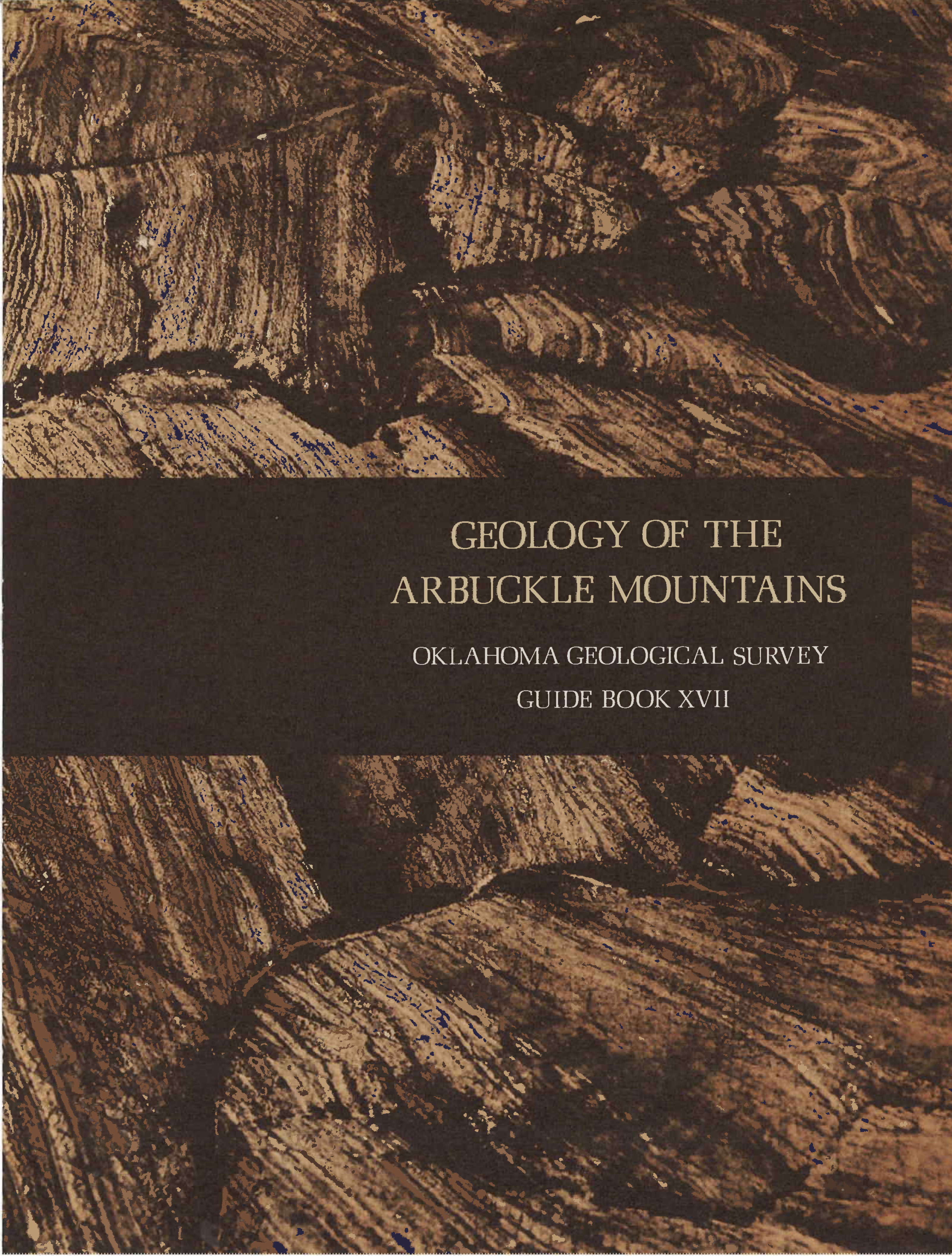


GEOLOGY OF THE ARBUCKLE MOUNTAINS

OKLAHOMA GEOLOGICAL SURVEY

GUIDE BOOK XVII

OKLAHOMA GEOLOGICAL SURVEY
CHARLES J. MANKIN, *Director*
GUIDE BOOK XVII

Regional Geology of the Arbuckle Mountains, Oklahoma

WILLIAM E. HAM
Geologist, Oklahoma Geological Survey; Visiting Professor of Geology, The University of Oklahoma

with contributions by
JAMES H. STITT
JAMES R. DERBY
ROBERT O. FAY
and
A. ALLEN GRAFFHAM

The University of Oklahoma
Norman
1969

CONTENTS

Table

Regional Geology of the Arbuckle Mountains Oklahoma

Part I. Regional Geology

William E. Ham

INTRODUCTION

The geological province known as the Arbuckle Mountains consists of a huge inlier of folded and faulted Paleozoic and Precambrian rocks, covered on the east, north, and west by gently westward-dipping Pennsylvanian and Permian strata and on the south by gently southward-dipping Early Cretaceous sediments of the Gulf Coastal Plain.

This inlier is a roughly triangular area of nearly 1,000 square miles, almost in the center of the southern third of Oklahoma. The geology is characterized mostly by outcrops of carbonate rocks. Immediately to the east begins the 200-mile-long exposure of the Ouachita Mountains, principally a flysch sequence that is quite unlike the Arbuckles in stratigraphic and structural development; and 100 miles to the west are the Wichita Mountains, unlike either the Arbuckles or Ouachitas and characterized chiefly by extensive outcrops of Cambrian (not Precambrian) igneous rocks. Thus, the three uplifted segments of southern Oklahoma actually share little in common, despite their geographic proximity, and each has a profoundly different geologic emphasis.

The primary emphasis of Arbuckle Mountains geology lies in its Early Paleozoic carbonates and Late Paleozoic clastics, deposited partly upon a craton of Precambrian) igneous rocks. Thus, the three uplifted clinal basin, the whole welded by Pennsylvanian orogeny and epeirogeny into a single geographic unit. This geographic simplicity is misleading, as will be shown on following pages.

Reference to the Arbuckle outcrops as the Arbuckle "Mountains" likewise is misleading because about 80 percent of the area consists of gently rolling plains. Only in the western area—that of the Arbuckle anticline—is the topographic relief sufficient to evoke comment from the newcomer. The greatest relief is along U. S. Highway 77. In this area, the Washita River flows at an elevation of 770 feet, and 3 miles away is the top of the East Timbered Hills—the crest of the Arbuckle anticline and, with an altitude of 1,377 feet, the highest point in the Arbuckle Mountains. This total relief of 607 feet is impressive only because it is some six times greater than that of any other topographic feature between Oklahoma City and Dallas.

Whether plains or hill country, the Arbuckle Mountains region is of irresistible interest to geologists. Its 11,000 feet of fossiliferous Late Cambrian through Devonian strata constitute the best outcrops and greatest area of exposure of this sequence in all the Midcontinent region. Stratigraphic names taken from the Arbuckles, such as Arbuckle, Simpson, Viola, Sylvan, Hunton, and Woodford, have been widely applied in the subsurface as far away as West Texas, Illinois, and Nebraska. The 150-square-mile exposure of Precambrian granites in the eastern Arbuckle Mountains is the largest and best outcrop of such rocks in the central United States between the Llano area of Texas and the Black Hills of South Dakota. Finally, as much as 19,000 feet of Mississippian and Pennsylvanian clastics are present in the region, partly in synclinal grabens of the Arbuckle Mountains and to a much greater extent in the adjoining Ardmore basin. Fusulinids from thin Pennsylvanian limestones in this sequence are widely used as standards of reference.

The processes of strong uplift and deep erosion that have produced the Arbuckle Mountains of today have also resulted in the surface exposure of rocks that normally are deeply buried. Among the rocks are many that are commercially valuable, such as limestones from thick and widely distributed outcrops of the Arbuckle and Viola Formations that are extensively quarried as a source of crushed stone, high-purity silica sand from the Simpson Group for glass making and other industrial use, cement-making raw materials from the Viola Limestone and Sylvan Shale, high-purity dolomite from the Arbuckle Group, and building and monumental stone from Precambrian granite. Geologists are especially indebted to the stone industries for the magnificent exposures in these quarries.

Of much greater economic value are the resources of petroleum and natural gas in southern Oklahoma. The intensive search for petroleum has resulted in the drilling of perhaps 75,000 wells. Pauls Valley, Fitts, Cumberland, Eola, Tatums, and Fox-Graham are well known to Oklahoma geologists as near-giant oil fields that occur as subsurface extensions of the Arbuckle Mountains. Thus, south-central Oklahoma, with its excellent outcrops and vast store of subsurface information, is one of the better known geological provinces in the world.

BASEMENT ROCKS

A geologic map of the United States strikingly illustrates the virtual absence of outcropping basement rocks in the vast central interior. Five major areas of relatively small outcrop are known, however, and each is important in representing the structural crest of a major uplift. In three of these areas—Black Hills of southwestern South Dakota, St. Francois Mountains of southeastern Missouri, and the Llano area of central Texas—Precambrian basement rocks are exposed at the crests of broad cratonic domes. In the fourth area, that of southern Oklahoma, the basement rocks are unique in that they are exposed along the margins of a profound intracratonic geosynclinal sag and consist mostly of igneous flows and intrusives of Cambrian, rather than Precambrian, age.

These young basement rocks of southern Oklahoma, isotopically dated at 500 to 550 million years, are exposed extensively in the Wichita Mountains of southwestern Oklahoma and in a much smaller area at the

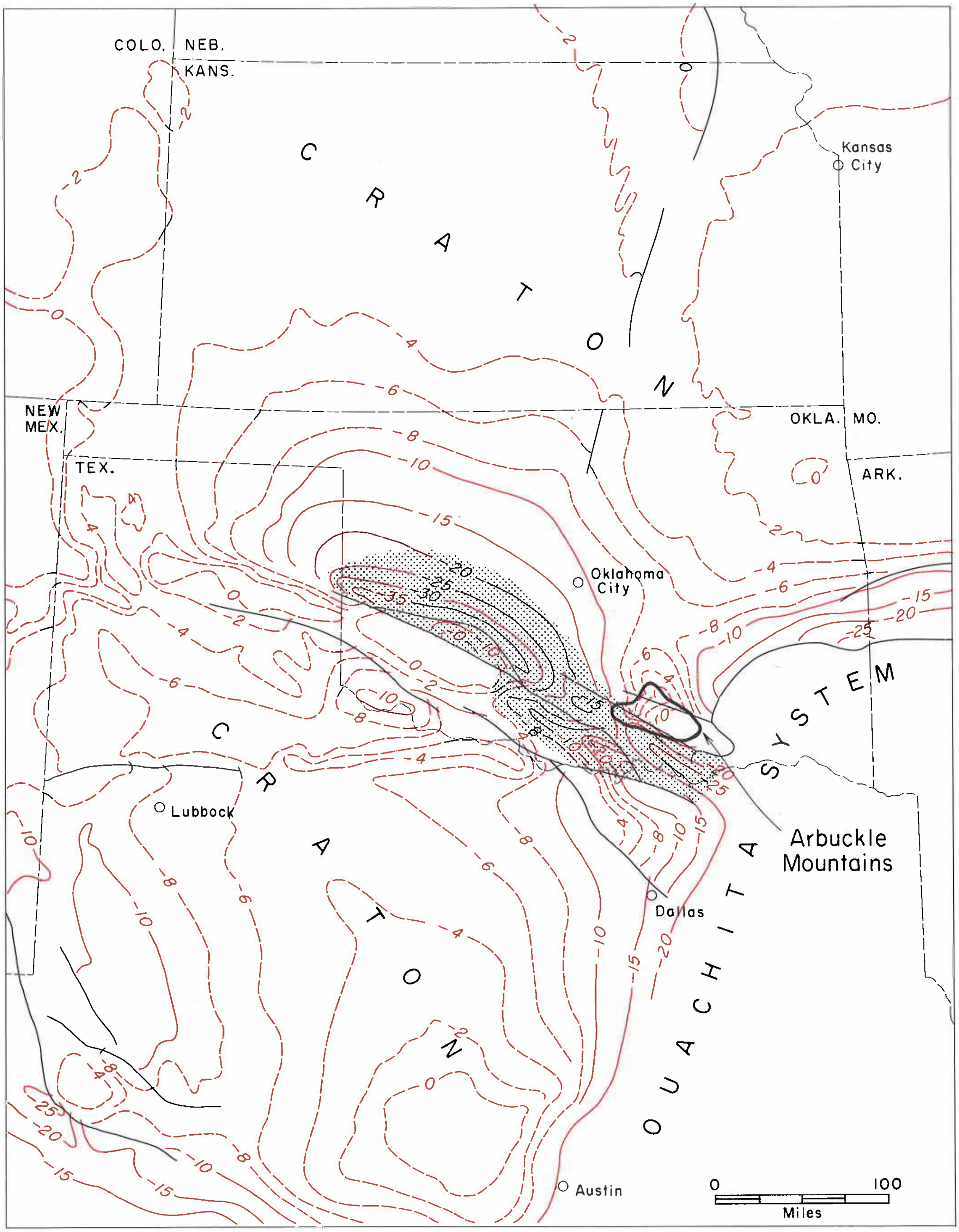


Figure 1. Basement Map of Oklahoma and Adjoining Areas
(See explanation, opposite page)

southwestern edge of the Arbuckle Mountains. Significantly, they are known from drilling data to continue in the subsurface between these uplifts and to underlie all or most of the intracratonic geosyncline.

At the top of the Cambrian basement-rock sequence are rhyolite flows and tuffs, called the Carlton Rhyolite Group, that attain a known thickness of nearly 5,000 feet, and these are underlain by spilitic basalts and tuffs with a maximum drilled thickness of 1,050 feet. A Cambrian basement floor of flows and tuffs, probably at least 7,500 feet thick, is not known elsewhere in the United States, and of even greater interest is the position of this sequence at the base of the outstanding deep basin, or geosyncline, of the North American craton. These two features cannot be related by mere coincidence; instead, the Cambrian flows and pyroclastics must represent the beginning stage of a transverse trough that persisted throughout Paleozoic time and was filled to a thickness of at least 45,000 feet. This trough has been named the Southern Oklahoma geosyncline.

Against this singular background, the Arbuckle Mountains play a further singular role in containing within their outcrop area the sharply defined contact between rocks of the Southern Oklahoma geosyncline and those of the adjoining cratonic shelf. Over the northern three-fourths of the Arbuckle Mountains, the basement rocks are Precambrian granites of the stable craton, extending from eastern Arbuckle Mountains outcrops northward through central Oklahoma into Kansas and beyond (fig. 1). At a fault contact, these rocks are separated from the southwestern segment of the Arbuckle Mountains, known as the Arbuckle anticline, in which the basement rocks are Cambrian rhyolites and the Paleozoic depositional and structural history is that of the geosyncline. The geosyncline includes the Arbuckle anticline and extends southward for about 50 miles, across the Ardmore basin and Marietta basin and terminating in the subsurface of northern Texas against the Precambrian cratonic rocks of that state (fig. 1).

Outcrops of basement rocks in the Arbuckle Mountains can be seen at three stops of the road log. In the Arbuckle anticline this rock is the 525-million-year-old Colbert Rhyolite, the equivalent of the Carlton Rhyolite Group but locally named for exposures along Colbert Creek in the West Timbered Hills. It is shown at Stop I-5, near the crest of the East Timbered Hills (fig. 2). The Colbert Rhyolite, with a drilled thickness of 4,500 feet on the southwest flank of the Arbuckle anticline and encountered in at least six wells on the north flank, marks the northeasternmost occurrence of Cambrian basement rocks. All other structural segments of the Arbuckle Mountains are underlain by deeply eroded Precambrian mesozone granites, exposed as the Tishomingo Granite and Troy Granite (Stops II-2, II-3) and encountered in many wells of the region. One of these wells penetrated nearly 11,000 feet of granites and diorites, isotopically dated at 1,200 m.y. to 1,350 m.y., and established a probable world-record penetration of basement rocks.

Details of basement-rock geology of southern Oklahoma, including petrology, distribution, and isotopic ages of the igneous rocks and their relation to the development of the Southern Oklahoma geosyncline, are contained in the comprehensive report by Ham, Denison, and Merritt (1964). An amplification of the geosynclinal concept is contained in the report by Ham and Wilson (1967).

PALEOZOIC STRATIGRAPHY

Southern Oklahoma Paleozoic sediments, exclusive of the Ouachita Mountains, are divisible into four major lithostratigraphic units: (a) Late Cambrian-Early Devonian marine sediments, mostly carbonates; (b) Late Devonian and Mississippian dark shales; (c) Pennsylvanian dark shales, sandstones, thin marine limestones, and local conglomerates; and (d) Permian red shales, sandstones, and halite-gypsum evaporites. As shown in figure 3, the thickness of sediments in each of these Paleozoic units is greatest in the Southern Oklahoma geosyncline and least on the cratonic margins. The fullest representation is in the Anadarko basin, or western deep segment of the geosyncline, where Late Cambrian through Permian sediments are 38,000 feet thick and rest upon Middle Cambrian volcanic flows and tuffs, probably at least 7,000 feet thick. An essentially similar Paleozoic sequence is present in the eastern deep segment of the geosyncline, including the Ardmore basin and Arbuckle anticline, except that in this area the youngest Pennsylvanian and most of the Permian sediments are eroded. The sediments preserved—Late Cambrian through late Middle Pennsylvanian—are 34,000 feet thick, and they too rest upon a floor of Middle Cambrian volcanics. Beyond the geosyncline are elements of the stable craton, characterized by Paleozoic sediments about 10,000 feet thick, a thickness that is only about one-fourth that found within the geosyncline. In addition to the marked differences in thickness are the following notable differences in facies: the Late Cambrian-Early Ordovician Arbuckle Group is dominantly limestone in the geosyncline and dolomite upon the craton; Mississippian sediments are dark shales in the geosyncline and limestones upon the craton; and the Pennsylvanian sediments are chiefly dark shales and sandstones in the geosyncline, whereas on the craton they contain, relatively, much more limestone. The remaining rocks display few facies differences, but it is noteworthy that the three systems cited above account for approximately 70 percent of the geosynclinal filling.

The Late Cambrian-Mississippian sediments are better exposed and better known in the Arbuckle Mountains than in any other part of the southern Midcontinent region. Stratigraphic nomenclature and age assignments, as given in figure 4, provide outcrop comparisons between geosynclinal and cratonic sediments and also serve as a basis for stratigraphic work over a vast, oil-rich subsurface region.

Figure 1. Basement map of Oklahoma and adjoining areas, showing regional setting of the Arbuckle Mountains. Configuration of the basement surface is given by contours drawn at 2,000-foot (dashed) and 5,000-foot (solid) intervals; sea-level datum. Modified from "Basement Map of North America" (Amer. Assoc. Petroleum Geologists and U. S. Geol. Survey, 1967). Cratonic elements of northern Texas, northern Oklahoma, and Kansas contain thin Paleozoic sediments underlain by stable Precambrian rocks dated at 1,000-1,400 m.y. The great intracratonic sag of southern Oklahoma, shown in black stipple, is geosynclinal and contains 38,000 feet of Late Cambrian through Permian sediments; it is underlain by thick volcanic flows and associated intrusive rocks dated at 525 m. y., probably of Middle Cambrian age. The Arbuckle Mountains (thick black line) lie astride the contact between the cratonic province and the geosynclinal province and thus manifest the strongly contrasting features of each.

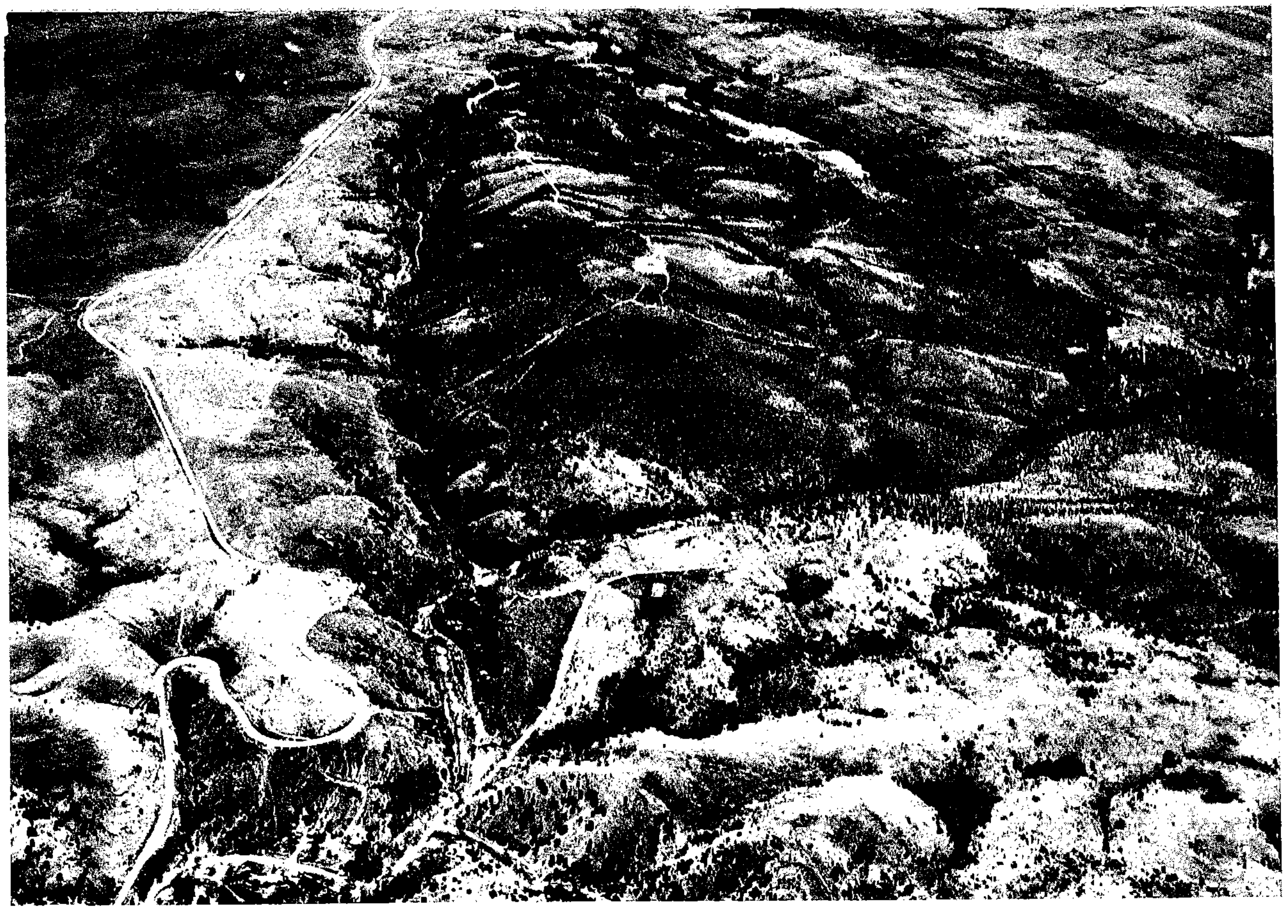


Figure 2. Oblique aerial photograph of the East Timbered Hills in the Arbuckle Mountains, looking southward along U. S. Highway 77. Rhyolite supporting the hills is the typical rock of the Southern Oklahoma geosyncline beneath Late Cambrian sediments, seen here in homoclinal succession at upper right of photograph.
(Photograph copyright by F. A. Melton)

Early Paleozoic Carbonates

Late Cambrian through Early Devonian sediments constitute about 90 percent of the Arbuckle Mountains outcrops and can be seen at many stops of the road log. In maximum development over the Arbuckle anticline the sequence is 11,000 feet thick and consists mostly of limestones (figs. 4, 5). Over the Hunton anticline the equivalent beds are 6,500 feet thick and also consist mostly of carbonates, although the Arbuckle Group, making up about two-thirds of the sequence, is dolomite rather than limestone. The stratigraphic units, listed in ascending order, are the Timbered Hills Group, Arbuckle Group, Simpson Group, Viola Limestone, Sylvan Shale, and Hunton Group. Details of distribution and stratigraphic relations of the major units are contained in other sections of the guidebook, at localities where representative strata are seen in the field. A condensed summary of outstanding regional characteristics is given below.

Timbered Hills Group. Following the long-continued exposure of the Precambrian granites and the somewhat shorter exposure of the Cambrian geosynclinal volcanics, craton-wide submergence permitted the widespread deposition of transgressive Late Cambrian sandstones. In the Arbuckle Mountains they are known as the Reagan Sandstone, a feldspathic and normally glauconitic sequence of Franconian age. Owing to the irregularity of its depositional surface, the thickness of the Reagan ranges from 75 to 450 feet, and the formation is absent around local granite islands that stood in the Late Cambrian sea. The sandstone is succeeded upward by the Honey Creek Formation, consisting of a thin, trilobite-rich pelmatozoan limestone that is 100 feet thick in the Arbuckle anticline and grades into a sequence of fossiliferous sandy dolomites about 225 feet thick upon the craton.

Arbuckle Group. Without stratigraphic discontinuity, the sediments continue upward as carbonates of the Arbuckle Group, which embraces late Franconian, Trempealeauan, and all of Canadian time. Of shallow-water marine deposition, the Arbuckle rocks are, in part, richly fossiliferous and contain trilobites, brachiopods, mollusks, pelmatozoans, sponges, and, well toward the top, graptolites. In the Arbuckle anticline the strata consist dominantly of interbedded thin carbonate mudstones, intraclast calcarenites, oölitic calcarenites, stromatolites, and laminated dolomites or dolomitic limestones. Upon the craton these strata consist of similar limestones that have been wholly dolomitized. Retained, however, are certain faunal elements that had been previously silicified, and, in this way, satisfactory interregional correlations have been established. The Arbuckle Group has a maximum thickness of 6,700 feet (column A, fig. 4), and thus it is one of the great carbonate sequences of the world. Because of this great thickness, outcrops of Arbuckle rocks dominate large segments of the Arbuckle Mountains.

Simpson Group. Rocks of the Middle Ordovician Simpson Group represent a great change in depositional environment over that of the Arbuckle Group. Cleanly washed sand is introduced in large volume for the first time, greenish-gray shale is present in well-defined beds, and many of the limestones are either skeletal calcarenites or algal-mat carbonates, of types that are decidedly rare in Early Ordovician rocks. Bryozoans make an abrupt and profuse appearance; cystoids are abundant and crinoids appear for the first time; brachiopods appear in new and much greater variety; and mollusks, sponges, and trilobites persist throughout. Conspicuously absent are (1) hemispheroidal stromatolites, which characterize the very shallow-water environment of the underlying Arbuckle Group, and (2) graptolites, which characterize the deeper water environment of the overlying Viola Limestone.

Division of the group, as originally made by Decker (Decker and Merritt, 1931), includes, at the base, the Joins Limestone, followed successively upward by the Oil Creek, McLish, Tulip Creek, and Bromide Formations. Each of the upper four formations contains a prominent basal sandstone, generally 50 to as much as 350 feet thick and consisting of well-sorted, rounded, and frosted quartz grains. In the subsurface these sandstone beds make excellent petroleum reservoirs, and on the outcrop they are mined as high-purity silica sands for the manufacture of glass and other industrial uses.

The Simpson Group embraces the post-Canadian and pre-Trentonian part of the Middle Ordovician Epoch and is assigned principally to the Chazy and Black River Stages, but it also includes the White Rock, Marmor, Ashby, Porterfield, and lower part of the Wilderness Stages of Cooper (1956). According to recent investigations by Derby (see pages 35-37), the base of the White Rock Stage in the Arbuckle Mountains is not at the base of the Joins, as previously believed, but nearly 100 feet below, in the upper part of the West Spring Creek Formation at the top of the Arbuckle Group. This faunal discontinuity is not accompanied by physical evidence for unconformity.

Maximum thickness of the Simpson Group is in the Arbuckle anticline (column A, fig. 4), where approximately 2,300 feet is normal for outcrops along the south flank (Stop I-8). Skeletal calcarenites and skeletal carbonate mudstones are interbedded with shale and sandstone in approximately equal proportions, whereas in the shelf environment (column B, fig. 4), the much-reduced thickness of barely 1,000 feet consists mostly of limestones. Outstanding is the limestone of the McLish Formation, about 400 feet thick, which is chiefly an algal-mat or "birdseye" limestone that locally contains great concentrations of *Girvanella* oncolites.

