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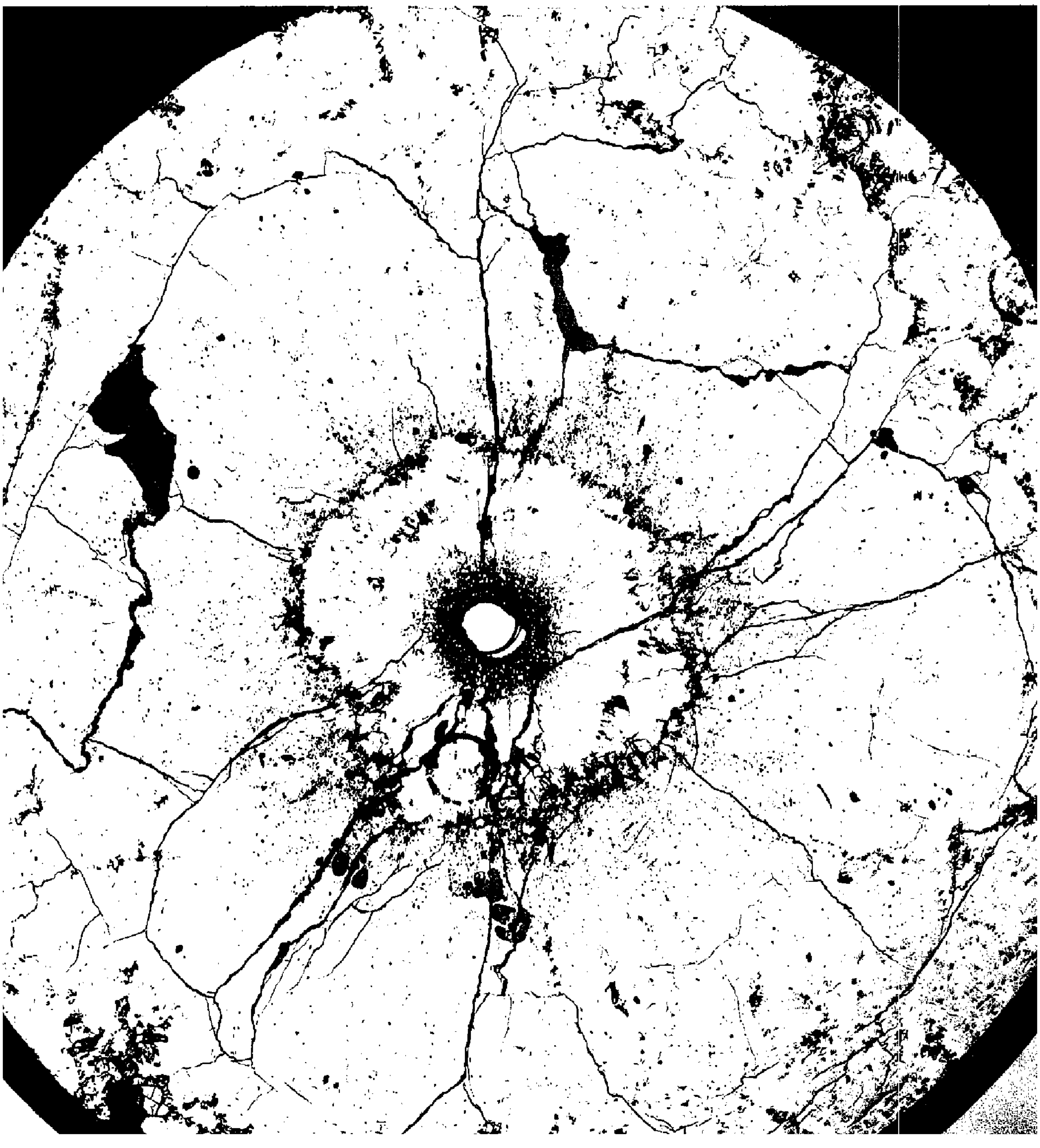

what's the scale?

Cover Picture

Thucholite Nodule, Hennessey Group
Kiowa County, Oklahoma

Shown on the cover is a low-power, bright-field photomicrograph of a thucholite nodule from an exposure in the Hennessey Group (Lower Permian) in eastern Kiowa County, Oklahoma. The term thucholite has been coined from the symbols of the various elements making up the compound: Th-U-C-H-O, with "lite" added at the end.

Nodules from this outcrop contain between 0.22 and 1.01 percent U, 66.6–72.3 percent C, 4.3–5.3 percent H, and 6.4–19.0 percent O. The thorium concentration is negligible and ranges between 0.1 and 7.8 ppm, but the term thucholite is sometimes applied to uraniferous carbonaceous matter that contains very little thorium, as in the Witwatersrand reefs of South Africa.

This photomicrograph shows a core of clausthalite, zoning, areas of different reflectivity, syneresis cracks, and some calcite in the outer zone of the nodule. The clausthalite is composed, by weight, of 72.6 percent Pb, 20.7 percent Se, and 6.7 percent S. This is the first reported occurrence of clausthalite in Oklahoma.

The outer edge of this nodule was ground off to reduce the diameter to 1 inch so that it would fit into the microprobe. Magnification: 8×.

–Salman Bloch

Photo by Roland Schmidt, Hazen Research Laboratory, Golden, Colorado.

Oklahoma Geology Notes

Editor: Connie Smith
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Oklahoma Geology Notes is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, an annual bibliography of Oklahoma geology, reviews, and announcements of general pertinence to Oklahoma geology. Single copies, $1.00; yearly subscription, $4.00. All subscription orders should be sent to the Survey at 830 Van Vleet Oval, Room 163, Norman, Oklahoma 73019.

Short articles on aspects of Oklahoma geology are welcome from contributors. A set of guidelines will be forwarded on request.

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MISSISSIPPIAN AND LOWER PENNSYLVANIAN STRATIGRAPHY IN OKLAHOMA

Patrick K. Sutherland[1]

Abstract—Mississippian and Lower Pennsylvanian strata are exposed in five areas in eastern and southern Oklahoma: (1) southwestern Ozark region, (2) frontal Ouachita Mountains, (3) central Ouachita Mountains, (4) northeastern Arbuckle Mountains, and (5) Ardmore Basin and southwestern Arbuckle Mountains. Marked differences in both facies and thickness occur between these different areas. The Ozark region exposes a thin, shallow shelf sequence dominated by limestones and thinner shales. A somewhat thicker but poorly exposed outer shelf section in the frontal Ouachita Mountains is dominated by shales with one limestone interval. In contrast, the central Ouachita Mountains are characterized by exceptionally thick, deep trough turbidites (sandstones and shales). Farther west, in the northeastern Arbuckle Mountain area, the sequence is thin, and deposition was presumably on a shelf; shale is the dominant lithology, with a few thin interbedded limestones, and exposures are poor. The Ardmore Basin–Southwestern Arbuckle Mountain section is thick, presumably representing deposition in a trough, and the strata are composed of interbedded sandstones and shales.

The Mississippian–Pennsylvanian boundary occurs in sequences of continuous deposition in the central Ouachita Mountains, in the Ardmore Basin, and possibly in the frontal Ouachita Mountains.

Introduction

The present paper gives a comprehensive summary of the complex stratigraphy of the Mississippian System and the Morrowan and Atokan Series of the Pennsylvanian System in Oklahoma. A similar paper by the author (Sutherland, 1979) was included in the chapter entitled *The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Oklahoma* (Fay and others, 1979), which was a part of the two-volume summary on Carboniferous stratigraphy in the United States published by the U.S. Geological Survey as Professional Paper 1110. In that paper, Sutherland (1979, fig. 4) summarized current usage in Oklahoma of Mississippian and Lower Pennsylvanian stratigraphic terminology and correlation. Several significant editorial changes were, however, inadvertently made in stratigraphic usage and correlation in that figure and in the text without the author's knowledge. The purpose of the present paper is to give, with the approval of the Director of the Oklahoma Geological Survey, a corrected rendition of the author's present-day interpretation of Mississippian–Lower Pennsylvanian stratigraphic usage in Oklahoma.

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Strata of Mississippian and Early Pennsylvanian age crop out in five regions in Oklahoma: (1) the southwestern Ozark region, in the northeast; (2) the frontal Ouachita Mountains; (3) the central Ouachita Mountains, in the southeast; (4) the northeastern Arbuckle Mountains, in the south-central part of the State; and (5) the Ardmore Basin and southwestern Arbuckle Mountains, in the south (fig. 1). These areas show marked differences in lithologic character, thickness, and depositional pattern.

Ozark Region

Mississippian and Lower Pennsylvanian strata in the Ozark region of northeastern Oklahoma are dominated by carbonate rocks. Unconformities are numerous. Represented in figure 2 is a typical shallow-water platform facies, which is thinner than the clastic, geosynclinal facies that crops out in the Ouachita Mountains. The maximum thicknesses recorded for Mississippian formations in the Ozark region of Oklahoma total about 250 m, but the total preserved thickness for the Mississippian in any local area does not exceed 150 m. The maximum recorded thickness for the Lower Pennsylvanian Morrowan Series is 94 m, and that for the Atokan Series, about 185 m (Sutherland and Manager, 1979).

The Upper Mississippian Pitkin Formation (fig. 3) is truncated northward by pre-Pennsylvanian erosion and is absent north of T. 18 N. The succeeding Morrowan Series is truncated by pre-Atokan erosion in T. 20 N. In T. 22 N., Desmoinesian strata overstep the Atoka Formation and rest directly upon eroded Mississippian strata.

Kinderhookian, Osagean, and Meramecian Series

The Chattanooga Shale, as much as 20 m thick in northeastern Oklahoma, ranges in age from Late Devonian to Early Mississippian (Kinderhookian) and correlates with the Woodford Shale in southern Oklahoma (Hass, 1956).

The Chattanooga is overlain unconformably by the "Boone" Group, which consists of beds of chert and limestone. This group ranges in age from latest Kinderhookian to early Meramecian but is predominantly Osagean. Included are the St. Joe, Reeds Spring, and Keokuk Formations. Their maximum recorded thicknesses are 12, 55, and 75 m, respectively (Huffman, 1958); the thickness of each averages much less, however, and all are missing in the southern part of the Ozark outcrop area, where the Moorefield Formation rests directly on the Chattanooga. The Keokuk is particularly distinctive lithologically, consisting of white- to buff-weathering chert that forms distinctive fractured rubble surfaces. It contains abundant fossils, mostly in the form of molds and casts. Various formations of the "Boone" Group are overlain unconformably by the Moorefield Formation, the Hindsville Limestone, or, locally, the Fayetteville Shale.

