER's opinion, the strata in which these erratics are embedded, do not belong to the Haymond, but carry upper-Marble Falls (Bend) fossils, what would make them equivalent to the Dimple, or the Ouachita Atoka. These beds would be included in a nappe or slice, underlying the Dugout Creek overthrust. POWERS believes that the entire deposit is a deltaic or beach formation.

The movements which we have already mentioned from Wolfcamp to Leonard time, are the after-phases of the Arbuckle orogeny, gradually decreasing in intensity. The sequence in the Glass Mountains shows that the Permian sea advanced from the northwest to the southeast upon the Marathon land, where movement continued spasmodically during most of the Permian. In consequence, the Permian shows baffling lateral variations in facies and also in thickness of the subdivisions, which it is difficult to explain by mere variation of conditions of sedimentation ; they also indicate sharp differences in the amount of subsidence within the basin in which these rocks were laid down. KING gives a stratigraphic diagram along the strike of the Glass Mountains range, which clearly illustrates these variations (**120**, fig. 17, p. 52). Regardless of these differences, the entire exposed Permian, from the base of the Hess upwards to well in the upper-Permian salt series, seems conformable in the Glass Mountains. The unconformity of the San Angelo-Duncan beds, so very widespread farther to the north and northeast, and even indicated in the Guadalupe Mountains in the northwest, does not seem to be represented by any angular break in the Marathon Permian. If, therefor, as MELTON thinks, a major orogeny occurred in the Permian, and later than the Garber sandstone, (equivalent to the Hess), it has either no equivalent in the Glass Mountains, or it must be represented by the basal unconformity of the Hess, what seems rather too early.

Very much later in the Permian, disturbance is, however, in evidence. On the northwestern side of the Glass Mountains, there occurs a coarsely clastic deposit, *the Bissett formation*, which contains heavy conglomerates and unconformably overlaps the Capitan beds of the Permian. It overlaps over some 1800 feet of eroded strata. The conglomerates are associated with some red and buff shales, sandstones and a few limestones. Well rounded pebbles and cobbles comprise all the limestones and dolomites of the Capitan sequence, and in the uppermost horizons some chert and quartzite of, probably, Word age. B. H. HARLTON identified ostracods as Permian ; fossil plants have also lately been determined as of late-Permian age [1]). This formation is overlain by the basal Cretaceous, with an angular unconformity. Although the Capitan beds, underlying the Bissett, show no indications of actual folding, but only of a regional tilt, the sudden appearance of these coarse clastics proves that, at least farther to the south, important uplift, if not a more serious orogeny must have taken place.

Farther toward the north, in the foreland, there exist unconformities at the base of the upper, "main" salt series, overlying the basal dolomites of the "Big Lime", partly equivalent to the Capitan formation. The unconformity is well indicated in the wells of the Big Lake oilfield, in Reagan county. In addition, there exist minor unconformities within the salt series (**114**, p. 159).

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[1]) Communications from E. H. SELLARDS and F. H. LAHEE.

Subsequent to the Bissett phase, further folding again affects the strata, and, at least in the northwestern Glass Mountains, the strongest pre-Cretaceous warping seems post-Bissett. In nearby areas to the northwest, where Trias is present, we have proof that this disturbance is pre-Triassic. In this entire region, however, these late foldings were confined to very slight undulating warping and tilting of the strata. Since, generally, even in the later Cretaceous and post-Cretaceous phases, the intensity decreases away from the mountains, we seem justified to assume stronger orogeny farther to the southeast, where no Permian strata have been preserved to give any evidence of these movements. (**120**, p. 88).

The importance of the Marathon Mountains as part of a major structural feature, is indicated by many signs.

The wide development of an early-Pennsylvanian, and then again, farther out, of an early-Permian foredeep, and the orogenic facies of the deposits, filling these troughs; the asymmetric profile of these foredeeps, and the fact that the depression moved progressively outward from the mountain front in later-Pennsylvanian and Permian times; the very great intensity and duration of the Arbuckle phase, and finally the important flat over-thrusting of the Dugout Creek and the metamorphic Solitario nappes, — *these all indicate a major orogeny. It is the history of a large and important mountain chain.* In 1927 SCHUCHERT expressed the opinion (**87**, p. 389) that the Caballos Mountains (the hills of folded and thrusted novaculite outstanding from the Marathon plain) were only local mountains of a minor order.

Everything seems to point to the probability that the Marathon-Solitario Mountains represent the southwesternmost visible extension of the greater Ouachita System, after it had swung around the buttress of the Llano-Burnett massif.

The foothills.

In the foreland of the mountains, in the adjacent southern part of the Great Salt Basin, folds occur, which, at least to some extent, seem to represent *the open folds of the foothills zone*. They are especially pronounced in the Sierra Madera, and have become known in the subsurface all over eastern Pecos county. The Sierra Madera was very strongly domed by a post-Comanchean orogeny, but there also is evidence of intense folding before the Cretaceous. This interpretation is also favored by PH. B. KING, after recent work in the field (**120**, p. 124). The sub-surface structures in Pecos county have an east-west strike and affect the upper-Permian. The latest disturbance may be of post-Bissett age. Their strike is conform to the presumable trend of the buried Marathon arc in this locality.

Wells on these structures indicate considerable uplift of the pre-Permian formations. The 5200 feet deep well of the Shell Company, on the crest of the important subsurface uplift at Fort Stockton, drilled through 4460 feet, regarded as Permian, in which the Castile, Capitan, Delaware Mountain, Leonard, Hess and Wolfcamp have been identified. The Permian is underlain by some 140 feet of partly fossiliferous, arkosic Cisco. This rests on basement rocks, which are considered a biotite shist by PH. B. KING, presumably pre-Cambrian. Some 100 feet of detrital material, consisting chiefly of red and green shale, with weathered limestone fragments, intervene between the sedimentary sequence and the basement (**120**, p. 117 and also **58**).

In the region intervening between the Marathon exposures and the Llano-Burnett Uplift, the saline series, including the basal dolomites, is underlain by *a very thick series of dark to black shales*, with some limestones. Apparently, this section fails on the crest of the Fort Stockton structure, where it was more probably eroded off, than that it was never deposited.

Very deep wells in the Big Lake oil field, in southwestern Reagan county provide a good section for the region. Here the upper-Permian salt series continues down to a depth of 3500 feet. Its basal dolomite ("Big Lime"), here 800 to 900 feet thick, is conformably underlain by the Black Shale Series, which has an aggregate thickness of not less than 4500 feet (**114**). This rests with a marked angular unconformity on an eroded anticlinal fold of pre-Carboniferous rocks: mostly Ordovician. The age of all of the black shale deposit is still uncertain. A mid-Pennsylvanian Triticites has been identified in samples from a depth between 7689—7701 feet (communication from B. H. HARLTON). SIDNEY POWERS advised the writer that from 6600 feet until 7200 feet, the wells drilled into Marble Falls (Morrow) strata, and then entered the Ordovician. In this case the black shale series might, to a considerable extent, be Pottsville, or even Tesnus. Though interesting, the problem is not of major importance for our discussion. *The essential point is, that there exists an important foredeep here*. The correct determination of the beds encountered in wells must determine whether the greater influence in causing this trough must be adjudicated to the Arbuckle or to the Wichita orogenic phase. Evidently, whatever the age of the complete series of the black shale formation may prove to be, the Arbuckle phase has very strongly affected this immediate foreland, and caused foothills folds in front of the mountains, as is notably indicated at Fort Stockton. It is evident that a great thickness of basal Permian, as well as Pennsylvanian, is present in the foredeep of the buried Marathon chain, to the east of the Marathon Basin outcrops, and that conditions here are very similar to the other region, affected by both the Wichita and Arbuckle orogenies, the Ardmore-Anadarko Basins.

Conditions farther out on the foreland and in the Great Salt Basin will be discussed in the next chapter.

Subsurface data, pointing to the eastern continuation of the Marathon chains, the evidence provided by wells, and the connection of the Marathon and Ouachita Mountains, will also be described afterwards.

PALEOZOIC ROCKS WEST, SOUTH AND NORTH OF THE MARATHON UPLIFT.

The Chinati Uplift.

Farther to the west of Marathon, in the region of Shafter, in Presidio county close to the Rio Grande, there occurs a cluster of smaller inliers along Cibolo Creek, exposing late-Paleozoic rocks.

In 1904 J. A. UDDEN published a paper on these outcrops (**100**). The area has again been described, after further work, and more in accordance with recent views on the Permian sequence, by CH. L. BAKER (**10**, 1929).

The Chinati Mountains form the southern end of the great Sierra Vieja range, that borders the Rio Grande valley in Presidio county. These latter mountains are composed of a very thick mass of rhyolitic effusives (lavas, tuffs and breccias), with large intrusive masses, which are probably all connected with one large buried batholith. The range belongs to the Cordilleran system. A large NNW striking faultzone: the Rim Rock fault, forms the west scarp of the mountains.

The uplift which causes the several exposures of Permian rocks is related to one of these intrusives of syenitic porphyry: the Ojo Bonito massif, of post-Trinity age. Against the flanks of the igneous rests a sequence of exposed upper-Paleozoics, overlain by lower Cretaceous, which in turn is covered by the rhyolitic lavas, which obscure most of the sediments on the west side of the uplift.

Several exposures of the Paleozoics are found along the Cibolo Creek, and another one again farther to the northwest, in an anticline at the northern base of the Chinati Mountains, along Pinto Canyon.

All these exposures contain members of the same series, which is confined to the sequence of the lower Permian of the Glass Mountains, with the inclusion of the Word [1]). The series is devoid of breaks and unconformities, although the facies, apparently, changes slightly from north to south. The most complete section is the one described by UDDEN, to the south of the Ojo Bonito intrusion. The more northerly ones expose only the middle members of the sequence. It is interesting that the basal beds, probably embracing the Wolfcamp, apparently rest on the pre-Cambrian basement, which is also uplifted by the porphyry intrusion. Evidently, we are in the Permian foredeep in front of the buried southwestern extension of the Marathon-Solitario mountain chains. These must be expected to pass farther to the south of the Chinati outcrops. The sediments are evidently derived from a southern source. Also the sequence, though devoid of unconformities, denotes a gradual grading upward from partly coarse detrital

[1]) In the older literature the Alta and Cieneguita beds are erroneously referred to the Pennsylvanian.

material in the basal portion, to pure limestones at the top. The unconformity, which in the Glass Mountains underlies the Hess, is not indicated.

What this outcrop learns us, therefor, is that detrital marine Permian occurs in this region in an orogenic facies, and that it evidently has its source from mountains in the south, subject to erosion after the Arbuckle orogenic phase. The Chinati exposures must lie within the early-Permian foredeep in front of these chains. The material in the conglomeratic basal beds is quartz and felspar, suggesting the nearby and underlying pre-Cambrian as source, and the pieces of a foreign white limestone and chert, may indicate the ranges to the south. (UDDEN, loc. cit. **100**, pp. 13—14). Nothing more of structural interest is revealed.

Beyond the already mentioned small outcrop at *Solitario*, 40 miles to the southwest of Marathon, where there is a repetition of the folded pre-Permian Paleozoics of the Marathon Mountains, we know next to nothing about any possible exposures of a continuation of the Marathon chains farther to the west or south in *Mexico*. It is by no means improbable that uplifts in this region, crossed by the folds of the Cordillera, should somewhere bring the Paleozoics or older rocks to the surface, and thereby give us farther indications of the west- or southwestward extension of the chains. We have an indication of this at *Boquillas*, just beyond the Rio Grande in Mexico, in the southern prolongation of the Santiago Range, where a small exposure of shists has been found by BAKER. It has the appearance of a pre-Cambrian or highly metamorphosed rock, as could be expected in the more central zones of the Marathon ranges. According to SIDNEY POWERS, it is different from old rocks which have been cored in Kinney county [1]. We have already mentioned that BAKER has identified presumably pre-Cambrian metamorphic rocks on a nappe in the center of the Solitario uplift. The rocks in Ouachita facies, which have been encountered in drilling in southern Val Verde county, underlying the Cretaceous, are still in doubt as to their age [2].

Redbeds are reported in certain exposures farther to the southwest in Mexico. These may be Permian or Triassic, from intra-mountainous basins in a continental facies, like we find them within the central zones of the Variscan chains of Europe. They may also be much older, or they may be younger (red lower Cretaceous as occurs in Louisiana?).

At *Las Delicias, north of Torreon, in Coahuila*, a marine Permian sequence of considerable thickness is known, containing sandy beds with an ammonoid fauna (*Waagenoceras* and *Perrinites*), associated with other Word and lower-Permian forms. Naturally, marine Permian may be expected in this general region, comprised within the Paleozoic Tethys.

The Cieneguita and Alta horizons (Wolfcamp to Leonard) have also been reported far to the southeast from the Sierra Madre near *Ciudad*

[1]) Communication from SIDNEY POWERS.

[2]) E. H. SELLARDS: News Letter Bur. Econ. Geology, January 1931.

TABLE VI.

PERMIAN SEQUENCE OF THE CHINATI UPLIFT IN PRESIDIO COUNTY, TEXAS.

THICKNESS IN FEET	DESCRIPTION	CORRELATION WITH MARATHON SEQUENCE
650	CIBOLO BEDS: hard yellow dolomite, cherty limestone, indistinctly stratified. *Fusulina cylindrica*, crinoids and other indistinct fossils.	UPPER-PERMIAN Vidrio-Tessey series?
470	dark, evenly bedded, compact, cherty limestone, containing some sandy strata and sandy shale. Few fossils: *ammonoids of Word age.*	
85	thinbedded limestones, grading up into sandstones. Sponge spicules very frequent. To the northward this member dwindles to a persistent bed, not over a foot in thickness, of hard siliceous limestone, composed largely of sponge spicules.	
133	greyish-white limestones in heavy ledges, south of Ojo Bonito intrusion (UDDEN's locality); changing to northward, in upper-Cibolo basin, to varicolored chert, with only a minor amount of fossiliferous limestone in thin beds. Fossils: *Waagenoceras, Fusulina elongata, Lyttonia, Tegulifera.*	WORD
100	grey marly shale with lenticular ledges of sand. This member does not seem to be represented in the facies of the northern exposures.	
1550	ALTA BEDS: fine grained, yellow, soft sandstone, locally indurated into a cream colored, brown or greenish quartzite	LEONARD?
2000	well bedded, somewhat sandy shales; only exposed in the Cibolo Ranch exposures.	
	CIENEGUITA BEDS: (not represented in northern exposures)	
at least 1000, possibly 2000	dark or almost black, locally cherty shales, alternating with heavy lenticular masses of "mortar rocks": (these are a conglomeratic mixture of calcareous mud and siliceous fragments of variable size and degree of wear); conglomerates in a limestone matrix; also contains dark fossiliferous limestones. The shales predominate.	HESS
	The series rests on granite (UDDEN **100**, 1904, p. 13), and contains decayed granite and gneiss boulders at its base. This suggests that the series immediately overlies the pre-Cambrian basement, part of which is preserved here and lifted up by the Ojo Bonito intrusive.	and WOLFCAMP.
	Fossils: Schwagerina occurs from bottom to top; *Tegulifera* at least in top of division (BAKER, **10**, 1929). UDDEN's fossils have a Pennsylvanian aspect. It seems probable the sequence extends to the very base of the Glass Mountain Permian. (Agreed by J. W. BEEDE). There is no trace of the Hess unconformity.	

Victoria, in Tamaulipas, Mexico, where the same foraminifera, the same shales and even "mortar beds" are said to occur (BAKER, **10**, p. 76). This, however is far in the hinterland, or beyond, and has no connection whatever with the frontal ranges of the Marathon region. It is interesting to note, however, that this lower-Permian is also *marine* there.

More northern development (see Plate 7).

In Culberson and Hudspeth counties, therefor more distant than the Chinati outcrops from the front of the possible western extension of the Marathon ranges, Permian rocks are exposed in the great doming of the *Wiley-, Eagle-* and *Van Horn Mountains*, in the *Hueco Mountains*, and farther to the northeast, in the *Guadalupe Mountains*. These latter form the western edge of the great Salt Basin and its great development of saline upper-Permian. There is only a small amount of detrital material in this Permian, and that at its base. It apparently originates from local uplifts of the granitic basement, and farther towards the north, it must be increasingly derived, from the Ancestral Rocky Mountains. It is not possible any longer to detect any influence from a southern source. The Marathon Mountains must not have spread their detritus this far. The bulk of the sediments are massive marine limestones, denoting the absence of shore influence. The lower dark limestone member of the Eagle, Van Horn, and Wiley Mountains has a thickness of about 1000 feet or more; it is overlain by a thick lighter grey limestone of Word age. This limestone series is the upper part of the great development of marine limestones, comprised under the name "Hueco"-formation in the Hueco, Sierra Diablo and Baylor Mountains. We have here over 4000 feet of lower-Permian and Pennsylvanian limestones, which unconformably overlie another massive older-Paleozoic limestone: the Helms and Lake Valley limestones, which comprise Mississippian as well as Devonian. These older Paleozoics have no relation to the development which we discuss here. They are situated far out in the foreland, where, in this western region, open marine conditions prevail. It is noteworthy, however, that the great unconformity and break between the upper-Pennsylvanian and the Mississippian continues to be strongly in evidence (**118**). This indicates again the foreland influence of THE WICHITA OROGENIC PHASE.

Another considerable unconformity separates the lower-Permian from the Pennsylvanian and older rocks in these mountains of West Texas and New Mexico. This is apparently the equivalent of the unconformity at the base of the Wolfcamp in the Glass Mountains. It indicates the ARBUCKLE OROGENIC PHASE, active also in these western chains with a Cordillerian trend (Ancestral Rocky Mountains).

In this marine limestone region we are in *the inlet strait, which connects the landlocked late-Paleozoic sea of eastern New Mexico, western Texas, Oklahoma and Kansas with the open sea to the west and southwest.*

There were two such inlets: an older one, coming more from the northwest, and bringing forms of a more boreal fauna out of the northern Pacific, and a southwesterly one, connecting with the Paleozoic Tethys. The latter opened freely into the ocean, the former was already of a decidedly more restricted character, all but limited to a brachiopod fauna when it reached the Midcontinent. The northern Cordillerian connection (Phosphoria seaway) has faunal affinities with Russia. It spread most widely in upper-Hess-Leonard (Phosphoria-Kaibab-San Andres) time, when finally, it became connected with the southern seaway. This latter extended originally into the interior beyond Nebraska. It gradually retreated toward western Texas, leaving a succession of salt basins in Kansas and Oklahoma, north of the Panhandle Arch (Amarillo Mountains), and some evaporites in the eastern shore zone of east-central Texas (pre-Blaine salts). Toward the close of Permian time, the Midcontinent had become nearly entirely land. Only in southwestern Texas there still remained a last remnant of the seaway from the Tethys, in which the Capitan formation was deposited.

It was this latter inlet which supplied the great Permian Salt Basin of West-Texas with the continuous inflow of fresh seawater, necessary to replace the water which evaporated and was leaving the immense volume of previously dissolved constitutents, as dolomite, anhydrite and salts. It entered from the southwest, south of the spur of the Ancestral Rocky Mountains.

This passage was evidently opened through the deepening foredeep in front of the Marathon-Solitario branch of the late-Paleozoic mountain system. This is another indication that, contemporaneously with the continued deepening of the foreland trough, uplifts in the mountains were renewed in Leonard time, both in the Marathon chains and in the Ancestral Rocky Mountain blocks. The two inlets mingled boreal and Tethys forms in the restricted Permian fauna of the inland sea. The southern west-Texas inlet brought a large and varied cosmopolitan fauna of ammonoids and fusulinids, as well as brachiopods and pelycipods. This purely marine facies of the Permian and Cisco-Canyon Pennsylvanian is notably represented in the Hueco, Guadalupe and Glass Mountains, and again farther west in the Permian of the Chinati Mountains. The area between the Apache and Glass Mountains, in Jeff Davis county, is unknown, being obscured by the great lava outpourings of the Davis Mountains region. Here probably was the main entrance channel. The exposures in the Chinati Mountains of Presidio county are also more or less within this channel. The Guadalupe Mountains represent about the northern edge of this southwestern inlet.

The open marine facies grades farther north and west, through the already restricted Gym-limestone facies of the northern Guadalupe and Hueco Mountains, into the Chupadera facies of redbeds, dolomite and gypsum : the Yeso—Abo redbeds of the San Andres and Sacramento Mountains, erosion products of the Ancestral Rockies. To the eastward it grades into the equally restricted facies of the dolomites of the lower part of *the "Big Lime" series of the Salt Basin*, and still farther east into *the Blaine and Clear Fork of the shore facies.*

In Word and Vidrio time the sea continued to retreat from the interior, leaving a further succession of younger saline basins, the last of which are *the Main Salt Basin of West Texas* and *the Delaware Mountain Basin.*

The extremely intricate problem of the Permian Salt Basin of West-Texas, Oklahoma and Kansas, and its sedimental sequence, is not discussed in details in this treatise. What interests us here is *the tectonic aspect* of this enormous basin, the floor of which was gradually being depressed, in its southern extremity, from 8000 to 9000 feet below the sealevel, as it existed at the time that saline deposition began. Its general north-south major axis indicates a predominant influence of the Cordillerian pressure to the eastward against Laurentia. In a way, it is a foredeep, associated with the upthrust horsts of the Ancestral Rocky Mountains, which seem in reality a great "pli de fond", if not a deepseated basement overthrust ("charriage à sec") in the sence of ARGAND. The great depth at its southern extremity, bordering the Marathon Ranges, marks the influence of the latter, and proves it also a foredeep of this branch of the late Paleozoic orogeny. The particularly deep depression of the Delaware Basin is, apparently, caused by the combined superimposed foredeeps of the Ancestral Rocky Mountains uplift and of the Marathon chains. As all tectonic features in this region, this great basin denotes the combined influence of pressures out of the Pacific, directed to the east, and out of the Tethys, to the northward, against the wedge shaped southern extremity of the Laurentian Plateau.

This depression of the great Permian Basin, with its area of some 390.000 square miles, through becoming landlocked behind the combined barriers of the Marathon chains and the swell of the Ancestral Rockies, caused the deposition of what may well be the greatest salt deposit, ever laid down in geologic history. The area occupied by actual desiccation products is not less than 150.000 square miles, with a variable thickness, which reaches a known maximum of some 4400 feet in eastern Reeves county. Several separate depressions, divided by barriers, which may partly be structural, but to a large extent are depositional or algal reefs, can be distinguished in the general basin.

The most prominent depression of this kind is the deep *Delaware Mountain Basin*, in the southwesternmost end of the great basin, just opposite the main inlet, in southern Eddy and Lea counties, New Mexico, and in eastern Culberson, in Reeves and Loving, and western Winkler and Ward counties, Texas. Here the greatest thickness of evaporites is known, but there may well be similar amounts deposited in the still entirely unexplored central area of the Main Salt Basin, south of the Panhandle barrier.

In Wichita-Albany time the inlet-channel of the basin extended, apparently, from the Hueco Mountains in northeastern El Paso county, through Hudspeth, Culberson, Jeff Davis and Presidio counties, all the way to the Glass Mountains, where the marine limestones of the Hess formation overlap against the Marathon Mountains. At this time the northern inlet was, possibly, also open.

In this period the sediments of the salt basin consisted chiefly of limestones, gradually becoming more dolomitic northward and also upwards. The underlying Wolfcamp formation in the Glass Mountains becomes only clastic toward the south, against the mountains. In the region between the Glass Mountains and the Llano-Burnett uplift the Hess and the Wolfcamp are still mainly black shales. In part, this is the very thick black shale sequence, which on the Big Lake structure in Reagan county is still 4500 feet thick (cf. page 75). The Permian part of these shales turns into the Albany limestones farther to the northeast and probably also to the north. This shale sequence marks the influence of the mountains to the south on sedimentation. It is a foredeep deposit. This trough may be compared to the Anadarko-Ardmore Basin in front of the Wichita Mountains, farther to the north, affected by both the Wichita and Arbuckle orogenic phases.

In the Glass Mountains the main unconformity occurs below the base of the still Permian Wolfcamp formation, but the Arbuckle orogeny happened in the middle-Cisco; the upper-Cisco is not preserved here, having been cut out by erosion and overlap. The corresponding lower-Permian Cieneguita beds in the Chinati Mountains (1000—2000 feet) are also clastic, indicating similar conditions. Here the Permian rests on pre-Cambrian, and the entire older-Paleozoic sequence was either cut out by post-Arbuckle erosion, or was never deposited.

Only north of the Wichita-Amarillo barrier ridge (the Panhandle Arch), anhydrite and salts were laid down during Wichita-Albany time, as *the Wellington salt sequence of Kansas;* here gypsum began already to form 50 feet above the Cottonwood limestone, the conventional top of the Pennsylvanian. This sequence is non-red in Kansas and Oklahoma.

In the Clear Fork stage, the inlet channel became gradually more restricted: the northern inlet did no longer remain open into Kansas. The southern inlet became narrower. The marine, gypsiferous, dolomitic and *redbed facies of the Chupadera* extends to the northern Hueco Mountains, and becomes more prominent in *the Yeso sediments* of all central New Mexico, behind a structural barrier, apparently caused by folds in the Bonespring Limestone of the Guadalupe Mountains. These folds and the narrowing of the channel through uplifts, and the further depression of the foredeep of the Marathon Mountains, are parts of a new, very widespread orogeny, indicated by unconformities and conglomeratic clastics at the end of Clear Fork time (*San Angelo phase*), which is in evidence both on the east and west sides of the Basin, and is, not impossibly, contemporaneous with a final overthrusting phase in Ouachita Mountains. At the same time detritus from the Ancestral Rockies increased, causing the more sandy sediments of *the Glorietta*, the western equivalent of the San Angelo-Duncan clastics, that emanate from the Ouachita ranges. In the Glass Mountains the equivalent Leonard formation borders the Marathon ranges, and also receives clastic detritus from this source, to a greater extend than the underlying Hess formation.