Viola Limestone. Above the Simpson Group is a

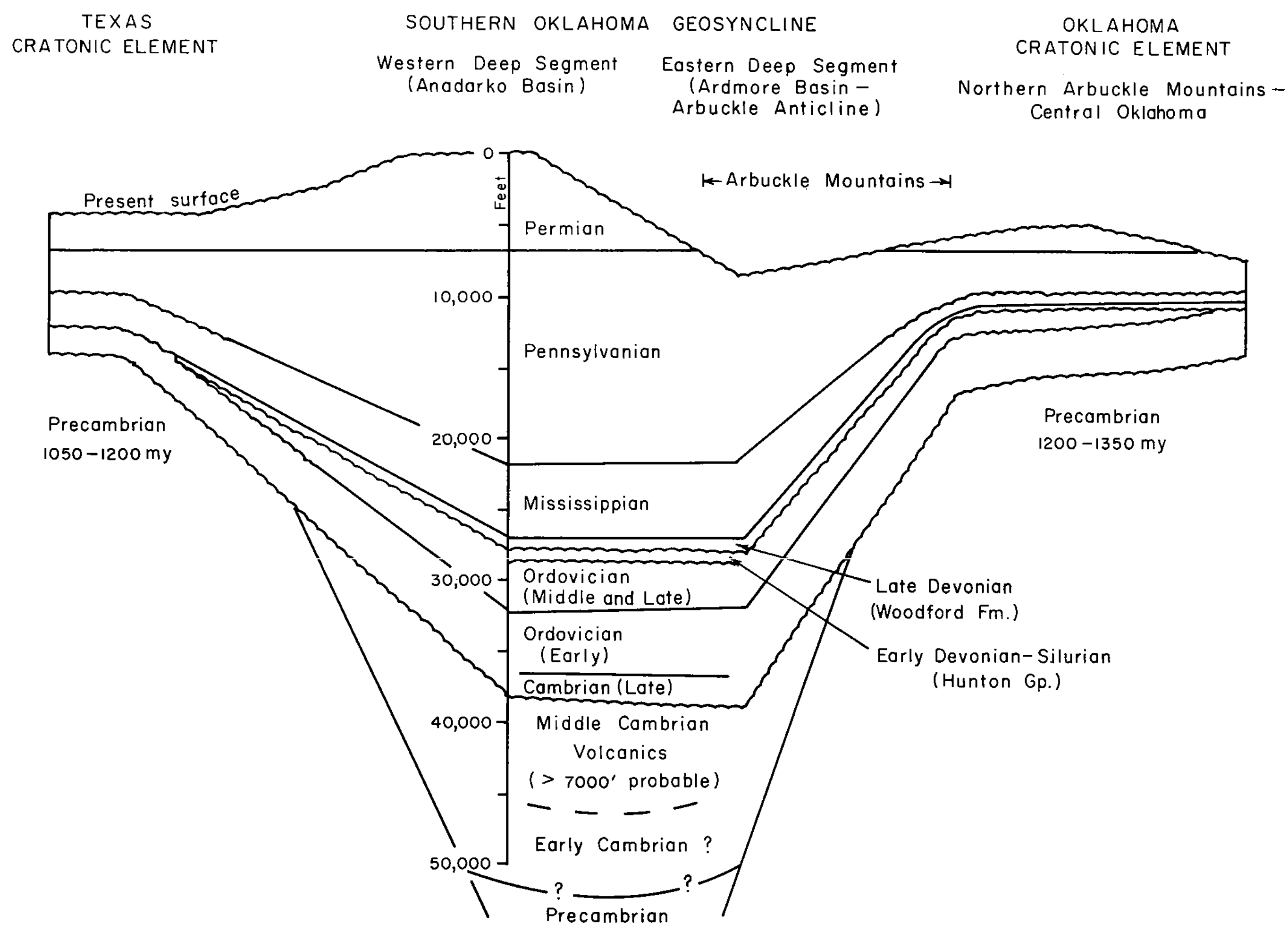


Figure 3. Regional stratigraphic section across the Southern Oklahoma geosyncline. Length of section is 200 miles. The geosyncline extends transversely across southern Oklahoma and contains as much as 38,000 feet of Late Cambrian through Permian sediments deposited upon a floor of Middle Cambrian flows and tuffs at least 7,000 feet thick. The Paleozoic filling of 45,000 feet contrasts with the approximately 10,000 feet deposited upon the stable cratonic elements of northern Texas and central Oklahoma.

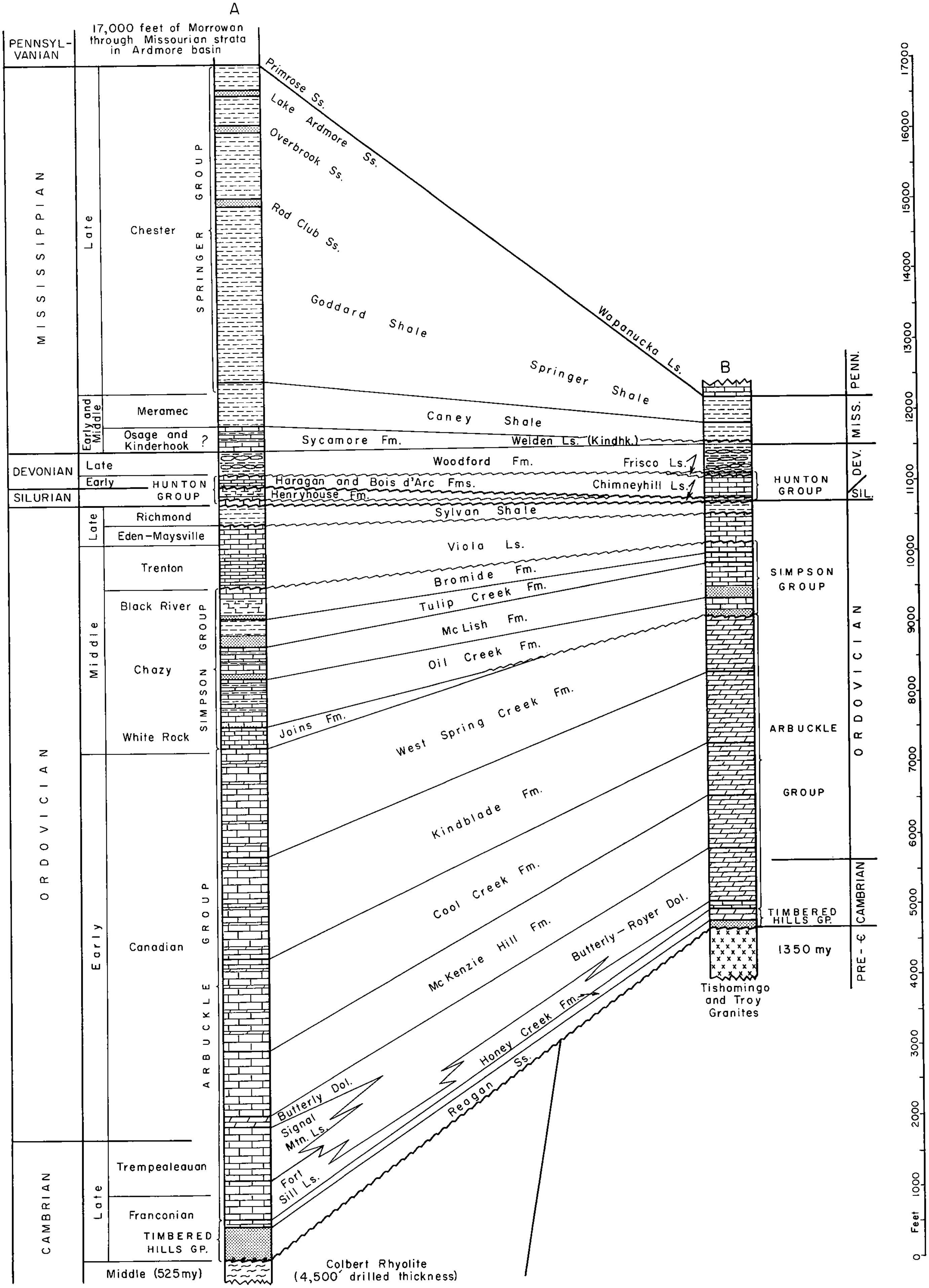


Figure 4. Pre-Pennsylvanian stratigraphic columns in principal segments of the Arbuckle Mountains.
(See explanation, opposite page)

widespread carbonate sequence named the Viola Limestone (fig. 6), shown by Glaser (1965) to be 600 to 900 feet thick in the Arbuckle anticline and 350 to 400 feet thick in the cratonic elements of the Arbuckle Mountains (fig. 16). The formation is divided into a basal unit of siliceous carbonate laminites, a middle unit of burrowed skeletal mudstones, and a top unit of pelmatozoan calcarenite. Each unit is continuous throughout the region, although each shows substantial variation in thickness. In general, the laminites are thicker in the basin and the calcarenites are thicker where developed upon the shelf. The vertical disposition of the carbonate types indicates an upward decrease in water depth, from laminites to coarse calcarenites, and a corresponding increase in the energy of the depositional system. Graptolites occur with trilobites in the laminated and burrowed mudstones, whereas pelmatozoans, brachiopods, bryozoans, and mollusks are dominant in the calcarenites.

From studies of graptolites (Ruedemann and Decker, 1934) and of brachiopods (Alberstadt, 1967), the stratigraphic age of the Viola is considered to range from the middle Trenton through the Eden-Maysville of the Cincinnati region and equivalent Utica-Lorraine strata of New York. No physical or faunal evidence of unconformity has been found within the Viola Limestone, but a prominent unconformity at its base probably represents all of early Trentonian time. Another unconformity, at the top of the Viola, presumably represents less time.

Sylvan Shale. Dark, greenish-gray shale, well laminated and locally containing bedding surfaces that are crowded with graptolites, rests disconformably upon the top coarse calcarenites of the Viola Limestone. This unit is the Sylvan Shale, of Late Ordovician (Richmondian) age. Like the older formations, the Sylvan thins northeastward across the Arbuckle Mountains from a maximum of 325 feet in the basin to 150-175 feet on the shelf.

In addition to graptolites, the Sylvan contains a rich fauna of chitinozoans but generally lacks other fossils. These characteristics and the well-developed lamination suggest that the Sylvan was deposited in the deepest waters of all pre-Mississippian formations of the Arbuckle Mountains. Moreover, the Sylvan is the only shale unit of the older Paleozoic rocks that persists throughout the Southern Oklahoma geosyncline and extends beyond it over large areas of the craton. Its known distribution is from West Texas to Iowa, where the equivalent formation is the Maquoketa Shale.

Hunton Group. The youngest rocks of the Early Paleozoic carbonate sequence in southern Oklahoma are those of the Hunton Group (fig. 6), of Silurian and Early Devonian age. Between 100 and 350 feet thick at most localities in the Arbuckle Mountains, the group is much thinner than the older sequences, partly because of numerous unconformities within and at the top of the Hunton Group. Without the reduction by erosion at unconformities, the Hunton Group would probably have a restored thickness of approximately 600 feet. Lithostratigraphic concepts and brachiopod paleontology of the group have been ably described by Amsden in numerous reports, chief of which are those published by the Oklahoma Geological Survey in 1958 and 1960. The most recent stratigraphic contributions deal with the distribution and thickness of Silurian and Early Devonian beds at the surface and in the subsurface throughout the State of Oklahoma (Amsden and Rowland, 1967a, 1967b).

Stratigraphic nomenclature and ages of Hunton units in the Arbuckle Mountains are given in Part II of the guidebook, which also contains two stratigraphic cross sections within the outcrop region (figs. 33, 35). The Silurian formations in ascending order are the Keel (chiefly oölite), Cochrane (chiefly glauconitic pelmatozoan calcarenite), Clarita (pelmatozoan calcarenite and skeletal mudstone), and Henryhouse (argillaceous skeletal mudstones with thin skeletal calcarenites). Overlying Devonian formations are the Bois D'Arc and Haragan (chiefly argillaceous skeletal mudstones), of Helderbergian age, and the Frisco (skeletal calcarenite), of Oriskanian or Deerparkian age. All of these formations produce petroleum at many localities in Oklahoma, although the Frisco Limestone and dolomitized Silurian beds have yielded the greatest reserves.

Depositional patterns of Silurian and Devonian strata are different from those of older and younger sequences of the Southern Oklahoma geosyncline. Neither the Hunton Group nor the overlying Woodford Formation are appreciably thicker in most parts of the geosyncline than upon the craton. Thickness of rocks of the Hunton Group is related more to the position of isolated cratonic basins and to the effectiveness of the several unconformities than to localization within a throughgoing trough. The maximum preserved thicknesses are 400 feet in Coal and Pontotoc Counties, just northeast of the Arbuckle Mountains, and 800 feet in the northern part of Caddo County, 75 miles northwest of the Arbuckle Mountains (Amsden and Rowland, 1967a). Both areas lie well within the craton. Similarly, the Woodford Formation's greatest thickness, 560 feet, lies upon cratonic elements in the eastern part of the Arbuckle Mountains and apparently increases toward the Ouachita Province.

These relationships clearly show that the Southern Oklahoma trough, thickly filled by rapid subsidence during the Cambrian and Ordovician, subsided at a much slower rate during the Silurian and Devonian. Rapid subsidence was renewed after this pause, however, and great thicknesses of Mississippian and Pennsylvanian sediments were deposited within the previously established trough (fig. 3).

Late Devonian and Mississippian Dark Shales

With the close of Hunton sedimentation, the Early Paleozoic phase, marked by dominance of carbonate

Figure 4. Pre-Pennsylvanian stratigraphic columns in principal segments of the Arbuckle Mountains. A—the geosyncline, as illustrated by rocks of the Arbuckle anticline and Ardmore basin. B—the craton, as illustrated by rocks of the Hunton anticline. The sequence begins with a Late Cambrian transgressive sandstone and continues upward through dominantly shallow-water marine carbonates to the top of the Early Devonian, embracing slightly more than 11,000 feet of strata in the geosynclinal segment compared to 6,500 feet on the cratonic segment. Regionally persistent unconformities characterize Late Ordovician, Silurian, and Early Devonian strata, and an especially widespread unconformity occurs at the base of the Late Devonian Woodford Formation. The rocks from the base of the Woodford to the top of the Mississippian are chiefly dark shales, about 5,800 feet thick in the Ardmore basin compared to 1,000 feet in the Hunton anticline. Thus, Late Cambrian through Mississippian strata are 17,000 feet thick in the geosyncline and less than half that thick—7,500 feet—upon the adjoining cratonic shelf. Pennsylvanian sedimentation in the Arbuckle Mountains region continues the depositional pattern and yields a total geosyncline/craton thickness ratio of about 3.5:1.

rocks, was at an end. Later Paleozoic strata of southern Oklahoma are chiefly of clastic derivation, and the first sediments (Late Devonian and Mississippian) are overwhelmingly dominated by dark shales. The sharply defined change from long-continued, shallow-water marine environments to those of euxinic deeper waters marks one of the great divisions in the Paleozoic evolution of southern Oklahoma.

The earliest representative is the Late Devonian Woodford Formation. Consisting of bituminous shales and chert, it was deposited upon an unconformable surface of substantial relief and wide extent. Overlying Mississippian strata begin with the Sycamore Formation, composed of silty limestone interbedded with dark shale. It shales ranges from 5,500 feet in the geosyncline to only 650 feet upon the craton (fig. 4).

The Woodford Formation is like the Mississippian rocks in that it consists mostly of black shale, but it does not change abruptly in thickness and, except for the loss of chert outside southern Oklahoma, does not show a significant facies change. Its maximum thickness of 350 to 550 feet is attained in southern Oklahoma. From this area it thins gradually to 100 feet or less, persisting as nearly black shale over several hundred thousand square miles of the craton. The Chattanooga Shale of the central United States is equivalent to the Woodford in lithology and age.

Woodford Formation. Over most of its outcrop area

Figure 5. Vertical aerial photograph showing homoclinal Early Paleozoic sediments on the south flank of the Arbuckle anticline. The Late Cambrian-Early Devonian sequence is dominated by carbonate rocks, primarily of Ordovician age, about 11,000 feet thick. In the center of the photograph, U. S. Highway 77 extends in a northerly direction for nearly 2 miles.

is succeeded upward by the Caney Formation and Springer Group, also consisting mostly of dark shales. Rocks of the Springer Group are characterized, in addition, by abundant thin siderite beds and plates.

This dark-shale sequence is 6,000 feet thick in the Southern Oklahoma geosyncline, of which slightly more than 5,500 feet is Mississippian. The Mississippian shales grade into carbonates well upon the craton, attaining a thickness of 2,500 feet in northern Texas and 500 feet in northern Oklahoma (fig. 3). Great contrasts in thickness are locally apparent within short distances along the craton margin, as for example in the Arbuckle Mountains, where the thickness of the Mississippian in the Arbuckle Mountains, the Woodford Formation is 350 to 400 feet thick and consists of dark, fissile shale, beds of vitreous chert, siliceous shale, and, in its upper part, concretionary nodules and plates of calcium phosphate. The formation covers the craton margin and geosyncline, with little change in thickness, but reaches its maximum thickness of 560 feet at the southeastern exposures of the Arbuckle Mountains, at a point barely 15 miles from the frontal belt of the Ouachita Mountains.

The Woodford dark shales are distinctive in being the oldest beds of southern Oklahoma that contain spores and forest trees, including silicified fragments of *Callixylon* that indicate an original trunk diameter of perhaps

Figure 6. Oblique aerial view of the Dougherty anticline and Vine's dome, showing a broad, light band of Viola Limestone and a narrower, but conspicuous, light band of Hunton limestone. Dolese Brothers Rayford quarry (Stop I-1) is just out of view at lower right corner of photograph.
(Photograph copyright by F. A. Melton)

4 feet. The shales also contain specimens of the alga *Tasmanites* that are sufficiently large and numerous to be seen with the naked eye.

In addition to plants, the Woodford contains conodonts, from a study of which it has been concluded by Hass and Huddle (1965) that the formation is mostly of Late Devonian age. Its range is from early Late Devonian (Frasnian) to Early Mississippian (Kinderhookian), all but the upper 1 to 10 feet being Late Devonian.

Stratigraphically and structurally, the Woodford Formation has great significance for the Arbuckle Mountains and the southern Oklahoma region. The unconformity at its base is of craton-wide extent and is of such magnitude that all Devonian and Silurian strata below it have been removed by erosion over wide areas (fig. 7). This major time of uplift and folding closed the Early Paleozoic episode of carbonate sedimentation in the Southern Oklahoma geosyncline and initiated the blanket deposition of dark shales.

Sycamore Formation. Next above the Woodford Formation is a sequence of poorly fossiliferous, fine-grained, silty limestones interbedded with thin layers of dark-gray shale. Called the Sycamore Formation, it occurs only in the southwestern segments of the Arbuckle Mountains and in subsurface parts of the adjoining Southern Oklahoma geosyncline, where it ranges in thickness from 230 to 350 feet. Some of the impure limestone beds are thick and massive, and the formation generally crops out as a conspicuous ridge above the plain of the stratigraphically younger Caney Shale.

The age of the Sycamore has not been clearly established, owing primarily to the lack of distinctive fossils. However, as the lower contact at most localities is gradational with the top beds of the Woodford, the lower part of the Sycamore is undoubtedly of Kinderhookian (Early Mississippian) age. Similarly, the upper Sycamore grades into Caney Shale, the lower part of which is of Meramecian (Medial Mississippian) age (Elias, 1956, p. 70). Thus, by inference, the stratigraphic span of the Sycamore is principally Kinderhookian and Osagian and possibly earliest Meramecian.

From the central part of the Arbuckle Mountains (Mill Creek syncline) and northward upon the craton, the Sycamore Formation is not recognized. Its absence in the northern part of the Arbuckle Mountains is due to an unconformity at the base of the Caney, which rests upon the 5-foot Welden Limestone of Kinderhookian age. Rocks of Osagian age are absent, explaining in small part the extreme thinness of Mississippian rocks in this area.

Caney Shale and Springer Formation. Dark-gray, fissile shales characterize the Caney Formation. Small phosphatic nodules and large calcareous septarian concretions are locally abundant, but limestone and sandstone are absent. Along the south flank of the Arbuckle anticline the shales are somewhat siliceous and weather to a much lighter color than is normal for the formation in all other parts of southern Oklahoma. The formation covers much of southern Oklahoma and ranges in thickness from 250 to 650 feet.

In appearance, the Caney Shale is much like the overlying Springer Formation (or Group). The boundary is drawn at the earliest appearance of siderite or clay-ironstone beds, which occur abundantly in and characterize the Springer sequence, even though the stratigraphic continuity of the boundary cannot be established. In the upper part of the Springer Shale in the Ardmore basin are prominent sandstones (fig. 4), locally of great economic importance as petroleum reservoir beds.

The Caney Formation of the Arbuckle Mountains is judged from its cephalopod fauna to be of Meramecian and Chesterian age (Elias, 1956, p. 56-71). The Springer Shale contains a greatly reduced cephalopod fauna and few additional marine invertebrates. It does contain, however, a great abundance of spores and pollen that have been investigated by Wilson (1966), who recognized some 200 species and concluded that the assemblage is of Late Mississipian (Chesterian) age.

The Springer Shale shows a marked increase in thickness from 350 feet in the Hunton anticline to 4,500 feet in the Ardmore basin, clearly reestablishing the

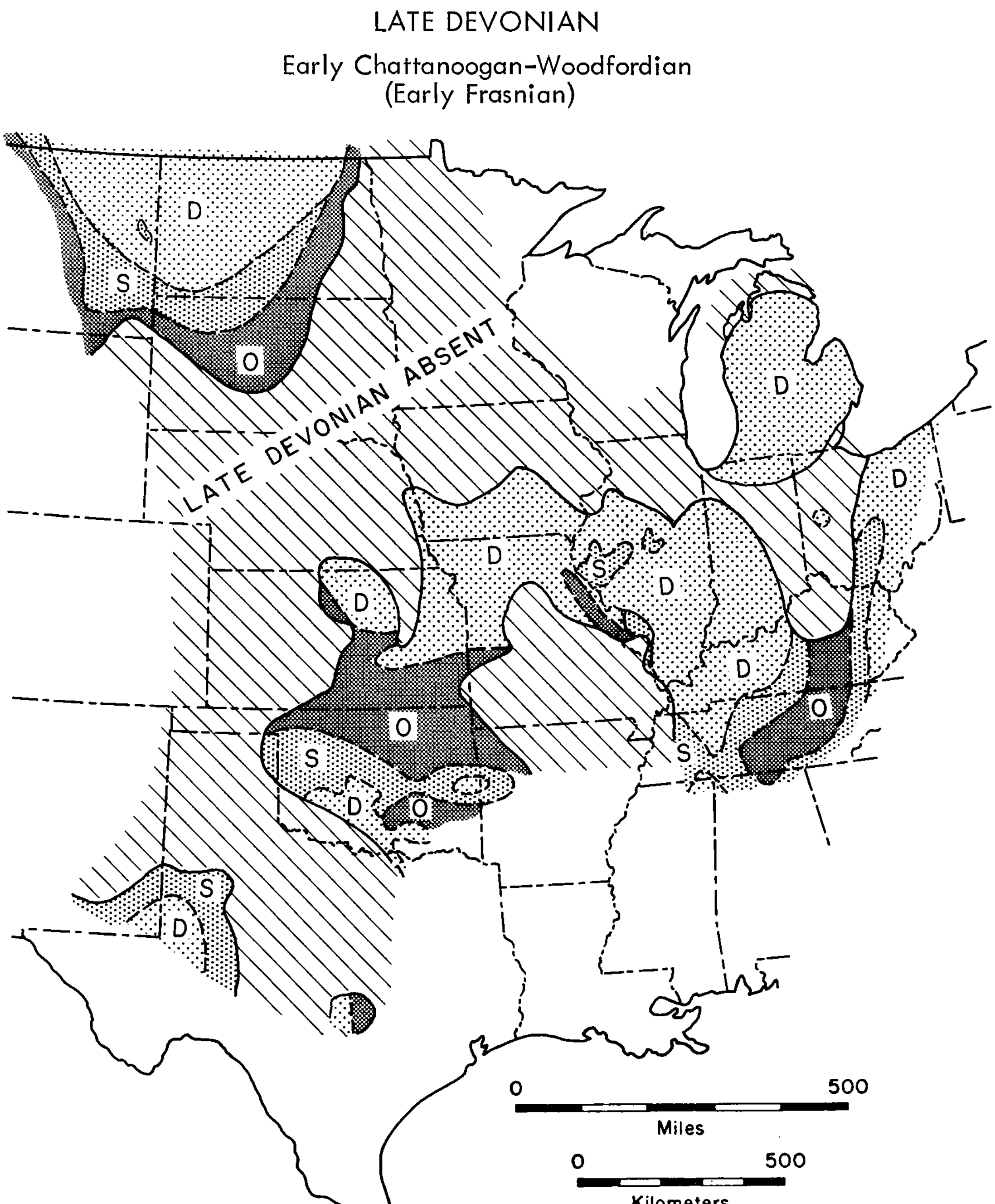


Figure 7. Pre-Late Devonian paleogeologic map of the central United States (Ham and Wilson, 1967, p. 363). Subcrops beneath the Woodford-Chattanooga and equivalents are Devonian (D), Silurian (S), and Ordovician (O) strata, showing influence and widespread extent of the Late Devonian unconformity. Uplift and erosion were most pronounced in the east (Nashville dome), north (margin of Williston basin), central (margins of Ozark dome), and southwest (Tobosa basin). The Arbuckle Mountains and other parts of southern Oklahoma also were involved in pre-Late Devonian epeirogeny, with the result that Woodford shales locally rest upon Silurian and Ordovician beds over much more area than can be shown at the scale of the map. This regional folding and tectonic consolidation temporarily masked the Southern Oklahoma geosyncline, closed its early stage of carbonate sedimentation, and began, with the deposition of the Woodford Formation, a new stratigraphic regime of dark shales.

Southern Oklahoma geosyncline as a major subsiding trough (fig. 4).

Pennsylvanian Sediments and Regional Geology

Southern Oklahoma was again the site of abnormally thick sedimentation during the Pennsylvanian, the Southern Oklahoma geosyncline receiving locally as much as 15,000 to 17,000 feet of shales, sandstones, and generally thin limestones (fig. 3). Equivalent beds upon the craton are about 3,000 feet thick and consist of shales and sandstones, with a much greater relative thickness of limestones.

The stratigraphic succession of Pennsylvanian beds in the Ardmore basin adjoining the Arbuckle anticline is 13,000 feet thick. In ascending order it comprises the Dornick Hills Group (3,000 feet: Morrowan and Atokan), Deese Group (6,000 feet: Desmoinesian), and Hoxbar Group (4,000 feet: Missourian). Early Virgilian beds presumably were deposited but have been eroded and are preserved nowhere in the Ardmore basin. The strata are mostly gray shales and sandstones inter-

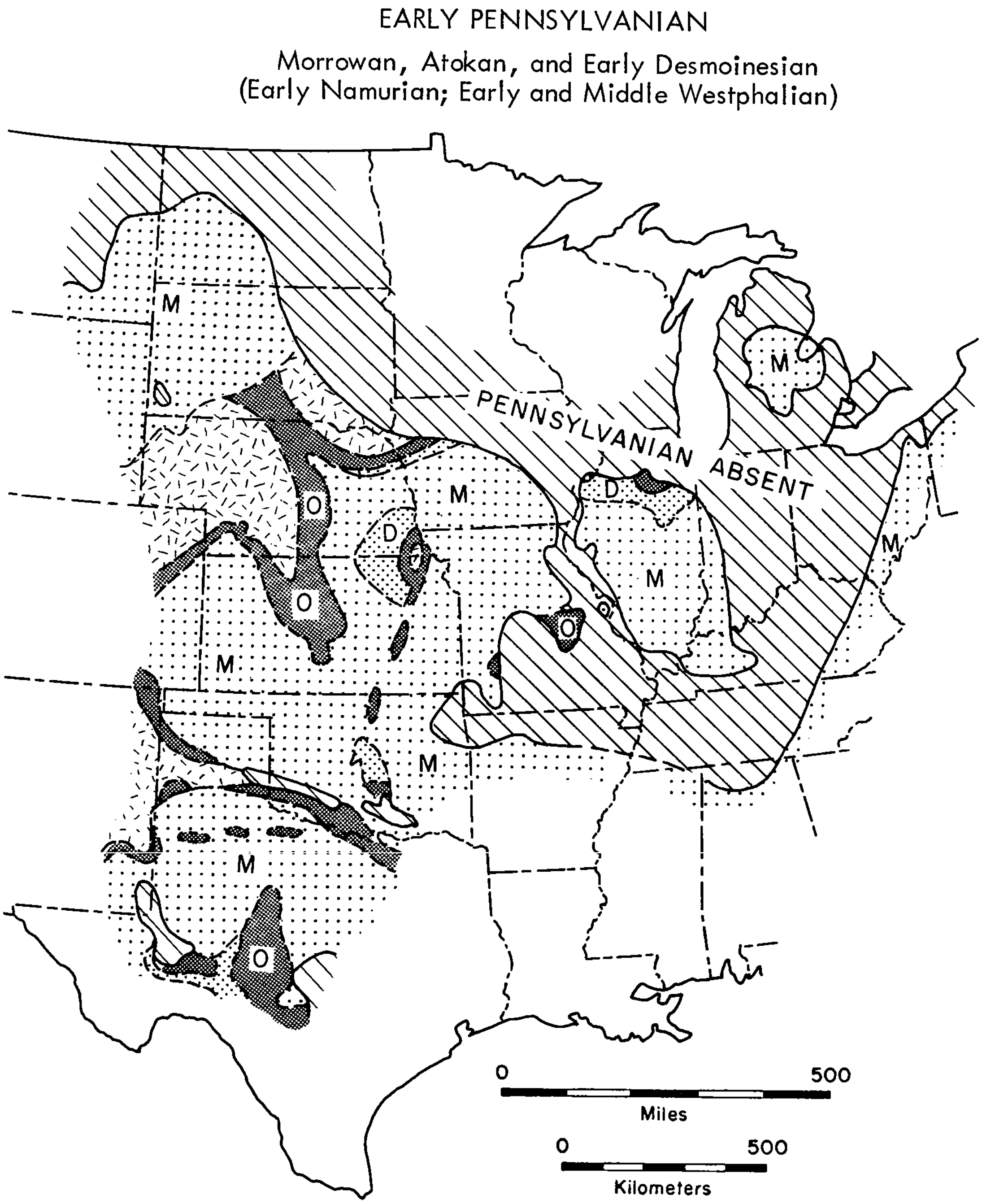


Figure 8. Pre-Pennsylvanian paleogeologic map of the central United States (Ham and Wilson, 1967, p. 373). Subcropping rocks beneath the Pennsylvanian strata are Precambrian (hachured) Late Cambrian through Ordovician (O), Silurian and Devonian (D), and Mississippian (M). Early Pennsylvanian episodes of folding, uplift, and erosion were the greatest of Paleozoic time, affecting all parts of the interior United States and uncovering, for the first time, extensive areas of Precambrian granites.

spersed with thin beds of limestone, many of which contain marine invertebrates, including fusulines. The fusulines have been described by Waddell (1966) and are of great value in establishing stratigraphic ages. In the upper part of the sequence, within the Hoxbar Group, are thin coal beds.

While Pennsylvanian sedimentation continued unabated in the central, rapidly subsiding parts of the Southern Oklahoma geosyncline, epeirogenic uplift was affecting much of the cratonic region of the central United States (fig. 8). Broad areas were uplifted, eroded, and covered unconformably by Early Pennsylvanian rocks at one of the most pronounced discontinuities of all Paleozoic time.

In Oklahoma the results were widespread and locally severe (fig. 9). Early Pennsylvanian (chiefly Atokan) uplift in the Wichita segment of southwestern Oklahoma was at least 15,000 feet, sufficient to denude the basement igneous rocks of the Wichita Mountains, which then contributed arkosic sediments to Desmoinesian beds of the Anadarko basin. Well toward the eastern end of the Wichita segment is the Criner Hills, at the southern margin of the Ardmore basin. It too was strongly elevated at this time, contributing the thick Bostwick conglomerates.

