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SUMMARY OF THE STRATIGRAPHY, SEDIMENTOLOGY, AND MINERALOGY OF PENNSYLVANIAN AND PERMIAN ROCKS OF OKLAHOMA IN RELATION TO URANIUM-RESOURCE POTENTIAL

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ABSTRACT

Pennsylvanian-Permian strata in Oklahoma were deposited in environments which ranged from deep marine to alluvial fan. The former was most common in the Ouachita geosyncline during Early Pennsylvanian, but parts of the Anadarko basin were also relatively deep water during Middle and Late Pennsylvanian. Alluvial-fan deposits in Oklahoma are related primarily to the Amarillo-Wichita-Criner, Arbuckle, and Ouachita uplifts.

As a result of erosion of the Wichita and Arbuckle areas during the Pennsylvanian-Permian, Precambrian and Cambrian felsic igneous rocks were exposed and became sources of significant quantities of feldspar in the sandstones and conglomerates, especially those on the flanks of the uplifts, and possibly sources of significant uranium concentrations in basinal waters. The Ouachita uplift, Sierra Grande-Apishapa uplift to the northwest, and possibly the Appalachian system also furnished feldspar to form the rather common subarkoses in the Upper Pennsylvanian-Permian.

Feldspar is an apparent source of uranium which is present in the alluvial-fan deposits associated with the Wichita and Arbuckle uplifts, the Permian sandstones on oil-producing structures in southern Oklahoma, the lenticular sandstones on the Muenster-Waurika arch, and the tidal-flat sandstone-siltstones in western Oklahoma and possibly in north-central Oklahoma.

Radioactive anomalies associated with Cherokee sandstones may be related to the Desmoinesian phosphatic shales, local depositional environments of deltaic complexes which influenced diagenetic conditions, and/or the pre-Pennsylvanian unconformity with respect to the radioactive Woodford Shale.

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Provinces and Elements

Most of the present structural features of Oklahoma formed during the Pennsylvanian, or they represent older structures which were reactivated to some extent during that period. Relatively minor movements (gentle folding and faulting) affecting some of the previously formed structural features occurred during the Permian. The age of development of the tectonic provinces (Fig. 1) is given in summary form in Figure 2.

The Amarillo-Wichita-Criner uplift, which extends for more than 300 miles from the Texas Panhandle into southern Oklahoma, separates the Ardmore and Anadarko basins on the north from the Marietta and Palo Duro-Hollis-Hardeman basins on the south. The uplift, or parts of it, was tectonically active during most of the Pennsylvanian, especially in part of Early and Late Pennsylvanian. The Muenster-Waurika arch, as a bifurcation of the Wichita uplift, trends southeastward from southern Oklahoma into north Texas. It forms the southern boundary of the Marietta basin.

The Arbuckle uplift, which formed somewhat later than the Amarillo-Wichita-Criner uplift, lies north of the Ardmore basin, and it extends into northeast Texas. Much of the uplift is buried below Cretaceous beds, and part of it on the southeast is below thrust sheets of the Ouachita uplift.

The Ouachita uplift in southeastern Oklahoma lies south of the Arkoma basin and east of the Arbuckle uplift and Pauls Valley-Hunton uplift. Major overthrusting of the Ouachita system began in Middle Pennsylvanian. Part of the frontal zone of the Ouachita system and the Arbuckle uplift interfered with one another during the various orogenic phases involving either or both of the provinces.

The Arkoma basin is a "foreland-foredeep" basin which grades into the Ouachita system, just as foothills are transitional structurally to front ranges of folded-belt orogens. In northeastern Oklahoma the stable Ozark uplift lies

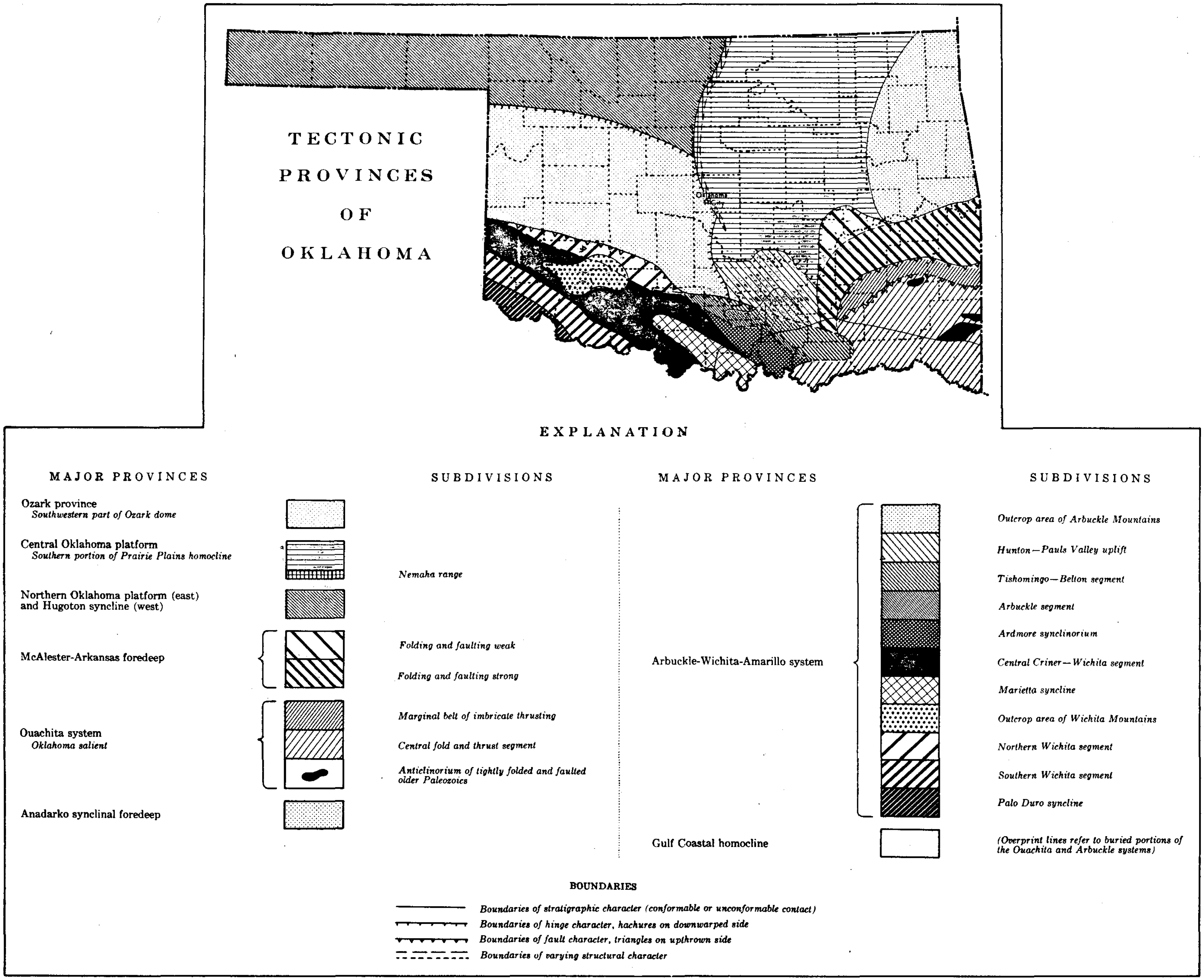


Fig. 1.--Tectonic provinces of Oklahoma. From Arbenz (1956).

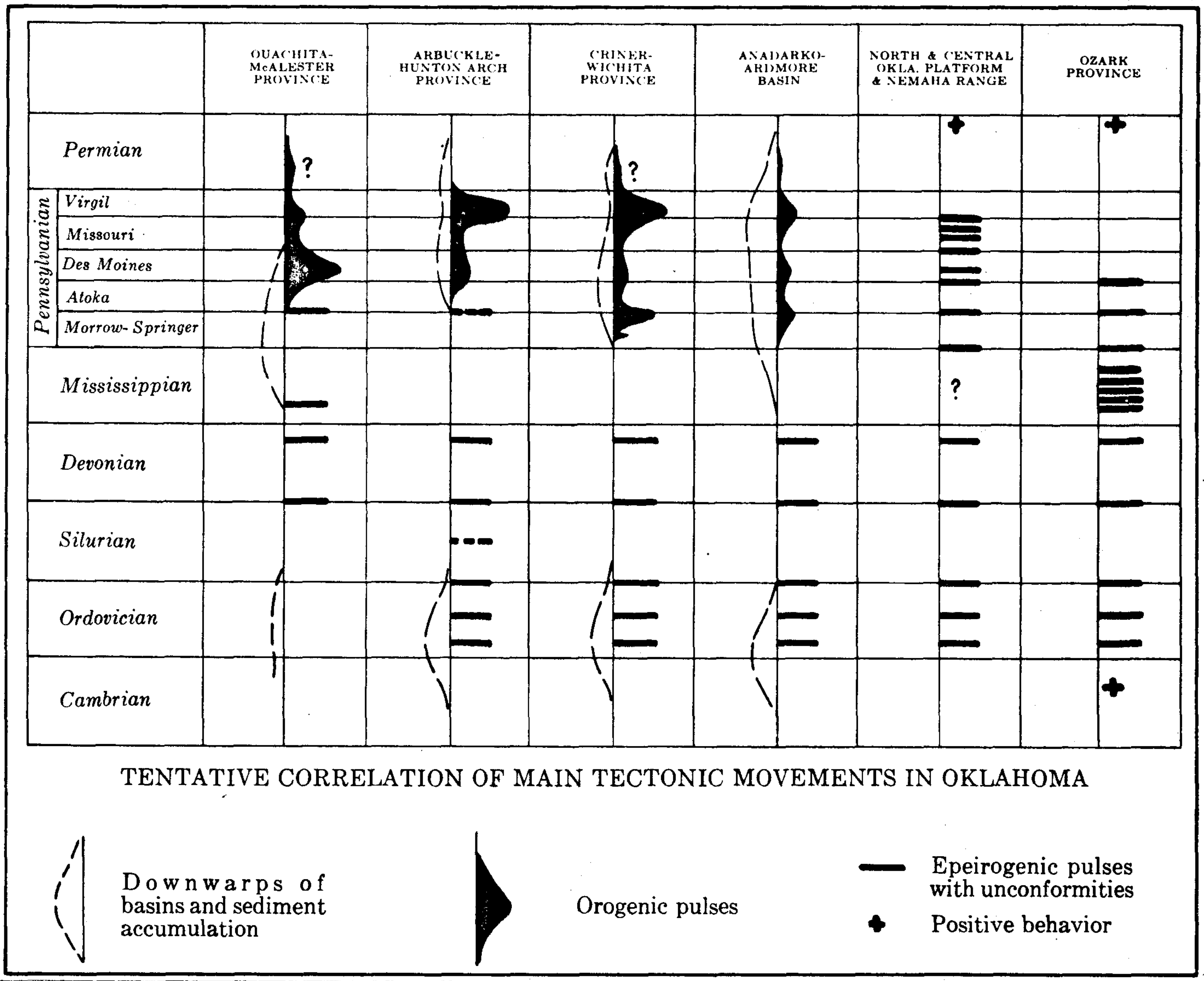


Fig. 2.--Development of tectonic provinces of Oklahoma. From Arbenz (1956).

north of the Arkoma basin and east of the Central (or Northeastern) Oklahoma platform.

The Nemaha ridge, which extends into Oklahoma from Kansas separates the Central Oklahoma platform from the Northern Oklahoma platform and the Anadarko basin. The southern extension of the Nemaha ridge through Oklahoma City joins the Arbuckle uplift (including the Hunton-Pauls Valley uplift). Major features with pre-Pennsylvanian history are shown in Plate 1.

Structural Styles

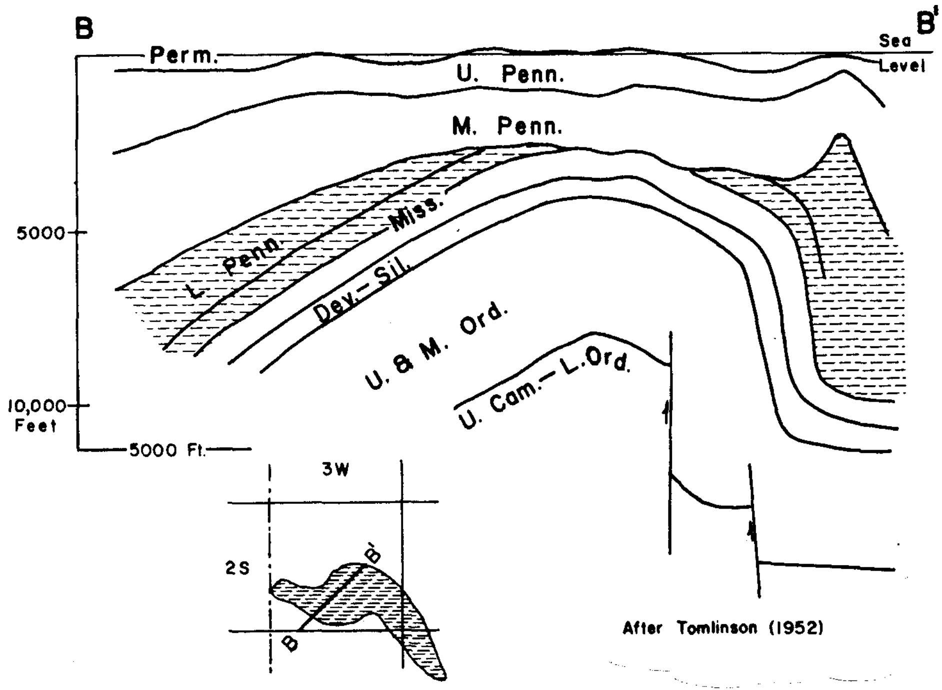
Upthrust is the structural style for the Amarillo-Wichita-Criner uplift, Arbuckle uplift, Nemaha ridge, and elements in the Ardmore basin, Anadarko basin, and the Central and Northern Oklahoma platforms. In some cases the upthrusts may represent dip-slip components of major strike-slip faults. For example, in the Arbuckle uplift, left lateral movement along the Washita Valley fault is thought to be some 40 miles (Tanner, 1967). In the Ardmore and Anadarko basins, disharmonic folds developed in association with upthrusts where ductile Mississippian-Pennsylvanian units are thick (Fig. 3).

The Ouachita uplift is characterized by overthrust faults with large-scale lateral displacement (Fig. 4). Structures in the Arkoma basin reflect the progressive decrease in horizontal compressive stress in a northward direction.

The Ozark uplift is a broad regional feature with recurring epeirogeny during the Paleozoic. Northern Oklahoma, together with the northern part of south-central Oklahoma, was affected by epeirogeny during the Mississippian and Early Pennsylvanian.

Paleogeology

The pre-Pennsylvanian unconformity is one of the most extensively developed erosional surfaces in the state. The Pennsylvanian directly overlies Precambrian and Cambrian igneous rocks in parts of the Amarillo-Wichita-Criner uplift and the



FOX—GRAHAM FIELD

Fig. 3.--Fox-Graham anticline, a disharmonic fold.

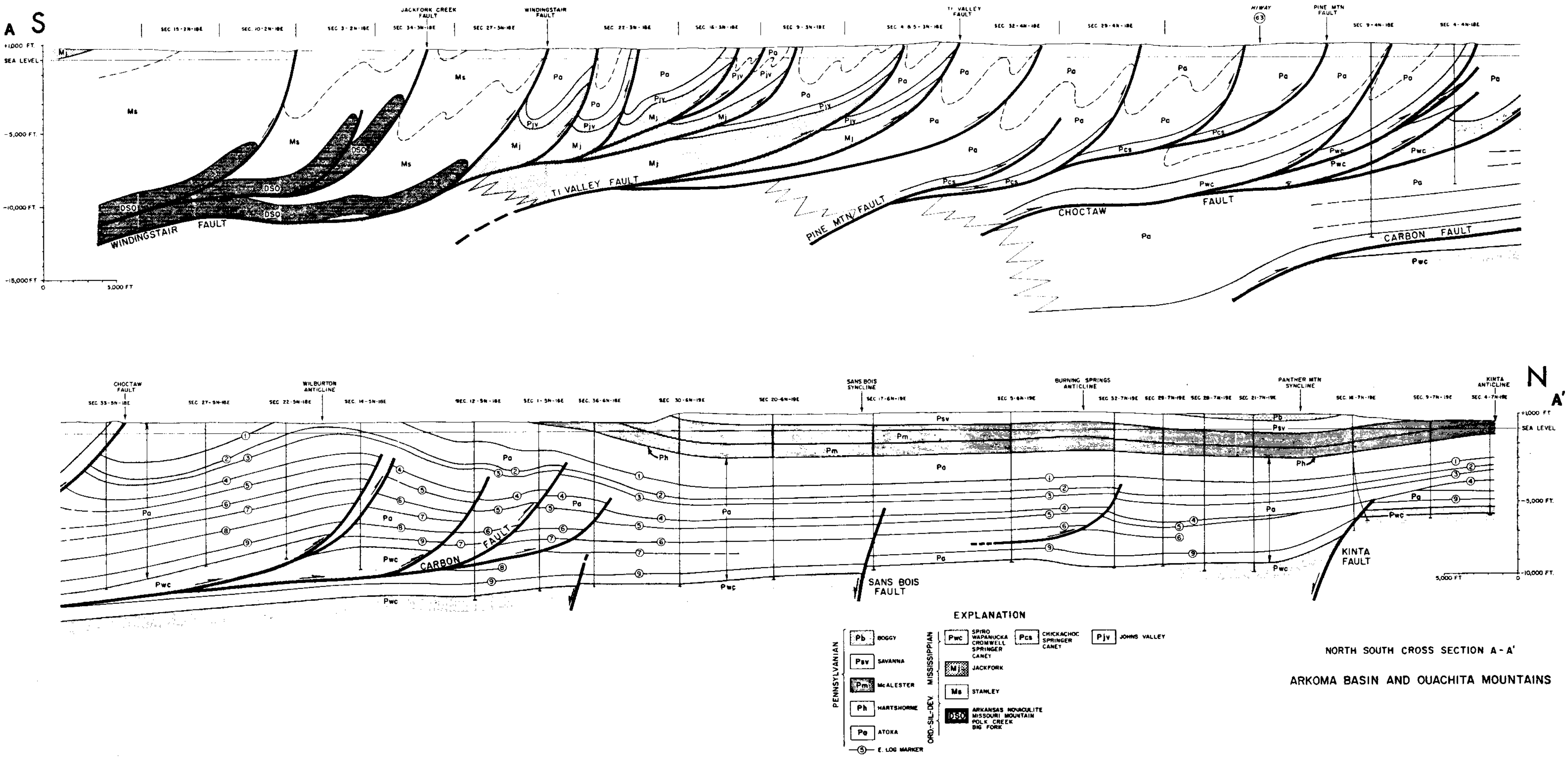
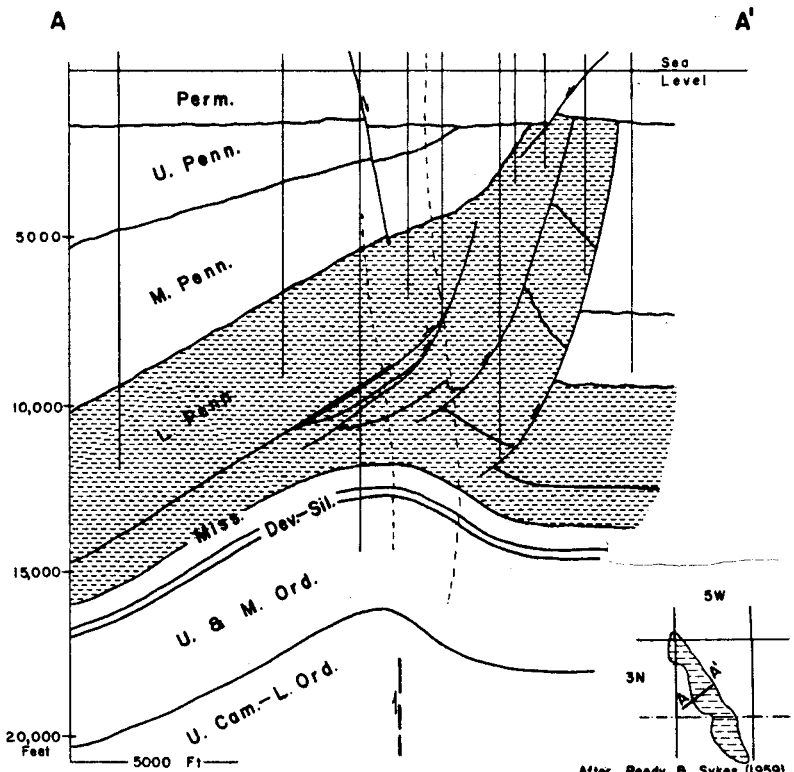


Fig. 4.--Cross section, Arkoma basin and Ouachita Mountains. Modified after Berry and Trumbly (1968).

Arbuckle uplift, and an angular unconformity separates the Pennsylvanian from older beds on a large number of structural elements (Plate 1). In the Criner Hills and the Muenster arch the pre-Pennsylvanian surface is commonly of Cambro-Ordovician and Ordovician units. An extensive area where the base of the Pennsylvanian is an angular unconformity includes the Pauls Valley uplift-Hunton arch-Seminole arch north of the Arbuckle Mountains. The northern extension of this extensive area is the Oklahoma City structure, which represents the southern part of the Nemaha ridge. North of Oklahoma City the ridge is expressed paleogeologically by a series of subcrops of Cambro-Ordovician, Ordovician, and Devonian strata (Plate 1).

In most of the state where the lower boundary of the Pennsylvanian is in the subsurface, Mississippian rocks underlie that surface (Plate 1). The contact between Mississippian and Pennsylvanian rocks is conformable in the southern part of the Anadarko basin, Ardmore basin, Ouachita system, and Arkoma basin (Plate 1). The northern edge of that area is convex southward. Excluding local structural elements, progressively older Mississippian rocks subcrop in a northwestward direction on the Central Oklahoma platform and in a northeastward direction on the Northern Oklahoma platform. Osagean units are present at the unconformity in north-central Oklahoma as a south-elongated belt.

Unconformities are locally developed at the base of Permian rocks on structural elements of southern Oklahoma, such as faulted anticlines in the Anadarko and Ardmore basins (Fig. 5). Also Permian rocks directly overlie pre-Pennsylvanian rocks, including Cambrian igneous and metamorphic rocks in the area of the Wichita uplift.



CARTER—KNOX FIELD

Fig. 5.--Carter-Knox structure, showing Permian structural activity.

STRATIGRAPHIC FRAMEWORK

Pennsylvanian strata are generally divided into five series, which in ascending order are Morrowan (or Springeran-Morrowan), Atokan, Desmoinesian, Missourian, and Virgilian (Fig. 6). Permian units in the United States have been divided into the Wolfcampian, Leonardian, Guadalupian, and Ochoan series, in ascending order. In Oklahoma where Mississippian and Pennsylvanian rocks are conformable, the contact is open to question. The Arkansas Geological Commission (Gordon and Stone, 1969) and the Oklahoma Geological Survey, informally, presently consider the boundary to be the Jackfork-Stanley contact in the Ouachita Mountains. Previously, on the basis of limited fauna, Cline (1956, 1960, 1968) and Elias (1959) regarded the base of the Pennsylvanian to correspond to the Johns Valley-Jackfork contact. Where the Springer Group is developed in the northwestern part of the frontal zone of the Ouachita Mountains and in the Ardmore and Anadarko basins, the base of the Pennsylvanian is commonly considered to lie within the Springer Group. In the Ardmore basin Tomlinson and McBee (1959) placed the boundary at the base of the upper sandstone-bearing part of the Springer. The Jackfork and the Springer in its entirety are herein considered Pennsylvanian because of the convenience associated with ease of their recognition.

The Pennsylvanian-Permian boundary is likewise disputed where strata of the two systems are conformable. The Oklahoma Geological Survey, in cooperation with the U.S. Geological Survey, has recently published hydrologic atlases in which Gearyan replaces the upper part of the Virgilian and the overlying Permian Wolfcampian Series and is assigned to the Pennsylvanian (Fig. 7). The areal geologic maps (Plates 2-4) conform in nomenclature to the recent definitions. In the text descriptions include both the formerly accepted nomenclature as well as that which has recently been introduced.

	Ouachita Mountains	Arbuckle Mountains and Ardmore basin	North of Arbuckle Mts. / Arkoma basin	Northeastern Oklahoma	Anadarko basin
VIRGILIAN		Vanoos Formation Collings Ranch Conglomerate	Vanoss Fm. Ada Fm. Lecompton Ls. Vamoosa Formation		Wabaunsee Group Shawnee Group Douglas Group
MISSOURIAN		Hoxbar Formation	Ochelata Group Skiatook Group	Ochelata Group Skiatook Group	Lansing Group Kansas City Group Pleasanton Group
DESMOINESIAN		Deese Formation Dornick Hills Formation	Marmaton Group Cabaniss Group Krebs Group	Marmaton Group Cherokee Group	Marmaton Group Cherokee Group
ATOKAN	Atoka Formation	Lake Murray Formation Dornick Hills Formation	Atoka Formation	Atoka Formation	Atoka Formation
MORROWAN	Johns Valley Shale Jack Fork Group	Golf Course Formation Dornick Hills Formation Springer Group	Wapanucka Formation Springer Group	Bloyd Formation Hale Formation	Morrow

Fig. 6.--Correlation chart of Pennsylvanian strata.

Generally accepted classification			Classification proposed by OKLA. GEOL. SURVEY		
Permian	Leonardian	El Reno Group	Permian	Cimarronian	El Reno Group
		Hennessey Shale			Hennessey Shale
		Sumner Group			Sumner Group
	Wolfcampian	Chase Group	Pennsylvanian	Gearyan	Oscar Group
		Council Grove Group			
		Admire Group			Vanoss Group
Pennsylvanian	Virgilian	Vanoss Formation			
		Ada Formation		Virgilian	Ada Formation
		Lecompton Ls			Lecompton Ls
		Vamoosa Formation			Vamoosa Formation

Fig. 7.--Correlation chart of Pennsylvanian-Permian strata.

Pennsylvanian

Morrowan (Springeran-Morrowan) Series

The Springer is underlain by Chesterian Caney shale. Shales of the Springer and the Morrow are commonly noncalcareous dark gray shale with thin sideritic beds or concretions. Upper Mississippian shales are also dark gray, but they generally are calcareous with a brownish streak (Weaver, 1958). Thin beds of limestone are locally developed in the Mississippian units. In the deeper part of the Anadarko basin, where the Mississippian-Pennsylvanian boundary is conformable, workers commonly include Springer equivalents in the "Morrow" (Davis, 1974).