The saline facies in the great basin now crossed the Panhandle barrier, at least as far south as the arch over the buried Red River chains of the Wichita system. We now find a salt series there, reaching a known thickness of some 1500 feet. Whether salts were deposited south of the Red River arch is not yet known.

With the beginning of the succeeding *Double Mountain stage*, in Blaine time, the Delaware Mountain Basin became a particularly pronounced depression. It received its influx through a still more narrow channel, now apparently confined to Presidio and Jeff Davis counties. This inlet brought an enormous amount of very fine marine sand, depositing 3500 feet of *Delaware Mountain sandstone*, for all we know, strictly confined to this basin and the inlet channel. We again find this sand in the upper-Alta beds of the Chinati Mountains (1500 feet); the Word formation in the Glass Mountains is also finely sandy. Not impossibly, the fine Delaware sand came from bared pre-Cambrian crystallines farther to the southwest, the presence of which is indicated in numerous localities, notably in the Chinati Mountains. The enormous quantity of this extremely fine sand, so fine that the beds often look like shales, marks the importance and volume of the current entering the basin through this inlet at the Delaware period.

In the middle part of this stage great depositional reefs formed, practically encircling the Delaware Basin, which may have reached their maximum *in Whitehorse time* [1]). The now most conspicuously exposed part of these reefs is situated in the Guadalupe Mountains (*Capitan Limestone*: 1800 feet at Guadalupe Point), the Apache Mountains, and the Glass Mountains *(Vidrio-Gilliam-Tessey dolomites:* 3000 feet). Buried parts of this same circle reef are known in Lea, Winkler and Pecos counties (also in a thickness of about 1800 feet). In these beds the seaward deposits, the reef, and the lagoon sediments can be distinguished. These reefs have been compared to the middle-Triassic Schlern, Marmolata and Esino dolomite and limestone reefs of the southern Tyrol.

The incoming seawater overflowed these reefs both to the west and northward, depositing beds in a lagoonary facies, grading farther into evaporites. In addition, the Main Basin seems to have been fed by a channel situated between a ridge in western Pecos county, the Fort Stockton—

[1]) These are not coral reefs, but partly algal, partly depositional reefs of chemical precipitates, as a result of concentration of seawater, and the mixing of bodies of water of different density along the course of the currents.

Yates "high" (apparently a buried uplift in the foreland), and the extension of the front of the Marathon chain. Less fine sand travelled through this channel; evidently the water became cleared of this sand in the Delaware Basin. Dark shales and limestones, with little sand, are deposited here.

A great thickness of marine deposits continued to be laid down during this stage: *the "Big Lime" in the Main Basin*; in the Delaware Basin, some 1000 feet of Delaware sandstone were still deposited around the growing reefs; later on, dark colored limestones, intercalated with the sand, and finally, capping the sand deposit, *the Carlsbad Limestone* was laid down in the Guadalupe Mountains (and similar deposits on top of the other buried reefs). This limestone forming sea overflowed the reefs to the west and northward, where it deposited beds in Chupadera facies: the *Seven Rivers Gypsum*. To the east, the upper part of the Big Lime grades into anhydrite. The total thickness of this "Big Lime" deposit of the Main Basin attains 3000 feet (down to the Pennsylvanian, and includes a few hundred feet of uppermost Cisco).

In the north, in the Panhandle and in Kansas, redbeds with local lenses of rocksalt were laid down, indicating that this part of the basin had now largely become filled, subsidence had slowed down, and that only local and temporary salt pans remained; the fresh supply of seawater and brines became very much restricted, but is still indicated later by occasional widespread, but thin layers of dolomite, like the Alibates-Day Creek dolomite (cf. p. 85). Possibly, saline deposition was more pronounced in the unexplored northern portion of the Texas Salt Basin, just south of the Panhandle barrier ridge.

In the southern province of the Texas Basin, a very active influx of seawater persisted during the final part of the Double Mountain period, probably more or less equivalent to Cloud Chief time farther east. *Here a truly enormous volume of anhydrite and salt was deposited: the lower- and upper-Castile formations.* The first of these remained probably restricted to the Delaware Basin, a break in the series possibly occurring beyond the barrier reefs. A break of this kind is indicated in a number of places in the shore region to the east, cutting out the Dog Creek formation and even parts of the top of the Blaine.

In the Delaware Basin the salt series of the lower Castile consists of beds of white, non-potash bearing salt, (aggregating some 600 feet), interbedded with great masses of regularly banded anhydrite and a little dolomite; this lower Castile series has a total thickness of about 1500 feet. The upper Castile develops the main mass of largely pink rocksalt of the Main Basin, with only very little anhydrite and dolomite; it contains many streaks of potash salt, notably polyhalite, in both the Delaware Basin and the Main Basin.

In the Delaware Basin the greatest thickness of the upper salt series occurs in south-central Lea county: 2400 feet. In the Main Basin the greatest thickness might be looked for in the unexplored central portion. This upper-Castile salt series must be correlated to the Cloud Chief stage of the eastern shore zone, and possible higher zones, not deposited there under the apparently unconformable overlap of the Quartermaster redbeds. It is only represented farther north by redbeds and gypsum (probably deposits from salt lakes), with occasional thin, wide spread dolomite beds (*Alibates* and *Day Creek dolomites*), indicating short lived marine influxes.

The whole basin series finally ends with a moderate thickness of redbeds: *the Quartermaster formation*. Only in the extreme southwest, *the Rustler dolomite* indicates a last inroad of flooding seawater. This Rustler transgression, which is again overlain by redbeds, extended as far to the eastward as Midland county.

Widespread unconformities are suspected at the base of the Rustler and the Quartermaster. This movement may correspond with the uplift, which in the Glass Mountains caused the abrasion, yielding the heavy conglomerates of *the unconformable Bissett formation*.

Apparently, the sinking movement of the great Salt Basin had now definitely come to a close, so that actual salt pans were no longer formed.

This ends the Permian sequence. It is unconformably overlain by *Triassic redbeds*, recognisable by their different red tint and their strongly micaceous sandstones. The source is in the Ancestral Rockies.

Folding is in evidence in the upper Permian strata of the Basin; this buried structure is best known from the Hendricks oilpool in Winkler county.

These folds seem to be *post-Triassic*, since the base of the Trias follows the Rustler dolomite down into the synclines. At other places, however, post-Permian but pre-Triassic warping is in evidence. These structures are not due to mere compaction, since the axes of the folds do not coincide with the nearby underlying reefs. (cf. R. WILLIS, **109**, 1929, p. 1040).

As a result, therefor, of the happenings, here described, we find five principal depositional provinces in the great Permian Basin of the Southwest: three basins, and two transition zones between them. The basins and barriers are the following:

the northern Wellington Basin of Kansas and Oklahoma;

the southern Main Basin of West-Texas and eastern New Mexico; these two are separated by *the Panhandle Arch* (the ridge of the Amarillo Mountains);

In the extreme southwest, *the trans-Pecos Delaware Mountain Basin* formed, separated from the Main Basin by *the Guadalupe reef barriers*.

In addition, there are minor basins and sinks, and dividing barriers, influencing the facies, and notably the distribution and character of the salt (potash salts). A quite possible, individual, larger basin, between the Panhandle Arch and the Red River ridges is still unexplored.

The developments, here briefly reviewed, have been condensed in the adjoined *Tables VII a., b.* and *c.*, as an attempt to give as clear a picture as possible of these complicated sedimentary cycles and the earthmovements which controlled them. The contemporary strata are particularly difficult to correlate, on account of the many radical changes in facies and the lack of characteristics in these evaporites.

The table also contains references to the authors, several of whom were the writer's collaborators, who have published papers on the subject here discussed (**7**, **11**, **15**, **19**, **22**, **26**, **33**, **36**, **71**, **109**).

This table may not prove correct in every detail, but the general picture is certainly exact; it is anyhow sufficient for the tectonic purpose of this treatise.

THE BURIED PORTIONS OF THE OUACHITA SYSTEM.

Only recently subsurface information has come forward, which permits to trace the buried portion of the Ouachita chains, at least the farther continuation of their outer front, with considerable certitude throughout eastern Texas. This is due to the sections revealed in hundreds of wells drilled all over this region. The American petroleum companies deserve the greatest credit, not only for the scientific manner in which these wells have been drilled and supervised, but particularly for the open-mindedness in which the results and the conclusions of the geologic staffs have been made public property. This has not only been of value to science, but has also proven to be profitable on account of the practical results of this practice, as compared to secrecy and concealment.

Our present knowledge has been much fostered by the painstaking work of E. H. SELLARDS [1]), M. G. CHENEY (**27**, **28**, 1929), SIDNEY POWERS (**83**, 1929) and R. H. DOTT (**38**, 1927), not to mention so many others, who have assembled and coordinated all these data into a picture, which now permits us to connect the visible Ouachita Mountains, through all central Texas, with the outcrops in the southwest.

The central portions of the chains, to the south of the frontal outcrops, as well as the eastern continuation of the mountains in the direction of the Mississippi River, remain very obscure. So the exact location and nature of the connection with the Appalachians of Alabama remains entirely conjectural. However, the writer fully agrees with H. D. MISER (**77**) and R. C. MOORE, who consider this connection most probable.

The connection with the Appalachians is not simple. These mountains are no mere eastern continuation of the Ouachita ranges. The Appalachians *present the Wichita, and not the Ouachita facies of sediments* in the entire Ordovician, Silurian, Devonian and Mississippian sequence! So it remains a possibility that the Wichita chains, rather than the Ouachitas, connect with the Appalachians, or — still more probable — that somewhere in the Mississippi Embayment the two branches come together and unite in the Appalachian system. (cf. page 117 and footnote on p. 107) [2]).

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[1]) E. H. SELLARDS is preparing a Handbook of the Stratigraphy of Texas, in which many of these data are being assembled; an advance notice regarding this region was given at the meeting of the Geological Society of America in December 1930. From the available abstract of this paper, and a map which SELLARDS has kindly sent the writer, it is evident that this author has been thinking along very similar lines as are put forward in this treatise.

[2]) SIDNEY POWERS drew the attention of the writer to geophysical evidence, suggesting that the Appalachians continue in the subsurface towards New Orleans, rather than towards southern Arkansas. Of course, such evidence is far from conclusive, unless the

We have mentioned already, that Ouachita Paleozoics have been reached by the drill up to 40 miles to the southeast of the outcrops, near Fordyce and Rison in Arkansas, and farther south of the Red River, in Grayson, Fannin, Lamar and Red River counties, Texas. In the southeastern corner of the State of Arkansas, two wells, south and west of Lake Village on the Mississippi River, have reached syenite and peridotite at a depth of about 3000 feet, underlying a moderate thickness of Cretaceous. The writer does not know whether any proof exists that these igneous rocks are Paleozoic, as represented on the cross section, accompanying the recent geologic map of Arkansas (**20**). Possibly, they are Cretaceous, like the (diamond-bearing) peridotite plugs of Pike county, and the syenite rocks near Little Rock, Benton, and Magnet, at the southeastern edge of the outcropping Ouachita Mountains in the same State.

Recently, several wells on the Preston anticline (along the Red River in Grayson and Fannin counties, Texas) have proven that Ordovician rocks, *in Ouachita facies*, directly underlie the Cretaceous [1]). This is the southwesternmost point where the Ouachita Mountains have been traced in the subsurface (before we reach the east-Texas wells in Dallas and Ellis counties; page 100). This is 50 miles from the outcrops in Oklahoma and 38 miles to the SSW of the Hansen well, mentioned on page 38.

The conclusions outlined here as to the buried elements of the Ouachita system are very largely the result of an analysis of the geologic history of late-Paleozoic sedimentation in this region. The mountains themselves are buried and have scarcely been reached by the drilling. We can reconstruct their nature and their course, and the phases of the orogeny which built them, from the effects on sedimentation and the paleo-geography of the region. These problems, in particular, have been the subject of the authors cited. CHENEY gives us a valuable map and cross sections of the subsurface in central Texas (**22**, Plate VII). This map is here reproduced, as our *Plate 8*, with the kind permission of the University of Texas and of the author.

The lower-Pennsylvanian foredeep of East-Texas.

CHENEY's maps (also those contained in **27**) are the first to bring clearly forward the distinct, mostly buried foredeep, which develops in the lower-Pennsylvanian in central Texas, which is an exact replica of the foredeep

survey has been most thorough and detailed. What a gravitational survey would most readily indicate, would be the presence of either positive or negative masses, blocks alined in this trend. This more or less southwest strike would be expected to prevail in much of the hinterland of the Ouachita Mountains, and be a favored direction, in which horsts and basins in the Paleozoic or older basement of the Gulf Coast would aline; igneous intrusions would be expected to follow this same trend. All these features, that would express themselves as geophysical trends on the gravitational map, are probably utterly independent from the strike of the Paleozoic folds. We will revert to this later, when discussing the subsurface of the Gulf Coast Plain.

[1]) See footnote on page 38.

in the Oklahoma and Arkansas Coal Basin, along the northern front of the Ouachita Mountains. Other similar maps, also including the Appalachian region, have since been published by A. I. LEVORSEN (**118**).

Most of the area in which the Texas foredeep is situated, is already obscured underneath the Cretaceous. Happily, this is oil territory, and explored by very many borings. This fails us in the Mississippi Embayment.

For a proper understanding of the writer's own conclusions, we may again briefly review the Carboniferous and Permian history of the region comprising central-Texas, Oklahoma and part of Kansas.

A short reference table is here inserted, for the benefit of the reader, who may not be familiar with the many formations and subdivisions of the Carboniferous which have to be mentioned. (*Table VIII*).

The Carboniferous period set in with the deposition of the Chattanooga shale, a quiet but extremely wide-spread marine transgression, extending from the Appalachian region well across Oklahoma and Kansas. The regularity of this great but thin overlap, and the remarkable absence of any coarse material postulate an almost perfect base levelling of the entire interior of the Midcontinent. Only a few isolated monadnocks protruded from this perfect peneplain. The most conspicuous of these occurred in the Nemaha Ridge of Kansas. The Chattanooga overlaps beds from Cambrian to Devonian : these latter formations were deposited over the entire Plateau, but are represented in particulary great thickness in the geosynclinal trough, from which the Wichita Mountain system was later to be raised.

The uneventful character of the earlier Mississippian, in which warping was singulary absent, came soon to an end. Conditions cuntinued to remain exceedingly quiet over the Plateau, but, probably already early in the Mississippian, certain movements occurred off its southern edge, in a region now underlying the Gulf Coast Plain and the Gulf of Mexico. This initial phase is marked by the erosional unconformity and considerable stratigraphic break, overlying the Arkansas Novaculite in the Ouachita Mountains, and the Caballos Novaculite in the Marathon region, and the apparent absence of all middle and lower Mississippian, except, possibly, in a chert facies, in the geosyncline. *This movement marks the birth of the Ouachita system, sometime in the Mississippian.*

Towards the end of the Mississippian, the Midcontinent Plateau, which had been receiving an almost complete covering of Mississippian sediments, predominantly limestones, bulged into a broad arch, emerged, and became subject to erosion. This arch extended from New Mexico, toward the north-east into Minnesota, and the pre-Cambrian shield of Canada. Along this arching, uppermost Mississippian and lower Pennsylvanian erosion bared the pre-Cambrian on the back of the axis; farther away, both east and west, progressively younger formations were preserved. This great unconformity and erosional break mark one of the most conspicuous events in the geologic history of the North-American continent (cf. A. I. LEVOR-

TABLE VIII.

N-CENTRAL TEXAS	SOUTHERN OKLAHOMA CENTRAL REGION	 EASTERN REGION	SOUTHEAST-KANSAS
CISCO. Putnam Moran Pueblo Harpersville	Pontotoc cgl. Break: Ada fm. Break: Vamoosa fm.	Absent Pawhuska fm. Nelagoney fm.	Wabaunsee group Shawnee group Douglas group
			ARBUCKLE OROGENY
Thrifty Graham	Hoxbar fm.	Belle City ls.	Lansing group
CANYON. Caddo Creek Brad Graford	Hoxbar fm.	Francis fm. Seminole cgl.	Kansas City group
STRAWN. Mineral Wells group Brazos River cgl.	Deese fm.	Holdenville fm. Wewoka ss. Wetumka sh. Calvin ss. Senora fm. Stuart sh. Thurman ss. Boggy fm. Savanna ss.	Marmaton group Fort Scott lm. Cherokee group
Mingus sh. Millsap fm.	Dornick Hills fm.	McAlester fm. Hartshorne ss. Atoka fm.	Absent *Upper Phase of* *WICHITA OROGENY*
BEND. Smithwick Marble Falls	Springer fm. Ardmore Basin flysch: Ardmore Caney	Wapanucka lm. Ouachita flysch: Jackfork ss.	Absent
MISSISSIPPIAN. (Break)	Ardmore Basin flysch: Arbuckle Caney	Ouachita flysch: Stanley sh.	Absent *Lower Phase of* *WICHITA OROGENY*
Barnett fm.	Break	Absent	Pitkin, Fayetteville, Batesville } Chester
Break?	Sycamore lm.		(Break)
Lampasas cherts	Woodford chert	Upper part of Arkansas Novaculite (Talihina) chert?	Boone (Osage) Chattanooga

SEN, **118**). It is contemporaneous with the sinking in the flysch geosyncline in the Ouachita-Marathon mountain system, and similar movements in the Appalachian trough and in the western Rocky Mountain region. It coincides, therefor, with the WICHITA OROGENIC PHASE, and emphasizes the tremendous importance of this world-wide diastrophism, not only for Eurasia, but also for North America.

Late in the Mississippian, after Chester (post-Pitkin) time, the principal phases of this orogeny set in. In the hinterland of southern Alabama, and of the present Ouachita and Marathon Mountains, an important elevated range came into existence. The erosion of these highlands yielded up to 20.000 feet of flysch sediments, filling a very wide geosynclinal area, in front of these ancestral Ouachitas [1]). The enormous mass of this orogenic material proves the importance of this initial phase. These shales, arkosic sandstones, graywackes and grits must, clearly, be derived, not merely from "highlands", but from actively rising important mountain ranges, consisting in a large measure of igneous and metamorphic rocks. It is not necessary that these ancestral chains were severely folded; it may have been a great elevated block, but, evidently, these masses were later thrust in a system of nappes over the original flysch geosyncline, and the folded chains, which had risen therein. In the southern Appalachians, this in evidence, and recently this fact has been ascertained by BAKER for the Solitario uplift. It is greatly developed in the Variscan chains of central Europe.

The flysch is confined to a geosyncline on the southeastern rim of the ancient Laurentian Plateau. We do not find a similar great development of orogenic latest Mississippian in the Appalachians [2]); it is entirely absent

[1]) This does not mean that the Ouachita system contributed all, and the arched continental Plateau nothing of the flysch material. The erosion of the continental landmass must also have yielded finegrained detritus, which mixed with the coarser outwash of the rising mountains on its edge. For each formation, this influence of the Plateau must be greatest in the interior zones, farthest away from the bordering ranges. The orogenic mountain-derived material, however, constitutes by far the predominant bulk of the late-Mississippian and early Pottsville flysch. In the foreland, north of the Variscan chains of Europe, we find the same condition, and a marked admixture of material, evidently derived from the simultaneously bulging Baltic Shield. The entire mechanism is almost identical.

[2]) In Alabama we still have the same development as in the Ouachita Mountains (Parkwood formation), but in eastern Kentucky and Ohio, we do not find any of this post-Chester latest Mississippian, though the Chester shows evidence of some thickening toward the Appalachians. Only very much farther in the northeast, in a Mississippian basin in West-Virginia, Pennsylvania and New-York, we find again a more important development of mostly clastic sediment, which reaches a maximum thickness of some 5000 feet, and thins away to the north, west, and south. In the mountains, which lie to east of these deposits, the relations have become very much obscured by compression and thrusting over each other of rocks, originally deposited in other, more distant regions.

This sequence is composed of a more clastic and coal bearing lower division, the Pocono series, which reaches a thickness of 2000 feet, and a red shaly upper division, the Mauch Chunk, a sub-aerial flood plain deposit, attaining a maximum thickness of 3000 feet in in the intra-continental Wichita system (the flysch in the Ardmore Basin embayment, the Springer-Caney sequence, is detritus from the Ouachita Mountains).

In the last stage of the flysch period, the sea which had been drawn almost entirely into the geosyncline, began to spread again over the foreland. The lower-Pennsylvanian Morrow sea, now depositing finegrained shales and limestone (Wapanucka), transgressed considerably farther than the extent of the flysch geosyncline. The Hunton Arch and all the southern part of the Ozark massif were submerged. This flooding of the edge of the foreland coincides with the beginning of the second phase of the Wichita orogenic cycle, at the end of Wapanucka time. New chains were now rising in the bulging geosyncline. These oscillatory migrations of the shoreline of the Plateau were clearly connected with orogenic phases, affecting the geosynclinal region beyond.

The early Pennsylvanian, following the Morrow, is characterized by the formation of a new foredeep trough, farther out on the Plateau, well in front of the original flysch geosyncline. It is filled by a new mass of clastic detritus, *derived from a new source*. In analogy with the Alps, we have called this orogenic Pennsylvanian *the Ouachita molasse*. Arkosic material now decreases and is being progressively replaced by cherts. Evidently the highlands of crystalline rocks were losing their importance, and new ranges were rising and became subject to erosion, composed of cherty old-Paleozoics of the Ouachita facies. That the flysch sediments themselves were involved in this folding is proven at Marathon. The procedure was now repeated, that the sea retreated into the new trough and the foreland became emerged to a greater extent than in Morrow time. In Oklahoma, the Morrow sea, though following the trend of the Ouachitas, and clearly confined to the foredeep of the chains, extended from northern Adair, through Creek and Cleveland counties, crossing the Red River into Texas in Cotton county. In Atoka time, the sea retreated to the southern line of Adair county, through Hughes, eastern Pontotoc and Marshall counties, leaving

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the southern anthracite fields. In West Virginia the two divisions are separated by the Greenbrier limestone.

Evidently, this deposit is of a far minor importance than the enormous mass of 17000 to 20000 ft. of late-Mississippian Ouachita flysch. It is also a much earlier Mississippian. Only the Mauch Chunk and Greenbrier are upper Mississippian, but not younger than Chester: the Pocono comprises middle and lower Mississippian. J. J. STEVENSON even regards the lower part of the Pocono as Devonian.

The source of these sediments is connected with the major orogenic phase, which the Appalachian system shows in New England, and notably farther to the northeast, in Canada. This disturbance caused the deposition of heavy conglomerates over the upturned and truncated edges of Devonian and Silurian strata (Acadian orogenic phase).

It is possible that the break overlying the Novaculites in the Ouachita system marks some reverberation of this orogeny in more southern regions. It is more probable, however, that the Acadian orogeny had no effect whatever on the southern edge of the Plateau, and that the unconformity on the top of the Novaculite only marks the beginning of the disturbance, which caused the deposition of the uppermost-Mississippian Ouachita flysch.

both the Ozark region and the Hunton Arch emerged. The latter also markedly contributed to the sediments. In Hartshorne-McAlester-Winslow time, the transgression of the geosynclinal sea on the Plateau was again repeated: the sediments progressively overlapping northward and westward, but this time the Hunton Arch was not submerged. In this period posterior movements of the Wichita phase continued to warp the strata into foothills folds; thus the Atoka formation is offlapped by the McAlester, and the latter again by the Savanna sandstone. Uplift is again repeated previous to Thurman time, but the foothills folding had come to end in Boggy time. The outward migration of the molasse sea became particularly marked in Cherokee and Marmaton time, in the upper part of the Strawn period, until a thorough change came by the great event of the Arbuckle orogeny in the Wichita system, the precursory movements of which started already in Canyon time in the Red River chains. The paleogeography of this period has been analysed by R. H. DOTT **38**.

The drill has revealed the existence of an entirely similar molasse foredeep in east-central Texas.

In this province of the Plateau, south of the Wichita geosyncline, conditions demonstrate entirely similar oscillations of the shorelines and identical sediments, as we described for the northern region in Oklahoma.

We saw that the Morrow shows a comparatively wide spread north of the Red River. In Texas the shoreline runs through Childress, Cottle, Motley, Crosbie, Garza, Borden, Howard, Midland, Ector, and Andrews counties, into Eddy county, New Mexico.

Even as in the north, the spread of the Strawn in Texas is very much more restricted: these sediments are also drawn more distinctly into the now intensified foredeep in the east, and are confined to a far narrower trough. The outer western edge of the Strawn age sediments runs through Pontotoc, Garvin, Comanche, Cotton counties, Oklahoma, (through the Anadarko deep); in Texas the shoreline traverses Clay, Wichita, Wilbarger, Foard, King, Stonewall, Jones, Callahan, Brown, San Saba, Llano and Blanco counties, along the northeastern side of the Concho Arch. Equivalents of the Cherokee and Marmaton formations spread farther than the lower divisions of the Strawn, and have been identified in northwest Texas, as well as in north and west Oklahoma.

In Texas, the Strawn formation increases in thickness from about 1000 feet in western Throckmorton county, to 3500 feet in Palo Pinto county, and (by interpolation, because the top of the formation is eroded under the basal Cretaceous) to 6500 feet in eastern Parker county, and even 8000 feet in central Coryell county (**27**, **28**). This increase is partly due to thickening of the upper-Strawn, but in addition, ever lower members of the Pennsylvanian sequence make their appearance to the east (Millsap formation, mostly Pottsville) between the Bend and the Strawn.

There is practically no Millsap in western Throckmorton county, and already over 4000 feet in Parker county. In the deepest part of this Texas foredeep no wells have reached the base of the Pennsylvanian, as for instance in Tarrant, Dallas, Johnson and Bosque counties. Here the complete thickness of the great molasse deposit can only be estimated.