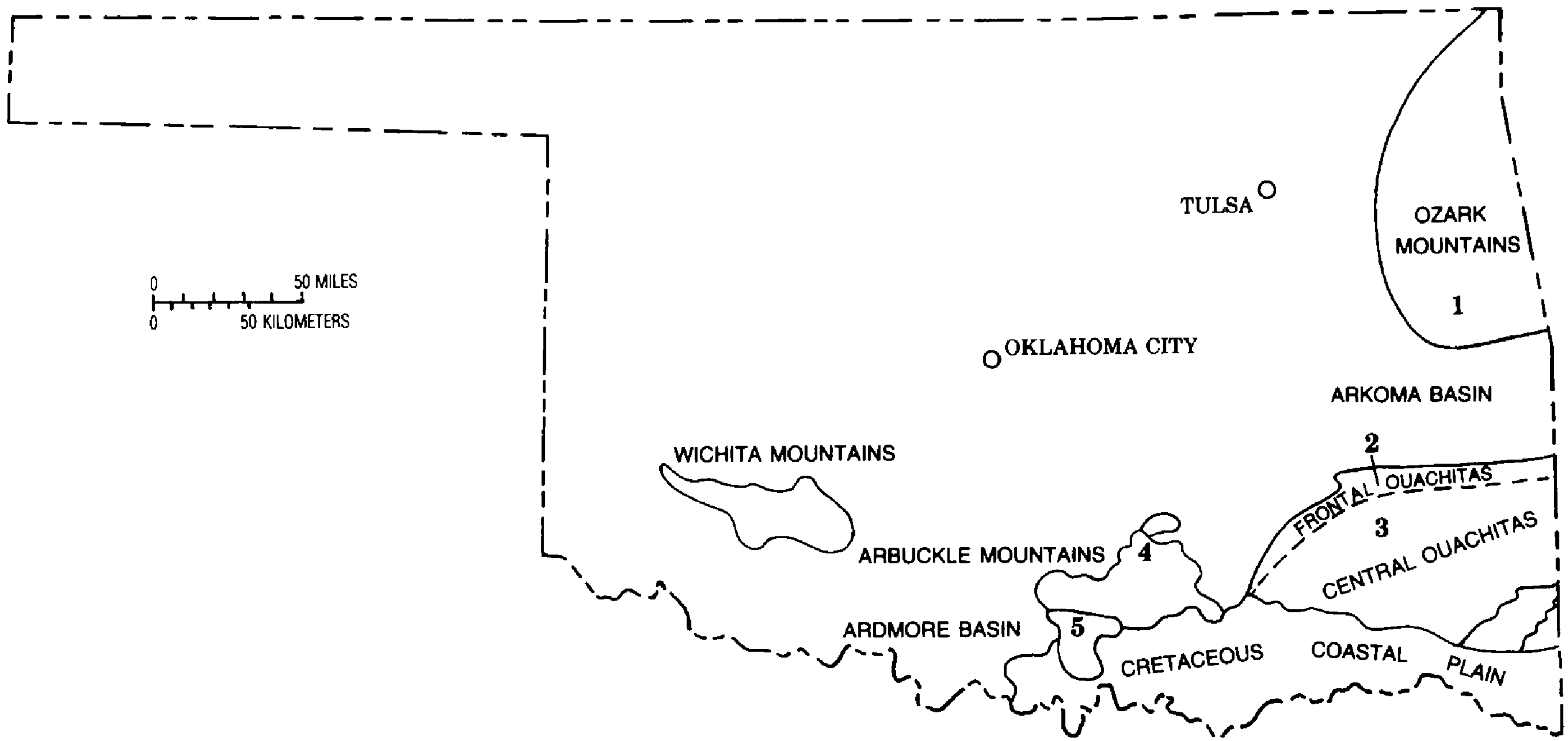


Figure 1. Map showing areas of exposure of strata of Mississippian and Early Pennsylvanian age in Oklahoma: (1) southwestern Ozark region, (2) frontal Ouachita Mountains, (3) central Ouachita Mountains, (4) northeastern Arbuckle Mountains, and (5) Ardmore Basin and southwestern Arbuckle Mountains.

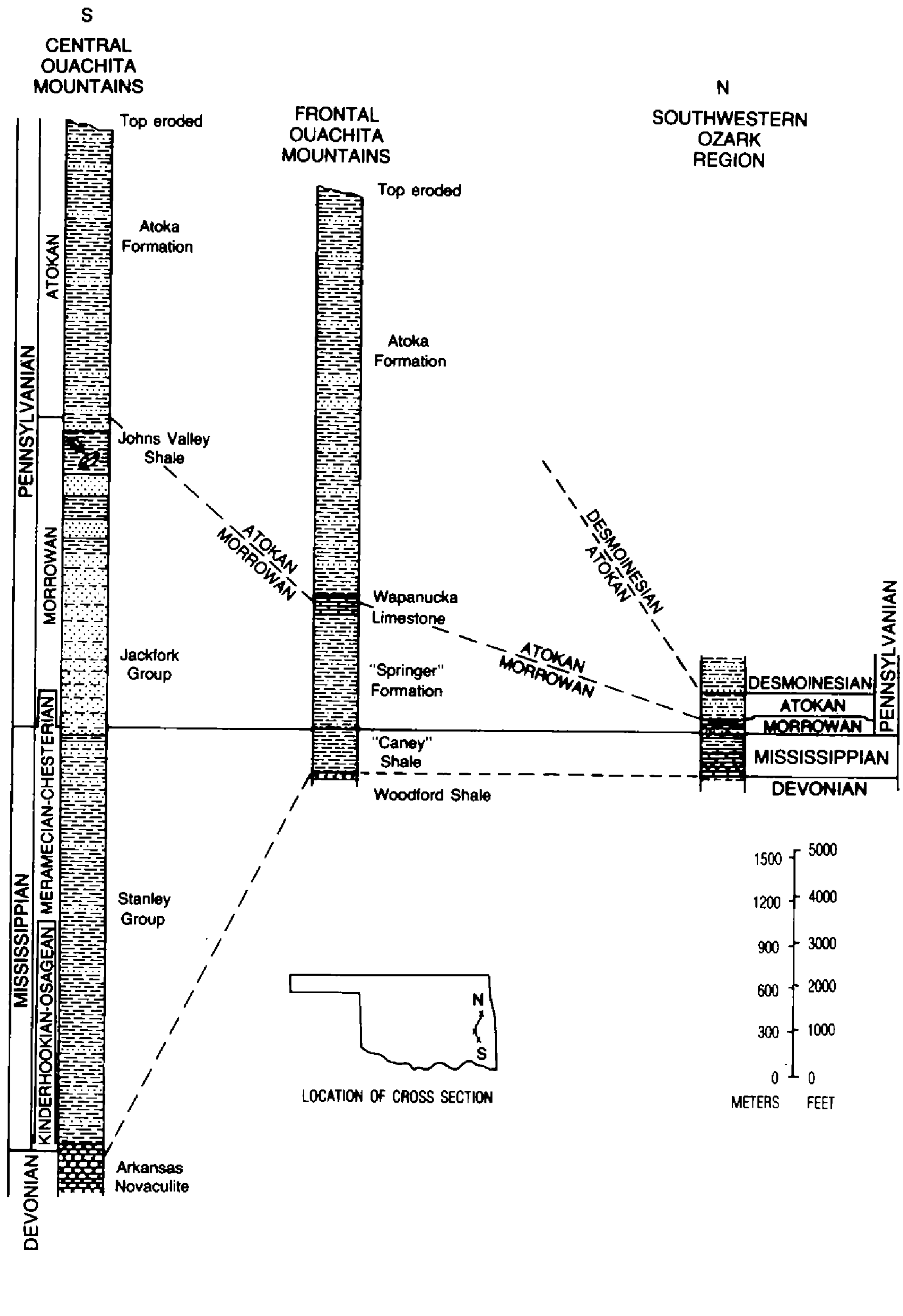


Figure 2. Stratigraphic cross section from central Ouachita Mountains northward to southwestern Ozark region.

The Moorefield Formation, predominantly of Meramecian age, consists mostly of argillaceous limestones, but other facies include oolitic and pelmatozoan grainstones and calcareous siltstones. Four facies were given local member names by Huffman (1958). The formation has a maximum thickness of about 30 m but is missing in Craig and Ottawa Counties, where the Hindsville rests unconformably on the "Boone" cherts.

Chesterian Series

The Hindsville Limestone, Fayetteville Shale, and Pitkin Limestone, all of Chesterian age, form a continuous depositional sequence in the Ozark region. The Hindsville is a widely distributed fossiliferous limestone that rests unconformably on the Moorefield Formation or on the "Boone." It has a maximum thickness of 15 m, but it averages 8–10 m (Huffman, 1958).

The Hindsville Limestone is overlain conformably by the Fayetteville Shale. The Fayetteville consists predominantly of black or gray-green shale, but it is interbedded locally near the base or near the top with dark nodular layers of carbonate mudstone. The formation has a maximum thickness of about 50 m.

The Pitkin Limestone conformably overlies the Fayetteville Shale and shows marked local variations in facies, ranging from crossbedded oolites to skeletal grainstones to dark carbonate mudstones. The formation is typically about 10 m thick but has a maximum observed thickness of 25 m (Huffman, 1958). The formation is unconformably overlain by the Pennsylvanian Sausbee Formation.

Post-Chesterian Erosional Surface

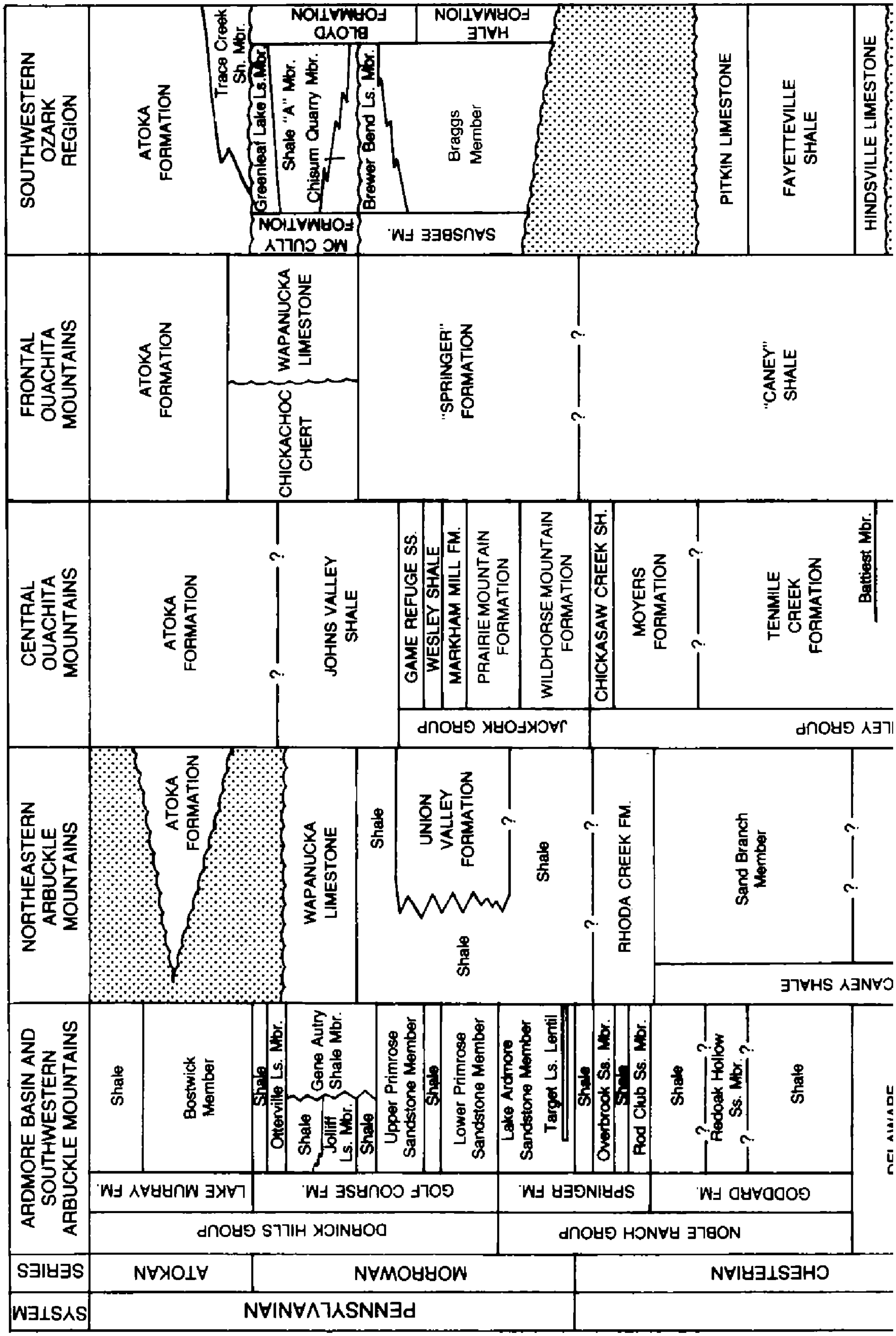
The Pitkin Limestone is regionally truncated northward in Oklahoma along a highly irregular line; the most northerly exposures are in T. 18 N., at the southern edge of Mayes County. Farther north, the Pennsylvanian rests directly on the Fayetteville Shale; locally it rests on the Hindsville Limestone. The post-Mississippian unconformity in northeastern Oklahoma has a regional relief of as much as 25 m (Sutherland and Henry, 1977b).