In addition to the Springer Group, the Morrowan includes the Wapanucka Limestone in the northeastern part of the Arbuckle uplift, the northwestern part of the frontal zone of the Ouachita Mountains, and part of the Arkoma basin. The series includes the Golf Course Formation of the Dornick Hills Group in addition to the Springer in the Ardmore basin and the lower part of the Dornick Hills and the Springer southwest of the Arbuckle Mountains (Figs. 6, 8).

South of the frontal zone of the Ouachita Mountains, the series includes the Jackfork Sandstone and the Johns Valley Shale. In the southern part of the Ouachita Mountains, the Morrowan series is represented by the Jackfork.

The Morrowan outside the area where the boundary is conformable presents minimal problems in recognition and in designation of age. On outcrop in northeastern Oklahoma, lower Atoka sandstones are rather easily distinguished from the underlying section of calcareous shale and sandstone and limestone. Locally where Desmoinesian strata overlie Morrowan units, the distinction is based on the calcareous nature of the latter. The lowermost part of the Atoka Group in some areas of the Ouachita Mountains contain Morrowan-age units (Cline, 1968), but no attempt is made herein to separate those beds from the main part of the group.

The Morrowan is as much as 8000 to 10,000 feet thick in the Ardmore basin, 6000 to 8000 feet thick in the Anadarko basin, 7000 feet in the Ouachita Mountains,

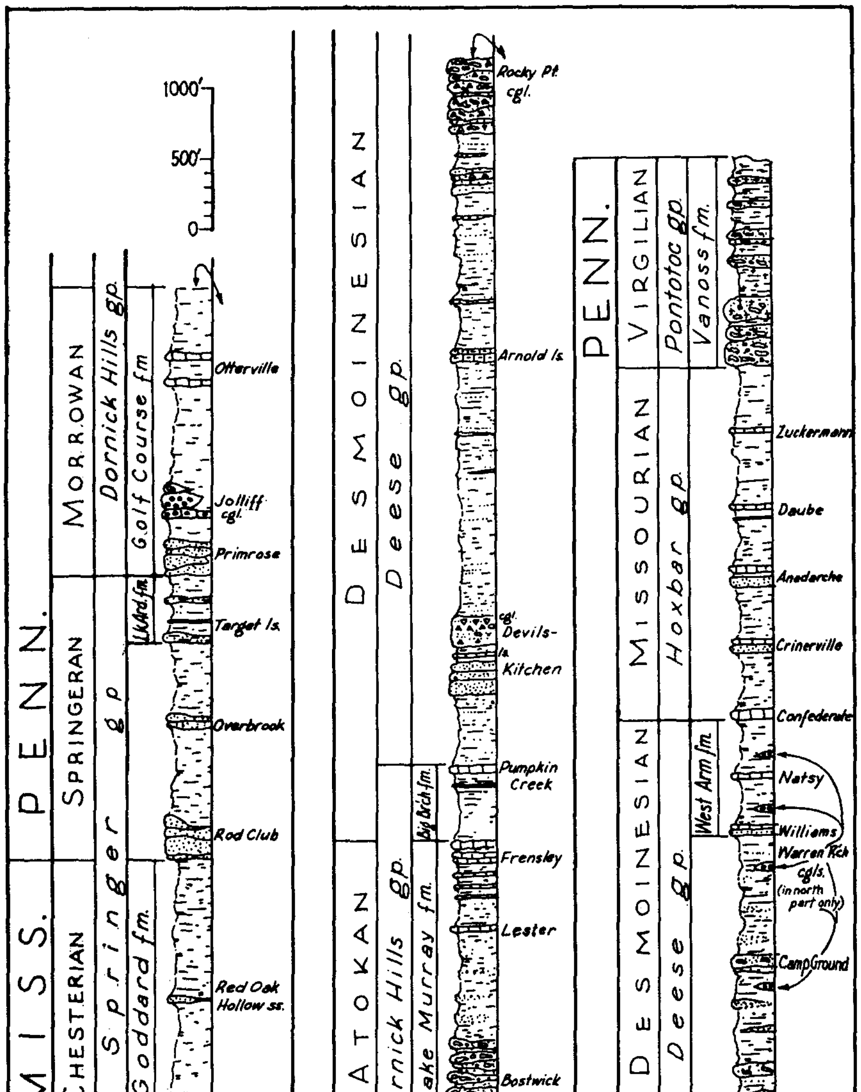


Fig. 8.--Stratigraphic section of Pennsylvanian rocks on outcrop in the Ardmore basin. From Tomlinson and McBee (1959).

and 1500 feet thick in the Arkoma basin. A hingeline separates the rather thick section of the Arkoma basin from the shelf-like section of the Ozark area. A similar feature is present in northwestern Oklahoma and Texas Panhandle. There the Morrowan on the shelf thickens southward at a rate of 10 feet per mile, whereas in the Anadarko basin the rate of thickening is 30 feet per mile (Rascoe, 1962).

The Springer consists of a lower shale, the Goddard, and an upper sandstone-bearing section. The Goddard, dark gray and commonly noncalcareous, is thick in a significant part of southern Oklahoma, where it is largely responsible for disharmonic folds and the local Overbrook overthrust fault. Where these types of structures developed, the Springer Group deformed as a ductible unit in response to upthrusting, probably associated with strike-slip movement.

On outcrop in the Ardmore basinal area sandstones in the upper part of the Springer include the Rod Club, Overbrook, and Lake Ardmore, in ascending order (Fig. 8). The subsurface equivalents, respectively, are Sims, Humphreys, and Markham (and Aldridge), which are hydrocarbon producers. They pinch-out rather abruptly toward the southwest near the northeast flank of the Criner Hills (Tomlinson and McBee, 1959). Units overlying the Springer Group in the Ardmore basin include a maximum of some 2000 feet of shale with a sandstone (Primrose), two limestones, and a conglomerate. The conglomerate (Jolliff) in a local area north of the Criner Hills overlies the Springer with an angular unconformity.

In the deeper part of the Anadarko basin "Morrow" sandstones are highly lenticular with individual units as much as 80 feet in thickness (Davis, 1974). On the shelf in northwestern Oklahoma, more than 40 sandstone bodies, arranged in an en echelon pattern vertically, have been mapped in the dominantly gray-to-black shale.

The Jackfork Formation in the Ouachita Mountains, which is dominantly sandstone, is underlain by the Stanley Shale. The Jackfork is an extremely thick unit which formed in the Ouachita geosyncline. Because of displacement due to overthrusting and subsequent erosion, the northern limit of deposition is not known.

The overlying Johns Valley Shale, cropping out in the Ouachita Mountains, contains boulder beds. These beds locally contain clasts more than 100 feet in greatest dimension. The clasts are composed dominantly of units of the "Arbuckle facies," with some of the Ozark facies and "Ouachita facies." The size of clasts apparently decreases in a southerly direction (Shideler, 1968).

Atokan Series

In the Ouachita Mountains, Arkoma basin, and Ozark uplift, the series is represented by the Atoka Formation, or Group. The base of the Hartshorne Formation is the top of the Atokan in parts of the Arkoma basin. Where the contact between the Atokan and Desmoinesian is unconformable, the top of the Atoka Formation is generally the base of the McAlester Formation.

The Atokan in the area of the Ardmore basin is the Lake Murray Formation, representing the upper part of the Dornick Hills Group (Tomlinson and McBee, 1959). The top of the Lake Murray is the Frensley Limestone which contrasts sharply with the overlying terrigenous clastics of the Deese. The oldest Pennsylvanian rocks in the Marietta basin are the relatively thin section of Atokan units. In the southern part of the Anadarko basin, the Atokan is the lower part of the subsurface carbonate and granite "wash" (Edwards, 1959). Dark, fine-grained clastics and limestone characterize the series in the central part of the Anadarko basin. On the shelf to the north and west, the Thirteen Finger Limestone is representative of the series. The upper contact there is not clearly established, and the limestone and shale possibly contain lower Desmoinesian units (Rascoe, 1962).

The maximal original thickness of the Atokan was 15,000 to 20,000 feet in the Ouachita Mountains-Arkoma basin, where the series show a southward increase in thickness by contemporaneous faulting (Buchanan and Johnson, 1968); (Koinm and Dickey, 1968). On the Ozark uplift, thickness is commonly 100-200 feet. Maximum thickness in the Ardmore basin is 2400 feet (Tomlinson and McBee, 1959), and thickness exceeds 3000 feet in the Anadarko basin (Rascoe, 1962). Thickness generally increases southward in the Anadarko basin toward the limiting fault zones of the Wichita uplift. On the northern shelf area the Atokan thickens at a rate of 10 feet per mile toward the Anadarko basin, the northern flank of which shows a thickening rate of 50 feet per mile (Rascoe, 1962). The Atokan hingeline is 30 miles shelfward (northward) of the Morrowan hingeline.

The Atokan in the Arkoma basin is characterized by interbedded sandstone, siltstone, and shale. Carbonates increase in percentage northward toward the Ozark uplift. The subsurface Gilcrease Sandstone is the basal Atokan unit in the area northeast of the Arbuckle Mountains. Thick sandstone and shale characterize the Atoka Formation in the Ouachitas. In some areas the Atoka is divided into 3 units, with the middle containing the most sandstone. In other areas the upper part is dominantly shale, whereas the lower part contains thick sandstone.

The Atokan generally is dark, fine-grained terrigenous clastics, with some limestone and lenticular sandstones in the Anadarko and Ardmore basins. In the former, limestone increases somewhat in percentage toward the northern shelf, where the section commonly contains more than one-third carbonate (Rascoe, 1962).

Conglomerate is the diagnostic lithology in the southern part of the Anadarko basin, where thick deposits of granite wash and carbonate wash are present. The Bostwick Conglomerate, as much as 800 feet thick, is present as the basal unit of the Atokan Series in the southern part of the Ardmore basin adjoining the Criner uplift. Conglomerates are also developed locally in the Atoka Formation near the type locality in the Ouachita Mountains.

Coal is a minor, irregularly distributed lithologic type in the Anadarko and Arkoma basins.

Desmoinesian Series

The Desmoinesian Series, on the basis of fusulines, contains the genera _Fusulina_ and _Wedekindellina_. In south-central Oklahoma (Ardmore and Marietta basin and southeastern part of the Anadarko basin), the rocks are represented by the Deese Group (Figs. 6, 8). In the Ardmore basin the Big Branch Formation, uppermost unit of the Dornick Hills Group, is lowermost Desmoinesian. The Hartshorne Formation is the basal unit in the southern part of the Arkoma basin. Because formations thin and wedgeout northward, the basal units of the series become progressively younger in that direction. The lower units on outcrop are assigned to the Krebs and Cabaniss groups, in ascending order. These rocks in the subsurface on the central and northern Oklahoma platform and in the Anadarko basin are referred to the Cherokee Group. The upper part of the Desmoinesian is the Marmaton Group. The Cherokee and Marmaton groups compose the Desmoinesian of eastern Kansas; only the former group is present in western Missouri. Formations on the surface in Oklahoma commonly include more than one formation of Kansas. Pennsylvanian rocks older than the Desmoinesian are restricted in western Missouri to very local deposits associated with paleokarst topography. The platform area of Oklahoma-Kansas, including the Nemaha ridge, apparently was first blanketed by Pennsylvanian sediments during the Desmoinesian.

The Desmoinesian is approximately 4000 to 5000 feet in parts of the Arkoma and Anadarko basins (Fig. 9). The Deese and Big Branch Formations, together, are as much as 8000 feet thick in the Ardmore basin. The Deese is up to 7000 feet thick in the Marietta basin, which began subsiding in the Atokan and by late Desmoinesian was a depositional basin (Reed, 1959). The Criner uplift was covered by 1000 feet of upper Deese sediments (Tomlinson and McBee, 1959). The southeastern limit for the Desmoinesian is controlled by erosion of the Ouachita uplift. In the Anadarko basin the series is limited on the south by the Wichita uplift which was a positive feature during deposition. The Desmoinesian thins northward, northwestward, and northeastward in the basin toward the shelf areas and the Nemaha ridge. It is less than 500 feet on the Cimarron uplift and Keyes dome in the Oklahoma Panhandle. In eastern Oklahoma the series thins toward the north and northwest toward the Central Oklahoma platform and westward toward the Nemaha ridge.

The Desmoinesian is dominantly terrigenous clastics, but carbonates are prominent

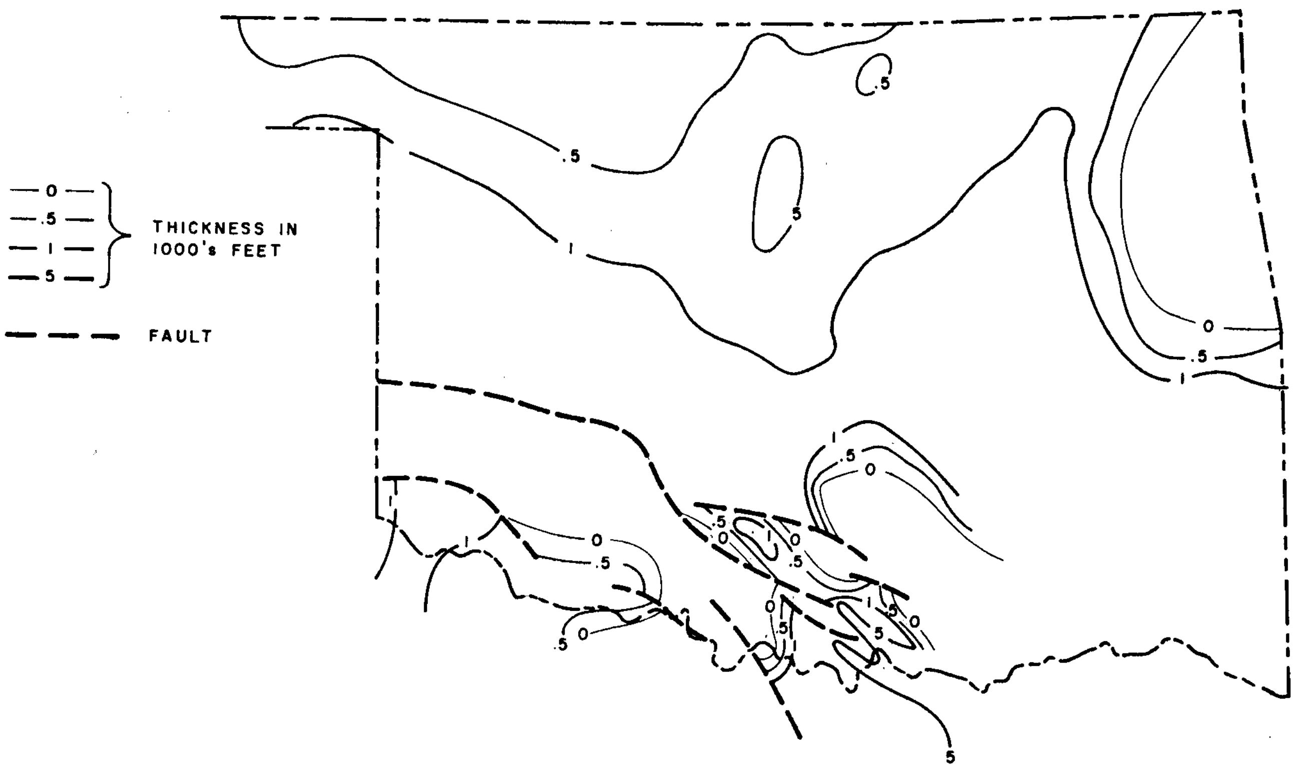


Fig. 9.--Thickness map for Desmoinesian Series.

in the platform areas, where the sequence is relatively thin. Thin limestones are quite widespread and are recognized as stratigraphic markers in mapping transgressive-regressive couplets. Together with coals, which are also thin and relatively widespread, the clastics and limestones form cyclothemic sequences, 25 of which have been recognized in the Krebs and Cabaniss groups in northeastern Oklahoma (Branson, 1954). The Marmaton contains the most significant carbonates, which are largely restricted to shelf areas. Dark shale characterizes the Marmaton of the Anadarko basin, whereas equivalent units south of the shelf in eastern Oklahoma contain sandstone, shale, and thin limestone.

Conglomerates are present near the uplifts of southern Oklahoma. Numerous unconformities are locally associated with conglomerates of the Deese. In addition to conglomerates, the Desmoinesian of the Ardmore basin includes a succession of sandstones and shales with fairly persistent limestones and several lenticular coal seams. The middle part is dominated by red shale.

Missourian Series

In northeastern and central Oklahoma, the Missourian includes the Skiatook and Ochelata groups, in ascending order (Fig. 6). The top of the widespread Drum Limestone is the top of the Skiatook. Equivalent rocks in the Ardmore basin and the southeastern part of the Anadarko basin compose the Hoxbar Group. Generally the Missourian in the subsurface west of the Nemaha ridge is referred to as the Pleasanton and Lansing-Kansas City Groups, which were originally defined on outcrop in Kansas.

The Missourian in Anadarko basin is as much as 3000 to 3500 feet thick (Rascoe, 1962). The series thins rather consistently northward, and it is thinnest on the shelf in the northernmost part of western Oklahoma and in southern Kansas. The average rate of thickening on the shelf is four feet per mile toward the basin, which included not only the Anadarko basin but also the area east of the Nemaha ridge. The southward rate of thickening in the Anadarko basin is 18 feet per mile. The hingeline separating the two areas is shelfward of the Desmoinesian hingeline, and it crosses the position of the Nemaha ridge, which was not active during the Missourian. Maximum thickness in the Ardmore basin is 3500 feet and 4000 feet in the Marietta basin (Tomlinson and McBee, 1959).

Although Missourian is dominantly clastic in Oklahoma, it contains more carbonate, less coal, and less sandstone-conglomerate than the Desmoinesian. Parts of it are distinctly cyclothemic. The carbonates are most prominent in the northern part of the state where the section is thinnest. The Lansing-Kansas City Group shows the typical shelf-basin relationships, with the massive limestones on the shelf and dark gray shales with some sandstones and thin limestones in the Anadarko basin. Two rather extensive developments of sandstone in the area south of the shelf are represented by the Cottage Grove (above the Drum Limestone) and the Tonkawa. Both developments are elongated and convergent in a westerly direction. Conglomerates are best developed in a narrow area north of the Wichita uplift and in the southwestern part of the state south of the uplift. Several limestone conglomerates are locally developed on the northeastern flank of the Criner uplift.

Virgilian Series

In Kansas rocks of the Virgilian include the Douglas, Shawnee, and Wabaunsee groups, in ascending order. Until recently the equivalent units on outcrop in Oklahoma--Vamoosa, Lecompton, Ada, and Vanoss Formations--were regarded by essentially all workers as Virgilian (Figs. 6, 7). The Oklahoma Geological Survey, in recent publications prepared in cooperation with the U.S. Geological Survey, has restricted the Virgilian to the Vamoosa, Lecompton, and Ada. Because the subregional maps of this report depict the recent work of the Oklahoma Geological Survey but most geologists follow the earlier classification scheme, both sets of terminologies are given in summary form and both are noted in the text.

In the subsurface of the Anadarko basin, excluding the southern part, the three groups characteristic of Kansas are commonly recognized. On both flanks of the Wichita uplift, the Virgilian is part of the section which includes granite wash, particularly in the lower part, shale, thin limestones, and several coal beds. The granite wash is less prevalent in the Virgilian than in the Missourian.

The top of the Virgilian Series is considered by most workers to be the top of the Pennsylvanian. The Oklahoma Geological Survey, however, on the basis of palynologic data considers the top of the Pennsylvanian to be the top of the Gearyan Series, which is considered to include the Vanoss Formation and overlying Oscar Formation. The top of the Virgilian, as formerly defined on outcrop was regarded as the top of the Brownville Limestone member of the Wood Siding Formation (of the Wabaunsee Group). This unit or its equivalent is apparently recognized in northern Oklahoma, including the Panhandle. In much of southern Oklahoma, where paleontologic data are sparse, it has been common practice to utilize various lithologic criteria to some extent in determining the top of the Pennsylvanian. The presence of chert has been used to distinguish Pennsylvanian units. Arkose is considered by some workers to be indicative of Permian units in the southwesternmost part of the state, whereas to the east arkose is known to be in both Pennsylvanian and Permian beds. In some areas where the boundary is obscure, Virgilian beds are thought to contain more carbonate or to be more calcareous than the Permian units (Dixon, 1967).

The unrevised Virgilian is as much as 3500 feet thick in the Anadarko basin. South of the Wichita uplift thickness is 1000 to 1500 feet. Post-Pennsylvanian erosion prevents a realistic estimate of thickness for the Virgilian in the Ardmore and Marietta basins, where the Vanoss is less than 750 feet thick. It is 1600 feet thick north of the Arbuckle uplift.

The Virgilian is characterized by fine-grained terrigenous clastics in the Anadarko and Hardeman basins away from the Wichita uplift. Coarser grained arkosic rocks are present on the flanks of the uplift and are peripheral to the Arbuckle uplift on the north, west and south. Polymictic conglomerate is well developed north of the Arbuckle uplift.

In northern Oklahoma the series is commonly cyclothemic in general character, without significant development of coal. Redbeds are more common in the Virgilian than in the underlying rocks.

The lithologic differentiation of the shelf-basin in western Oklahoma is displayed by the Shawnee and Wabaunsee groups, whereas the Douglas Group is more uniform in gross lithologic character in the two different settings. The most widely developed sandstones in each group, respectively, are the Lowell, Elgin, and Laverty-Hoover, in ascending order (Rascoe, 1962).

Gearyan Series

The Gearyan Series, as defined by the Oklahoma Geological Survey consists of the Vanoss and Oscar Formations (or Groups) (Fig. 7). The Vanoss in the southern part of the outcrop belt is undifferentiated, whereas in north-central Oklahoma the Reading Limestone Member of the Emporia Limestone is the basal unit of the Vanoss, and the upper boundary is the base of the Neva Limestone. By this definition, the Vanoss is expanded to include the Admire Group and part of the Council Grove Groups, both of which are generally considered to be Permian units. The Oscar is also undifferentiated in southern Oklahoma. In north-central Oklahoma it consists of strata from the base of the Neva Limestone to the top of the Herington Limestone.

The Gearyan apparently is not recognized in the subsurface; instead rocks are assigned to the formally defined Virgilian and the Permian Wolfcampian. Thicknesses, lithologies, depositional environments, and petrography are discussed according to the prior stratigraphic nomenclature.

Permian

The Permian is represented by a section more than 6000 feet thick in the Anadarko basin and more than 4000 feet thick in the Hollis basin. Elsewhere in the state it is present in the Wichita uplift area and on the platform east of the basins which includes the western part of the Ardmore basin and the Marietta basin.

Lower Permian in the Hollis basin and adjoining areas in southern Oklahoma is underlain by Virgilian rocks. To the north the Wichita Mountains stood above the surface of the deposition (MacLachlan, 1967).

West of the Wichita Mountains, in the subsurface, Permian strata locally rest on basement. To the north and east of the Wichita Mountains, the upper part of the Pontotoc Group of Permian age rests on Pennsylvanian rocks of the lower part of the Pontotoc. Farther north in the Anadarko basin, Permian is underlain by Virgilian units.

In much of Oklahoma the lower boundary of the Permian System is not clearly defined because lithologies suggest continuous deposition during Late Pennsylvanian and Early Permian. The Brownville Limestone Member of the Wood Siding Formation, recognized in Kansas as the youngest Pennsylvanian unit, is difficult to trace southward as Upper Pennsylvanian and Lower Permian rocks become increasingly clastic in character. At the south edge of the Anadarko basin coarse arkose obscures the boundary. In the eastern part of the Hollis basin, south of the Wichita Mountains, uppermost Virgilian strata consist of limestone and mudstone, but farther east they are predominantly clastics and the systemic contact is obscure.

Wolfcampian Series

In north-central Oklahoma the Wolfcampian Series includes the Admire, Council Grove, and Chase groups. The Admire Group, which is generally undifferentiated in Oklahoma, is a sequence of red and gray shale, lenticular sandstone units, and thin limestone lenses. One limestone, the Five Point, is recognized in the northernmost part of the state. Sandstone is prominent in the lower part of the group.

The Council Grove Group consists of red to gray shale, lenticular sandstones, and thin limestones. On outcrop red shales and sandstones increase in percentage in a southward direction, and limestones thin and change into dolomites before the carbonates pinch out southward. In general there is a northward shift of the southern edges of successively younger carbonate units. The Red Eagle Limestone, which apparently extends farthest south among carbonates, is recognized as far south as northeastern Pottawatomie County.

The Chase Group is characterized by the same types of units as the Council Grove. Carbonates of the former group do not extend as far south as those of the latter, whereas sandstones and red shale are generally more prominent.

South of Payne County the groups of the Wolfcampian are generally undifferentiated because of the dominance of clastics. It is common practice to map the Wolfcampian and Leonardian as one unit in central Oklahoma. The Oklahoma Geological Survey has utilized the base of the Neva Limestone, above the Red Eagle Limestone, in mapping the Oscar and Vanoss groups.

In south-central Oklahoma the Wolfcampian is represented by the Pontotoc Group, or part of that group. The Hart Limestone member of the Stratford Formation is commonly the basal Wolfcampian unit in Pontotoc, Garvin, and Murray counties. However, it is absent in the Pauls Valley field area (Hicks, 1956). The Stratford is red and gray shale, with limestone conglomerates. Thin-bedded, arkosic and/or cherty sandstones are present, particularly in the lower part.

The Wolfcampian in southwestern Oklahoma, according to Gouin (1956) is the upper part of the Pontotoc Group. It consists of massive brown, cherty sandstones, purplish-maroon shales, with some baritic concretions. On outcrop the Post Oak Conglomerate is a member of the Wolfcampian-Leonardian Wichita Formation (Chase, 1954). In Elk City field, Beams (1952) recognized the Mid-Continent groups. The Admire consists of granite wash, red-brown and green shale and several limestone and dolomite conglomerates. The Council Grove is similar lithologically to the Admire; it includes some dolomite and crinoidal limestone. Granite wash is less common in Chase units; limestone and gray or gray-green shale are more common. Hicks and others (1956) consider the Post Oak and the Coleman Junction Limestone in the Hollis basin as Wolfcampian, with the Wichita Formation being the lowest unit of the Leonardian.