Across the Anadarko-Ardmore basin to the north, in central and northern Oklahoma, the principal Early Pennsylvanian folding resulted in the formation of a broad, north-trending arch, designated as the central Oklahoma segment. This uplift was wholly epeirogenic, although early Desmoinesian strata unconformably cover rocks that locally are as old as Early Ordovician. The southern anchor of the central Oklahoma segment is the Hunton anticline, which constitutes approximately the northern half of the Arbuckle Mountains.

At the time of Early Pennsylvanian folding, the Arbuckle anticline was not yet in existence and the Ardmore basin was still the site of thick sedimentation.

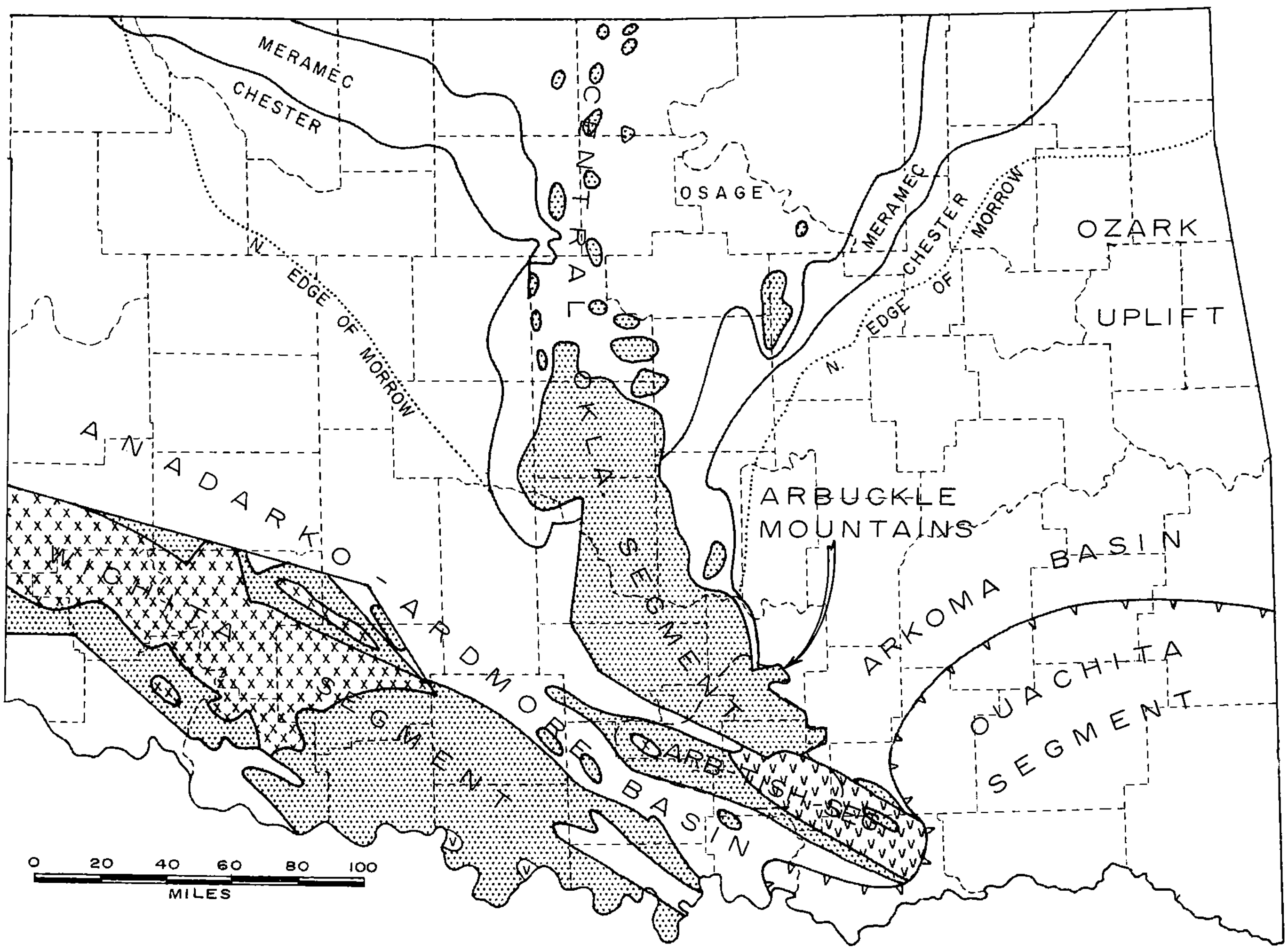


Figure 9. Pre-Pennsylvanian paleogeologic map of Oklahoma (exclusive of the Panhandle), showing rocks below Pennsylvanian in subsurface and restored surface at the close of Pennsylvanian time in areas where Pennsylvanian has been eroded (modified from Jordan, Bellis, and Rowland, 1962). Stippled areas = Devonian through Late Cambrian (Woodford through Reagan); X pattern = Middle Cambrian intrusives and flows of the Wichita Province; V pattern = Precambrian granites.

Regions of greatest Pennsylvanian uplift are: (1) the northwest-trending Wichita segment, (2) the en echelon Arbuckle-Tishomingo segment, (3) the north-trending central Oklahoma segment, and (4) the linear fold-and-thrust belt of the Ouachita segment. Interpretations of paleogeology at the close of Pennsylvanian time in the Ouachita segment are not well known and are not shown on the map.

Sites of thick Pennsylvanian sedimentation were the Arkoma basin (26,000 feet, Morrowan through early Desmoinesian) and the Anadarko-Ardmore basin (15,000 feet, Morrowan through Virgilian). The Arkoma basin was a Pennsylvanian foredeep of the Ouachita segment in Oklahoma and Arkansas, whereas the Pennsylvanian sediments of the Anadarko-Ardmore basin were deposited in the previously established intracratonic Southern Oklahoma geosyncline.

These elements became structural fold belts during the Arbuckle orogeny of late Virgilian time.

PENNSYLVANIAN CONGLOMERATES AND STRUCTURAL HISTORY OF THE ARBUCKLE MOUNTAINS

Rocks of Pennsylvanian age crop out around most of the Arbuckle Mountains and are preserved within them in the Mill Creek syncline, Wapanucka syncline, and Franks graben. Dornick Hills (Wapanucka and Atoka) strata within and adjoining the Arbuckle Mountains generally are nonconglomeratic, but the Desmoinesian and younger Pennsylvanian rocks are conglomerate-bearing and record the beginning and close of mountain-building in the Arbuckle Mountains region.

The four principal conglomerate sequences within and contiguous with the Arbuckle Mountains are "Franks," Deese, Collings Ranch, and Vanoss. All but the Vanoss, the youngest, are preserved in synclinal grabens and are moderately to strongly folded and faulted.

The "Franks" and Deese conglomerates are closely related; both were deposited at about the same time in marine sediments bordering the Hunton anticline, which began to emerge as a broad domal fold in McAlester (early Desmoinesian) time. The Hunton anticline remained emergent until late Virgilian time, when the western margin was covered by conglomerates and shales of the Vanoss Formation. Uplift of the Hunton anticline was accompanied by contribution of coarse clastics to the bordering marine areas of deposition, particularly in the northern area around Ada and in the present sites of the Franks graben and Mill Creek syncline. The conglomerates extended as far southward as the northern edge of the Ardmore basin, where they are present as thin beds in the Deese (Warren Ranch Conglomerate) and Hoxbar Groups.

In the Franks graben was deposited about 1,500 feet of conglomeratic strata, ranging in age from McAlester through Francis, or through much of Desmoinesian and part of Missourian time. These rocks have been called the Franks conglomerate, although the name can be applied only to the conglomeratic marginal facies of mid-Pennsylvanian strata and hence has little stratigraphic connotation.

Outside the Franks graben, younger conglomeratic strata, especially in the Ada Formation of middle Virgilian age, accumulated on the northern margin of the Arbuckle Mountains. The faults bordering the Franks graben and the steep dips within it were produced in post-Francis, pre-Ada time, as the main fault of the graben passes beneath the Ada Formation northwestward, in the north-central part of T. 2 N., R. 5 E. The time of faulting and folding is probably middle Virgilian and is believed to coincide with the beginning of strong folding in the Arbuckle anticline to the southwest. Both the "Franks" and Deese participated in this strong folding, whereas the Collings Ranch and Vanoss were deposited after the folding was accomplished and are in fact the products of that orogeny.

The Deese conglomerates in the Mill Creek syncline are similar in most respects to the "Franks." In the vicinity of Mill Creek, sec. 7, T. 2 S., R. 5 E., the Deese is about 1,950 feet thick (top eroded) and consists of pebble-cobble limestone conglomerates interstratified with red and gray shales and a few thin limestones. The conglomerate sequence rests disconformably upon the Atoka Formation. The oldest conglomerates, at the bottom of which the base of the Deese is placed, are made up largely of Woodford chert, the first resistant formation to be exposed by erosion of the Hunton anticline, whereas the conglomerates higher in the sequence are made up chiefly of Hunton and Viola limestones.

In the Buckhorn area, south of Sulphur, sec. 26, T. 1 S., R. 3 E., the Deese is at least 1,300 feet thick and also consists of conglomerates interbedded with marine shales and limestones. The top is eroded and is covered unconformably by the Vanoss Conglomerate. The youngest conglomerates exposed in the Deese sequence contain limestone pebbles and cobbles from the Oil Creek Formation and from the uppermost part of the Arbuckle Group. Fusulines from the fossiliferous limestones and shales have been identified by Dwight Waddell as of Deese (early Desmoinesian) age. In the Buckhorn area of the Mill Creek syncline, the Deese rests disconformably upon Springer Shale (Chesterian).

Deese rocks in the Mill Creek syncline of the central Arbuckle Mountains generally dip 30° to 70° but are overturned near major faults in the Buckhorn area. About 1 mile east of Mill Creek village, the Wapanucka Limestone is overturned on the north flank of the syncline and presumably the nearby Deese is overturned as well, although Deese outcrops are too poorly exposed for reliable measurement.

The westernmost outcrops assignable to Deese are in the Lake Classen area, secs. 2, 9, 10, T. 1 S., R. 1 E., on the northeast flank of the Arbuckle anticline. In a regional sense these outcrops are also on the south flank of the Mill Creek syncline and thus are related to the Buckhorn and Mill Creek areas. According to Dunham (1955), the sequence consists of shales, conglomerates, fossiliferous limestone, and sandstone totaling about 1,100 feet in thickness, the top being eroded and covered nonconformably by the Vanoss Conglomerate. An age assignment to upper Deese (Wetumka-Wewoka) was made from *Fusulina* contained in fossiliferous limestone 360 feet below the top at one locality, and the possibility was recognized that the beds above the occurrence of *Fusulina* are of early Missourian age. The conglomeratic Deese rocks in the Lake Classen area rest disconformably upon Caney Shale (Mississippian). They are steeply dipping to locally overturned and are structurally conformable with the older folded rocks of the Arbuckle anticline.

Clearly the Deese and "Franks" contain erosional products derived from the first great period of uplift in the Arbuckle Mountains, which began as broad domal folding of the Hunton anticline in early Desmoinesian (early Deese) time. It also is clear that these conglomerates were closely folded, locally overturned, and faulted by later Pennsylvanian orogeny. This later deformation, to which the name Arbuckle orogeny has long been applied, produced the structurally complex Arbuckle anticline and the major folds of the Ardmore basin and was certainly the most intense deformation to affect the Arbuckle Mountains region. The folding can be dated from the evidence seen in the Ardmore basin as post-Hoxbar, from the Mill Creek syncline and Lake Classen area as post-Deese (and possibly post-Hoxbar), and from the Franks graben as post-Francis (middle Missourian). From a comparison with widely distributed marine rocks north of the mountains, the date of the Arbuckle orogeny can be correlated with the unconformity at the base of the Ada Formation, in the middle

Figure 10. Collings Ranch Conglomerate in road cut along U. S. Highway 77. It is principally a boulder conglomerate derived from carbonate rocks of the Arbuckle Mountains and is the principal depositional product of the Arbuckle orogeny.

part of the Virgil Series. Conglomerates of the Ada Formation consist dominantly of limestone pebbles from the Arbuckle Group and have been derived almost exclusively by erosion of the Arbuckle anticline. No other conglomerates of comparable character are known in the region. Moreover, rocks of the Ada conglomerate are exactly like those of the Collings Ranch Conglomerate at its type locality in the Arbuckle Mountains, where it is unconformable upon vertically dipping beds of the Arbuckle anticline. The major conclusions are that the Collings Ranch and Ada conglomerates are equivalents and that the strongest pulse of Arbuckle orogeny was mid-Virgilian.

The Collings Ranch and Vanoss Conglomerates rest with pronounced angular unconformity on older rocks that were steeply folded during culmination of the Arbuckle orogeny. These conglomerates, resulting from this uplift and deposited peripheral to the Arbuckle Mountains, are exposed now only around the Arbuckle anticline and northward into the Sulphur area. Most of these coarse clastic sediments were derived from the Arbuckle and Tishomingo anticlines.

The Collings Ranch was the first, thickest, and coarsest orogenic deposit following this folding. Undoubtedly, it was spread over a wide area in irregular sites of deposition, but the mountain system was still actively rising. Thus, most of the conglomerate was uplifted, eroded, and lost. The only area where the conglomerate has been extensively preserved is in the synclinal graben near Turner Falls on Highway 77 (fig. 10).

A late phase of Arbuckle orogeny, chiefly faulting and uplift without strong folding, came in the last stage of deposition of the Collings Ranch Conglomerate. At this time the conglomerate was folded and faulted into a graben. Some of the faults bordering the graben extend northwestward to the edge of the mountains, where they pass underneath the Vanoss Conglomerate, thereby showing the Vanoss to be younger than the Collings Ranch.

The Vanoss Formation in the vicinity of the Arbuckle Mountains consists of a lower conglomerate member and an upper shale member. Their combined maximum thickness is about 1,550 feet. The conglomerate member has a maximum thickness of 650 feet and is restricted to the northern edge of the mountains in the area between Sulphur and Hennepin. Northward from Sulphur the conglomerate member disappears by gradation into the shale member, whereas westward and southward around the Arbuckle anticline it is overlapped by the shale member. Both members locally contain abundant feldspar and granite fragments, although lenses and beds of arkose, in particular, characterize the shale member. At most places the rocks have gentle dips and are not faulted, yet in a few areas they dip as much as 40° and are cut by small faults, the displacements of

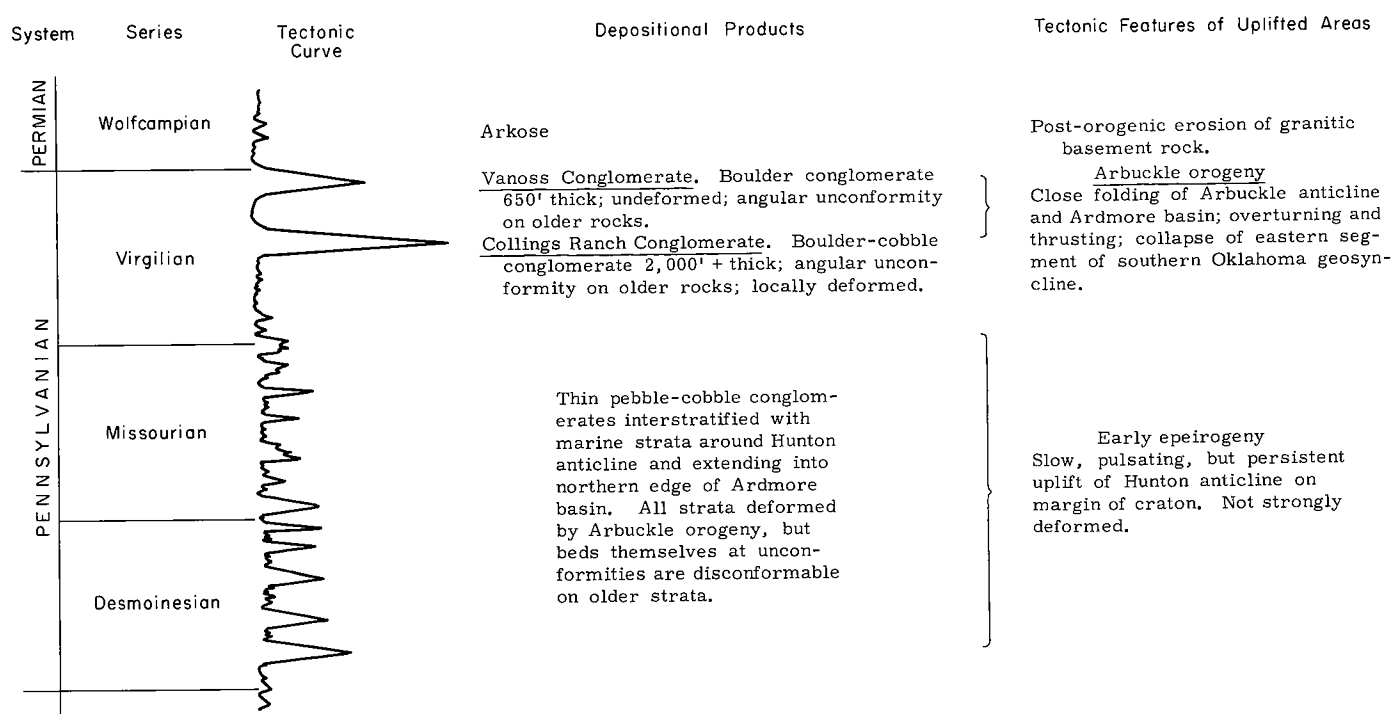


Figure 11. Summary of Pennsylvanian tectonism in the Arbuckle Mountains.

which die out upward in the conglomerate sequence. Such post-Vanoss local deformation was produced by the dying pulse of the Arbuckle orogeny.

In summary (fig. 11), the principal conglomerates in the Arbuckle Mountains region are readily divisible into two general groups, an older, consisting of the "Franks" and Deese, and a younger, consisting of the Collings Ranch and Vanoss. Each group is characterized by specific derivation that in turn is reflected in the composition of pebbles and cobbles in the conglomerates. The "Franks" and Deese contain rocks chiefly from Hunton through uppermost Arbuckle, derived almost exclusively by epeirogenic uplift of the Hunton anticline. The Collings Ranch and Vanoss Conglomerates are orogenic products of middle and late Virgilian uplifts, respectively, which together constitute the Arbuckle orogeny. The Collings Ranch, being younger, contains mostly upper and middle Arbuckle rocks; and the Vanoss, being youngest, contains granite, feldspar, and vein quartz from Precambrian granites that were exposed only after the highest uplift and deepest erosion of the Arbuckle Mountains.

Summary of Depositional and Structural Evolution of the Arbuckle Mountains

With the close of the Arbuckle orogeny, the building of the Arbuckle Mountains was at an end. A geosynclinal margin had been welded to the margin of the craton, and a total structural relief of about 7 miles had been achieved. The long-continued evolutionary series began with Cambrian volcanics, continued with sedimentation throughout most of Paleozoic time, and culminated in a Late Pennsylvanian orogeny. Major steps in the evolution are illustrated in figure 12 (p. 20-21) and are summarized as follows.

A. Pre-Pennsylvanian stage of sedimentation, yielding 17,000 feet of Late Cambrian through Mississippian strata in the geosynclinal segment, compared with 6,500 feet on the adjoining craton. Beneath geosynclinal sediments are Middle Cambrian flows and tuffs probably at least 7,500 feet thick, representing an earlier phase of geosynclinal filling. Sediments of the craton are underlain by massive Precambrian granites dated at 1,350 m.y. and slightly downflexed at craton margin. Exposed at present in the Arbuckle Mountains are elements of both geosyncline and craton, each with contrasting stratigraphic and structural features genetically related to its depositional province.

B. Early Pennsylvanian stage of continued thick sedimentation in geosyncline and thinner sedimentation on craton, with first emergence of Hunton anticline in early Desmoinesian time. Resulting conglomerates are preserved in bordering Desmoinesian strata but did not extend into present site of Ardmore basin, with exception of Warren Ranch Conglomerate in Deese Group. Epeirogenic rise of Hunton anticline is localized near border of craton.

C. Missourian through mid-Virgilian sedimentation, with development of thin conglomerates marginal to the continually rising Hunton anticline. Virgilian sediments are eroded from the Ardmore basin but are preserved on the central Oklahoma shelf. The distinction between geosyncline and craton has persisted to this closing stage of sedimentation. Accumulated in the geosyncline was approximately 30,000 feet of Late Cambrian through Pennsylvanian sediments, deposited principally as carbonates during the Ordovician (8,800 feet) and as clastics during the Mississippian (5,500 feet) and Pennsylvanian (13,000 feet). The thin pre-Pennsylvanian sediments of the craton margin were further reduced in thickness by erosion accompanying Pennsylvanian epeirogenic uplift of the Hunton anticline. The basement-granite surface of the craton was now standing at least 6 miles above the floor of the geosyncline.

D. Same as C, simplified and without vertical exaggeration, showing the Arbuckle Mountains region immediately preceding the late Virgilian Arbuckle orogeny. All uplift in the Arbuckle Mountains until this time was epeirogenic, and structural discordance, even at the early Desmoinesian unconformity, was slight.

E. Late Virgilian Arbuckle orogeny, resulting in close folding and high-angle thrust faulting of thick geosynclinal sediments. The Arbuckle anticline and Ardmore basin were folded at this time by compression of the thick prism of sediments against the cratonic buttress. The strongly folded Mill Creek synclinal graben was formed along the previously downflexed craton margin, but the Hunton anticline and other elements of the craton were only slightly affected. Two orogenic pulses yielded two orogenic conglomerates, derived chiefly from pre-Pennsylvanian limestones of the Arbuckle anticline; the older is the mid-Virgilian Collings Ranch Conglomerate and the younger is the late Virgilian Vanoss Conglomerate. Slight additional folding persisted into Early Permian time.

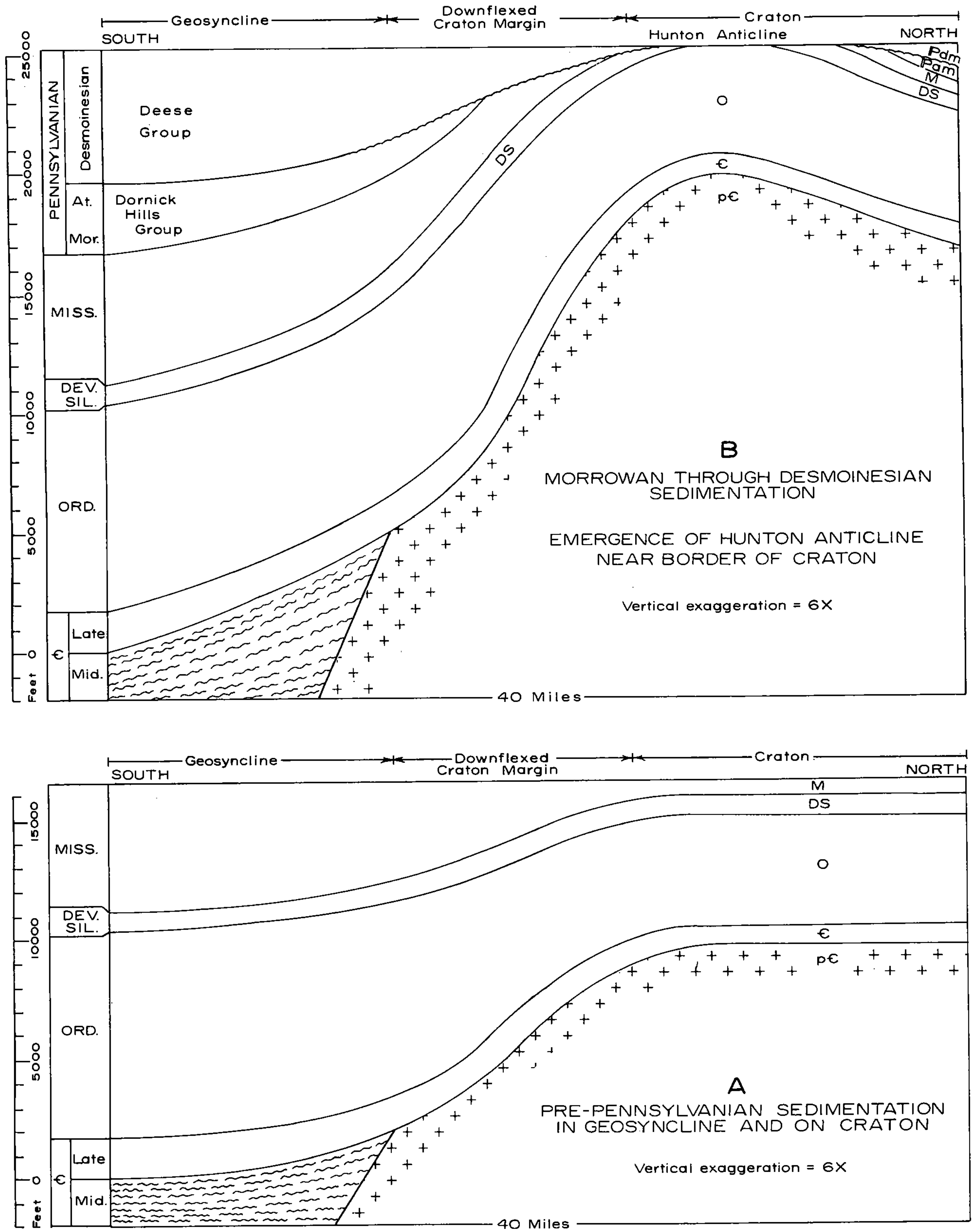
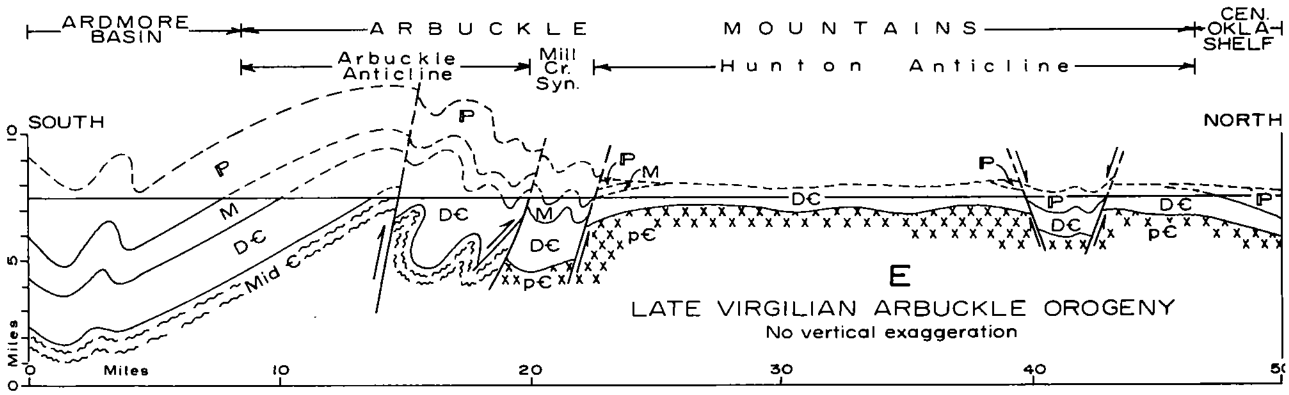
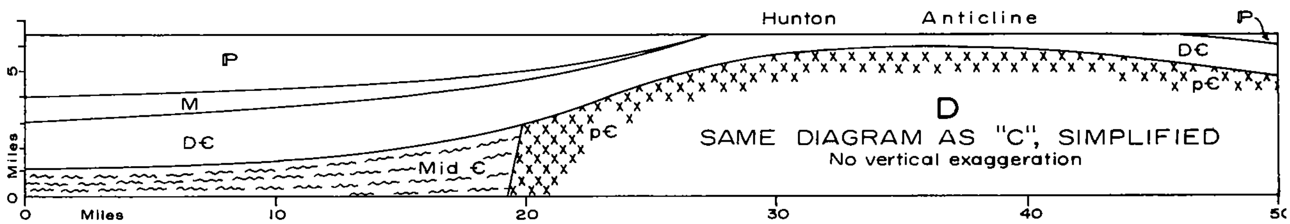
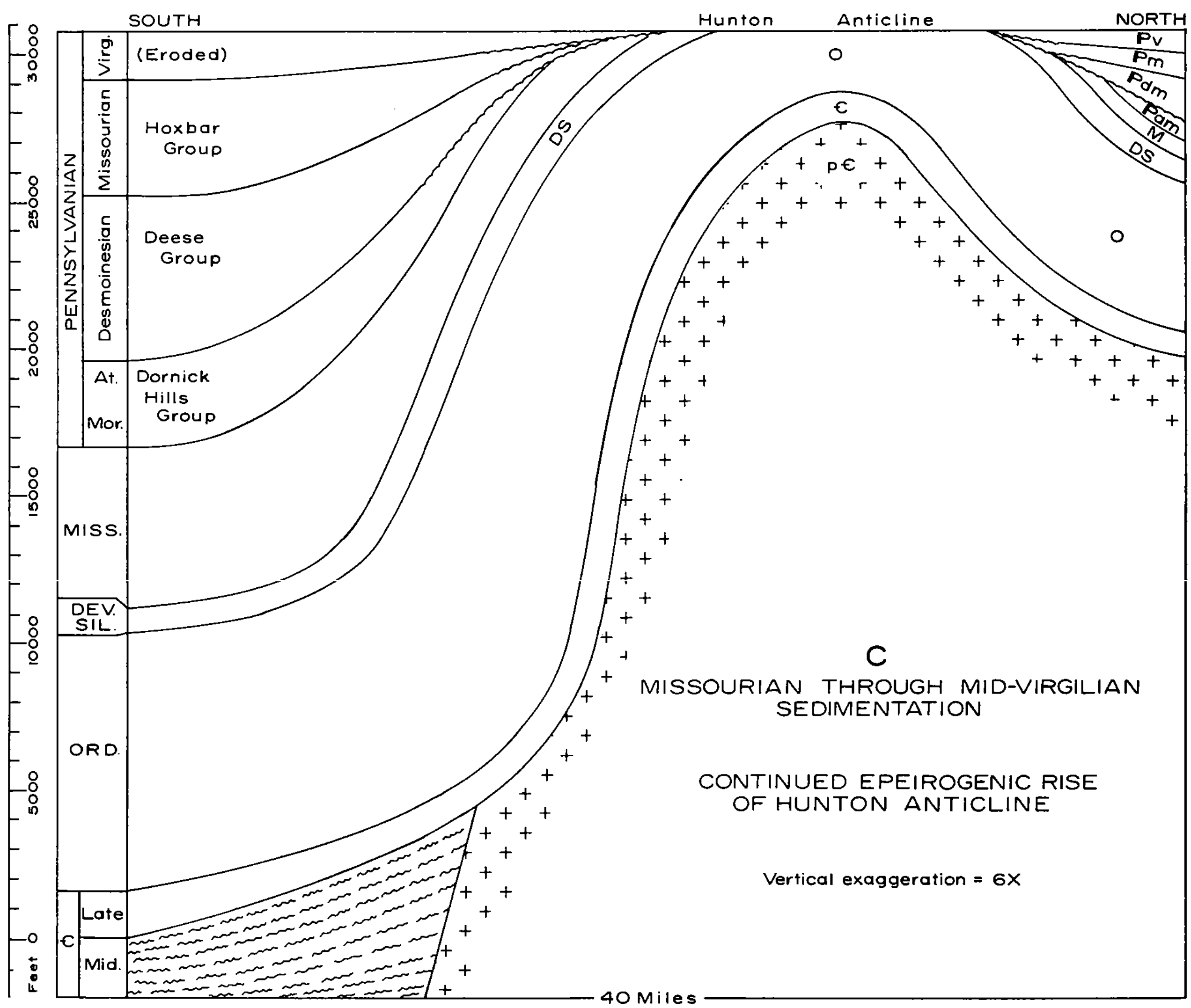


Figure 12. Major elements in the depositional and structural evolution of the Arbuckle Mountains. For explanation, see text.