The magnitude of the post-Pitkin unconformity decreases eastward. In Searcy County, Arkansas, about 240 km to the east, the Imo Formation of late Chesterian age partly fills the gap (Saunders and others, 1977). The Imo overlies the Pitkin Formation and is in turn overlain unconformably by strata of Morrowan age.

In Arkansas, reworked Pitkin boulders are found in the Chickasaw Creek Shale at the top of the Stanley Group.

Morrowan Series

In northwestern Arkansas, the Pennsylvanian Morrowan Series is divided into the Hale and Bloyd Formations (in ascending order). These units can be recognized in Oklahoma only in Adair County. Farther west, the lithologic distinction is lost, as there is a marked westward increase in the


SYSTEM
SERIES
ARDMORE BASIN AND SOUTHWESTERN ARBUCKLE MOUNTAINS
NORTHEASTERN ARBUCKLE MOUNTAINS
CENTRAL OUACHITA MOUNTAINS
FRONTAL OUACHITA MOUNTAINS
SOUTHWESTERN OZARK REGION
PENNSYLVANIAN
ATOKAN
MORROWAN
CHESTERIAN
DORNICK HILLS GROUP
NOBLE RANCH GROUP
LAKE MURRAY FM.
GOLF COURSE FM.
SPRINGER FM.
GODDARD FM.
Shale
Bostwick Member
Shale
Otterville Ls. Mbr.
Gene Autry Shale Mbr.
Shale
Jolliff Ls. Mbr.
Shale
Upper Primrose Sandstone Member
Shale
Lower Primrose Sandstone Member
Lake Ardmore Sandstone Member
Target Ls. Lentil
Shale
Overbrook Ss. Mbr.
Shale
Rod Club Ss. Mbr.
Shale
Redoak Hollow Ss. Mbr.
Shale
DELAWARE
ATOKA FORMATION
WAPANUCKA LIMESTONE
Shale
UNION VALLEY FORMATION
Shale
Shale
RHODA CREEK FM.
Sand Branch Member
CANEY SHALE
ATOKA FORMATION
JOHNS VALLEY SHALE
JACKFORK GROUP
GAME REFUGE SS.
WESLEY SHALE
MARKHAM MILL FM.
PRAIRIE MOUNTAIN FORMATION
WILDHORSE MOUNTAIN FORMATION
CHICKASAW CREEK SH.
MOYERS FORMATION
TENMILE CREEK FORMATION
Battiest Mbr.
ILEY GROUP
ATOKA FORMATION
CHICKACHOC CHERT
WAPANUCKA LIMESTONE
"SPRINGER" FORMATION
"CANEY" SHALE
ATOKA FORMATION
Trace Creek Sh. Mbr.
Greenleaf Lake Ls. Mbr.
Shale "A" Mbr.
Chisum Quarry Mbr.
Brewer Bend Ls. Mbr.
Braggs Member
MC CULLY FORMATION
BLOYD FORMATION
SAUSBEE FM.
HALE FORMATION
PITKIN LIMESTONE
FAYETTEVILLE SHALE
HINDSVILLE LIMESTONE

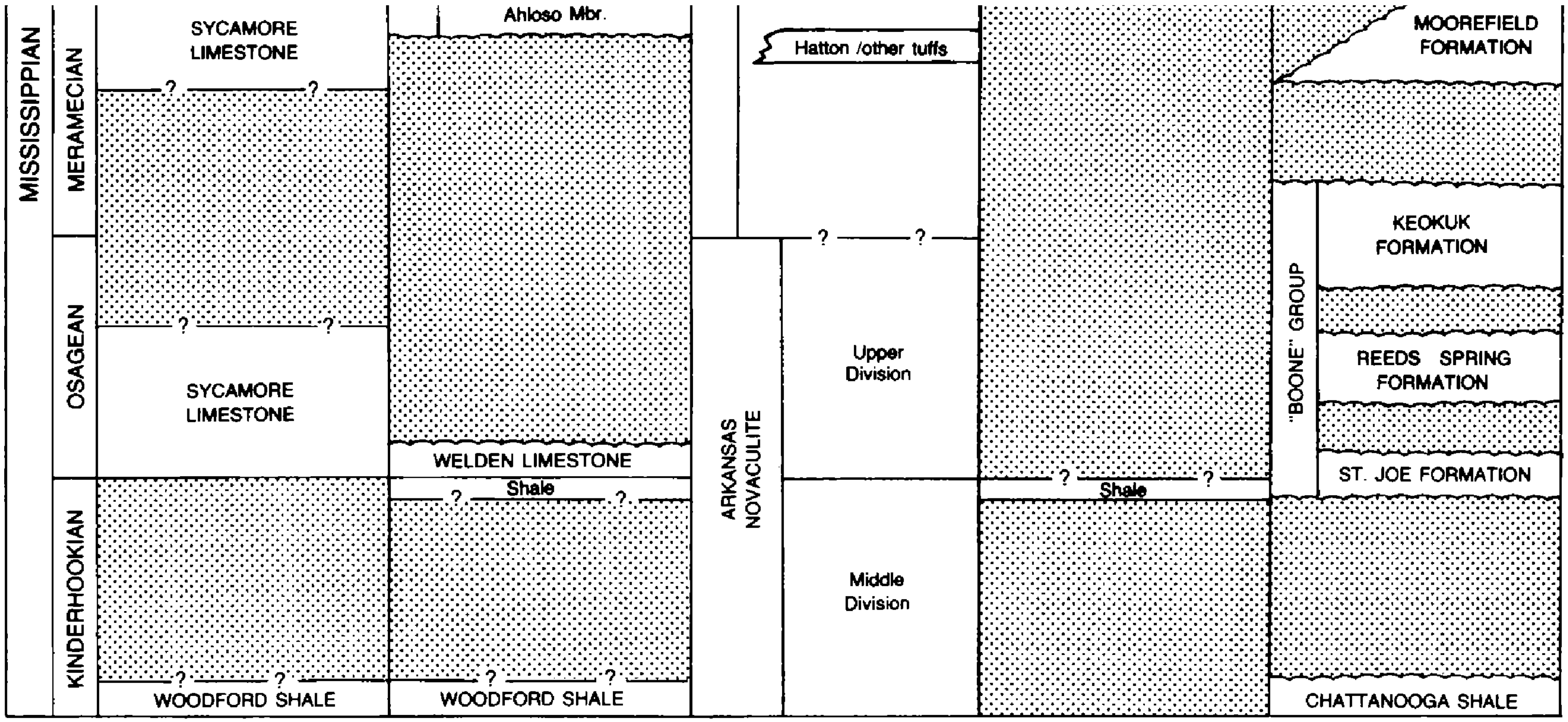


Figure 3. Correlation chart of Mississippian and Lower Pennsylvanian rocks in five outcrop regions of Oklahoma.

percentage of limestone and a corresponding decrease in the percentage of terrigenous-rock types. Sutherland and Henry (1977a) divided this carbonate facies into the Sausbee and McCully Formations on the basis of a regional disconformity at the top of the Sausbee. This break coincides in Washington County, Arkansas, with a regional unconformity at the base of the Dye Shale Member of the Bloyd Formation. The Sausbee Formation consists typically of skeletal grainstones interbedded with shale (Braggs Member), overlain by beds of algal wackestone and mudstone (Brewer Bend Limestone Member). The formation has a maximum thickness of 61 m. The overlying McCully Formation is composed of interbedded limestones and shales and has a maximum recorded thickness of 23 m.

Atokan Series

The Atokan Series, which consists of the Atoka Formation, crops out in a wide belt along the south and west flanks of the Ozark Dome in northeastern Oklahoma. It consists of interbedded thick shales and thinner sandstones and a few beds of thin discontinuous impure limestone. Wilson (1935) gave member names to six of the ridge-forming sandstones in Muskogee County, but Blythe (1959) was unable to differentiate most of these members in areas north of Muskogee County. The Atoka Formation is about 185 m thick in Muskogee County.

The Atoka Formation is truncated northward in T. 23 N., R. 19 E., by a regional unconformity at the base of the overlying McAlester Formation.

Frontal Ouachita Mountains

Describing and interpreting Carboniferous strata in the frontal Ouachitas is complicated by both faulting and lateral facies changes in each of the fault blocks from north to south. The column in figure 3 labeled "Frontal Ouachita Mountains" is a composite section for the several fault blocks north of the Ti Valley Fault. The block directly south of the Choctaw Fault, the leading edge of the frontal Ouachitas, exposes, in ascending order, the "Caney" Shale, "Springer" Formation, Wapanucka Limestone, and Atoka Formation. Farther south, the block south of the Katy Club Fault exposes the "Caney," "Springer," Chickachoc Chert, and Atoka. The block south of the Pine Mountain Fault, still north of the Ti Valley Fault, exposes the Woodford Shale (Devonian), "Caney," "Springer," and Atoka.

Kinderhookian Series

Rocks of Kinderhookian age have been reported from only a single locality in the frontal Ouachitas. Hass and Huddle (1965) recovered conodonts of this age from the basal 0.15 m of shale that directly overlies the Woodford Shale at a locality near Pine Top School in Pittsburg County, Oklahoma, between the Pine Mountain and Ti Valley Faults.

Chesterian Series

The "Caney" Shale of Chesterian age reaches a maximum thickness in the frontal Ouachita Mountains of possibly 275 m, but in the frontal block directly south of the Choctaw Fault, only the upper 15 m or so is exposed. Farther south, in the fault block between the Pine Mountain and Ti Valley Faults, the "Caney" Shale rests directly on the Woodford Shale.

The Chesterian age assignment for the "Caney" Shale is based on several occurrences of goniatites and microfossils.

Morrowan Series

Overlying the "Caney" Shale is the "Springer" Formation, which contains, at a few localities, goniatites of Morrowan age that correlate with the Hale Formation and the Brentwood Limestone Member of the Bloyd Formation in northwestern Arkansas (Gordon and Stone, 1977). Hendricks and others (1947) stated that the "Springer" apparently rests conformably on the "Caney" but that both units are poorly exposed. The Mississippian-Pennsylvanian boundary has in fact not been established precisely in this outcrop belt. They also reported a thickness of as much as 760 m for the "Springer" in the fault block directly southeast of the Choctaw Fault.

The Wapanucka Limestone overlies the "Springer" in the frontal fault ridges of the Ouachitas, where it consists of interbedded spiculiferous packstones, carbonate mudstones, pelmatozoan and oolitic grainstones, and shales and is typically about 90 m thick. Basinward (southward), successive fault blocks expose changes to the Chickachoc Chert facies, with which the Wapanucka is correlative. This facies consists predominantly of shale interbedded with as much as 10 layers of dark-gray to black spiculite and a few thin beds of spiculiferous limestone. The thickness is typically 180–215 m. Conodonts have been recovered from this facies, as have rare goniatites (Gordon and Sutherland, 1975). The conodonts make possible a correlation between the Chickachoc and Wapanucka (Grayson, 1979). These units are equivalent in age to the Dye Shale and Kessler Limestone Members of the Bloyd Formation plus the lower part of the Atoka Formation in northwestern Arkansas and the McCully Formation and lower part of the Atoka Formation in northeastern Oklahoma.

Atokan Series

The uppermost parts of the Wapanucka Limestone and the Chickachoc Chert are Atokan in age, on the basis of conodonts (Grayson, 1979), and these units are overlain conformably in the frontal Ouachitas by the Atoka Formation. In this area, the Atoka consists mostly of gray silty, micaceous shale containing a few beds of medium-grained sandstone. The Atoka is poorly exposed, and only the lower part is preserved in the frontal Ouachitas, where Hendricks and others (1947) estimated the maximum thickness preserved to be 2,750 m.