All this is, therefor, *exactly the same evolution as in the better known foredeep of southeastern Oklahoma.*

The presence of an open fold zone is also indicated in Texas: rather sharp folds with NE-SW axes are noted in the Brazos and Colorado River valleys. These affect strata nearly as late as the close of Strawn time.

The Millsap and Strawn do not only thicken to the east, but indicate an eastern source of the sediments through their physical development. The lower Strawn is still arkosic, as are the early Pennsylvanian beds of the Oklahoma Coal Basin, but the felspars become ever less frequent after the Mississippian, and a new material, chert, comes progressively in evidence. This indicates that the same changes occur in the source region, as are indicated for the Ouachita Mountains (**27**, p. 572). Much chert conglomerate in the middle and upper Strawn, becoming coarser to the eastward and grading into normal sandstones westward, proves the presence of much cherty rock, in other words sediments of the Ouachita facies, subject to erosion farther to the east or southeast.

On account of the very restricted exposures, largely supplemented by well logs, the above data concerning the development of the lower Pennsylvanian are very much generalized, but we know more than enough to rest assured that an entirely typical orogenic foredeep develops here in the subsurface, and that this occurs as a progressive overlap of strata from the east in a sinking trough in the foreland.

Farther to the southwest, in the southwestern corner of Texas, still another, very similar lower-Pennsylvanian basin is again in evidence, with a great thickness of orogenic sediment: *the Tesnus-Gaptank Basin,* bared in the Marathon and Solitario windows. Here we again encounter lower Pennsylvanian, as well, probably, as latest Mississippian, in a typical flysch facies, rapidly thickening to the south and reaching 5000 to 10.000 feet in the neighborhood of the Rio Grande, (**27**, p. 565). Here the Tesnus is bared in windows of the nappes, exposing the autochtone. This is clearly an identical foredeep in front of the Marathon mountains complex. Farther to the southwest the trend becomes lost in Mexico, where not unlikely further traces await discovery and description.

In *the higher zones of the Strawn formation* the parallelism between the Oklahoma-Arkansas and Texas developments continues.

In the Mineral Wells division of the Texas Strawn the formation of local coalseams indicates that in places the surface emerged, and either subsidence lessened, or sedimentation balanced the sinking. In Oklahoma

DEVELOPMENT OF THE STRAWN FORMATION.

(CORRELATIONS AFTER B. H. HARLTON, R. C. MOORE, C. O. DUNBAR).

TEXAS			OKLAHOMA—KANSAS		
REMARKS.	EAST-CENTRAL TEXAS	ARDMORE AND RED RIVER BASINS	SOUTHERN OKLAHOMA IN OUACHITA FOREDEEP	NORTHERN OKLAHOMA AND KANSAS (PLATEAU REGION)	REMARKS
The Texas Strawn is largely a wedge shaped mass of mostly clastic material. Only the western part of the upper-Strawn carries limestones of more conspicuous thickness. In the eastern part of the area, the eastward thickening of the Strawn is at least 100 ft. to the mile; in the central and western parts the thickening averages 25 ft. to the mile or less.	UPPER DIVISION: MINERAL WELLS (COALMEASURES): Rather clastic formation, containing three thick beds of rather coarse, pebbly sandstone, still somewhat arkosic, separated by clays and thin inconspicuous limestones; locally important coal seams. BRAZOS RIVER SANDSTONE, with conspicuous chert conglomerate in lower portion. (25—50 feet.) MINGUS SHALE (250—300 ft.) with Thurber Coal at base.	Lower part of HOXBAR FORMATION: Chiefly shales, including much brownish, yellow and reddish beds, as well as bluish shale. A few limestone conglomerates. The Ouachita Mts have ceased to yield much material to the sediments.	SEMINOLE: Conglomerate of white chert in brown matrix, succeeded by brown Sandstone. (Canyon ?), 50—300 ft. HOLDENVILLE FORMATION largely shales, with some limestones and sandstones, ± 200 ft.	Lower part of KANSAS CITY GROUP: limestones and shales.	Period of comparative quiescence; sea begins to flood the Hunton Arch, but emerged southern part continues to yield clastic sediments. Ouachita Mts have ceased to yield much erosion detritus. Ozark region emerged.
The lower Strawn sandstones are arkosic. Conglomerates in middle and upper Strawn contain increasing quantities of chert from an eastern source. There are fragmentary evidences of post-Wichita phase crustal movements that did not much affect the overlying strata of Canyon and Cisco time. Anticlines in Strawn near Locker and Regency in the Colorado River valley, and on Allen Ranch in the Brazos River valley are much more steeply folded and faulted than the gently plunging warpings in the Canyon and Cisco of east-central Texas. (84, p. 203).	LOWER DIVISION: MILLSAP. Mostly dark blue and black clays, with a series of irregular lenticular limestones and several thin light colored and friable sandstones.	DEESE FORMATION: (6000—7000 ft.) Succession of often massive, crossbedded sandstone beds and chert conglomerates, separated by bluish, tan and red shales, with minor and relatively inconspicuous limestone members. *Devil's Kitchen sandstone* (100—200), 800 feet above base, grading southeastward, *toward the Ouachitas,* into coarse chert conglomerates, without limestones. Source of sediments predominantly in Ouachita region.	SECTION AT STONEWALL, OKLA (T. 2 N, R. 7 E): WEWOKA SANDSTONE: partly cherty conglomerate, in part arkosic, 550 ft. WETUMKA SHALE, with few thin sandstones, 800 ft. CALVIN sandstone: 850 ft. SENORA FORMATION: shales and sandstones: 970ft. STUART shale: 1050 ft. THURMAN sandstone and conglomerates (cherty): 1150 ft. BOGGY FORMATION: shales, sandstones and few limestones: 2250 ft. SAVANNA: sandstones and shales, conglomerates, few impure limestones: 3550 ft.	MARMATON GROUP: limestones and shales: at base: FORT SCOTT LIMESTONE. CHEROKEE GROUP:	Sinking of Ouachita foredeep ceases and area emerges; eastern shoreline of Marmaton sea retreats westward. Ouachita region probably rising; active erosion on Hunton Arch, including Arbuckle Mts. Cherokee sea spreads rapidly to N and NW from Ouachita foredeep, flooding Ozark dome, but leaving much of Hunton Arch emerged. Rate of denudation in Ouachita Mts decreases visibly. Posterior movements of Wichita orogeny, causing foothill folds in Ouachita foredeep; well developed by end of Boggy time.
	The formation increases rapidly in thickness to the east: west of Palo Pinto county line the formation thins abruptly. The maximum total thickness of the Strawn reaches 8000 ft. in Coryell county.	DORNICK HILLS FORMATION: (up to 4000 ft.) bluish, tan, and rarer reddish and brown shales, with limestone ledges, limestone conglomerates and beds of sandstone.	MCALLESTER FORMATION: coalmeasures: sandstones, shales and coalseams; at base: HARTSHORNE sandstone and coal: total 5050 ft. ATOKA FORMATION: shales, sandstones and conglomerates: 6250 ft. at Stonewall.	In Kansas, the Cherokee group is very thin and in most localities it is absent. Some red and variegated shales, with abundant plantremains, indicate, where present, land character of much of this period. Some limestones mark that the featureless and stable plain was about at sealevel and became repeatedly flooded. The formations gradually increase in thickness, and ever lower members appearing under overlapping higher horizons, as we approach the mountain front in the southeast.	Foredeep in front of Ouachita Mts flattens in McAlester time; sea spreads to NW and W, particulary in Wichita region. Sedimentation continues very active. Deepening of foredeep of Ouachita Mts. and retreat of Morrow sea into this sinking trough. Emergence of Hunton Arch and Ozark dome.
	general unconformity				*WICHITA OROGENIC PHASE.*

The Wichita orogeny brings a different type of sediments. Chert conglomerates, which had been conspicuously lacking, become increasingly frequent from the Colorado River in Texas to the Mc Allester district in Oklahoma, and arkosic materials, which were so conspicuous in the Jackfork and Stanley sandstones, decrease in importance, until a new supply of felspathic detritus is created by the mountain chains uplifted by the Arbuckle orogeny. Evidently, the crystalline ridges in the hinterland of the Ouachitas become eliminated as a source of sediment, and a new system of mountains has taken their place; these largely contain red, green and banded cherts. This points to ridges built of rocks like those which were afterwards thrust to the northwest, and now form in part the present Ouachita nappes.

this happened in the McAllester division, earlier in the sequence and then again in the Cherokee formation. It is evident that certain movements in the hinterland, which may have been more general uplift than folding, must have caused oscillations, in the yield of coarsely clastic material over a wide region; mere local phenomena may have been caused by deltas. The regional character of these events is also indicated by the gradual change in mineral constituents after Deese-Millsap time. As we have already mentioned, the lower portion of the Strawn displays a quantity of coarse conglomerates from the Colorado river in Central Texas to the Mc Allester district in Oklahoma. As we ascend in the sequence, cherts increase in the constituents, and felspars diminish in frequency. This, together with the outward shifting of the axes of the foredeeps, suggests that uplift and erosion continued to spread from the more central crystalline region of the hinterland to outer zones, composed of pre-Carboniferous Paleozoics. Presumably, the old central highlands had become leveled by this time, or broke down. Evidently, new chains had been progressively elevated by the second phase of the Wichita orogeny, yielding the new material. The green, red and banded cherts of the upper Strawn conglomerates of the Brazos River could only have been derived from the Ouachita facies. All these clastic elements become finer away from the mountain front: westward in Texas and northward in Oklahoma and Arkansas, indicating without any doubt their origin in the Ouachita mountain chains. In the post-Mingus part of the Mineral Wells divison, equivalent to the Hoxbar of the Ardmore Basin, the clasticity of the sediment decreases, though not so markedly as in the Hoxbar and Kansas City formations of Oklahoma, some coarse pebbly, very slightly arkosic sandstones still occur, but the much reduced thickness and the formation of coal seams suggest more general quiescence.

The comparative development of the Strawn in Texas and the equivalent Marmaton-Cherokee groups of the Pennsylvanian in Oklahoma can best be summarized in the following tabulated synopsis. (*Table IX*).

In Texas, *the Canyon formation* seems to mark a very decided slackening of orogenic activity in the eastern chains. It is largely a limestone series, deposited in clear water, under quiet conditions. At the same time, the western shoreline of the sea again moves farther out. In Oklahoma this absence of clastic materials is also pronounced, but limestones are but little in evidence; muddy waters continue to lay down deposits of shale in the foreland mountains. Farther to the north and northwest, the equivalent Kansas City Group of northern Oklahoma and Kansas also consists largely of limestones, with intercalated shales, and is devoid of sand.

We must also bear in mind that ranges of *the Wichita complex* played a part in the molasse deposits of southern Oklahoma and northern Texas. In the region now occupied by the Ouachita Mountains, these ranges were probably not yet covered by the overthrust Ouachita-facies rocks, which

TABLE X.

DEVELOPMENT OF THE TEXAS AND OKLAHOMA-KANSAS CANYON.

EAST-CENTRAL TEXAS	ARDMORE AND RED RIVER BASINS	SOUTHERN OKLAHOMA NORTH OF ARBUCKLE MOUNTAINS	NORTHERN OKLAHOMA AND KANSAS	
			NE. OKLAHOMA	SE. KANSAS
Limestones and shales, subdivided in: *Caddo Creek fm.* *Brad formation* *Graford formation* *Palo Pinto lm.* In contrast with both the Cisco and the Strawn, the Texas Canyon is a clear water deposit, largely of limestone, except in the northeastern part of the region, in Young, Jack, and Wise counties, where sandstones and even conglomerates begin to indicate the initial phases of the Arbuckle orogeny in the Red River chains. S. Powers describes upper-Canyon unconformably overlapping Strawn in Wichita and Clay counties, (**83**, p. 1061.)	Middle part of HOXBAR FORMATION: *Zuckermann member:* (400—500 ft. above Daube) Conglomerate and Calcareous sandstone. ± 450 ft. of shaly beds. *Daube limestone:* (400—600 ft. above Anarche lm) = top of Graford formation (F. B. PLUMMER) *Coal Seam* (4 ft. max.) ± 500 ft. of Shaly beds. *Anadarche Limestone:* (2200 ft. above base of Hoxbar) dense limestone, with conglomerate at base, pebbles of local source. = Palo Pinto lm (F. B. PLUMMER).	FRANCIS FORMATION: Dark blue and black shales, with beds of sandstone and thin limestones (500 ft. in Pontotoc county).	*Nelly Bly fm.* *Hogshooter lm.* *Coffeyville fm.:* blue to greenish homogeneous shales, with some sandstones in upper part.	KANSAS CITY FORMATION: *Drum lm.* *Cherryvale sh.* *Winterset lm.* *Galesbury sh.* *Bethany Falls lm* *Ladore sh. Herta lm.*
		Absent	*Lenapah lm.*	*Dudley sh.*
		Seminole conglomerate (Strawn ?)		

now override the older Wichita-facies autochtone. Here the molasse of Oklahoma, Arkansas and northeastern Texas should be expected to be a mixture of Wichita and Ouachita detritus. This seems particularly to have been in evidence during the lowermost Strawn, but less during upper Strawn and Canyon time. Precursory movements of the oncoming Arbuckle orogeny reactivated erosion from Wichita elements. During Cisco time, this difference between the east-Texas and the south-Oklahoma—north-Texas Red River province becomes ever more pronounced.

The adjoining *Table X* summarizes the development of the Texas—Oklahoma-Kansas Canyon.

The Cisco comes increasingly under the influence of the Arbuckle orogeny of the Wichita chains in the borderzone between Texas and Oklahoma. A great renewal of erosion and the spreading of new detritus came with this phase. This is greatly in contrast with the immediately preceding Canyon and lower Cisco. The first conglomerates spreading from the new mountains raised by this Arbuckle phase (preserved in the Vamoosa and Ada formations of Oklahoma, north of the Arbuckle Mountains) were not yet generally arkosic. Erosion, evidently, had not yet completely denudated the pre-Cambrian basement. With the Pontotoc and its equivalents, immediately above the Saddle Creek Limestone, arkosic elements come suddenly in evidence everywhere in northern Texas and southern Oklahoma.

The uplifting and beginning erosion of chains in the Wichita complex is indicated already in the Canyon of Young, Jack and Wise counties, in the northeastern part of the Texas area. They continue in Graham time (lowermost Cisco), and become most pronounced in the Thrifty division. Large quantities of sand and conglomerates were washed into a shallow sea over Jack and Young counties. The Wichita ranges also controlled the red color of the upper Cisco and Permian sediments in their surroundings (cf. pp. 30 and 49). Simultaneously with the Arbuckle diastrophism, the Ancestral Rocky Mountains in the west must have been strongly raised at a time, possibly equivalent to the end of the Texas Canyon. They spread their detritus over the west of Oklahoma and northwestern Texas.

The Arbuckle phase movements, consequently, extended from about late-Canyon to middle Cisco time. Their climax can be placed near the end of the Thrifty period in Texas, equivalent to the end of Lansing time in Kansas. Most of the Harpersville (Texas) and Douglas (Kansas) deposition would seem to be posterior to the diastrophism. Probably, the earlier phases affected first the more southern Red River chains, and spread somewhat later to the frontal Criner Hills and Arbuckle ranges. Sedimentation in the Ardmore and Waurika Basins seems to confirm this. We have seen (p. 66) that at Marathon the disturbance during the equivalent upper-Gaptank period, spread progressively northward in a very similar manner.

Following the Arbuckle orogeny, the sea first withdrew a considerable distance from the folded belt. The connection of the Cisco seas of Oklahoma and Texas becomes lost. Later, in the closing stages of the Cisco period, transgression of the Pueblo-Moran-Putnam (Texas) = Pontotoc-Shawnee-Wabaunsee (Kansas) seas reestablishes connection with the Texas province, but the Hunton Arch, Arbuckle Mountains and the Red River chains remain emerged for a time (**38**). Absence of beds of this age in southeastern Oklahoma does not permit to trace any effects of the Arbuckle orogeny in the eastern area controlled by the Ouachita Mountains. The Wichita facies autochtone of these chains should have been affected as much as the exposed ranges farther west.

South of the zone affected by the Arbuckle orogeny, Cisco deposition in Texas continued under the same conditions as in the earlier periods. In McCulloch county, the Cisco includes almost as much limestone as shale, with only occasional minor sandstones. The dividing line between the Pennsylvanian and the Permian (Coleman Junction Limestone) is purely paleontologic, not marked by any change in sedimentation. (It is exactly the same in northern Oklahoma and Kansas.) This absence of any signs of the Arbuckle orogeny and orogenic facies in the Cisco sediments farther south in Texas, is a very strong indication that the buried Ouachita Mountains in eastern Texas were not involved in this disturbance: *they had no Arbuckle phase.*

The upper Pennsylvanian seas spread ever farther westward over the Plateau region of Oklahoma and Kansas, which was largely emerged during early Strawn time. At the same time the eastern shoreline withdrew ever farther from the Ozark and Ouachita regions. The water was gradually drawn westward into the Salt Basin of western Kansas, which begins to sink at this period [1]).

In western Texas, the depression of the Great Salt Basin also begins to develop rapidly at about the same time. The increasing subsidence of the western basin, finally reaching a total of 10.000 feet, buried the Red River ranges and the Amarillo Mountains beneath Permian sediments, to a thickness exceding 5000 feet in the latter area (cf. pp. 79—86, *Tables VII*, and *Plate 7*).

The orogenic history of the Wichita mountain system ceases herewith.

The *higher Permian beds* above the Clear Fork, however, of central Oklahoma, as well as of eastern Texas, indicate a renewed importance of

[1]) The west Kansas salt basin is not to be confused with the Salina Basin. This latter is a pre-Pennsylvanian depression between the Nemaha Ridge and the Barton Arch. About 1600 feet of pre-Pennsylvanian strata, comprising Ordovician limestone to Mississippian inclusive, lie in a broad depression in the pre-Cambrian basement. These old-Paleozoics were unconformably capped by the upper Strawn-time Marmaton formation, which overlaps the edges of the entire pre-Pennsylvanian (truncated by the Wichita orogenic phase). This tectonic feature seems not related to the Permo-Carboniferous chains on the southeastern edge of the Plateau, but an older basin, a minor duplication of the Wichita geosyncline (cf. J. S. BARWICK: A. A. P. G. bull. 1928, pp. 177—199).

the Ouachita province, long after the Wichitas had ceased to be a factor in sedimentation (A. J. FREIE, **25**). The continuous San Angelo-Duncan conglomerate and sand deposits, and the sudden appearance of a redbed facies over the western basin, give evidence of a renewed westward recession of the eastern shorelines, and an accentuation of uplift along the eastern margin of the salt basin. The sediments above the Duncan have the same eastern origin in the adjacent portion of the Permian basin. Although they are very fine grained, they are less so in the eastern outcrops, where they consist repeatedly of sand. The source must be somewhere in the south and southeast. In the western half of the basin the Ancestral Rockies contribute and indicate simultaneous movements with the San Angelo phase (Glorietta sandstone and unconformity in the Guadalupe Mountains). There is no evidence that the Wichita system yielded anything to these higher Permian deposits. In these upper horizons the source may be less a highly elevated area, than a flat shore drained by rivers, which deposited reworked older material. These higher shores, however, must be in some way connected with the Ouachitas, which must have been somewhat lifted at this time.

It is very evident from the foregoing discussion, that the upper-Paleozoic sediments in this entire area are controlled by the Ouachita Mountains. The piedmont basins of Texas, which we have described, have been made very visible by CHENEY on isopach maps for the lower Pennsylvanian (**27**, pp. 566 and 571, figures 2 and 3). The perfect alinement and similarity of these basins in Texas and the Oklahoma-Arkansas Coal Basin clearly point to a common cause, and outline the general trend of the front of the Ouachita chains. These data have been incorporated in our maps, *Plates 1 and 7*.

The here described development of the Texas Pennsylvanian has generally been ascribed to the influence of a mere landmass, a "borderland": *Llanoria*, which should extend to the east and southeast. This seems insufficient. It does not explain these typically orogenic shifting foredeeps and the very rapid deposition of such enormous quantities of clastic material. Instead of mere inert highlands, the writer assumes a great chain of mountains, consisting of an outer zone of old-Paleozoics in Ouachita facies, succeeded farther back by crystalline, metamorphic and granitic rocks of the more central, and presumably older ranges, or incorporated ancient massifs: the same structure as we find in the Variscan chains of Europe. The arkosic development of the latest Mississippian and the gradual replacement of this crystalline detritus by cherty material, as we ascend in the Pennsylvanian, points to this explanation. The outcropping Ouachita Mountains only show the Paleozoic belt, pushed to the northwest. The more central metamorphic-crystalline zone is well exposed in the southern Appalachians of Alabama, and has become known from Solitario. The constant outward migration of the elevated folded zone points to a major orogeny, and not to a mere synclinal trough in front of an inert borderland, that only acted as a vise jaw, and a source of sediment.

The buried mountain front in East-Central-Texas.

The foregoing description of the paleogeography of east-central Texas consistently points to the existence of a great mountain chain to the eastward under the Cretaceous cover of the Gulf Coast Plain. These mountains must be in the same facies as the Ouachita Mountains, and have to be considered as the southern prolongation of the great loop in southeastern Oklahoma and Arkansas, which abruptly plunges under the Cretaceous. We cannot wonder, therefor, that as drilling for petroleum proceeded ever farther to the east, *wells have actually hit the older Paleozoics.*

This happened a short distance west of the belt of the Balcones Faults. Very recently E. H. SELLARDS has assembled these wells in a yet unpublished map (cf. p. 88, and the footnote on page 38). Old rocks, often reported as metamorphics and pre-Cambrian, were struck in a belt paralleling the fault zone to the west, from Fannin and Grayson counties, over Dallas, Ellis, Hill, McLennan, Falls, Bell, Williamson, Travis, Hays, Caldwell, Comal, Kendall, Beaver, and Medina counties, and finally again in Kinney, Val Verde, and Terrell counties, making a complete loop around the Llano-Burnett massif, and connecting the Ouachita Mountains of Oklahoma, with the Marathon Mountains of southwestern Texas. All these wells have hit rocks in pronounced Ouachita facies, wholly distinct from innumerable wells scattered to the west and northwest, which reached old-Paleozoics in the foreland facies of the Texas-Oklahoma Plateau.

In several of these wells the rocks have been identified as representing certain horizons known in the Ouachita and Marathon Mountains. H. D. MISER and M. P. WHITE obtained graptolites from one of the wells in Grayson county, which they identified of a type found in the Stringtown shale, the Womble, and in the Normanskil fauna. The collection at Austin also contains samples from wells in Bell county with graptolites. The rocks in a well in Ellis county (red slickensided shale and grey quartzite), according to MISER, more nearly resembles the Stanley than any other of the Ouachita formations. The wells in the southern counties are mostly reported as having reached the pre-Cambrian. SELLARDS, however, refers to these as altered shales, probably of old-Paleozoic age. The only location, where, in his opinion, pre-Cambrian rocks may have been reached, is in Caldwell county, where two wells struck decidedly shistose rock. This could be expected, because it is the location farthest back from the front zone. The formations encountered under the Cretaceous in southern Val Verde county are still in doubt as to their age [1]).

Whatever may be the detailed structure of the front, it is evident that

[1]) Communications from E. H. SELLARDS.

the Ouachita range has been encountered in the subsurface of east-Texas, closely associated with the Balcones fault zone.

The echelon fractures of the Balcones faults can be traced in a zone from Uvalde county in the southwest, to Bowie county in the northeast, on the Arkansas State line. The strike of this zone seems to follow the general trend of the buried mountains exactly. Wherever the pre-Cretaceous has been reached along this zone, pre-Carboniferous rocks in Ouachita facies have been encountered.

The basin of early-Pennsylvanian deposition sweeps around the southeastern side of the Llano-Burnett uplift. Quite certainly, no Strawn was ever deposited in parts of Concho and McCulloch counties, northwest of the uplift. CHENEY points to the existence of a NW-SE striking arch (again the possibly pre-Cambrian trend, also in evidence in the Llano rocks), extending northwestward from the uplift. He called this *the Concho Divide*. The Llano massif, evidently, is the culminating southeastern end of this arch [1]). Farther to the southeast, the importance of this buttress is shown by the sweep of the Balcones faultzone around it, turning to WSW in Bexar, Medina and Uvalde counties.

The Concho axis and the Llano uplift interrupt the regular development of the foredeep.

The lower-Pennsylvanian foredeeps follow a general arcuate strike, strongly convex, to the northwest around the great northwestern lobe of the Oklahoma Ouachitas. Farther to the south, the strike becomes first concave, around the Llano buttress, and finally turns west and southwest toward the Marathon basin. Here another strong convexity to the north is indicated, as the chains pass to the SW toward Solitario. This seems a very similar loop to the great arc in southeastern Oklahoma.

The east-west foothills folds in eastern Pecos and western Crockett counties, Texas, may be considered as indicating the general strike of the mountain front in this region. Southern Reagan county is still within the Pennsylvanian molasse foredeep, since the structure of the Big Lake oil field contains lower-Pennsylvanian (Bend, and possibly even Tesnus), directly overlying the old-Paleozoics in foreland facies. A lower Permian basin is also indicated here (cf. page 75).

An apparent discrepancy is presented by the Ardmore Basin, which has now the shape of a narrow WNW-ESE trough, crossing the general trend of the Ouachitas at right angles, following the Arbuckle-Wichita strike. This, however, is only apparent. The Ouachita molasse-trough must originally have formed a somewhat wider embayment here, and also played the part of a foredeep along the Wichita front. Here sedimentation was thickest of all: 20.000 feet. This deep hole became strongly compressed in Cisco time by the Arbuckle phase, which shoved the basin into a long and

[1]) The Concho arch had little effect upon sediments accumulating later than earliest Canyon.

narrow, but extremely deep trough, which thereby acquired a NW-SE axis: the Ardmore Basin as we now know it. This was only a posterior deformation of the originally quite regular plan.