The Admire and Council Grove Groups in the Anadarko basin are shelf limestone units in northwestern Oklahoma and the Oklahoma Panhandle on the east flank of the Apishapa-Sierra Grande uplift. The Chase Group contains limestone formations which are present in the Texas and Oklahoma panhandles, northwestern Oklahoma, and Hollis basin. The group grades abruptly into red silty sandstones and shales to the west; toward the southeast it passes gradually into an interbedded limestone and shale sequence which grades into fine-grained sandstones and shales (Rascoe, 1962).

The limestones of the Chase Group do not change to basinal shales. However, in West Texas an abrupt transition of limestone on the shelf to dark shale is present in the Midland basin (King, 1942). Apparently, the Chase shelf-limestone facies extends over the western Mid-Continent, the Amarillo uplift, and the shelf area adjoining the Midland basin (Rascoe, 1962).

In western Oklahoma the upper contact represents a transition from normal marine limestone below to dolomite, anhydrite, and mudstone of the Wellington Formation above. The contact is also transitional in central Oklahoma. Wolfcampian limestone beds are progressively sandier southward toward source areas in the Wichita and Arbuckle Mountains. Near the Arbuckle Mountains the upper part of the Pontotoc Group and the overlying Wellington Formation are mainly detrital. In the Wichita Mountains area the Post Oak Conglomerate on outcrop may include both Wolfcampian and Leonardian units.

Wolfcampian rocks thicken westward from an eroded edge in central Oklahoma (Fig. 10). This trend is modified near the Wichita Mountains, north of which the rocks thicken abruptly to as much as 2250 feet (Fig. 10) (MacLachlan, 1967). The rocks are less than 900 feet thick near the Kansas state line. In the Hollis basin Wolfcampian units are more than 1500 feet thick.

Leonardian Series

The Leonardian (or Cimarronian of the Oklahoma Geological Survey), which crops out in the central and western parts of the state, is represented in part by Wellington and Garber Formations of the Summer Group in north-central Oklahoma, the Sumner

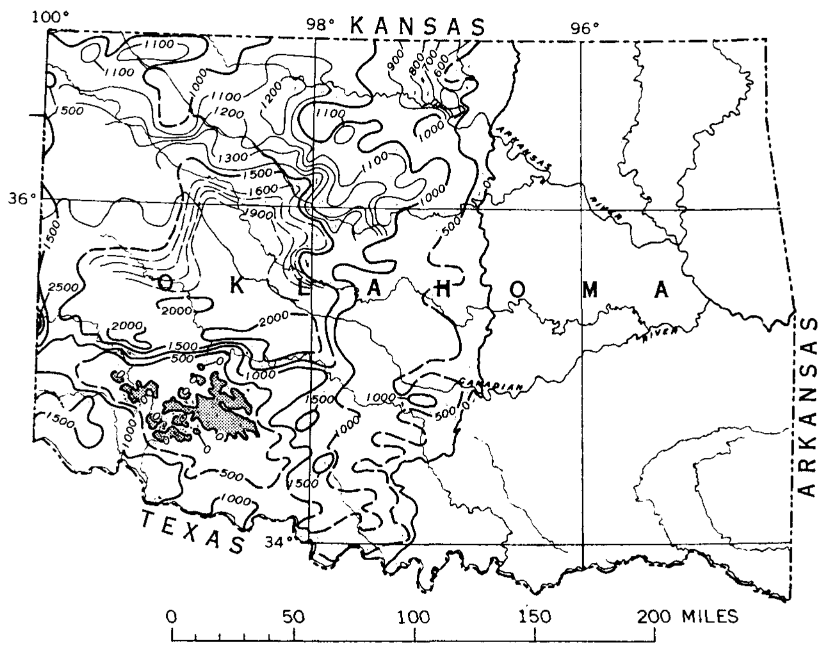


Fig. 10.--Thickness map for Wolfcampian Series. From MacLachlan (1967).

Group along with the Hennessey Shale in central Oklahoma, and the Sumner Group, Hennessey Shale, and the El Reno Group in western Oklahoma. It is common practice to consider the Sumner equivalent in southwestern Oklahoma to be the Wichita Formation, including the Post Oak Conglomerate (Chase, 1954; Miser, 1954). However, Fay (1968), Hart (1974), and Havens (1975) consider the Post Oak Conglomerate to be equivalent of the Hennessey Shale in the Wichita Mountains area. To the east the Hennessey consists of the Fairmont Shale, Purcell Sandstone, and Bison Shale, in ascending order.

In north-central Oklahoma the Wellington is a 800-ft sequence of red shale or claystone, lenticular sandstone, gray-green shale, and thin dolomite beds. To the west in the subsurface the lower part is an evaporite sequence, largely anhydrite, and the upper part is a red mudstone with a small amount of evaporite. A dominant feature of the Wellington on outcrop is its facies change whereby lenticular sandstones are developed southward at the expense of red mudrock and thin dolomite units. The Wellington was divided by Patterson (1933) into a lower member, the Fallis, dominated by sandstone, and an upper shale member, the Iconium. These members are difficult to follow because of the southward increase in sandstone. With the increase in sandstone, the Wellington and Garber become essentially indistinguishable. In western Oklahoma the Wellington is dolomite, anhydrite, and red mudstone, in contrast to the normal marine carbonates of the underlying Wolfcampian section.

The Ryan Sandstone is at the base of the Wellington Formation in southern and southwestern Oklahoma. Around the northwest end of the Arbuckle Mountains the Ryan consists of two massive sandstones separated by a thick shale interval. The basal sandstone is massive, fairly well cemented, and black to brown in color (Dott, 1930). It is overlain by red shales which contain several light-colored sandstone lenses. The upper sandstone is thin-bedded, well cemented, yellow, gray, or black in color, and stained by manganese oxide. Copper and silver have been produced from the sandstone in Sec. 4, T4N, R2E (Dott, 1930).

An approximately equal thickness of shale overlies the lower sandstone member. The interval is composed largely of red shale units with some thin and a few locally massive sandstone lenses.

In the southernmost part of the state the Ryan is recognized by the large, dark-gray to reddish-brown, calcareous concretions which weather out of the sandstone. In many places the sandstone contains concentrations of bituminous material and may be locally asphaltic. The Ryan consists of lenticular, gray to buff or yellow, medium- to fine-grained, friable sandstones. The sandstone are locally thin-bedded and calcareous, measuring from 20 to over 60 feet in thickness. On weathered surfaces the sandstones are dark in color due to concentrations of iron and manganese oxide (Flood, 1969). The remainder of the Wellington Formation consists of more than 100 feet of reddish-brown to gray, blocky shales and siltstones. Sandstone lenses composed of buff to gray, friable sandstones are common in this upper sequence.

The Garber Sandstone is a series of red sandstones and shales which have been divided on outcrop into a lower Lucien Shale member and an upper Hayward Sandstone member. Thickness ranges from 300-600 feet. Some of the variation in thickness is due to problems in recognizing the boundaries because of southward increase in sandstone. In the southernmost part of Logan County the Garber is 90 percent sandstone, whereas in the northernmost part of the county, it is approximately 50 percent sandstone.

The sandstones of the Garber Sandstone in southern and southwestern Oklahoma are generally distinguished from those of the underlying Wellington Formation, and the Wolfcampian as well, by their reddish-brown color. The basal Garber sequence consists of the Asphaltum Sandstone (Bunn, 1930), a buff to gray, calcareous sandstone which is locally asphaltic. Bunn described the Asphaltum as massive- to thin-bedded and ranging from 20 to over 50 feet in thickness. It consists of one or more members separated by shale beds and contains lenses of a carbonate, clay-pebble conglomerate. The conglomerate was mapped in southwestern Oklahoma by Munn (1914) as the Auger Lentil. He observed that toward the east in eastern Cotton County the conglomerate is more sandy and in many places has the appearance of a calcareous sandstone.

Several locally massive sandstone lenses occur within the Garber section. In Garvin County, these massive beds cap many of the prominent escarpments. Elsewhere, the sandstone members are reddish-brown, gray, or black in color and are thin, hard, and crossbedded (Dott, 1930). They are present as lenses in reddish-brown to gray siltstones and shales. The Garber Sandstone is 100 to 200 feet thick in southern Oklahoma.

In Garfield and Kingfisher Counties the Hennessey Shale is a series of red claystones and mudstones, approximately 400 feet thick. At the type locality it was originally divided into the Bison Sandstone above the Fairmont Shale (Aurin and others, 1926). The Cedar Hills Sandstone member, which apparently is the approximate equivalent of the Bison Sandstone, is recognized by Miser (1954) from the Kansas-Oklahoma state line to the Oklahoma City area. The Hennessey exhibits southward facies changes similar to those expressed by the Wellington and Garber.

In central Garvin County the upper 40 to 80 feet of the Garber Sandstone grade upward into red, blocky shales which contain numerous red sandstone lenses. This sequence was mapped as the Fairmont Shale by Hart (1974). Overlying the Fairmont Shale are reddish-brown, fine- to coarse-grained, lenticular sandstones which mark topographic highs in much of western Garvin County. The sandstones, which are collectively referred to as the Purcell Sandstone, are crossbedded and contain some shale and mudstone conglomerates (Hart, 1974). North of T2N, R3W, these sandstones are generally red in color; however, west and south of that area they are buff to gray (Dott, 1930). The Purcell Sandstone is overlain by a series of gray to reddish-brown, blocky, calcareous shales. This sequence is named the Bison Shale.

West of Duncan, Oklahoma, the Bison Shale and Purcell Sandstone are undifferentiated, and the sequence is mapped as the Hennessey Shale. In Stephens County the Hennessey is gray; however, toward the west, in Comanche County and around the

Wichita Mountains it is reddish-brown. A few small, light-colored sandstone lenses are scattered throughout the section. The thickness of the Hennessey Shale ranges between 150 and 600 feet in south-central and southwestern Oklahoma. In the vicinity of the Wichita Mountains the Hennessey Shale grades laterally into the Post Oak Conglomerate, which is several hundred feet thick at the surface.

Chase (1954) described four lithofacies of the Post Oak Conglomerate, which crop out in southwestern Oklahoma. An unconsolidated granite-boulder conglomerate, composed of rounded granitic boulders embedded in a browish-yellow clay, crops out from near the center of T3N, R16W, to the center of T2N, R13W, and on the north side of the mountains in R15W. In the subsurface the boulders are well cemented with calcite, limonite, and clay and are surrounded by an arkosic matrix. A short distance from the mountains the boulder conglomerate grades into a gravel facies containing a number of arkosic lenses. Chase observed that six to eight miles south of the mountains the conglomerate is a coarse-grained arkosic sandstone which in places grades into the Hennessey Shale. The interbedded arkose and shale is about 400 feet thick and occurs in the subsurface 20 to 30 miles south and north of the mountains.

Near the center of T2N, R13W, the granite boulder conglomerate grades eastward into a mixed granite-rhyolite porphyry, boulder conglomerate (Chase, 1954). The conglomerate crops out around the southeastern end of the mountains and consists of light-pink to yellow-brown, angular and subangular rhyolite pebbles and boulders with some limestone conglomerates.

The third conglomerate facies crops out around the northeast margin of the Wichitas. It is composed of limestone cobbles and boulders which change abruptly into calcareous sands and shales away from the mountains (Chase, 1954).

Although the Post Oak Conglomerate is stratigraphically equivalent and gradational to the Hennessey Shale at the surface (Chase, 1954), in the subsurface it interfingers with the Garber Sandstone, Wellington Formation, and Wolfcampian to Lower Pennsylvanian rocks. Close to the mountains, on the north, the conglomerates are several thousands of feet thick (Adler, 1971).

The El Reno Group consists of the Duncan Sandstone and Chickasha Formation, along with their lateral equivalents, the Flowerpot Shale, Blaine Formation, and Dog Creek Shale. In the southeast part of the Anadarko basin the Duncan Sandstone and Chickasha Formation form a clastic wedge which grades into shales toward the northwest. The El Reno Group is 670 feet thick in Grady County and thins to less than 200 feet in northern Stephens County (Fay, 1964).

The Duncan Sandstone consists of two or three massive sandstones which are exposed along a prominent west-north-west-trending escarpment that extends through northern Stephens and Comanche counties. The Duncan is a buff to gray-green, fine- to very fine-grained sandstone, with some dolomitic lenses (Self, 1966). The Duncan is gray-green near the City of Duncan; however, it is buff colored in the southeasternmost part of the Anadarko basin. Northward from that part of the basin the sandstone is orange-brown to red-brown. It is coarser upward, and near the top it is cherty and conglomeratic, with clay galls. In T4N, R4W, the upper conglomerate is arkosic (Brown, 1937).

The sandstone is crossbedded, and in certain areas it has channel-like, lenticular characteristics. A number of siltstone and shale beds are scattered throughout the section. The sandstone is finer grained westward and northward along the flanks of the Anadarko basin. It grades laterally into the Flowerpot Shale to the north. The Duncan is 100 to more than 400 feet thick.

Overlying the Duncan Sandstone are 100 to 200 feet of varigated sandstones, siltstones, shales, and mudstone conglomerates of the Chickasha Formation. The Chickasha is distinguished from the underlying Duncan Sandstone by its purple color and shaly characteristics. At its base the Chickasha consists of a deep red to purple, crossbedded sandstone, with mudstone conglomerate and some concretionary boulders (Brown, 1937). The lower part corresponds to the arkosic conglomerate member of the Duncan Sandstone of Green (1936). The conglomerate attains its maximum thickness of 150 feet and has its greatest arkosic content in Ts2-3N, R5W

(Green, 1936). The wedge-shaped conglomerate is abruptly thinner toward the north.

Approximately 50 feet of uncemented pink sandstones with thin beds of red shale separate the lower sandstone members from an upper unit consisting of purple sandstones and mudstone conglomerates (Gould, 1924). The lower portion of this upper member consists of purple mudstone conglomerates overlain by thin pink sandstones. The uppermost unit of the Chickasha Formation consists of 25 to 30 feet of massive, purple, crossbedded sandstones, with several lenses of thin mudstone conglomerate.

Northward and westward along the limbs of the Anadarko basin, the Chickasha Formation grades laterally into brick red, gypsiferous shales and siltstones of the Flowerpot Shale, the Blaine Formation, and Dog Creek Shale, in ascending order (Fig. 11).

Davis (1955) did not differentiate the Blaine Formation from the overlying Dog Creek Shale in Grady County. The section, which grades southward into the upper Chickasha Formation, consists of dark red, blocky, silty shales. Several two- to three-foot mudstone conglomerates are present locally in the undifferentiated unit. In the lower and middle portions of the sequence the shales are interbedded with fine-grained, gypsiferous sandstones which grade into relatively pure gypsum. A fossiliferous dolomite, which is increasingly sandy toward the south, crops out at the base of the section (Brown, 1937). The Dog Creek-Blaine section is between zero and 230 feet thick.

The upper boundary of the series is at the base of the Marlow Formation of the Whitehorse Group. In northwestern Oklahoma Marlow sandstone is underlain by bedded anhydrite and red mudstone of the Dog Creek Shale. In southwestern Oklahoma the contact is between orange-red sandstone and sandy mudstone of the Whitehorse above and sandstone and dark-red mudstone of the Chickasha Formation below.

Leonardian strata thicken westward across Oklahoma from an eastern edge that extends almost due south from central Kansas to the Arbuckle Mountains, then west to the Red River (Fig. 12) (MacLachlan, 1967). In the Anadarko basin, the greatest thickness is more than 3700 feet. In the Hollis basin to the

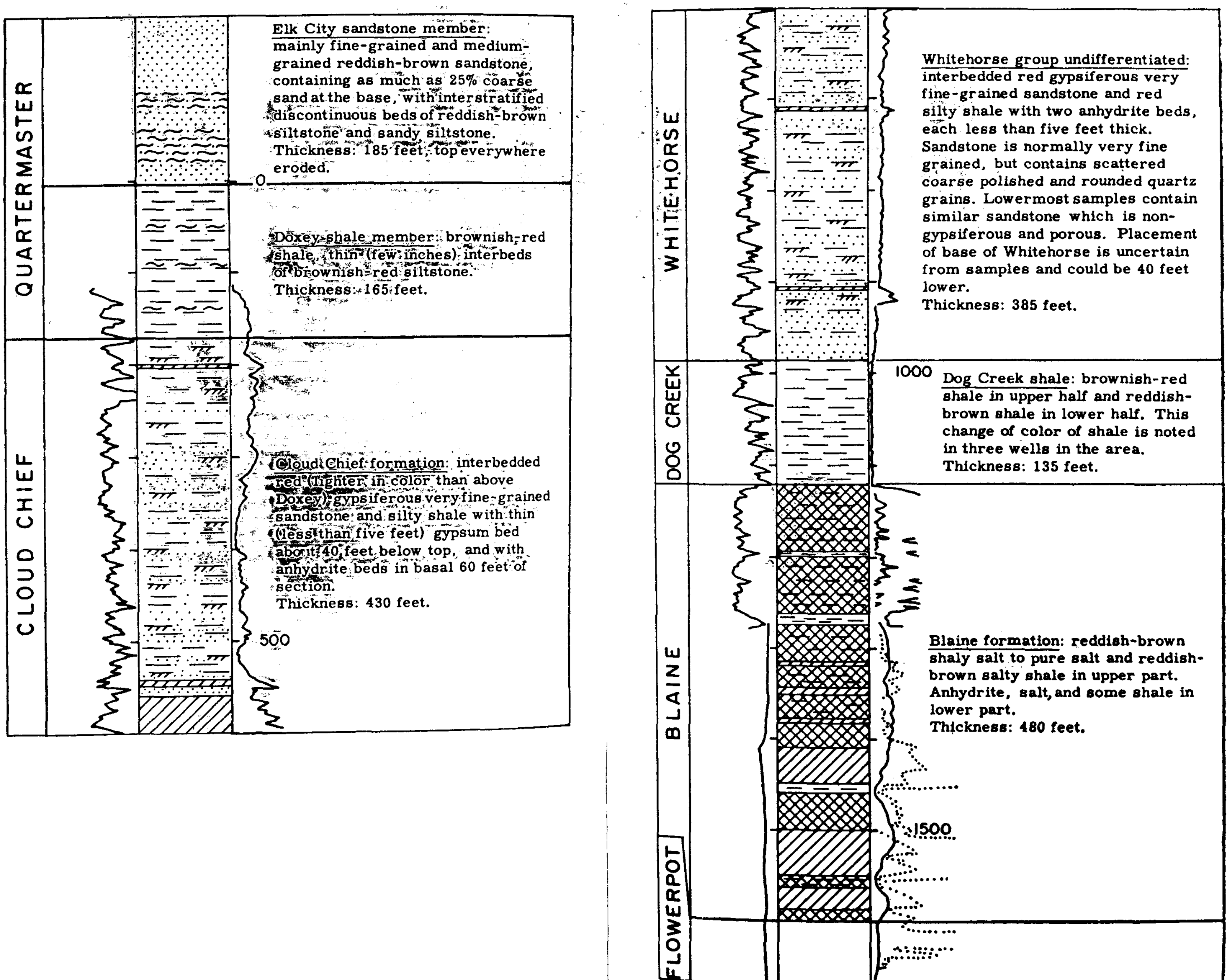


Fig. 11.--Upper part of Permian section in western Oklahoma. From Ham and Jordan (1961).

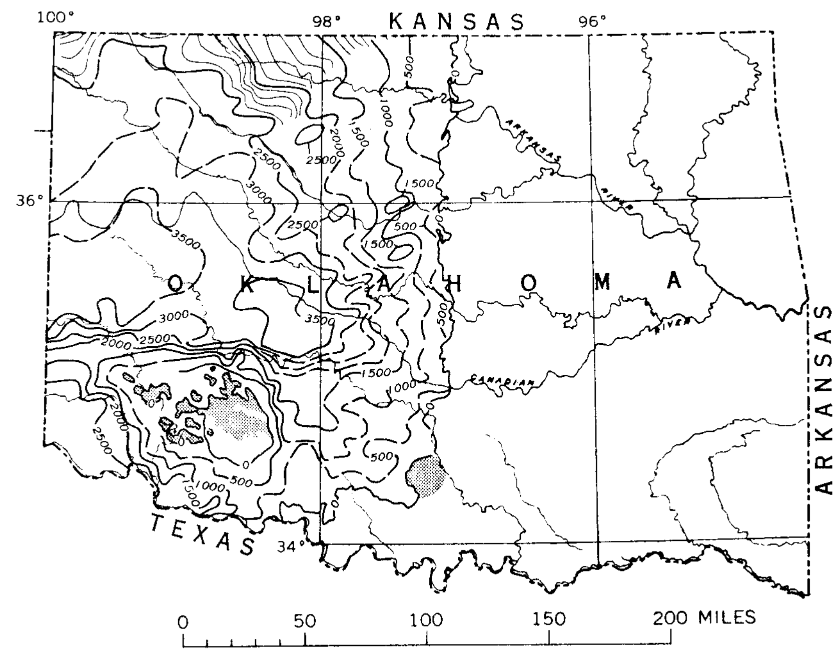


Fig. 12.--Thickness map for Leonardian Series.
From MacLachlan (1967).

southwest more than 2800 feet are present (MacLachlan, 1967). The series thins eastward from these basins and over the buried Wichita ridge. It is locally absent around the Wichita Mountains.

Guadalupian-Ochoan Series

These series include the Marlow Formation and the Rush Springs Sandstone of the Whitehorse Group, Cloud Chief Formation, and the Doxey Shale and Elk City Formation of the Quartermaster Group, in ascending order (Fig. 11).

The Whitehorse Group consists of fine-grained sandstones and siltstones which contain thin dolomite and gypsum beds. The Marlow and overlying Rush Springs Formations are 435 feet thick in Grady County (Fay, 1964).

The Marlow Formation consists of 105 to 135 feet of reddish-brown, silty shales and fine-grained sandstones. The formation is gypsiferous throughout, containing randomly oriented veins of satin spar. In the upper part of the formation 15 to 20 feet of sandstones and shales separate two persistent thin-bedded dolomitic limestones, the Relay Creek and Emanuel Beds. A thin, pink, sandy shale (the Gracemont Bed) lies below the upper limestone (Emanuel Bed). This shale unit and a similar shale which occurs about 60 feet above the base of the formation may be altered volcanic ash deposits (Davis, 1955). Satin-spar veins and gypsum concretions are common in the lower part of the formation.

A light-brown, lenticular Verden Sandstone is present near the middle of the Marlow Formation. It crops out in a northwest-trending linear belt in the Caddo-Grady County area (Shelton and Mack, 1970). The medium- to coarse-grained, cross-bedded sandstone is composed of quartz and chert with calcite cement (O'Brien, 1963).

In Caddo, Grady, and northern Stephens Counties the Rush Springs Formation consists of a crossbedded to even-bedded, quartzose sandstone. Iron-oxide coatings on the sand grains gives the sandstone its characteristic medium- to light-red coloration (O'Brien, 1963). At Cement, in southeast Caddo County, the normal red coloration of the sandstone has been altered to a buff or white color. In this area the sandstone, which contains minute concentrations of pyrite, is well indurated with carbonate cement (McKay and Hyden, 1956).

Very coarse, frosted, spherical grains are common in the lower part of the formation. The Rush Springs is generally friable, being weakly indurated with iron oxide and clay cement. The sandstone displays remarkable homogeneity. Siltstone and shale constitute only a minor part of the formation. However, a silty shale does crop out south of the Town of Rush Springs (Davis, 1955).

A massive pink gypsum in the upper part of the Rush Springs Formation, Weatherford Gypsum Bed, is one to 40 feet thick. Throughout most of Caddo County the unit is dolomitic with local variations to anhydrite or gypsum (Tanaka and Davis, 1963). The Weatherford Gypsum Bed is separated from the overlying Cloud Chief Formation by 10 to 15 feet of dolomitic sandstones and siltstones. The total thickness of the Rush Springs Formation is more than 300 feet. The formation is thicker westward toward the axis of the Anadarko basin (Tanaka and Davis, 1963).

The Cloud Chief Formation crops out over much of Beckham, Washita, Custer, and Roger Mills Counties and in part of Caddo County. This formation is composed dominantly of pale-red, fine-grained sandstone, siltstone, and silty shale. It is distinguished from the overlying Doxey Formation by its lighter color and coarser grain size.

At or near the base is a locally thick unit of gypsum-anhydrite evaporites, the Moccasin Creek Gypsum. It is as much as 85 feet thick in Caddo County. Thin beds of gypsum and vein satin spar also occur in the middle and upper parts of the formation.

The lower and principal evaporite unit in southeast Custer and eastern Washita Counties may be as much as 120 feet of continuous sulfate rock. Westward, this evaporite unit thins to only 5 feet in Roger Mills and Beckham Counties where it marks the base of the formation. Locally in the eastern part of the outcrop area the Dog Creek Dolomite (1-5 feet thick) marks the base.

The thickness of the Cloud Chief Formation ranges from 250 feet in south central Custer County, where there are no thick beds of gypsum, to 430 feet in eastern Beckham County, where beds of anhydrite are present in the basal 60 feet.

The Doxey Formation crops out in northern Beckham, northwest Washita, southeast Custer, and eastern Roger Mills Counties. It is composed of alternating, moderately reddish-brown beds of siltstone, mudstone, and claystone. Greenish bands are common throughout the formation. The mudstones and claystones are devoid of bedding while the siltstones may or may not be well stratified. The unit has a conchoidal fracture, and ripple marks are the only known sedimentary structures.

The siltstone, cemented by calcite, forms prominent benches and caps on the "haystack" hills. The maximum thickness of the Doxey is about 190 feet.

A dolomite is present near the base of the Doxey Formation (Suffel, 1930). It caps the buttes in the northwest corner of Caddo County, where it is up to 15 feet thick. The dolomite is platy and banded at the base and brecciated at the top. The lower banded part shows flow structures and imprints of brachiopods. The dolomite contains considerable tourmaline, rutile, zircon and other heavy minerals. Conglomeratic dolomite has been found at the base of the Doxey Formation in other areas.

The Elk City Formation is the youngest Permian unit in western Oklahoma. It crops out in the axial part of the Anadarko basin in Washita, Beckham and Roger Mills Counties.

The Elk City Sandstone is brownish-orange, noncalcareous, friable, crossbedded, very fine-grained sandstone, with zones of well rounded, medium- to coarse-grained sandstone. Ripple marks have been found in the Elk City Sandstone.

The Guadalupian-Ochoan series thickens from less than 20 to more than 1400 feet toward the south edge of the Anadarko basin (Fig. 13) (MacLachlan, 1967). Thickness trends are difficult to evaluate because of extensive erosion. Locally, thickness of the Quartermaster Group has been modified by slumping.