Central Ouachita Mountains

Kinderhookian and Osagean Series

The Kinderhookian and Osagean Series are presumed to be represented in the Ouachita Mountains of Oklahoma; the location depends upon the distribution in Oklahoma of Hass' (1951) middle and upper divisions of the Arkansas Novaculite. Most of the Arkansas Novaculite is Devonian in age, but Hass (1951) recorded a Kinderhookian age on the basis of conodonts for the top 8.5 m of the middle division of the formation at Caddo Gap, Montgomery County, Arkansas. In addition, he assigned a tentative latest Kinderhookian or Osagean age for another conodont collection made 25 m below the top of the 38-m-thick upper division of the formation at a locality in Polk County, Arkansas. Thus, Hass considered the upper 47 m of the formation to be Mississippian in age in Arkansas. Hass (1951) quoted H. D. Miser as stating that the upper division of the Arkansas Novaculite occurred in Oklahoma only in McCurtain County. The only conodonts recovered by Hass (1951) from the Arkansas Novaculite on Black Knob Ridge, near Atoka, Oklahoma, were Devonian in age.

Meramecian and Chesterian Series

Rocks of the Stanley Group are conformable with the underlying Arkansas Novaculite in McCurtain County, Oklahoma (Honess, 1923), and are generally so in the Potato Hills and at Black Knob Ridge, although a local conglomerate is at the base at some localities on Black Knob Ridge (Goldstein and Hendricks, 1962). Nowhere can an unfaulted sequence of the Stanley be seen, but a maximum thickness of 3,300 m has been estimated in the central Ouachitas. The group thins abruptly westward and northward toward the frontal Ouachitas (Cline, 1960). Harlton (1938) divided the Stanley Group into the Tenmile Creek, Moyers, and Chickasaw Creek Formations on the basis of the occurrence of several thin siliceous shales that are apparently widespread and locally mappable. The Stanley is composed predominantly of black shale, but sandstone beds are more common in the upper part. The Chickasaw Creek Shale was originally described as the basal unit of the Jackfork by Taff (1902), but since it is primarily a shale, most modern authors have followed the usage of Harlton (1938) and have assigned it to the Stanley Group.

The Stanley Group contains few fossils. Hass (1950) collected conodonts of Meramecian age from the lower part of the group in both Oklahoma and Arkansas. Higher conodonts, collected from 23 to 45 m above the base of the Stanley in Arkansas, were believed by Hass to be of Meramecian age but are now considered to be of early Chesterian age (Gordon and Stone, 1977). Plant fossils of Chesterian age have been recovered from the upper middle part of the group in Arkansas, and fossiliferous erratic blocks of Pitkin Limestone (Chesterian) have been recovered from the Chickasaw Creek Shale, at the top of the Stanley in the frontal belt of the Ouachitas in Arkansas (Gordon and Stone, 1977).

The Jackfork Group is gradational with the underlying Stanley Group. The Jackfork contains few fossils, and considerable disagreement exists in the literature regarding its precise age. Of particular importance is the recovery from the lowermost beds of the group a short distance west of Talihina, Oklahoma, of plants of Chesterian age (Gordon and Stone, 1977).

The plants from this locality are similar to but less varied than the Stanley shale flora discussed earlier. These plants suggest—but, since they could be resedimented remains, do not necessarily prove—a Mississippian age for the lower part of the Jackfork (Gordon and Stone, 1977, p. 81).

Morrowan Series

Identifiable marine invertebrate fossils of definite Morrowan age have been collected from several localities in the middle and upper parts of the Jackfork Group in the vicinity of Little Rock, Arkansas (Gordon and Stone, 1977). Included are several species of both goniatites and brachiopods.

The Jackfork Group consists mostly of sandstones, although shales make up as much as 40 percent of the group in some areas (Shelburne, 1960). The Jackfork is more resistant to erosion than the underlying Stanley Group, which is composed mostly of shale, and is one of the main ridge-forming units in the Ouachitas. The Jackfork Group is typically 1,750 m thick in the central Oklahoma Ouachitas. Cline (1960) and Shelburne (1960) recorded as much as 1,980 m in northern McCurtain County, Oklahoma. These authors reported that the group thins abruptly northward toward the frontal Ouachitas. The Jackfork was divided by Harlton (1938) into the following formations, listed in ascending order: Wildhorse Mountain, Prairie Mountain, Markham Mill, Wesley, and Game Refuge.

The Johns Valley Shale overlies the Jackfork Group conformably. It is well known for its great variety of erratic limestone boulders, mostly of the Arbuckle facies, that range in age from Cambrian to Early Pennsylvanian and for its huge slump blocks, some more than 900 m in length, of "Caney" Shale. The formation is typically 130–275 m thick in the central Ouachitas in Oklahoma (Cline, 1960). Gordon and Stone (1977) recorded a maximum thickness of 565 m, but they did not give a locality.

An indigenous fauna from the lower part of the Johns Valley Shale, from localities in both Oklahoma and Arkansas, includes cephalopods of the *Branneroceras branneri* Zone (Gordon and Stone, 1977). This fauna occurs also in the upper part of the "Springer" Formation in the frontal Ouachitas and in the Brewer Bend Limestone Member of the Sausbee Formation in northeastern Oklahoma. From the middle part of the Johns Valley Shale, Gordon and Stone (1977) recorded the *Axinolobus modulus* Goniatite Zone. This zone occurs in the frontal Ouachitas in the lower part of the Wapanucka Limestone and in northeastern Oklahoma in the Chisum Quarry Member of the McCully Formation. Distinctive fossils have not yet been reported from the upper part of the Johns Valley.

Morrowan and Atokan Series

The Atoka Formation in the central Ouachitas consists of interbedded gray shale and fine-grained sandstone commonly having convolute bedding and sole markings. Shelburne (1960) recorded no more than 25-percent sandstone in the Boktukola Syncline and a maximum preserved thickness in that area of 2,065 m. The top of the formation is eroded.

The Atoka Formation is virtually unfossiliferous in the central Ouachitas. However, L. R. Wilson (oral communication, 1978) reported that the lower part contained palynomorphs of Morrowan age.

Northeastern Arbuckle Mountains

Kinderhookian and Osagean Series

The Woodford Shale in the northeastern Arbuckle Mountains is similar to that found in the southwestern Arbuckle Mountains, except that the percentage of chert decreases northeastward. In the northeast, the formation is composed predominantly of platy dark shale interbedded with some chert layers. The regional thickness is about 100–125 m (Ham, 1969). In the northeastern Arbuckle Mountains, the formation is apparently all Late Devonian in age at most localities, but a Kinderhookian conodont fauna has been recovered from the top 0.3 m or less at a few localities (Hass and Huddle, 1965).

The Sycamore Limestone, conspicuous in the southwestern Arbuckles, is absent from the Mill Creek Syncline northeastward in the Arbuckle Mountains (Ham, 1969). The same stratigraphic position is locally occupied by the Welden Limestone. It is a buff to gray thick-bedded argillaceous limestone that is moderately fossiliferous. It has a maximum recorded thickness of 1.5 m, but it is typically 0.6 m thick (Barker, 1950). Cooper (1939) described a conodont fauna from an underlying shale that contained 105 different species. This fauna was assigned a late Kinderhookian age by Ormiston and Lane (1976). Probably this pre-Welden shale rests unconformably on the underlying Woodford, and most of the Kinderhookian Series is missing in this area. Ormiston and Lane (1976) gave an early Osagean age to the Welden Limestone on the basis of conodonts.

Meramecian and Chesterian Series

The primary unit of Late Mississippian age in this area is the Caney Shale, named by Taff (1901). Taff's original discussion included shales in both the Arbuckle and Ouachita regions and extended, in the Arbuckle Mountains, from the top of the Woodford Shale to the base of the Wapanucka Limestone. Thus, both Chesterian and Morrowan shales were included. Later usage has restricted the term Caney to a part of the Late Mississippian sequence. The original type locality of the Caney was in the Ouachita Mountains, in a large erratic block in the Johns Valley Shale of Early Pennsylvanian age. Elias and Branson (1959) defined a new type section for the Caney on the northeastern flank of the Arbuckle Mountains, and their usage is followed here. Those authors discussed the nomenclatural history of this unit.

As presently defined, the term Caney is used with certainty only in the northeastern Arbuckle Mountain area and ranges in age from late

Meramecian to late Chesterian. It has an average thickness of about 130 m. Elias (1956) divided the formation into three members, but these are not easily differentiated lithologically and are primarily paleontological in concept. The lowest, the Ahloso Member, about 7.5 m thick, consists of fossiliferous calcareous shales and calcareous siltstones with a basal glauconitic, sandy zone. This unit rests unconformably on the lower Osagean Welden Limestone. The Ahloso grades upward into the Delaware Creek Member, about 50 m thick, which consists of mostly noncalcareous shale with common limestone concretions. This member in turn grades upward into the Sand Branch Member, about 75 m thick, which contains black septarian limestone concretions.

Ammonoid cephalopods are fairly common in the concretions of various parts of the Caney Shale, and Gordon and Stone (1977) listed the occurrence of seven different ammonoid zones in this formation in the northeastern Arbuckle Mountains. However, because of poor, discontinuous exposures, many of the known ammonoid occurrences are from isolated localities, and the stratigraphic relationships of some are not precisely known. Of particular interest is the occurrence in the Sand Branch Member, in the upper part of the Caney Shale, of the *Eumorphoceras bisulcatum–Cravenoceras richardsonianum* assemblage (Saunders, 1973). This important fauna also occurs in the upper part of the Pitkin Formation in northern Arkansas. The Sand Branch Member of the Caney Shale, in the Arbuckle Mountains, contains the type locality of the type species of *Eumorphoceras, E. bisulcatum* Girty.

Elias (1956) gave the name Rhoda Creek to what he thought were basal Pennsylvanian shales overlying the Sand Branch Member of the Caney. It is now known that this unit is also Mississippian in age. The Rhoda Creek consists of fissile, partly sandy shales that include a zone of thin sideritic concretions that are said to differ in character from the septarian concretions of the underlying Sand Branch. The Rhoda Creek Formation, in its type section, is 42 m thick and contains *Fayettevillea friscoense*. This occurrence correlates with the *Eumorphoceras richardsoni–Fayettevillea friscoense* Zone that occurs in the Imo Formation in northern Arkansas (Saunders, 1973). This zone represents the youngest Mississippian ammonoid fauna known in North America.

Morrowan

The Mississippian–Pennsylvanian boundary has not been defined in the northeastern Arbuckle Mountains. It falls somewhere in a sequence of poorly exposed shales that overlie the Rhoda Creek and extend upward for an estimated 90 m to the base of the Union Valley Formation. These shales are presumed to be mostly Morrowan in age and have been called previously, along with the Rhoda Creek, "Pennsylvanian Caney" by some and "Springer" by others.

The Union Valley Formation crops out in a limited area on the Lawrence Uplift, in the northernmost Arbuckle Mountains, and it covers an extensive area in the subsurface of the Arkoma Basin, northeast of the

Arbuckles. Where exposed on the Lawrence Uplift, it consists of 45–80 m of sandstone overlain by 3.5–7.5 m of sandy limestone (Barker, 1950).

The limestone at the top of the Union Valley is highly fossiliferous locally. Gordon and Stone (1977, fig. 4) recorded the *Branneroceras branneri* Goniatite Zone from this interval. This limestone is of middle Morrowan age and is correlative with the Brewer Bend Limestone Member of the Sausbee Formation in northeastern Oklahoma and the upper Primrose Sandstone in the Ardmore Basin.

On the northeast flank of the Arbuckle Mountains, the Union Valley Formation is missing on the outcrop, and the Wapanucka Limestone is underlain by 100 m or so of poorly exposed and poorly known shales.