The Llano uplift interrupts the Texas foredeep in a very similar manner as the Arbuckle uplift, but instead of being a folded piece of the foreland as the Arbuckles, which were subject to the strong Wichita pressure, the Llano massif behaved more as a passive element.

The uplifting of the Llano massif, later accompanied by some folding [1]), took place before the deposition of the Strawn, during the post-Bend—pre-Strawn epoch. The basal Strawn beds rest on an eroded surface of the Bend. This is the second phase of the Wichita orogeny. Folding continued during the Strawn, as in the foothills folds of the Oklahoma Coal Basin.

At the end of the Strawn, there is evidence of a renewed slight uplift of the massif, so that in the adjacent Colorado River valley the Canyon is locally unconformable on the Strawn. The basal limestones were not deposited, but in their place came conglomerates, washed from a southern direction (**84**, p. 205). This proves that, also in this area, stresses continued, originating from the Ouachita front.

As the foreland basins became ever more depressed under the load of molasse sediment, and their base subsided, the basement strata naturally became flexed along the outer margin of the trough. The upward side remained a low emerged plateau, which was even subject to a moderate amount of denudation at certain periods. This gave these flexures the appearance of uplifts; this is especially marked in *the Bend Arch* of Texas, because of the subsequent westward tilting, when at a later time the Permian basin of the Great Salt Basin developed. This, however, does not seem the only reason why the Bend Arch was formed exactly at this location, (cf. pp. 103—104). In the Oklahoma-Arkansas area we have a similar feature, *the Tahlequah flexure* of CHENEY. This, however, was not similarly emphasized by posterior tilting of its opposite side, which is here occupied by an uplift, the ancient massif of the Ozarks.

SUMMARY OF THE OUACHITA SYSTEM AS A WHOLE.

The great Ouachita range in its wider sense, and its general foreland present the following picture.

It is *a major orogeny*, of which we only know the frontal part, composed of late-Mississippian and early Pottsville flysch, and older Paleozoic rocks. This front can be traced from central Arkansas, through southeastern Oklahoma and central Texas, to southwestern Texas. Presumably, the chains

[1]) This folding was along NE-SW axes. This Carboniferous folding is not to be confused with the ancient, possibly, pre-Cambrian NW-SE trend in the uplifted basement. These Carboniferous folds are best seen in western San Saba and southern Mc Culloch counties. (cf. *Plate* 8).

connect, east of the Arkansas outcrops, with the southern Appalachians of Alabama.

The central, certainly crystalline ranges are almost entirely unknown; they stay back from the front and have everywhere subsided beyond any means of observation. Our only chance to find exposures, indicating their nature and structure, would be in the mountains of Chihuahua in Mexico. Small exposures at Solitario and at Boquillas suggest this zone.

The northernmost loop of the Ouachita front overran the Wichita ranges, which were formed, and practically peneplained before the final paroxysm of overthrusting in the Ouachita front. Certain ridges, however, must have stood out in relief in the autochtone, now overrun by the western Ouachitas of Oklahoma, yielding exotic blocks of Wichita facies rocks in this overthrust.

In south-central Texas, the Ouachita front swings around the foreland buttress of the Llano-Burnett uplift, a massif of pre-Cambrian rocks, showing old, pre-Carboniferous, NW-SE axes, a trend which is maintained in the Concho Divide farther to the northwestward.

From here the Ouachita front resumes a westerly and finally southwesterly direction through the Marathon ranges, Solitario and, presumably, beyond.

The great northern loop is somewhat astounding, particulary as it swings so close to the rigid buttress of the Ozark massif. To the writer, this emphasizes the major importance of the ancient Hunton Arch, as do the uplift of the Arbuckles, and the emergence of the Criner Hills.

It would appear that the folding and sliding masses of the Ouachitas were dammed back by the Hunton obstacle, and only just to the east of it, were able to push past, thereby forming this great northward lobe. The previous upthrust of the considerable competent mass of the Arbuckle massif, which antedated the overthrusting of the Ouachitas, would increase the buttress effect of the Hunton Arch.

The Bend Arch and the Llano Uplift follow more or less the same alinement to the south, and may form a southerly continuation of the same basement feature, or at least of a closely related en echelon duplicate. This positive zone would then cross the complex subsurface uplifts in Wilbarger and Wichita counties, Texas, and the main granite uplift of the Wichita Mountains in Comanche county, Oklahoma, which C. M. BECKER brings in relation to an assumed axis of the Nemaha system farther north in Oklahoma, which would cross the Anadarko Basin in a northeastern direction and extend as far to the north as Township 14 N, Range 9 W, to the northwest of El Reno, Oklahoma. (**13**, p. 41). Anyhow, the relatively great uplift and emergence of the Criner Hills indicates the southern continuation of the Hunton Arch, beyond the Arbuckle Mountains. The shallow depth at which the old rocks are encountered in the subsurface on the Muenster Arch in Cooke county, Texas, (pre-Mississippian at 1450 feet), is an additional suggestion that this positive north-south element continues farther to the south (CHENEY, **28**, Plate VII and our *Plate* 8). CHENEY's map and his east-west cross section (loc. cit. Plate III) through Coleman, Brown, Mills, Hamilton, Coryell and McLennan counties, Texas, shows a second bulge, notably in the older Carboniferous and the Ordovician, paralleling the Bend Arch to the east, more or less in line with the Hunton strike. This axis, though indistinct, through much faulting along SW-NE lines, points more directly to the Llano-Burnett massif than the Bend Arch.

Whatever there may be to all this: one thing is evident: the NNE-SSW subsurface line of overthrusting, which marks the buried front of the Ouachitas in this region, *closely follows the eastern flank of this old axis in the basement, and, a short distance farther east, the Balcones Faults again follow the same trend.*

We have seen that CHENEY wishes to replace the term "Bend flexure" for Bend Arch, since he believes that it was not caused by any uplifting, but merely by westward tilting of originally eastward dipping monoclines, which were developed in Strawn time. The writer admits that this influence of Permian tilting to the westward, towards the depression of the Salt Basin, is a factor, but he holds that, nevertheless, the fact that the hinge was determined to occur at this particular location, and in this strike, was due to the old grain in the basement and a very ancient positive element, similar to, if not identical, with the Hunton Arch. Another important indication for this would appear in the very conspicuous uplift of the Llano massif, along this same feature, where the Concho axis crosses it. This *important massif*, which acted as a sufficiently resistant buttress to deflect the entire course of the Ouachita chains, seems clearly to indicate that a much more important primary cause existed in the structure of the underlying basement. The Llano uplift was not *caused* by the pressure of the Ouachita chains against the Concho Arch, since it was only very slightly deformed along Ouachita trends, totally unlike the manner in which the Arbuckles were affected by the Wichita push on the Hunton Arch. All the Ouachita onslaught may have done to the Llano uplift, is to have accentuated, possibly, the elevation, and to have caused some NNE faulting. In the same manner the pressures to the NNE, which caused the folding of the Wichitas, may also have accentuated the bulging of the Concho Arch along this same strike.

In successive phases, we have seen two great pushes at work in this region in later Paleozoic times, acting at almost right angles to each other; the Wichita pressure to the northeast, and the Ouachita pressure to the northwest. The Marathon-Solitario chains, though still folded in a northeastern strike, show a somewhat intermediate action. Later, particularly in the Permian, and again after the Comanchean (lower Cretaceous), this crossfolding became more clearly expressed in the Glass Mountains, and the NW-SE folds in Winkler, Crane, Upton and western Pecos counties, extending into southeastern New Mexico.

These two strikes, in the opinion of the writer, are the components of a generally northward creep against the comparatively narrow southern end of the old rigid nucleus of the North-American continent. We are here at the southern extremity of this somewhat wedge shaped spur.

The Appalachian chains are the expression of forces pressing against the side of the Plateau from the southeast.

On its now much more indistinct western flank, forces are in evidence which have pressed to the eastward during almost the entire history of the continent, from pre-Cambrian times to this present date. They have thereby so much crushed and involved the western margin of the old nucleus by later deformations, as to have obliterated distinct traces of the old continental border west of the Wasatch Range of Utah. In Utah, and, possibly, as far as Nevada, the unconformable overlap of the Pottsville is still in evidence, indicating the disturbance by the Wichita orogenic phase.

The repeatedly mentioned two major trends in the old grain are in accordance with this general conception. The predominant old north-south asymmetric ridges in the basement have generally a faultscarp on their eastern side, which may well be a thrustfault at depth, indicative of eastward pressure already active in pre-Carboniferous times.

We may here summarize again the effects of the Paleozoic orogenies on the Midcontinent Plateau itself [1]). They run parallel to the much more distinct orogenic phases in the bordering geosynclines, as described in the foregoing pages.

Orogenic phases in the Oklahoma and Kansas Plateau region.

Old-Paleozoic movements.

1. *Pre-Caledonide* unconformable overlap of the upper-Cambrian over basement rocks, and a minor later hiatus below the Simpson formation (middle-Ordovician: Chazyan) over truncated Arbuckle limestone.

2. *Caledonide orogeny?*

   In Oklahoma there exist slight unconformities, overlaps and faunal breaks in the Silurian, and notably between Silurian and Ordovician. In northeastern Kansas, east of the Nemaha ridge, there is a hiatus from the base of the middle-Devonian to the middle-Silurian. All this, however, consists in only very gentle warping.

1) We refer to a recently published synopsis by H. W. Mc Clellan (117. 1930).

LATE-PALEOZOIC MOVEMENTS.

3. *Precursory "Acadian" phase?*

A gentle regional pre-Mississippian upwarping and tilting is in evidence over much of the Midcontinent, in the Ozarks, on the Barton Arch, the Nemaha Mountains, the Hunton Arch, and in the Arbuckle region, followed by peneplaining of the pre-Mississippian, and subsequent unconformable overlap of the Chattanooga.

4. *Wichita phase.*

a. *First sub-phase:* following the deposition of the Mississippian, there are indications of post-Chester warping, very widespread regional uplift and doming of the entire Midcontinent, and simultaneous creation of a late-Mississippian—early-Pottsville trough in the south. On the Plateau, this movement was apparently confined to mere regional arching, and tilting of the entire area to the southeast, towards the flysch geosyncline of the later Ouachitas. (A strong diastrophism of this age raised the central crystalline hinterland of the Ouachita system, to become a source of the enormous Ouachita flysch deposits).

b. *Second sub-phase:* resulting in distinct north-south lines of structure, rejuvenated lines of uplift, caused by faulting in the deep basement; the principal of these structures are the Nemaha Mountains, the Blackwell, Garber, Cushing, Oklahoma City, and numerous smaller anticlines in Oklahoma and Kansas. The Hunton Arch was raised.

Since most of these are outside the area of Morrow deposition, it is impossible to know with certitude whether these movements were exclusively caused by the second Wichita phase [1]). (This

[1]) Results of deep wells in the Blackwell and Garber oil fields of Oklahoma indicate a relatively thin section of Arbuckle limestone on top of the pre-Cambrian granite. This suggests that already in Cambro-Ordovician time these structures stood out as ridges of granite. At Oklahoma City we do not yet know the relative thickness of the Arbucke limestone, on and off structure, since no wells have sofar reached the granite, but, presumably, conditions are similar in this anticline, which is in every other way identical with the other structures in this region. On the Nemaha ridge the entire older-Paleozoics are lacking; it is impossible to prove whether this is due to pre-Cherokee or pre-Chattanooga erosion, or through older Paleozoic emergence. The surrounding region, however, suggests that the ridge existed already in Ordovician, pre-Simpson time, and was again elevated previous to the Mississippian. The major, present expression of the Nemaha ridge, however, was certainly caused by the Wichita orogenic phase.

The Barton-Chautauqua Arch is probably a very ancient feature. A few miles south of Ellsworth, Kansas the basal, probably Cambrian sand of the sedimentary sequence over the granite, is about 1000 feet thick. This must indicate a nearby pre-Canbrian emergence. This was probably the Barton Arch, which was certainly in existence in pre-Arbuckle limestone time. (**117**).

major diastrophism folded the Ouachita flysch into new ranges, to contribute as a source of the molasse deposits; the Wichita system of mountain chains was created at this time, and also contributed to the molasse).

5. *Arbuckle phase.*

There are no known repercussions of the Arbuckle orogeny on the Plateau, outside those in the immediate vicinity of the chains, and which must be considered as foothills-structures. (The entire Wichita system was reelevated and strongly compressed; the Hunton Arch was crumpled and folded into the Arbuckle Mountains; the Ancestral Rocky Mountains were strongly uplifted; the eastern Ouachitas were not affected, but the Marathon region was severely folded and overthrust by the Arbuckle phase).

6. *Permian phase.*

Slight Permian, pre-Triassic warping is in evidence over much of the Plateau, particularly in the region adjoining the Marathon extension of the Ouachita system. Jointing and movement along faultlines, radiating from the Ouachita Mountains, is considered a reflection of the pressure, which caused the final overthrusting of the Ouachita nappes **(73)**.

It seems permitted to consider the major Ouachita system, perhaps together with the Appalachians [1]), as part of the great belt of late-Paleozoic chains, that almost encircles the world; a great southwestern branch. passing along and around the southern end of Laurentia. The Ouachitas in particular would be an arc, pressing against the southeastern side of this wedge shaped nucleus.

The Wichita system is only an intra-continental counter-coup of the Paleozoic northward creep against the southwestern side of the wedge.

The main system of the western component is unknown. It probably lies hidden in the older basement, so much broken and overrun by the repeated phases of the Cordilleran system. It might be expected to assume a more western or northwestern direction. Certain trends in Utah (Uinta Mountains), in Arizona, in the Mohave desert of California, the San Bernardino Spur, and even the configuration of the Pacific bottom off Southern California, may be suggestive for research in this direction.

The Wichita counter-coup only affected a zone of weakness caused by

[1]) The Appalachians, north of the southern development in Alabama, are, possibly, only an intra-continental branch, and not a part of the major Ouachita system. The main ranges might pass out to the eastward into the present Atlantic, to the south of the piedmont massif of Georgia and Carolina (SCHUCHERT's Appalachia). This idea, however, is a mere suggestion, and still so entirely hypothetical, that it is not expressed on the map of our *Plate 1*. It is offered only as a subject for further thought and, possibly, geophysical research.

a pre-existing intra-continental pre-Carboniferous geosyncline, which had escaped compression at the time that elsewhere in the world the pre-Devonian (Caledonide) cycle was active. When the great late-Paleozoic northward push buttet against the southwestern extremity of Laurentia, the Wichita syncline also gave way and was squeezed into folds and block-faulted uplifts. It was then partly overrun, afterwards, by the oncoming thrustsheets of the far more important Ouachitas, in the later phases of the Paleozoic cycle.

Very shortly after their formation, the central zones of the great chain broke down and subsided, as we see it happen almost regularly in all major orogenies all over the earth. Only certain, principally frontal, fragments remained as horsts. The Ouachitas seem to have broken down more than the Appalachian branch, and the latter, also, was more strongly rejuvenated by the Cretaceous-Tertiary Alpine cycle, an event in which, possibly, the younger Atlantic played a part.

The survival of the great mountain front of the Ouachitas in Texas, as an active, though deeply buried element, in much later structural history of the region, is proven by the striking parallelism of the post-Cretaceous Balcones Fault zone, along this same strike, only 10 miles or so to the east. This parallelism is maintained from Arkansas to the Mexican border. That it should be exactly along this line that the Cretaceous-Tertiary Gulf Basin subsided, is extremely suggestive [1]).

[1]) While this treatise was in the press, SIDNEY POWERS drew the writer's attention to a publication of R. RUEDEMANN (New-York State Museum Bulletin 260, 1924), containing very interesting views, rather concordant with such as are expressed here, on the influence of the old grain of pre-Paleozoic America on later structure. Considerable literature relating to this subject is cited by the author.

COMPARISON OF THE OUACHITA SYSTEM WITH THE APPALACHIAN MOUNTAIN CHAIN; CONNECTIONS.

Although outside of the real subject of this study, it is of interest to compare the great Appalachian chain of the eastern States, which the mountains we have discussed before. They are certainly somehow connected under the Mesozoic and Tertiary filling of the Mississippi Embayment.

The Appalachian chain in general.

The physiographic Appalachian range is not identical with the true geologic Appalachians. In their northern portion these mountains do not belong to the North-American Altaids, but in the Maritime Provinces of Canada and in New Foundland, we have a Caledonian chain, in the exact prolongation of the strike of the Appalachians in the eastern United States. The older chain can be traced through the Gulf of St. Lawrence and New Brunswick, and strikes out into the Atlantic through New Foundland. Toward the south it can be traced as far as central eastern Pennsylvania, and dies out near the boundary of Maryland. It is an intensily overthrust chain, containing great nappes, of the Taconian (Caledonian) orogeny, late in the Ordovician. The same area was refolded, along the same strike, by the Acadian (Bretonic) disturbance, late in the Devonian, continuing into the Mississippian. The true Appalachians, however, emerged out of the present Atlantic in central Nova Scotia and the Bay of Fundy. They do not fold New Foundland. Here, and in New Brunswick, the Carboniferous lies undisturbed on the truncated folds of the Acadian chain. In this northern area, only epeirogenic uplift and faulting occurred at the time of the Appalachian revolution. The true Appalachian folding crosses the southern end of the Caledonian-Acadian chains in New England in a wide arc, striking almost E-W in Nova Scotia, and gradually turning to the southwest in the Appalachians of Virginia; the actual crossing of the Caledonian folds continues as far as southeastern New York, where the late-Paleozoic mountain front steps clear of its Caledonian predecessor. In the northern element the greatest intensity of deformation is nearest the Canadian shield, in the southern true Appalachians the close folding and overthrusting are in the east, nearest to the borderland (cf. CH. SCHUCHERT, **119**).

In our further discussion we only treat of the late-Paleozoic, true Appalachian Mountains.

General Stratigraphy.

The Appalachians proper originated in a long geosynclinal trough (1500 miles over its visible extent), which began to develop already in the lower Cambrian, over a previously peneplained older surface. The geosyncline spread and deepened, particularly in upper-Cambrian and Ordovician time. Although the sea, apparently, never reached great depth, the base of the continuously filling trough reached a depression of some 30.000 feet in individual basins.

The Cambro-Ordovician is characterized by a thick siliceous, and generally clastic Cambrium, overlain by an enormous development of calcareous sediments, with prevailing massive, partly dolomitic limestones. These latter exceed a thickness of 5000 feet in some of the sections, which aggregate 11.000 feet. To the east, these sediments show the influence of near highlands and become ever coarser; this source region is known as SCHUCHERT's "Appalachia and Nova Scotia".

During the Silurian, Devonian and Mississippian, sedimentation remained extremely active in the northern section, but became restricted in the south, only aggregating some 2000 to 3000 feet in Alabama.

In the upper-Carboniferous, extensive thick coalmeasures were deposited in a frontal trough of the chain, over the entire length of the Appalachians. Deposition continued in the Permian, culminating in a phase of intense overthrusting of the entire chain.

Farther east, in the more central regions of the complex, the sequence becomes highly metamorphosed and difficult to unravel. In the vicinity of Philadelphia, the still determinable beds have been changed into shists and even gneisses; the limestones become highly crystalline, micaceous, and are traversed by beds of siliceous or micaceous shists. In eastern Tennessee and Carolina, some beds of this metamorphic series have yielded determinable Carboniferous plant remains, as is also the case in Alabama.

What strikes us here particulary, is that along the entire length of the Appalachian front, the geosynclinal sequence is of Wichita-, not Ouachita type: the older Paleozoics are largely limestones, not the cherts and graptolite shales of the Ouachita facies. A great development of late-Mississippian flysch is also absent. South of West-Virginia, thick orogenic deposits in the frontal zone are confined to the Pennsylvanian and lower Permian. The stratigraphy of the metamorphosed zones farther back is not clear. The old Paleozoics become clastic to the eastward.

Orogeny and structure.

The folding, generally, originated some time in the Carboniferous; the climax of the great overthrusting is Permian.

The concluding Appalachian diastrophism, which gave the mountains their present structure, affected the earlier Permain, but not the Triassic Newark sequence. This major phase affected the entire frontal zone. The orogenic deposits of the coalmeasures, however, indicate earlier movements, when uplifting affected zones farther back, and the foreland depression became filled with the sandy and muddy detritus of their erosion (BAILY WILLIS, **108**, 1892).

The structural deformation is caused by an intense push to the west and northwest against the Laurentian plateau foreland. This resulted in long folds, strongly asymmetric and inverted, broken by remarkably long overthrusts, which divide the chain in a number of strangely regular parallel slices, thrust upon each other. The controlling stratum in each major overthrust of the Valley province is mostly the massive Ordovician limestone. In the southern section the overthrusts change in sofar, that they are no longer directly connected with inverted folds. This begins in Tennessee and Georgia. Here the Cambrian is found to rest over large areas, without apparently being disturbed, upon folded and faulted Carboniferous. There are indications that peneplaining erosion had been active on the substratum before the thrusting (BAILEY WILLIS' "erosion thrusts").

A. KEITH described another type of overthrusting in the more eastern metamorphic masses of the Blue Ridge province, in North Carolina, more of the type of the Alpine thrustsheets, without relation to any folds, except such as were induced in strata in the line of displacement (**60**, Roan Mountain Folio; BAILEY WILLIS: Geologic structures, 1929, p. 105).

In Alabama we have a western zone: the Birmingham Valley thrust mass, where the upper-Cambrian is represented by a great thickness (about 2000 feet) of rather fossiliferous, thinbedded, finely crystalline limestones, interbedded with more or less fissile shales (Conasauga Limestone series). This sequence is entirely absent on the next great thrustsheet east of the Helena fault, where the basal member of the massive dolomite series, the lower Ordovician Ketona Dolomite, immediately rests on the lower Cambrian Rome Shales. In the upper members of the Ordovician, the sequence also varies on the two thrustsheets: in the eastern mass some 2000 feet of massive limestones represent the top of the Ordovician, whilst in the Birmingham Valley mass only some 250 feet of argillaceous limestone (Chickamauga) take its place. Thus, in the frontal sheet, all the rocks of Trenton age (except a few feet of basal Trenton), and all the rocks of Cincinnatian age, except locally a few feet of early Lorraine (Eden) age, are absent. On the eastern sheet, on the contrary, the entire Silurian system and all of the Devonian, below the Frog Mountain sandstone, are absent. (In Ohio, New York and Pennsylvania, these beds attain an aggregate thickness of 5000 feet; the thickness, notably that of the Devonian, decreases rapidly toward the southwest).

The Conasauga limestone series also varies considerably in facies from one locality to another, sometimes it is more shaly, elsewhere it develops massive limestones, reaching several hundred feet in thickness (**53**). This also was probably caused by thrusting, bringing side by side rocks which had originally been deposited in more remote regions of the Ordovician sea.

Farther to the east of the here described area, still another thrustsheet appears: a great thickness of often coarsely clastic strata, together with some finer grained sediments, *the Ocoee-Group* of STAFFORD. This feature is important for purposes of comparison with the Ouachita mountain system, where similar more central zones must be expected in the buried area south of the outcrops, and are in fact indicated by the arkosic nature of the foredeep sediments, and small exposures at Solitario and Boquillas.

The Ocoee series is in general much metamorphosed. This increases toward the southeast, where the rocks gradually pass into shists and gneisses, with granite and other igneous intrusions. These rocks have often been considered as pre-Cambrian, but it is not proven whether much Proterozoic is included in them. Limestones and shales occur, very similar to those in portions of the adjacent Valley province. Through the usual absence of fossil evidence, their age is still undetermined, but some Carboniferous plant remains from near Erin, in Clay county, Alabama, prove that even strata as high up as the Carboniferous are locally included in rocks of the Ocoee complex. Very similar conditions seem to develop to the eastward in Pennsylvania.

The Ocoee nappe of the South is thrust from the southeast over strata which consist mostly of Cambrian in the un-metamorphosed Valley-facies. In northeastern Tennessee, however, KEITH (**60**) describes an apparently complete conformable sequence from Ocoee-type rocks into the fossiliferous Cambrian, the Ocoee underlying some 1000 feet of Shady Limestone and 800 feet of Hesse Quartzite (equivalent to the Weisner Quartzite of Alabama). Whether these metamorphics, similar in type to the Ocoee thrustmass, are also *identical*, is another question. Metamorphism and overthrusting make it very difficult to distinguish truly lowermost Cambrian and pre-Cambrian from metamorphosed rocks of higher Paleozoic horizons, including even the Carboniferous. This holds true for much of the Appalachian hinterland.

Stratigraphy.

Devonian. Along the trend of the Appalachians, the Devonian formations exhibit a very marked change. In Maryland their thickness is 7800 to 10.000 feet (orogenic, in conjunction with the older diastrophism), but the series thins toward the south; the lower formations appear only locally or not at all in Georgia and Alabama. *Lower Mississippian Chattanooga shale overlaps unconformably upon older* strata, and is reduced to a thickness of ony a few feet. This is the same unconformity that persists over the entire Midcontinent.