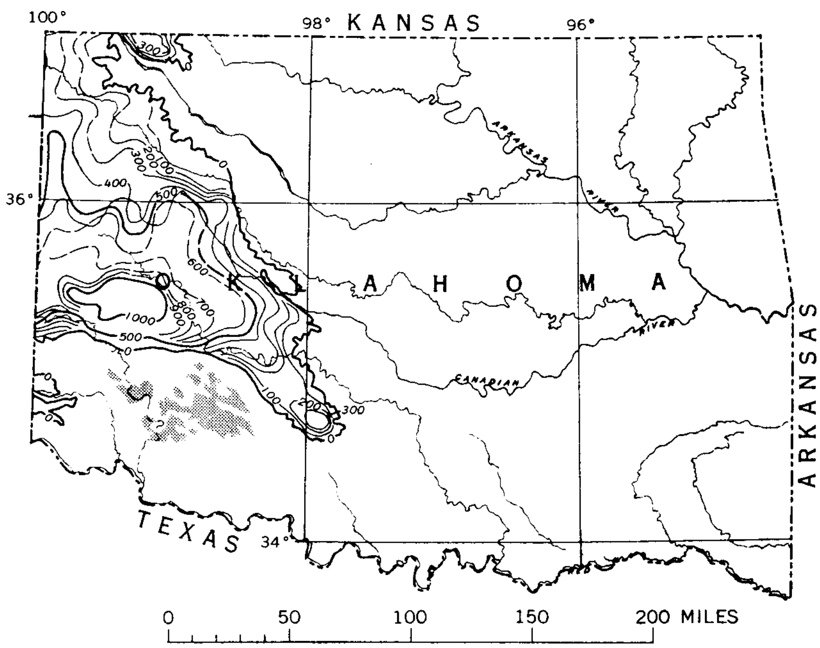


Fig. 13.--Thickness map for Guadalupian-Ochoan Series. From MacLachlan (1967).

DEPOSITIONAL ENVIRONMENTS

Pennsylvanian

Morrowan (Springeran-Morrowan) Epoch

The gross depositional environment of the Springeran-Morrowan units is considered to have been shallow marine. However, papers reporting the criteria for recognizing specific depositional environments outside the Ouachita geosyncline have not been published.

Several Springer sandstones contain a limited marine fauna and at least two contain the plants *Calamites* and *Lepidodendron* (Tomlinson and McBee, 1959). A rich marine fauna, which has been described by Elias (1956), is present in a Goddard sandstone. Limited data are available on sedimentary structures. Features reported include thin beds, interbeds, ripple marks, and bioturbation. Morrowan units above the Springer Group in the Ardmore basin are considered to be shallow marine deposits--including the sandstones, Jolliff conglomerate, the shales, and the limestones. The Primrose Sandstone contains bioturbated bedding, casts of goniatites, and siliceous spicules (Tomlinson and McBee, 1959). The shale above the Primrose contains both a microfauna and macrofauna, with a bituminous band and carbonaceous shale in the lower part. Conglomerates of the Jolliff grade into limestones with crinoid debris. The Otterville Limestone characteristically contains oolitic, skeletal grainstones, suggesting tidal-current deposition.

Depositional trends are not well known from the literature. The southern edges of the Springer sandstone in the Ardmore basin are on the northeast flank of the Criner Hills and trend northwesterly. In the central part of the Anadarko basin, where the Morrowan sandstones are characterized by abnormally high pore pressure, the sandstones are very lenticular, and some show overall northerly trends (Davis, 1974).

Morrowan sandstones in northwestern Oklahoma are generally elongated toward the west-northwest (Khaiwka, 1973). They were deposited during an overall transgression of the erosional Mississippian surface. The lowermost units are commonly alluvial deposits, although some shoreline sandstones apparently impinge upon the unconformable surface. In the Oklahoma Panhandle, the widespread basal Keyes Sandstone, with some conglomerate, is commonly glauconitic. Small arcuate deltas formed during periods of stillstand. Barrier bars separated lagoons from marine areas to the south and southwest where clay was deposited.

The Jackfork and Johns Valley are flysch deposits which formed in deep-marine environments. The Jackfork is typically regarded as turbidity-current deposits which formed dominantly by west- to southwest-flowing currents paralleling the structural trend of the Ouachita province. The proximal facies of deep-marine sediments, representing deposits of fluidized flows, grain flows, and debris flows in addition to turbidity currents, are probably present as submarine-fan deposits, especially in the sand-rich Wildhorse Mountain Formation in the lower part of the Jackfork. The boulder beds of the Johns Valley Shale are wildflysch facies, which apparently formed by debris flows. Other parts of the Johns Valley are thought to be distal facies of deep-marine environments. The Wapanucka Limestone on outcrop in the western part of the frontal zone of the Ouachita system contains both deep-marine and shallow-marine facies (Shelton and Rowland, 1974). The deep-marine facies, which is best developed in the Hartshorne area (T4N, R16E) of Pittsburg County consists of cherty, spicular limestone with wackestones containing sponges and shelf fossil fragments, dark shale, and calcarenites which apparently were transported across the shelf and deposited on the slope. The shallow-marine facies consists of grainstones and algal, mud-supported carbonates which formed in subtidal and intertidal waters, typical of Morrowan carbonates of northeastern Oklahoma. Where deep-marine units are present, they are overlain by shallow-marine units. Sandstone overlying the Wapanucka Limestone is a shallow-marine deposit; the Spiro Sandstone in the southernmost part of the Arkoma basin apparently is its subsurface equivalent. The apparent equivalent to the northwest near the Central Oklahoma platform is the oil-productive Cromwell Sandstone, which pinches out to the north and northwest. The Cromwell is thought to have been deposited in shallow-marine waters. The area to the north, where the oldest Pennsylvanian is Cherokee, evidently was a low-lying area which was not a major source of sediment.

Atokan Epoch

On outcrop in eastern Oklahoma the Atoka Formation reflects three structural-stratigraphic frameworks. On the southwestern flank of the Ozark uplift, it is a relatively thin sequence of alluvial, or deltaic, to shallow-marine deposits. A thick sequence of deep-marine units is present in the Ouachita Mountains on the south (Fig. 14). The Atoka in the Arkoma basin is a southward-thickening sequence deposited contemporaneously with faulting in a delta-marine environment.

In the area northeast of the Arkoma basin, sandstone, which is more common than shale, includes alluvial (or deltaic distributary) units, with medium-scale crossbedding and medium grain size, and the shallow marine deposits with fossils and/or burrows (Blythe, 1959). Occasional thin limestones and thin coals developed at widely separated intervals, along with the sandstone and shale units, represent cyclic depositional conditions.

In the Arkoma basin sandstone is present in repetitious, interbedded sequences with dark gray shale and siltstone. Sandstone beds on outcrop contain an abundance of ripple marks and burrows, several medium-scale crossbeds and intraformational fragments, and an occasional marine fossil. Paleocurrent indicators exhibit a predominant southerly transport direction (Briggs, 1962; Briggs and Cline, 1967). The repetitious development suggest a subtle deltaic influence; the depositional environment for sandstones on outcrop is thought to be distal delta-fringe to shallow marine. Undoubtedly, distributary sandstones are present in the subsurface between the outcrop belt on the southern flank of the Ozark uplift and the belt adjoining the Ouachita frontal zone.

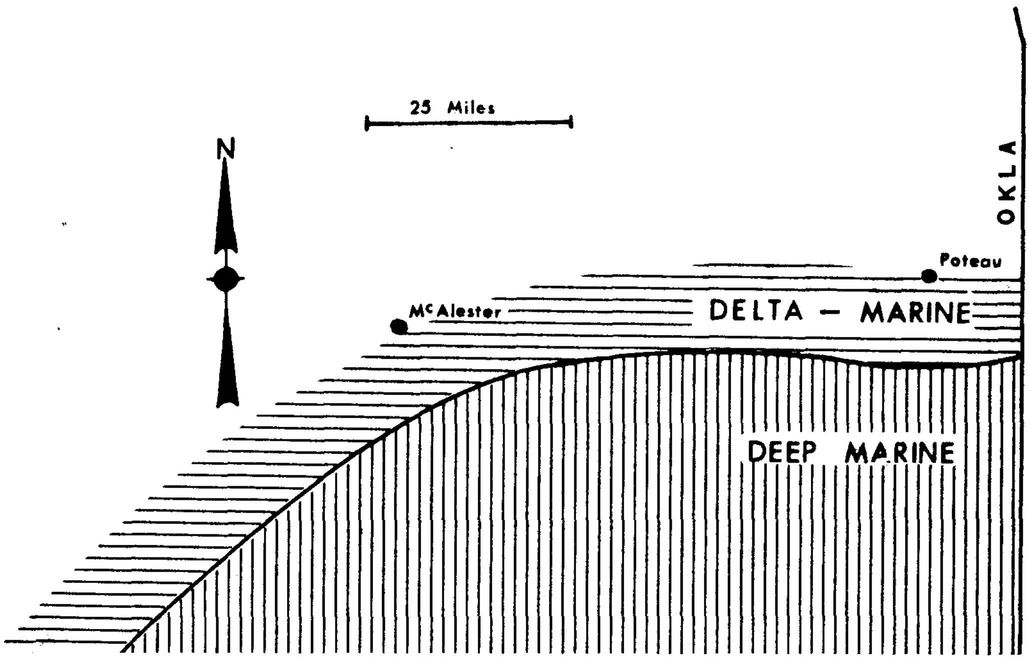


Fig. 14.--Depositional framework during the Atokan.

In the northwestern part of the Arkoma basin the Gilcrease Sandstone shows an overall northeasterly pinch-out. Sandstone trends of similar orientation (Fig. 15) are suggestive of deltaic distributaries. The Central Oklahoma platform apparently continued to be a low-lying area which was not a significant source area.

Sandstone units in shale-rich parts of the Atoka Formation in the Ouachita Mountains show characteristics of distal turbidity-current deposits in that each contains sole marks along a sharp basal contact, horizontal bedding, convolute bedding, small-scale crossbedding, and a gradational upper contact. The microfauna in dark gray shale of foraminifera, sponge spicules, and radiolaria indicates deep marine (Stark, 1966). Sandstones in sand-rich parts of the Atoka contain graded bedding along with the other features of the thinner bedded sandstone units. The upper contacts may not be gradational because of the development of multistoried units. This type of sandstone is the product of turbidity-current deposition downcurrent from any proximal deposits but upcurrent from the distal deposits of shaly Atoka units. Paleocurrents are dominantly westerly, subparalleling the structural framework (Briggs, 1962; Briggs and Cline, 1967). The average direction changes to a southwesterly direction in the western part of the Ouachita province, where the structural trend also changes from west to southwest.

Paleocurrents indicate that the general source area for the Atoka on the shelf and in the Arkoma basin was the craton to the north and northeast. Currents in the Oklahoma part of the Ouachita geosyncline during deposition of the Atoka were primarily axial even though source areas included the craton and a tectonic belt to the south and southeast (Walthall and Bowsher, 1966) as well as the Appalachians to the east.

Shallow-marine units were deposited in the Ardmore basin. Even the Bostwick conglomerates preserved along the northeastern flank of the Criner uplift apparently formed in that environment, for they are associated with limestones. Alluvial fans (or fan deltas), if they developed, must have formed a very narrow belt along the Criner uplift. To the west-northwest the conglomerates along the northern flank

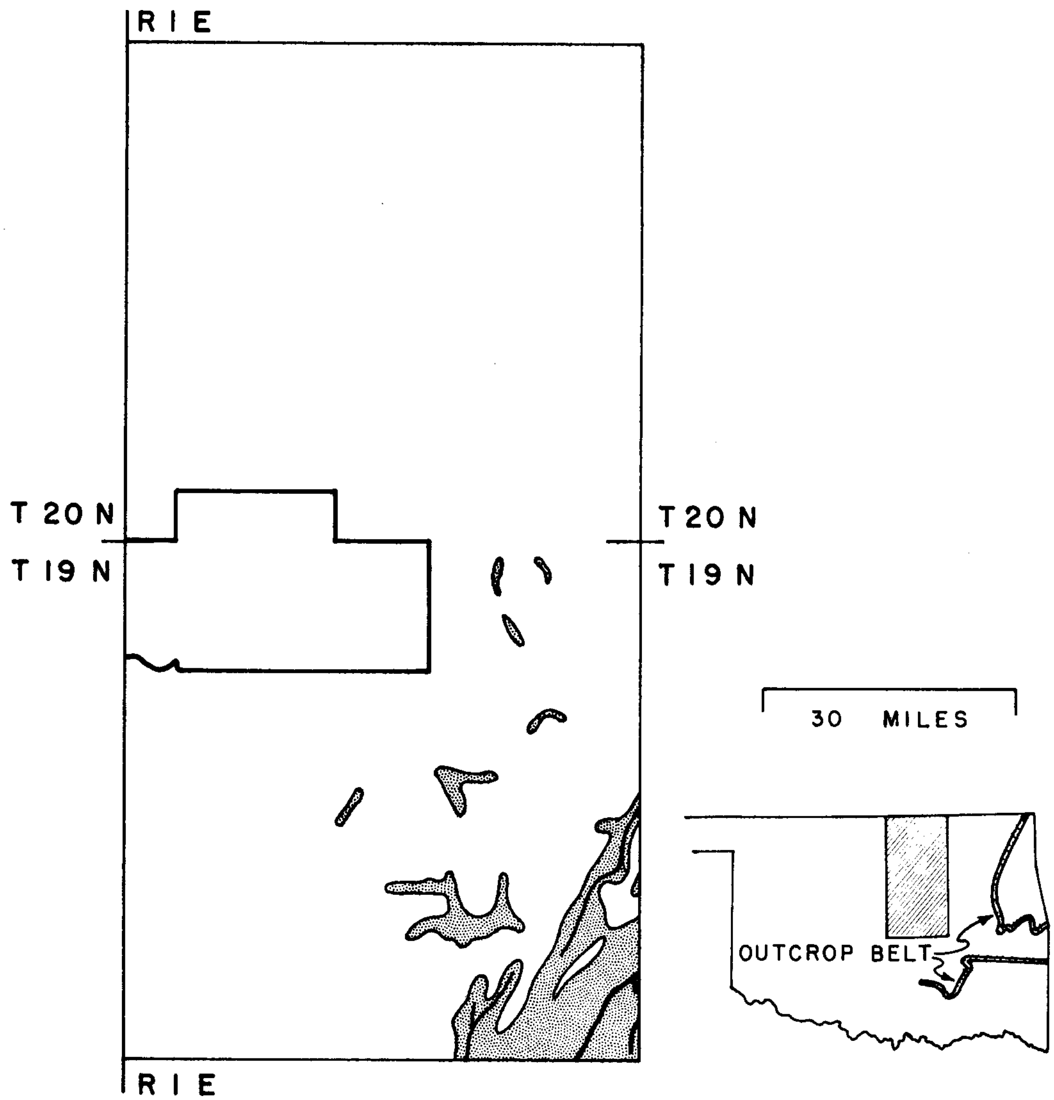


Fig. 15.--Sandstone distribution map, Gilcrease Sandstone. After Cole (1969). Minor trends (20-60 feet thick) shown by light lines. Major trends (more than 60 feet thick) shown by heavy lines. Payne County outlined.

of the Wichita uplift were deposited both as alluvial fans (fan deltas) and as shallow-marine units. Similar conditions apparently existed on part of the southwest flank of the Muenster-Waurika arch in southwestern Jefferson County. Atokan shales in the Ardmore basin generally contain shallow marine fossils and several fossiliferous limestones. The specific depositional environments of sandstones, generally best developed in the lower part of the Atokan in association with the Bostwick and in the upper part of the series, are not known from the literature.

In the Anadarko basin, the fine-grained sequence underlying the dominant limestone section is regarded as shallow-marine deposits. However, some of it may have formed in deeper water as a result of the basin subsiding more rapidly than the rate of deposition. Limestones in the Anadarko basin and the northwestern shelf area were deposited in intertidal water depths in similar environments to the younger carbonates exposed in eastern Kansas (e.g., Heckel and Cocke, 1969; Frost, 1975).

Desmoinesian Epoch

The terrigenous Cherokee units in eastern Oklahoma, with cyclothemic features, range from prodeltaic for marine shales to alluvial for major sandstones. In addition to prodeltaic environments, clays were deposited in interdistributary areas and in backswamps adjoining distributaries and rivers. Sandstones on the Central Oklahoma platform are dominantly stream channels, whereas in the Arkoma basin, south of the hingeline for each unit, delta-fringe (delta-front and delta-margin) units are significant parts of sandstone sections. The distribution and trends for major sandstone units are shown in Figures 16-21. A significant feature is that the dominant source area for each sandstone on the platform was the craton to the north. The southerly source (Ouachita system) contributed to the deposition of the Prue (Lagonda)-Calvin Sandstone and possibly the Skinner Sandstone in the Arkoma Basin (Figs. 19-21). The Nemaha ridge was an insignificant source area before it was blanketed during deposition of the Red Fork Sandstone, when part of the Northern Oklahoma platform and the Central Oklahoma platform became one depositional province.

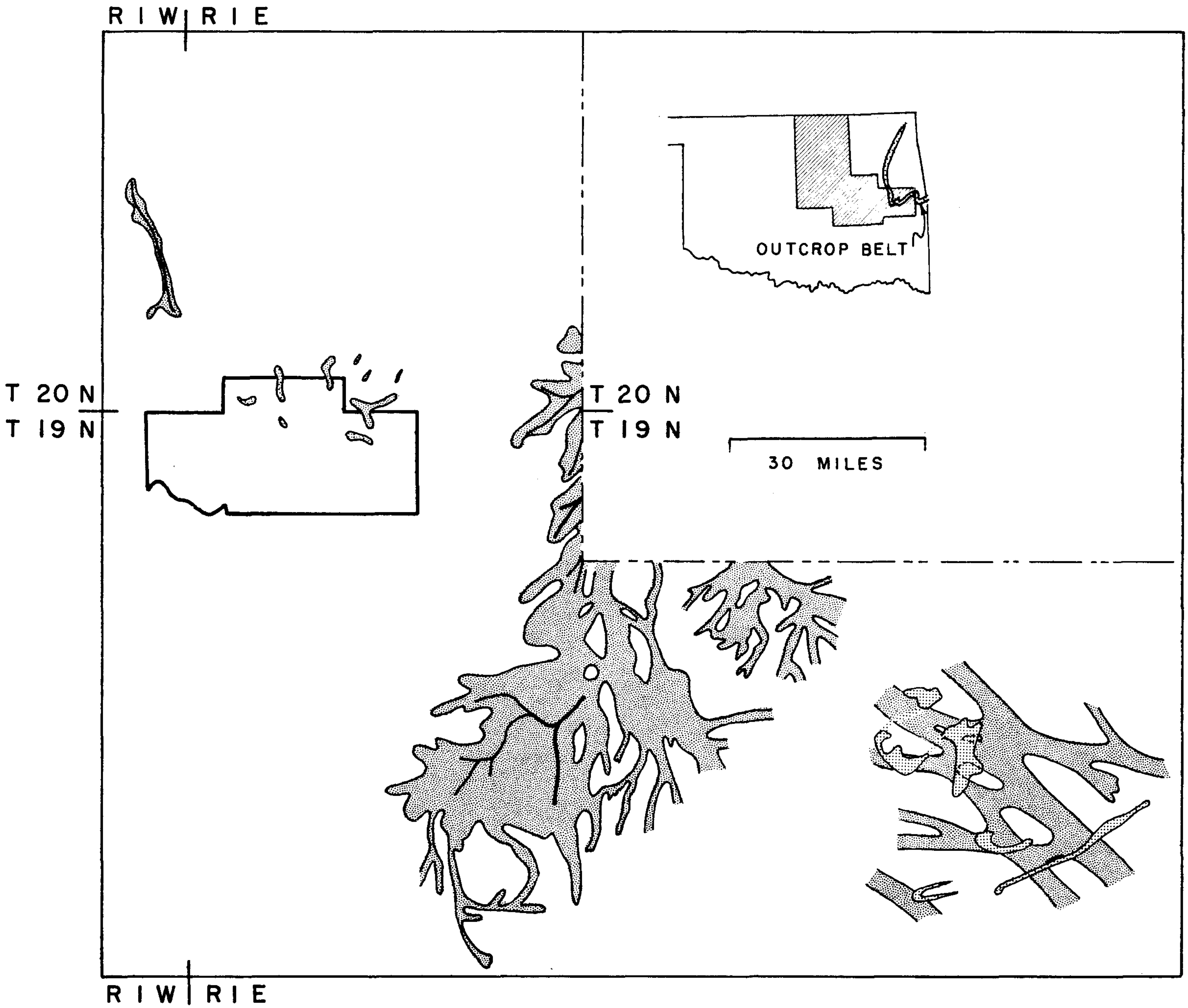


Fig. 16.--Sandstone distribution map, Warner-Booch Sandstone. After Cole (1969), Karvelot (1972). Minor trends (20-60 feet thick) shown by light lines. Major trends (more than 60 feet thick) shown by heavy lines. Payne County outlined.

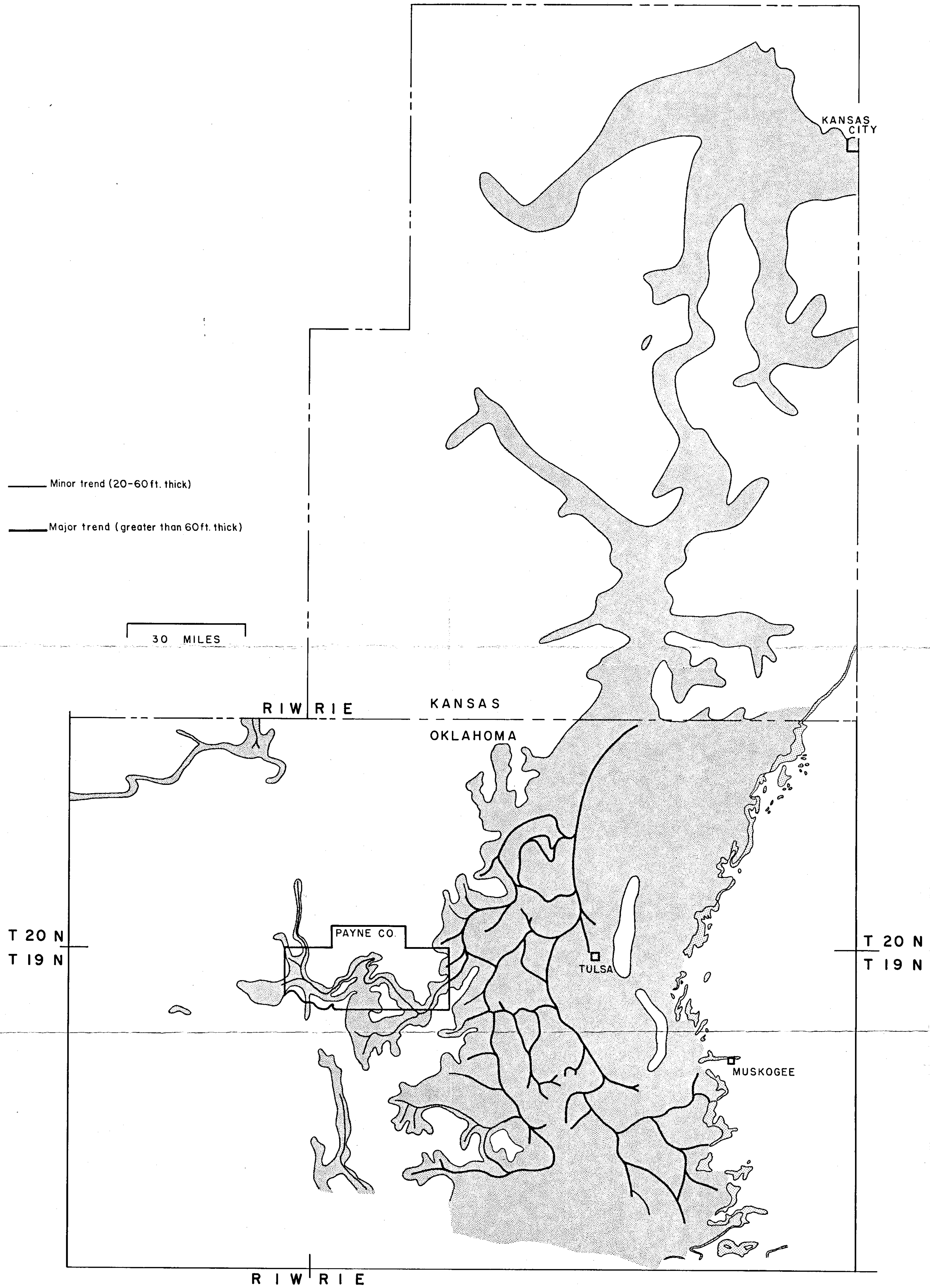


Fig. 17 — Sandstone distribution map, Bartlesville – Bluejacket Sandstone, (After Visher, 1968; Cole, 1969).