The Wapanucka Limestone in this area includes a wide variety of carbonate-rock types, including crossbedded oolites and skeletal grainstones and packstones. In the more westerly exposures, significant shale interbeds are present. The maximum observed thickness for the Wapanucka in this area is about 55 m, not including underlying shales (Rowett and Sutherland, 1964). The Wapanucka is truncated westward along the south margin of the Franks Graben. The Wapanucka is highly fossiliferous and is late Morrowan in age. It has produced the ammonoid *Axinolobus quinni* McCaleb and Furnish, which occurs also in the upper part of the Bloyd Formation in northwestern Arkansas and in the Gene Autry Shale in the Ardmore Basin (Strimple and Nassichuk, 1965).

Atokan Series

Morrowan rocks are overlain unconformably in the northeastern Arbuckle Mountain area by the Atoka Formation, which consists of thick shales interbedded with thinner fine-grained sandstones. The Atoka onlaps westward and is itself truncated farther west by an unconformity at the base of overlying Desmoinesian formations. It ranges in thickness in this area from about 950 m to a featheredge.

Ardmore Basin and Southwestern Arbuckle Mountains

Kinderhookian Series

The Woodford Shale consists of interbedded dark shale and chert and is 107–122 m thick over most of its outcrop area in the Arbuckle Mountains. It is Late Devonian in age except for the top 0.3 m or less at a few localities, from which a Kinderhookian conodont fauna was recovered by Hass and Huddle (1965).

Osagean and Meramecian Series

The Sycamore Limestone overlies the Woodford Shale and occurs only in the southwest segments of the Arbuckle Mountains (Ham, 1969). It consists of fine-grained silty limestone interbedded with thin layers of dark-gray shale. It is 115 m thick on the south limb of the Arbuckle Anticline and

64 m thick on the north limb (Fay, 1969). The Sycamore Limestone has produced very few identifiable megafossils, and age determinations thus far available are based on a few conodont faunas. These have been reported only from the lowest and the highest strata. Ormiston and Lane (1976) recovered conodonts from four samples from Fay's (1969, p. 68) measured section on the north limb of the Arbuckle Anticline. Three of their samples came from the lowermost 17 m of the Sycamore Limestone (64 m total thickness) and indicate an early Osagean age for this part of the formation. The lowermost sample, of earliest Osagean age, was taken 1 m above the base of the formation; it carries the same fauna as that from the Welden Limestone in the northeastern Arbuckle Mountains (Ormiston and Lane, 1976).

The fourth sample described by Ormiston and Lane was from a zone 14 m below the top of the Sycamore Limestone, in the same measured section. They reported conodonts from this zone to be latest Meramecian or early Chesterian in age. The unfossiliferous middle part of the Sycamore Limestone is assumed to be Osagean and (or) Meramecian in age.

Chesterian Series

The name Delaware Creek was proposed by Elias (1956) to designate a member of the Caney Shale in the northeastern Arbuckle Mountains. Elias also applied the name to shales in the same stratigraphic position in the Ardmore Basin, where he used it as a formation name. The same usage is followed here. The Delaware Creek Shale rests directly on the Sycamore Limestone at the northern margin of the Ardmore Basin. It consists in this area of dark-gray, partly siliceous shale that weathers to a lighter color than is normal for the formation in the northeastern Arbuckle Mountains. Small phosphatic nodules and large calcareous septarian concretions are locally abundant, but limestone and sandstone are absent (Ham, 1969). The formation ranges in outcrop thickness in this area from 69 m on Oil Creek to 134 m on Henryhouse Creek (Elias, 1956); it is 228 m in the subsurface of the Ardmore Basin (Hart, 1974). Gordon and Stone (1977, fig. 4) recorded three goniatite zones in the unit in this area, all early Chesterian in age.

The contact with the overlying Goddard Shale is drawn at the earliest appearance of siderite or clay–ironstone beds, which occur abundantly in and characterize the Goddard (Ham, 1969). Its thickness in its type section is estimated to be 870 m (Westheimer, 1956). The lower Goddard shales differ from the Delaware Creek Shale in being more friable and less cliff forming (Tomlinson and McBee, 1962). The Goddard, as defined by Elias (1956), includes only the beds of shale and thin sandstones between the top of the Delaware Creek and the base of the Rod Club Sandstone. Goniatites that possibly belong to the *Eumorphoceras bisulcatum–Cravenoceras richardsonianum* Zone (Elias, 1956, p. 74) occur in the middle and upper parts of the Goddard Shale. This zone is found elsewhere in the Sand Branch Member of the Caney in the northeastern Arbuckle Mountains and in the Pitkin Limestone of northern Arkansas (Saunders, 1975).

Overlying the Goddard Formation in the Ardmore Basin is the Springer Formation, which encompasses the Mississippian–Pennsylvanian boundary (see next section). The total thickness of the Springer is about 600 m (Tomlinson and McBee, 1962), and the unit consists of interbedded shales separating three ridge-forming sandstone intervals, the Rod Club, the Overbrook, and the Lake Ardmore. These noncalcareous sandstones are all fine grained and well sorted. The Rod Club is 75 to 122 m thick, and the Overbrook, 14 to 30 m thick (Tomlinson and McBee, 1962).

Mississippian–Pennsylvanian Boundary

The Mississippian–Pennsylvanian boundary currently is placed arbitrarily at the base of the Lake Ardmore Sandstone Member of the Springer Formation. The boundary is most precisely limited by sparse conodont faunas from the Springer Formation described by Straka (1972) and Lane and Straka (1974). Of particular importance is the occurrence in the lower part of the Lake Ardmore Sandstone Member of the Target Limestone Lentil. Lane and Straka (1974) reported the occurrence of the *Adetognathus unicornis* Zone in the upper part of the Goddard Shale and upward into the middle part of the Rod Club Sandstone Member at the base of the Springer Formation. The interval from the middle part of the Rod Club to the base of the Target Limestone Lentil in the lower Lake Ardmore Sandstone Member of the Springer did not produce conodonts except for a small collection of a single form taxon, *Gnathodus girtyi intermedius,* from the lower part of their Shale "B," which overlies the Overbrook Sandstone. Lane and Straka (1974) thought that this species could be Mississippian.

The Target Limestone Lentil, near the base of the Lake Ardmore Sandstone Member of the Springer Formation, contains the earliest Pennsylvanian *Rhachistognathus primus* Conodont Zone. In turn, the overlying interval from the upper part of the Lake Ardmore Sandstone to the lower part of the lower Primrose Sandstone Member of the Overlying Golf Course Formation contains the *Idiognathoides sinuatus* Zone. It occurs also in the lower part of the Prairie Grove Member of the Hale Formation in northwestern Arkansas.

Thus, based on conodonts, the Mississippian–Pennsylvanian boundary falls somewhere within the 130-m-thick interval that extends from the upper part of the Rod Club Sandstone to the lower beds of the Lake Ardmore Sandstone, and more likely occurs near the base of the Lake Ardmore Sandstone, based on limited conodont evidence. This interbedded shale–sandstone sequence apparently was deposited continuously. No goniatites have as yet been reported from the Springer Formation.

Morrowan Series

The Lake Ardmore Formation consists, in the northern part of the Ardmore Basin, of 152 m of shales interbedded with three beds of ridge-forming fine-grained sandstone (Tomlinson and McBee, 1962). Each of these sandstone intervals is 9–21 m thick. The Target Limestone Lentil, referred to in the previous section, is about 15 m above the base; it is only about 1 m thick and is poorly exposed along a distance of 3 km or so in the northern part of the Ardmore Basin.

The overlying Golf Course Formation, of Morrowan age, extends from the base of the ridge-forming Primrose Sandstone to the base of the ridge-forming Bostwick Formation (Atokan age). The Golf Course Formation includes the members listed as follows, in ascending order: Primrose Sandstone, Gene Autry Shale (in the north only), Jolliff Limestone (in the south only), Otterville Limestone, and an unnamed shale. The Golf Course attains a thickness of about 610 m (Tomlinson and McBee, 1962).

The Primrose Sandstone Member is 46–76 m thick and differs from the underlying beds of sandstone of the Springer Formation in being distinctly calcareous in several zones. *Arkanites relictus* Zone goniatites have been reported from the lower Primrose Sandstone (Manger and others, 1974), and this zone correlates with the upper part of the Prairie Grove Member of the Morrowan Hale Formation in northwestern Arkansas.

North of Ardmore, the Primrose is overlain by the Gene Autry Shale Member, which is about 360 m thick. The Gene Autry contains the late Morrowan *Axinolobus modulus* goniatite fauna in the lower part.

South of Ardmore, a thin shale overlies the Primrose, which is in turn overlain by the distinctive Jolliff Limestone Member. The Jolliff is highly variable in character and thickness. A basal limestone-cobble conglomerate as much as 9 m thick occurs typically, as do irregularly distributed higher conglomerates, packstones, and carbonate mudstones. The formation varies in thickness from 6 to 39 m by lateral replacement of the lower part of the overlying shale (Cromwell, 1975).

The unnamed shale between the Jolliff and Otterville Limestone Members is as much as 137 m thick. The Otterville is either covered or missing in the area west of Ardmore, and the covered (and apparent shale) interval between the Jolliff and the base of the Bostwick Member of the Lake Ardmore Formation is as thick as 360 m (Cromwell, 1975).

The Otterville ranges from 2.5 to 6 m in thickness and consists of fossiliferous oolitic grainstones. It is overlain by an unnamed shale as much as 91 m thick that extends to the base of the Bostwick.

The Jolliff Limestone Member contains the *Axinolobus modulus* goniatite fauna. The interval from the Jolliff to the shale above the Otterville is late Morrowan in age and correlates with the whole of the McCully Formation in northeastern Oklahoma.

Atokan Series

This series in the Ardmore Basin includes that part of the Lake Murray Formation that extends from the base of the Bostwick Member to the base of the Lester Limestone. The Bostwick Member, composed of beds of conglomerate, sandstone, limestone, and intercalated shale, has a maximum thickness of 152 m (Cromwell, 1975). Limestone-cobble conglomerate in the south grades into chert-pebble conglomerate in the central part of the Ardmore Basin. This part of the sequence is characterized by marked lateral facies changes. The Bostwick is the most conspicuous ridge-forming unit in the southern Ardmore Basin.

The Atokan age assignment of the Bostwick is based primarily on fusulinids. Waddell (1966) defined his Fusulinid Zone I as including the Bostwick Member and part of the overlying shale. This zone is characterized by the occurrence of several specis of *Fusulinella*.

Overlying the Bostwick, an unnamed shale, which has a maximum thickness of 228 m, was included in the Atokan Series by Waddell (1966). He placed the base of the Desmoinesian Series at the base of the Lester Limestone Member of the Lake Murray Formation, on the basis of the lowest occurrence in the Ardmore Basin of the genera *Fusulina* and *Wedekindellina*.

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New Hydrologic Atlas Released by OGS and USGS

Oklahoma Geological Survey Hydrologic Atlas 8, *Reconnaissance of the Water Resources of the Woodward Quadrangle, Northwestern Oklahoma,* is now available to the public. The atlas, consisting of four large, colored map sheets, offers graphic information on the availability and quality of ground and surface water in a 7,800-square-mile area in the northwestern part of the State. The $1° \times 2°$ quadrangle includes Alfalfa, Harper, Major, Woods, and Woodward Counties and parts of Blaine, Dewey, Ellis, Garfield, Grant, and Kingfisher Counties.

Robert B. Morton, hydrologist with the U.S. Geological Survey's Water Resources Division in Oklahoma City, compiled the new atlas.