ARDMORE BASIN
ARBUCKLE MOUNTAINS
CEN. OKLA. SHELF
Arbuckle Anticline
Mill Cr. Syn.
Hunton Anticline
SOUTH
NORTH
E
LATE VIRGILIAN ARBUCKLE OROGENY
No vertical exaggeration
Miles
Mid Є


Hunton Anticline
Mid Є
D
SAME DIAGRAM AS "C", SIMPLIFIED
No vertical exaggeration
Miles


SOUTH
Hunton Anticline
NORTH
PENNSYLVANIAN
Virg.
Missourian
Desmoinesian
At.
Mor.
MISS.
DEV. SIL.
ORD.
Late
Mid.
(Eroded)
Hoxbar Group
Deese Group
Dornick Hills Group
C
MISSOURIAN THROUGH MID-VIRGILIAN SEDIMENTATION
CONTINUED EPEIROGENIC RISE OF HUNTON ANTICLINE
Vertical exaggeration = 6X
40 Miles
Feet

Part II. Road Logs and Descriptions of Stops

William E. Ham

with contributions by James H. Stitt, James R. Derby, Robert O. Fay, and A. Allen Graffham

The road logs and stop descriptions were prepared for a postconvention field trip held in conjunction with the 1968 annual meetings of the American Association of Petroleum Geologists and the Society of Economic Paleontologists and Mineralogists. The trip was conducted on two days (April 26-27), and the road log is so presented here. Since that time, much work has been done on the construction of Interstate Highway 35 through the Arbuckle Mountains, and parts of U. S. Highway 77 have been rerouted. The departure point (junction of U. S. 77 and State 7 at Davis) is 80 miles south of downtown Oklahoma City.

The reader is cautioned that some of the stops are on private land and that he should observe the customary precautions regarding fire, littering, and trespass.

ROAD LOG FOR FIRST DAY

Davis to Springer

Mileage Cumulative	Mileage Between points	
0.0	(0.0)	Davis. Traffic-light intersection of U. S. 77 and State 7. Turn left (east) on State 7.
1.7	(1.7)	Turn right (south) on paved road to Dolese Bros. Rayford quarry (note highway sign). Leave State 7.
5.6	(3.9)	Intersection. Curve right, continuing southward.
6.0	(0.4)	Entrance to quarry. Turn right.
6.7	(0.7)	Proceed to quarry and stop.

STOP I-1. Viola Limestone (Middle and Late Ordovician) at Rayford quarry of Dolese Bros. Co., NW¼ NE¼ NE¼ sec. 28, T. 1 S., R. 2 E., Murray County. Strike N 45° W, dip 63° SW.

With eight quarries and plants in southern Oklahoma, the Dolese Brothers Company is the largest producer of crushed limestone in the State. At Rayford the Viola Limestone, which crops out as a dissected hogback on the southwest flank of the Dougherty anticline, is worked as a source of crushed stone used chiefly in road-building and portland-cement concrete.

On the northwest wall of the quarry, the Viola Limestone is fully exposed in homoclinal sequence (fig. 14), undoubtedly the finest exposure of the formation in the Arbuckle Mountains. From its unconformable basal contact with the Bromide Limestone to its unconformable upper contact with the Sylvan Shale, the Viola Limestone is 625 feet thick and displays its typical division into three members.

The basal member, 145 feet thick, consists of laminated spicular calcilutite (fig. 15b). Disseminated silica and layers of chert are common. Many of the bedding surfaces are crowded with *Climacograptus, Diplograptus,* and *Glossograptus,* some of which are compressed, and these graptolites are accompanied in lesser abundance by *Cryptolithoides, Robergia,* and other trilobites. Numerous sponge spicules and chitinozoans are also present, but benthonic shallow-water forms, such as brachiopods, mollusks, bryozoans, and pelmatozoans, are absent. This restricted assemblage of nektonic and planktonic organisms, in association with the perfectly developed laminations, indicates a depositional environment of deep and quiet waters, probably the deepest of all Paleozoic limestones of the Arbuckle Mountains. The laminated spicular limestone itself is so distinctive of the basal member of the Viola that it cannot be confused with any other rock in the region.

The basal laminated limestones of the Viola rest disconformably upon the Bromide Formation, the upper beds of which are intensely burrowed calcilutites, containing brachiopods, pelmatozoans, ostracodes, and bryozoans. Graptolites, so characteristic of the basal Viola, are conspicuously absent, as are the laminations and chert. Thus the discontinuity separates shallow-water deposits of the upper part of the Bromide from the deep-water deposits of the lower part of the Viola. Missing at the unconformity through hiatus, according to age assignments from graptolites by Ruedemann and Decker (1934), are rocks of early Trentonian age. Here in the quarry the unconformity also is marked by a concentration of pyrite.

The middle member of the Viola, 460 feet thick, grades upward from the basal member. It too is well bedded but differs from the basal member in its lack of laminations, relatively high content of skeletal elements, and the common occurrence of burrowed structures. The

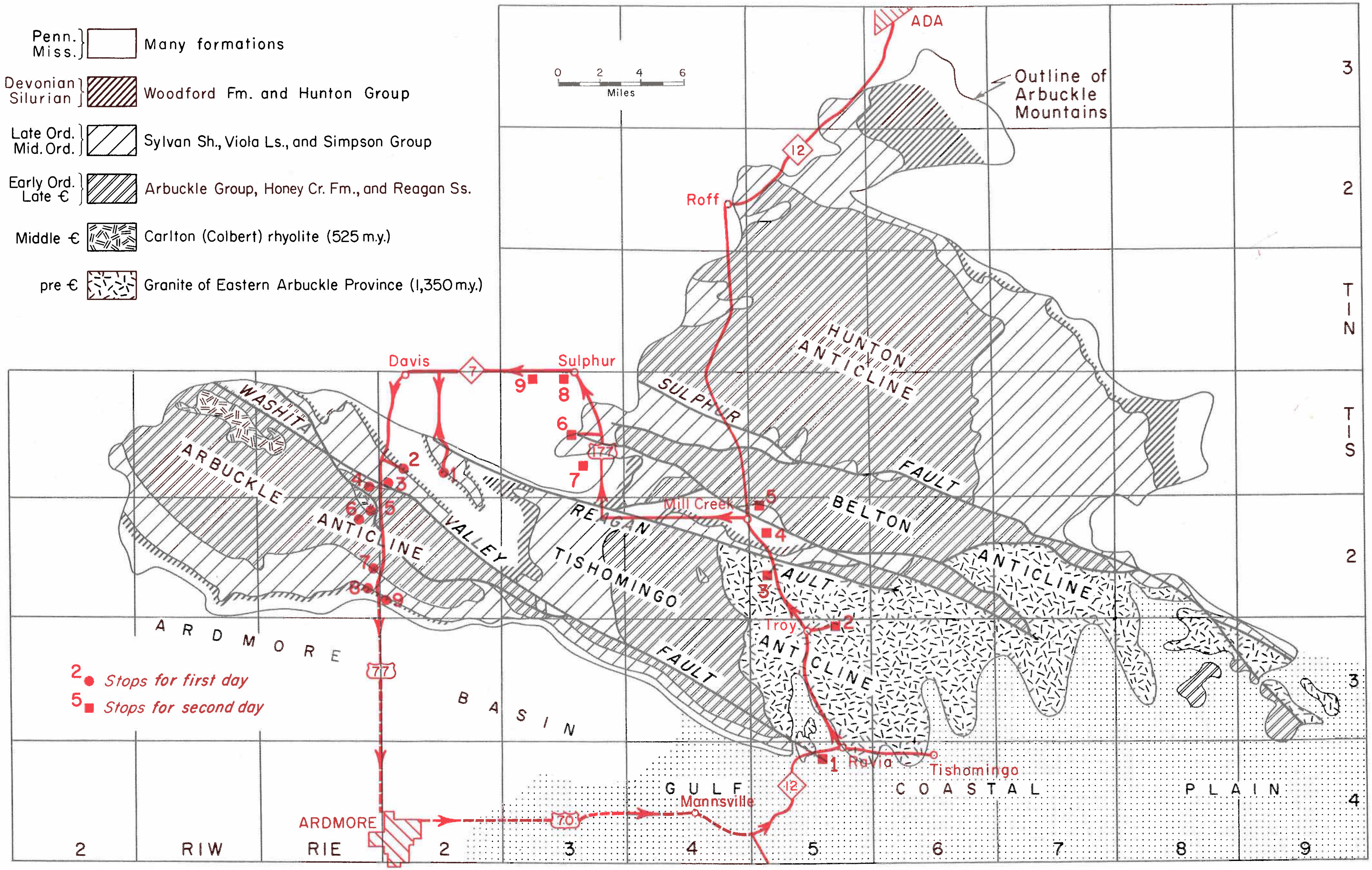


Figure 13. Geologic map of Arbuckle Mountains with route of road log.

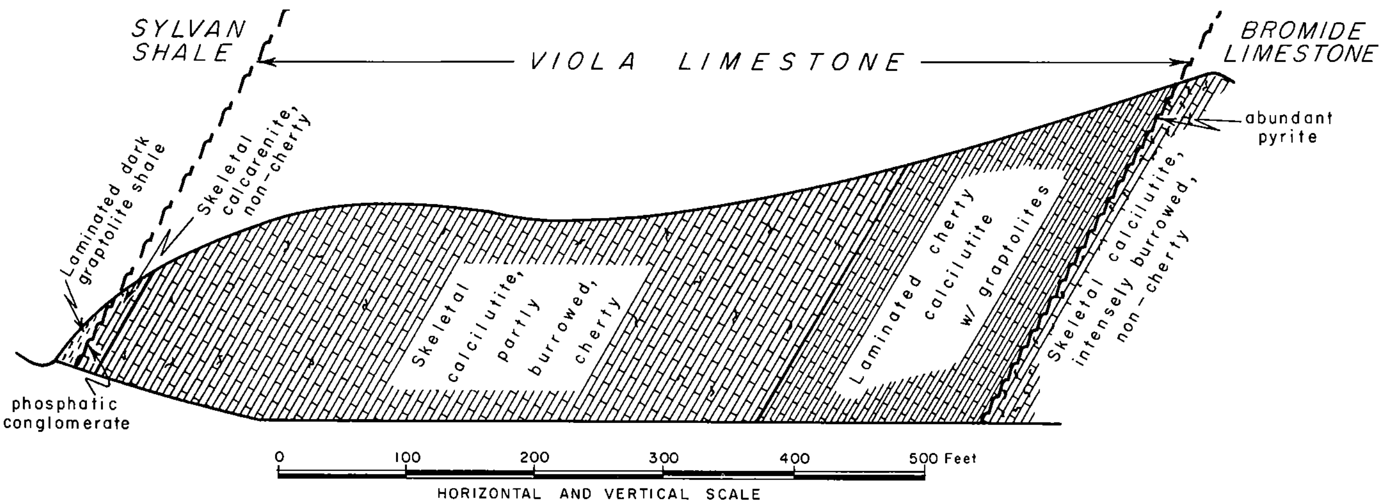


Figure 14. Stop I-1. Section of Viola Limestone as exposed in northwest wall of Dolese Brothers Company Rayford quarry, NW¼ NE¼ NE¼ sec. 28, T. 1 S., R. 2 E., Murray County.

rock is characterized as a burrowed skeletal calcilutite. Many chert nodules are present locally, and some of the layers are nodular bedded to wavy bedded. The contained fauna includes graptolites, pelmatozoans, bryozoans, trilobites, brachiopods, ostracodes, and mollusks, together with scattered sponge spicules and chitinozoans. From the burrowed sediment structures and the incoming of a benthonic marine fauna, a shallowing of the environment to moderate water depth is inferred.

By upward increase in abundance of skeletal elements, particularly pelmatozoans, the middle member grades into the top member of the Viola Limestone. It is a typical well-washed skeletal calcarenite, cemented with sparry calcite, lacking in chert nodules, and of high chemical purity (fig. 15a). At this locality it is 20 feet thick. Upon the craton in the northern and eastern parts of the Arbuckle Mountains it has a maximum thickness of 130 feet, and at the Lawrence quarry near Ada it is used as a high-purity limestone in the manufacture of portland cement.

Disconformably upon the Viola Limestone lies the Sylvan Shale, the basal beds of which are perfectly exposed at the road-cut entrance to the quarry. A three-inch pyritic phosphate conglomerate occurs at the base and is overlain by thinly laminated, graptolite-rich, dark shales. Here again is a marked discontinuity at an unconformity between the shoaling waters of skeletal calcarenites and the much deeper waters of graptolitic shales. At the unconformity the hiatus is an indefinite but small part of the Late Ordovician, representing a gap between the Eden-Maysville age of the upper Viola and the Richmond age of the Sylvan Shale.

Major divisions and facies relations of the Viola Limestone in the Arbuckle Mountains have been investigated jointly by Glaser (1965) and Alberstadt (1967), and the brachiopods have been described by Alberstadt. The Viola is shown to consist of a gradational limestone sequence divided into three members, as at the Rayford quarry, and to range in age without discontinuity from mid-Trenton to Eden and Maysville. The greatest thickness of approximately 900 feet is in the geosynclinal region of the western Arbuckle Mountains, whereas the thickness diminishes markedly to less than 400 feet upon the craton (fig. 16). The tripartite division persists throughout but is modified by relative increase in thickness of calcarenites in the cratonic environment.

13.4	(6.7)	Retrace route to Davis, traffic-light intersection. Continue ahead (west) on U. S. 77.
13.6	(0.2)	Santa Fe Railroad (five tracks).

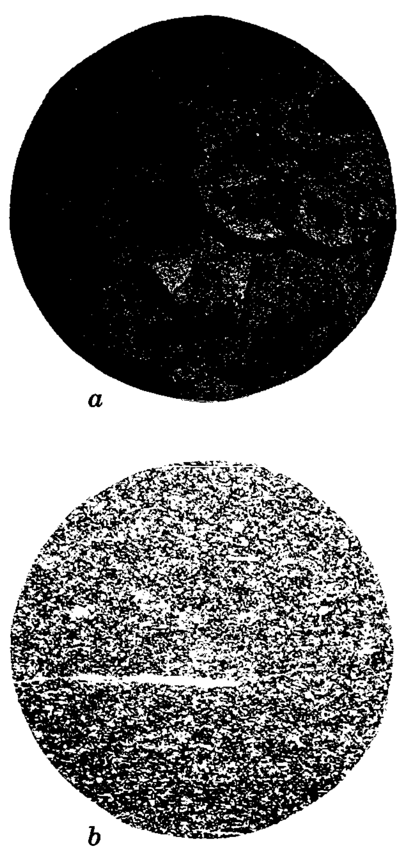


Figure 15. Photomicrographs of Viola Limestone, x12.5.
a. Skeletal calcarenite at top of formation, consisting of crinoid and brachiopod fragments cemented with sparry calcite.
b. Basal laminated calcilutite, containing abundant sponge spicules.

13.8	(0.2)	Curve left (south), following U. S. 77.
16.9	(3.1)	Jollyville on left.
17.3	(0.4)	Bridge over Washita River.
17.8	(0.5)	State 77D. Turn left (southeast) across Honey Creek.
18.9	(1.1)	Park in turnout at curve; cross fence toward valley to top of hill.

STOP I-2. **Seven Sisters overlook, NW¼ SE¼ SW¼ sec. 29, T. 1 S., R. 2 E., Murray County.**

This beautiful panoramic view is seen from a part of the Seven Sisters, a prominent chain of knobs distributed along a high hogback ridge of steeply dipping and resistant Viola Limestone.

This point is 200 feet above Washita River, which flows in an alluvial valley that is cut upon thick Mississippian shales along the trough of the Washita Valley syncline. Across the valley are folded strata of the Dougherty anticline (fig. 6), including the Viola Limestone in the Rayford quarry. Beds of the Dougherty anticline are in normal superposition, but southward from the center of Washita Valley the beds are inverted along the overturned north limb of the Arbuckle anticline (fig. 17).

The Viola Limestone itself is a key bed in structural restoration. From the Rayford quarry outcrop it dips southwestward under the valley to a depth of 7,500 feet, is overturned, and emerges at the Seven Sisters, with a 60° southwest dip (120° rotation). In restoration, it then extended 20,000 feet above the present land surface before resuming an upright attitude and connecting with the present-day outcrops on the south flank of the Arbuckle anticline.

Toward the southwest are the East Timbered Hills, at the top of which are microwave relay towers. The supporting rock is Colbert Rhyolite, the basement rock and structural crest of the deeply eroded Arbuckle anticline.

The Arbuckle anticline is the most intensely deformed part of the Arbuckle Mountains. The structure section of figure 17 shows it as a faulted anticline, overturned to the north. However, eastward from this line of section the south limb is overturned as well, and the resulting feature is a fan fold.

20.0	(1.1)	Retrace route to U. S. 77. Turn left (south).
20.1	(0.1)	Limestones of Hunton Group exposed as vertical beds in road cut at right.
20.2	(0.1)	Sylvan Shale in road cut at right, underlain by steeply dipping Viola Limestone.
20.5	(0.3)	Viola Limestone in road cuts on right.
20.8	(0.3)	Bridge over Honey Creek. Methodist Assembly Grounds on left. Travertine-cemented terrace deposits of probable Pleistocene age occur along Honey Creek in this area. These flat-lying conglomeratic sediments contain much rhyolite derived from the East Timbered Hills, a fact that led early geologists to mistake them for the much older Vanoss and Collings Ranch Conglomerates.
21.2	(0.4)	Entrance to Turner Falls recreation area. Continue ahead on U. S. 77.
21.4	(0.2)	Pull over to parking area on right of highway.

STOP I-3. **Collings Ranch Conglomerate (middle Virgilian), NE¼ SE¼ NE¼ sec. 36, T. 1 S., R. 1 E., Murray County.**

Exposed in the road cut on the east side of the highway are magnificent outcrops of the Collings Ranch Conglomerate (fig. 10), which occurs principally as a synclinal fold within a graben 0.5 to 1 mile wide. Highway 77 crosses the approximate middle of the outcrop belt. Consisting of limestone boulders and cobbles derived from the upturned beds upon which they lie with marked angular unconformity, the Collings Ranch Conglomerate is the first and thickest orogenic deposit of the Arbuckle anticline. It has a measurable thickness of 2,000 feet, but the top is eroded and the original thickness may have been as much as 3,000 feet. Most of the fragments have been derived from the thick Arbuckle Group, and the oldest so far found is a single cobble of Reagan sandstone. No feldspar, granite, or rhyolite is present to suggest that the basement rocks had been exposed by Collings Ranch time.

The unconformable contact of the conglomerate is particularly well displayed about 1 mile west of U. S. Highway 77 and on the hill directly south of the Methodist Assembly Grounds, where gently dipping conglomerate beds cap vertically dipping Viola Limestone beds. In normal relations, all underlying beds dip 70° or more.

Faulting is conspicuous at the north and south boundaries of the graben in which the Collings Ranch beds are contained. The north fault probably is continuous along the graben but is concealed for about 0.5 mile east of U. S. Highway 77 by a cover of young conglomerate beds that extend into the graben from the north, near the Methodist Assembly Grounds. This occurrence indicates that most, but not all, of the Collings Ranch was deposited before faulting ceased at this locality. The south fault of the graben is one of the principal throughgoing faults of the Arbuckle Mountains (Washita Valley fault). It has nearly vertical dip, is well exposed in three cuts on the hairpin curve, and continues westward to the edge of the Arbuckle Mountains. Here it passes beneath the Vanoss Conglomerate, thereby showing the Vanoss to be younger than Collings Ranch.

As discussed in Part I, the age of the Collings Ranch Conglomerate, and thus the time of formation of the Arbuckle anticline, is considered to be Late Pennsylvanian (mid-Virgilian).

		Continue ahead along double hairpin curve, three times crossing the fault trace of Collings Ranch against Cool Creek Limestone of Arbuckle Group, marking south edge of graben.
22.1	(0.7)	Park to right at paved parking area.

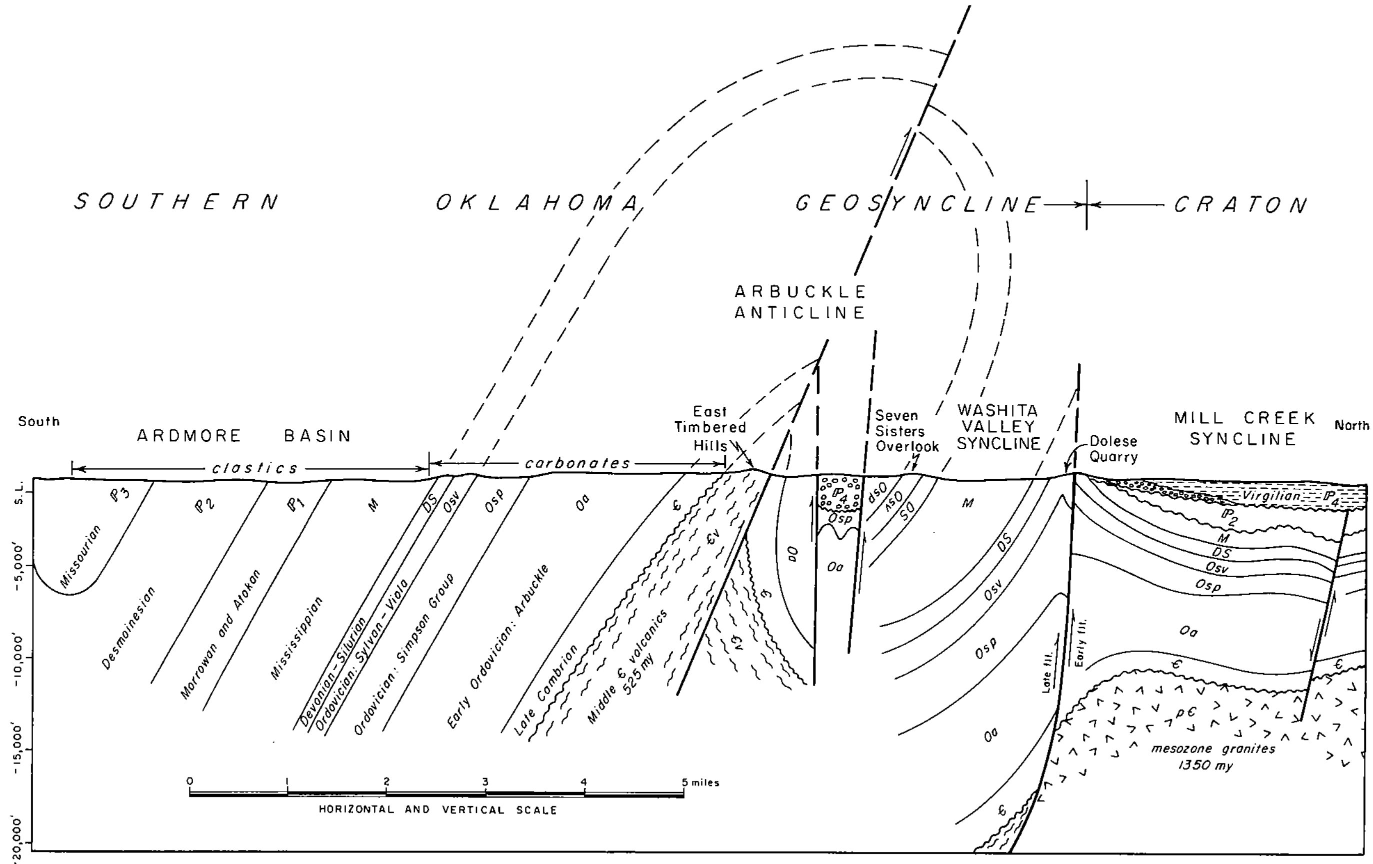


Figure 17. Stop I-2. Structure section of the Arbuckle Mountains in the vicinity of U. S. Highway 77. In this area the Arbuckle Mountains consist chiefly of the Arbuckle anticline, which displays sedimentational and structural features of the Southern Oklahoma geosyncline.

STOP I-4. **Turner Falls overlook, SW¼ SE¼ NE¼ sec. 36, T. 1 S., R. 1 E., Murray County.**

All streams flowing across the limestone beds of the Arbuckle Mountains dissolve calcium carbonate, carrying much of it away in solution. But at Turner Falls on Honey Creek, an edifice of calcium carbonate has been deposited from the stream waters (fig. 18). The deposit consists of spongy-textured travertine. The thickness of the travertine gradually increased with the passage of water over it, until the falls reached a maximum height of 150 feet. Then, probably during Middle Pleistocene time, increased rainfall caused Honey Creek to cut a chasm into the depositional platform it had just built, and the waterfall was reduced to half its former height. This beautiful waterfall is now in a stage when it is maintaining a steady state, receiving about as much calcium carbonate in the form of stream-floor deposits as is mechanically abraded during floods. Blue-green algae assist in precipitating the calcium carbonate.

Unlike the typical waterfall, which results from the exhumation of a preexisting resistant rock layer by stream erosion, Turner Falls is a subsequent creation of Honey Creek. The creek itself provided the materials to construct the precipice over which it falls.

Behind the falls, as a scenic background, are the East Timbered Hills, composed of Carlton Rhyolite and to be visited at the next stop. Between the rhyolite and the overlook are complexly folded and faulted Late Cambrian and Early Ordovician rocks on the north limb of the Arbuckle anticline. A fault trace parallels

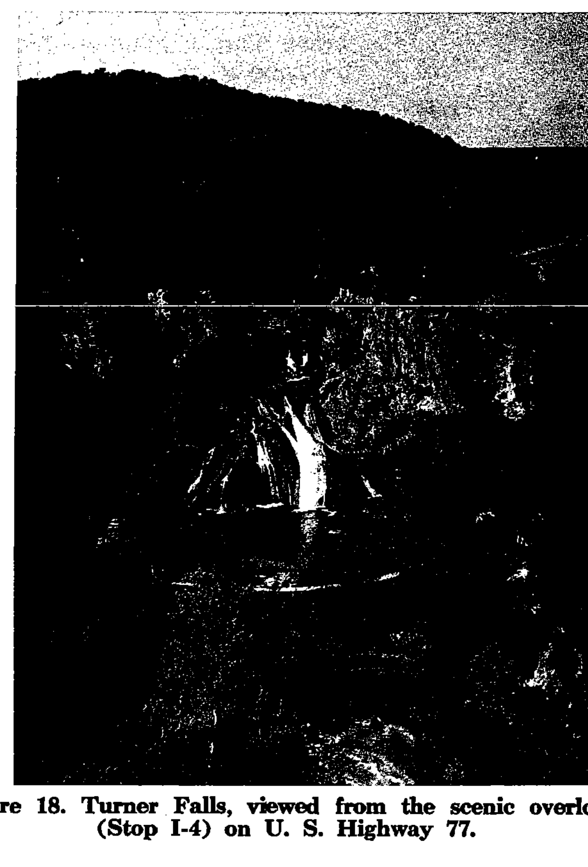


Figure 18. Turner Falls, viewed from the scenic overlook (Stop I-4) on U. S. Highway 77.

Figure 19. Algal stromatolite beds in Cool Creek Limestone at Turner Falls overlook.

Figure 20. Sparse digitate algal bed in laminated dolomitic limestones of the Cool Creek Formation, U. S. Highway 77, opposite Turner Falls overlook.

the valley of Honey Creek, separating Cool Creek Limestone at the overlook from McKenzie Hill Limestone, well exposed downstream and across the valley in a bold cliff face. Above the cliff and barely behind it is a small lateral valley, occupied by a few deciduous trees, which marks the trace of the Washita Valley fault. Beyond the fault is the Collings Ranch Conglomerate.

The Cool Creek Limestone, upon which the overlook is situated, is of middle Canadian age and is about 3,300 feet stratigraphically below the top of the Arbuckle Group. The extreme shallowness of the Arbuckle depositional environment is displayed by the common types of Cool Creek strata (figs. 19, 20) that crop out here, including hemispheroidal algal stromatolites, edgewise conglomerates, and mud-cracked calcilutites.

		Leave Turner Falls overlook and continue south on U. S. 77.
24.0	(1.9)	Turn right (west) through aluminum gate at geologic cross-section sign onto pasture road.
24.3	(0.3)	Carlton Rhyolite exposed in hillside to left of road.
24.9	(0.6)	Park near crest of hill.

STOP I-5. **Colbert Rhyolite (Middle Cambrian) in the East Timbered Hills, W½ NE¼ sec. 1, T. 2 S., R. 1 E., Murray County.**

The huge Arbuckle anticline covers 200 square miles on the outcrop and makes up the western one-third of the Arbuckle Mountains. The East Timbered Hills (fig. 2) are at the crest of this anticline. A similar crest is visible 6 miles to the west, in the West Timbered Hills, across an intervening structural saddle of Late Cambrian strata. The Timbered Hills are composed of Colbert Rhyolite, dated at 525 m.y. and shown by Ham, Denison, and Merritt (1964) to be coextensive with the Carlton Rhyolite Group of the Wichita Mountains. The Colbert Rhyolite clearly belongs to the Wichita Province, and, like the rocks of that province, it is part of a Middle Cambrian sequence that underlies all parts of the Southern Oklahoma geosyncline.