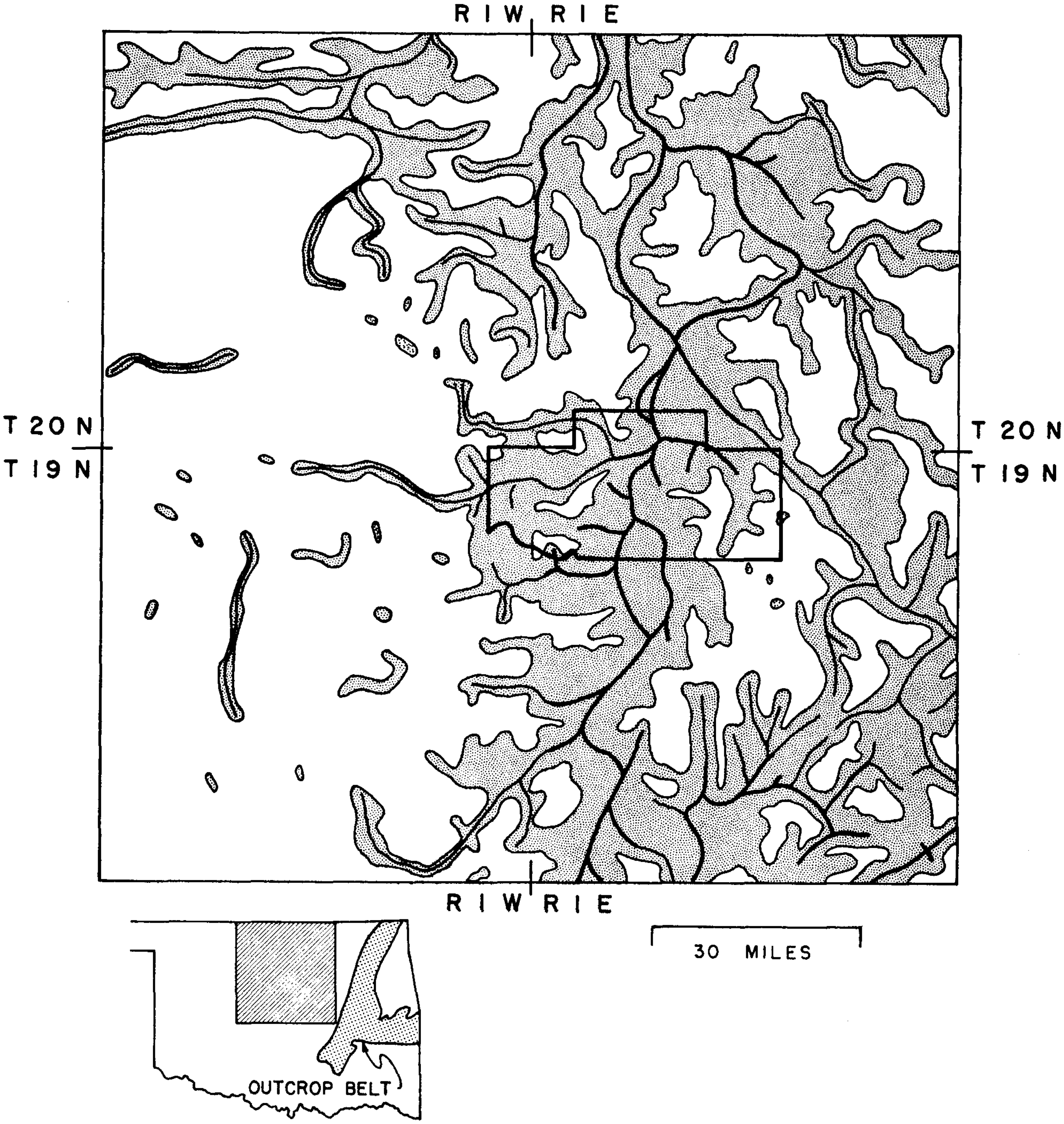


Fig. 18.--Sandstone distribution map, Red Fork Sandstone. After Cole (1969), Berg (1969). Minor trends (20-60 feet thick) shown by light lines. Major trends (more than 60 feet thick) shown by heavy lines. Payne County outlined.

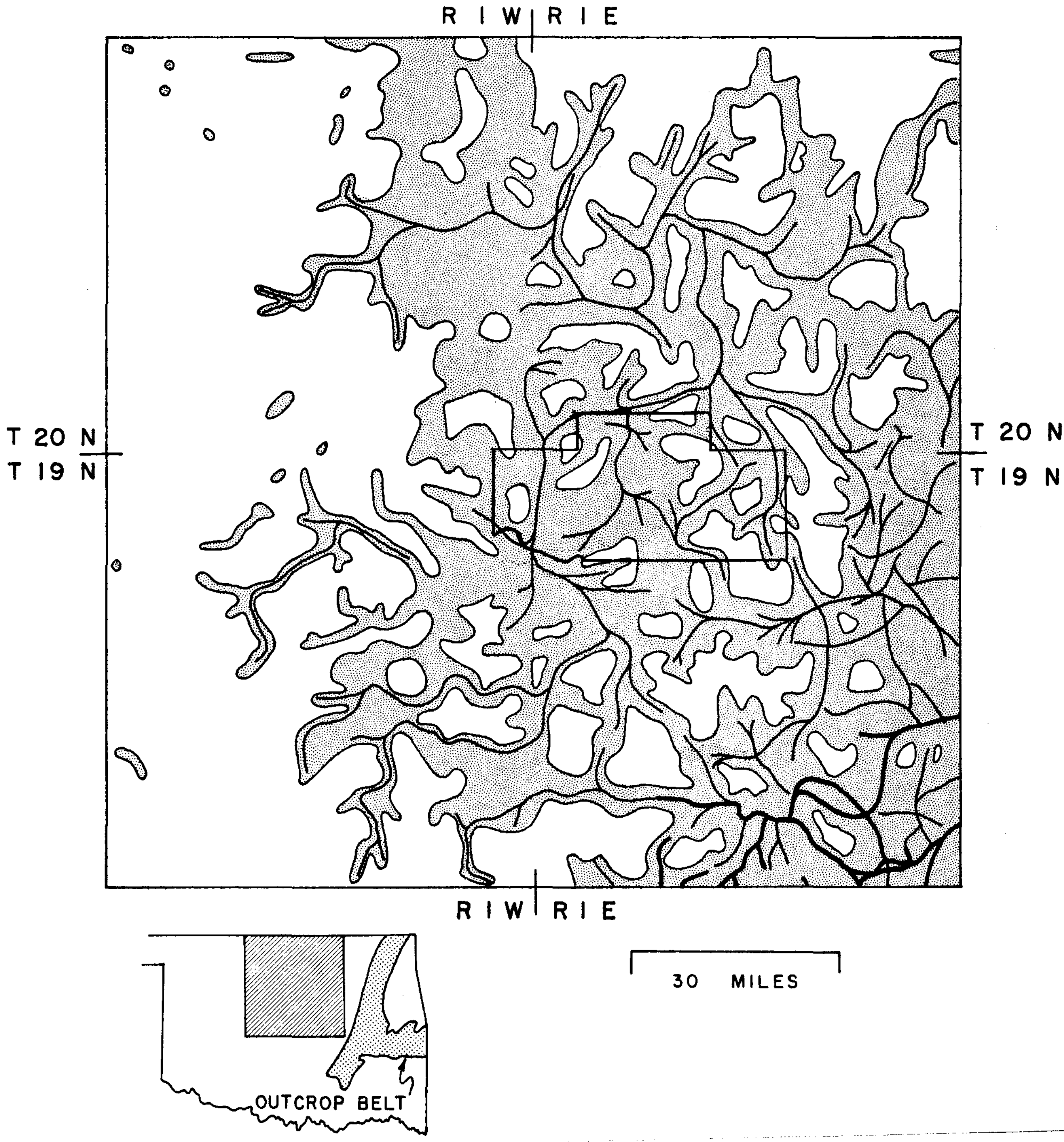


Fig. 19.--Sandstone distribution map, Skinner Sandstone. After Cole (1969), Berg (1969). Minor trends (20-60 feet thick) shown by light lines. Major trends (more than 60 feet thick) shown by heavy lines. Payne County outlined.

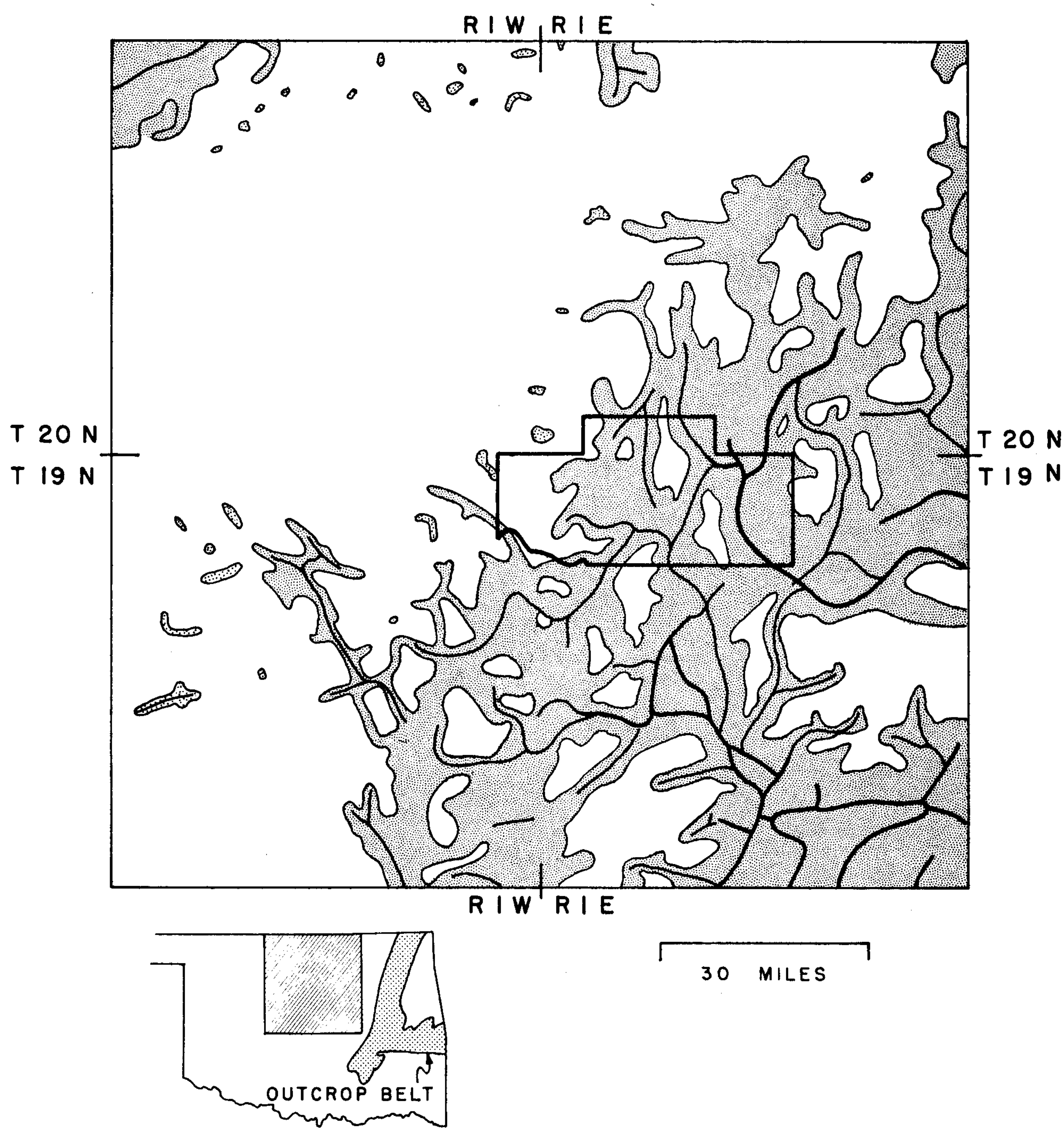


Fig. 20.--Sandstone distribution map, Prue-Calvin Sandstone. After Cole (1969); Berg (1969). Minor trends (20-60 feet thick) shown by light lines. Major trends (more than 60 feet thick) shown by heavy lines. Payne County outlined.

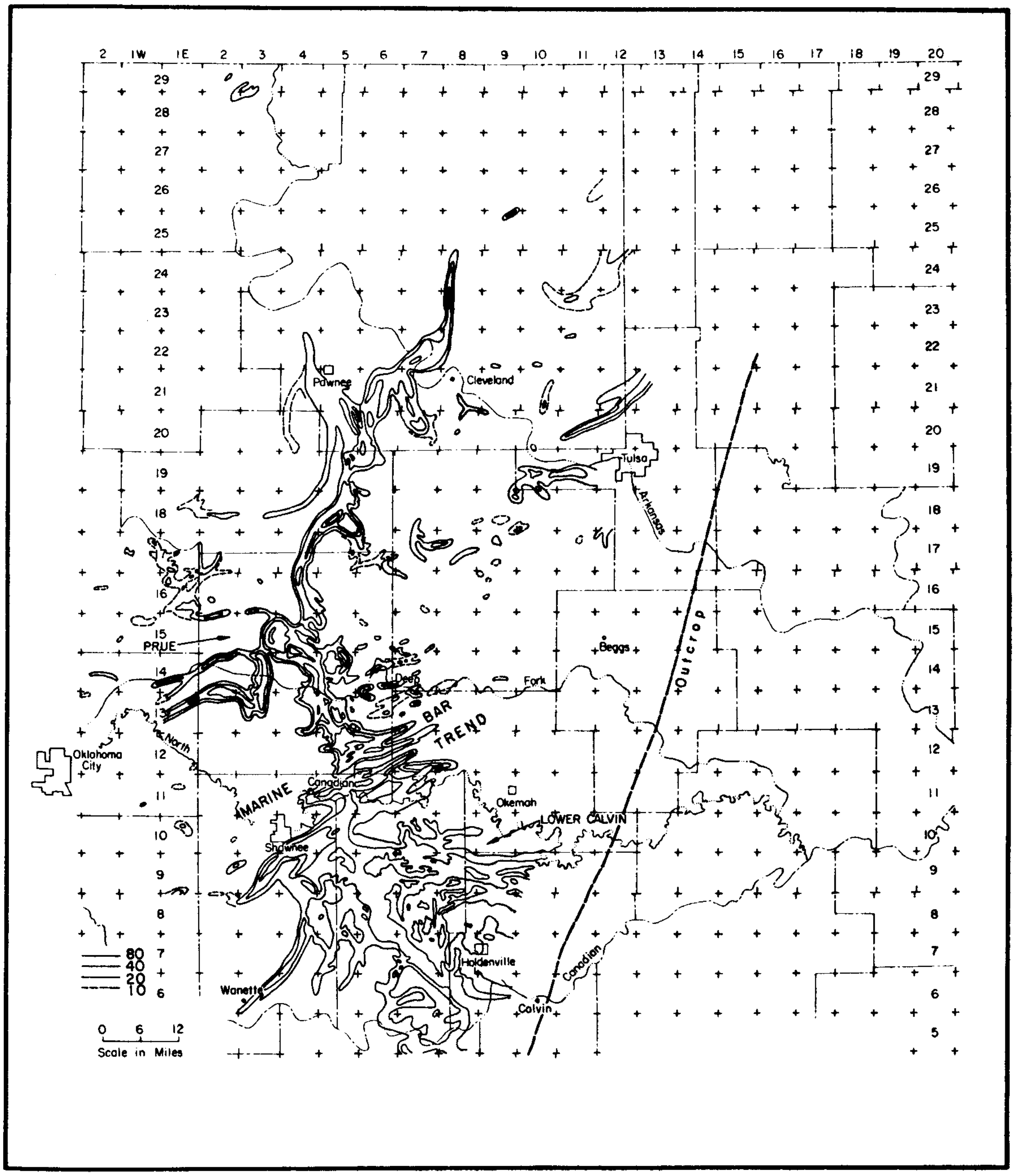


Fig. 21.--Depositional environments, Calvin-Prue Sandstones. From Krumme (1975).

Representative sandstones are the Warner, the subsurface equivalent of which is the Booch (Busch, 1953), and the Bluejacket (or the Bartlesville in subsurface).

Warner-Booch Sandstone. The geometry and internal features of the Warner have been described by Karvelot (1972), and the following summary is largely his findings.

Stratigraphic Framework. The Warner Sandstone is the most prominent unit within the McAlester Formation, a coal-bearing section of cyclothem-like sequences. The McAlester increases in thickness from less than 200 feet to more than 2800 feet into the Arkoma basin from the Oklahoma platform. The Warner is underlain by the McCurtain Shale and is overlain by the Lequire-Cameron Sandstone interval below the unnamed shale containing the Stigler Coal (Fig. 22). The subsurface equivalent of the Warner-Lequire section is the Booch Sandstone, with its finger-like trends, which are considered by Busch (1953) to be the major components of a deltaic complex. The Warner can best be described as an interval containing two different genetic sequences (Karvelot, 1972).

Geometry. The lower Warner sequence is composed of a system of widely spaced major channels which generally trend east or southeast. Primarily from topographic expressions, the major individual channels do not appear to exceed 1/2 mile in width, whereas channel systems are thought from limited data to range in width from 1.4 mile to about four miles. Thin interchannel sandstones are present over most of the area. Maximum thickness varies from 50 to 63 feet in the north to as much as 150 feet at the southeastern edge of the study area (Knechtel, 1949). Most of this lower sequence seems to maintain a rather constant thickness, with a variation of some 10 to 20 feet. The base is commonly gradational, although minor channeling contributes to locally sharp lower contacts.

The approximate limits of the upper sequence are better defined than the lower sequence. The sandstone crops out in a southeast-trending band at least 20 miles long (Fig. 16). Width varies from seven to 10 miles, although continuity is not demonstrable everywhere within this band. Maximum thickness is approximately 35

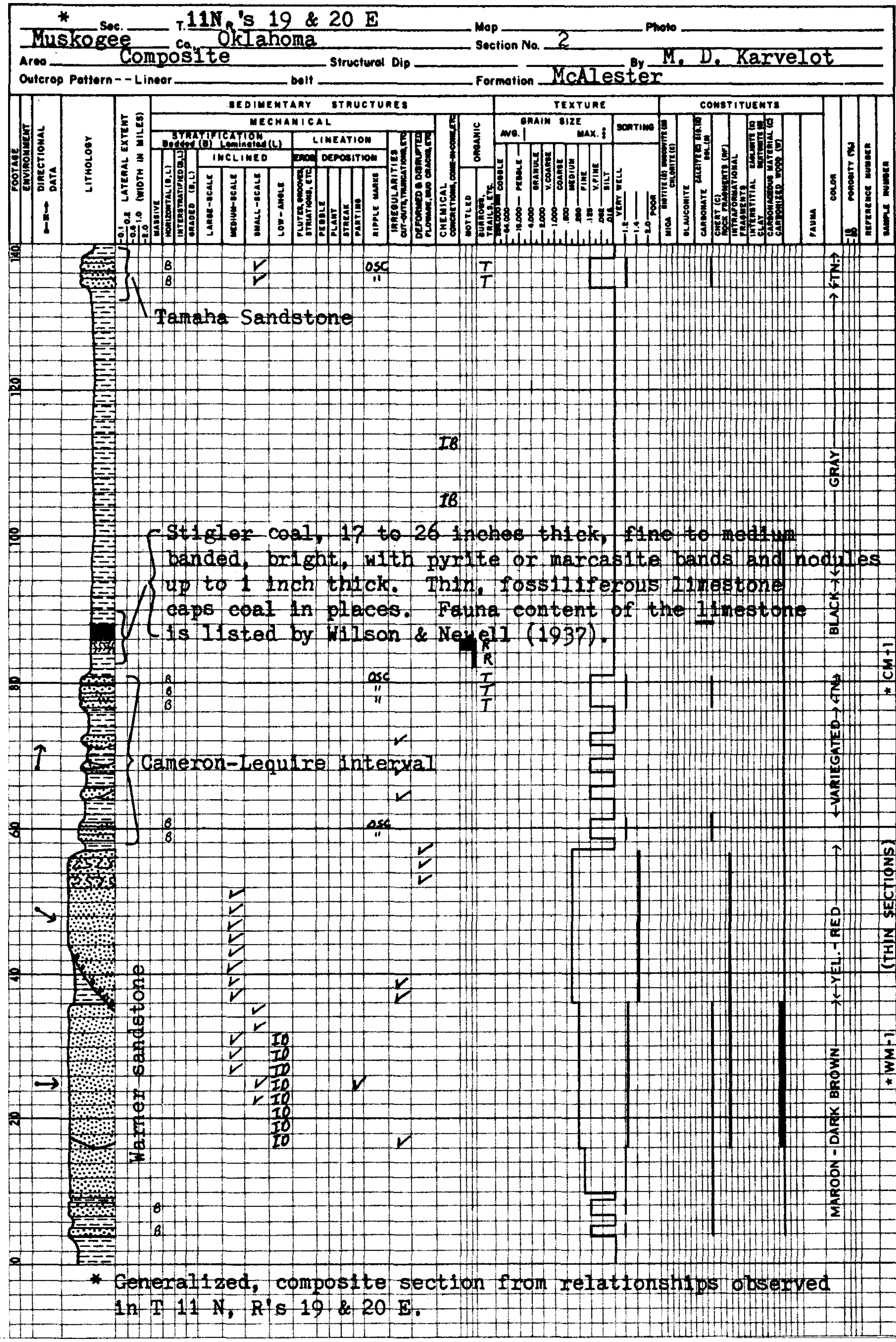


Fig. 22.--Composite measured section of Warner Sandstone and associated strata. Modified after Karvelot (1972).

feet near its northern boundary. The interval appears to thin southward, but this apparent characteristic may be due to weathering and subsequent erosion rather than change in thickness. Near its southern boundary the sandstone is only five to seven feet thick. Lateral contacts and the upper contact were not observed; the lower contact is erosional.

Internal Features. In the lower sandstone, medium-scale crossbedding and accretionary bank slope (initial dip) predominate in the major channels, with subordinate small-scale crossbedding, rib-and-furrow, and parting lineation near the top where the sandstone is finer grained. The interchannel sandstone normally exhibits only interstratification and medium- and small-scale crossbedding, although a few localities show parallel ripple marks and distorted bedding. Limited paleocurrent data suggest that sediment transport direction was toward the east or southeast.

The channels generally show an overall upward decrease in grain size from upper fine- to very fine-grained sandstone. The sandstone is feldspar-rich quartzarenite, generally with approximately five percent chert and five percent feldspar and some rock fragments. Carbonate is present as prominent sideritic clay drapes, scattered sideritic concretions (clay-ironstone), finely crystalline siderite cement, and calcite cement. Clay pebbles, wood fragments, and carbonaceous zones are locally common.

The lower part of the upper sandstone is characterized by medium-scale, tabular crossbed sets, up to 30 inches thick. At each locality, they show little variability in dip direction, generally less than 20^{o}. The average paleocurrent direction is toward the southeast. The upper part is characterized by penecontemporaneously deformed beds, including recumbent foresets, convolute bedding, and diapiric structures.

Texturally, medium-grained quartz sand predominates, and vertical changes in grain size are not obvious. Locally, however, the sandstone shows a slight upward fining. Feldspar, rock fragments, and chert are present in subordinate amounts, ranging from five to 10 percent.

Depositional Environment. Channels within the lower Warner sequence are interpreted as deltaic distributaries. Sandstone and shale associated with these distributaries are thought to be delta front, delta margin, and interdistributary deposits. The upper part of the Warner Sandstone represents deposits of an alluvial plain which was built on the deltaic units during maximum regression. The Warner and Lequire together represent two sequences, or cycles, of delta-lobe progradation eastward from the Booch depocenter (Fig. 16). The cyclic deltaic lobes were probably the result of a combination of delta shifts, basinal subsidence, and eustatic changes in sea level.

Bartlesville-Bluejacket Sandstone. The geometry and internal features of the Bluejacket (and Bartlesville) have been studied by Visher (1968)and Visher and others (1971). The following summary includes a significant amount of their data.

Stratigraphic Framework. The Bluejacket Sandstone on outcrop constitutes the basal member of the Boggy Formation, the uppermost formation of the Krebs Group. The Bluejacket on outcrop is underlain by shale and siltstone of the upper part of the Savanna Formation and is overlain by a variable section of unnamed Boggy units. Most commonly the sandstone is a ridge-former; in the subsurface the Bartlesville Sandstone composes the major part of a sequence between the Inola Limestone above and the "Brown Lime" below. The Bluejacket-Bartlesville is composed of a large number of genetic, multistoried, and multilateral sandstone units, formed in several specific depositional environments. It has been recognized in an extensive area in eastern Kansas (Fig. 17).

Geometry. In Oklahoma the Bluejacket-Bartlesville Sandstone is developed in two general areas, one with major channels and the other with minor channels (Fig. 17). Within the larger area in the east sandstone is locally absent, and sandstone is not developed at numerous localities in the smaller area which adjoins the Nemaha ridge. In the northern part of the larger area, the overall sandstone trend for the many genetic units present is north-northeast. The trend in the southern part is southeast, with even an easterly trend in the southeasternmost part. Sandstone has been recognized in the larger eastern area of development for a distance in Oklahoma of 180 miles along the arcuate trend of major channels. Sandstone is generally thin or not developed in the southern part of the Arkoma basin.

The sandstone-bearing interval ranges in thickness from zero to more than 200 feet. The thickest section is present as a branching pattern in an area south of Tulsa. The channels are narrower than the intervening areas of rather uniform sandstone development, where average thickness is approximately 50 feet. The basal contact is generally sharp along the channels; the upper contact may be gradational or sharp. Away from thick trends, the base most commonly is gradational. Lateral boundaries of the Bluejacket-Bartlesville complex are sharp only where channels are present near the sandstone edge.

Internal Features. Medium-scale crossbedding, along with cut-outs, is a common feature in channel sandstones. Present also is massive bedding with irregularly distributed carbonized filaments or with clay pebbles. Considerable variation exists in local paleocurrent directions on outcrop, but the average of S30^{o}E to S35^{o}E corresponds quite well to the average of channel trends. The more uniform sandstone contains parting lineation, rib-and-furrow, current and wave-generated ripples, burrows, and interstratification. The channel sandstones are commonly coarsest at the base. Pebbles and cobbles of intraformational fragments may be present at several levels in that type of sandstone. Average sand size is fine- to medium-grained, and the sandstones are well sorted. The uniform sandstone units between thick trends, above or below well developed sandstone, and in the southeastern part of the area are very fine-grained, moderately sorted, and they commonly show an upward increase in grain size. In addition to intraformational clay fragments, accessory materials in the coarser grained sandstone include carbonaceous material and carbonized wood, pyrite (in cores), and siderite or iron oxide. In the finer grained sandstone and interbedded shale, concretionary siderite (or iron oxide) is rather common.

Depositional Environment. The Bluejacket-Bartlesville Sandstone is thought to represent various units of a deltaic complex (Fig. 23). The channels are deltaic distributaries for the most part. A genetic distributary sandstone for the Bluejacket-Bartlesville is thought to be less than 70 feet thick. A sandstone body, 200 feet in thickness, probably represents a minimum of three genetic units. The thinner, more widespread sandstone units are considered to be delta-fringe and/or interdistributary. The former includes delta front, distributary mouth, and marginal deltaic plain deposits. Those types of units are present in the Arkoma basin where the section is thicker and south of the major distributaries.

The southerly deltaic advance may have been determined by the Ozark uplift and the Nemaha ridge. During maximum regression, depositional conditions in the northern part of the study area became indistinguishable from those of an alluvial plain. In a vertical section distributary sands overlie or occupy channels cut into delta-fringe sandstones. Interbedded sandstone and shale in the southeastern part of the area of development represent distal delta-fringe units bordering prodelta clays.

Widespread coal seams apparently formed as peat in marshes which developed during the initial phases of transgressions as they terminated deltaic progradations. The major transgressions may have resulted from eustatic changes in sea level. Local developments of coal most commonly formed in backswamps or floodbasins. Carbonized wood and carbonaceous material are very common in almost all sandstones. Thin, widespread limestones and/or dark gray shales, reflecting euxinic conditions, developed during the transgressions which in many cases were initiated by formation of peat. Upon stabilization of sea level following a particular transgression, progradation was resumed and a subsequent deltaic sequence began to form.