Because mineral content, porosity, and permeability of rocks play a major role in determining the quality and, to some extent, the quantity of recoverable water in an area, an updated areal geologic map is included in the four-sheet set. The map, published at a scale of 1:250,000, shows that rocks underlying the quadrangle are chiefly Permian sandstones and shales, with numerous beds of dolomite and gypsum and some salt beds. A few exposures of Cretaceous rocks occur as small outliers of shale and limestone with a basal sandstone. The Pliocene Ogallala Formation, consisting of gravel, clay, sand, silt, caliche, and limestone, covers a large area in the west-central and southwestern parts of the quadrangle and also an area in northern Woods County. Younger terrace and alluvial deposits of lenticular and interfingering gravel, sand, silt, clay, and volcanic ash cover much of the northeastern three-fourths of the quadrangle.

The geologic map was updated by Robert O. Fay, Oklahoma Geological Survey geologist.

Rock type is of special significance in determining the availability of ground water, and, as Morton says, "Water users in the Woodward Quadrangle rely heavily on ground water as the principal water supply." Data on yields from wells drilled into underground aquifers are given on sheet 2 of the atlas and show that the most productive aquifers are the porous, permeable younger deposits that lie near the surface.

Sheet 3 contains information on the chemical quality of the ground water in the quadrangle, presenting the data graphically on a large map and in tables summarizing chemical analyses. Results indicate that water from many aquifers exceeds U.S. Public Health Service standards in concentrations of dissolved solids, sulfate, and chloride, although most meets the standards for nitrate.

Sheet 4 presents maps, tables, and charts of surface-water sources: water-quality ratings, flow duration of streams, streamflow distribution, water usage, rural water districts, precipitation and runoff, and reservoirs. Most of the surface water is rated fair to poor for municipal use and fair to good for irrigation.

Hydrologic Atlas 8 can be obtained from the Oklahoma Geological Survey by writing to the address on the front cover. The price is $5.

U.S. Bureau of Mines Releases Highlights of Oklahoma Mineral Study

The U.S. Bureau of Mines recently released the preliminary highlights of the annual mineral-industry survey for the State of Oklahoma. A table of nonfuel mineral production in Oklahoma and the following excerpts have been selected from the report:

- The value of nonfuel mineral production in Oklahoma in 1980 was estimated to be $223.7 million, according to the U.S. Bureau of Mines. Portland cement, crushed stone, and sand and gravel, in that order, were the leading nonfuel mineral commodities produced. A major factor in the increase in value over the preceding year was the rise in value of portland cement.

- A $270,000 cooperative study of the environmental impact of past lead-zinc mining in the Tri-State mining district of Oklahoma, Missouri, and Kansas was undertaken by the Bureau of Mines and the three states. The study will survey surface integrity with respect to areas of collapse as well as other potential hazards that are a result of mining. Production of ore in the 600-square-mile area amounted to more than 500 million tons between 1848 and 1970.

- Bankruptcy of the Chicago, Rock Island and Pacific Railroad Co. created serious transportation problems for the sand and gravel and crushed-stone industries.

- The State's first barite-grinding mill began production at a site near Clinton, in Custer County, central western Oklahoma. Built and operated by Milchem, Inc., with a capacity of 325 tons per day, the plant processes barite from Battle Mountain, Nevada, for use in the oil-well-drilling industry.

- The Oklahoma Supreme Court ruled in November that salt water is a mineral; that brine water and any natural gas it contains belong to the owner of the mineral rights, not the surface land owner. The ruling applied to PPG Industries' production of iodine from salt water at the Woodward Iodine Facility, the only commercial producer of iodine in the nation. A Japanese firm constructed a small test plant near Dover to extract iodine crystals from oil-field brines. Favorable test results could lead to a full-scale plant at Dover, which would be Oklahoma's and the nation's second commercial iodine plant.

- Oklahoma Brick Co. began construction of a $7 million, 50-million-brick-per-year plant near Muskogee. The fully automated plant is expected to be 30 percent more efficient than existing brick plants and ready for operation by late 1981.

TABLE 1.—NONFUEL MINERAL PRODUCTION IN OKLAHOMA[1]

Mineral		1979 Quantity	1979 Value (thousands)	1980[p] Quantity	1980[p] Value (thousands)
Clays	thousand short tons	949	$1,999	932	$1,971
Gypsum	do	999	5,668	1,224	9,051
Helium:					
High purity	million cubic feet	388	10,801	310	8,090
Crude	do	109	1,307	50	600
Pumice	thousand short tons	1	W	1	W
Sand and gravel	do	12,101	32,502	12,900	29,600
Stone:					
Crushed	do	28,312	66,666	28,300	74,200
Dimension	do	38	1,383	40	1,532
Combined value of cement (masonry and portland), feldspar (feldspathic sand), iodine, lime, salt, tripoli, and items indicated by symbol W		XX	80,696	XX	98,675
Total		XX	201,022	XX	223,719

[p] Preliminary. W Withheld to avoid disclosing company proprietary data; value included in "Combined value" figure. XX Not applicable.
[1] Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

North African Oil-Shale Deposits Target of New Research Project

Oklahoma Geological Survey petroleum geologist William E. Harrison and German scientist Uwe Tröger are joining forces in a research project involving oil-shale deposits in North Africa.

Areas west of the Red Sea recently were mapped for the first time by two German research institutions—the Technical Institute of Berlin and Berlin's Free University—as part of a program concentrating on studies of climatology, meteorology, and some earth sciences in North Africa.

The maps show that oil-shale deposits exist in a region near the Red Sea in southeastern Egypt, a discovery that prompted Technical Institute scientist Tröger to propose an "organic-geochemical investigation" of the shales.

Harrison is involved in the project through a pending exchange agreement between the Technical Institute and The University of Oklahoma.

An agreement that already existed between the institute and OU's Department of Chemistry probably will be expanded to cover OU departments concerned with earth sciences, Harrison explained. It will call for collaboration between the institutions' faculty and staff on research projects like the Egyptian study, which would be one of the first projects completed under the agreement.

Most of the work will be completed during 1982, Harrison said. He and Tröger will spend approximately two months working in the field collecting samples before returning to Berlin to conduct preliminary chemical analyses of the shales.

In the late stages of the project, more detailed chemical analyses will be conducted at a West German federal research institute managed by Dietrich Welte, one of the world's leading authorities on organic and petroleum geochemistry, Harrison said.

Harrison recently traveled to Berlin to visit with Tröger about the project and to "identify responsibilities." During the project, the Technical Institute will take charge of inorganic-geochemistry studies as well as mineralogy and field work. OU will be responsible for conducting organic-geochemistry work.

The project's results probably will be reported by the two researchers at an international energy conference. Additional studies of shales in the western Egyptian desert, near Libya, may be added as a second phase of the project.

The study has attracted interest from the Egyptian Academy of Science, which has endorsed the project, and from commercial oil interests because of the proximity of the shale deposits to oil fields in the Red Sea and the Gulf of Suez.

The oil in the Red Sea may have originated in the Egyptian shale, Harrison said, because high temperatures at deeper depths are capable of turning organically rich shale into oil.

"The Egyptian Academy wants a detailed description of these oil shales, and industrial interests have a practical interest in finding where the oil in the Red Sea fields originated," Harrison said.

The project also offers Harrison and OGS colleagues an opportunity to test potentially valuable techniques for determining an oil supply's origin.

Techniques for checking correlations between the chemistry of oil shales and the chemistry of oil have been developed by an OGS research assistant and doctoral candidate, Joseph A. Curiale. These techniques will receive their first "full-blown test" in the Egyptian study, Harrison said.

"If the correlation techniques hold up, they will have immediate applications in the petroleum industry," Harrison said. "You couldn't pick a better geologic medium in which to test these techniques than the Egyptian shale."

New OGS Bulletin Describes Cretaceous Pollen and Spores

A new bulletin describing microscopic plant fossils from Cretaceous rocks in four southern Oklahoma counties and a small area in northern Texas has been released by the Oklahoma Geological Survey. The region covered in Oklahoma includes parts of Love, Marshall, Bryan, and Choctaw Counties. The report, prepared by Frederick Huston Wingate, western region palynologist for Cities Service Co. in Denver, describes spores, pollen, and microplankton from the Denton Shale Member of the Bokchito Formation. The fossils he describes are pictured on 17 plates of photomicrographs, and a large chart folded in a pocket indicates their distribution and abundance.

Wingate, who received his Ph.D. at The University of Oklahoma under the direction of L. R. Wilson and George J. Goodman, found the Denton Shale to contain a large and diverse assemblage of the microfossils, including 193 species of pollen and spores. He recovered and described three new form-genera, eight new form-species, and 11 new combinations.

The shale has been dated by ammonite studies of the Denton in north Texas as being of late late Albian age, and this exact dating of the unit and its floral content makes the microfossils described in the bulletin of great value in dating other rocks containing similar assemblages.

Gymnosperm pollen, especially pollen of conifers, is dominant in the assemblage, with angiosperm pollen making up a small but important portion. Fossil microplankton also constitute a valuable part. These microplankton are useful in sedimentological interpretation, occurring in relative abundance at the base of the member and decreasing gradually upward, indicating that the Denton was deposited during a time of marine regression.

Oklahoma Geological Survey Bulletin 130, *Plant Microfossils from the Denton Shale Member of the Bokchito Formation (Lower Cretaceous, Albian) in Southern Oklahoma,* by F. H. Wingate, is available from the Oklahoma Geological Survey at the address on the front cover. The price for the 93-page volume is $12 for clothbound and $8 for paperbound copies.

USBM Grant to Fund Abandoned-Zinc-Mine Project

The Oklahoma Geological Survey (OGS), in cooperation with the state geological surveys of Kansas and Missouri, will begin a two-year project to investigate surface-stability problems associated with past lead and zinc mining in northeastern Oklahoma. The project is funded by a grant from the U.S. Bureau of Mines (USBM) in the amount of $88,643.

Co-principal investigators for the study are Kenneth V. Luza, OGS engineering and environmental geologist, and Donald A. Preston, subsurface and petroleum geologist with the Survey. The area under examination covers the region in the vicinity of Miami, Picher, and Peoria in Ottawa County, the Oklahoma segment of the larger Tri-State Mining District.

Luza and Preston will compile maps showing the location and extent of past mining activities and the resulting surface effects of underground and open-pit mine workings, shafts, ground subsidence, accumulations of mine wastes, and tailing ponds. This background data will then be used to identify hazardous areas that have potential for future damage to people and (or) property, and to propose methods protecting the public from existing and potentially hazardous conditions.

Luza says that the study "will be based largely on available information from public and private records, interviews, visual site inspections, and air-photo interpretations" and that "no drilling of test holes or instrumental surveys are envisioned."

He states further that water-quality problems have been referred to other agencies and will not be included in the investigations, although "the physical effects of the water on surface stability and the effect of recommended corrective measures on future water quality will be considered."

Mining of lead in the Tri-State District began near Joplin, Missouri, in 1848, and the Galena field opened in Kansas in 1876. From 1901 to 1907, several lead-zinc mines were opened near Commerce and Quapaw, Oklahoma, southwest of what became the large Picher field. By 1920, however, most other mines had closed or cut back. From that time through 1950, the Picher field was the leading zinc producer in the United States, with 135 mines and 46 concentrating mills in operation in 1946. All activity in the district ceased with the closing of the last mine in 1970.

Some ore in the area was recovered by open-pit mining, with excavations either isolated or connected to underground workings. The pits are now filled with water, making them attractive spots for sport and recreation. Steep, sometimes unstable slopes, however, make them also potentially dangerous, a condition not always recognized by adventurous youths and others.

In the Picher field, mining was mostly underground, and beds were mineralized over a large vertical range. Chambers with ceilings up to 75 feet high were excavated, supporting pillars were stripped before abandonment of the mines, and overlying beds were not competent to carry the unsustained weight. Roof instability and subsidence have been the result, and, unfortunately, workings are now flooded, making physical inspection of underground conditions difficult or impossible.

The potential safety hazards engendered by these conditions, plus the possibility of harm to the environment, have been recognized for years, and in 1979, congressmen from the three states involved made recommendations to correct the problems. The USBM grant program was formulated in response to those recommendations.