The Colbert and its equivalents consist of massive and flow-banded rhyolites (fig. 21) with welded glassy tuffs, agglomerates, and some water-laid tuffs. A well drilled just southwest of the West Timbered Hills penetrated 4,500 feet of these rhyolitic rocks—a record penetration for southern Oklahoma.

Rhyolite from the East Timbered Hills consists of massive and flow-banded rhyolite porphyries, normally containing phenocrysts of perthite (6%), albite (3%), and quartz (2%) set in a reddish devitrified groundmass. A chemical analysis of rhyolite from this locality showed 74.71 percent SiO_2, 12.25 percent Al_2O_3, 3.99 percent Na_2O, 4.40 percent K_2O, and 2.28 percent Fe_2O_3.

Nothing but a vast expanse of carbonate rocks of the Arbuckle Group lies to the east, south, and west on the broad south flank of the Arbuckle anticline. With a thickness of 6,700 feet, the Arbuckle Group, which contributes about two-thirds of the folded bulk of this great composite anticline, lies barely above the basement rhyolite, yet it dips steeply and is locally overturned. Such folding would not be possible unless the basement rock also yielded by folding in the same way.* The stratiform flows of basement-rock rhyolite provide the foldable base, and it is demonstrable in both the Arbuckle anticline and Wichita Mountains that dips of the rhyolite are structurally conformable with those of the Arbuckle Group.

The deformed Arbuckle anticline is the greatest of all structural units of the Arbuckle Mountains, standing in marked contrast to the gentle folding and block faulting of the Tishomingo, Belton, and Hunton anticlines, each of which is underlain by massive Precambrian granites. The folding of the Arbuckle anticline is manifestly different from all other parts of the Arbuckle Mountains because it is underlain by basement rocks of a different type and of a different province.

		Return to south point of East Timbered Hills, thence right (northwest) along pasture road.
26.1	(1.2)	Park in pasture by fence.

* A décollement separation of stratified rocks above a massive basement could result in close folding, but in southern Oklahoma there is no reason for believing that any décollement is present.

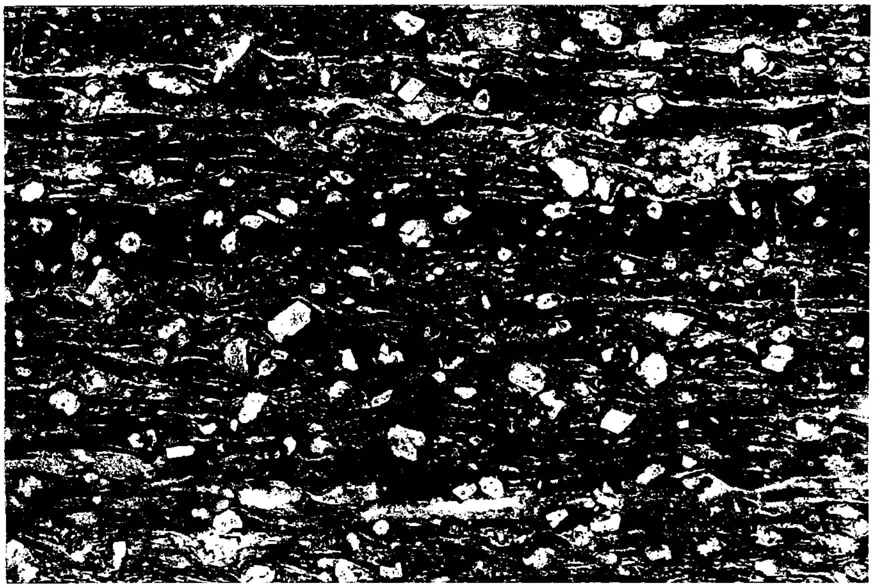


Figure 21. Strongly flow-banded Colbert Rhyolite from the East Timbered Hills (Stop I-5), x1.5.

STOP I-6. Cambrian strata on south flank of Arbuckle anticline near Honey Creek, W½ SW¼ sec. 1 and SE¼ SE¼ sec. 2, T. 2 S., R. 1 E., Murray County.

Concepts of distribution and stratigraphic relations of Cambrian strata in the Arbuckle Mountains are summarized in figure 24. Deposited upon the basement floor is the Reagan Sandstone. It grades upward into the Honey Creek Limestone, which in turn grades into carbonates of the overlying Arbuckle Group. The Cambrian sediments have a maximum thickness of 1,700 feet in the western part of the Arbuckle anticline (Joins Ranch) and an average thickness of 750 feet in eastern and northern parts of the Arbuckle Mountains. Accompanying this change in thickness is a gradation of the carbonate rocks from limestones in the west to dolomites in the east.

The stratigraphic section at Stop I-6 (fig. 23) is the U. S. Highway 77 section shown in figure 24, intermediate in position between the limestone and dolomite facies and therefore consisting of both rock types. The principal dolomite is in the Royer Formation (figs. 22, 26f), which occurs regionally as a westward-tapering wedge of coarse-grained dolomite that has replaced limestones of the Fort Sill and Signal Mountain Formations.

The homoclinal sequence shown in figure 23 is well exposed. From the base upward, the stratigraphic thicknesses (in feet) of the several formations are as follows:

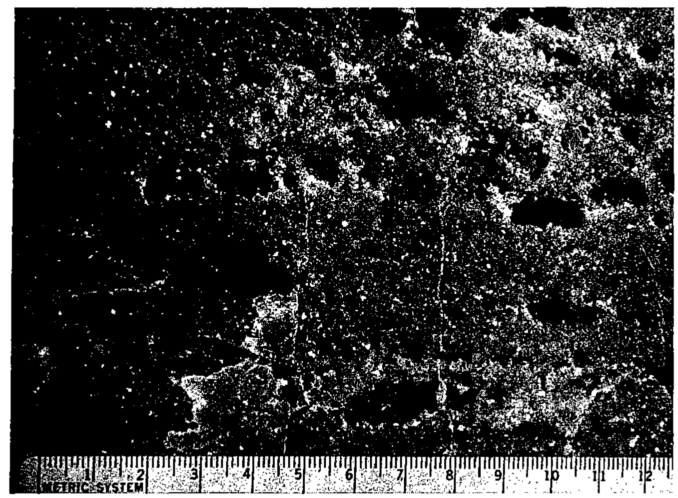


Figure 22. Coarsely crystalline Royer Dolomite from the Arbuckle Mountains, showing development of vugs parallel to bedding.

Reagan Sandstone, 235; Honey Creek Limestone, 105; Fort Sill Limestone (fig. 26b), 155; Royer Dolomite (fig. 26f), 750; Signal Mountain Limestone (fig. 26d), 415; and Butterly Dolomite, 300.

The trilobite zonation of this section is described in the following article.

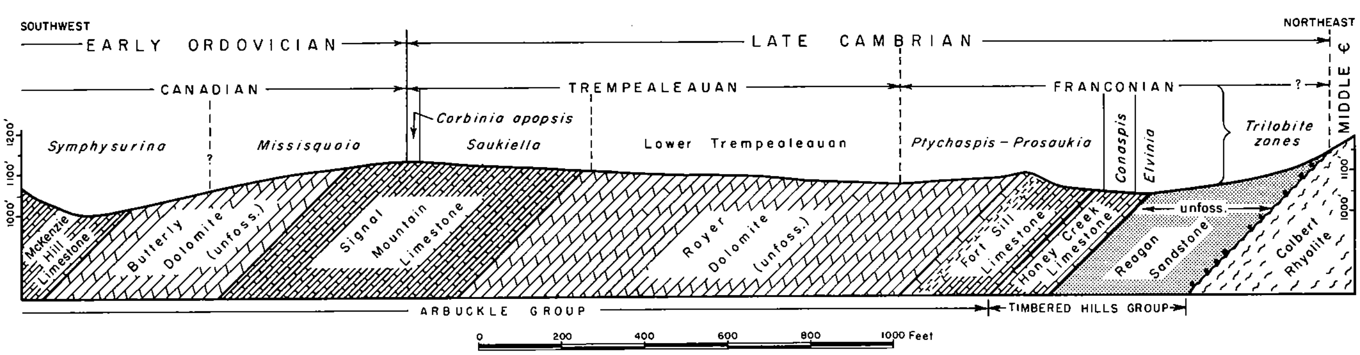


Figure 23. Stop I-6. Stratigraphic section of Cambrian strata on south flank of Arbuckle anticline near Honey Creek, W½ SW¼ sec. 1 and SE¼ SE¼ sec. 2, T. 2 S., R. 1 E., Murray County.

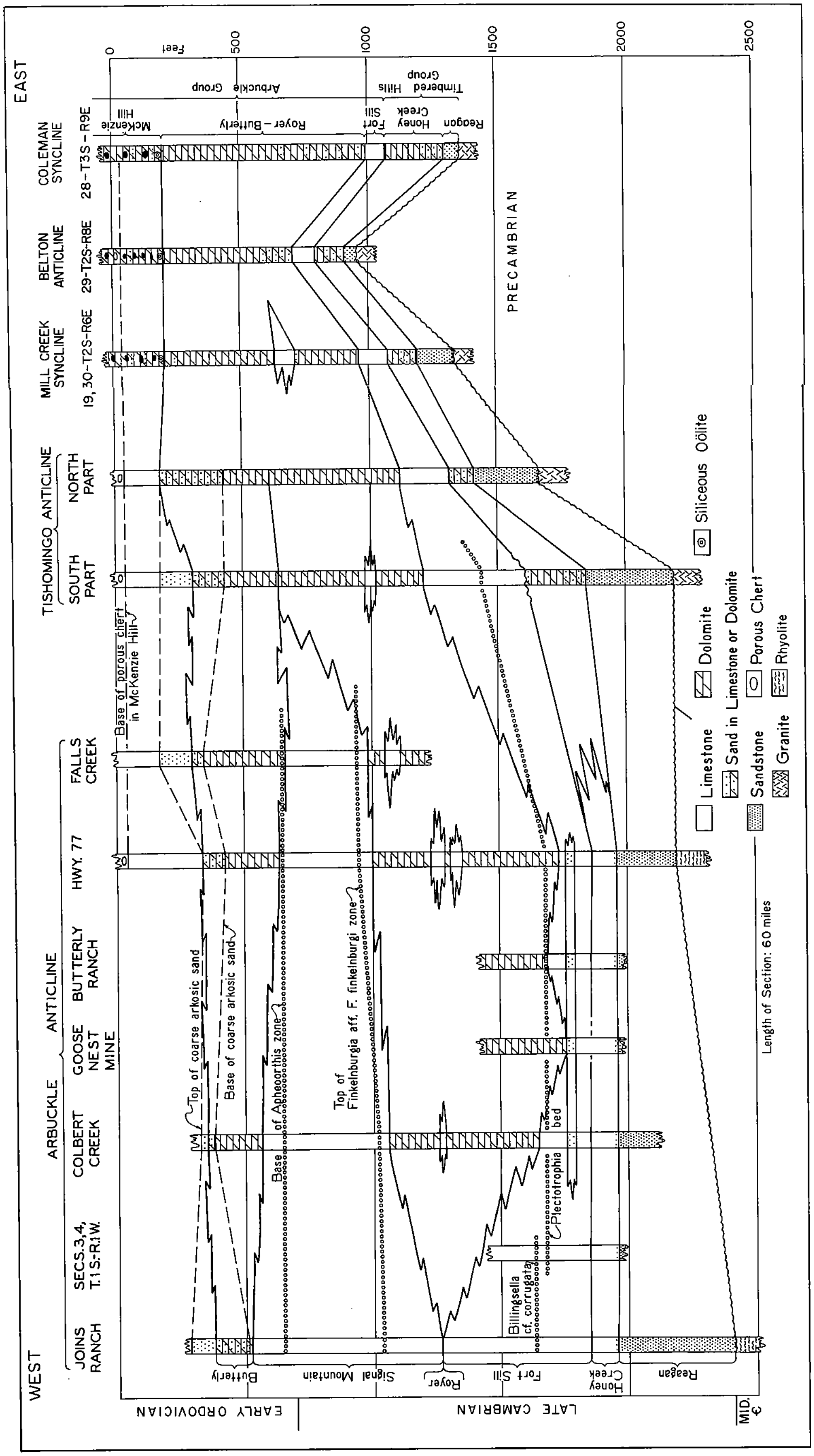


Figure 24. Regional stratigraphic section of Timbered Hills Group and lower part of Arbuckle Group (modified from Ham, 1955).

Late Cambrian and Earliest Ordovician Trilobite Faunas Western Arbuckle Mountains, Murray County, Oklahoma

James H. Stitt*

This is a progress report on a Ph.D. dissertation begun in 1964 under the supervision of Dr. W. C. Bell of The University of Texas at Austin. No new species are named in this paper, and, because a little more work remains, the conclusions presented here may be changed slightly before the dissertation is published.

The data available to date (April 1968) are summarized in figure 25. Most of this information was obtained from collections from the Joins Ranch section, where the Fort Sill and Signal Mountain Limestones are thickest and the unfossiliferous Royer Dolomite is not present. In the Joins Ranch section, the unfossiliferous Butterly Dolomite at the top of the Signal Mountain is thinnest in the Arbuckle Mountains (fig. 24). Additional data from the U. S. Highway 77 section have been utilized to prepare a composite trilobite range diagram for this paper. It should be pointed out that the thickness measurements for the formations and trilobite zones given near the bottom of figure 25 are cumulative thicknesses above the base of the Honey Creek Limestone. They have been drawn to scale for the Joins Ranch section only. Thickness measurements given for the Highway 77 section show relationships between the formations and the trilobite zones and especially the position of the eastwardly thickening Royer and Butterly Dolomites, but these thicknesses are not drawn to scale.

CAMBRIAN SYSTEM

Franconian Stage

The oldest trilobites found in the Arbuckle Mountains constitute the faunas of the *Elvinia, Conaspis,* and *Ptychaspis-Prosaukia* zones of the Cambrian correlation chart (Howell et al., 1944) and are assigned to the Franconian Stage. The *Elvinia* and *Conaspis* zones occur within the Honey Creek Limestone, and the *Ptychaspis-Prosaukia* zone begins in the upper part of the Honey Creek and extends to slightly above the middle of the Fort Sill Limestone in the Joins Ranch section (fig. 25).

The trilobite fauna of the *Elvinia* zone in the Arbuckle Mountains is similar to that found in central Texas and in the upper Mississippi Valley. There are also some species in common with the *Elvinia* fauna of the Great Basin, described by Palmer (1965b), and that of the central Appalachians, described by Wilson (1951).

The trilobite assemblages of the *Conaspis* and *Ptychaspis-Prosaukia* zones are similar to those from central Texas and the upper Mississippi Valley, differing from the latter principally in the scarcity of specimens of *Conaspis, Ptychaspis,* and *Prosaukia,* which are abundant in the upper Mississippi Valley and rare in Oklahoma and Texas.

The sharpest faunal change in the Franconian Stage occurs between the *Elvinia* and *Conaspis* zones. None of the *Elvinia* zone trilobite species, genera, or families survives into the *Conaspis* zone. This abrupt faunal change has been recognized as the top of the Pterocephaliid biomere by Palmer (1965a, 1965b) and is present in central Texas, the upper Mississippi Valley, the Great Basin, and the central Appalachians.

Trempealeauan Stage

Trilobites found in the Arbuckle Mountains that constitute the fauna of the *Saukia* zone are assigned to the Trempealeauan Stage.

* University of Missouri, Columbia.

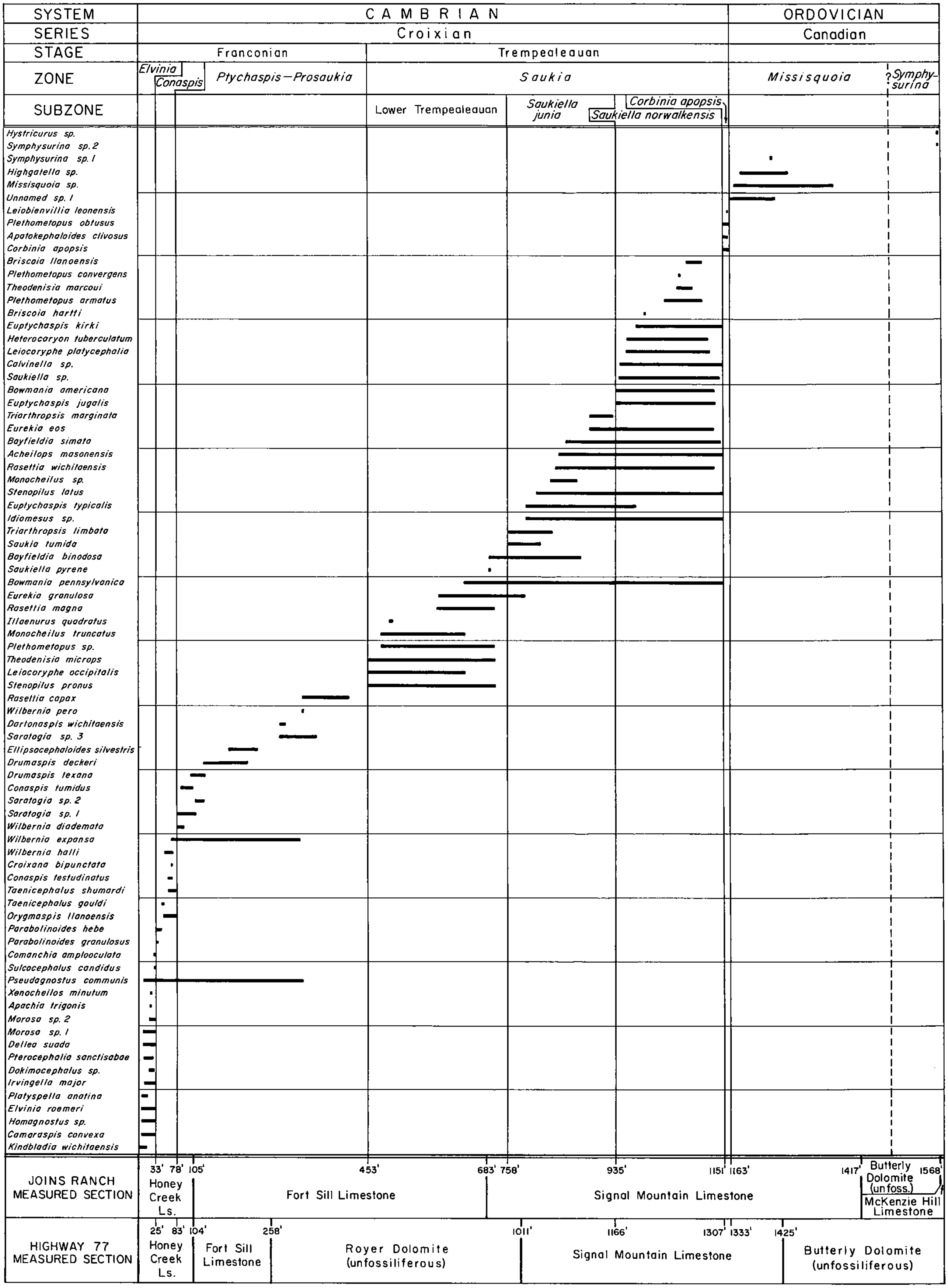


Figure 25. Ranges of trilobite species in the Honey Creek Limestone and lower part of the Arbuckle Group in the Arbuckle anticline.

Winston and Nicholls (1967), working in central Texas, have recently subdivided the *Saukia* zone into four subzones that can also be recognized in the Arbuckle Mountains (fig. 25).

Trilobite assemblages from the lower Trempealeauan in the Arbuckle Mountains are similar to those in central Texas described by Bell and Ellinwood (1962) and Longacre (1968). The lower Trempealeauan trilobites occur in the upper part of the Fort Sill Limestone and continue into the lower part of the Signal Mountain Limestone.

Trilobite faunas of the *Saukiella junia*, *Saukiella norwalkensis*, and *Corbinia apopsis* subzones occur in the lower and middle part of the Signal Mountain Limestone. Trilobite associations from these subzones in the Arbuckle Mountains are similar to those in central Texas described by Winston and Nicholls when they proposed their subdivision of the *Saukia* zone. The principal difference is that specimens of *Saukia* and *Saukiella*, which are numerous in central Texas and have been used as name-bearers for the subzones, are rare in the Arbuckle Mountains.

ORDOVICIAN SYSTEM

Perhaps the biggest surprise to come out of my work so far is the discovery that the Cambrian-Ordovician boundary does not occur at the base of the McKenzie Hill Limestone, as previously believed (e. g., Ham, 1955), but actually occurs within the Signal Mountain Limestone. In the Joins Ranch section, the boundary occurs 254 feet below the top of the Signal Mountain, which, when the 150 feet of Butterly Dolomite is added, places the boundary 404 feet below its previously accepted position. Because the Butterly thickens toward the east at the expense of the Signal Mountain and the McKenzie Hill (fig. 24), the Cambrian-Ordovician boundary in the Highway 77 section occurs only 92 feet below the top of the Signal Mountain.

Trilobites that occur in the upper part of the Signal Mountain constitute the fauna of the *Missisquoia* zone, which is the lowest Ordovician zone recognized in central Texas by Winston and Nicholls (1967). Similar trilobites have been found at the base of the Ordovician in Vermont by Shaw (1951, 1958) and in Montana by Lochman (1964). A few trilobites were collected from the basal part of the McKenzie Hill, and they appear to correlate with the *Symphysurina* zone recognized in central Texas by Winston and Nicholls, in Utah and Nevada by Ross (1951) and Hintze (1952), and in Montana by Lochman (1964).

The Cambrian-Ordovician boundary is marked by another abrupt faunal change similar to that between the *Elvinia* and *Conaspis* zones. In the Arbuckle Mountains, none of the Cambrian trilobite species, genera, or families survives into the Ordovician. This change marks the top of the Conaspid biomere, whose base was proposed by Palmer (1965b) as the base of the *Conaspis* zone. No evidence of physical disconformity is shown in the numerous measured sections throughout the country where these two sharp faunal changes have been observed. This faunal change appears to have affected the trilobites only, because there is little change in the associated brachiopod or gastropod fauna.

Retrace route to U. S. 77.

26.9 (0.8) Turn right (south) on highway. For next 0.8 mile the outcropping rocks are Royer Dolomite, complexly folded on north flank of Arbuckle anticline.

27.7 (0.8) Chapman Ranch fault. This fault cuts through the axial part of the Arbuckle anticline, thrusting Fort Sill Limestone (older) upon Royer Dolomite (younger) at the highway and continuing northwestward along the east side of the

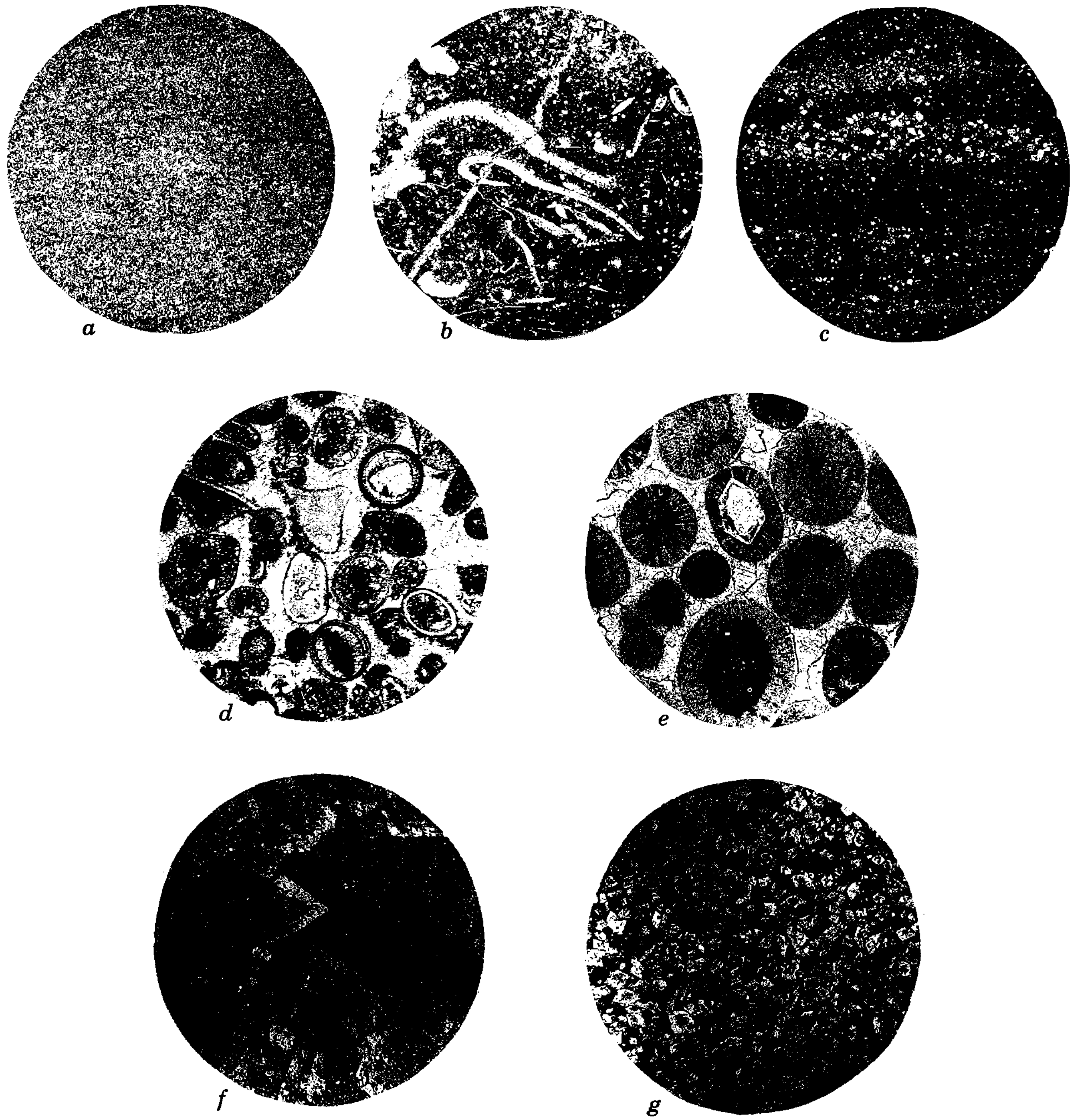


Figure 26. Photomicrographs of typical Arbuckle Group limestones in the Arbuckle Mountains.

a. Calcilutite or carbonate mudstone, faintly banded but otherwise homogeneous. Kindblade Limestone, x12.5.

b. Burrowed skeletal calcilutite. Skeletal elements are trilobites, pelmatozoans, and a few sponge spicules; a filled burrow of calcisiltite occurs at top. Fort Sill Limestone, x12.5.

c. Laminated dolomitic calcilutite. Lamination results from layered concentration of silt-sized dolomite rhombohedrons. West Spring Creek Formation, x28.

d. Intraclast-skeletal-oöid calcarenite cemented with sparry calcite. Most grains are coated by a thin micritic envelope. Signal Mountain Limestone, x12.5.

e. Oölitic calcarenite, cemented with void-filling sparry calcite. Nuclei are intraclasts and quartz sand grains; one euhedral quartz crystal regenerated from a rounded nucleus is prominent. Cool Creek Limestone, x28.

f. Partly dolomitized calcilutite. Incomplete dolomite rhombs are invading and replacing the carbonate mudstone. From a limestone lens in the Royer Dolomite, x28.

g. Dolomitic calcilutite. Euhedral dolomite rhombs about 60 microns in diameter have uniformly replaced a fine-grained limestone. West Spring Creek Formation, x28.

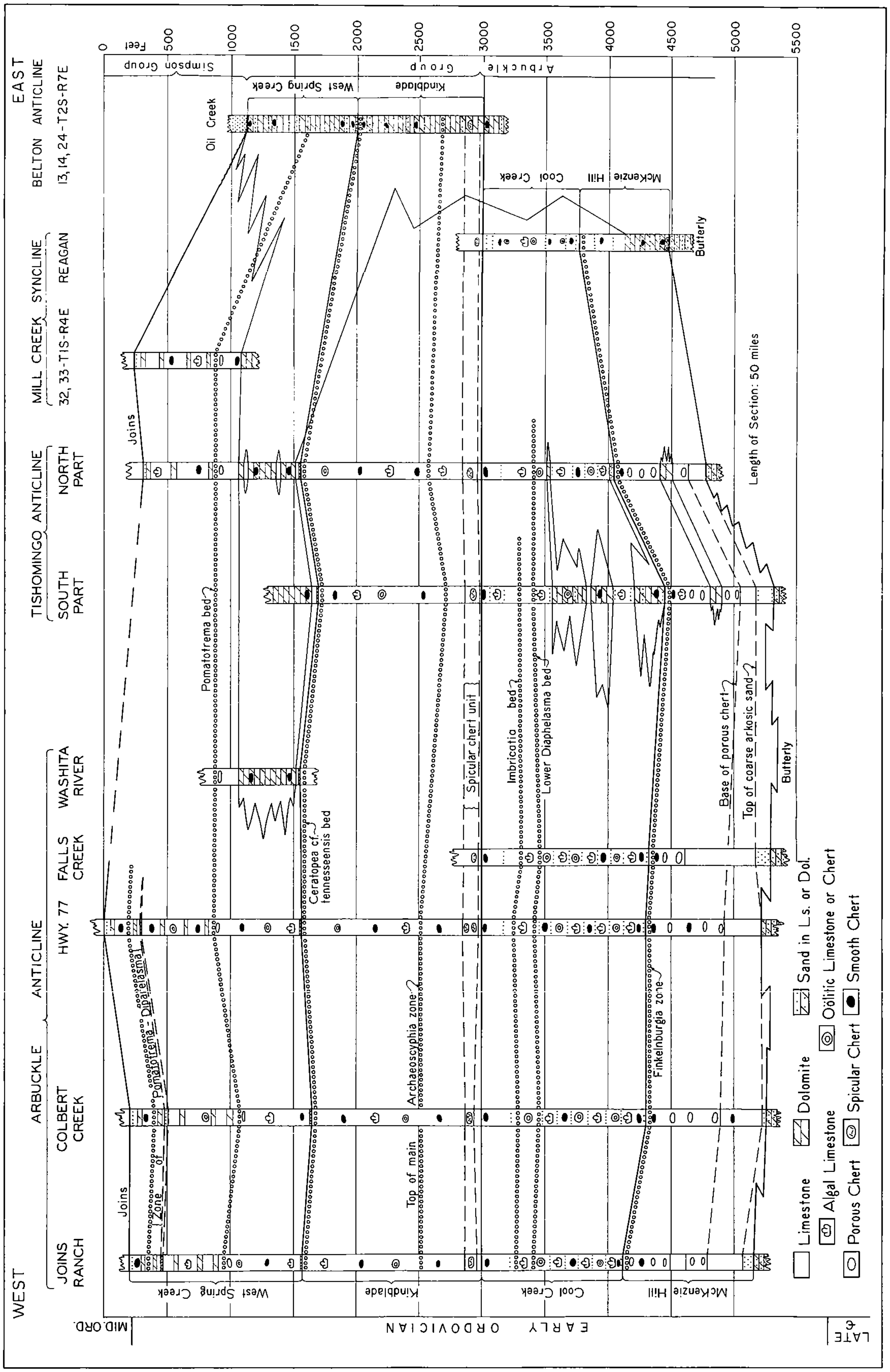


Figure 27. Regional stratigraphic section of middle and upper part of the Arbuckle Group (modified from Ham, 1955).