Limestone formations of the Marmaton Group are the oldest Pennsylvanian carbonates which are restricted to the northern shelf, where they formed primarily in subtidal and intertidal depths. Thick developments apparently correspond to phylloid

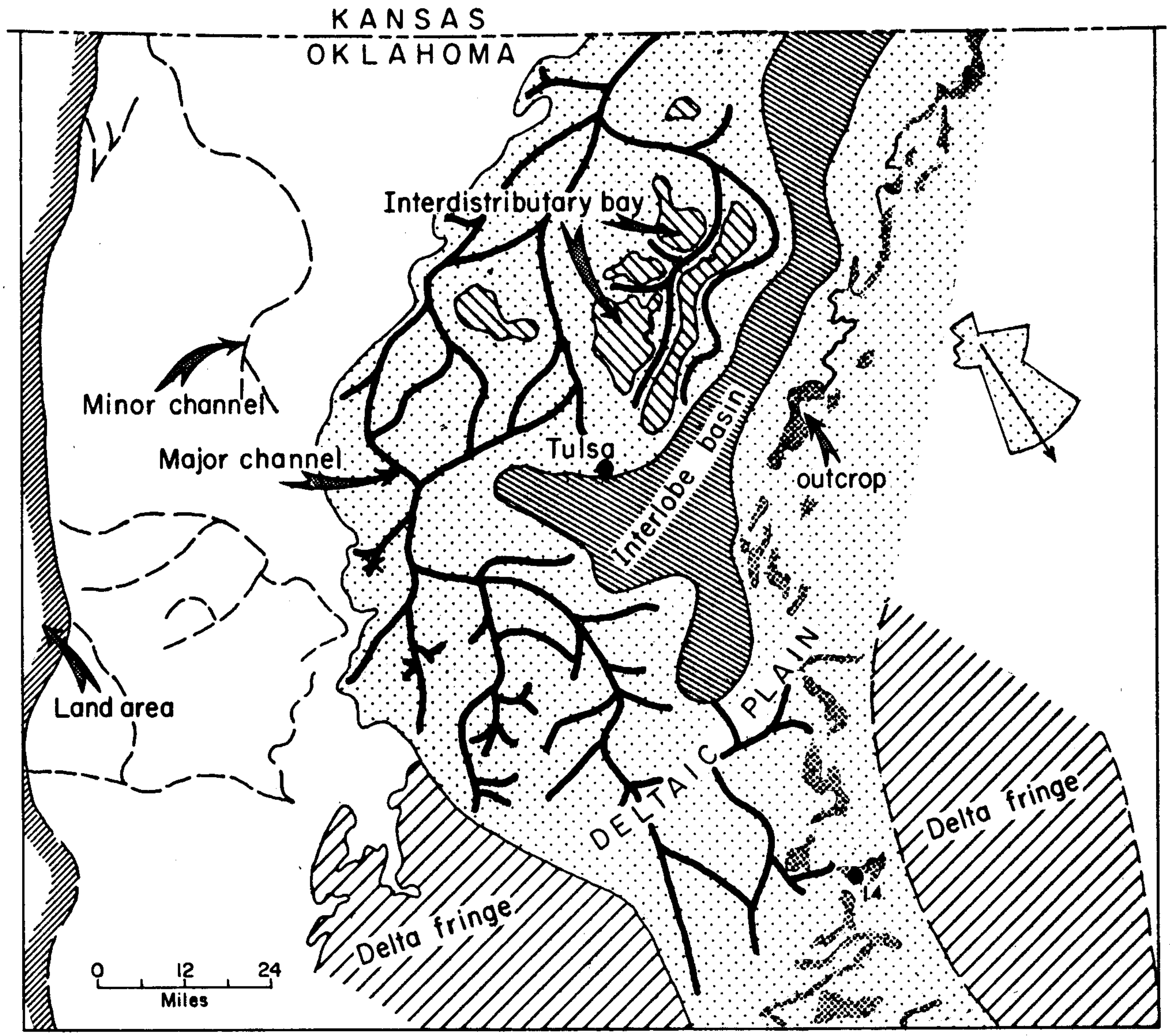


Fig. 23.--Paleogeographic map for Bartlesville-Bluejacket complex. Modified after Visher (1968).

algal banks (Heckel and Cocke, 1969; Frost, 1975). A phosphatic shale between two limestone units of the Oswego represents euxinic depositional conditions which temporarily replaced the oxygenated marine waters for formation of the algal limestones. The transition from the shelf limestones to basinal shales in the Anadarko basin may reflect the change from shallow marine conditions to deeper slope depths. In northeastern Oklahoma the southward decrease in thickness of the Oswego (Fig. 24) and Oologah and their changes into terrigenous clastics are similar to those in the Anadarko basin. However, it is generally thought that the southward increase in sandstone, some of which is conglomeratic, indicates that the limestones formed offshore from a terrigenous depocenter. Chert pebbles in the conglomeratic sandstones indicate the Ouachita system was a source area, and limestone and igneous pebbles were probably derived from the Arbuckle Mountains (Krumme, 1975). Facies distribution, therefore, indicates that the dominant paleoslope in eastern Oklahoma changed from the south to the north.

In the Ardmore basin, sandstones and conglomerates were deposited on alluvial fans-plains which sloped northwestward (Tomlinson and McBee, 1959). Other sandstones and conglomerates or parts of sequences were deposited in shallow-marine and/or deltaic-marine environments. Red shales, which are particularly common in the eastern and southern parts, apparently were deposited on the alluvial plains. Similar conditions existed in the Marietta basin. The tectonic instability of the Criner uplift and the Wichita uplift modified the overall paleoslope which was away from the Ouachita system to the southeast. Local southerly paleoslopes away from the Arbuckle Mountains are indicated by the Warren Ranch conglomerates. Conglomerates in the northeastern part of the Arbuckle uplift and thick conglomerates north of the Wichita Mountains are indicative of considerable relief and steep gradients. Although the Criner uplift was covered by only 1000 feet of upper Desmoinesian sediments, it was a passive positive area rather than a source area during the epoch. The Desmoinesian in the southern part of the Andarko basin adjacent to the Wichita uplift formed as alluvial fans and/or fan deltas and

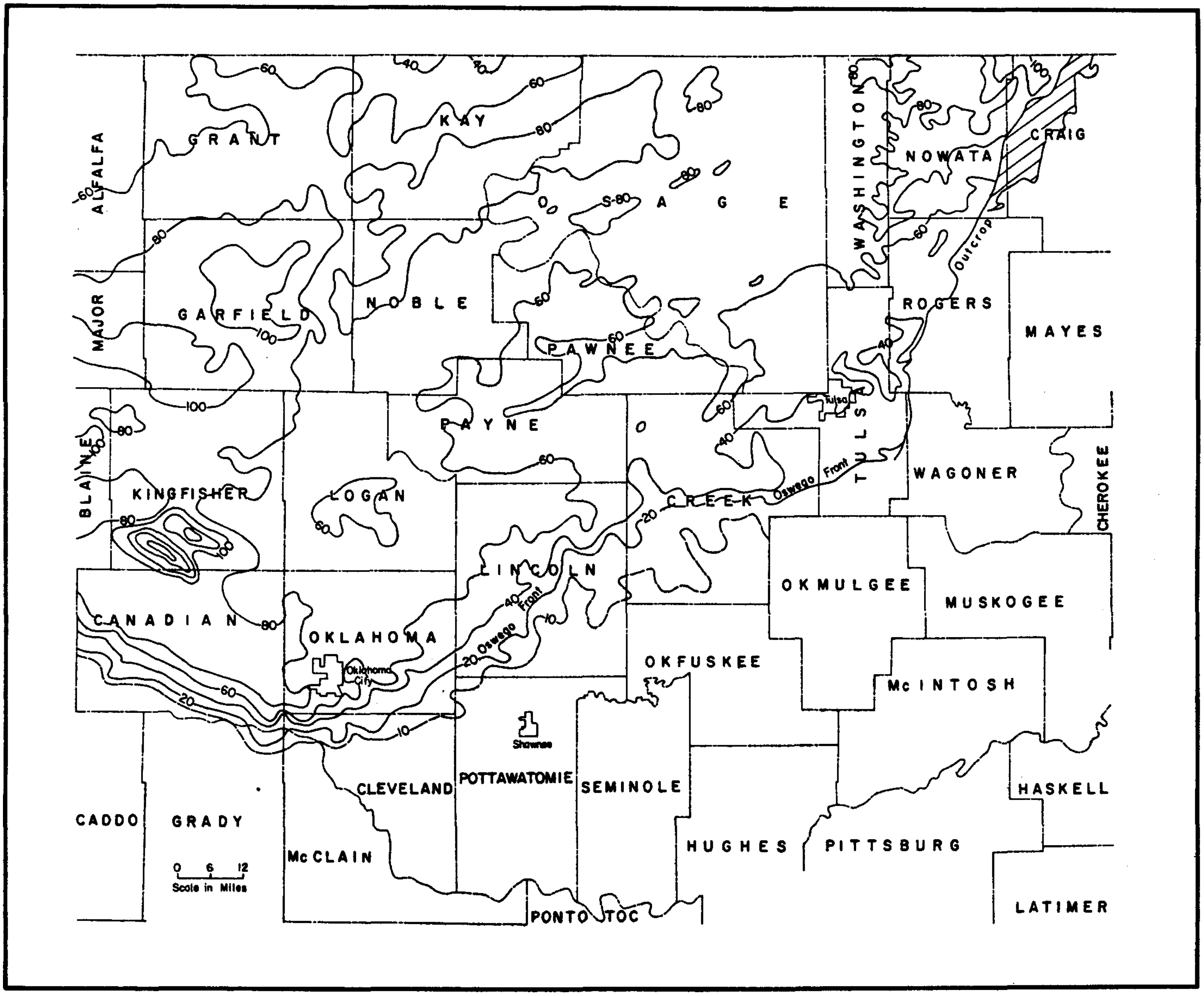


Fig. 24.--Thickness map of Oswego Limestone, showing abrupt southerly changes. From Krumme (1975).

shallow-marine units.

Tectonism in southern Oklahoma obscured the cyclothemic pattern which characterizes the Desmoinesian in eastern Oklahoma. However, conditions were relatively uniform during deposition of several fairly persistent limestones in the Ardmore basin. Marine shale and lenticular coals are other units which show repetitious development. Thin coal beds are also present on the north flank of the Wichita uplift. Fusulinid-bearing limestone, interbedded with granite and carbonate wash, denote periods of marine deposition.

Missourian Epoch

The range in depositional conditions during the Missourian was very similar to that which characterized the Desmoinesian, but marine conditions apparently were more prevalent whereas marshes and alluvial plains were less widespread. A mid-continent seaway extended from Kansas to Ohio (Fig. 25) (Krumme, 1975). Diminished tectonic activity was responsible for a relative restriction of alluvial fans and plains. The Wichita uplift continued to be a prominent source area for fan deposits and associated coarse-grained deposits on the flanks of the uplift. To the north the belt of conglomerates extends basinward for only about 10 miles. South of the uplift the fans extended an even shorter distance basinward, and prominent limestone banks formed south of the fans.

The Ouachita system was less prominent than during the Desmoinesian. However, chert conglomerates, with clasts as large as six inches, are present in the Arkoma basin. Although the Ardmore basin was the depositional site of a larger percentage of marine shale, cyclothems are present, each with a basal sandstone, shale, and an upper limestone. To illustrate further the range in depositional environments, the most significant coal on outcrop in the Ardmore basin is present in the upper part of the Missourian.

The northern carbonate shelf area apparently retreated northward with time, and the southern edge is concave southward (Rascoe, 1962). Thin limestones south

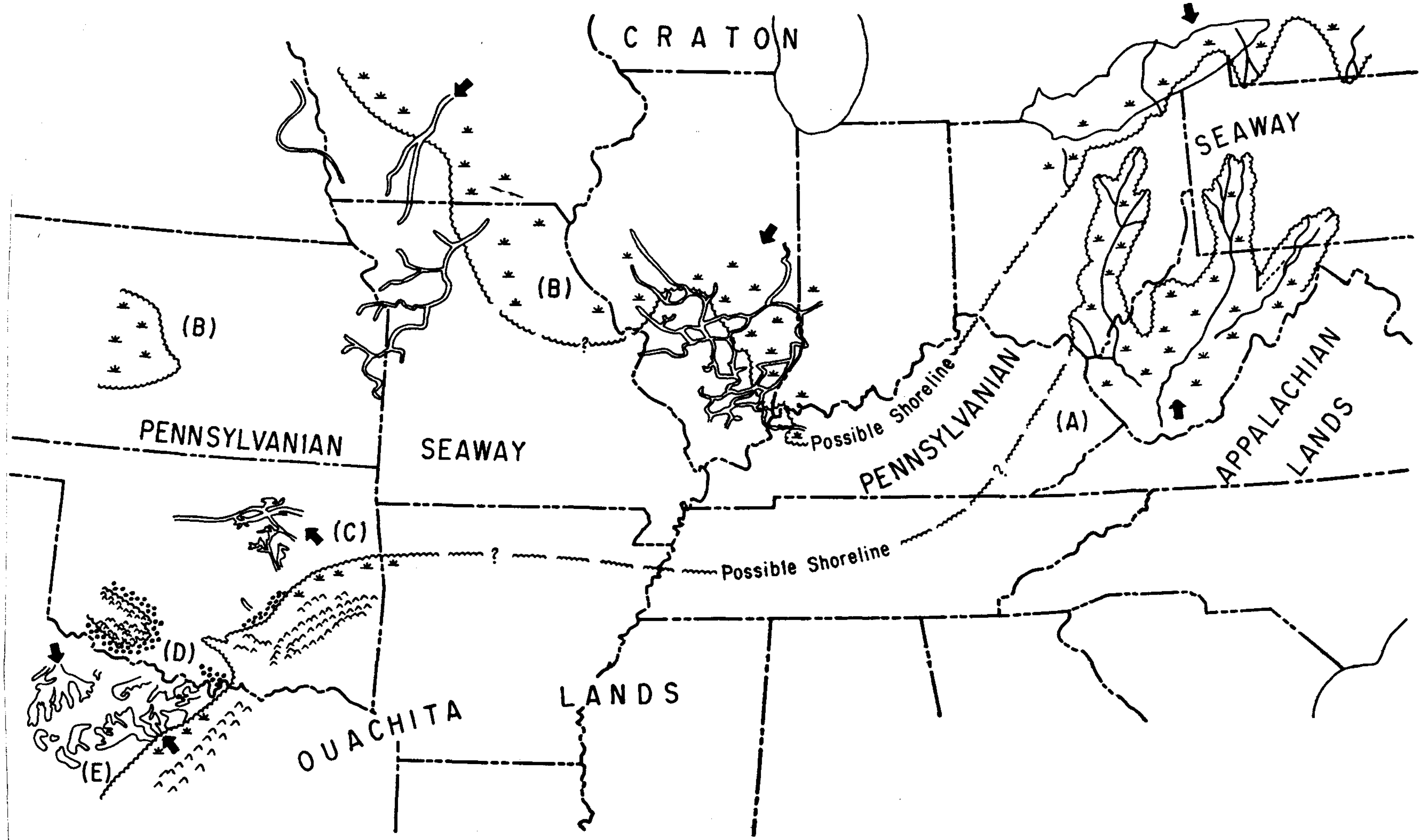


Fig. 25.--Paleogeography during Early Missourian. From Krumme (1975).

of the shelf formed during transgressions which were responsible in large part for the cyclothemic-type of variations in depositional environments. Typically these limestones pinch-out southward. In eastern Oklahoma that feature reflected changes to deeper water and/or coastal-nonmarine conditions which existed near the Ouachita system, the dominant source area. During deposition of some of the Missourian, the southern part of the Anadarko basin subsided more rapidly than the area to the east, where deltaic sandstones such as the Cleveland (Holdenville) (Figs. 26, 27) and the Layton (Coffeyville) formed. In these types of deltaic complexes, channel sands are the dominant sand type. Some of the deltas advanced westward, northwestward, or southwestward to the eastern shelf edge, and some sand units were deposited basinward of the shelf as slope deposits. Commonly these slope sands near the shelf are significantly thicker than their conventional deltaic counterparts. The slope sandstones, represented by the Marchand of Grady County (the Layton equivalent), are characterized by fan-like distributions. Internally they are fine-grained, with little vertical change in grain size, interbeds of clay, abundant clay fragments, deformed beds, and scattered crossbeds. The repetitious nature of the sedimentary structures suggest that a typical sequence is approximately 10 feet thick.

In the area north of Oklahoma City, where the eastern edge of the Anadarko basin was not sharply defined, two major deltas advanced westward as lobes. The Cottage Grove Sandstone above the Dewey Limestone extends westward almost to the Oklahoma Panhandle, and the younger Tonkawa Sandstone extended westward as a finger-like projection across the northeastern part of the Texas Panhandle (Rascoe, 1962). These units are generally regarded as representing typical deltaic sequences; they also contain slope deposits south of the carbonate shelves (Rascoe, 1976). In eastern Oklahoma the depocenters, or clastic wedges shifted progressively northward with time, in a similar fashion to the retreat of the carbonate shelf (Krumme, 1975).

Widespread euximic conditions occurred sporadically during the Missourian. These types of conditions are represented by the basal shale of the Coffeyville

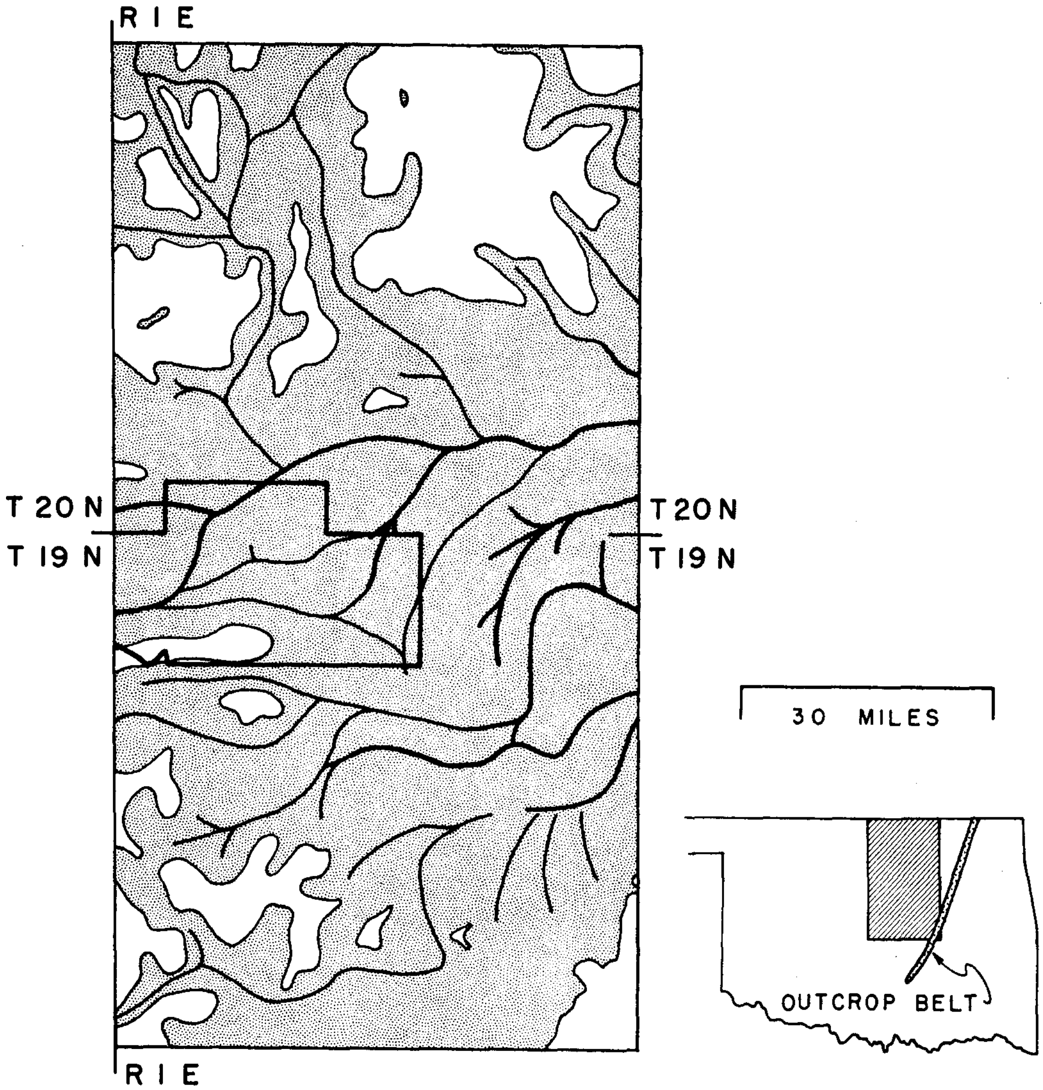


Fig. 26.--Distribution of Cleveland Sandstone. After Cole (1969). Minor trends (20-60 feet thick) shown by light lines. Major trends (more than 60 feet thick) shown by heavy lines. Payne County outlined.

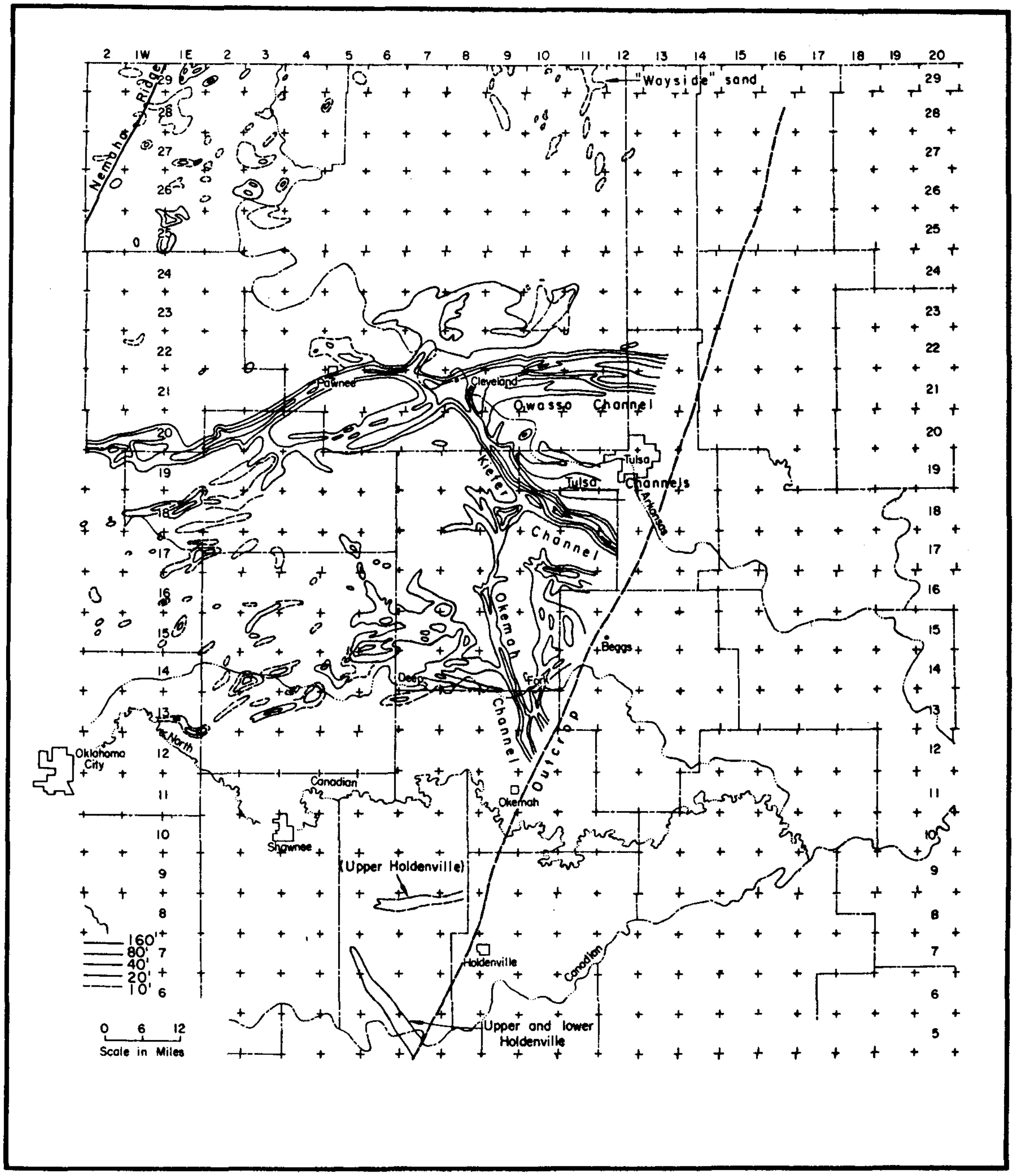


Fig. 27.--Distribution of Cleveland Sandstones and paleophysiography. From Krumme (1975).

Formation above the Checkerboard Limestone and the "Hot Shale" above the Marchand Sandstone and below the Hogshooter Limestone.

Virgilian Epoch

Alluvial fans and/or fan deltas were very widespread in the Virgilian in response to major uplift of the Arbuckle and Ouachita Mountains and continued prominence of the Wichita uplift. The average shoreline during transgressions was oriented northeastward from the eastern end of the Arbuckle uplift which was expressed as a prominent peninsula (Tomlinson and McBee, 1959). During regression the average shoreline was more westerly.

The Wichita uplift with associated aprons of alluvial fans and fan deltas was an island during transgressions, and during regressions the entire shoreline may have lain north of a line connecting the Wichita and Arbuckle uplifts. In the Anadarko basin north of the fanglomerates, marine shale is the dominant type of unit. Deltaic advances, which are similar to the Missourian deltas, are illustrated by the Lovell Sandstone of the Douglas Group and the Elgin Sandstone of the Shawnee Group (Rascoe, 1962).

Elgin Sandstone. On outcrop the Elgin is representative of the sandstones with southern, southeastern, and eastern sources, and the following summary is taken in large part from Terrell (1972).

Stratigraphic Framework. The stratigraphic interval of the Elgin, which is a transgressive-regressive couplet of the Vamoosa Formation, is 100 to 170 feet thick and consists of lenticular sandstone with shale. The upper transgressive marker lies approximately 130 feet below the base of the Lecompton Limestone.

On outcrop 80 to 100 feet of the interval are exposed. The top of the couplet is a well defined unit, characterized by a maroon, marine, fossil-bearing shale.