Bob Arndt Named to Top OMMRRI Post

Robert H. (Bob) Arndt, a geologist well-known to many Oklahomans —particularly those associated with the mining industry—has been named director of the Oklahoma Mining and Minerals Resources Research Institute (OMMRRI). He takes over the post from Oklahoma Geological Survey Associate Director Kenneth S. Johnson, who has been administrator of the Institute since its establishment at OU in 1978. Johnson asked to be relieved of the directorship of the Institute in order to resume his full-time duties with OGS.

In addition to directing activities of the Institute, Arndt will serve concurrently on the staff of the Survey as a research geologist, coordinating multidisciplinary research programs focused on mineral production and mineral-industry problems.

OMMRRI (or M_2R_2, as it's known informally) was funded by an initial grant of $110,000 from the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement in accordance with a program designed for states having significant mineral resources. Centers were established to sponsor research and training in economic geology, mining technology and associated fields of mineral processing, marketing, natural resources and supply, and the economic, social, and environmental impacts of the minerals industries (see *Oklahoma Geology Notes,* v. 39, p. 58 and p. 247). Funding has been renewed and supplemented annually, with additional grants awarded to graduate students and faculty members in support of specific research projects.

Bob Arndt is a native of Wisconsin and was born in Milwaukee. He graduated from high school in Wauwatosa, Wisconsin, and received his first degree in geology from Lawrence College in Appleton, Wisconsin. He earned a master's degree, also in geology, from Harvard and pursued additional graduate studies at Harvard during two separate subsequent periods. He is married to Marjorie J. (Herrmann) Arndt, and they have a daughter, Geraldine J. (Arndt) Calderon. Geraldine and her husband, Joe, a U.S. Air Force officer, live in California with their two children. The Arndts own several acres east of Norman and are making plans for a new house on the property.

Bob comes to the Norman campus from a position as State Mineral Specialist for the U.S. Bureau of Mines, where he coordinated information on mineral-related activities of governmental agencies and private industry in a five-state area that covered Kansas, Missouri, Nebraska, New Mexico, and Oklahoma. He also served as project officer, consultant, and observer on USBM programs.

The State Mineral Specialist offices were established in 1979 through consolidation of USBM's structure into regional offices. Prior to that time, the Bureau had maintained an office in each state. Under this system, Bob served for nine years as liaison officer for Oklahoma.

Before coming to the Survey, Bob represented the USBM on numerous boards and committees, served as visiting professor in the School of Geology and Geophysics at OU, as a federal allocation officer for the Federal Energy Office/Federal Energy Administration, and as acting chief of the USBM Bartlesville Mineral Resource Office. For the seven preceding years, he worked as geologist and physical scientist for the Bartlesville office.

Bob has also functioned as a private consultant in magnetite exploration, as a subsurface geologist with Shell Oil Co., and as an engineering assistant for American Smelting and Refining Co. He has held faculty positions at the University of Tulsa, the University of Arkansas, and Hamilton College at Clinton, New York. He was a teaching fellow at Harvard.

Bob Arndt is eminently qualified for the dual appointment he has accepted, and we are extremely glad to have him with the Survey staff.

New Officers Head Oklahoma AIPG

Frederick V. Ballard took over the reins of the Oklahoma Section of the American Institute of Professional Geologists on January 1, 1981. Ballard, a Tulsa consultant, automatically became president on that date, having been first vice president of the group during 1980.

Other Oklahoma Section officers for 1981 include Gary F. Stewart, Oklahoma State University, Stillwater, first vice president and president-elect; Donald P. Moore, Cities Service Co., Tulsa, second vice president; and Thomas C. Cronin, Hoover and Bracken, Oklahoma City, secretary-treasurer.

Rounding out the executive committee are Dorothy J. Smith, consultant, Oklahoma City district representative; Charles C. Riecken, Cities Service Co., Tulsa district representative; Charles W. Johnston, Jr., Seminole consultant, representative-at-large; and Gary A. McDaniel, Oklahoma City consultant, past president.

Notes on New Publications

Future Supply of Oil and Gas from the Permian Basin of West Texas and Southeastern New Mexico: Circular 83

A report of the Interagency Oil and Gas Supply Project, U.S. Department of the Interior and the U.S. Department of Energy, this publication is the first resulting from a projected series of pilot studies on methods of estimating the future supply of oil and gas from the United States.

Mean values of undiscovered oil and gas suggest that about 95 percent of the oil and 83 percent of the gas originally contained in the basin may already have been found.

Order from: Branch of Distribution, U.S. Geological Survey, 604 South Pickett St., Alexandria, Virginia 22304.

Preliminary Map of Coal Strip-Mine Areas in the Conterminous United States

This map, by J. B. Epstein, consists of one oversized sheet, scale 1:5,000,000. The report is on open file at the Oklahoma Geological Survey office in Norman; or order from: Open-File Services Section, Branch of Distribution, U.S. Geological Survey, Box 25425, Federal Center, Denver, Colorado 80225. Price: 50c microfiche; $3.50 paper copy. Order number 80–926.

Leasable Mineral and Waterpower Land Classification Map of the McAlester Quadrangle, Oklahoma and Arkansas

Compiled by D. A. DeCicco, M. A. Baca, and K. M. Robinson, the map is one oversized sheet, scale 1:250,000.

On open-file at the OGS office in Norman; or order from: Open-File Services Section, Branch of Distribution, U.S. Geological Survey, Box 25425, Federal Center, Denver, Colorado, 89225. Price: 50c microfiche; $3.50 paper copy. Order number 80–1037.

National Gazetteer of the United States

The first *National Gazetteer of the United States,* containing over 1½ million place and feature names, is being prepared by the U.S. Geological Survey in cooperation with the U.S. Board on Geographic Names.

Along with the official name of a natural or cultural feature, the Gazetteer will list the kind of place or feature named, the county and geographical coordinates, elevation, the date the name became official, and the USGS map or maps on which the feature can be found.

The publication, which will help eliminate large expenses incurred by other agencies and institutions for duplicate information, is expected to be complete by 1982, with individual state chapters being finished earlier.

For more information on the Gazetteer program, contact: Donald Orth, USGS Branch of Geographic names, 523 National Center, Reston, Virginia 22092.

Seismic Stratigraphic Interpretation and Petroleum Exploration

A new publication of the AAPG Education Department, this book is authored by L. F. Brown, Jr., and W. L. Fisher, Bureau of Economic Geology, University of Texas at Austin.

Order from: AAPG, P.O. Box 979, Tulsa, Oklahoma 74101. Cost: $11 ($10 each for 10 or more copies). Catalog number 890.

Volumes I and II: Fall Education Conference '80

The AAPG Fall Education Conference was held August 25–28, 1980, in Houston, by the Education Department of the AAPG. A limited supply of course notes (Vols. I and II) are available for those who were unable to attend the conference and who are first to order.

Order from: AAPG Education Department, P.O. Box 979, Tulsa, Oklahoma 74101. Cost: $55 for both volumes (not sold separately).

Seismic Exploration for Sandstone Reservoirs

Author Nigel A. Anstey reviews briefly the seismic method, and then sets out the seismic signatures for sandstone bodies that are recognized mainly by their appearance in section. He continues with a discussion of those whose recognition depends also on their appearance in plan. The book reviews existing and emergent techniques for the seismic delineation of sandstone reservoirs.

Order from: IHRDC, 137 Newbury Street, Boston, Massachusetts 02116. Price: $32.

The Oklahoma Petroleum Industry

Written by Kenny A. Franks and published by The University of Oklahoma Press, *The Oklahoma Petroleum Industry* tells the story of the men, the technology, and the luck that shaped the oil business in this State.

Dr. Franks, with the cooperation of the Oklahoma Petroleum Council and numerous individuals and companies, interviewed early-day pioneers and gathered first-hand information in many areas of the State.

Order from: The University of Oklahoma Press, 1005 Asp Avenue, Norman, Oklahoma 73019. Price: $17.50.

Seismic Stratigraphy

The concepts and methods of seismic stratigraphy are outlined in this book by Robert E. Sheriff. Twelve four-color seismic sections and a glossary of terms are included with information particularly useful to exploration geologists and geophysicists.

Order from: IHRDC, 137 Newbury Street, Boston, Massachusetts 02116. Price: $29.

Seismic Prospecting for Oil

C. Hewitt Dix received the SEG's 1979 Maurice Ewing Award for his various achievements, which include this reference book for the practice of exploration geophysics. The 414-page volume was first published in 1952. Dr. Dix has now added comments from the perspective of a lifelong geophysicist to each chapter in the new edition.

The Australian Mineral Foundation comments that the text is "designed to update the seismic operator and interpreter, whether he be geologist or geophysicist. It is first class material."

Available from: IHRDC, 137 Newbury Street, Boston, Massachusetts 02116. Price: $29.

America's Energy Famine: Its Cause and Cure

Domestic and foreign issues underlying the current energy crisis are discussed in this new publication of The University of Oklahoma Press.

Ruth Sheldon Knowles, internationally known petroleum specialist and the daughter and granddaughter of independent Oklahoma oilmen, spells out the hard choices she sees the American public facing on energy priorities in the near future.

In this book, the author examines the roles of conservation and solar power, the timetable for America's energy self-sufficiency, and the politics and economics of today's energy programs.

A resident of New York City, Knowles is the author of *The Greatest Gamblers: The Epic of American Oil Exploration,* which is also published by The University of Oklahoma Press.

America's Energy Famine is available from: The University of Oklahoma Press, 1005 Asp Ave., Norman, Oklahoma 73019. Price: $14.95.

OKLAHOMA ABSTRACTS

GSA Annual Meetings
Atlanta, Georgia, November 17–20, 1980

The following abstracts are reprinted from *Abstracts with Programs* of the Geological Society of America, v. 12, no. 7. Page numbers are given in brackets below the abstracts. Permission of the authors and of James R. Clark, publications manager of GSA, to reproduce the abstracts is gratefully acknowledged.

Distance From Shoreline in Unfossiliferous Marine Mudrocks

HARVEY BLATT and MATTHEW W. TOTTEN, School of Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma 73019, and K. and E. Petroleum, Inc., Wichita, Kansas 67202

The Blaine Formation (Guadalupean) in western Oklahoma is a widespread sequence of shale and gypsum beds 10-60m thick deposited in a shallow seaway within 20my. The position of the shoreline was established from stratigraphic studies. A regional collection of 89 surface and 17 subsurface shale samples from the Blaine was analyzed using sodium bisulfate fusion and micromesh sieving to determine whether the grain size and percentage of quartz decreased in a systematic manner with distance offshore.

The percentage of quartz silt in Blaine shales decreases with increasing distance from shoreline (sand/mud line); $r = -.68$ ($P = .999$). The mean size of the quartz also decreases; $r = -.67$.

$$\%\ \text{qtz} = -0.17\ \text{distance from shore (km)} + 56.0$$
$$\text{mean size qtz } (\phi) = 0.007\ \text{distance from shore (km)} + 4.82$$

Samples were collected at distances between 60 km and 270 km from the sand/mud line in the Blaine Sea. Extrapolation of the regression lines to the sand/mud line indicates 56% quartz, 44% clay minerals, and $\overline{x}_{qtz} \times 4.8\phi$. These values are consistent with accepted definitions of conditions at a sand/mud boundary.

OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings, that have not yet been published.

Hypopycnal plane jet flow provides a satisfactory explanation of the relationships found. Muddy sediment from deltas is spread hundreds of km into a depositional basin as a surface layer above the denser saline water before settling to the basin floor. While settling, the mud is partially dispersed by currents to produce the scatter in the data. Resulting trends are sufficiently precise to establish the location of the sand/mud line in the Blaine Sea to ±100 km with 95% certainty. [388]

Different Modes of Formation of Anomalously High Radioactivity in Oil-field Brines: Possible Applications in Exploration for Hidden Uranium Mineralization in Petroliferous Areas

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Many oil-field brines contain anomalously high Ra-226 and/or Ra-228 concentrations and are characterized by a severe disequilibrium between these isotopes and their parents, U-238 and Th-232. The transfer of radium isotopes from rock to fluid can take place through partial or complete dissolution of mineral grains, leaching (which, unlike dissolution, does not involve the destruction of the crystal lattice of minerals), and alpha-recoil processes. A straightforward correlation between Ra-226 in oil-field brines and its parent, U-238, in rocks would be a very useful tool in exploration for uranium in petroliferous areas. However, such a correlation is not known to exist.