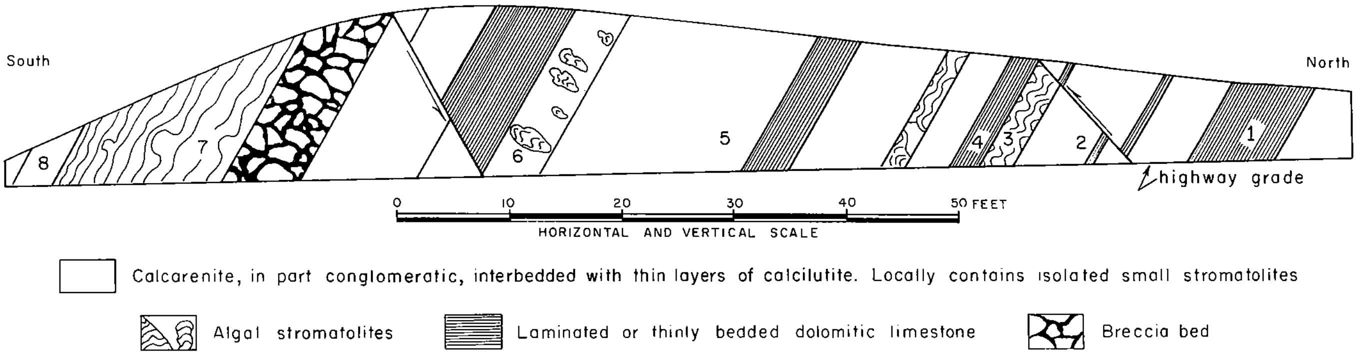


Figure 28. Stop I-7. Road-cut exposures of carbonate rocks in basal part of West Spring Creek Formation on west side of U. S. Highway 77, NE¼ NW¼ SW¼ sec. 19, T. 2 S., R. 2 E., Carter County. Strike N 50° W, dip 60° SW.

East Timbered Hills, where Colbert Rhyolite is thrust over various Late Cambrian strata.

28.2 (0.5) Entrance to Chapman Ranch on left. Rough-weathering crags are massive-bedded Butterly Dolomite. For the next 1.5 miles are limestones of the Arbuckle Group, homoclinally dipping 45-60° southwestward. Successive units up to the next stop are the McKenzie Hill, Cool Creek, and Kindblade Formations, together aggregating 3,700 feet. Parking along this stretch is hazardous because of lack of space and heavy traffic. Regional relations of the middle and upper parts of the Arbuckle Group are given in figure 27, which shows, as in the Cambrian beds, an eastward thinning and gradation of limestone into dolomite.

29.4 (1.2) Slow down at curve and cross highway with extreme caution to roadside parking area on left.

STOP I-7. **Carbonate rocks in basal part of West Spring Creek Formation (Early Ordovician) on west side of U. S. Highway 77, NE¼ NW¼ SW¼ sec. 19, T. 2 S., R. 2 E., Carter County. Strike N 50° W, dip 60° SW.**

Approximately 110 feet of carbonate rocks in the basal part of the West Spring Creek Formation is exposed in this cut, representing typical strata of Early

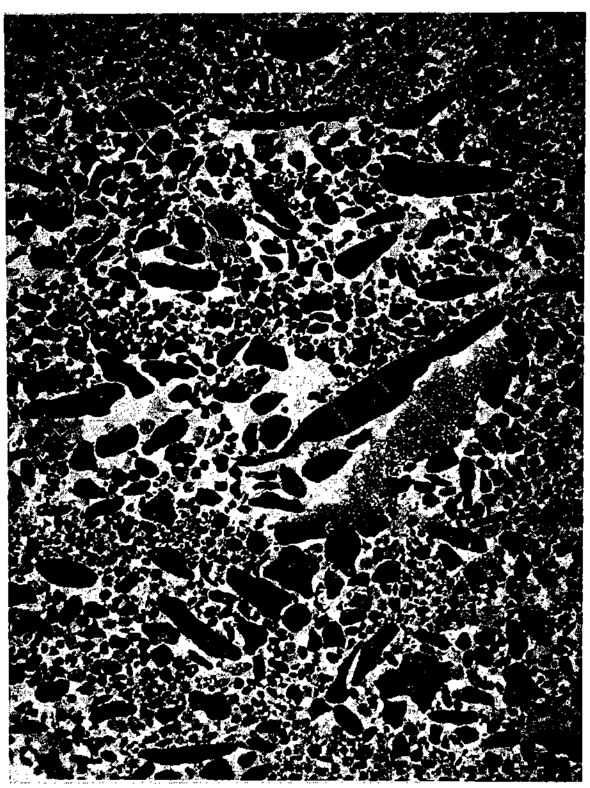


Figure 29. Intraclast calcarenite, a common medium-grained limestone of the Arbuckle Group that consists of irregularly shaped carbonate-mudstone grains cemented with sparry calcite. With increase in grain size, the rock grades into an intraformational conglomerate. x5.

Figure 30. Algal stromatolite colonies (s) have grown upon a floor of laminated carbonate mudstone (m) and are surrounded by coarse calcarenite (c). The central colonies are about 2 feet high. Bed 6 of stop I-7.

Ordovician age in the upper 4,500 feet of the Arbuckle Group (fig. 28; the numbers in parentheses below refer to labels in this figure).

The dominant rocks are calcarenites, generally in layers 2 inches to 2 feet thick, consisting mainly of calcite mudstone intraclasts (fig. 29) with lesser skeletal grains and oöids (8). Some of the calcarenites are conglomeratic (2). Interbedded with the calcarenites are normally thin and discontinuous layers of calcite mudstone or calcilutite, partly occurring with mud-cracked surfaces (5). Algal stromatolites (fig. 30) occur principally as three types: isolated hemispheroidal colonies in calcarenite (6), hemispheroids coalesced into a continuous bed (3), and algal mats with sparse and poorly developed hemispheroids (7).

The marine fauna of the Arbuckle Group is contained mostly in the calcarenites and to a lesser extent in the mudstones, demonstrating a shallow-water, marine origin for these rocks. The stromatolites are believed to have grown partly in subtidal and partly in intratidal environments, whereas the laminated or thinly bedded dolomitic limestones (1, 4) probably originated in the supratidal environment of temporarily isolated salt pans. They contain rare graptolites but otherwise are unfossiliferous. Bed 1, a quartzose dolomitic limestone, is the base of the West Spring Creek Formation.

A 6-foot-thick block-breccia bed near the southern edge of the road cut represents a rare rock type in the Arbuckle Group. Angular limestone fragments of diverse lithologies, ½ inch to 3 feet in diameter, characterize the bed. Probably of tectonic origin, such breccias are known to occur both as beds and as irregular masses nearly a hundred feet thick and covering an acre or more.

Two normal faults, each with a throw of about 5 feet, cut the beds of the exposure.

Continue ahead on highway.

29.8 (0.4) Top of Arbuckle Group, indicated by geologic sign on left.

At this point is shown one of the major changes in lithology in Paleozoic rocks of the Arbuckle Mountains. Mudstones, intraclast calcarenites, oölites, and stromatolites of the Arbuckle Group give way to skeletal calcarenites of the Simpson Group. For many years this division was believed to coincide with the end of the Canadian Epoch, but recent faunal investigations by Derby have shown this conclusion to be in error, as discussed in the following contribution.

Revision of Lower Ordovician-Middle Ordovician Boundary in Western Arbuckle Mountains, Oklahoma*

James R. Derby†

The contact between the West Spring Creek Formation of the Arbuckle Group and the Joins Formation of the Simpson Group has long been thought to coincide with the Lower Ordovician (Canadian)-Middle Ordovician boundary. The evidence for this time-stratigraphic assignment was straightforward as far as the well-known faunas were concerned. The West Spring Creek Formation contains a brachiopod-gastropod-graptolite fauna that all workers agree is Early Ordovician (Ulrich and Cooper, 1938; Decker, 1939, 1941; Cooper, 1952; Yochelson and Bridge, 1957). Similarly the Joins Formation contains a brachiopod-ostracode-graptolite fauna of Middle Ordovician age, earlier assigned to the Chazyan (e. g., Decker and Merritt, 1931; Harris, 1957; Schramm, 1965) but now assigned to the basal Middle Ordovician Whiterockian Stage (Cooper, 1956; Berry, 1960). Recently, I, with the aid of W. B. Creath and Gilbert Klapper of Pan American Petroleum Corporation, have found faunal evidence which shows that the uppermost West Spring Creek Formation is Whiterockian (Middle Ordovician) in age at two localities in the western Arbuckle Mountains.

The Early Ordovician age of the previously known fauna from the West Spring Creek is not in dispute here. The following fauna, most of which has been previously reported, occurs in the upper half of the West Spring Creek Formation.

Brachiopods: *Syntrophopsis magna* Ulrich and Cooper, 1936
Diparelasma typicum Ulrich and Cooper, 1936
Pomatotrema oklahomense Ulrich and Cooper, 1936
Tritoechia planodorsata Ulrich and Cooper, 1938

* Permission to publish granted by Pan American Petroleum Corporation.
† Pan American Petroleum Corporation, Research Center, Tulsa, Oklahoma.

Gastropod:	*Ceratopea unguis* Yochelson and Bridge, 1957
Trilobites:	*Aponileus latus* Hu, 1963 *Goniotelina subrectus* (Bradley, 1925) *Isoteloides* aff. *I. polaris* Poulsen, 1927
Graptolite:	*Didymograptus protobifidus* Elles, 1933
Ostracodes:	7 undescribed species being studied by Creath.
Conodonts:	Lower Ordovician fauna (see note by Klapper, below).

This fauna represents the youngest known Early Ordovician fauna in North America. It is known only from widely scattered areas where the Lower Ordovician section is exceptionally complete. We have found, through detailed sampling, that this fauna terminates abruptly approximately 100 feet below the top of the West Spring Creek Formation in the Arbuckle anticline. A thorough search of the literature revealed that all of the previously reported species had also been found 100 or more feet below the top.

An entirely different fauna has been found in the West Spring Creek Formation from the top down to no more than 90 feet, everywhere separated from the fauna below by a significantly barren interval. Part of this fauna has already been reported by Harris (1960), Harris and Harris (1965), and Creath (1966).

Brachiopod:	*Desmorthis nevadensis* Ulrich and Cooper, 1936
Ostracodes:	*Ceratoleperditia arbucklensis* Harris, 1960 *Isochilina kamara* Creath, 1966 3 undescribed species with affinity to Middle Ordovician Baltic forms (Creath, pers. comm., 1967).
Conodonts:	Middle Ordovician fauna described in part by Harris and Harris (1965).

The brachiopod *Desmorthis nevadensis* is here reported for the first time from the West Spring Creek Formation. Previously, the species was known in the Arbuckle Mountains only from the Joins Formation (Cooper, 1956, p. 118) and was reported as *Orthis costalis* by early workers (e. g., Decker and Merritt, 1931, p. 15). *Desmorthis nevadensis* has never been found in association with Early Ordovician faunas; it indicates correlation with the Middle Ordovician Whiterockian Stage (Cooper, 1956). The brachiopod correlation is supported by conodont evidence; Gilbert Klapper (pers. comm., 1967) commented as follows:

> The conodont fauna from the upper 90 feet of the West Spring Creek Formation at U. S. Highway 77 is Middle Ordovician (Whiterock) in age. The fauna is dominated by several forms of *Multioistodus* Cullison, *Erismodus* Branson and Mehl, and *Coleodus* Branson and Mehl, all of which preclude a Lower Ordovician assignment. Some of the *Multioistodus* from this fauma were illustrated by Harris and Harris (1965). The upper West Spring Creek conodont fauna shows affinities with that of the overlying Joins and Oil Creek, and not at all with the subjacent faunas.
>
> The conodont fauna from as high as 160 feet below the top of the West Spring Creek at Highway 77, as well as from lower horizons in the formation, is Lower Ordovician in age and is dominated by *Acodus* Pander and *Paltodus* Pander.

The following conclusions are clearly indicated.

1. The time-stratigraphic boundary between the Lower and Middle Ordovician falls *within* the West Spring Creek Formation of the Arbuckle Group, rather than at the Arbuckle-Simpson lithologic boundary (table 1).

Table 1. Revised Classifications of Upper Arbuckle and Lower Simpson Rocks in Western Arbuckle Mountains

TIME-STRATIGRAPHIC UNITS		ROCK UNITS	
Middle Ordovician	Whiterockian Stage	Simpson Group	Oil Creek Fm. Joins Fm.
		Arbuckle Group	West Spring Creek Formation
Lower Ordovician			

2. The uppermost 90 feet of Arbuckle strata in the western Arbuckle Mountains is Middle Ordovician in age.
3. A major faunal change in the brachiopod, conodont, and ostracode faunas is present about 100 feet below the top of the Arbuckle Group.
4. The fauna of the upper 90 feet of the West Spring Creek is more closely related to the fauna of the overlying Joins Formation than to the underlying fauna in the West Spring Creek.

These conclusions suggest that no major hiatus is present at the top of the Arbuckle, but one may be present within the Arbuckle. It may be significant, however, that the trilobite fauna does not show such a dramatic change. For example, *Goniotelina hesperia* Ross, 1967, a recently described species from the Whiterockian *Orthidiella* zone in Nevada, is present in the Joins Formation, and a very similar species is present near the top of the Lower Ordovician beds in the West Spring Creek Formation. The full significance of this faunal change can be better evaluated when studies by Fred Shaw (Mount Holyoke College) and myself on the Simpson and Arbuckle trilobites and by W. B. Creath on the Arbuckle ostracodes are completed so that comparisons can be made with other regions.

30.3	(0.5)	Turn right (west) across cattle guard onto unpaved road.
30.5	(0.2)	Go beyond Interstate 35 underpass and park.

STOP I-8. **Bromide Formation (Middle Ordovician) on Tulip Creek, NW¼ NW¼ NE¼ sec. 25, T. 2 S., R. 1 E., Carter County. Strike N 60° W, dip 56° SW.**

Bromide Formation on Tulip Creek and in the Arbuckle Mountains Region

Robert O. Fay* and A. Allen Graffham†

The Bromide Formation is the uppermost of five formations of the Simpson Group. A generalized measured section of the Bromide at Tulip Creek (fig. 31) is as follows.

Pooleville Member (120 feet thick):

		Feet
1.	Limestone, gray, fine-grained, dense, massive; eroding into a ledge (bed 5, fig. 31)	14.0
2.	Limestone, gray to tan, fine-grained, dense, thin-bedded; eroding into a ledge	16.0
3.	Limestone, gray, fine-grained, dense, medium-bedded; eroding into a ledge	9.5

* Oklahoma Geological Survey, Norman, Oklahoma.
† Geological Enterprises, Ardmore, Oklahoma.

	Feet
4. Limestone, gray to tan, medium-granular, medium-bedded, fossiliferous	7.0
5. Limestone, gray to tan, with interbedded shale, very fossiliferous	22.0
6. Limestone, gray, fine-grained, dense, massive; eroding into a ledge	1.0
7. Limestone, gray to tan, argillaceous, thin-bedded to medium-bedded, fossiliferous; with interbedded shale	43.5
8. Shale and limestone, tan, thin-bedded, very fossiliferous	7.0
9. Limestone, tan, medium-granular, thin-bedded, very fossiliferous; eroding into a ledge	4.0
Mountain Lake Member (300 feet thick):	
10. Shale, tan, with interbedded limestone, thin-bedded, very fossiliferous; *Amygdalocystites* 1 foot below top (upper Echinoderm zone)	4.0
11. Limestone, tan, fine-grained, massive, fossiliferous; eroding into a ledge (bed 4, fig. 31)	1.25
12. Shale, tan, with interbedded limestone, thin-bedded, very fossiliferous; *Amygdalocystites, Sinclairocystis, Glyptocystites* (upper Echinoderm zone)	7.0
13. Shale, greenish-gray; with medium-granular, thin-bedded limestone	30.0
14. Limestone, gray to tan, fine-grained to medium-granular, thin-bedded; eroding into a ledge	7.0
15. Shale, greenish-gray, blocky; with a 1-foot fossiliferous limestone 20 feet below the top with abundant *Sowerbyella*	70.0
16. Limestone, tan, fine-grained to medium-granular, thin-bedded; with interbedded greenish-gray shale; eroding into a ledge	11.0
17. Shale, greenish-gray, blocky (bed 3, fig. 31)	20.0
18. Limestone, gray to tan, fine-grained to medium-granular, thin-bedded, fossiliferous; with interbedded greenish-gray shale and lower Echinoderm zone about 22 feet above the base	48.0
19. Limestone, brown to gray, medium-granular, arenaceous, echinodermal, massive; gradational into a sandstone; eroding into a ledge (bed 2, fig. 31)	1.5
20. Shale, greenish-gray, with some interbedded medium-granular limestone and fine-grained to medium-grained sandstone; mostly covered	70.0
21. Sandstone, brown, fine-grained to medium-grained, quartzose, massive, well-indurated; eroding into a ledge	4.0
22. Shale, greenish-gray, with interbedded sandstone	12.0
23. Sandstone, light-tan, fine-grained to medium-grained, thin-bedded to medium-bedded, quartzose; eroding into a prominent ledge (bed 1, fig. 31)	14.0
Tulip Creek Formation (only 86 feet described):	
1. Shale, greenish-gray, blocky, weakly indurated; with some interbedded limestone and sandstone	76.0
2. Sandstone, brown, fine-grained to medium-grained, quartzose, medium-bedded; eroding into a ledge just south of the road	10.0

At this stop (fig. 31), the Bromide Formation is about 420 feet thick, cropping out in a bench below the scarp face of Viola Limestone in the high ridge to the south. The Viola-Bromide contact is well defined and is much like that in the Rayford quarry seen at Stop I-1.

The Bromide is subdivided into two members, the Pooleville Limestone (upper 120 feet) and Mountain Lake Shale (lower 300 feet), with much sandstone in the lower 100 feet (beds 1 and 2, fig. 31).

The Mountain Lake is mostly greenish-gray shale and crinoidal limestone (bed 3, fig. 31). A lower 3-foot echinoderm zone, about 170 feet below the top, or about 22 feet above bed 2 (fig. 31), is sparsely

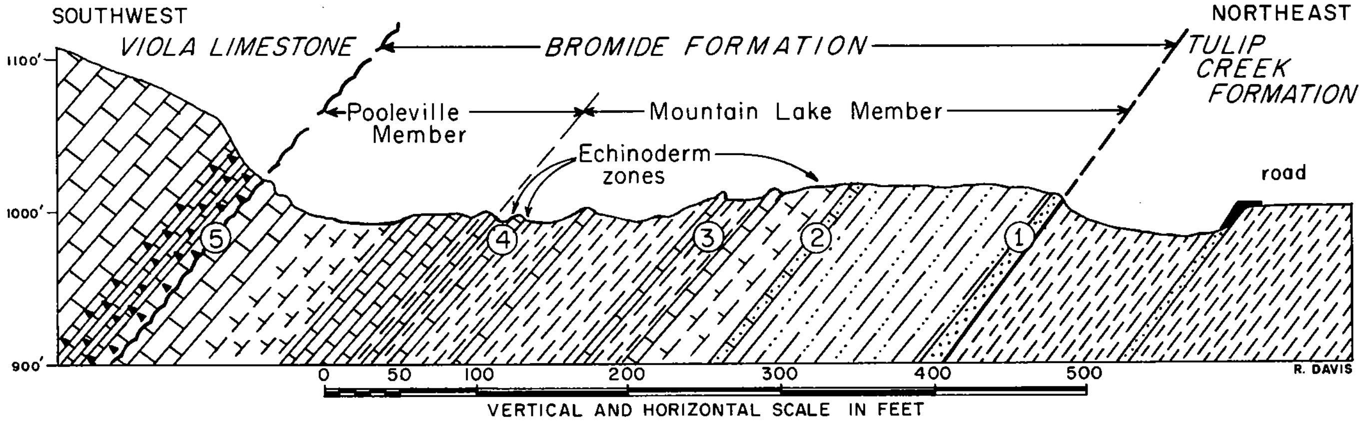


Figure 31. Stop I-8. Stratigraphic section of Bromide Formation on Tulip Creek, NW¼ NW¼ NE¼ sec. 25, T. 2 S., R. 1 E., Carter County. Strike N 60° W, dip 56° SW.

fossiliferous and not well developed. *Platycystites* (a paracrinoid) and *Hybocrinus* (a crinoid) commonly occur in this zone, along with the brachiopod *Mimella extensa* and many bryozoans. Near the top of the Mountain Lake is a 10-foot upper echinoderm zone (bed 4, fig. 31). It is characterized by *Amygdalocystites* and *Sinclairocystis* (paracrinoids), which are rare here, along with *Prasopora fritzae* and other bryozoans and brachiopods.

The Pooleville is mostly a gray, fine-grained, dense limestone, or argillaceous limestone, with some fossiliferous shale at the base and near the middle. At the top is about 14 feet of massive limestone, in contact with the overlying thin-bedded, dark, cherty, lithographic Viola Limestone, with a thin, greenish-gray shale at the contact (bed 5, fig. 31).

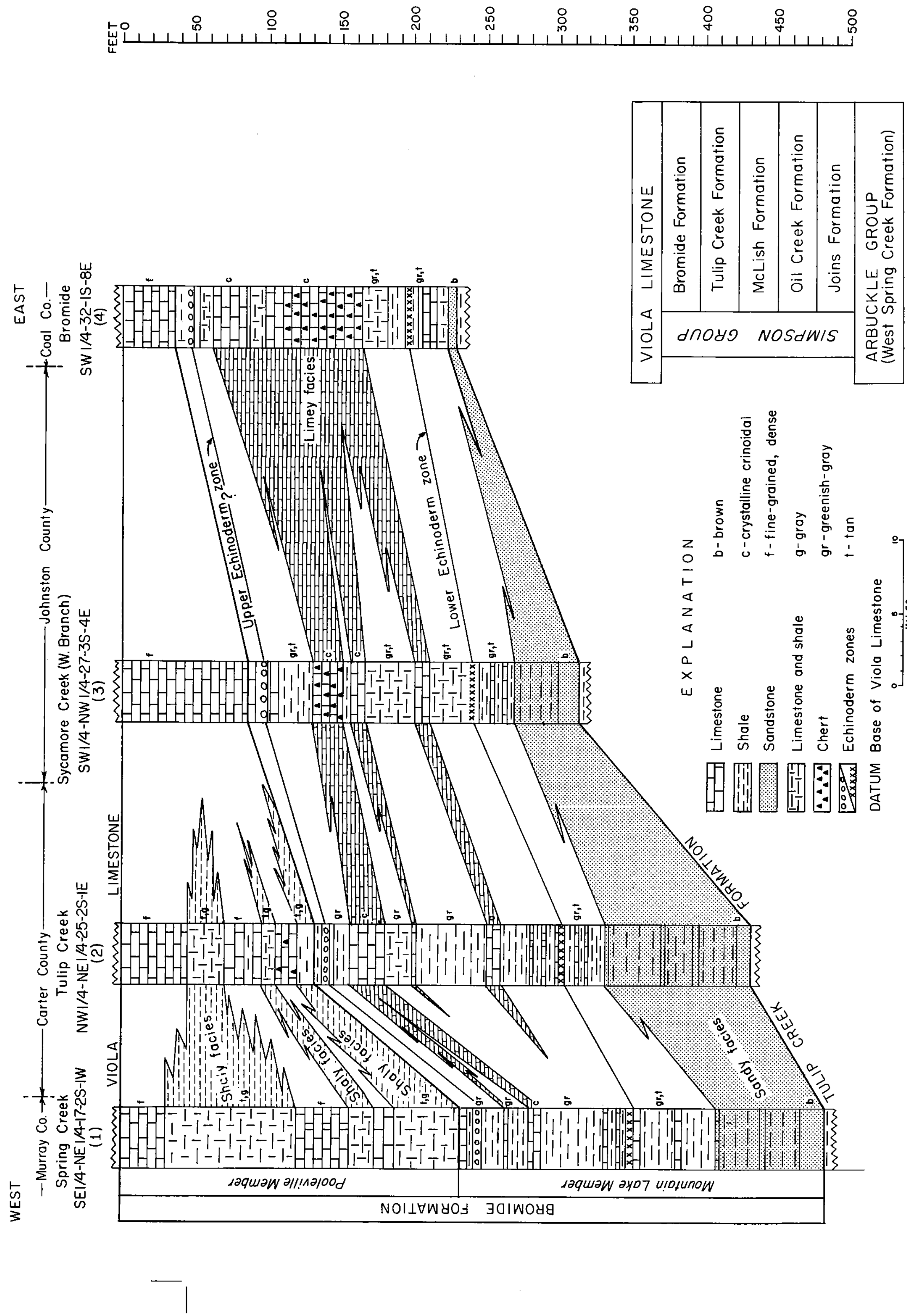
Regionally, the Bromide has much sandstone to the north, shale to the west and south, and limestone to the east (fig. 32). The Bromide is thinner eastward and northeastward, along with other formations of the Simpson Group, and appears to be thinner southward in the Criner Hills. Much of the eastward thinning appears to be within the Pooleville Member, and the southward thinning is mostly within the Mountain Lake Member. The echinoderms occur abundantly in areas where shale and limestone are about equally developed, especially along edges of bryozoan bioherms. The Pooleville echinoderms have been found almost exclusively in the Criner Hills, and the Mountain Lake echinoderms have been found almost exclusively in the Arbuckle Mountains, being abundant in the Camp Classen, Dougherty, Sulphur, and Sycamore Creek areas (shaded area, fig. 32).

		Retrace route to U. S. 77.
30.7	(0.2)	Turn right (south).
31.0	(0.3)	Park in roadside rest area at right.

STOP I-9. **Hunton Group (Silurian-Devonian) and lower part of Woodford Formation (Late Devonian), NE¼ SE¼ sec. 25, T. 2 S., R. 1 E., Carter County. Strike N 65° W, dip 48-53° SW.**

As measured and described by Amsden (1960, p. 198-199) at Tulip Creek, just west of the highway, the Hunton Group is 202 feet thick and consists mostly of Silurian strata. The basal 26 feet is composed of resistant limestones (fig. 33) that make a low escarpment above the valley of Sylvan Shale and is divided from the base upward into the Keel Limestone (2 feet), Cochrane Limestone (14 feet), and Clarita Limestone (10 feet). The limestones are oölitic calcarenite, glauconitic calcarenite, and skeletal carbonate mudstones, respectively (fig. 34). They are overlain by the Henryhouse Formation, 152 feet thick, which crops out as fossiliferous mudstones and calcareous shales. The contained faunas are of Silurian age. Above the Henryhouse is the Haragan Formation, 24 feet thick, of virtually identical lithology but containing an entirely new suite of Early Devonian fossils. At this locality the precise boundary is difficult to locate in the field, but at other localities in the Arbuckle Mountains it occurs as a well-defined unconformity.