Geometry. Sandstone on outcrop extends beyond the area studied by Terrell (Plate 5) both to the north and the south. Sandstone is best developed in the southern part, where trends are diverse in orientation. The most significant however, are northerly and northwesterly.

Genetic lenticular units are as much as 20 to 30 feet thick and are less than 600 feet wide. Some coarse-grained lenticular units, developed in the upper part of the interval, are thought from limited data to be 10 times the width of genetic units. Very thin units commonly extend beyond the limits of a single surface exposure.

Major sandstone belts, representing multilateral and multistoried units, contain 100 to 150 feet of sandstone and range in width from one to three miles. The Elgin is less than 20 feet thick in two areas in the northern part of the study area.

The upper boundary of the couplet is generally sharp, both on outcrop and in subsurface (Fig. 28), whereas the lower contact is neither so abrupt nor so well defined. The couplet is characterized at many localities by poorly developed sandstone, with interbedded shale in the lower part and well developed sandstone in the upper part. The boundaries of the latter are sharp, whereas the former type of sandstone shows a gradational base. Genetic units of lenticular sandstones are characterized by sharp upper and lower contacts and abrupt lateral contacts. The laterally persistent sandstone units are characterized by gradational lower and lateral boundaries.

Internal Features. Prominent sedimentary structures in lenticular sandstones are medium-scale crossbedding, high-angle initial dip, cut-outs, and small-scale crossbedding. Thin-bedded sandstones are characterized by small-scale crossbedding, ripple marks, interstratification, parting lineation, and an occasional trace fossil.

Lenticular sandstone bodies are commonly characterized by an overall upward decrease in grain size from fine- to medium-grained to very fine-grained. The thin-bedded sandstones are dominantly very fine- to fine-grained. They are finer grained and are more poorly sorted than the lenticular sandstones. The average Elgin sandstone is very fine-grained and well sorted.

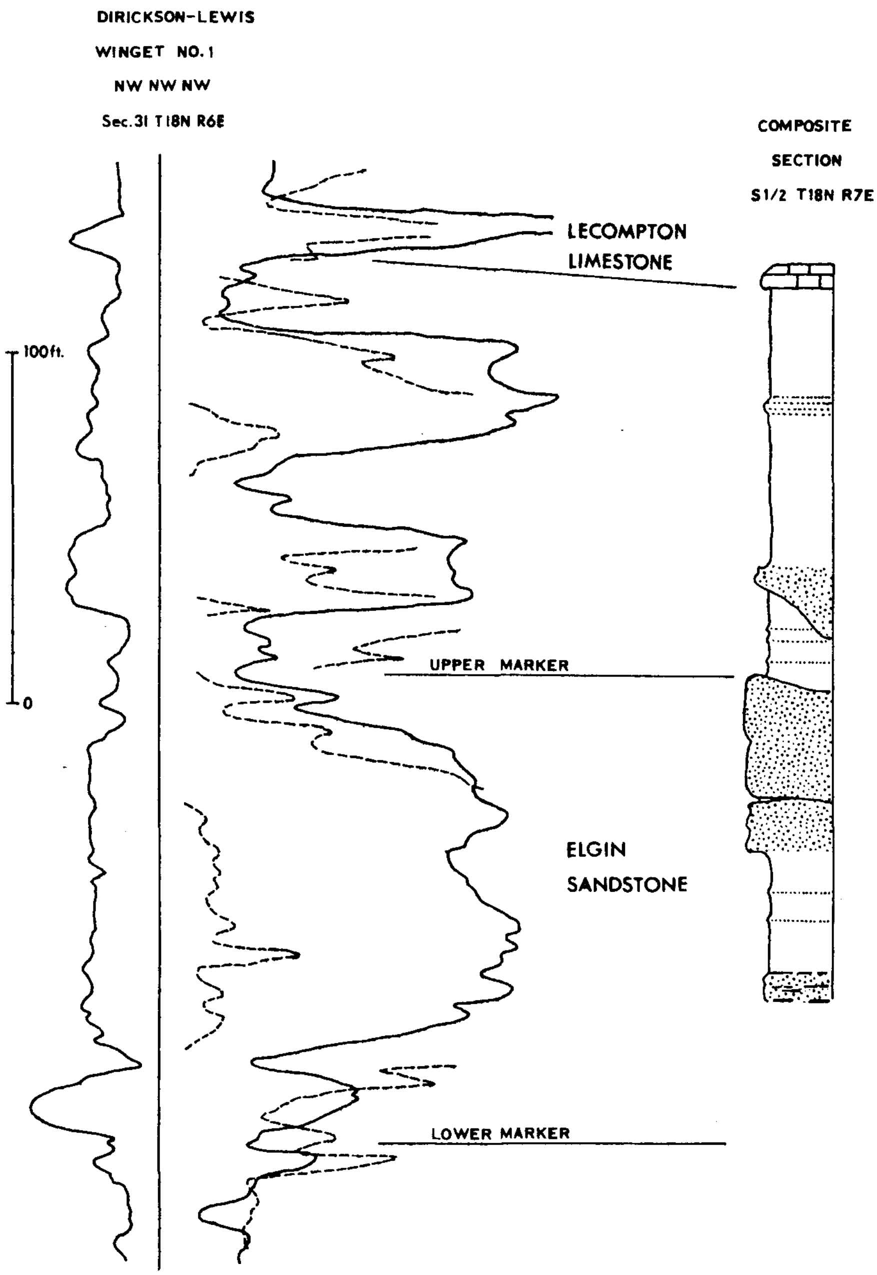


Fig. 28.--Correlation of Elgin Sandstone, outcrop to subsurface. From Terrell (1972).

Prominent constituents of the thin-bedded sandstones are finely divided plant material, small wood fragments, and very fine-grained muscovite on upper bedding surfaces. In the basal part of some lenticular sandstones are locally derived clay pebbles and casts of small logs. In parts of the southern area, where the Elgin is coarse-grained, chert is recognized on outcrop as a significant constituent. Overall the sandstones contain 90.5 percent quartz, quartzite, and chert, three percent feldspar, 4.5 percent rock fragments, and two percent accessories, such as muscovite, tourmaline, and zircon.

Depositional Environment and Paleogeography. Lenticular sandstones, which comprise the bulk of sandstone in the Elgin interval, are multilateral and multistoried deltaic distributary and alluvial channel deposits. The maximum thickness for a genetic distributary unit is 20 feet and 30 feet for an alluvial sandstone. Stream width probably averaged 200 feet for Elgin distributaries and 300 feet for Elgin rivers. The distributary sandstones are commonly represented by fine- to very fine-grained narrow bodies, whereas the alluvial sandstones are coarser grained and more extensively developed laterally. The thin-bedded sandstones are coastal and/or marine delta-fringe units, deposited in front of, or marginal to, the distributaries. Delta-fringe units were eroded in part by the seaward-advancing streams.

Holocene deltas with minor delta-fringe sand deposits and low sand percentages generally reflect high riverine input, whereas high sand percentages and major delta-fringe deposits reflect strong wave and tidal processes (Fisher and others, 1969). Because sandstone percentages are greater than 50 percent in approximately 2/3 of the study area, the Elgin, to a large extent, represents a sand-rich deltaic sequence. However, the riverine input is considered to have been dominant because channel deposits are the major sandstone type.

As a result of a minor marine transgression which advanced southward and southeastward, shallow marine and delta-fringe units associated with the marker below the Elgin Sandstone were deposited. Regressive conditions rapidly returned as the

Elgin delta prograded northward and northwestward. Distributaries advanced over delta-fringe deposits, and during maximum regression an alluvial plain, built on deltaic deposits, formed south of deltaic environments (Fig. 29). Based on paleocurrents, regional distribution of sandstone, and significant chert content, the dominant source areas for the southern part of the area were probably the Ouachita and Arbuckle uplifts. A westward shift in paleocurrents in the northern part of the area suggests sediment contribution from the east, possibly the low-lying Ozark province (Hicks, 1962) or the eastern extension of the Ouachita uplift.

The northern area of shelf carbonates was more extensive in the Anadarko basin area than during the Missourian as the area of basinal marine shale decreased. The carbonate shelf apparently extended into West Texas through an inlet between the Amarillo and Apishapa-Sierra Grande uplifts.

Deltaic sandstones in the Anadarko basin south of the carbonate shelf may include slope deposits, similar to those in the Missourian. Whereas the older Virgilian basinal shales were flanked on the southwest by fanglomerates, the younger basinal shales apparently extended across the Amarillo uplift toward the West Texas basin--and the open sea (Rascoe, 1962).

Although cylcothemic-type variations in depositional environments existed, coal developed less commonly and redbeds formed more commonly. Euxinic conditions were widespread sporatically during the epoch, such as during deposition of the Heebner Shale, which formed after deposition of the upper Douglas sandstones (Endicott Sandstone?) during the early part of the Virgilian. The redbeds represent incipient development of evaporitic cycles which characterize the Permian. The fanglomerates reflect the youngest major movement of uplifts in southern Oklahoma.

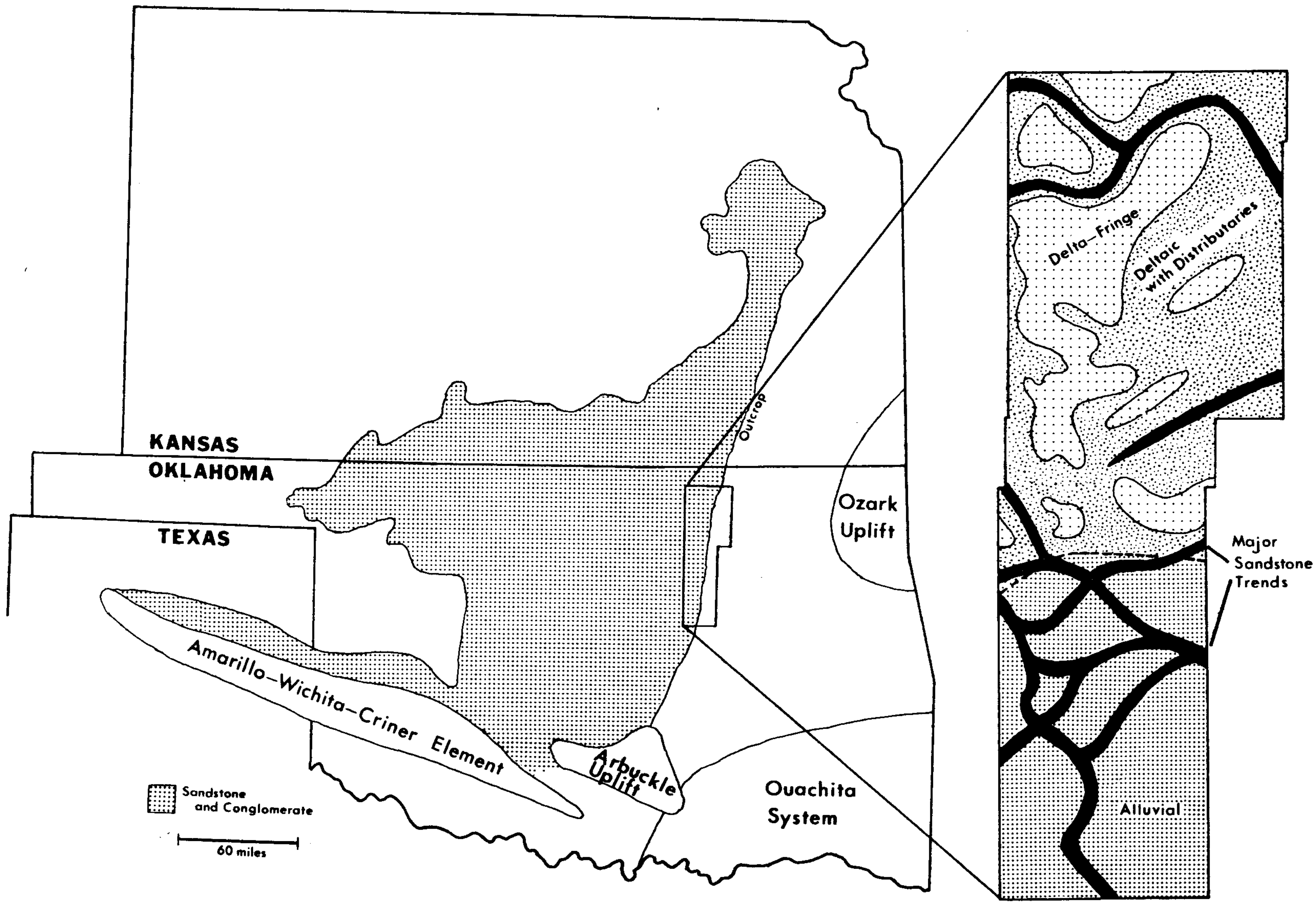


Fig. 29.--Paleogeography during Elgin regression. From Terrell (1972).

Permian

Permian strata in large measure reflect the gradual change from conventional cyclothemic conditions, probably due to eustatic changes in sea level, to desiccation cycles. Gypsum, anhydrite, and salt together with thin dolomites and redbeds not only portray restrictive marine conditions but also arid to semiarid climatic conditions. Uplifts of southern Oklahoma were source areas for clastic wedges which formed in piedmont areas during Early Permian. During that time in those areas flanking the uplifts, variations in environments apparently were less than in areas where typical cyclothems or desiccation cycles developed.

Wolfcampian Epoch

In north-central Oklahoma normal marine conditions prevailed during the rather widespread transgressions up to and including the one represented by the Neva Limestone. Units, with repetitious sequences keyed to thin limestones, are somewhat similar to Pennsylvanian cyclothems. However, in a southward direction there is an increase in dolomite in the carbonates, and the beds are commonly red. It is thought that intertidal conditions existed during deposition of units in the south which are fossiliferous dolomites. The shales and sandstones in the lower part of the Wolfcampian were deposited principally during regressions. Most shale units probably represent prodeltaic conditions. The lenticular sandstones are considered representative of deltaic distributary environments. Thin-bedded sandstones with some lateral persistence may be delta-fringe units, which formed in front of and marginal to distributaries. A tidal flat extended north and northwest of each delta.

The southern limits of successive transgressions shifted northward, and supratidal, nodular carbonates became more common than bedded limestones south of northern Noble County. During Chase transgressions, for example, intertidal and supratidal carbonates formed south of the normal marine waters in the northern part of the county. The higher part of each tidal flat lay to the southeast where carbonate-free sediments were deposited. Paleocurrents suggest an average paleo-slope of N50^{o}W-N70^{o}W.

During each Chase regression the tidal flat became more expansive; tidal creeks and an occasional small stream crossed the expansive mudflat. Tidal-creek deposits are considered to be those with undulatory bases, initial dip, and small-scale crossbedding which shows much local variation in paleocurrent direction. A locally thick sandstone with medium-scale crossbedding showing rather consistent paleocurrent direction is regarded as a distributary deposit.

In the Anadarko and Hollis basins, where Wolfcampian rocks consist of lime-stone, mudstone, and some dolomite, deposition was in a marine environment. Eastward, on the Oklahoma shelf, the mainly fine detrital material was probably deposited along or near the margin of a fluctuating sea (MacLachlan, 1967).

The Anadarko basin became shallow northward toward the Kansas embayment. Westward-to northwestward-flowing streams carried detrital materials from the Ouachita System together with the Arbuckle and Wichita uplifts into a depositional area which extended from Kansas through western Oklahoma and Texas into eastern New Mexico. The Wichita positive element acted as a barrier between the Anadarko and Hollis basins, apparently as an archipelago that furnished clastics to adjoining areas. The coarse sediments were deposited as alluvial fans on the flanks of the uplift (Fig. 30).

Sandstone lenses in southern Oklahoma, especially in western Jefferson County, were deposited by westward flowing streams from the Ouachita uplift or Arbuckle system (Flood, 1969). Pebbles of Colbert Rhyolite Porphyry and Tishomingo Granite were derived from the Arbuckle Mountains. The siltstones and shales which surround these lenses represent the finer grained materials which were deposited on flood plains or basins.

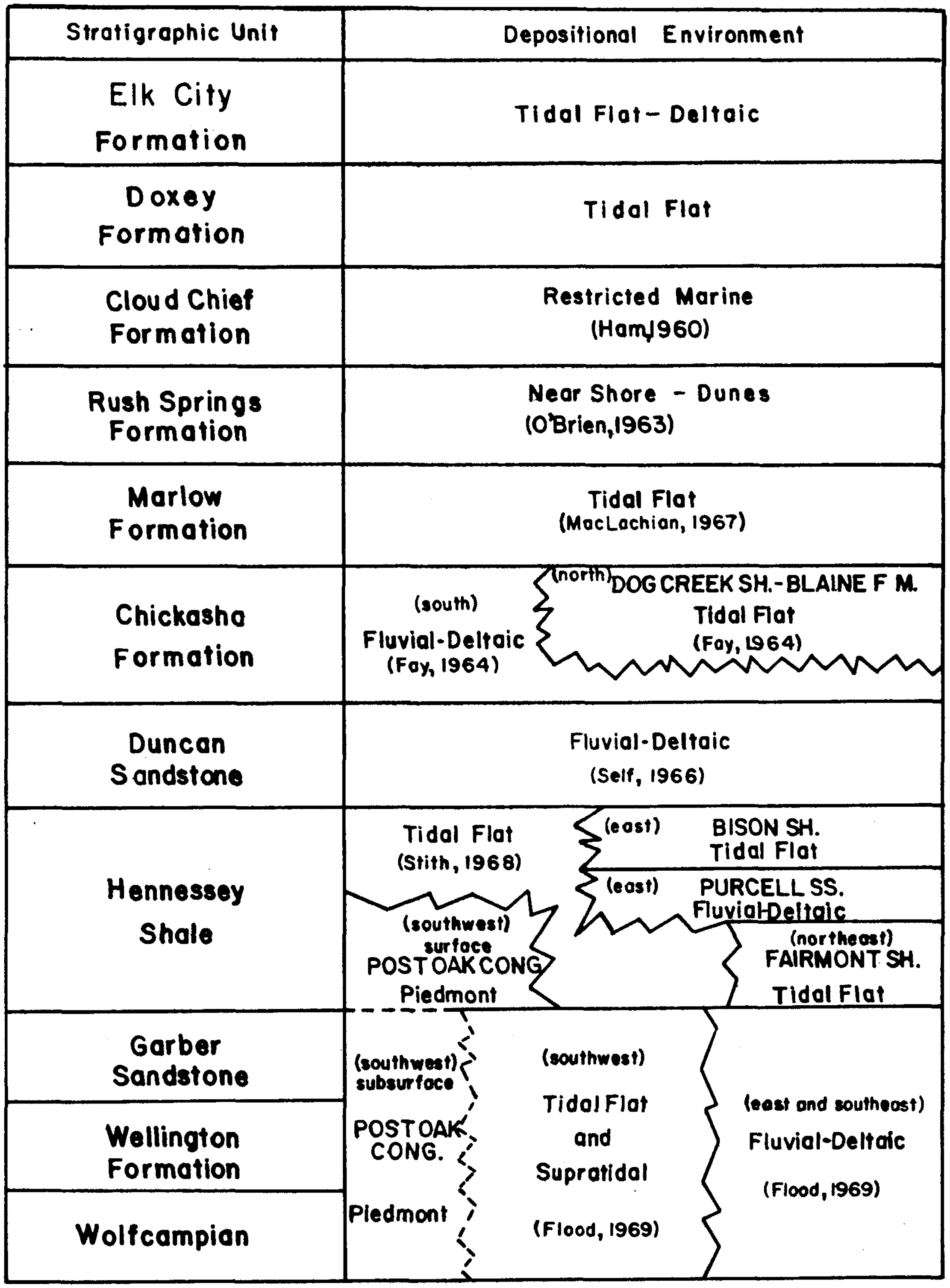


Fig. 30.--Depositional environments of Permian stratigraphic units, western and southwestern Oklahoma.

Leonardian Epoch

The average depositional environment on outcrop in north-central Oklahoma during deposition of the Wellington Formation was deltaic in the south and tidal flat in the north. The Wellington characteristically does not contain any marine limestone. Nevertheless, cyclic conditions existed, as Raasch (1946), Tasch (1964), and Olson (1967) have noted.

Lenticular sandstones are thought to represent regressive deposits in distributary and tidal channels. Sandstones with gradational bases and horizontal interbeds are believed to represent delta fringe. Mudrock is thought to have been deposited in interdistributary bays and on tidal flats. During maximum regression mud may have been deposited in flood basins. Tidal-flat conditions are suggested by thin nodular dolomites. Each dolomite is thought to represent an authigenic/diagenetic unit which formed under supratidal conditions during a minor transgression. Seasonal and storm tides supplied water for deposition, and evaporation was responsible for production of dolomitizing water. The specific conditions may have been similar to those described by Lucia (1972, p. 162-163), Cook (1973, p. 1000-1001), and/or Walter and others (1973, p. 1025-1026). On a typical tidal flat were creeks, an occasional larger channel, and lakes and ponds. Although widely spaced streams crossed the tidal flat, major delta-building did not extend as far north as Noble County. Thin sandstones with oppositely directed crossbeds, steep initial dip, and locally varying paleocurrents are regarded as tidal-creek deposits. Thicker sandstone bodies with opposing crossbeds are thought to be tidal channel sediments, and those with more consistent paleocurrent indicators are apparently distributary deposits. With the expansion of a flat, beds of the higher tidal flat, which formed under more nearly terrestrial conditions, overlie lower tidal flat deposits. Within the Wellington, the change of dominant (or average) depositional environment was from lower tidal flat during deposition of the lower part of the formation to upper tidal flat during deposition of the upper part.

The northwesterly trend of paleocurrents suggests a northeasterly depositional strike. The eastern edge of anhydrite beds in the lower part of the Wellington Formation, while it may reflect some secondary leaching, points to a depositional strike of north-northeast. Paleocurrent data support the interpretation that the Ouachita Mountains were the prominent source area.

The general climate during formation of the Wellington redbeds with nodular dolomite was arid (Walker, 1967) or possible semiarid (McBride, 1974). The repetitious nature of redbeds, dolomites, and anhydrite (in the shallow subsurface) are indicative of desiccation cycles or periods (Tasch, 1964).

In Noble, Garfield, Kay, and Grant counties average depositional conditions for the Garber Sandstone were similar to those of the upper part of the Wellington. Deltaic and alluvial features are common in equivalent beds to the south in Logan County.

The average shoreline trend is thought to have been northeasterly during deposition of the Garber. Paleocurrents from sandstone bodies suggest a prevailing northwesterly depositional slope.

During deposition of the Sumner Group north-central Oklahoma was part of a much larger area which was repetitiously connected to the open Permian sea some distance to the southwest. During those times the area was a very shallow, restricted sea which experienced regression by desiccation and gradual extension of the tidal flat. Undoubtedly local lacustrine environments existed repeatedly on the mudflat, as Raasch (1946), Tasch (1965), and Carlson (1968) have indicated. The paleocurrent data, along with the facies changes, point to the Ouachita system as the predominant source area.

Widespread thick anhydrite deposits and associated redbeds of the Wellington Formation in the Anadarko basin indicate the change there from normal marine deposition during Wolfcampian to restricted evaporitic conditions. Circulation of water within the Anadarko and Hollis basins apparently not only became more restricted but the water depths became shallower (MacLachlan, 1967).

Flood (1969) concluded that by the beginning of Wellington time detritals deposited in western Jefferson County were derived primarily from the Ouachita Mountains in northern Texas and southern Oklahoma. The Wichita Mountains did furnish detrital material to the adjoining areas, as evidenced by the Post Oak Conglomerate. According to Ham and others (1957) the Wichitas were at least partly exposed during deposition of most of the Hennessey Shale. The Hennessey Shale probably formed as a nearshore deposit (MacLachlan, 1967). Tongues of coarse conglomerate in equivalent strata, which are composed of granite pebbles derived from the Wichita Mountains, formed as alluvial fans (Fig. 30).

The Duncan Sandstone and the overlying Chickasha Formation formed in a deltaic environment (Tussy delta) at the mouths of westward- and northwestward-flowing streams, which drained source areas to the southeast and east (Fig. 30) (Fay, 1965; MacLachlan, 1967). The Duncan Sandstone may have extended over the Wichita Mountains (Ham and others, 1957). Basinward equivalents (Duncan Sandstone, Flowerpot Shale, Blaine Gypsum, and Dog Creek Shale) with evaporites, evaporitic mudstone, and small amounts of dolomite, apparently were deposited on a tidal flat (Fig. 30) or in a shallow, restricted marine environment (MacLachlan, 1967).

The Blaine Gypsum includes thin dolomite beds, which contain pelecypods, brachiopods, and gastropods. The Blaine was probably deposited in shallow water, which experienced significant variations in salinity.

Gaudalupian-Ochoan Epoch

During deposition of the Guadalupian-Ochian, Oklahoma was probably part of a vast mudflat-tidal flat containing local evaporite basins and intersected by channels. The Arbuckle Mountains and Ouachita Mountains to the southeast apparently provided most of the clastics, although some were probably derived from as far away as Colorado.

MacLachlan (1967) regards the Marlow Formation as tidal-flat deposits, whereas Fay (1964) considers the siltstones and sandstones of the Marlow to have been deposited in a shallow-water, brackish-marine environment which formed after transgression of the Tussy delta. The Verden Sandstone probably represents a distributary channel which formed on the tidal flat (Shelton and Mack, 1970).

The Rush Springs Sandstone has been considered as coastal dune deposits by MacLachan (1967). However, the lower part contains horizontal bedding and bioturbation, which suggest accumulation in a marine environment. The Rush Springs may have formed as a coastal deposit, where dunes are associated with marine-strandline deposits (O'Brien, 1963; Ham and others, 1957). The silt and clay in the Rush Springs may have been deposited in shallow lakes and ponds formed during regression of the sea. Deposition of the Cloud Chief took place in a semi-enclosed arm of a sea which had periodic influxes of sulphate-rich waters (Ham, 1960) during minor transgressions. The restricted environment extended across a wider area than did those during deposition of thin-bedded, localized gypsum beds (MacLachlan, 1967). Mudstones and siltstones of the upper Cloud Chief and Doxey Formations were deposited in tidal-flat environments (Fig. 30), similar to those represented by the Marlow.

A final regression resulted in the deposition of a blanket of very fine, crossbedded sand in the Elk City Formation. It formed in tidal flat-deltaic areas.