A proposed theoretical model suggests that high Ra-226 concentrations in brines can be either a function of the geochemical environment of petroleum reservoirs or uranium occurrences associated with oil pools. Relatively high Ra-226/Ra-228 and Ra-226/Ba ratios occurring simultaneously in brine samples can be interpreted as being associated with subsurface uranium mineralization. Ra-228 provides a measure of the significance of recoil events as a factor responsible for the presence of excess radium in brines, whereas the amount of Ba indicates the importance of dissolution as a possible cause of anomalously high Ra-226 concentrations in brines.[388]

The Layered Nature of the Upper Precambrian Crust South of the Wichita Mountains, Oklahoma, Revealed by COCORP Deep Seismic Reflection Profiling

JON A. BREWER, DAVID STEINER, LARRY D. BROWN, JACK E. OLIVER, and SIDNEY KAUFMAN, Department of Geological Sciences, Cornell University, Ithaca, New York 14853

COCORP deep crustal seismic profiles in the Hardeman basin and Wichita mountains of northern Texas and southwestern Oklahoma reveal unusually strong and persistent reflecting horizons in the Precambrian crust south of the Wichita mountains at depths at about 7.5, 10 and 13 km. Thus the Precambrian has a distinctive layered nature, very rarely seen on COCORP data. The reflecting horizons are remarkable because of their high amplitude and continuity over an area of at least 2500 km^2 and perhaps much more. If these horizons could be traced to subcrop or outcrop and hence unequivocally unidentified, the Precambrian geology of a large part of the midcontinent might be revealed.

Distinctive reflecting horizons in Precambrian crust could be caused by sedimentary, igneous or tectonic processes, but the seismic character and extent of the layering suggest that depositional processes were at least partly responsible. Thus a deep Proterozoic basin may lie on the south side of the Wichita uplift, probably filled largely with clastic sediments and felsic volcanics. The horizons are truncated on the south side of the Wichita uplift, and the crust within the uplift does not have the same layered nature. The truncation could be caused by faulting or intrusions. Gravity and magnetic data indicate little density or magnetic contrast across the truncation, and a major Precambrian fault (high-angle reverse or strike-slip) seems most consistent with all the data. The position of the Wichita mountains (a Pennsylvanian uplift) was probably controlled by these Precambrian structures. The trend of the Wichita mountains can be traced into Colorado, where similar Precambrian structures may have influenced some of the uplifts of the Ancestral Rockies. [391]

Deep Burial Diagenesis of Carbonates in the World's Deepest Wells

GERALD M. FRIEDMAN and S. ANNE REECKMANN, Department of Geology, Rensselaer Polytechnic Institute, Troy, New York 12181

The world's deepest wells from the Anadarko Basin of southwest Oklahoma penetrate Late Ordovician to Early Devonian carbonates at depths of around 30,000′ (9 km). The rocks at this depth are at 210°C and approximately 2.5 kb of pressure which corresponds to the zone of very low-grade metamorphism.

Within the limestones large calcite crystals show extensive twin development with bending and multiple displacement along twin lamellae. Granulation or cataclastic textures have developed around large calcite crystals and along twin glide planes. Pressure solution has produced numerous stylolitic surfaces and there has been extensive aggrading recrystallization of micrite which increases with depth of burial. There are no obvious changes which would indicate the development of metamorphic minerals in the limestones even though the rocks are approaching the greenschist facies of metamorphism.

At 30,000′ the limestones are tight compared to dolomites which, at 26,500′, still retain in excess of 20% porosity and are viable gas producers. [429]

Metallogenic Map of North America

PHILIP W. GUILD, U.S. Geological Survey, Reston, Virginia 22092

An international project to depict the principal ore deposits of North America in relation to their geologic settings is approaching completion. A moderately complex symbology shows the following information about a deposit or district: 1) the principal metals (and some nonmetallic minerals) contained; 2) its relative size (large, medium or small); 3) its geologic environment with respect to a) the enclosing sedimentary and (or) volcanic rocks and b) associated igneous rocks, if any; 4) its geologic class; 5) the age of mineralization; and 6) the general class (oxide, sulfide, etc.) of the ore minerals. The geologic base map distinguishes stratified rocks on the basis of: 1) their age, 2) their nature, especially if they have volcanic constituents, and 3) their general structural and metamorphic condition (undeformed, folded, moderately or highly metamorphosed). Intrusive rocks are divided on the basis of their petrologic nature (alkaline, granitic, mafic, or ultramafic) and ages (of granitic rocks only) relative to principal orogenies.

The base map is that of the 1969 "Tectonic Map of North America" compiled by P. B. King, scale 1:5,000,000. The geologic background will be in relatively pale colors and patterns; mineral deposits, in bright colors. More than 4,000 deposits (or districts) have been plotted on the map and also entered into a computer file for sorting, retrieval, and automatic plotting. [439]

Early Geologic Education at the Universities of Oklahoma and Chicago: Comparisons and Contrasts

DANIEL J. JONES, Department of Physics and Earth Sciences, California State College, Bakersfield, California 93309

The early history of the Departments of Geology of the Universities of Oklahoma and Chicago is quite similar in that both institutions developed their curricula in response to the mineral resource development of the regions near which they were established.

Both institutions opened their doors to students in 1892. The early curriculum and faculty at Chicago reflect the intense interest in the Precambrian iron and copper ores of Michigan and Minnesota, and the igneous and metamorphic terrain of the Great Lakes region. Chicago's first faculty included T. C. Chamberlin, R. D. Salisbury, C. R. Van Hise, Arthur P. Iddings and R. A. F. Penrose, Jr.

The discovery of oil in Oklahoma in 1897 prompted a demand for training of geologists for oil and gas exploration. The Department of Geology was established in 1901 under Dr. Charles N. Gould, who taught introductory geology, physiography, mineralogy, economic geology, paleontology, and "lithology". The summer field course utilized the excellent Paleozoic exposures of the Arbuckle Mountains.

The increase in demand for iron, copper, lead, zinc, and petroleum induced by World War I continued into the 1920's, and both departments grew rapidly in size and in scope of curricula. Many of the Ph.D. graduates from Chicago became the foundation of the strong department at Oklahoma, including Professors C. E. Decker, C. A. Merritt, F. A. Melton, M. G. Mehl, and G. E. Anderson.

The American Association of Petroleum Geologists was established in 1916 on the campus of the University of Oklahoma and many successful petroleum geologists endowed scholarships and fellowships at the University of Chicago. [456]

Sulfur Isotope and Hydrochemical Variations in Ground Water in the High Plains of Kansas and Oklahoma

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The Ogallala Formation is the principal aquifer underlying the High Plains and the only source of water for irrigation in a large part of the plains. Withdrawal of water from the aquifer is depleting the supply of ground water in many areas of the High Plains. Water quality has deteriorated in some areas due to leaching caused by irrigation and the upward leakage of poorer quality water from lower aquifers. This paper is part of a 5-year study of the High Plains Regional Aquifer System being conducted by the United States Geological Survey.

Regional ground-water flow is from west to east across Kansas and Oklahoma and the specific conductance of ground water increases in the direction of flow. The increase in dissolved solids may be influenced by residence time but bedrock appears to control ground-water chemistry. The Ogallala Formation is underlain by Mesozoic rocks in the west and Permian rocks in the east. The average specific conductance is 650μ (micromhos at 25°C) and 6770μ in the water from the Mesozoic and Permian respectively. The water in the Ogallala Formation overlying the Mesozoic and Permian rocks has mean specific conductance values of 482μ and 650μ respectively. $\delta^{34}S$ values range from a high of 3.6°/oo in the west to −25.1°/oo in the east. Dissolved oxygen values range from a high of 13.4 mg/l in the west to a low of 3.9 mg/l in the east. Sulfate increases from 20 mg/l to 300 mg/l from west to east.

Increasing specific conductance, lighter $\delta^{34}S$ values, lower dissolved oxygen and increasing SO_{42-} in the east indicate that ground water in the Permian rocks is flowing upward into the Ogallala Formation. [466]

Silurian–Devonian Boundary Correlation in Eastern United States

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The Silurian-Devonian boundary has been widely recognized using biostratigraphic criteria other than the first occurrence of *Monograptus uniformis* for correlation to the boundary stratotype in Czechoslovakia. The conodont *Icriodus woschmidti,* which occurs an average of two meters below the boundary in Europe, the Yukon, and Nevada, also occurs in skeletal packstones and grainstones of the Decatur and Rockhouse formations of west-central Tennessee. In its type area, the Decatur is essentially a thickly bedded stylolitic sequence of echinodermal packstones with thin, well-washed grainstones and contains an extremely sparse brachiopod and bryozoan fauna with occasional fistuliporid bryozoan boundstones. Microbiota include a variety of arenaceous foraminifers, ostracodes, and the conodonts *Ozarkodina* sp., *O.* cf. *O. remscheidensis, Belodella* sp., and *Panderodus* sp.; *Icriodus woschmidti* occurs in the upper one to two meters. In contrast to the Decatur, the thinner bedded overlying Rockhouse contains a more diverse macrobiota with co-dominant crinoids and brachiopods and is commonly glauconitic. The Rockhouse brachiopod fauna resembles that in the Haragan Formation (Early Devonian) of Oklahoma. Rockhouse condonts include *O.* cf. *O. remscheidensis, Belodella* sp., and *I. woschmidti* that differ from specimens in the Decatur in possessing a denticulate rather than a smooth lateral process. Similarly denticulate forms have been reported previously from the Coeymans Formation in New York and from the Yukon and Nevada (*I. w. hesperius*). Thus, based on faunal correlation, the Decatur is late Silurian (Pridoli) in age and possibly as young as earliest Devonian (Lochkov) at the top, and the Rockhouse is probably entirely of Lochkovian age. [479]

Stratigraphic Patterns of Pennsylvanian Coal Swamps in Midcontinent and Appalachian Regions of the United States

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Stratigraphic patterns of swamp vegetation are compared with identified coal resources in eastern United States, regionally plotted for 123 coals with $>10^8$ short tons each. Resources of Western and Eastern Interior Coal Provinces (20 and 23 coals; 51×10^9 and 241×10^9 short tons, respectively) are 93-99% of Desmoinesian age, the wettest interval. Appalachian resources (79 coals and 296×10^9 short tons) occur as follows: 1.9% Pocohontas; 10.2% New River; 30.6% Kanawhan; 34.8% Alleghenian; 1.8% Conemaughian, the least wet interval; and 20.7% Monongahelan and lower Dunkard. Transition from wettest to least wet conditions coincided with major changes in Euramerican swamp vegetation from dominant lycopod trees to tree-fern swamps and some marshlands.

Interregional differences in basinal subsidence, drainage systems and proximity to sediment sources and seas are superposed on comparisons of wetness derived from coal resources and vegetational patterns derived from fossilized peat. Appalachian swamp patterns have a south-north trend with rainfall generally diminishing westward across the Interior Coal Province. Rainfall in the Illinois Basin was augmented by freshwater from the Michigan River System. Freshwater supply is implied for brackish, mangrove-like swamps which occurred early in middle Pennsylvanian in the Appalachians and attained a zenith in the Western Interior Coal Province by early Desmoinesian. Such swamps diminished west to east, ending prior to Springfield (No. 5) Coal deposition. The wet interval in the Dunkard Basin in the latest Pennsylvanian also diminished westward but some major swamps occurred in the Interior Coal Province. [498]

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