The Mississippian of the Appalachians has a rather changeable facies and development. It overlies the Devonian (where represented) unconformably, and is in turn overlain unconformably by the lower Pennsylvanian. *This latter disturbance is the Wichita orogenic phase, with the same great break, which characterizes this diastrophism over the entire continent.*

We find the same prevalent development of limestone on the foreland, which generally characterizes the Mississippian of the Midcontinent Plateau. Towards the mountains, the limestones change into shales and the entire sequence becomes more arenaceous, the formation thickening at the same time. In northern Tennessee, the Bangor grades into shales, and the Mississippian becomes almost wholly sandstone and shale in Virginia, increasing very greatly in thickness to the eastward, due to increasing landderived detritus. In West Virginia, the ancient embayment of New York and Pennsylvania, there are 5000 feet of orogenic Mississippian: 3000 feet of largely red shales, Mauch Chunk formation, underlain by 2000 feet of sandstones and conglomerates, Pocono (cf. the footnote on page 91). All this indicates a supply of terrigenous detritus from more central zones of the mountains, where highlands related to the Acadian orogenic phase, must have been subject to erosion at this period. The degree to which the facies of the Mississippian changes, varies locally, indicating the formation of different basins, mountains varying in elevation, or local deltas.

The following *Table XI* gives the development of the Mississippian in the southern part of the Appalachians, in the Birmingham Valley of Alabama. *Here we note a very different development, from that farther north.* The fact of major importance is that there appears, above the beds of Chester age, a great mass of very poorly fossiliferous, grey shale and sandstone, devoid of calcareous beds, *a deposit of flysch-type*. In the southern part of the Birmingham and Shades Valleys, the underlying Chester beds, notably the Bangor limestone, also change into grey to black shales, with a few calcareous members, and beds of sandstone. The post-Chester Parkwood formation does not extend far to the west. It is absent along the western side of the Birmingham Valley. The area of the Warrior coalfield, west of Birmingham, was above sealevel during all or past of Parkwood and early Pottsville time; there is a sharp unconformity between the Floyd shale and the Pottsville in that area. Great masses of coarse conglomerate in the Pottsville were derived from old-Paleozoics, elevated in the region to the east and southeast.

In this southern part of the Appalachians, therefor, we have conditions which begin to resemble very closely those which we have described for the Ouachita Mountains; notably, we have this same post-Chester flysch, confined to the zone immediately adjacent to the mountains, which farther on the foreland is represented by a stratigraphic break of increasing importance. The older Mississippian, on the contrary, begins to disappear, and what is left, turns into shales and loses its limestone Plateau facies.

Pennsylvanian. The Pennsylvanian of the Appalachian foreland rests unconformably upon slightly warped Mississippian. The lower Pennsylvanian occupies a typical foredeep trough, largely overrun by the over-

TABLE XI.

DEVELOPMENT OF THE MISSISSIPPIAN IN THE SOUTHERN APPALACHIANS.

CORRELATION	THICKNESS IN FEET	DESCRIPTION
Pottsville	up to 2000 feet	*Pottsville Coalmeasures*
		~~ unconformity: *WICHITA OROGENY*
Post-Chester Mississippian		*Parkwood Formation*: grey shales and sandstones, no calcareous beds(flysch facies); fossils are scarce.
Chester	60—300	*Pennington Shale*: grey, green and red shales, some chert, some sandstones and a few conglomerates; very fossiliferous.
	700	*Bangor Limestone*: thickbedded crystalline limestone: a 100-foot sandstone and shale member in the midst (Hartselle Sandstone member); becomes cherty in lower portion.
Hiatus		———— < *BREAK* > ————
Keokuk	200	*Fort Paine Chert*: thinbedded fossiliferous chert; few feet of *Chattanooga* at base.
Chattanooga		
	Total of ca. 3100 ft.	~~~~~~~~~~ unconformity. ~~~~~~~~~~

thrusting of the mountain front. In the western zones the ever more thinning Pennsylvanian is nearly horizontal; in the next zone to the east open folds occur; the folding increases to sharp overturned folds, broken by thrust-faults in the frontal zone of the mountains. In the east, the coalseams are metamorphosed into anthracites. The foredeep widens and expands outward from the mountain front in the higher horizons of the Pennsylvanian. All this is an exact analogy with conditions in front of the Ouachita Mountains.

The source of the sediments is very evidently in the mountains to the east: the sequence thickens greatly in this direction and becomes more coarsely clastic.

The general sequence is condensed into *Table XII*.

In Alabama the coalmeasure zone expands from a width of 30 miles in the north, to 85 miles in the south, and is represented well back into the mountains. Practically only the lower Pottsville series is present. These measures increase to more than 10000 feet in the easternmost coalfields; at

TABLE XII.

DEVELOPMENT OF THE PENNSYLVANIAN IN THE APPALACHIAN FOREDEEP.

Correlation		Thickness in feet	Description
Permian		up to 1200	*Dunkard Formation:* prevalent *limestones:* coals, alternating with limestones and sandstones (confined to portions of Pennsylvania, West Virginia and Ohio).
Pennsylvanian	Wabaunsee Shawnee	325 or less	*Monongahela Formation:* prevalent *limestones* with very thick coals (Pittsburgh coal). *There is no indication of a late-Pennsylvanian (Arbuckle) orogeny.*
Pennsylvanian	Douglas Lansing Kansas City	700 in Maryland	*Conemaugh Formation:* *sandstones* (conglomerates at base), shales and some few limestones. Red color prevalent. Coals few and thin ("Barren Measures").
Pennsylvanian	Marmaton Boggy McAlester	250—350	*Allegheny Formation:* *shales,* some limestones, coals.
Pennsylvanian	Hartshorne Atoka	reaches over 10000 ft. in Alabama	*Pottsville Formation:* *sandstones* prevalent, with shales and clays, coals, some rare limestones: thickens rapidly toward the east by ever older divisions appearing in this direction, and by increasing supply of coarse terrigenous material.
Wapanucka			~~~ Unconformity ~~~ (*WICHITA OROGENY* or closely equivalent)

the same time conglomerates become frequent. In the Cahaba coalfield the series is developed as follows:

Upper conglomerate division:	475	feet.
Productive division:	2200	,,
Micaceous sandstone division:	1055	,,
Milstone Grit division: conglomerates and sandstones	1800	,,
Total circa	5500	feet.

(cf. J. Squire, **91**, 1890.)

In the still deeper southeastern portion of the coalfield this sequence increases to more than 7500 feet (base not exposed).

Still farther to the east, in the Coosa coalfield, the lower Pottsville section is still more developed; portions measured exceed 5000 feet, with all formations thickening relative to the Cahaba field. The total thickness cannot be accurately determined, but, according to latest views, exceeds 10.000 feet. This great thickening of orogenic molasse clearly indicates that we approach a more important mountain structure toward the south. (G. K. GIBSON: Report on the Coosa Field. Alabama Geol. Survey. 1895).

In Tennessee, Kentucky and Virginia the maximum thickness of the Pottsville does not exceed 5000 feet.

The general character of the southwestern end of the Appalachian chain in Alabama becomes, therefor, increasingly similar to the Ouachita Mountains of southeastern Oklahoma and Arkansas.

The same kind of overthrusting is in evidence in the southern Appalachians, as we find in the Ouachita system. The frontal zones do not contain any highly metamorphic slates, crystalline shists or igneous rocks. In fact no older rocks than Cambrian are exposed over the entire length of the Appalachian frontal zone. These rocks only appear farther back, in the more central region; here the metamorphics may contain anything from the (identified) Carboniferous downward. This suggests that conditions in the more central zones of the Ouachita system may be entirely similar.

A notable difference is that, along the entire long front of the Appalachians, we again find the great development of massive Ordovician limestone of the Arbuckle type. The metamorphic Ocoee group, apparently, should contain Ordovician members, as was well established for the metamorphic zone of eastern Pennsylvania. Limestones and marbles, however, are very little in evidence, but mostly slates, quartzites and massive conglomerates. The thickbedded whitish Murphy Marble (150 to 200 feet) in the extreme southwestern corner of North Carolina, is the only important limestone member mentioned in the literature (KEITH: Geol. Atlas, No. 143, 1907). It would seem, therefor, that farther back in the interior zones of the Appalachian geosyncline, the facies is more like that of the Ouachitas, particularly in the southern section. It remains possible, however, that most of the Ocoee group consists of rocks which are older than the Rome formation (middle Cambrian), which also contains a great thickness of shales and sandstone. The limestone facies of the Ordovician, however, seems the normal facies of the frontal Appalachian chain; the non-metamorphosed, much reduced shaly and cherty facies of the Ouachita Ordovician is at least unproven for the southern Appalachians; all we can say is that it *may* be represented in the metamorphic belt.

It is the opinion of the writer that the Ouachita facies, which evidently originated a considerable distance to the south of its present location in the Ouachita Mountains, was deposited in a region off the southern edge of the North American continent, whilst the Appalachians came from a more intracontinental geosyncline. Whatever we may hold of the origin of the present Atlantic Ocean, whether we consider it as a rift in the crust, or as a subsided region, it certainly was not an ancient ocean as the eastern Pacific. The genetic similitudes between the Permo-Carboniferous sediments of both North-America and Europe, and between the North-American orogenies and the Variscan Altaids, are very conspicuous. Even the crossing of the late-Paleozoic and the Caledonian chains, begun in the British Isles, is completed in New England (**119**, p. 720). We cannot further discuss the problem of the Atlantic here; the writer refers to the literature cited under **93** and **107**. All this suggests that the Appalachian geosyncline may have been more intra-continental, of the general type of the Wichita geosyncline, and that the Ouachita facies of the old-Paleozoics originated off the southern edge of STAUB's "Laurasia". In this case the Wichitas might possibly, be conceived as the disappearing westernmost extremity of the pre-Carboniferous Appalachian geosyncline. The writer, however, prefers the conception that the Appalachian intra-continental geosyncline gradually merges to the southward into the inter-continental Tethys condition, represented by the Ouachita Paleozoics, and that the Wichita geosyncline is a distinct intra-continental zone of weakness, particularly influenced by pressure from the southwest, though farther to the east it might also merge into the Appalachian trough. The Appalachians and the Wichitas would both be intra-continental foreland chains, though not identical (cf. pages 87 and 107).

The orogenic phases are practically identical in the Appalachians and the Ouachita Mountains.

The upper-Pennsylvanian *Arbuckle phase* is very doubtful for both systems, contrary to what we find in the Wichita mountains and the entire West, including the Marathon Mountains. Some disturbance may be indicated by the conglomeratic "Barren Measures" of the Conemaugh division of the Appalachian Pennsylvanian, but it is not proven by known unconformities. We also fail to notice this orogeny in the Ouachita Mountains. *It may well be that the Arbuckle phase is only connected with pressures operating on the southwestern side of Laurentia, and that it is entirely absent or only very weak on the southeastern side of the wedge. In this case, the Arbuckle phase would be related to the Pacific push,* which is so much in evidence on the entire western side of the American continent through all geologic history. It is certainly suggestive that this phase is so extremely important in the entire Wichita system, as well as at the *western* end of the Ouachita complex at Marathon, the Hueco and Guadalupe Mountains and, finally, the Ancestral Rocky Mountains, always indicative of pressures directed to the northeast and east.

THE HINTERLAND OF THE LATE-PALEOZOIC CHAINS IN THE SOUTHERN STATES.

Prevailing American opinion has always considered both the Appalachians and the Ouachitas as mountains that have risen out of intra-continental geosynclines. According to this view, which has been advocated particularly by SCHUCHERT, and followed in nearly all the literature, the hinterlands of these mountains would have been the "borderlands" *Appalachia and Llanoria* [1]). We have seen that this interpretation seems justified for the Appalachians, notably for the northern, Acadian part of this great mountain complex, but it is questionable whether it also holds for the Ouachitas. *Does Llanoria exist at all*, if we view it as an ancient rigid block in the earth's crust, acting first as a source region of the clastic flysch sediments, and then, subsequently, as a vise jaw relative to the Ouachita geosyncline? In the writers opinion, the chains of the Ouachita system have risen out of another, far more important type of geosyncline, a major inter-continental depression of the crust, the kind which SCHUCHERT has described as a "mediterranean" geosyncline. In this case, the masses back of the very wide geosynclinal region would be a far greater crustal block, belonging to another continental unit, and the immediate hinterland of the exposed frontal chains would merely represent the more central metamorphic and crystalline zones of the very complex system of ranges, generated in a geosynclinal area of this nature.

In a major mountain complex of this magnitude, the original geosyncline was never a simple trough, but a complex geosynclinorium. Several distinct troughs are separated by ridges, which themselves are either beginning anticlinoria or even embryonal thrustsheets, or not uncommonly, older massifs, truncated horsts, left from some older orogeny, entirely foreign to the later structure, acting the part of independent, passive subordinate nuclei. Such a mountain complex thereby becomes very wide. The Variscan system of Europe, where a structure of this nature is clearly in evidence, has a present width of approximately 800 miles, and the original geosyncline must have measured, at the very least, 1200 miles across, before it was shoved together (**93**).

The chains of the anticlinoria surround the passive subordinate nuclei, whilst the entire geosynclinal area is being deformed by the complex activity of the controlling continental blocks, forces which may be alternately

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[1]) The name Llanoria was derived from the Llano Uplift, which was originally conceived as an exposed part of the borderland. It has been shown that this massif is no part of the hinterland at all, but of the foreland of Central Texas.

compressive and expansive, as exposed in the theory of R. STAUB (93). While the geosyncline is subject to compression, "ground folding" (*plissement de fond*, as described by E. ARGAND) may be a considerable factor, as distinguished from superficial "cover folding" (*plissement de couverture*). Groundfolding may, in particular, be the initial phase, creating the primary geosyncline with an elevated hinterland. Unlike the coverfolds, the groundfolds move much greater weights, with a far greater expenditure of energy; this is shown by the greater breadth and radius of curvature. The groundfolds, not infrequently, develop into particularly far reaching horizontal displacements of major blocks, also on a larger scale than the superficial cover-overthrusts. ARGAND named these ground thrusts *charriages à sec*: "dry overthrusts". Much of the initial upwarping of the hinterland, back of a nascent major geosyncline, may be structure of this nature. The older a mountain system is, the greater is the chance, that erosion has reached down into levels, where primary ground thrusts have been bared, especially when subsequent gravity compensations have caused regional uplift of the entire structure.

In this manner, bundles of great ranges, often encompassing more inert, comparatively undeformed, older nuclei (*Zwischengebirge*), come into existence in an inter-continental geosyncline of great magnitude, the original extent of which was of oceanic width. When the entire region has been shoved together, various basins of deposition may become superimposed in different nappes, the travelling blocks having transported on their backs differentiated facies of stratigraphical sequences, although in age they may be more or less equivalent.

The primary continental blocks themselves, outside of the geosyncline, are only relatively more rigid. They also are deformed, warped, broken, and shoved, when forces of this magnitude act on the relatively thin crust. Notably near the margin of the continents, accidentally present preexisting zones of relative weakness may be compressed into intra-continental subordinate mountain systems, which, however, are only counter-coups of the major events which occur in the inter-continental expanse.

The Wichita mountain system is a beautiful illustration of a large anticlinorium, squeezed and blockthrust out of an intra-continental geosyncline. The front of the Rocky Mountains has the appearance of the front of an intra-continental ground thrust, which moved at several periods, without ever evolving into a great folded chain, probably through the lack of a sufficiently thick and pliable sedimentary blanket deposited in a preexisting geosynclinal depression.

The pelagic facies of the old-Paleozoics of the Ouachitas, the great compression of these chains, and the intensity of overthrusting, would seem to postulate sufficient importance for the entire system, to justify considering it as the frontal element of an inter-continental mountain complex. Its general location, trend and relationship to what must have been the Paleozoic Tethys in these regions, support this supposition. The Wichitas, on the contrary, were formed out of rocks in the same epeiric facies as prevails over the whole Plateau; the sequence is merely considerably thicker. The old-Paleozoics of the Ouachitas are of a strikingly different type. These cherts and graptolite-bearing siliceous shales, and minor dark limestones, need not necessarily imply abyssal depths, but they are off-shore, oceanic sediments. The true hinterland was originally far removed, and must belong to the continental complex, generally known as the Paleozoic Gondwana block. A very complicated system of anticlinoria, ridges and chains, and probably ancient Zwischengebirge, must now fill the original geosyncline, generated by its late-Paleozoic compression stage. Since then, complete abrasion and renewed sedimentation, and several phases of, possibly, almost equally important later orogenic cycles, have obscured the original structure. A period of expansion has succeeded the original compressive stage, and has created wide sunken basins of Mediterranean magnitude in the Mesozoic era (the Mesozoic Tethys). In the late Cretaceous and the Tertiary, a new compressive movement began, in a part of this new Mesozoic geosyncline. This was related to the Alpine revolution. This stage was again followed by renewed tension and down warping. In America, in addition, the Laramide revolution of the Cordilleran system has crossfolded the western region of the Tethys. The result of these great revolutions of worldwide extension is the complex regional structure of the present Central America. The immediate result in the area which interests us here, is the Gulf Basin and the adjacent coastal plain, extending northward into the Mississippi Embayment. These basin deposits now obscure the entire hinterland and even most of the frontal chains of the Ouachita system in its widest sense.

In this chapter we will summarize and discuss what very little is known about this hinterland, or rather what we may vènture to deduce from the development and structure of the overlying Mesozoic and Tertiary formations. The far better exposed system of the Variscan and Alpine complexes of Europe can well guide the line of our throughts. Here the various stages of evolution, decline, and rejuvenation of a great inter-continental zone are becoming unravelled in considerable detail, though problems and controversies still abound and even multiply. Notably the late-Paleozoic (Variscan) mountains of central and western Europe, contemporaneous, and in many other respects related to the North American mountains, are important for purposes of suggestive comparison. For this reason a short description of the latest conception of the structure and genesis of the European ranges has been added, as an Appendix, to this treatise.

We may, therefor, expect that south of the exposed, or otherwise known frontal chains of the Ouachitas, including the Marathon Mountains and probably the southern Appalachians, a *very wide* hinterland zone exists, consisting of numerous and probably complex ranges, encircling some older massifs. This entire structure has broken down; after peneplaination, it subsided into early Mesozoic or even late-Paleozoic (Permian?) intramontane basins. The whole was covered later by the thick mantle of later Mesozoic near-shore sediments of the Tethys.

The Gulf Coast Basin is already a coastal shelf part of the Mesozoic Tethys. The oldest definitely known strata are lower-Cretaceous. They have a great thickness, though far below orogenic dimensions. The thickness certainly exceeds 4000 feet in northern Louisiana, and possibly more in the more central area. We know that lower-Cretaceous, in a Tethyc facies, is largely developed over most of Mexico. It is mostly composed of flaggy and marly limestones, alternating in places with calcareous shales and some heavy Rudistes-limestones. On the Gulf Coast, the lower-Cretaceous grades laterally into a great thickness of more near-shore, partly lagunal desiccation deposits, and upward into upper-Cretaceous and Tertiary. These sediments thicken toward the south, and on the Gulf coast the entire sequence must exceed 15000 feet.

A very long time intervenes between the late-Carboniferous and the deposition of the lower-Cretaceous. Of what happened in this time interval on the Gulf coast, we know extremely little, if anything.

Those portions of the Gulf of Mexico, which we can know, appear to have originated during the Jurassic in Mexico, during the lower Cretaceous in Texas, and towards the close of the Mesozoic era, at the latest, in the westernmost region. However we do not know anything about the deeper central deposits in the Texas-Louisiana portion, and whether older Mesozoics and even young Paleozoics may be present there, overlying the Carboniferous or older bedrock.

Evidently, the Gulf Coast Plain represents a sunken basin over old central chains, equivalent to such European basins, as occur in France and central Germany, overlying the central zones of the Variscan Altaids.

The writer believes that, shortly after the last, possibly Permian overthrusting of the Ouachita Mountain front, and possibly already antedating this last phase, the bulk of the central chains broke down, a repetition of a phenomenon known from almost every major mountain chain the world over, and of all geological periods.

In the Alpine region considerable portions of the pre-Alpine late Paleozoic system, which forms the autochtone substratum, broke down already in the Permo-Carboniferous. These sediments are known best from the eastern Alps. Many of them were land deposits, but, gradually, through the intermediate stage of the Triassic Buntsandstein, they became involved in a more general marine transgression, spreading northward, perfected with the upper-Triassic Muschelkalk. The same thing occurred in the Variscan area of Central France and Germany: Permian and Buntsandstein basins at first, followed by transgression of the Muschelkalk. Continuous oscillations ocurred, and a repeated formation of landlocked desiccating basins, all through the Permian and the Triassic.

The southern zone, later occupied by the Alpides, finally developed the great Mesozoic inter-continental geosyncline of the Tethys, probably not by mere subsidence, but also by crustal stretching in the sense of ARGAND and R. STAUB: a drifting apart of large crustal masses, possibly of entire continents. After the conception of many European geologists (KOSSMAT, HEIM, STILLE, and many others), there should be a certain relationship between the subsidence of a foredeep and the breaking down of older central chains in a mountain complex, whilst the maximum uplift migrates outward in the direction of the push. It would be the reflection on the surface of deepseated gravity compensations by the movement of basal magmas, after the piling up of the folded lighter material. This explanation must demand subsidence of the hinterland chains, more or less contemporaneously with the elevation of the front zone and the formation of the last outermost foredeep of the cycle.

It seems doubtful whether considerable highlands still existed in the region of the presumed more central chains of America at the time that the frontal overthrusts moved forward. The apparent failing of a coarsely clastic Permian detritus suggests their absence. Of course, we do not know how much of such material may once have been deposited over southern Oklahoma and Arkansas. Land deposits may have existed, but been eroded before the deposition of the Cretaceous. At Marathon, where we can fix the major overthrusting as of late-Cisco age, and the mountains were affected by the Arbuckle orogenic phase, which is absent from the more eastern Ouachitas, this Permian detritus is better preserved in a marine basin, adjoining the frontal range.

We must note that in the frontal zone of the Variscan ranges, we have another equivalent of apparent absence of erosional detritus. Only a few small remnants of the clastic Permian erosional detritus (Rotliegendes) have been preserved in northern France and in the Ruhr coalfields. It is also possible that the central zones had already subsided when the younger frontal chain of the Ouachitas was being eroded, and that most of the detritus went southward, to collect there in intra-montane basins. This appears to have happened in Europe (cf. page 148).

The Mesozoic and Tertiary strata filling the subsided Gulf basin are not undisturbed. This again is similar to what we find in central Europe.

The lower Cretaceous was considerably folded before the deposition of the upper-Cretaceous, both on the Gulf Coast and in the post-Variscan basins of Europe.

The Paleozoic basement of the Gulf Goast Plain is entirely unknown, except in a belt, only two score miles wide, along the southern edge of the Ouachita mountains. No wells have reached Paleozoic or older rocks of the floor farther away from the outcropping frontal zone. Whether two wells in Ashley and Chicot counties, in the southeastern corner of the State of Arkansas, which touched nepheline syenite and peridotite below the upper Cretaceous, reached the pre-Mesozoic basement, is entirely doubtful. These igneous rocks may be Cretaceous (cf. page 88). Quite recently J. Y. SNYDER announced another discovery of a black aphanitic igneous rock at a depth of 4266 feet in a well in Franklin Parish, Louisiana, which might possibly be Paleozoic or older, but by no means necessarily (Bull. Amer. Ass. Petrol. Geologists, 1930, p. 967). This is 32 miles southeast of Monroe. Very possibly this igneous rock is Cretaceous. Other occurrences have been reported.

In Alabama, the southern Appalachians plunge very rapidly down into the depression of the Gulf Coast, which is particularly pronounced in Mississippi. On the Jackson anticline, as far as the writer knows, only early Cretaceous has been reached (directly below the base of the Eocene Midway). The break in the Appalachians is accompanied by great northwest striking downthrow faults, crossing the trend of the mountains at nearly right angles. The Cretaceous and Tertiary folds in this region also have this NW-strike. It would appear, therefor, that the basement were cut into horst-blocks, the outlines of which have no relation to their internal structure. The latter had become solidly cemented before the desintegration of the mountain structure. In the Mesozoic and Tertiary, these individual blocks themselves moved as solid units, regardless of the strike of the Paleozoic strata contained in them. In central Europe, the same condition is beautifully illustrated in the horst-blocks of the old Variscan Mountains. We will discuss further evidence of the same behavior in the basal blocks under the Cretaceous blanket of the Gulf Coast.

Older Mesozoics, only known in Mexico.

We must go all the way to Mexico to get any indications of pre-Cretaceous strata, and here we are already well in the heart of the Tethys.

Jurassic, comprising the entire series from the Purbeck-Portlandian inclusive, down to the Liassic, is known from a series of localities, where certain members are exposed, from the Isthmus of Tehuantepec to Nuevo Leon and Chihuahua; in the latter State upper-Jurassic is very widely distributed. These beds are all marine limestones, with shales and some arenaceous members at the base of the Lias, and in the middle-Jurassic around Tlaxiaco (plantfossils).

Triassic occurs in marine facies in Zacatecas, and possibly in Guanajato: siliceous slates, alternating with shales, sandstones and quartzites, with submarine diabasic tuffs ("roca verde"); fossils point to upper Triassic (Carnian).

Permian marine sandstones, with some lenticular limestones with silicified brachiopods and corals, occur in Coahuila, north of Torreon [1]).

The only facts from which we may attempt to draw any conclusions regarding the nature of the pre-Cretaceous basement of the American Gulf Coast Plain, are the behavior and nature of the Cretaceous and Tertiary.

1) Cf. E. T. DUMBLE (39. 1918). This paper cites all the more prominent earlier publications, notably of E. BÖSE.

In southern Texas and Louisiana, we know nothing older than lower-Cretaceous, but in Florida a well has reached the basement of the hinterland of the southern Appalachians [2]).

Warping in the Gulf Coast Plain.

Several *regional uplifts* are in evidence along the Gulf Coast area, which look very much like reflections of positive elements in the basement. SIDNEY POWERS already in 1926 (**82**, p. 9) expressed the opinion that *the Sabine Uplift* reflects a buried portion of the Wichita mountain system.

Another notable feature of the Gulf Plain are *the numerous salt domes*. They must be connected with some very deep seated saline sediments in pre-Cretaceous horizons, which are nowhere exposed. The extrusion of these salt plugs proves that considerable compressive forces were active in these lower horizons, although folding is conspicuously absent in the more superficial strata.