In much of the eastern Arbuckle Mountains, the Hunton Group consists dominantly of Devonian formations, including the Frisco Limestone, the top of which is an excellent petroleum reservoir in parts of central Oklahoma (fig. 35). Erosion at the Early Devonian unconformity is particularly severe in some areas, with the result that all Silurian strata, which here are 178 feet


WEST
EAST
Murray Co.
Carter County
Johnston County
Coal Co.
Spring Creek
SE1/4-NE1/4-17-2S-1W
(1)
Tulip Creek
NW1/4-NE1/4-25-2S-1E
(2)
Sycamore Creek (W. Branch)
SW1/4-NW1/4-27-3S-4E
(3)
Bromide
SW1/4-32-1S-8E
(4)
VIOLA LIMESTONE
Shaly facies
Upper Echinoderm zone ?
Limey facies
Lower Echinoderm zone
Sandy facies
TULIP CREEK FORMATION
Poolevile Member
Mountain Lake Member
BROMIDE FORMATION
FEET
0 50 100 150 200 250 300 350 400 450 500
EXPLANATION
Limestone
Shale
Sandstone
Limestone and shale
Chert
Echinoderm zones
DATUM Base of Viola Limestone
b-brown
c-crystalline crinoidal
f-fine-grained, dense
g-gray
gr-greenish-gray
t-tan
0 5 10
MILES
VIOLA LIMESTONE
SIMPSON GROUP
Bromide Formation
Tulip Creek Formation
McLish Formation
Oil Creek Formation
Joins Formation
ARBUCKLE GROUP
(West Spring Creek Formation)

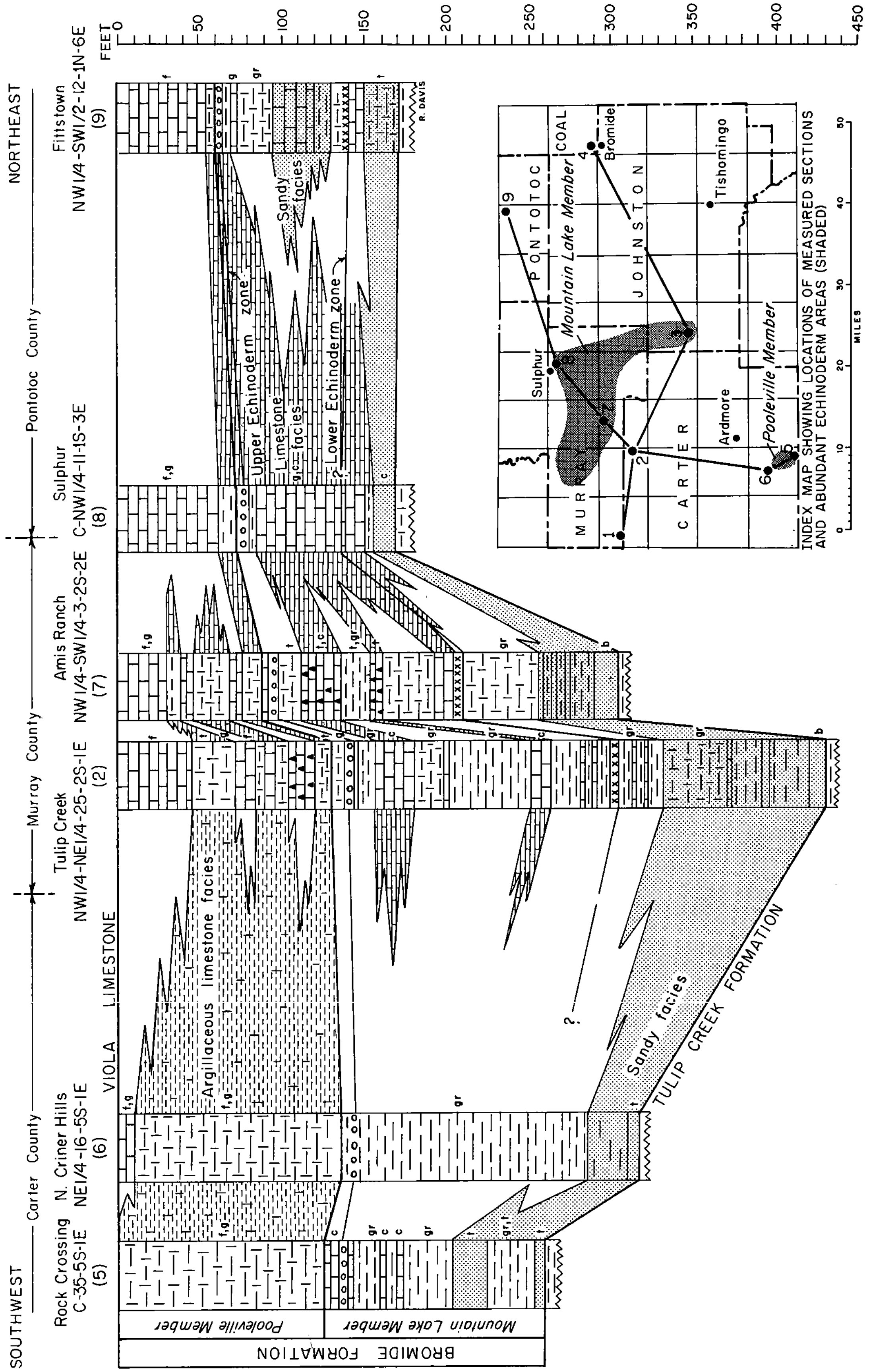


Figure 32. Regional stratigraphic sections of the Bromide Formation in the Arbuckle Mountains and Criner Hills.

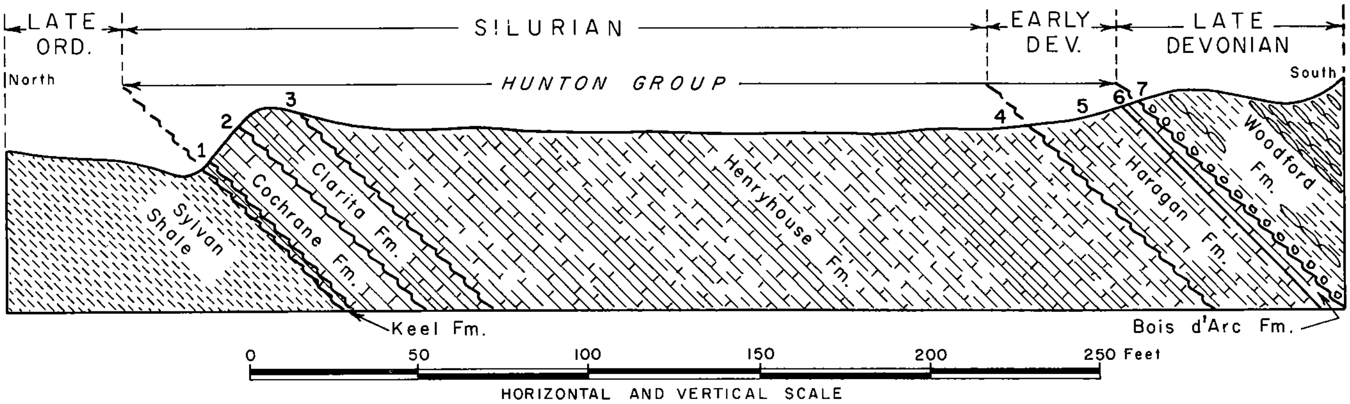


Figure 33. Stop I-9. Outcrops of the Hunton Group and lower part of the Woodford Formation on east side of U. S. Highway 77, NE¼ SE¼ sec. 25, T. 2 S., R. 1 E., Carter County. Strike N 65° W, dip 48-53° SW. At this locality the Hunton Group consists mainly of Silurian strata. Erosion at the pre-Woodford unconformity has removed at least 150 feet of Devonian strata, including all the Frisco Limestone and most of the Haragan-Bois D'Arc Formations. A 1-foot-thick conglomerate marks the base of the Woodford Formation.

thick, are removed, and Devonian beds rest upon Ordovician Sylvan Shale.

At Stop I-9, the Hunton formations crop out in a kind of open glade. To the south, beginning at the line of trees, is the outcrop of the Woodford Formation. It typically consists of laminated dark shale interbedded with thin layers of chert, as shown in the road cut ahead. The base itself is a 1-foot bed of glauconitic and sandy chert conglomerate, marking the pre-Woodford unconformity that extends through much of the central United States craton.

Still farther ahead in the road cuts are exposures of Sycamore Limestone, a well-bedded, highly silty, and generally unfossiliferous limestone of Mississippian age. Conspicuous on the outcrop are yellowish weathering coronas around the blue-gray interiors of fracture polygons. Much limestone of this type is used as building stone in southern Oklahoma.

33.0 (3.0) Springer.

End of trip for first day

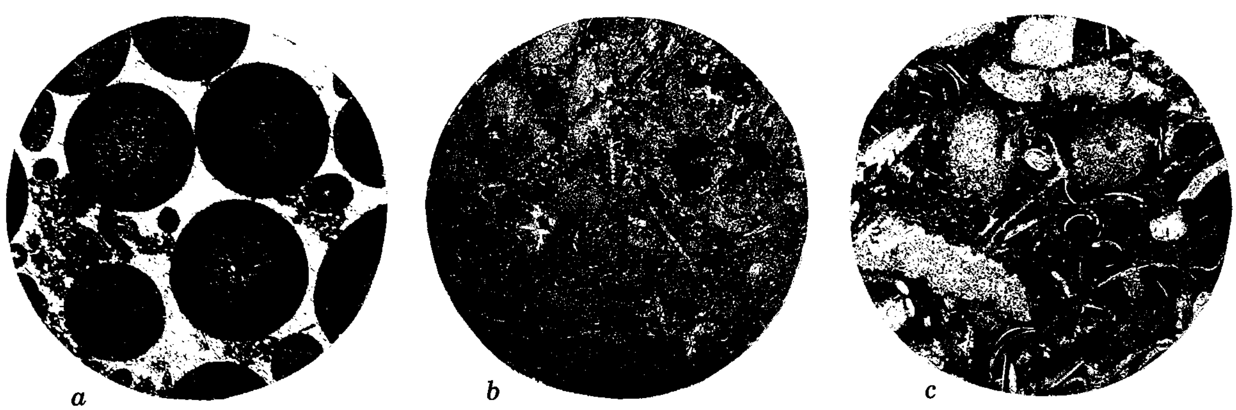


Figure 34. Photomicrographs of typical lower Hunton limestones, x12.5, from the Arbuckle Mountains.

a. Keel Limestone. An oölitic calcarenite that locally contains either a micritic matrix or sparry calcite cement. A strong bimodal distribution of oöids is common.
b. Cochrane Limestone. A micritic pelmatozoan calcarenite containing dark grains of glauconite.
c. Clarita Limestone. A skeletal calcilutite containing pelmatozoans, trilobites, brachiopods, and ostracodes. The formation shows wide variability in percentage of skeletal grains.

ROAD LOG FOR SECOND DAY

East of Mannsville to Davis

Mileage Cumu-lative	Between points	
0.0	(0.0)	Starting point is junction of U. S. 70 and State 12, 2.9 miles east of Mannsville, Johnston County. Turn left (north), then bear east on State 12.
2.3	(2.3)	Russett.
2.5	(0.2)	Russett School on left.
5.3	(2.8)	Washita River.
7.6	(2.3)	Just beyond curve turn to right shoulder and park.

STOP II-1. **Tishomingo block of craton faulted against Ardmore basin of Southern Oklahoma geosyncline, SE¼ NW¼ sec. 3, T. 4 S., R. 5 E., Johnston County, 0.5 mile west of Ravia.**

In the south road cut are exposures of dark shale with thin skeletal calcarenites of probable Morrowan (Dornick Hills) age, faulted against Reagan Sandstone of Late Cambrian age. The Reagan in turn is faulted against Precambrian Tishomingo Granite, which at this locality is poorly exposed. The strata as well as the faults have nearly vertical dip, and the two faults together comprise the Washita Valley fault zone.

The inconspicuous outcrops at this locality belie their great regional importance, for rocks of the Arbuckle anticline-Ardmore basin on the south are sharply faulted against massive granites of the Tishomingo anticline on the north (fig. 36). The Washita Valley fault here separates geosyncline from craton, the relations and geologic histories of each being directly related to the basement rocks.

Under the Ardmore basin and Arbuckle anticline are thick flows of basement-rock rhyolite, dated at 525

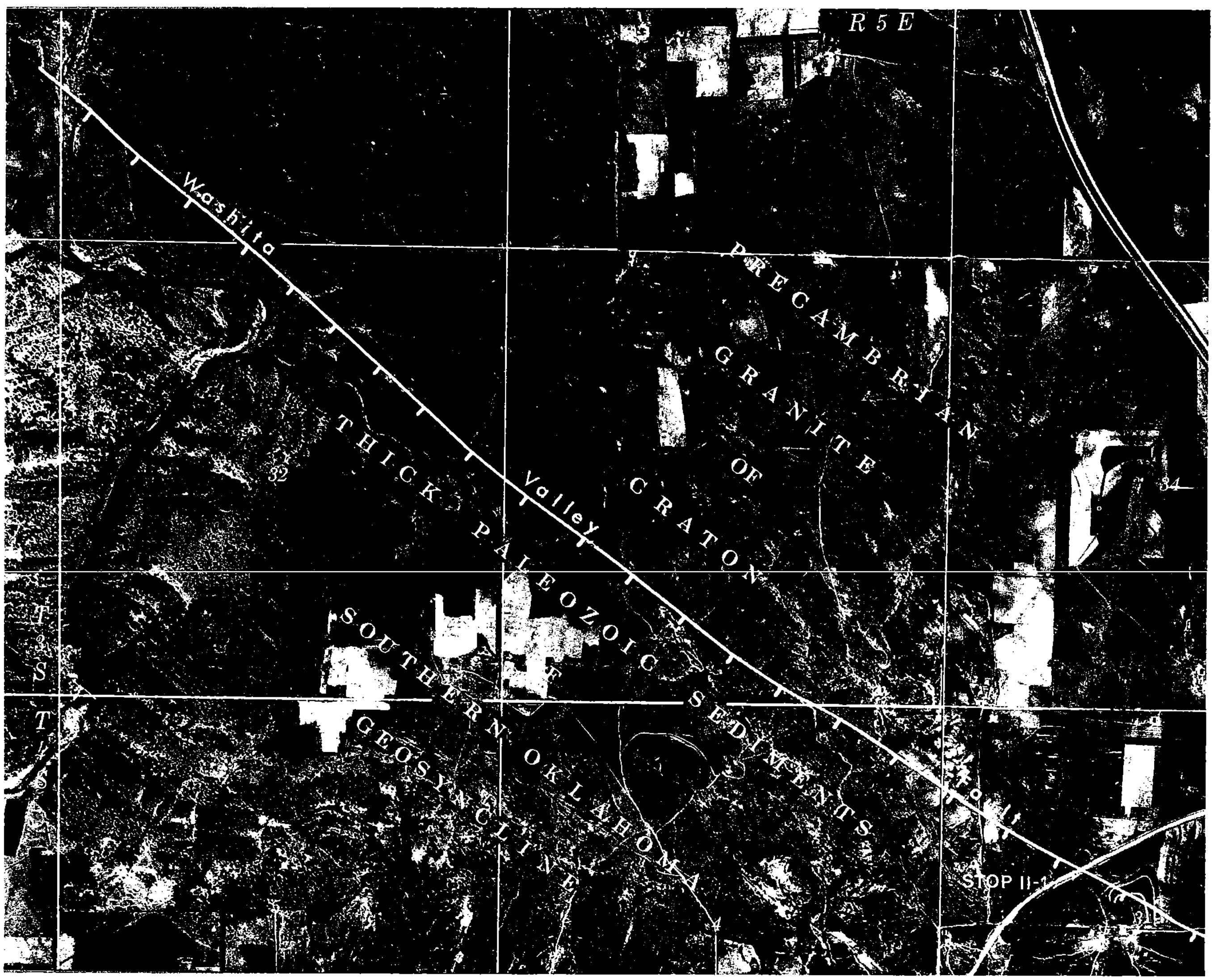


Figure 36. Vertical aerial photograph of the area near Ravia, showing sharp demarcation between cratonic granite and thick sediments of the Southern Oklahoma geosyncline along the Washita Valley fault. Rarely is the separation between major continental divisions so clearly defined in one photograph. (Stop II-1 is in lower right corner of photograph.)

million years, which in turn are underlain by basalt and probably by graywacke. At least 7,000 feet of basement rock beneath the Reagan Sandstone is of Middle Cambrian age and is assigned to the Wichita Province. This rock provides a foldable thick floor for the 34,000 feet of Paleozoic sediments above. The 40,000-foot sequence behaves geologically as a single unit, as is typical of rocks in the Southern Oklahoma geosyncline.

On the opposite side of the fault is granite of the Eastern Arbuckle Province, dated at 1,350 million years and thus of undoubted Precambrian age. It is the oldest dated rock of southern Oklahoma. Exposed by deep erosion in the eastern area of outcrop in the Tishomingo and Belton anticlines, it everywhere underlies the Reagan Sandstone of this area. From here northward into Kansas, granite of this type and general age makes up a stable cratonic floor upon which relatively thin Paleozoic sediments have been deposited. The sedimentary cover itself is characterized structurally by gentle folding and block or en echelon faulting, in strong contrast with the close folding, overturning, and thrust faulting of the Southern Oklahoma geosyncline.

8.1	(0.5)	Enter Ravia.
8.6	(0.5)	Frisco Railroad crossing.
8.7	(0.1)	Junction of State 12 and State 22. Turn left (north) on State 12. Gently rolling plains are underlain by Tishomingo Granite, poorly exposed.
15.6	(6.9)	Troy. Turn right (east) at Texaco filling station, leaving State 12.
16.7	(1.1)	Rock Creek crossing, concrete low-water bridge.
16.9	(0.2)	Park to right.

STOP II-2. **Tishomingo Granite in Capitol quarry at Ten Acre Rock, C NE¼ sec. 3, T. 3 S., R. 5 E., Johnston County.**

The largest area of exposure of Precambrian rocks in Oklahoma is in the eastern part of the Arbuckle Mountains, within the Tishomingo and Belton uplifts. Ten Acre Rock, probably the best known locality for these rocks, is a low, bare hill of coarse-grained Tishomingo Granite that rises above Rock Creek near Troy. In early days of settlement it served as a prominent landmark for the region, and it achieved some fame when in 1915 a quarry was opened on its north slope for the production of dimensional granite for constructing the ground floors of the state Capitol at Oklahoma City. Since that time it has been known as the Capitol quarry, although the quarry face itself has not been actively worked in succeeding years.

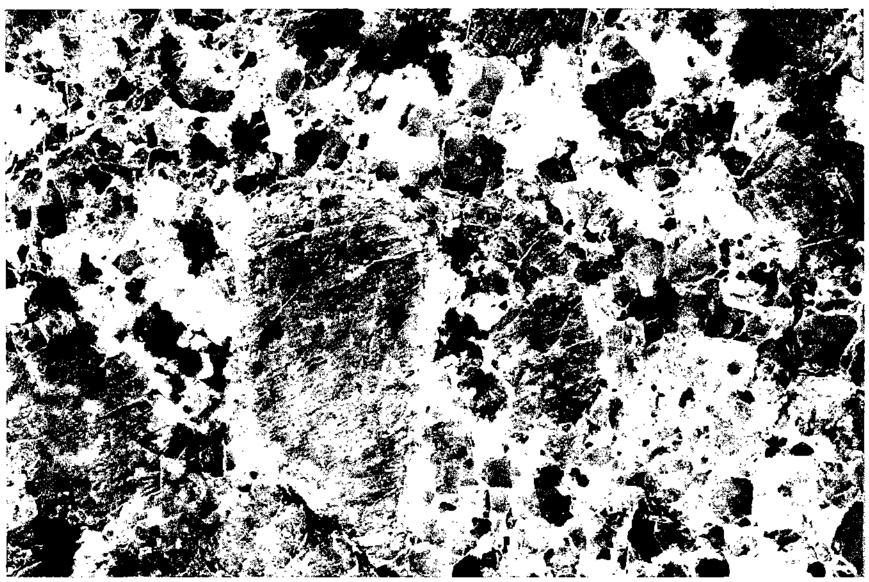


Figure 37. Tishomingo Granite, Capitol quarry (Stop II-2). Polished specimen, x1.7, showing large phenocryst of microcline near center surrounded by white plagioclase and clear quartz.

The Tishomingo Granite is coarse grained and porphyritic (fig. 37). Flesh-pink subhedral crystals of microcline, as much as 1.5 inches long and 1 inch wide, are set in a matrix of colorless quartz, black biotite, pink microcline, and dull-gray oligoclase. The matrix grains have an average diameter of about 0.25 inch. Thin-section examination (Ham, Denison, and Merritt, 1964) shows that the microcline is microcline-perthite. It normally makes up 50 percent of the rock, whereas the re-

The Washita Valley fault probably originated in basement-rock time. Colbert Rhyolite, at least 4,500 feet thick, has been drilled in the Arbuckle anticline, and much thicker sediments and flows probably lie below it, down to the top of the Tishomingo Granite. These rocks are not present above Precambrian granite in the Tishomingo anticline, either having been eroded before Reagan time or, more likely, never having been deposited. The line of separation between the two provinces is so sharp that a fault of great magnitude is clearly implied. Presumably this pre-Reagan fault was approximately coincident with the northwestward-trending Washita Valley fault, along which substantial movement again took place in Pennsylvanian time. With a known length of 90 miles, it is one of the major faults of southern Oklahoma.

Northward from this stop the route traverses rocks of the craton (fig. 38).

Continue ahead.

maining essential constituents are oligoclase, 20 percent; quartz, 22 percent; and biotite, 2 to 5 percent. Accessory minerals are magnetite, apatite, zircon, and sphene, which occur together with epidote and fluorite of hydrothermal origin.

The rock locally is cut by pegmatite dikes and veinlets of epidote. In the central parts of some pegmatites are open spaces lined with euhedral microcline and quartz. Dark-purple fluorite also occurs but is decidedly uncommon.

Diabase dikes cut Tishomingo granite near Ten Acre Rock. Locally, the diabase was worked for gold in pre-statehood days. No gold was recovered and none has been found in any rock of the region, but the diabase itself is of interest geologically as the second most common rock type in the Eastern Arbuckle Province. The diabase consists of small laths of plagioclase (labradorite) set ophitically in pyroxene, accompanied by abundant magnetite and some biotite. The exceptional abundance of diabase in this province is shown by cuttings of the Honeymon 1 Townsend well (SE¼ SE¼ NW¼ sec. 30, T. 5 S., R 8 E., Bryan County) that penetrated 3,653 feet of granite and diabase basement rock. Of this penetration, 2,630 feet is granite and 1,023 feet, or 28 percent, is diabase. The diabase occurs in the form of dikes and sill-like bodies, some of them having a drilled thickness of 150 to 200 feet.

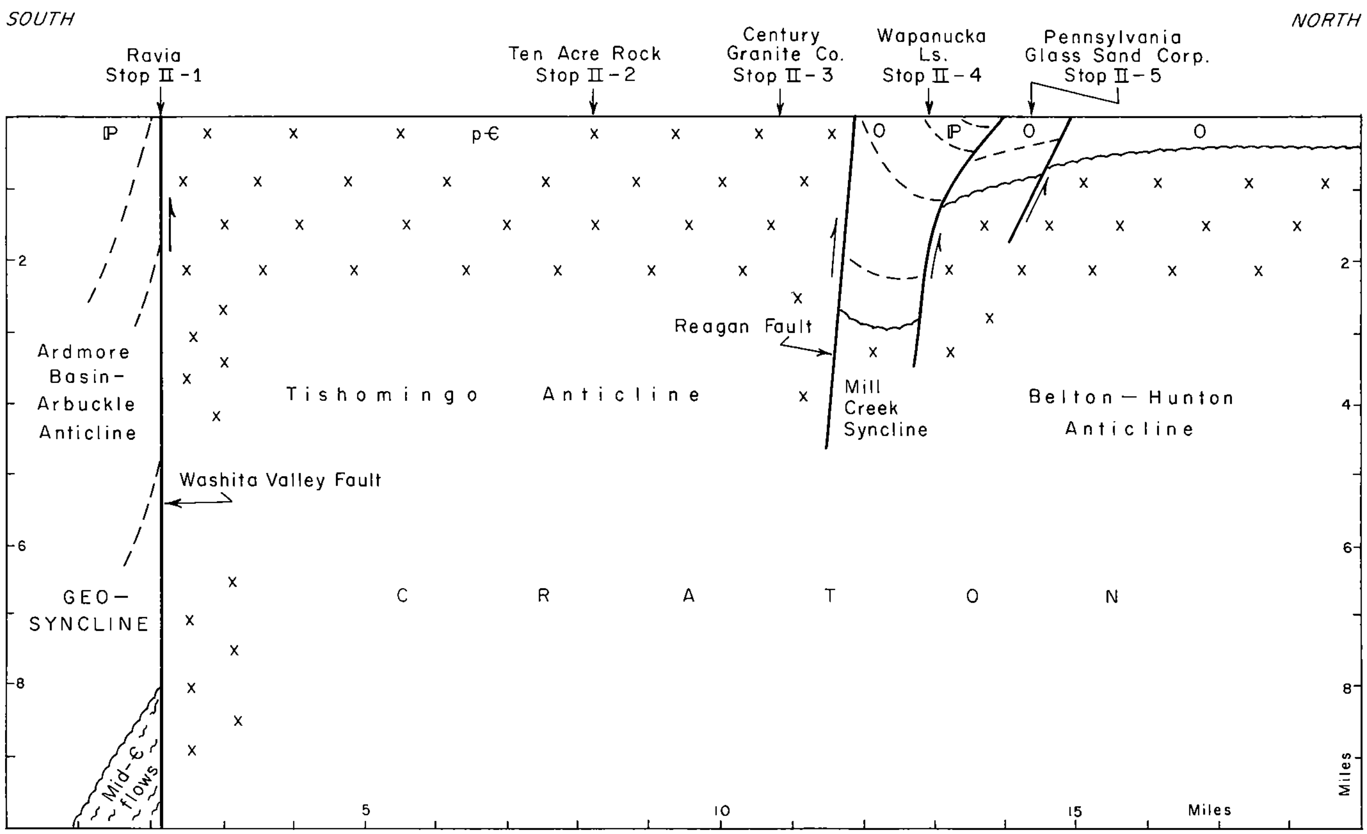


Figure 38. Stops II-1 through II-5. Idealized structure section along State Highway 12 in the south-central part of the Arbuckle Mountains, from the geosynclinal province at Ravia northward across the cratonic province.

Petrologically the rock is characterized as a two-feldspar granite of igneous origin, emplaced at moderate depths within the Earth's crust. After its emplacement the granite was uplifted, denuded of overlying rocks, and exposed at the surface. It was the surface rock over much of central Oklahoma at the time of deposition of the Late Cambrian Reagan Sandstone.

Ten Acre Rock has the distinction of being the first locality in Oklahoma from which granite was definitely established as Precambrian. In 1957 and 1958, George Tilton and George Wetherill (the Carnegie Institution of Washington) collected samples and determined the age of the Tishomingo Granite by an investigation of radioisotopes. By separating zircon crystals from the granite and analyzing the zircon concentrates in mass spectrometers, they determined, quantitatively, the isotopes of uranium, thorium, and lead. By using the rates of radioactive disintegration of uranium and thorium into lead, it was possible to calculate that the age of the granite is 1,350 million years. This analysis firmly established the granite as Precambrian, equivalent in age to similar basement rocks in parts of Missouri, Texas, and Colorado.

		Return to State 12 and continue on to Troy.
18.2	(1.3)	Troy. Turn right (north) on State 12.
19.3	(1.1)	On left, at Ryder siding, is plant and shipping point of Delta Mining Corp., which produces crushed and ground high-purity dolomite from a quarry 3 miles west in the Royer Dolomite of Late Cambrian age. The processed dolomite is widely used in making glass and in mineral feeds.
21.3	(2.0)	Entrance to Century Granite Com-

		pany quarry. Turn right (west) across Frisco Railway tracks to quarry.
21.5	(0.2)	Park.

STOP II-3. **Troy Granite, quarry of Century Granite Company, SW¼ SW¼ SW¼ sec. 20, T. 2 S., R. 5 E., Johnston County.**

Early study of igneous rocks in the eastern part of the Arbuckle Mountains revealed that two types of granite are common. Named the Tishomingo and Troy Granites, they were mapped in a general way within the relatively poor exposures of the block-faulted region. Noting that the mineral composition of the two rocks was essentially the same, the early workers distinguished the Troy Granite by its medium-grained, equigranular texture, and the Tishomingo Granite by its much greater coarseness and the widespread occurrence in it of pink microcline phenocrysts.

A Rb/Sr age of microcline from the Troy Granite shows that it is a contemporaneous phase of the Tishomingo Granite and is 1,350 million years old (Muehlberger et al., 1966, p. 5421).

Judging from point counts of large thin sections, the Troy Granite contains more quartz and less feldspar than the Tishomingo Granite. Normal granite from the Century quarry contains 37 percent microcline-perthite, 25 percent oligoclase (An_{13}), and 35 percent quartz, together with 2 percent biotite and 0.8 percent magnetite. Like the Tishomingo Granite, it is a batholithic intrusion of the mesozone.

Outstanding in the quarry walls at this locality are the steeply dipping schlieren, or streaks and bands rich in dark minerals. They were drawn out, probably from segregations, during active injection of the granite magma. Schlieren locally characterize granite of the Eastern Arbuckle Province but are conspicuously absent from the epizone granite intrusions of the Wichita Province.

About 1 mile south of the Century Company quarry, the Troy Granite grades into diorite, apparently the result of contamination around a large inclusion of biotite-hornblende schist. This inclusion and similar inclusions of biotite schist in Precambrian granite of the Muenster arch in Jefferson County are important because they show the nature of the host rocks into which the granite was injected.

Diorite locally is a conspicuous rock of the Eastern Arbuckle Province in subsurface. It has been found in core holes drilled in Johnston and Atoka Counties, but most of the knowledge about diorites of this province is derived from a study of samples from the Phillips 1 Matoy well in northeastern Bryan County, about 18 miles southeast of the nearest granite outcrops of the Arbuckle Mountains.

The Matoy well penetrated 11,823 feet of basement rock, much of it pink granite of the Tishomingo and Troy types. In the upper 3,300 feet of the basement rocks, to a depth of 4,000 feet, diorite occurs in abundance as sheetlike bodies or possibly as dikes cutting the granite. Thirteen separate intrusive bodies of diorite are distinguishable from the cuttings and electric log. The bodies have a drilled thickness ranging from 20 to 270 feet, and the aggregate thickness of diorite is 1,380 feet, or 35 percent of the total rock. An isotopic determination of Rb^{87} and Sr^{87} in biotite from a diorite core at 1,001 feet gave an age of 1,200 million years, showing it to be Precambrian but considerably younger than the 1,350-million-year granite it cuts.

The Century quarry has been developed as a pit in a boss (a low, rounded granite hill) chosen because the stone is massive and free from closely spaced joints. The first step in quarrying is the separation of large blocks from the solid ledge. At first this was accomplished by channeling, a process by which holes about 10 feet deep are drilled vertically into the rock; the space between the holes (webs) were then drilled out or broached. Now the company quarries by jet-piercing, the vertical channels being cut by disaggregating the granite with jets burning a mixture of fuel oil and oxygen. The block is removed after drilling horizontal holes at the base and shooting with black blasting powder. The "rough saw block" is then shipped to the company's plant at Frederick in southwestern Oklahoma for sawing and processing into polished slabs for tombstones and exterior trim.

		Retrace route to State 12.
21.7	(0.2)	State 12. Turn left (north).
22.5	(0.8)	Outcrops of Troy Granite in south base of railroad trestle to west of road and in road ditches to the north. About 0.1 mile ahead is the poorly exposed trace of the Reagan fault, the south fault of the Mill Creek graben, at a locality where the throw is at least 8,000 feet down to the north. Fifty feet north in low road cuts on the west side of State 12 are outcrops of uppermost Arbuckle limestones. The rocks nearest the fault have been strongly brecciated by the tectonic movement. Block faulting, as represented by the Mill Creek graben, is a typical structure of the craton.
22.8	(0.3)	Early Paleozoic strata dip northward on south limb of synclinal fold in Mill Creek graben.
24.6	(1.8)	Entering Mill Creek. Turn right (east) at Deep Rock filling station and go past school.
24.9	(0.3)	Turn right (south) on State 7.
25.2	(0.3)	Iron gate on right (west) side of road. Park and walk through gate to quarry.

STOP II-4. **Wapanucka Limestone (Early Pennsylvanian; Morrowan) in abandoned quarry at south edge of Mill Creek, S½ NW¼ SW¼ sec. 7, T. 2 S., R. 5 E., Johnston County. Strike N 60° W, dip 23° NE.**

In the synclinal fold that centers on Mill Creek are the best outcrops of Wapanucka Limestone in the central part of the Arbuckle Mountains. The Wapanucka in this area is as much as 550 feet thick and represents a massive limestone bank deposited upon the craton, whereas equivalent strata deposited in the Ardmore basin are mostly shales, such as those exposed at Stop II-1.

The Wapanucka Limestone consists typically of well-washed oölite or skeletal calcarenite (fig. 39), with thinner beds of skeletal carbonate mudstones. The beds locally contain a profusion of sponge spicules and thus grade into spiculites, although common elements of the

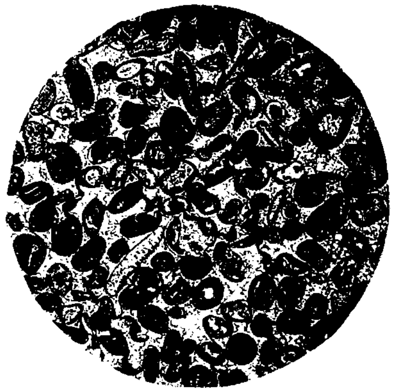


Figure 39. Skeletal oölitic calcarenite, x12.5; typical Wapanucka Limestone from the quarry of Stop II-4. Many skeletal grains have thick micritic envelopes rather than oölitic coatings.

fauna in the limestones are pelmatozoans (chiefly crinoids), bryozoans, brachiopods, foraminifers, and corals.

Overlying the Wapanucka near Mill Creek are sandstones, shales, and fusulinid (*Fusulinella*) limestones of the Atoka Formation, 245 feet thick. Both Wapanucka and Atoka strata are progressively truncated westward by Deese (Desmoinesian) strata, and in the Buckhorn area (Stop II-7) the Deese rests upon Springer Shale. This unconformity, so prominent upon the North American craton, disappears southward within the thick Pennsylvanian sediments of the Southern Oklahoma geosyncline.

		Return north on State 7 to main intersection in Mill Creek.
26.3	(1.1)	Intersection with State 12. Turn right (north).
26.4	(0.1)	In road cut to right are exposures of Deese conglomerates interstratified with reddish-brown and greenish-gray shales, dipping 60° southwest and lying just north of the axis of the Mill Creek syncline.
26.5	(0.1)	Trace of Mill Creek fault, concealed by alluvium, at north edge of Mill Creek synclinal graben. Deese is faulted against Oil Creek Formation (mid-Ordovician) of the Belton anticline, the stratigraphic displacement being about 5,500 feet. Drilling 1.5 miles to the west shows it to be a normal fault, dipping 45° southward.
27.1	(0.6)	Turn right (east) to office of Pennsylvania Glass Sand Corp.
27.4	(0.3)	Park. Do not enter sand pit without permission.

STOP II-5. **Oil Creek Sandstone (Middle Ordovician) in quarry of Pennsylvania Glass Sand Corp., SW¼ NE¼ sec. 6, T. 2 S., R. 5 E., Johnston County. Dip 10-15° S.**

Silica sand, primarily for glass manufacture, has been produced at this locality for 50 years. Thick deposits of high-purity, loosely consolidated sandstone have been worked in five principal pits over an area of about 200 acres, all in a gently plunging syncline that is sharply cut off at the south by the Mill Creek fault.

The sandstone member of the Oil Creek Formation in the syncline is 350 feet thick, the thickest of all Simpson Group sands in the Arbuckle Mountains. North of the plant are outcrops of the underlying West Spring Creek Formation, consisting of laminated fine-grained dolomites. Overlying the sandstone, and exposed near the top of the south walls of the southern pits, are skeletal calcarenites typical of the upper, or limestone, member of the Oil Creek Formation.

In the quarry faces are fine examples of nearly pure quartzose sandstone, typifying supermature cratonic quartz concentrates of the Simpson Group and St. Peter Formation, derived as polycyclic products of prolonged weathering and transport. Well-rounded, pitted, and frosted quartz grains occur with a few grains of tourmaline and zircon, but feldspar is so rare that counts of 3,000 grains in the fine and very fine sand sizes from this quarry revealed no feldspar at all. A pale-green illite clay, distributed in parallel thin layers that define bedding and also indicate a probable marine rather than eolian depositional environment, also occurs here.

Crude sand from the quarry contains 99.57 percent SiO_2. After being shot from the face, pumped to the plant, washed, and dried, the sand contains 99.87 percent SiO_2 and 0.02 percent or less Fe_2O_3. It is widely sold in the United States and as far south as Mexico as melting sand in glass-making, as foundry sand, as a source of silica in making sodium silicate, and, in ground form (silica flour), as an abrasive, potters flint, or inert filler. About 69 percent of the washed product is fine sand (½ to ⅛ mm) and 26 percent is very fine sand (⅛ to 1/16 mm).

Cleanly washed, well-sorted sands of the Oil Creek, McLish, Tulip Creek, and Bromide Formations are widely distributed in southern Oklahoma, where they locally are prolific oil-producing reservoirs.

		Return to State 12.
27.7	(0.3)	Turn left (south).
28.5	(0.8)	Mill Creek. Turn right (west) on paved farm-to-market road.
28.6	(0.1)	Railroad crossing (three tracks).
28.7	(0.1)	Bridge over Threemile Creek.
36.1	(7.4)	Curve right (north) at fork in road.
36.3	(0.2)	Stop sign. Intersection with U. S. 177. Turn right (north).
40.4	(4.1)	Intersection. Watch oncoming traffic; turn left, leaving U. S. 177.
41.9	(1.5)	Park to left of road. Walk north to abandoned asphaltic-sand pits.

STOP II-6. **Asphaltic sand of Oil Creek Formation (Middle Ordovician) in abandoned workings, N½ SW¼ SE¼ sec. 15, T. 1 S., R. 3 E. Dip 15° SE.**

In a broad sense, all the rock-asphalt deposits about 3 miles south of Sulphur are referred to as the Buckhorn asphalt district. Bedrock strata of various ages and rock types under or near the unconformable cover of Vanoss Conglomerate contain asphalt locally, and many quarries have been opened since mining began in 1890. The asphaltic rocks were eagerly sought in earlier days and extensively used for road surfacing. Mining was particu-

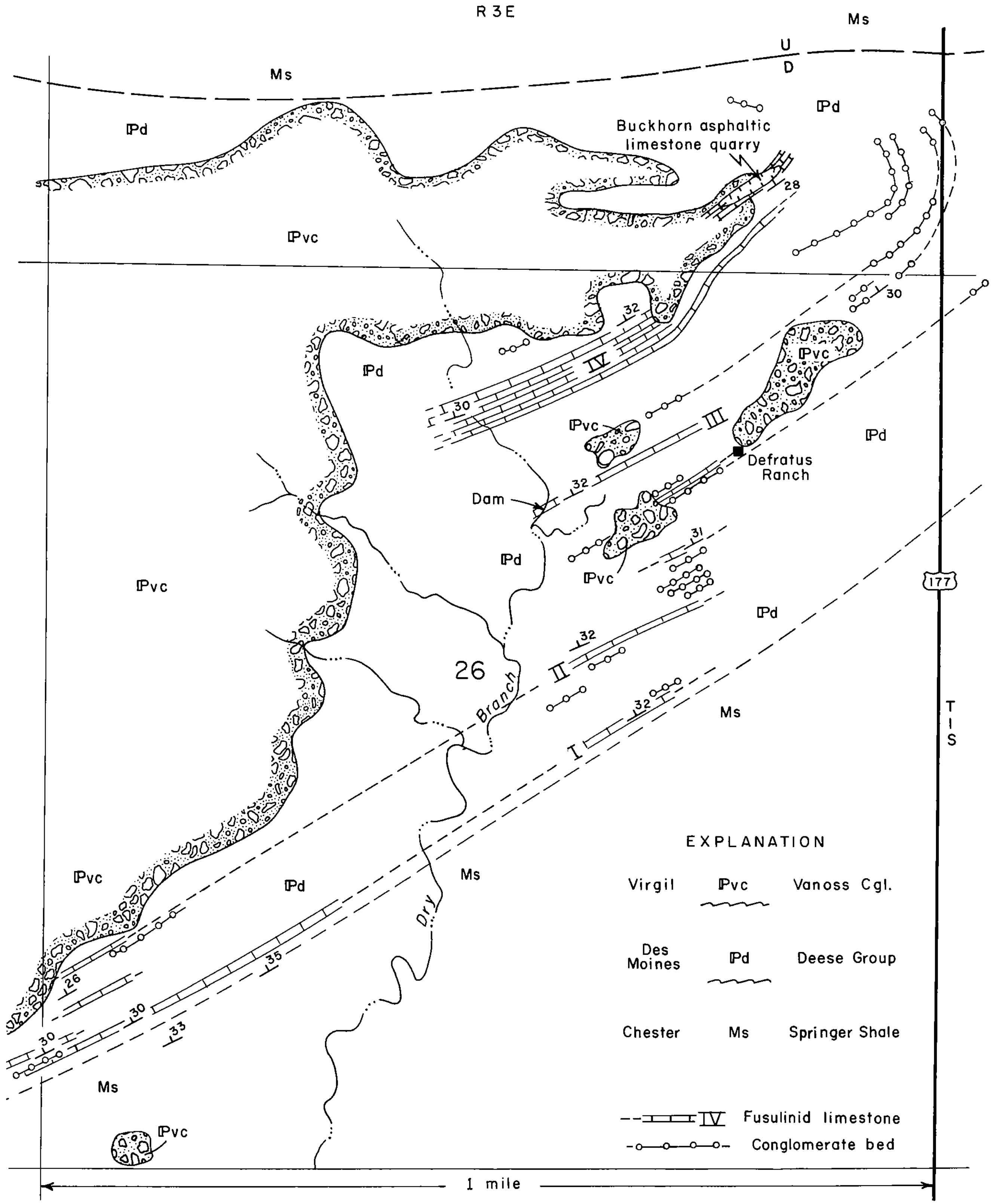


Figure 40. Stop II-7. Outcrops of Deese strata in the Buckhorn area of the Mill Creek syncline; Dry Branch on Defratus ranch in sec. 26, T. 1 S., R. 3 E., Murray County. Early Pennsylvanian epeirogeny is demonstrated by disconformable relations of early Desmoinesian Deese beds on Late Mississippian Springer Shale and by occurrence of numerous conglomerate beds within the Deese.

larly active before refiner's asphalt was available in quantity, but even as late as 1943 the district produced slightly more than 100,000 short tons of asphaltic rock per year. Total cumulative production exceeded 1 million tons before mining ceased in 1962.

Although the range in age of asphaltic rock in the Buckhorn district is from Middle Ordovician to Desmoinesian, virtually all production has been obtained from the Oil Creek Sandstone. With a thickness of 350 feet and a bitumen content of approximately 8 percent, it has been the richest asphaltic rock of the area. It was blended with Viola Limestone, quarried near Dougherty and containing 3 percent bitumen, in a proportion of about two-thirds limestone and one-third sand and sold for road patching and surfacing.

Asphaltic rocks occur locally beneath the Vanoss Conglomerate on the northern margin of the Arbuckle Mountains along a distance of approximately 25 miles. The asphalt occurs without regard to structural traps but rather is sealed by the overlying conglomerate. This situation seems to indicate that oil migrated from nearby basins into the localities presently seen, there decomposing into asphalt through loss of the volatile fractions.

A superlative example of unconformity is seen along the north wall of the pit. Oil Creek Sandstone of early Middle Ordovician age is unconformably overlain by the Vanoss Conglomerate of Late Pennsylvanian age. Fragments of the sandstone are mixed in the conglomerate with other rocks of the Arbuckle Mountains, including Precambrian granite, all derived by folding and uplift accompanying the mid-Virgilian Arbuckle orogeny.

		Retrace route to U. S. 177.
43.4	(1.5)	Turn right (south).
44.8	(1.4)	Turn right (west) across cattle guard to yard of Mr. Elmer Defratus.
45.0	(0.2)	Park and walk ahead to valley of Dry Branch.

STOP II-7. **Deese (Desmoinesian) strata on Dry Branch of Buckhorn Creek, north-central part of sec. 26, T. 1 S., R. 3 E., Murray County. Strike mostly N 60° E, dip 32° NW.**

This area is of classic importance because its excellent outcrops afford documentation for major geologic concepts in the building of the Arbuckle Mountains. A homoclinal sequence of Desmoinesian strata, stratigraphically dated by fusulinids, disconformably overlies the Late Mississippian Springer Shale. Morrowan and Atokan sediments have been eroded as a result of epeirogenic uplift of the craton. The Hunton anticline in the northern part of the Arbuckle Mountains was undergoing uplift and erosion throughout Desmoinesian time and was intermittently contributing pebble-cobble conglomerates to the shallow marginal basins.

On Dry Branch the lower Desmoinesian conglomerates consist mostly of debris from limestones of the Hunton Group, whereas the middle Desmoinesian conglomerates consist mostly of fragments from the Viola Limestone, thus representing a stratigraphic inversion resulting from progressive uplift of the source area.

Desmoinesian and older beds were then folded during the mid-Virgilian Arbuckle orogeny, and the strata were nonconformably covered by a gently dipping blanket of late Virgilian Vanoss Conglomerate. The Vanoss in this area consists chiefly of boulders and cobbles from the Arbuckle Group, together with all other rocks of the Arbuckle Mountains down to and including Precambrian granite. The low dip of the Vanoss Conglomerate may be seen in the field and inferred from the outcrop pattern of figure 40.

An item of special interest is the Buckhorn asphaltic-limestone quarry in the SW¼ SE¼ sec. 23, T. 1 S., R. 3 E., about one-fourth mile north of the Defratus ranch house. Middle Desmoinesian (Arnold-Boggy) fossiliferous limestones are impregnated with asphalt, evidently introduced as petroleum shortly after deposition of the Vanoss Conglomerate. As a result, the molluscan shells of the limestone retain their original aragonite mineralogy, and the cephalopods retain, in addition, their original iridescence.

Figure 41. Fusulinid calcilutite, x12.5, from limestone bed II of the Buckhorn area (Stop II-7). The micrite matrix is partly recrystallized into microgranular calcite.

Investigations of fusulinids from the Dry Branch section by Dwight W. Waddell, Shell Oil Company, Midland, Texas, have been especially helpful in ascertaining stratigraphic ages and correlations. The principal fusulinid-bearing limestones are indicated in figure 40 as beds I, II, III, and IV, which range through a stratigraphic thickness of 1,000 feet. The oldest is bed I, about 50 feet above the base of the sequence, containing *Fusulinella* of Waddell's zone III of the Ardmore basin (Waddell, 1966). It is of early Desmoinesian age, approximately equivalent to the Pumpkin Creek Limestone of the Ardmore basin and to the Savanna Formation of the Oklahoma coal basin. In beds II (fig. 41), III, and IV are species of *Fusulina* and *Wedekindellina*, belonging to Waddell's zone IV of the Ardmore basin, of early middle Desmoinesian age and including the lower-middle part of the Deese Group as well as the Boggy-Sonora of the Oklahoma coal basin.

		Return to U. S. 177.
45.2	(0.2)	Turn left (north) toward Sulphur.
49.1	(3.9)	Entrance to Platt National Park.
49.2	(0.1)	Turn left (west) on park road. In next 2 miles are numerous exposures of Vanoss Conglomerate.
50.4	(1.2)	Bromide Hill overlook on right. Continue straight ahead.
50.8	(0.4)	Intersection. Keep right.
50.9	(0.1)	Rock Creek crossing.
51.1	(0.2)	Turn right toward museum and park.

STOP II-8. **Vanoss Conglomerate (late Virgilian) at Platt National Park, SE¼ NW¼ SW¼ sec. 3, T. 1 S., R. 3 E., Murray County.**

Platt National Park was established in 1902 to preserve and feature numerous mineral springs that arise through the Vanoss Conglomerate from underlying beds of the Simpson Group. The springs and wells are artesian, welling up under a hydrostatic head provided by the westward-plunging Sulphur syncline. The shallow-seated ephemeral springs are rich in calcium bicarbonate derived from the carbonate rock fragments in the Vanoss Conglomerate, whereas water of the artesian springs and wells has a high chloride content resulting from mixture with connate waters.

Ahead in the south wall of Rock Creek are excellent exposures of Vanoss Conglomerate, showing the characteristic low dip and lack of faulting of these strata in the Sulphur area. Limestone cobbles and boulders, chiefly from the Arbuckle Group, typify the formation.

The Vanoss Formation, of latest Pennsylvanian (Virgilian) age, is the chief depositional product of the Arbuckle orogeny. Named from the time of formation of the Arbuckle anticline, the Arbuckle orogeny was the last and most intense of several orogenic episodes in southern Oklahoma.

In the vicinity of the Arbuckle Mountains, the Vanoss Formation consists of a lower conglomerate member and an upper shale member. Their combined maximum thickness is about 1,550 feet. The conglomerate member has a maximum thickness of 650 feet and is restricted to the northern edge of the mountains, in the area between Sulphur and Hennepin. Northward from Sulphur the conglomerate member disappears by interfingering into the shale member, whereas westward and southward around the Arbuckle anticline it is overlapped by the shale member. Both members locally contain abundant feldspar and granite fragments. At most places the rocks have gentle dips and are not faulted, although in a few areas they dip as much as 40° and are cut by small faults whose displacement dies out upward in the conglomerate sequence. Such post-Vanoss local deformation occurred as the dying pulse of the Arbuckle orogeny.

As recorded by the presence of arkose in the Vanoss Formation, the first unroofing of the Precambrian granite in the Arbuckle Mountains was during Late Pennsylvanian time. Earlier Pennsylvanian uplifts, although powerful, were insufficient to denude the granite of its thick sedimentary cover.

		Return to park road.
51.2	(0.1)	Stop sign. Turn right (east) on park road, then curve sharp left (north) at fountain.
51.3	(0.1)	Leave Platt National Park; enter town of Sulphur.
51.9	(0.6)	Traffic signal. Turn left (west) on State 7.
54.9	(3.0)	Sandy Creek.
55.0	(0.1)	Turn in to parking lot on right.

STOP II-9. **Arkose lenses in Vanoss Formation (late Virgilian), SW¼ SW¼ SW¼ sec. 31, T. 1 N., R. 3 E., Murray County.**

In the south road cut are exposures of nearly horizontal beds of maroon and gray shales, with lenses of arkose in the shale member of the Vanoss Formation. Fragments of coarse, pink microcline occur with granules of quartz, both derived from the Tishomingo and Troy Granites, such as those seen at earlier stops. Arkose occurs abundantly from here northward for about 20 miles, then disappears by gradation outward into shale.

The tectonic history of the Arbuckle Mountains has now been completed. Beginning with early Desmoinesian epeirogenic uplift and culminating with Late Pennsylvanian orogeny, a total uplift exceeding eight miles has been achieved locally, and the final orogenic products consist of granitic debris laid down upon the margins.

		Return to State 7 and continue ahead (west).
60.4	(5.4)	Davis, traffic intersection with U. S. 77.

References

Alberstadt, L. P., 1967, Brachiopod biostratigraphy of the Viola and "Fernvale" Formations (Ordovician), Arbuckle Mountains, south-central Oklahoma: Okla., Univ., unpublished doctoral dissertation, 308 p.

American Association of Petroleum Geologists and **U. S. Geological Survey**, 1967, Basement map of North America between latitudes 24° and 60° N.: Washington, D. C., U. S. Geol. Survey, scale 1:5,000,000.

Amsden, T. W., 1960, Stratigraphy, **part VI of** Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Okla. Geol. Survey, Bull. 84, 311 p., 17 pls., 56 figs.

Amsden, T. W., and **Boucot, A. J.**, 1958, Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region (parts II-IV): Okla. Geol. Survey, Bull. 78, 199 p., illus.

Amsden, T. W., and **Rowland, T. L.**, 1967a, Geologic maps and stratigraphic cross sections of Silurian strata and Lower Devonian formations in Oklahoma: Okla. Geol. Survey, Map GM-14, 1 sheet, 1 map at 1:750,000 and 6 maps at 1 in. = 64 miles.

————1967b [1968], Silurian-Devonian relationship in Oklahoma, **in** Oswald, D. H. (ed.), International symposium on the Devonian System, vol. II: Alberta Soc. Petroleum Geologists, p. 949-959, 10 figs.

Bell, W. C., and **Ellinwood, H. L.**, 1962, Upper Franconian and lower Trempealeauan Cambrian trilobites and brachiopods, Wilberns Formation, central Texas: Jour. Paleontology, vol. 36, p. 385-423, pls. 51-64, 1 text-fig.; **also** Texas, Univ., Bur. Econ. Geology, Rept. Inv. 47 (1962).

Berry, W. B. N., 1960, Graptolite faunas of the Marathon region, West Texas: Texas, Univ., Bur. Econ. Geology, Pub. 6005, 179 p., 20 pls.

Bradley, J. H., Jr., 1925, Trilobites of the Beekmantown in the Philipsburg region of Quebec: Canadian Field-Naturalist, vol. 39, p. 5-9, 1 pl.

Cooper, G. A., 1952, New and unusual species of brachiopods from the Arbuckle Group in Oklahoma: Smithsonian Misc. Coll., vol. 117, no. 14, 35 p., 4 pls.

————1956, Chazyan and related brachiopods [U. S.-Canada]: Smithsonian Misc. Coll., vol. 127, pts. 1, 2, 1245 p., 269 pls.

Creath, W. B., 1966, New isochilinid ostracode from the West Spring Creek Formation (Arbuckle Group) of Oklahoma: Okla. Geology Notes, vol. 26, p. 243-246, 1 pl.

Decker, C. E., 1939, Progress report on the classification of the Timbered Hills and Arbuckle Groups of rocks, Arbuckle and Wichita Mountains, Oklahoma: Okla. Geol. Survey, Circ. 22, 62 p., 5 pls., 1 fig.

————1941, **Didymograptus protobifidus** in North America: Jour. Paleontology, vol. 15, p. 362-365, 2 pls.

Decker, C. E., and **Merritt, C. A.**, 1931, The stratigraphy and physical characteristics of the Simpson Group: Okla. Geol. Survey, Bull. 55, 112 p., 15 pls., 2 figs.

Dunham, R. J., 1955, Pennsylvanian conglomerates, structure, and orogenic history of Lake Classen area, Arbuckle Mountains, Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 39, p. 1-30, 8 figs.

Elias, M. K., 1956, Upper Mississippian and Lower Pennsylvanian formations of south-central Oklahoma, **in** Petroleum geology of southern Oklahoma—a symposium, vol. 1: Tulsa, Amer. Assoc. Petroleum Geologists, p. 56-134, 2 figs., 6 pls., 6 tables.

Elles, G. L., 1933, The Lower Ordovician graptolite faunas with special reference to the Skiddaw slates [England]: Great Britain, Geol. Survey, Summary Progress 1932, p. 94-111, 13 figs.

Glaser, G. C., 1965, Lithostratigraphy and carbonate petrology of the Viola Group (Ordovician), Arbuckle Mountains, south-central Oklahoma: Okla., Univ., unpublished doctoral dissertation, 197 p.

Ham, W. E., 1954, Collings Ranch Conglomerate, Late Pennsylvanian, in Arbuckle Mountains, Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 38, p. 2035-2045, 4 figs., 1 table.

————1955, Field conference on geology of the Arbuckle Mountain region: Okla. Geol. Survey, Guide Book 3, 61 p., 21 figs., 1 map, scale 1:72,000.

Ham, W. E., **Denison, R. E.**, and **Merritt, C. A.**, 1964, Basement rocks and structural evolution of southern Oklahoma: Okla. Geol. Survey, Bull. 95, 302 p., 19 figs., 16 pls., 18 tables.

Ham, W. E., and **Wilson, J. L.**, 1967, Paleozoic epeirogeny and orogeny in the central United States: Amer. Jour. Science, vol. 265, p. 332-407, 12 figs., 1 table.

Harris, R. W., 1957, Ostracoda of the Simpson Group of Oklahoma: Okla. Geol. Survey, Bull. 75, 333 p., 19 figs., 10 pls., 5 charts.

————1960, An index ostracode from the Arbuckle limestone, Oklahoma: Okla. Geology Notes, vol. 20, p. 211-216, 1 fig., 1 pl.

Harris, R. W., and **Harris, Beth**, 1965, Some West Spring Creek (Ordovician Arbuckle) conodonts from Oklahoma: Okla. Geology Notes, vol. 25, p. 34-47, 1 pl.

Harris, R. W., Jr., 1964, **Ceratoleperditia arbucklensis** in Criner Hills of Oklahoma: Okla. Geology Notes, vol. 24, p. 93-95, 1 fig.

Hass, W. H., and **Huddle, J. W.**, 1965, Late Devonian and Early Mississippian age of the Woodford Shale in Oklahoma, as determined from conodonts, **in** Geological Survey research 1965, chapter D: U. S. Geol. Survey, Prof. Paper 525-D, p. 125-132, 2 figs., 1 chart.

Hintze, L. F., 1952, Lower Ordovician trilobites from western Utah and eastern Nevada: Utah Geol. Mineral. Survey, Bull. 48, 249 p., 28 pls., 2 figs.

Howell, B. F. (chm.), et al., 1944, Correlation of the Cambrian formations of North America: Geol. Soc. America, Bull., vol. 55, p. 993-1003, 1 chart.

Hu, Chung-Hung, 1963, Some Lower Ordovician trilobites from Franklin Mountains, Texas: Palaeont. Soc. Japan, Trans. Proc., new ser., no. 51, p. 86-90, pl. 13.

Jordan, Louise, **Bellis, W. H.**, and **Rowland, T. L.**, 1962, Geologic map and section of pre-Pennsylvanian rocks in Oklahoma, showing surface and subsurface distribution: Okla. Geol. Survey, Map GM-5, scale 1:750,000.

Lochman, Christina, 1964, Basal Ordovician faunas from the Williston basin, Montana: Jour. Paleontology, vol. 38, p. 453-476, pls. 63-67.

Longacre, Susan, 1968, Trilobites of the Upper Cambrian Ptychaspid biomere, Wilberns Formation, central Texas: Texas, Univ., Austin, unpublished doctoral dissertation.

Muehlberger, W. R., **Hedge, C. E.**, **Denison, R. E.**, and **Marvin, R. F.**, 1966, Southern area, **part 3 of** Geochronology of the Midcontinent region, United States: Jour. Geophys. Research, vol. 71, p. 5409-5426, 3 figs., 5 tables.

Palmer, A. R., 1965a, Biomere—A new kind of biostratigraphic unit: Jour. Paleontology, vol. 39, p. 149-153, 2 figs.

————1965b, Trilobites of the Late Cambrian Pterocephaliid biomere in the Great Basin, United States: U. S. Geol. Survey, Prof. Paper 493, 105 p., 16 figs., 23 pls.

Poulsen, C., 1927, The Cambrian, Ozarkian and Canadian faunas of northwest Greenland: Meddelelser om Grønland, vol. 70, p. 233-343, 10 figs., 8 pls.

Ross, R. J., Jr., 1951, Stratigraphy of the Garden City Formation in northeastern Utah, and its trilobite faunas: Yale Univ., Peabody Mus. Nat. History, Bull. 6, 161 p., 36 pls.

————1967, Some Middle Ordovician brachiopods and trilobites from the Basin Ranges, western United States: U. S. Geol. Survey, Prof. Paper 523-D, p. 1-43, 11 pls.

Ruedemann, Rudolf, and **Decker, C. E.**, 1934, The graptolites of the Viola Limestone: Jour. Paleontology, vol. 8, p. 303-327, 4 pls.

Schramm, M. W., Jr., 1965, [1966], Résumé of Simpson (Ordovician) stratigraphy: Tulsa Geol. Soc., Digest, vol. 33, p. 26-34.

Shaw, A. B., 1951, New Late Cambrian trilobites, **part 1 of** The paleontology of northwestern Vermont: Jour. Paleontology, vol. 25, p. 97-114, pls. 21-24.

————1958, Stratigraphy and structure of the St. Albans area, northwestern Vermont: Geol. Soc. America, Bull., vol. 69, p. 519-568.

Tomlinson, C. W., and **McBee, William, Jr.**, 1959, Pennsylvanian sediments and orogenies of Ardmore district, Oklahoma, **in** Petroleum geology of southern Oklahoma —a symposium, vol. 2: Tulsa, Amer. Assoc. Petroleum Geologists, p. 3-52, 11 figs.

Ulrich, E. O., and **Cooper, G. A.**, 1938, Ozarkian and Canadian Brachiopoda: Geol. Soc. America, Spec. Paper 13, 323 p., 58 pls., 14 figs.

Waddell, D. E., 1966, Pennsylvanian fusulinids in the Ardmore basin, Love and Carter Counties, Oklahoma: Okla. Geol. Survey, Bull. 113, 128 p., 11 figs., 13 pls.

Wilson, J. L., 1951, Franconian trilobites of the central Appalachians: Jour. Paleontology, vol. 25, p. 617-654, pls. 89-95, 1 fig.

Wilson, L. R., 1966, Palynological evidence for Mississippian age of the Springer Formation, **in** Pennsylvanian of the Ardmore basin, southern Oklahoma: Ardmore Geol. Soc., Field Conf. Guidebook, p. 20-24, 3 figs.

Winston, Don, and **Nicholls, Harry**, 1967, Late Cambrian and Early Ordovician faunas from the Wilberns Formation of central Texas: Jour. Paleontology, vol. 41, p. 66-96, pls. 9-13, 4 figs.

Yochelson, E. L., and **Bridge, Josiah**, 1957 [1958], The Lower Ordovician gastropod **Ceratopea**: U. S. Geol. Survey, Prof. Paper 294-H, p. 281-304, 4 pls.