After lower Cretaceous time, northern Louisiana and southern Arkansas were uplifted and warped, and major structural features were formed; quite possibly, they are rejuvenations of older *elements*, though not of Ouachita *trends*. Drilling in the Gulf Coast Plain has revealed a large structural complex, embracing the oil fields of southern Arkansas and northern Louisiana, including *the Monroe Uplift* in the east, corresponding with *the Sabine Uplift* in the west. Numerous minor folds and faults, chiefly alined NE-SW, cross the region.

Of these structures *the Sabine Uplift* is the predominant feature. Good maps, showing the subsurface contours, are given by SIDNEY POWERS (**82**, p. 5) and R. C. MOORE (Bull. Amer. Ass. Petrol. Geologists, 1926, p. 216) [1]).

The axis of the doming as a whole is NW-SE; minor folding in both upper and lower Cretaceous strikes SW-NE, at right angles to the major axis. The lower formations are far more sharply affected than the upper-Cretaceous, which is separated by a marked unconformity from the lower-Cretaceous.

Domes similar to the Monroe Uplift have been recognised by means of areal geology *in Florida and in Georgia*, in the hinterland of the southern Appalachians [2]).

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[1]) Earlier publications are: SIDNEY POWERS: Bull. Amer. Assoc. Petrol. Geologists: 1920. pp. 117—136;

L. G. HUNTLEY: Bull. Amer. Assoc. Petrol. Geologists: 1923;

W. C. SPOONER: Bull. Amer. Assoc. Petrol. Geologists: 1926.

[2]) That the Cretaceous of Florida is underlain by crystalline metamorphics was proven by the Ocala well, 16 miles WSW of Ocala, and about 3 miles south of York, on *the Ocala Uplift*. The total depth attained was 6180 feet. Eocene and Cretaceous limestones were pierced to a depth of more than 3800 feet. Samples, very unfortunately, were taken only at rare intervals. Somewhere between the depths of 3970 and 4245 feet, the drill

The presence of *Permian, Triassic* or *Jurassic* sediments is entirely possible along the Gulf coast (they are absent in Florida at Ocala), since they are proven in the Mexican region of the Gulf depression, but here we are already in the Tethys. As in the Variscan complex of Europe, intramontane basins may occur, underlying the Gulf Coast Cretaceous, in which such formations may have been deposited from marine transgressions out of the Tethys.

The lower Cretaceous sea invaded all Louisiana and southern Arkansas. A shoreline lay near the western edge of Mississippi, as represented by L. W. STEPHENSON (**66**, 1928). The sediments increase rapidly in thickness toward the southwest.

It is interesting to note that no evidence of the existence of the Sabine Uplift prior to lower Cretaceous time is indicated in the lithology or structure of these formations. Either the doming did not yet exist as such, or it had been completely peneplained before the lower Cretaceous transgression

Deep drilling has now explored the subsurface development of the lower Cretaceous to a depth of 6350 feet below the surface, on the crest of the Pine Island dome, within the Sabine Uplift. The well of the Dixie Oil Company traversed 4100 feet of lower Cretaceous here, without reaching the base.

The section for the Pine Island region can be generalized in the following *Table XIII*.

At Pine Island, a considerable thickness of strata at the top of the lower-Cretaceous has been cut out by erosion, before the deposition of the upper-Cretaceous, when a relief of up to 2000 feet was raised and subsequently peneplained. The missing horizons belong to the Washita and Fredericksburg groups of the lower-Cretaceous, and comprise some 1600 feet of sediments: red shales with ledges of limestone and some sandstones, underlying the Woodbine Sand and resting on the upper Glen Rose.

Similar conditions prevail on the Monroe Uplift: here red shales immediately underlie the Annona Chalk, which is the gas bearing stratum, with the underlying Eagle Ford Clay group entirely missing. In other parts of the uplift, the Eagle Ford, now constituting the second gas horizon, is present. Consequently, at Monroe, there exists a buried hill of these redbeds. The writer is unaware whether it has been established that they are of post-Glen Rose, Washita or Fredericksburg age, and not, possibly, the older redbeds underlying the lower Glen Rose.

The entire Glen Rose, which reaches a thickness of 1850 to 2250 feet in the Sabine area and at Bellevue (L. P. TEAS; **98**, p. 236), dwindles to

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passed into metamorphic rocks: micaceous shists, slates and quartzites (H. GUNTER, **47**. 1928. pp. 1107—1108). This indicates further, that the coastal plain of Florida is far less deeply buried than the Gulf Coast Plain. This basement, however, may quite possibly, have nothing to do with the hinterland of the Ouachitas, but may still be a part of the Piedmont massif of Georgia. These rocks might even belong to the Ouachitas themselves, if these should pass to the eastward into the present Atlantic (cf. page 107).

TABLE XIII. Gulf Coast Cretaceous.

At Pine Island (Sabine Uplift).

	Thickness in feet	Description
Eocene	over 300 (very much more off the Uplift)	*Wilcox Formation*: lignitic sands and clays. (Unconformably overlain by Claiborne Group).
		Unconformity
	500—700	*Midway Shales*: dark clays, with siderite concretions.
		Unconformity
Gulf series Upper-Cretaceous	ca. 100	*Arkadelphia Clay*: dark clay, with some chalk.
	200	*Nacatoch* Sand and sandy limestone.
	260	*Saratoga* chalk and *Marlbrook* marl formations.
	ca. 250	*Annona*: hard white chalk, irregular in thickness.
	225	*Ozan*: grey calcareous shales, with sandy layers at the base.
	100	*Blossom Sand*.
	200—450	*Brownstone Marl* and *Tokio Sands*, equivalents to *Eagle-Ford Clay* of western area, at base: volcanic ash and varicolored arenaceous tuff in layers.
	± 50	*Woodbine sand*.
		major erosional and angular unconformity
Lower-Cretaceous	(Break of 1600—2000 ft.)	Break in strata, represented elsewhere by a considerable thickness (1600—2000 feet) of *redbeds* of *Washita* and *Fredericksburg* age. Effect of peneplaining erosion.
	200	*Upper Glen Rose*: argillaceous limestone, red and brown shales and sandstone layers.
	450—500	*Anhydrite zone*: massive and thinbedded anhydrite, interbedded with dolomitic beds, argillaceous limestone and calcareous shale. (An impoverished marine fauna in some of the limestone layers).
	900—1150	*Lower Glen Rose*: limestone and grey to black shales, some red and brown layers.
	2030	*Red shales* and red and white sandstones (non-marine). [1] (These redbeds are also known from the Bellevue oil-field and from wells in southern Arkansas.)
	425 feet have been penetrated; base and thickness unknown	*Marine marly limestones*: partly sandy, fossiliferous, interbedded with dark grey calcareous shales: fossils definitely still lower-Cretaceous. *Base not reached*. (In the Bellevue field, 330 feet of these same shaly limestones, also fossiliferous, were pierced).

[1]) These lower redbeds may be related to the pre-Trinity beds of northern Mexico.

125—200 feet in the outcrops in Sevier, Howard and Pike counties, Arkansas. The 500 feet of anhydrite zone dwindles to less than 20 feet of gypsum in the outcrops. On the western margin of the coastal plain, anhydrite has recently been found in the Glen Rose in wells in Fannin, Hill, Caldwell, Maverick, and Gillespie counties, Texas[1]).

The upper-Cretaceous was deposited in a sea that transgressed progressively over the peneplained surface of the uplifted and warped lower-Cretaceous, overlapping the older beds from west to east. The lower zones of the upper Cretaceous form either a shore line, or an erosional edge against the Sabine Uplift, and cause the recently discovered prolific oilfields in Rusk and Gregg counties, on the southwestern edge of the doming.

At the close of the upper Cretaceous, there was another warping, but of decidedly less importance than that which affected the lower Cretaceous. The lower-Eocene Midway is still represented on all the anticlinal folds. During the Eocene, however, the Sabine dome continued to rise: successively younger units of the Wilcox formation overlap the Midway. Also the Wilcox thickens in all directions away from the Sabine Uplift. The top of the Wilcox is again characterised by extensive erosion after renewed warping. Outliers of Claiborne age rest unconformably on Wilcox strata on the uplift.

Later movements consisted principally of a rhytmic downwarping of the Gulf Coast Plain, as proved by rapid thickening of all the formations Gulfward, and by successive fracture zones tangential to the Tertiary shoreline. These accentuated the structural relief of the Sabine dome. (C. D. FLETCHER, **40**, p. 189).

Of these fracture zones *the Angelina-Caldwell Flexure* is the most important. It constitutes a 5 to 20 miles wide zone, within which the gently dipping monocline of the lower Tertiary rapidly drops to an approximately 800 feet lower level. This zone is sharpest (narrowest) in the southwest, and widens perceptibly toward the northeast, in LaSalle, Caldwell and Richland parishes, Louisiana, where it seems to lose itself in irregularly undulating structure (Urania oilfield and Richland gas field on local anticlinal doming). In Sabine parish, along the south side of the Sabine Uplift, the dip is sharpest (180 feet to the mile). (cf. C. W. SCHNEIDER, **85**, 1929).

Saltdomes.

The salt domes, in general, occur in two or three groups in the coastal Plain of the Gulf of Mexico. The group of *the interior domes* spreads in two clusters, east and west of the Sabine Uplift, both in Texas and in Louisiana. The western one of these groups lies within the deep depression of the Tyler Basin, west of the uplift, but the eastern cluster, though

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1) E. H. SELLARDS: Bureau of Economic Geology News Letter, October 1930.

situated in the relative depression between the Sabine and Monroe Uplifts, is still within the generally elevated area.

Here columnar cores of salt are squeezed out from some unknown beds at great depth. A large part of the movement of the salt plugs occurred previous to Claiborne (Eocene) time. The oldest formations, sofar encountered when drilling these domes, either in place or in the salt breccia, is still Lower Cretaceous (Glen Rose).

The group of *the coastal domes* is an entirely different assemblage A gap without any known salt domes separates the two groups. Also no domes are known east of the Mississippi River (except on the very east bank), and they furthermore assemble in several distinct clusters along the coast.

A possibly separate group is formed by several salt domes in southwest Texas and in the northeastern corner of Mexico, near Brownsville.

The interior domes occur in an area, where Eocene sediments (Wilcox and Claiborne) constitute the surface. The zone barren of salt domes lies within the belt of outcropping Catahoula formation. The coastal domes all lie in the zone where only late Pliocene and recent deposits form the surface.

A great many salines, not connected with known salt domes, occur over the plain, and a number of previously unknown plugs, which do not reach the surface with visible topographic expression, have been discovered by geophysical methods. Consequently, at present, the map of the coastal plain is dotted over by a very great number of these saltdomes, and new ones are continuously being found [1]). In many, the salt comes close to the surface; these are usually expressed in the topography as decided knolls; in many others, the salt core lies deeply buried; in some, finally, although they are evidently salt domes, no rock salt or caprock has ever been reached by the deepest modern drilling (Goose Creek, for instance). Geophysical work suggests that the top of the salt in some of these deep plugs may be deeper than 7000 feet (D. C. BARTON).

Broader and more gentle structural uplifts, like those on which the Homer, Bellevue and Van oilfields are located, are also suspected by many geologists to be caused by bulges of a deep lying salt deposit, although they embrace many square miles, whilst the proven real salt domes cover only an average of about three square miles each. Salt anticlines, where the salt may lie very deeply buried, are also indicated by geophysical work.

Origin of the Gulf Coast salt.

On the coast, we are as much in the dark regarding the mother rock of the salt as for the interior domes. No well has ever reached any stratum which could be so considered.

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[1]) In 1929 alone, some 30 new prospective very deep saltdomes were discovered by geophysical methods. (Incidentally the writer was the first to introduce seismic exploration in the United States).

The presence of a 500 feet thick anhydritic zone in the Glen Rose, around the Sabine Uplift, and found over most of east-Texas, suggests that, at least the interior salt domes, might originate from salt beds in this horizon. Salt, however, has never been found in any wells within this formation, even in such as were drilled far enough away from any salt dome, through which the salt might have been ejected out of its primary stratum, or become subject to leaching. Many hold the opinion that the salt, at least for the interior salt domes, has its origin in much older rocks than have yet been penetrated by the drill in these areas (FLETCHER, **40**, p. 186). Unhappily, we have no evidence sofar that any determinable blocks of such mother rocks, or even immediately overlying beds, have been brought up by the rising salt plugs.

The oldest rock which has ever been found in any coastal salt dome is upper-Cretaceous (Navarro). This was determined from a breccia on top of a salt plug at South Liberty, Texas [1]).

At Avery Island, Louisiana, a thin mass of brecciated tough red sandstone is included in the salt in the local mine. It forms a streak, extending vertically at least 80 feet, and 75 feet in strike. The rock consists of quartz and a few fresh felspars in silica cement, cemented before it entered the salt. It is evidently a fragment of red sandstone picked up by the salt on its upward course (T. E. VAUGHAN, **104**, 1925, p. 770). Although this rock may be highly similar to red Permian sandstones of West Texas and Kansas, its mere petrographic character should by no means prove its age. Similar rocks occur in the saline facies all over the world, in formations ranging from Cambrian to Tertiary in age. For this particular region, however, the presence of fresh felspars is very suggestive of late-Paleozoic. At Belle Isle a well found several "layers" (?) of limestone and anhydrite and also of "sand" in the salt, at a depth of some 2500—3000 feet, but nobody has described these rocks any further.

Fossil algae were discovered in a core from a depth of 4800 feet, in conjunction with potash salts, in the Markham salt dome in Matagorda county, Texas. JOSEPHINE E. TILDEN identified these as identical with algae occurring in Permian salt at Kanopolis, Kansas (S. POWERS, **82**, p. 10 and E. DE GOLYER, **44**, p. 348). Whether algae, however, can be considered adequate key fossils, is doubtful. This is also the opinion of SCHUCHERT.

Anyhow, apart from the question of these algae, SIDNEY POWERS and many others believe that the plugs of the salt domes originated from strata

[1]) Eocene, formerly the oldest formation known on the coast, was pierced from 1943 to 2012 feet (Yegua = Upper-Claiborne). The well then passed apparently into the caprock of the salt, but encountered the upper-Cretaceous marl at 2057 feet, and found a dolomitic crystalline limestone immedialy after, before passing into the solid anhydrite and rocksalt, reached at 2120 feet. It would seem to the writer, that this Cretaceous, and also the unidentified dolomite, were blocks in a tectonic breccia brought up by the salt plug. Abundant foraminifera proved the Navarro age of the marl. (T. E. MORRISON, **81**, 1929, pp. 1065—1069, and a personal communication from W. E. WRATHER).

of Permian age. SCHUCHERT, however, does not believe that it is possible that marine Permian accurred in the hinterland of the Ouachita Mountains. He considers that the landarea of his assumed Llanoria would prevent this (**86**, p. 872).

The writer does not consider this reasoning justified. The central zones of the Variscan mountains of Europe, a region which seems very similar to what must be assumed for the hinterland of the Ouachita front zone, subsided and broke up in several basins, which became submerged under the upper-Permian Zechstein sea, the subsequent desiccation of which caused extensive saltdeposits. This happened partly over the foreland (North-Germany), partly over the central metamorphic zones, south of the Harz Mountains, intensily folded and overthrust in late-Carboniferous (Pennsylvanian) time. These salt basins lie far back of the frontal mountain chains of Westfalia (cf. p. 121). The occurrence of the Texas and Louisiana saltdomes in distinct clusters, also suggests that they were extruded from separate lenticular salt deposits, which may have been formed in distinct basins, rather than from one continuous sheet of salt, underlying the entire Gulf Coast Plain.

Age of the upthrust in the saltdomes.

The salt plugs of the interior domes began to grow at the end of the lower Cretaceous, at the time of the general folding of these strata. Other distinct movements occurred during the Eocene phase. The Wilcox is considerably tilted by the salt plugs; the Claiborne less, but it is still distinctly lifted by several of the Louisiana domes. This is the same phase which is in evidence by so much overlapping of the Wilcox and Claiborne on the Sabine Uplift. The upward movement was completed in Neogene time by upthrust amounting to more than 3000 feet in several instances (**121**).

The Cretaceous history of the coastal domes is entirely unknown; the only sign of Cretaceous we have, is the already mentioned pice of Navarro marl in the caprock breccia of the South Liberty dome (cf. p. 129). We know these plugs to have intruded the Tertiary sequence after Jackson (upper-Eocene) time. The Jackson and Catahoula pinch out against them, but the Miocene passes over the top of the salt in many domes. Others have continued to ascend until recent time, and pierce even the latest Quaternary sediments, with pronounced effect on the topography.

Stratigraphy and structure of the Gulf Coast Tertiary.

The Tertiary blanket reaches an enormous thickness in the coastal zone. An actual thickness of some 7500 feet has been explored by the drill, as far as information is at the writer's disposal. (At present the strongly competitive geophysical activity of several large petroleum and sulphur companies causes much secrecy and withholding of geologic information along the Gulf Coast). The lowest horizon reached in any coastal saltdome is the Wilcox (lower Eocene); this was in the northernmost dome of the coastal group, the recently discoverd Clay Creek dome, to the north of the Brenham dome. In the coastal section, only upper-Eocene has been reached by drilling. In the latitude of Houston, the top of the Jackson was found at a depth of 5000 to 5500 feet on the flank of the Esperson dome; its depth off this uplift must be at least 6500 feet, and the top of the Wilcox must lie at least at 9000 feet. The results of reported seismic work, and calculations based on torsion balance surveys suggest that the unconsolidated sediments extend down to a depth of at least 15000 feet. Eastward the Miocene and Pliocene are known to thicken greatly, and in the area of the Mississippi delta, below New Orleans, the depth to the base of the Claiborne can only be guessed, and possibly is much greater than 10000 feet[1]).

At the very coast, the Quaternary becomes enormous. At Avery Island a well went down 2600 feet in apparently entirely recent sediments, with buried logs of wood, in no way different from modern kinds (T. E. VAUGHAN, **104**, pp. 771—772). A condensed list of the Tertiary formations of the Gulf Coast is added as *Table XIV*, after C. L. MOODY (**121**).

The dawn of Tertiary time shows a widespread advance of the waters of the Midway sea. A long period of time, however, had elapsed between the termination of Cretaceous deposition and the base of the Eocene. In addition to paleontologic evidence, recent drilling in eastern Louisiana and central Mississippi has furnished evidence of this hiatus. In the Richfield gasfield, in Louisiana, the basal Tertiary lies on an erosional surface of truncated late- and early-Cretaceous strata. In the Jackson anticline, in Mississippi, the Midway rests on early Cretaceous, and in Sharkey county the same formation lies directly on andesite, the age of which is unknown.

During the Midway, the region was remarkably stable, the sinking was uniform, and 600 feet of homogeneous mud were laid down over a wide area. In the Wilcox, on the contrary, a great unrest set in, pronounced folds were formed, both local and regional. The Sabine region was slowly rising. During the succeeding Clayborne time, the shoreline of the Gulf withdrew twice almost to its present limits. Much of the Wilcox sediment is lagunal, or even a land deposit; lignite and carbonaceous clays abound.

It is thinkable that there exists some relationship between this period of Eocene disturbance, the Alpine orogenic cycle, and the Laramide revolution in the Cordilleran region. These movements, however, cannot be regarded as a rejuvenation of the buried Appalachian-Ouachita structure, because the disturbance is of least effect in southern Alabama and in Arkansas, where the deformation consisted only of a gentle downwarping. Evidently, only certain solid blocks, into which the ancient mountains had been dissected, moved as units, without any regard to the preexisting Appalachian of Ouachita trends in their structure.

Eocene deposition closed with the withdrawal of the extensive Jackson

[1]) D. C. BARTON: Amer. Ass. Petrol. Geologists, Bull. 1930, pp. 1385—88).

sea, which had transgressed as widely again as the Midway, and laid down a sediment, which closely resembles the latter in general character. Oligocene deposits (Vicksburg group) are restricted to a contracting gulf. This calcareous stage was suddenly terminated by an influx of coarse terrigenous detritus (Catahoula group), which accumulated landward and in the coastal zone of a rapidly retreating sea. The Texas coastal Miocene is characterized by quantities of remanié Cretaceous foraminifera, absent from the Pliocene, indicating that this clastic Miocene had its source in uplifted Cretaceous. The Gulf of Mexico receded far beyond the present shoreline, erosion remained active, and the Tertiary period closed with the entire region deeply covered with a mantle of Pliocene sand and gravel. Quaternary time has been largely consumed in the removal of this detritus (cf. C. L. MOODY, **121**).

Tertiary warping.

A decided unconformity occurs at the base of the Miocene, and below this the strata are warped in considerable anticlinal folds. Geophysical exploration indicates the presence of numerous anticlines of considerable amplitude and length in the subsurface. These observations have, in part, been confirmed by drilling. Torsion balance work suggests the presence of very deeply buried salt anticlines, which are many miles in length, and in which the salt lies probably at least 9000 feet deep (D. C. BARTON, 1930, loc. cit. p. 1389).

Anticlines near the Rio Grande, in the region of Uvalde, and then again near Corpus Christi, strike NE-SW, parallel to the trend of the Balcones faults north of San Antonio. These folds are evidently genetically related to the faults. The warping seems, at least in part, of very recent nature. Some of the mentioned subsurface folds in the area farther to the east follow the same strike. As we have seen before, the strike of the Balcones faults is obviously similar to that of the buried front of the mountains in East-Texas. This is the only instance, where structure in the Gulf Coast sequence might be considered as following a trend already known in the Paleozoic.

The age of the Balcones faults is difficult to determine, because no formations are present, which fill the stratigraphic gap between the displaced Wilcox group (lower Eocene) and the, not affected, Reynosa formation, which is doubtfully referred to the Pliocene [1]).

Much information, regarding the pre-Miocene folding on the Gulf coast is doubtlessly in the hands of the petroleum companies, who explore the region by advanced geophysical and paleontological methods. For the time being, however, this information is very carefully guarded.

Evidently, the end of the Pliocene indicates a renewed subsidence of the

[1]) A. DEUSSEN: Geology of the Coastal Plain of Texas, west of the Brazos River: U. S. Geological Survey, Professional Paper 126, 1924, pp. 127—128.

TABLE XIV

PROVISIONAL CORRELATION OF TERTIARY FORMATIONS OF EAST TEXAS, LOUISIANA, AND ARKANSAS, WITH MISSISSIPPI AND ALABAMA (AFTER C. L. MOODY. 121)

			EAST TEXAS	LOUISIANA & ARKANSAS	MISSISSIPPI	WESTERN ALABAMA
QUATERNARY	RECENT		Alluvium; marsh and beach deposits	Alluvium; marsh and beach deposits	Alluvium; beach sands	Alluvium, beach sands
	PLEISTOCENE		PORT HUDSON; BEAUMONT CLAY	PORT HUDSON; BEAUMONT; loess	PORT HUDSON; loess	High stream and beach terraces
TERTIARY	PLIOCENE		CITRONELLE	CITRONELLE	CITRONELLE	CITRONELLE
	MIOCENE		FLEMING CATAHOULA SANDSTONE.	FLEMING CATAHOULA SANDSTONE	PASCAGOULA HATTIESBURG- CATAHOULA SANDSTONE	PASCAGOULA HATTIESBURG
	OLIGOCENE [1]		(Overlapped)	VICKSBURG GROUP	VICKSBURG GROUP BYRAM MARL GLENDON LIMESTONE MARIANNA LIMESTONE FOREST HILL - RED BLUFF	VICKSBURG GROUP BYRAM MARL GLENDON LIMESTONE MARIANNA LIMESTONE RED BLUFF CLAY
	EOCENE		JACKSON	JACKSON	JACKSON { YAZOO CLAY MOODY'S BRANCH	JACKSON - OCALA LIMESTONE
		CLAIBORNE	COCKFIELD	COCKFIELD	COCKFIELD	COCKFIELD — GOSPORT
			COOK MOUNTAIN	COOK MOUNTAIN	WAUTUBBEE MARL	LISBON
			SPARTA SAND	SPARTA SAND	KOSCIUSKO SAND	
			MOUNT SELMAN	MT. SELMAN } CANE RIVER	WINONA SAND	
			QUEEN CITY SAND	QUEEN CITY } CANE RIVER	TALLAHATTA	TALLAHATTA
			REKLAW	REKLAW } CANE RIVER		
		WILCOX	WILCOX GROUP (UNDIFFERENTIATED)	WILCOX GROUP (UNDIFFERENTIATED)	GRENADA	HATCHETIGBEE
						BASHI
					HOLLY SPRINGS	TUSCAHOMA
					ACKERMAN	NANAFALIA
		MIDWAY	MIDWAY (UNDIFFERENTIATED)	MIDWAY (UNDIFFERENTIATED)	TIPPAH SANDSTONE	NAHEOLA
					PORTERS CREEK CLAY	SUCARNOCHEE
					CLAYTON	CLAYTON

[1] There is difference of opinion regarding the occurrence of the Oligocene in the western part of the Gulf coastal area. A. DEUSSEN, and many others assign the Catahoula sandstone to the Oligocene, and consider it *to grade eastward* into the Vicksburg limestone facies of Alabama. DEUSSEN only considers the Oakville sandstone as Miocene, unconformably overlying the Catahoula.

Gulf coast, submerging strata, which were until then non-marine. At the present time there is again emergence. The coastal prairie, the zone of a width of 80 miles along the shore, is in extreme physiographic youth. Three to four distinct terraces, bounded by beach ridges, indicate general emergence[1]). The enormous thickness, however, of the Quaternary sediments proves, that these must be minor oscillations, and that, taken as a whole, the bottom of the basin is still continuously sinking.

Even at this present date, the Gulf coast is evidently an unstable region, subject to regional changes of level, and with the plugs in several saltdomes still active.

Cretaceous and Tertiary volcanic activity is much in evidence in the subsurface of the entire Coastal Plain. We know it from north Louisiana and southern Arkansas, from near the close of the upper Cretaceous. A great thickness of tuffs and efflata is particularly in evidence in the Monroe area. In Taylor time ashes are frequent over the entire Gulf region. The Jackson carries ashes over a large portion of southern Texas. This continues in the higher Tertiary all over the coast. An ash bed was described in more detail, from what must have been Miocene, in Calcasieu parish, Louisiana. (M. A. HANNA; **48**, 1926, pp. 93—95).

CONCLUSION.

The poor information, which has here been summarized, is all we have to build on when drawing conclusions concerning the buried hinterland of the great Ouachita chain. The salient points are that the Paleozoic floor is very deeply depressed; that in northeastern Texas, northern Louisiana and southern Arkansas, middle-Cretaceous uplifts and warping, and again folding in the middle-Tertiary along the coast, indicate continuing disturbance, which is still active at the present time. These movements, however, are no rejuvenation of Appalachian or Ouachita structure in the older trend of the Paleozoic mountains, but they must be considered merely as a result of differential displacement of buried block-horsts, in which the old structure had been cut up. Evidently, the old folds had already become so solidly cemented, that an rigid mass had been created, which was no longer subject to rejuvenation, except along the dissecting younger faults. (This is exactly like what is known from most of the Variscan region of Europe). The

[1]) D. C. BARTON has recently pointed to the fact that an uplift of about 20 feet is in evidence all along the coast of Texas and western Louisiana, from Corpus Christi, Texas, as far as Cameron and Calcasieu parishes, Louisiana; it seems to become less clear farther east, unless the curious shape of the outer Mississippi delta indicates its continuation.

BARTON also drew attention to the rather striking physiographic relief of the sea bottom off the coast. Within 50 miles off shore, the normal relief is far more rugged (and associated with coarse sand) than for more than 75 miles inland, where all the sediments consist of extremely fine silt.

(Discussion of A. C. TROWBRIDGE'S papar at New Orleans meeting of Am. Ass. of Petrol. Geologists, March 20; Bulletin 1930, p. 900, and also pp. 1301—1320).

new trend is a different one: a NW-SE strike prevails. Only in the Balcones faults and related anticlines, the Paleozoic trend of East-Texas seems revived. Continuous volcanism in the Tertiary era, and the numerous salt plugs indicate deep seated stresses.

The salt domes also prove the existence of a considerable salt formation, probably in several distinct and separated basins. The salt is almost certainly pre-Cretaceous, not improbably Permian, for the so-called interior salt domes. In the coastal domes, it might be possible that the Glen Rose anhydrite zone had developed salt deposits farther down in the basin, but the salt can just as well be of the same age as that in the interior domes. It would also be possible that Triassic or even Jurassic strata developed salt in landlocked basins.

Since the Gulf of Mexico and the Caribbean, in the writer's opinion, are expansion rifts in the sense of ARGAND, it may not be without interest to draw attention to the great thickness of red and green sandsones and shales (Jiron beds), overlying normal marine upper-Carboniferous in Colombia (16.000 feet in the Bucaramanga district), and the probably identical Todos Santos beds of Guatemala. The age of these strata cannot be determined exactly, but they come in between the upper-Carboniferous and the middle-Cretaceous, and may represent a part or all of the Permian, Triassic and Jurassic, and even lower Cretaceous. The Todos Santos beds contain gypsum near San Mateo Ixtatan, and both gypsum and *rock-salt* near Quetzal (H. DE BÖCKH, G. M. LEES and F. D. S. RICHARDSON, **21**, pp. 163—164). The plugs of *saltdomes* in the neighborhood of Bogota, that penetrate marine Cretaceous beds, must originate in this selfsame formation, which also carries salt in Guatemala. Underlying these saliferous redbeds, Paleozoics in marine facies have been determined, comprising Ordovician graptolite shales, Devonian and Carboniferous. Marine upper Carboniferous has also been described from Chiapas, Mexico: 900 feet of grey to black fossiliferous limestones and dolomites, partly siliceous, underlain by 3000 feet of unidentified unfossiliferous Paleozoic conglomerates.

Of course, these various regions are now very remote from Texas and Louisiana. If, however, with R. STAUB, we consider the intervening sea basins as the result of crustal stretching and drift ("buttonholes" of ARGAND), the distance between the original sedimentary provinces may not have been too excessive to permit comparison of the formations. If the Guyana nucleus is the true major hinterland of the late-Paleozoic folded zone off the southern end of Laurentia, the here discussed deposits still lie to the north of it, and belong to the inter-continental geosyncline.

To sum up, we find very many features in common between the hinterland of the Ouachita chains and the basins over the broken — down and subsided central chains of the Variscan Altaids in France and Germany. We also find continuously repeated folding in the Basin of Paris, overlying the central Paleozoic chains (the type locality for "posthumous folding").

In other respects, notably the deposition of extensive redbeds and saliferous formations, conditions overlying the central Variscan chains of Germany may have been repeated.

Although we have no direct proof whatever, there is nothing to disprove the opinion of the writer, that there is more probability that a complex system of folded and overthrust metamorphic central Paleozoic chains underlies the Gulf Coast Plain, representing the central zones of the Ouachita system, than a rigid old "Llanoria borderland".

SUMMARY OF THE LATE-PALEOZOIC OROGENIES OF SOUTHERN NORTH-AMERICA.

The complete picture of the late-Paleozoic orogenic cycle of the North-American continent may now be summarized as follows:

The northward creep out of the Tethys (or the southward drift of the American continent, whatever it may be), striking the southern wedge-shaped extremity of the ancient resistant Laurentian Plateau, dissolves in *two components*. One branch pushes against the southeastern edge, creating the northwestward pressing, probably intra-continental foreland chain of the Appalachian system. These ranges join in their southern extension the Ouachita system, meant in its wider sense, and extended as far as southwestern Texas, and probably beyond.

The other component pushes against the southwestern edge of the continental plateau, with a pressure directed toward the northeast. The main outer complex of this western component is not known: it is obscured by the age-old pressures, which act on the western edge of the continent, out of the Pacific (this again regardless of the cause, whether the Pacific creates eastward directed pressures, or the North-American continent itself presses westward against the Pacific).

The Ouachita-Marathon-Solitario ranges are still pressed to the northwest; they all belong to the same southeastern component as the Appalachians. The Wichita system, on the contrary, belongs to the southwestern component and presses toward the northeast. The two systems intercross in the Ouachita Mountain region of southeastern Oklahoma and Arkansas. In the subsurface of eastern Texas, the extension of the Ouachita chain is plainly demonstrated, sweeping around the Llano-Burnett uplift toward Marathon, generally pressing to the west and northwest.

Paleo-geography in later-Paleozoic times was greatly influenced by the orogenic phases. Practically the entire Plateau region of the Mid-continent was covered by epeiric seas since the general transgression of the Chattanooga (lowermost-Mississippian) over a perfectly peneplained continent. Only in the Permian this came definitely to an end. There occurred one great intermediate universal period of emergence at the end of the Mississippian; all the others are local and transient. In general, the late-Paleozoic seas, though very widespread, were shallow, and the sediment mostly fine silts, with only subordinate limestones, though these latter more open-sea, at least clear-water deposits became more prevalent at certain horizons. Toward the southwest, however, in Texas and southern New Mexico, the Carboniferous and the Permian become ever more open-marine; limestones with a pelagic, though shallow-water fauna prevail. This general picture is locally modified by the orogenic events.

SUMMARY OF THE OROGENIC PHASES.

I. *Older-Carboniferous* "WICHITA OROGENY".

This cycle comprises *two distinct sub-phases:*

1) *The first pulsation* occurred in the latest-Mississippian (shortly before Parkwood = post-Pitkin time); in this same period the Midcontinent Plateau bulged and became generally emerged.

In the entire Ouachita system, this phase created „*the Ouachita flysch*", derived from active erosion of newly uplifted chains far in the hinterland, exposing crystalline and metamorphic rocks. The flysch was laid down in a practically continuous geosyncline from Alabama and Arkansas to southwestern Texas.

This phase is also indicated by minor disturbance in the southeastern chains of the Wichita system: the Red River ranges.

2) Practically without intervening break, *the second pulsation* arrived in the early-Pennsylvanian, at the end of Morrow time.

This phase created a new system of folded chains over the full length of the Ouachitas, clearly located in front of the older crystalline ranges, and composed of pre-Carboniferous Paleozoic sedimentaries, including the flysch deposited as a result of the first phase.

The erosion of these chains deposited "*the Ouachita molasse*" in a new foredeep, situated considerably in front of the earlier flysch-geosyncline.

This second phase of the Wichita-orogeny was also the major diastrophism which created the chains of the Wichita system.

The Wichita orogeny as such, though it is not possible to determine the actual sub-phase, affected the entire Plateau region, creating innumerable minor structures, many of which appear as a rejuvenation of older-Paleozoic or pre-Cambrian structural features.

A very faint precursory phase, in the early-Mississippian—late-Devonian is doubtfully indicated (*Acadian orogeny*?). There is also local evidence of slight warping by pre-Devonian (Caledonide) diastrophism.

Continuous intermediate movements, becoming especially indicated in later Canyon time, bridge the period before the advent of the second cycle.

II. *Late-Carboniferous* "ARBUCKLE OROGENY" *and succeeding early-Permian phase.*

The Wichita orogeny was followed by a second intense phase in middle-Cisco time, affecting the foreland, the Ancestral Rockies, the Wichita system, and, particularly strongly, the Marathon branch of the Ouachita system, but neither the eastern Ouachitas, nor the Appalachians.

In the southwest, in the Glass Mountains and in the chains of westernmost Texas and New-Mexico (Ancestral Rocky Mountain system) these movements continued over much of the earlier Permian.

The Arbuckle orogeny, therefor, was a phase markedly expressed in the west, and apparently increasing in intensity and duration in that direction.

The erosion detritus of the uplifted chains of the successive phases of these Carboniferous orogenies was deposited in foredeep depressions, bordering the front of the mountains, and gradually moving farther outward, as folding and uplift affected zones successively farther out from the original range.

The Ouachitas, including the Marathon mountains, had a notable effect of this nature in late-Mississippian time; the development continued all through the Pottsville, when the Appalachians also became an source region. The Ouachitas became largely peneplained in the late-Pennsylvanian, before their rejuvenation in the Permian.

The greatest topographic expression of the Wichita system, of the Ancestral Rocky Mountains, and of the Marathon Mountains was achieved by the Arbuckle phase in middle-Cisco time. Posterior uplifts continued during much of the Permian. A great belt of emerged highlands was formed in southern Oklahoma and northern Texas, and also in Colorado, spreading red, largely arkosic material, often heavily conglomeratic, originating from deeply eroded pre-Cambrian formations, bared in the ridges and horsts. This erosion cycle, however, became insignificant shortly after the close of the Pennsylvanian, and was only rejuvenated by certain orogenic phases later in the Permian; the Wichita system had, apparently, ceased to be a source region before the final overthrusting of the Ouachita Mountains.

The older-Pennsylvanian foredeep troughs had been filled and flattened out at the advent of the Permian, and a new broad depression, generally trending north-south in its major axis, gradually formed in western Texas, Oklahoma and Kansas, becoming particularly pronounced in the upper Permian: *the great Permian Basin of the Southwest.* Evidently this depression has a genetic relation with the pressures which created the ancestral and final Cordillera. (Very similar features were repeated in the Mesozoic and the early Tertiary along the eastern front of the Rockies, extending far into Canada).

This broad Permian basin became filled by seas, communicating with the open southwestern ocean, the Tethys, and also through more involved northern channels north of the swell of the Ancestral Rocky Mountains, with the northern Pacific.

The uppermost-Pennsylvanian and lower-Permian sediments are still partly clastic material, derived from the highlands uplifted by the Arbuckle phase in the Wichitas, the Marathon chains and also, farther to the northwest, in the Ancestral Rockies. In the early-Permian, the great Permian Basin itself is filled by silts and finegrained sandstones, grading upward into limestones and dolomites, partly organic reefs.

Already in the Wichita-Albany—Wolfcamp stage of the basal Permian, local desiccation products: dolomites and anhydrite, formed in outlying lagoons along the eastern and northern shoreline. The landlocked saline facies increases gradually: salt formed already in earliest Permian time in Kansas; in Leonard time it crosses the Panhandle barrier into Texas, and great deposits were laid down from Kansas to northern Texas. In this way the great *Permian Salt Basin of the Southwest* was formed, with its enormous deposits of evaporites, reaching a culmination point in the upper-Permian, in southwestern Texas and eastern New Mexico. The limestone facies retreated to southwestern Texas, in the Marathon region and the Sierra Diablo and Hueco Mountains; this is the region of *the inlet channel*, through which the salt sea was provided with a continuous influx of fresh seawater, to replace the water lost by evaporation. This inlet coincided with the Permian foredeep of the Marathon branch of the Ouachita system.

III. *The late-Permian* ("APPALACHIAN"?) OROGENY.

Late in the Permian, in Leonard time, widespread warping is in evidence over Kansas, Oklahoma, Texas, New Mexico and eastern Colorado, particularly expressed by a general unconformity, overlain by more clastic material: the San Angelo-Duncan-Glorietta beds, and by a marked influence on the redbed facies in the Permian Basin. This may be a counter-coup of the far away Appalachian orogeny, and may also coincide with a later phase in *the final overthrusting of the eastern part of the Ouachita mountain system*, which cannot be sharply dated in Oklahoma and Arkansas. (It is certainly late-Cisco in southwestern Texas at Marathon).

A still later Permian movement, high in the upper-Permian, is indicated by unconformable overlap and local clastics: the Bissett conglomerates in the Glass Mountains, and overlap of the Rustler and Quartermaster formations. Unconformities underlying the Whitehorse sandstone, and in the corresponding top of the Big Lime series of southwest Texas, seem slightly older.

All this relatively slight post-Arbuckle warping can only be observed and accurately timed in the Permian Basin, since outside of this depression, the Permian was either never deposited, or had been completely eroded before the transgression of the Cretaceous.

The central chains of the Paleozoic mountains followed the same evolution as all other great orogenies in the world: they broke down and subsided. This had started already in the late-Carboniferous (Cisco). The central zones lie now at the bottom of deep basins, filled with a great thickness of Cretaceous and Tertiary sediment, and not impossibly earlier

Mesozoics, and even Permian: the Gulf Coast Plain and the Rio Grande Embayment.

Posthumous movements are in evidence within these depressions, notably at the end of the lower-Cretaceous ; they continue in the upper-Cretaceous, and all through the Tertiary. In the west-Texas and Oklahoma Permian Basin, Mesozoic or later movements are also indicated in the structures of the oil fields, which affect both the Triassic overlap and the Cretaceous. Along the Gulf coast, these movements are no rejuvenation of the Paleozoic structural trends, but mere relative displacements of buried block-horsts, moving as units which are rigid in themselves. The only instance of apparent rejuvenation is in the Balcones Faults and related structures of East-Texas.

Volcanism is also in evidence in Cretaceous and Tertiary time in the sequence of the Gulf Coast Plain.

APPENDIX.

Comparison of the Structure of the Permo-Carboniferous Mountains of the South-Central States with similar tectonic Features in Europe and notably their Equivalents: the Variscan System.

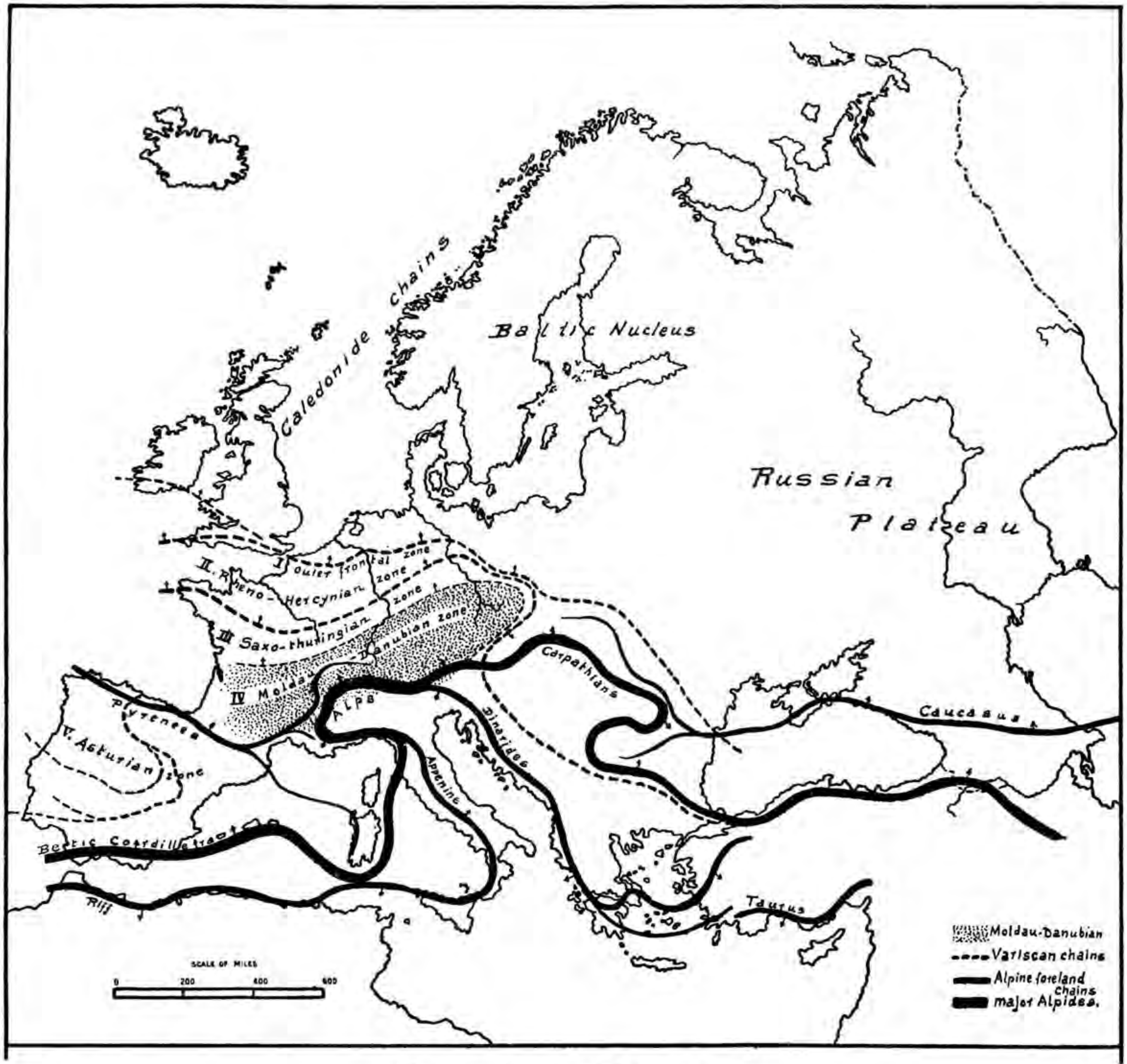
In the foregoing pages we have had repeatedly occasion to compare some other, better known, and analagous mountain systems with those of the south-central States. Prolonged and detailed studies of the mountain chains of various orogenic phases in Europe have shown how very similar the general mechanical principles are on which they are constructed. In many ways the Permo-Carboniferous (Variscan) chains can be compared to Tertiary ranges like the Pyrrenees, the Alps, and the Carpathians. We have already discussed that the Ouachitas and the Appalachians in America are in many ways similar in structure amongst themselves, and also compared to the great frontal zone of the Variscan system of northwestern Europe. The American chains may even be genetically connected in some still obscure manner, with the contemporaneous mountains on the other side of the present Atlantic.

Eduard Suess, in his classic: The Face of the Earth, included the Oklahoma mountains, with the Appalachians, in his worldwide system of "*the Altaids*". This idea was further developed, and in part modernised, by F. E. Suess (**96**). R. Staub (**93**) also discusses the North-American chains in their relationship to the general structural plan of the earth's crust. So do E. B. Bailey, F. B. Taylor, E. Argand, H. Stille, and others. There unmistakingly exist certain connections, involving forces acting on the entire crust of the northern hemisphere. We cannot enter into these problems further within the scope of the present treatise, but the writer wishes to emphasize the importance of a correct conception of the Paleozoic structure of the North-American continent for general geology, and the understanding of the evolution of the earth.

Here only structural and mechanical comparisons will be mentioned, leaving the original causes out of the discussion.

As regards mere form, the wide swung loop of the Ouachitas is very much alike in general outline, and also in dimensions, to similar loops in the Variscan and also the Tertiary mountains of Europe.

The arc of the Ouachita loop, from Atoka county to the Mississippi River, would measure about 300 miles, but extended to central Alabama, to connect there with the southern Appalachians, the arc would span over 500 miles.



Tectonics of Europe.

The loop of the eastern Variscan system of Europa, from the Vosges Mountains to Silezia, measures about 470 miles; the arc of the Alps from the Rhone River to Vienna, spans about 600 miles. The great western loop of the Variscan system, from the Central Plateau of France to its branches in Ireland, has about the same dimensions.

The comparison of these European structures with those in America has offered to the writer many helpful suggestions for the solution of problems which face us there. The fact that a certain suppositive structure is an actual reality in one or more, generally comparable areas, offers a very acceptable check to one's theorizing. It has always to be born in mind, however, when comparing Paleozoic mountain structures with such of a more recent origin, that the first have usually been eroded down very much deeper into their foundations, and consequently show a different picture than younger chains, where more of the upper structure is preserved.

Two major systems crossing each other at a considerable angle, as has been described for the Wichita and Ouachita ranges, is no exceptional occurrence. In America we see the northern Appalachians in New Foundland crossfold the older Caledonian structure. In Europe something very similar happens in England. Crossfolding occurred in several localities, when the arcuate chains of the Alpides were folded and thrust across the pre-existent Variscan structures.

In the eastern Alps, we find not only tolerably well preserved massifs of the older structures, but also the merging of two great, roughly contemporaneous, at least Alpide chains, which in part crossfold and overrun each other. Here we have (probably already since early times) two different elements which intercross: the generally east-west striking Alpides and the northwest-southeast striking Dinarides. Notably A. WINKLER (**110**, 1928 and **112**, 1929) has described and analized this complicated problem in a more recent general synopsis. Here the S $\rightarrow$ N push of the Alps is the paramount feature, possibly already in the Variscan basement, and notably in the Mesozoic-Tertiary structure, whilst the greatly curved Dinaric strike, looped around and pushing toward the Adriatic depression, is the other factor. In the southeastern Alps, this has led to very complicated structure, including great incongruous overthrusts, which emphasize the complexities which arise out of intercrossing trends.

The relationship between the western Alps and the Pyrenees is again a different case of intercrossing trends, which, as the writer believes, can be particularly well compared with the Ouachita-Wichita conjunction. Here also, two orogenies, and this time also roughly contemporaneous, and at least belonging to the same Alpine cycle, meet at a high angle, without, however, exactly running into each other, as the eastern Alps and the Dinarides, but meeting each other more like the American chains. There still is a difference, however, since the American chains intercross far more thoroughly. The picture is rather similar. Here we also have a (Tertiary) chain, the Pyrrenees, originating from a minor intra-continental foreland geosyncline, and a (similarly Tertiary) major system, the Alps, originating from a greater inter-continental geosyncline, the Tethys.

R. STAUB (**93**) has recently summarized and analysed the structural relations between the Pyrrenees (with their presumable minor eastern branches) and the Alps. He considers the Pyrrenees as an intra-continental counter-coup of the terrific pressure of the Alps and their hinterland against the southern edge of Europe. The area intervening between the great Russian plateau and the Iberian-Amorican masses was, apparently, weaker than these two buttresses, regardless of the pre-existent complex of the Variscan system. This latter includes the very resistent unit of the metamorphic Massif of Bohemia, as a lose interjacent individual nucleus. Rigid fragments of the same unit seem preserved in the old horsts of the Schwarzwald, the Vosges and the central Plateau of France. Between these buttresses, the Alpide front surged forward in the enormous loop of the Alps and the Carpathians, very similar in outline to the loop of the Ouachitas in Texas, Oklahoma and Arkansas [1]).

The projecting buttresses west and east of the arc cracked, however. They gave way, where intra-continental geosynclinal zones, superimposed on old structural lines in the pre-Mesozoic basement, had weakened the structure. Thus, in the west, the system of the Pyrrenees originated, and in the east, that of the Caucasus. They both belong to the general orogenic cycle of the Alpides, but they did not move simultaneously, and both began to give way already before the later, most clearly expressed final paroxysm in the Alps. The Pyrrenees show two important phases: middle Cretaceous and late Eocene—lower Oligocene; the Caucasus already an upper Jurassic, and finally a pronounced lower Pliocene phase. The orogeny in the Alps was active from the middle Mesozoic on, with two principal phases, in the middle Cretaceous and in Oligocene-Miocene time.

The similitude of this general structural picture with the Wichita-Ouachita plan in America, is obvious, regardless of the fact that the just described European aggregate belongs to the mainly Tertiary, and the American one to the late-Paleozoic revolution. Even details are comparable: we may venture to view the Ozark Dome as a replica of the part played by the Massif of Bohemia, and the rigid Hunton Arch as an equivalent of the eastern edge of the nucleus of the Plateau Central of France. The Pyrrenees die out in the west against the older folds of the Iberian Meseta, which cross

[1]) The writer remarks again that he only discusses the mechanics of the individual structures and not the ultimate causes of the creep. When he speaks of S → N pushes and pressures, he unterstands them *relatively*, and does not discuss whether, in ad absolute sense, the northern continental masses drifted and pressed toward the south, as accepted by F. B. TAYLOR, or whether the southern Gondwana massifs drifted and pressed to the north in the sense of E. ARGAND and R. STAUB. Here we only note that a S → N *effect* is in evidence, regardless of the primary cause.

their path almost at right angles, as do the blockmasses of the Ancestral Rockies west of the Wichitas. Farther to the south, the Alpide chains trend north-south, along the eastern side of the masses of Corsica and Sardinia, to resume a due westward course in the Baleares and the Betic Cordillera of southern Spain, almost exactly as the writer presumes for the western continuation of the Ouachitas into the Marathon region of southeastern Texas, after they swung around the buttress of the Llano Uplift [1]).

Although, naturally, the American structure varies in a great many details, the general picture offers such striking mechanical analogies, that the writer feels that, whether right or wrong, his general conception of the Wichita-Ouachita complex is neither impossible nor improbable.

The writer is fully aware of the controversies, which still rage regarding the views of STAUB, which have largely been followed in this construction. He may not agree himself with all of STAUB's theories concerning the structure of the Alps. However, he believes that the principles here referred to are sufficiently correct in their general effects, to permit their use for purposes of comparison.

The entire problem of the Alpides is far from solved; we are only beginning to realize the full extent of its complexity.

The Variscan structure in Europe.

A concise synopsis of modern views regarding the Variscan mountain system of the European continent has recently been published in the english language by F. E. SUESS, in the symposium "The Structure of Asia", edited by J. W. GREGORY (**96**, London 1929). The writer follows it closely in the following paragraphs. In addition, we may mention the standard publication of F. KOSSMAT (**66**, 1927), and another short summary by W. VON SEYDLITZ (**89**, 1929). Both the last mentioned papers contain a practically complete more recent bibliography on the subject.

It would take too long to discuss these mountains in any detail, but we may mention a few salient points, of particular importance to demonstrate the great analogy with the Permo-Carboniferous chains of the North American continent. Special reference should be made to the map in the cited paper by KOSSMAT, schematically followed in our *Plate* 9.

Like in America, the late-Paleozoic chains of Europe are now largely broken down; they have subsided, and only several fragmentary horstblocks indicate the course of the buried mountains at the present surface. The boundaries of these horsts cut across the lines of the old plan and are autonomous in direction. The old Paleozoic trend seems completely solidified.

The modern picture, as presented by the authors quoted, may be summarized in the following paragraphs:

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[1]) See R. STAUB: **93**, 1928, and F. BEYSCHLAG, W. SCHRIEL and H. STILLE: **17**, 1925. See also our *Plate* 9.

1. *The Frontal zone*, pressed against the foreland, comparable to the flysch and molasse zone of the Alps. To this belt belong the Variscan ranges of southern Ireland, Wales and southeastern England, the coalfields of northern France, the Ardennes, the Eifel, the front of the Rhenish Schiefergebirge, the northern Harz and adjacent ridges. The foreland is characterized in the west by the old rigid Caledonide mass of the Brabant Massif, extending from the Meuse River into England. **(105)**

This frontal zone is a truly folded orogeny, with very conspicuous thrust-sheets, consisting of a Variscan "flysch", made up of lower-Carboniferous (Culm) and older sedimentaries, pushed over and against a depressed foreland, which was, afterwards, covered by a great thickness of "molasse": the coalmeasures of southern England, France, Belgium, Holland and Westfalia. Batholithic intrusions do not occur in this zone.

The Culm-facies: marine arkosic sandstones, graywackes and shales, is replaced away from the mountains, by the Carboniferous limestone facies of the foreland. This fact, clearly established in Europe, is identical with what we described for America. In Belgium and northern France, the Culm-facies is not visible: the limestone facies lies directly in front of the overthrust mountains and is even involved in their outer zone. The overthrusting has been intensified here by the buttress of the Caledonide Brabant Massif. To the east of this buttress, in Westfalia, where overthrusting is less intense, the Culm facies is widely exposed, in the foothill zone as well as in the mountain front. **(105)**

2) The next zone to the south, *the "Rheno-Hercynian Belt"*, has already been lifted from greater depths, and begins to show metamorphism. Far reaching overthrusts occur here, but being less conspicuous in these metamorphosed rocks, it took much longer before they were recognized.

To this second zone belong the early-Paleozoic sediments of the southern belt of the Rhenish Schiefergebirge and the Taunus Mountains, and the main mass of the Harz Mountain horst. Here a few restricted batholiths already make their appearance, particularly in the Harz.

3) A third "*Saxothuringian Zone*" has been pushed northward against the second belt. Originally these rocks had been depressed to still greater depth. This zone is characterized by the predominance of crystalline rocks and much more batholithic intrusion. There is overwhelming evidence that this already higly metamorphic zone consists of a system of great overthrust sheets, piled up and driven northward. The core and foundation is formed by the gneiss arches of the Saxon Erzgebirge: a system of flat overthrusts, covering the altered cores of granite, to a certain extent comparable to the Pennine gneiss arches of the Simplon region in the Alps.

4) A fourth "*Moldanubian Zone*" occupies the whole of the Massif of Bohemia to beyond the Danube River, and also reappears in the Schwarzwald and the Vosges. The main portion of the Central Plateau of France also belongs to it.

These masses must have been elevated from still greater depths. Granites now attain an enormous extension. These intrusions are surrounded by crystalline rocks, the result of katametamorphism (in the sense of BECKE: through high temperature rather than by pressure) of, possibly, old Paleozoic and pre-Cambrian sedimentaries. This resistent Moldanubian block has been pushed forward as a rigid unit against the series of blanketing slices, which make up the Erzgebirge. All these masses must have been moved forward over very considerable distances. This great, now generally eroded nappe has left "klippen"-remnants far to the north: the gneisses of Münchberg in the Fichtelgebirge; even small outliers of crystalline shists in the Spessart and the northern Odenwald, near Darmstadt, are considered as belonging to this thrust. The Saxon Granulitgebirge, south of Dresden, is also considered by some as an outlier of this sheet; with more certitude this can be assumed for the Eulengebirge of Silesia. These outlying klippen demonstrate an original extent of this nappe of at least 150 kilometers in front of its present continuous exposure. It has been compared to the Austride nappes of the Alps (after the conception of the Swiss geologists). That the present Moldanubian complex, or at least much of it, is not autochtone, but itself also a floating nappe, is suggested by the fact that on the eastern side of the arc, it appears to override an entirely different system: the Moravo-Silesian range, a truly folded and overthrust chain of Alpine type, not only thoroughly discrepant in structure and exotic as to its sediments, but even belonging to a different magmatic province.

This southern intrusive zone continues a long distance to the south, and is finally overrun by the frontal folds of the Alps. To it belong the entire southern portion of the French Plateau Central, as well as the great autochtonous massifs in the western Alps, from the St. Gothard, the Aar massif and the Montblanc, as far as the Mercantour.

This region seems to merge into a general hinterland, elevated from great depths and so thoroughly changed by repeated metamorphism, that any general strike is lost. The katametamorphic recrystallisation of the shists has caused the now apparent strike of the rocks to conform more to the outlines of the greater granite batholiths, than to any anterior directions which may have existed. Most of the older structure and the sedimentary facies have been obliterated and replaced by a later rearrangement.

Conditions of this nature must be fairly general in the earth's crust at medium depth. They are now exposed on the surface in many other regions, where deep zones have become exposed through regional doming. *These rocks are not necessarily Archean, whereever they form part of an extensive orogeny.* Their metamorphism dates chiefly from the orogenic phase of the structure, and any of the older Paleozoic sediments (or even Mesozoic for the Alpides) may be incorporated in these shists. This same condition is suggested for part of the eastern, highly metamorphosed sequence of the southern Piedmont hinterland of the Appalachians, which seems to have many points in common with the more central Variscan zones of Europe.

The Massif of Bohemia, as well as the Central Plateau acted as rigid units, resistent to true folding, but nevertheless they were pushed forward. The earlier sliding movements were obliterated by the metamorphism, but movements of later phases were preserved in the form of thrustplanes, mostly accompanied by zones of foliation and mylonites, as the great overthrusts near St. Etienne in the Plateau Central, and the flat thrust, with a broad mylonite zone, in both the southern Schwarzwald and the Vosges. These thrusts themselves are traversed by the latest granite intrusions. These latter were contemporaneous with the latest phases of the diastrophism.

All this is very difficult to unravel with any certitude: it will long remain a subject of controversy to distinguish between older orogenies and movements belonging to the Variscan cycle. This is also the case for the Alpide complex of the Eastern Alps.

5) KOSSMAT distinguishes still a fifth zone: the "*Paleodinaric Belt*", south of the central Moldanubian Zone, in the Carnian Alps, the ancestral pre-Alpide basement of the Pyrrenees, and in Asturia. This is the southern sedimentary flank of the central chains of the Variscan system, nearer to the southern shoreline of the Paleozic Tethys. It again contains paralic, as well as marine Carboniferous and Permian.

In the Alps, this zone is much obscured by the Tertiary orogeny, and its interpretation in the Eastern Alps is still much in dispute (**112**), but the good sections in Spain, also of a Dinaric type, seem very representative.

Posterior subsidence.

Already in the uppermost Carboniferous and basal Permian, parts of the more central zones began to break down in wide depressions; intramontane basins were filled with upper-Carboniferous and Dyassic coal-measures, and other lower Permian sediment. They are characterized by effusives of porphyry. The coarse erosional detritus of the higher ranges forms the Dyassic "Rotliegende", which, however, has in turn been largely reduced by post-Permian erosion, and, therefor, seems so much less significant than the equivalent enormous molasse deposits of the younger Alps. It has been pointed out that the same applies, probably, to the Permian erosion detritus, which must once have been deposited after the great final overthrusting of the American Ouachita system. It is significant, how extremely little of this Dyassic material is left in the outer Variscan zone of northern France and of Westfalia: only a few very small patches, preserved in downfaulted depressions. The larger remaining deposits are all confined to basins within the interior zones, which were already breaking down, whilst the frontal belt was still rising. In Europe, where these central areas are accessible to observation, we know that the sea broke in, and deposited the saliferous upper-Permian Zechstein, and later Triassic (also with local saltbeds in the Röt), Jurassic and Cretaceous, and finally Tertiary. In the south-central States of North America, we described exactly the same development for the Cretaceous and the Tertiary, and we suspect the presence of Permian or Triassic, as a source of the salt plugs of the Gulf Coast. We even have middle-Cretaceous and Tertiary folding of these sediments, strangely synchronous with the posthumous phases affecting the European basins and, apparently influenced by buried horst-blocks of the Paleozoic structure.

The enormous width of the orogenic zone and the extent of compression demonstrated by the overthrusts, indicate that the late-Paleozoic diastrophism of Europe (and in fact of all Eurasia) was certainly of no less importance than the Alpine revolution, rather still more so. If the present Alpine chains were abraded to some 5000 to 10.000 feet lower levels, they would surely present a very analogous picture. In many respects the chains are entirely similar. This applies especially to the Carpathians, as was already mentioned by KOSSMAT.

Time of the Variscan orogenic phases.

In regard to the time of the Variscan diastrophism, we have another analogy with the Alps, and also with the American late-Paleozoic chains. In each case, the orogenic process, though pulsating, has continued for a very long period and has still been outlived by the period of magmatic intrusions. In each case, the rising mountains have been, intermediately, submerged under extensive transgressions, which divide the folding process into two major phases, with intervening minor movements.

In the Variscan mountains, the earlier phase is the widespread unconformity of the lower Carboniferous, the Dinantian-Culm overlapping the various deeply eroded older elements. In the Alps, we have, as an earlier phase, the unconformity preceding the deposition of the upper-Cretaceous Gosau beds. In both cases there is a migrating foredeep, moving ever northward in front of the thrustmasses, and filling with detrital sediments from chains back of it, to become finally folded and overridden itself by the later orogenic events. The older phases are the most prominent in the more central zones, the frontal ranges are only affected by the final climax, that ends the mountain building cycle, immediately precursory, if not even contemporaneous, with the breaking down and subsidence of the entire structure, notably in the interior zones.

The analogy with what we described in detail for the Ouachita mountain system, as well as the Appalachians of America, is obvious, and very suggestive.

H. STILLE (**95**, 1925) has analysed and correlated the orogenic phases of geologic history all over the world. Even if his picture may appear somewhat far fetched for a multitude of minor phases, the synchronism of not only the major cycles, but also of the culminating phases, is remarkable.

STILLE defines the culminating phases of the Variscan orogeny as follows (the ones in bolder type are the most important):

BRETONIC PHASE: between upper-Devonian and lower-Carboniferous;
SUDETIC PHASE: between the lower-Carboniferous and the lower upper-Carboniferous;
ASTURIC PHASE: in the uppermost portion of the upper-Carboniferous;
SAALIC PHASE: in the lowest Permian (Dyas);
PFALZ PHASE: in the higher Permian, between Dyas and Zechstein.

The oldest, Bretonic, phase is particularly important in several of the more central structures. The outer Westfalian zone is specially affected by the Asturic phase only. The foredeep was finally overrun by this folding; it shows no unconformities of an earlier date within the more than 12.000—15.000 feet of lower- and upper Carboniferous strata, which fill this trough. In Belgium and France, the Caledonide Massif of Brabant bulges as a regional uplift in front of this foredeep. The Coal Basin has been squeezed into a narrow, deep and much broken trough between this massif and the masses overthrust from the south. These conditions continue in England and Wales. East of the Brabant Massif, in the Rhineland and in Westfalia, the front is open, causing the coalmeasure belt of the Ruhr to widen, and the whole range to sweep farther to the north in a broad swung arc. The analogy with the Wichita-Arbuckle mountains and the Ardmore Basin is again very obvious.

Some of the striking analogies between the Variscan orogeny of Europe and that of the American chains are summarized in the following *Table XV*.

Finally, it is not without interest to note how in the hinterland, that is to say over the central chains of the Ouachita Mountains, the thick Mesozoic and Tertiary blanket has again become affected by *later folding*, exactly as in Europe. There, the Alps have largely an autochtone that was already a part of the Variscan system, before it became the site of the Mesozoic Tethys, after the Paleozoic chains broke down. Out of this new inter-continental geosyncline, the Alps rose.

In Europe, the Alpine compression, evidently, was far greater than in America. The great northern arc of the Alps and Carpathians encroaches far upon the Variscan structure. In America the Alpide chains remain altogether south of the Gulf of Mexico, in Chiapas, Guatemala and Honduras, and spread in great virgations through the West Indies. The development of the Cretaceous-Tertiary Tethys, however extended far more to the north. This facies is in evidence all over Mexico, and begins to show already in New Mexico, Texas and Louisiana. The Gulf Coast and Rio Grande depressions belong already to the shelf area of the Tethys.

The major phases of the Alpine chains of Europe fall in the middle Cretaceous and in the middle Tertiary. In Central America the principal phase seems to occur between Eocene and Oligocene, succeeded by less important later Tertiary movement. (This does not exclude a possibly still unknown Mesozoic phase).

TABLE XV.

SUMMARY OF THE ANALOGIES BETWEEN THE LATE-PALEOZOIC OROGENIC SYSTEM OF NORTH-AMERICA AND THE VARISCAN ALTAIDS OF EUROPE.

PERMO-CARBONIFEROUS CHAINS OF THE SOUTH-CENTRAL STATES AND THE RELATED APPALACHIANS	VARISCAN ALTAIDS OF EUROPE
ACADIAN PHASE : *Pre-Mississippian.* Most pronounced in northern *New-England, New-Brunswick, New-Foundland* ; extends southward into the hinterland of the Appalachians of Pennsylvania. Insignificant, if at all represented, in other areas subject to observation. *In the foreland,* lower-Mississippian rests unconformably on Devonian or older strata in the entire Mid-Continent : this *Chattanooga unconformity* is largely a wide-spread quiet transgression, without indications of orogeny. In the Ozarks, and on the Hunton Arch, disconformities exist in the early-Mississippian, as well as at the base of the Woodford (Chattanooga). In the Llano-Burnett region, Mississippian (Barnett) unconformably overlies the Ellenburger (Ordovician). No indications of movements are known in the Ouachita or Wichita systems.	BRETONIC PHASE. *between upper-Devonian and lower-Carboniferous (Culm).* Generally not important. Mostly in evidence in more central zones. Most pronounced in Brittany. Indicated in the Rheinische Schiefergebirge, in the Unter-Harz, in the Sudeten ; problematic in Saxony and in the Vosges.
WICHITA OROGENY : *middle-Carboniferous.* 1. FIRST PHASE : *at the end of the Mississippian (post-Chester).* Not directly visible in the exposed portion of *the Ouachita system,* but must be strongly represented *in the hinterland.* Chains of this phase account for the enormous upper-Mississippian orogenic *flysch of the Ouachita Mountains* (Jackfork-Stanley), becoming increasingly clastic toward the south, and originating from crystalline and metamorphic mountains. The flysch is unconformable on Devonian (or possibly lower-Mississippian). Entirely similar flysch in the *Marathon Mountains* (Tesnus-Dimple), unconformable on Caballos Novaculite (Devonian). Indicated for *the hinterland of the southern Appalachians,* by similair, though less pronounced phenomena in Alabama (Parkwood-flysch). Indicated for the *Wichita system,* by unconformity underlying the Bend on the Red the River Arch, and possibly by the absence of all Mississippian, Devonian and Silurian on the flanks of the Wichita Mountains	SUDETIC PHASE : (undifferentiated). *between lower-Carboniferous and lowermost-upper-Carboniferous.* Principal Variscan phase in *central zones of Germany,* but absent in the frontal zone, from Wales to Westfalia ; also absent from the coalmeasure belt in the foredeep, but indicated as source of the great orogenic deposit of the Culm and the Coalmeasures. Important in the *Rheinische Schiefergebirge, Harz Mountains, Schwarzwald* and *the Vosges.* Undetermined, but probably represented in Central France. Less important, but indicated in the Sudeten and in Saxony.

TABLE XV *(Continued).*

PERMO-CARBONIFEROUS CHAINS OF THE SOUTH-CENTRAL STATES AND THE RELATED APPALACHIANS	VARISCAN ALTAIDS OF EUROPE
2. SECOND PHASE : *in lower-Pennsylvanian ; between Morrow (Bend) and lowermost-Strawn (Atoka).* Strongly in evidence in the *entire Wichita system :* Wichita Mountains, Criner Hills, Red River ranges. Not directly visible, but clearly represented in *the intermediate zone* of the Ouachita system, creating mountains composed of old-Paleozoic sedimentaries, and also of flysch ; the erosion products are deposited as *the Ouachita molasse,* in southeastern Oklahoma and Arkansas, East-Texas, and Marathon. *In the foreland :* generally, the two phases of the Wichita orogeny are not differentiated in the foreland, but *two oscillations of the shoreline* are in evident relationship to the two pulsations in the mountains. Only in the Llano-Burnett massif, both phases are indicated by unconformities overlying and underlying the Bend. Unconformities, indicating the lower phase, are absent from the foredeep of both the Ouachita and Wichita systems : the Ardmore Basin, Arbuckle Mountains, Coal Basin, and the Glass Mountains. The upper phase is indicated by *unconformity, overlying the Springer in the Ardmore Basin.* *Farther out on the Plateau,* the Wichita phase, undifferentiated, is represented in many blockfault uplifts all over the region, notably in the Hunton Arch, including the northern Arbuckles, north-central Oklahoma, the Salina Basin, and the Nemaha region ; also in the Ancestral Rocky Mountains. It is not possible to differentiate here between the two phases, since the Bend and lower Strawn strata are all absent. Only slight unconformities exist in the foreland of the Appalachians.	See preceding page.
ARBUCKLE PHASE : *in uppermost Pennsylvanian (early-Cisco).* *Important in Wichita system :* Wichita Mountains, Ardmore Basin, Red River chains, Amarillo Mountains. *Very important in Marathon Mountains,* and their foreland as far as Reagan county. Important in *Ancestral Rocky Mountains :* and related chains, as Hueco and Guadalupe Mountains, Chinati Mountains, etc.	ASTURIAN PHASE : *in uppermost upper-Carboniferous.* *Principal phase in outer frontal zone from Wales to the Ruhr Coal Basin.* (Exact time of this folding is not well proven ; certain is only that it occurred previous to the Zechstein and the Dyassic conglomerates.)

TABLE XV (*Continued*)

PERMO-CARBONIFEROUS CHAINS OF THE SOUTH-CENTRAL STATES AND THE RELATED APPALACHIANS	VARISCAN ALTAIDS OF EUROPE
Absent or quite indistinct in the Ouachita Mountain system, east of the Marathon region, and in the Appalachians. The Arbuckle phase is restricted to the west and southwest.	*Important in Spain* (southernmost belt), but only faintly indicated, or absent, in central Variscan belt.
An early-Permian orogeny is not indicated by any important *folds*, but warping, emergence and erosion continued spasmodically in the Wichita, and notably the Marathon systems: conglomerates in Hess and Leonard formations in the Glass Mountains; unconformable overlap overlying the Wolfcamp formation.	SAALIC PHASE: *in the lower-Permian (Dyas).* Apparently only unimportant movements in central Variscan chains.
APPALACHIAN PHASE: *between lower-Permian and base of Triassic.* *Main folding and overthrusting in the entire front of the Appalachian chains;* cannot be accurately timed. *Possibly, a final overthrusting of the Ouachita front* occurred in this phase. The overthrusting in the *Marathon Mountains* (Dugout Creek thrust) is not in this phase, but pre-Wolfcamp, late in the Cisco. *Several pulsations are in evidence within the Permian in the Salt Basin:* 1. Unconformity overlying the Bonespring limestone in the Guadalupe Mountains; 2. Unconformable overlap of the clastic *San Angelo formation* in Texas = *the Duncan formation* in southern Oklahoma; marked change of facies in the Salt Basin. 3. Breaks at the base of the *Whitehorse*, and apparently unconformable transgression of the *Rustler and Quartermaster formations*. The unconformity of the *Bissett* conglomerates in the Glass Mountains is probably the same, but may be younger. There is still later, post-Bissett, but pre-Triassic disturbance in West-Texas. These movements are only visible in the Salt Basin, where the contemporaneous Permian is present.	PFALZ PHASE: *in the higher Permian.* Unimportant movements in central Variscan chains.

The folding in the Salt Basin continued after the Permian. Structural folds affecting the oil field structures of southwest-Texas (notably investigated in the Hendricks Pool) are *post-Triassic.*

They strike generally NW-SE and are quite at an angle to the Cordilleran trend.

The same movenents may affect many of the oil field structures in central Texas and southern Oklahoma, where the absence of Triassic does not permit exact timing of the pre-Cretaceous folds, affecting Permian and Pennsylvanian strata.

Surely, the hinterland of the Quachitas was not disturbed by any serious orogeny, at the time of the orogenic paroxysm of the European Alps, and, in comparison, deformation is insignificant. Yet, we note the same two phases which are so prominent in the Alps: one affecting the lower Cretaceous before the deposition of the upper Cretaceous, and another one in the Oligocene and Miocene of the coastal zone.

It is only to be expected, that the orogenic pressure, in both the late Paleozoic and the Tertiary cycles, affected the south-central States of North America less than southern Europe. We miss the tremendous vise jaw action between Gondwana and Eurasia in this extreme western portion of "Laurasia". Although the relations are far from cleared, it is evident that on the western side of both the American continents, entirely different conditions arise, which will surely have prevented the South American mass to play as great a part as the central bulk of Gondwana. Nevertheless, the general picture remains closely related.

The American foreland of the Tethys chains of the Alpides is extremely similar to that of Eurasia: an ancient plateau region, bordered by a wide zone of late-Paleozoic folding.The difference is, that in Europe, the Alpides encroach far over this foreland, by the enormous northward pressure of their hinterland. The post-Alpide Mediterranean rift lies largely *within* the Alpine system.

In America, the Alpides stay farther back, the northward pressure is less violent and the rifts of the latest, recent Tethys spread over a wider zone, both north of and within the Alpides; farther west, the rifts merge into the Pacific. The Gulf of Mexico lies entirely north of the Alpides.

R. STAUB has lately advocated very similar views (**93**, 1928, pp. 101—110).

CLOSING REMARKS.

The writer hopes that, by the present analysis and discussion of the southern province of late-Paleozoic orogeny in North America, he may have contributed to the understanding of the westernmost branch of this so very important world-wide revolution. At the same time, he is very cognisant of the probable defects of his conclusions, based as they are on so scanty information. Fundamental problems and controversies still remain unsolved for mountain systems as the Variscan an Alpine chains of Europe, which have been the tilting ground of the world's best geological talent for over a hundred years. The problem of the Alps shows its complexities ever more, as detail work provides us with a greater store of well established facts. Increasing knowledge of the details of what is left exposed of the great Paleozoic Variscan system, continuously opens new riddles, and impresses the student with a realisation of the enormous importance of these ancient structures, now disguised as mostly insignificant and but poorly rejuvenated hills. So we may not wonder that the relatively hasty work of only comparatively few geologists, mostly worried by many other demands upon their time, has not been able to solve the problems presented by the orogeny in the western hemisphere.

The writer is aware that his treatise is only an initial attempt to correlate and explain the structure and history of the Paleozoic orogenies of the south-central region of the North-American continent: a synopsis and a theory, useful for future discussion of the problems, rather than a final solution. He hopes that the unsolved riddles, or disagreement with his views, will be a stimulus to continued research, and that he may at least have pointed a way. The petroleum industry, which we have to thank so largely for our present knowledge of the buried features, should be greatly interested in a further unravelling of problems, which must lie at the bottom of every wide swung exploration. We are already assured that the Paleozoic orogenies control the accumulation of these valuable fuels, even far in the foreland of the actual chains.

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AAPG: American Association of Petroleum Geologists.
Univ. Texas Bull.: Bulletin of the University of Texas.
Bull. Geol. Soc. Am.: Bulletin of the Geological Society of America.
U. S. Geol. Survey: United States Geological Survey.

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