PETROLOGY AND PETROGRAPHY

Sandstones and Conglomerates

Pennsylvanian

The Jackfork Formation in the Ouachita Mountains ranges rather widely in composition (Bokman, 1953; Goldstein, 1961; Klein, 1966), but feldspar generally composes less than 10 percent of the sandstones. Rock types present include subarkose, protoquartzite (sublitharenite), subgraywacke (quartzarenite), and orthoquartzite (quartzarenite) (Table 1). Sandstones in the underlying Stanley generally contain more feldspar than the Jackfork. The Johns Valley Shale contains sandstones which Weaver (1958) classifies as protoquartzites and which have essentially no feldspar. The Morrowan (Springer-Morrow) sandstones of southern Oklahoma are low in feldspar content (Table 1; Lucas, 1934; Hill, 1955; Weaver, 1958; and Jacobsen, 1959). The Morrowan of the Anadarko basin is generally characterized by the absence of an arkosic clastic facies (Rascoe, 1962). However, Morrowan in the Oklahoma Panhandle contains granite wash (Forgotson and others, 1966). Morrowan conglomerates north of the Criner Hills are composed of clastics of Paleozoic sedimentary strata exposed in the Criner uplift (Tomlinson and McBee, 1959).

The Atokan Bostwick Conglomerate in the Ardmore basin contains sandstones which vary in feldspar content from three to 13 percent (Lucas, 1934; Jacobsen, 1959). They range from quartzarenites and litharenites to subarkoses (Table 1). The Atokan units in southern Oklahoma which were studied by Weaver (1958) are low-rank graywackes to quartzose graywackes (sublitharenites), with feldspar being an accessory. Two sandstones in the Arkoma basin studied by Lumsden and others (1971) are quartzarenites. Granite wash is present along the flanks of the Wichita uplift (Fig. 31).

TABLE 1.--COMPOSITION OF PENNSYLVANIAN SANDSTONES

Stratigraphic Unit	Number of Samples	Location	Classification	Feldspar %	Reference
VIRGILIAN					
Vanoss	1	Murray-Pontotoc Co.	Arkosic Congl.	32	Thomas (1973)
	7		Sublitharenite	0-9	
	13		Feldspathic Lith.	11-28	
	29		Lithic Arkose	25-40	
	6		Lithic Subarkose	14-24	
	11		Litharenite	0-9	
	3		Quartzarenite	2-4	
	2		Arkose	27-32	
	11		Subarkose	5-19	
	3	Pontotoc Co.	Arkose	25-35	Spencer (1930)
	1		Subarkose	24	
	32	Seminole Co.	Subarkose	6-23	Thomas (1973)
	5		Lithic Subarkose	10-23	
	5		Quartzarenite	0-5	
Ada	3	Pontotoc Co.	Subarkose	12-14	Spencer (1930)
	12	Seminole-Pontotoc Co.	Quartzarenite	0-1	Iranpanah (1966)
	9		Sublitharenite	0-3	
	4		Litharenite	0	
Vamoosa	1	Creek Co.	Subarkose	5	Morganelli (1976)
	7	Pawnee-Osage-Creek Co.	Quartzarenite	1-3	
	1	Creek Co.	Subarkose	5	
Elgin	2	Creek Co.	Quartzarenite	1	Terrell (1972)
	1		Subarkose	6	
	1		Sublitharenite	4	
Collings Ranch	-	Arbuckle Uplift	Litharenite	0	Ham (1954)
U. Granite Wash	-	Washita Co.	Arkose	> 25	Gelphman (1960)
M. Granite Wash	-	Washita Co.	Feldspathic Lith.	> 10	Gelphman (1960)

TABLE 1 CONTINUED

Stratigraphic Unit	Number of Samples	Location	Classification	Feldspar %	Reference
L. Granite Wash	-	Washita Co.	Lithic Subarkose	> 10	Gelphman (1960)
MISSOURIAN					
U. Granite Wash	-	Washita Co.	Lithic Arkose	> 25	Gelphman (1960)
L. Granite Wash	-	Washita Co.	Lithic Arkose	> 25	Gelphman (1960)
Granite Wash	-	Washita Co.	Feldspathic Lith.	10	Edwards (1959)
	-	Kiowa-Washita-Beckham Co.	Arkose	65	
	-	Beckham-Roger Mills Counties	Lithic Arkose	80	
Hoxbar					
Zuckerman	1	Ardmore Basin	Litharenite	-	Jacobsen (1959)
Crinerville	3		Subarkose	9-11	Lucas (1934)
Basal	2		Sublitharenite	.8	Jacobsen (1959)
Francis	5	Pontotoc-Hughes Co.	Subarkose	8-15	Spencer (1930)
Seminole	4	Pontotoc-Hughes Co.	Subarkose	-	Spencer (1930)
DESMOINESIAN					
Granite Wash	1	Beckham-Washita Co.	Lithic Arkose	> 25	Edwards (1959)
U. Granite Wash	1	Washita Co.	Feldspathic Lith.	> 40	Gelphman (1960)
L. Granite Wash	1	Washita Co.	Arkose	> 40	Gelphman (1960)
Wetumka	3	Pontotoc-Hughes Co.	Subarkose	11-13	Spencer (1930)
Wewoka	8	Pontotoc-Hughes Co.	Subarkose	6-15	Spencer (1930)

TABLE 1 CONTINUED

Stratigraphic Unit	Number of Samples	Location	Classification	Feldspar %	Reference
Calvin	51	Hughes Co	Quartzarenite-Subarkose	1-20	McDade (1953)
	-	Pontotoc-Okmulgee Counties	Quartzarenite	.2-4.9	Greene (1965)
	8	Hughes Co.	Subarkose	8-20	Spencer (1930)
Prue	-	NE Oklahoma	Quartzarenite	Trace	Ware (1955)
Senora	-	NE Oklahoma	Quartzarenite	Trace	Ware (1955)
L. Skinner	-	Central Oklahoma	Sublitharenite	Trace	Valderrama (1974)
Red Fork	-	Woods Co.	Quartzarenite	None	Thalman (1967)
Bluejacket	12	Pittsburg Co.	Quartzarenite	None	Vanderpool (1960)
Bartlesville	-	Osage Co.	Sublitharenite	.5-2.0	Leatherock (1937)
Tamaha	-	Arkoma basin	Quartzatenite	Trace	Karvelot (1972)
Lequire	-	Arkoma basin	Quartzarenite	≤ 5	Karvelot (1972)
Cameron	-	Arkoma basin	Quartzarenite	< 5	Karvelot (1972)
U. Warner	-	Arkoma basin	Sublitharenite	< 5	Karvelot (1972)
L. Warner	-	Arkoma basin	Quartzarenite	< 5	Karvelot (1972)
Hartshorne	-	SE Oklahoma	Quartzarenite	Trace	Roach (1955)
U. Deese	5	Ardmore basin	Subarkose	5-15	Lucas (1934)
	1		Quartzarenite	4	
	1		Sublitharenite	3	Jacobsen (1959)
Natsy	1		Quartzarenite	1	
M. Deese	-		Sublitharenite	1-4	
	-		Quartzarenite	2	
	1		Litharenite	2	

TABLE 1 CONTINUED

Stratigraphic Unit	Number of Samples	Location	Classification	Feldspar %	Reference
L. Deese	1	Ardmore basin	Sublitharenite	1	Jacobsen (1959)
Arnold	2		Quartzarenite	4	Lucas (1934)
	-		Subarkose	6-10	
Fusulinid	1		Sublitharenite	4.2	Jacobsen (1959)
L. Deese	1		Sublitharenite	2.4	
Devils Kitchen	3		Quartzarenite	2-5	Lucas (1934)
	10		Subarkose	5-10	
	-		Sublitharenite	3-7	
Big Branch	3		Quartzarenite	2.2	Jacobsen (1959)
ATOKAN					
Bostwick	2	Ardmore basin	Quartzarenite	0-3	Jacobsen (1959)
	4		Quartzarenite	2-3	Lucas (1934)
	2		Litharenite	4-5	
	9		Subarkose	13	
Atokan	-	So. Oklahoma	Sublitharenite	Trace	Weaver (1958)
Spiro	-	Arkoma basin	Quartzarenite	Trace	Lumsden and others, (1971)
Foster	-		Quartzarenite	Trace	
MORROWAN					
Primrose	36	Ardmore basin	Quartzarenite	0-3	Lucas (1934)
Springer	-	So. Oklahoma	Quartzarenite-Sublitharenite	1	Weaver (1958)
Lake Ardmore	25	Ardmore basin	Quartzarenite	0-.3	Lucas (1934)
Overbrook	62		Quartzarenite	0-3	
	1	Arbuckle uplift-Ardmore basin	Quartzarenite	.4	Hill (1955)
	1	Ardmore basin	Quartzarenite	.2	Jacobsen (1959)
Humphreys	5		Quartzarenite	.4	
Rod Club	28		Quartzarenite	0-2	Lucas (1934)
	-		Quartzarenite	.2	Jacobsen (1959)

TABLE 1 CONTINUED

Stratigraphic Unit	Number of Samples	Location	Classification	Feldspar %	Reference
Sims	-	Ardmore basin	Sublitharenite-Quartzarenite	.6-1.4	Jacobsen (1959)
Goodwin	-		Quartzarenite	.4	
Johns Valley	-	Ouachita	Sublitharenite	Trace	Weaver (1958)
Jackfork	-	Ouachita	Quartzarenite	0-2	Bokman (1953)
	-		Sublitharenite	0-2	Weaver (1958)
	-		Quartzarenite	1-4	Klein (1966)
	-		Subarkose	5-20	

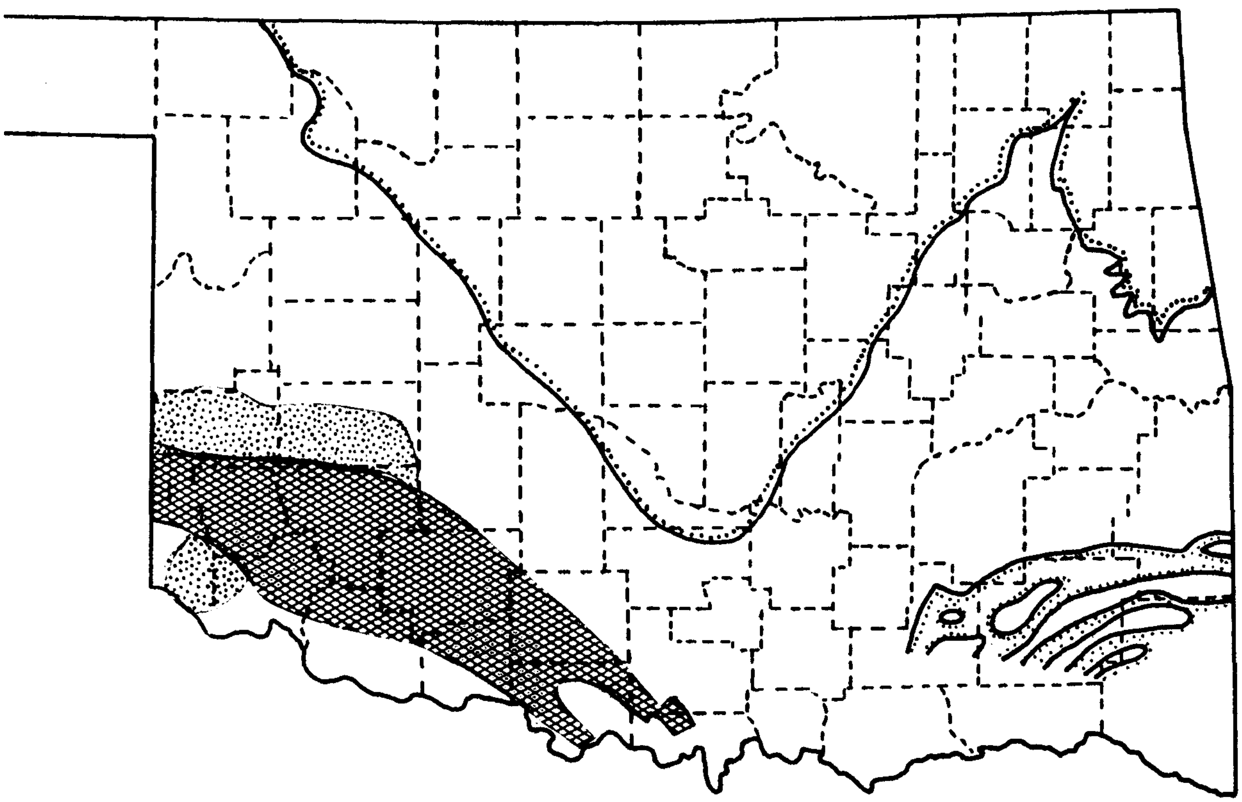


Fig. 31.--Distribution of arkose, Morrowan-Atokan Series.

Lower Desmoinesian sandstones in eastern Oklahoma, such as the Warner and Bluejacket, generally contain little feldspar (Table 1). However, the Calvin in Hughes County contains as much as 30 percent feldspar, and the Wewoka and Wetumka contain units which have 10 to 15 percent feldspar (Table 1; Spencer, 1930, McDade, 1953). The Deese in southern Oklahoma contains one to 15 percent feldspar (Table 1; Lucas, 1934; Jacobsen, 1959). Feldspar in most Deese units constitutes less than 10 percent of the grains. The Big Branch Sandstone of the Ardmore basin is quartzarenite, with less than three percent feldspar (Table 1, Jacobsen, 1959). The Redfork Sandstone is a quartzarenite in Woods County in northwestern Oklahoma, with essentially no feldspar (Thalman, 1967). Granite wash is well documented on the north flank of the Wichita uplift, and it probably is also present in the northern part of the Hollis basin (Fig. 32).

The Missourian sandstones-conglomerates are characterized by granite wash on the north flank of the Wichita uplift and probably also on the south flank (Table 1; Fig. 32). The Hoxbar in the Ardmore basin ranges from subarkose, with approximately 10 percent feldspar, to sublitharenite and litharenite, which contain less than one percent feldspar (Lucas, 1934; Jacobsen, 1959). In south-central Oklahoma, north-northeast of the Arbuckle uplift, the Francis and Seminole Formations are subarkoses; they contain eight to 15 percent feldspar.

Virgilian sandstones and conglomerates below the Vanoss Group in the area north of the Arbuckle uplift contain relatively little feldspar. For example, the Vamoosa in Creek County is largely quartzarenite. The Ada Formation in Seminole and Pontotoc Counties contains a variety of rock types, but feldspar is commonly less than three percent (Iranpanah, 1966). Subarkoses, with 12-14 percent feldspar, are present in T4N, R5E (Spencer, 1930). The Vanoss contains abundant feldspar north of the Arbuckle uplift (Table 1; Figs. 33, 34; Thomas, 1973); arkoses characterize Pontotoc County, and subarkoses characterize Seminole County. Granite wash (or arkose) is representative of much of the section on the north flank of the Wichita uplift and a significant part of the south flank (Fig. 34).

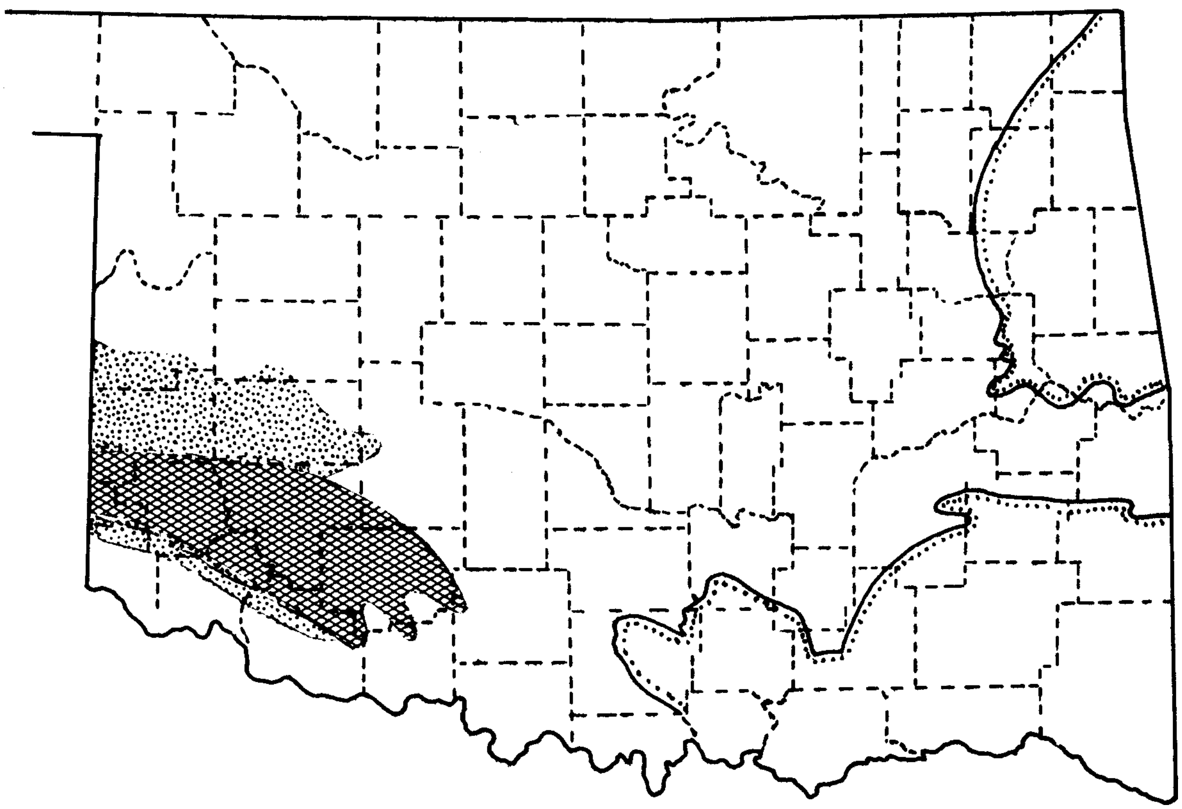


Fig. 32.--Distribution of arkose, Desmoinesian-Missourian.

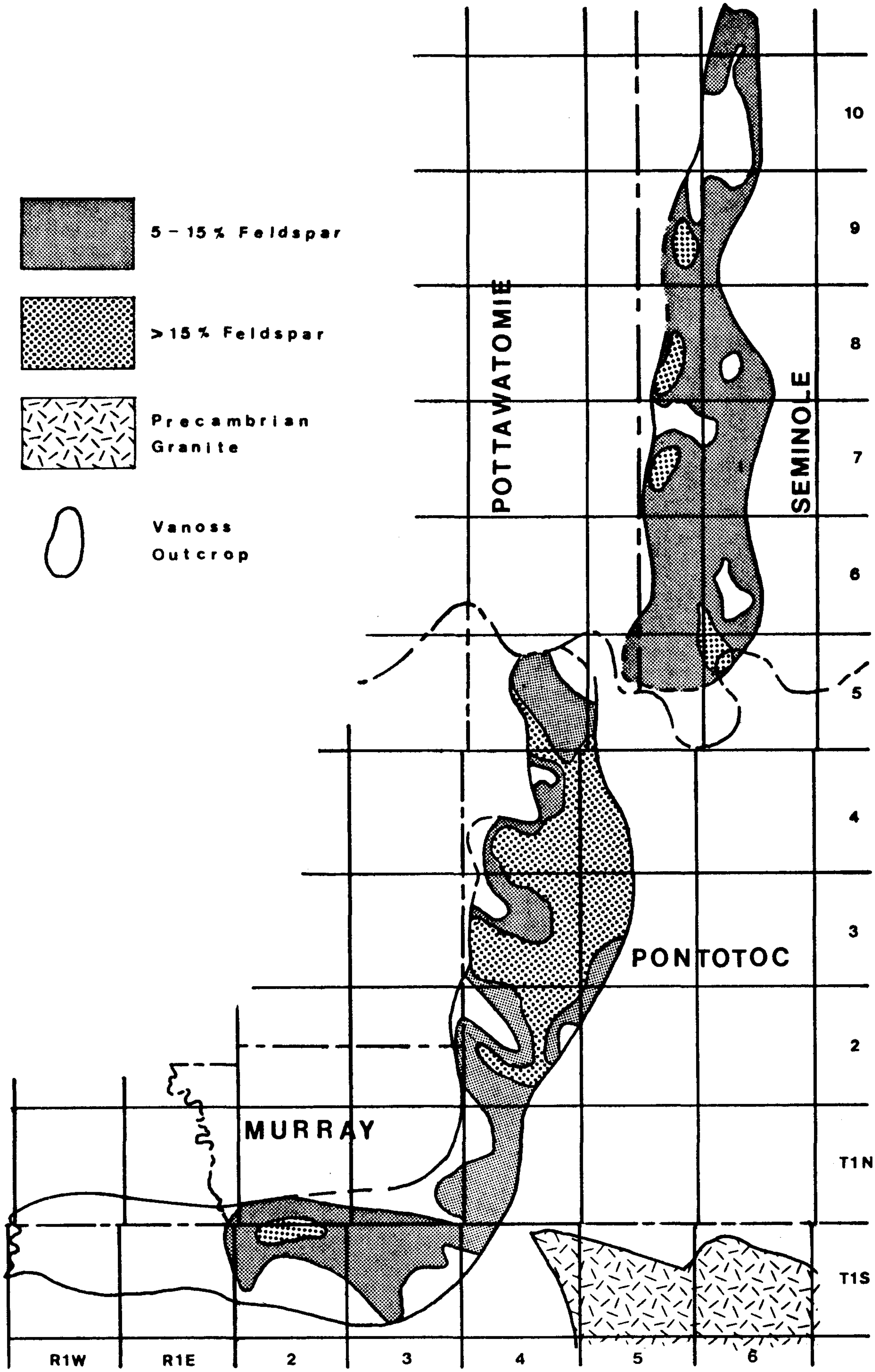


Fig. 33.--Feldspar in Vanoss Formation, south-central Oklahoma. After Thomas (1973).

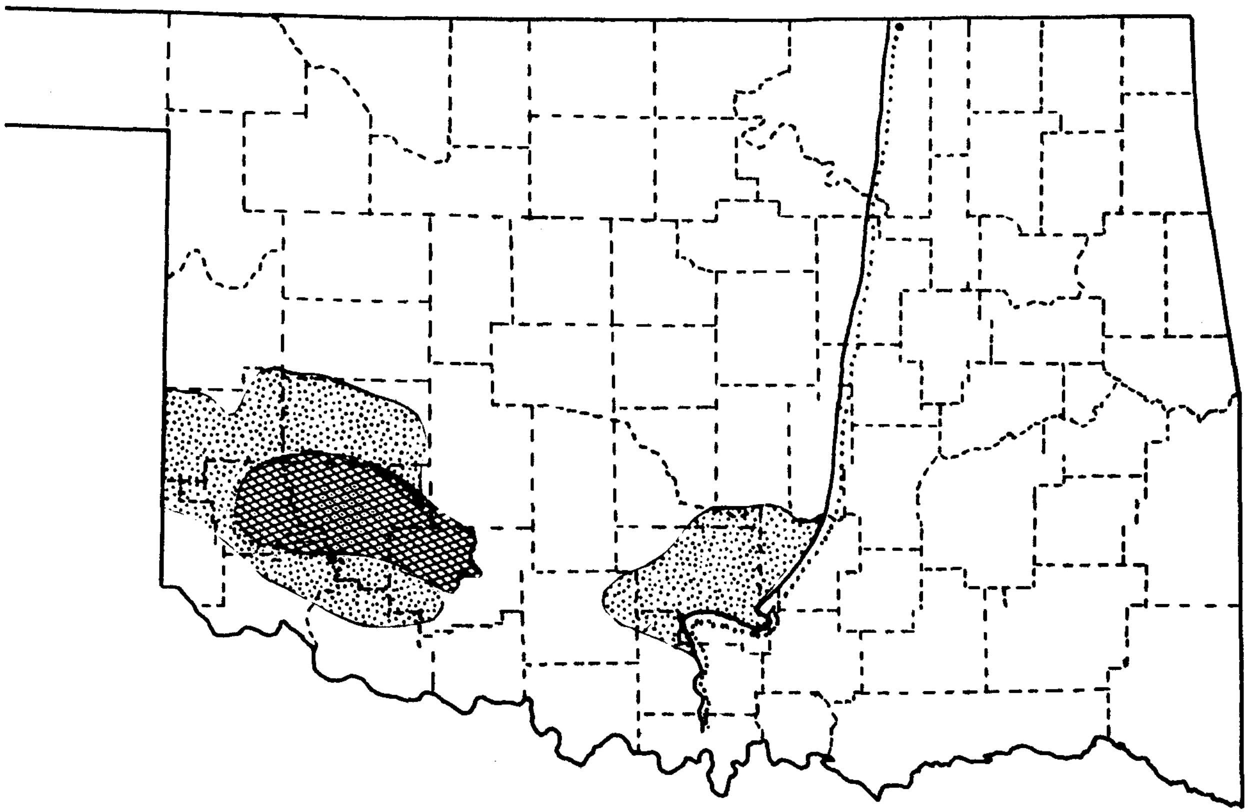


Fig. 34.--Distribution of arkose, Virgilian Series.

Pennsylvanian beds in Oklahoma, exclusive of the Panhandle, reflect five major sources. The craton supplied much of the feldspar-poor units of northern Oklahoma. The areas to the east and south of the Ouachitas supplied considerable clastics to the Ouachita geosyncline, and the Ouachita facies are not particulary feldspar-rich. The Ouachita uplift itself became a major source in the Desmoinesian, and some of the subarkoses in the Ardmore and Arkoma basins may have been derived from it. The Arbuckle uplift supplied feldspar present in the Vanoss Group north of the uplift. The Wichita uplift was the source of feldspar from the Atokan on into the Permian.

Permian

Wolfcampian units in north-central Oklahoma, apparently with approximately five percent of feldspar, are quartz-rich subarkoses and quartzarenites (Table 2). In central Oklahoma, stratigraphic equivalents contain eight to 18 percent feldspar (Table 2; Spencer, 1930). Arkose is a common rock type in southern Oklahoma north of the Arbuckle uplift and around the Wichita Mountains (Fig. 35; MacLachlan, 1967).

Arkoses in Leonardian strata are not so widely distributed as in Wolfcampian units. The Wellington is generally a quartz-rich subarkose in north-central Oklahoma, but one unit in Payne County is an arkose (Table 2). Another occurrence of arkose is in central Oklahoma (Fig. 36), where the Wellington is generally subarkosic, with 15-23 percent (Table 2; Spencer, 1930). In that area the Garber and Hennessey are also subarkoses. Both are arkosic in areas around the Wichita Mountains. The Hennessey locally contains quartzarenites in western and central Oklahoma. The Post Oak Conglomerate, partially equivalent to the Hennessey, is characterized to a large extent by granite wash. An area northeast of the Wichita Mountains, which is relatively free of arkoses (and granite washes), contains carbonate conglomerates. In south-central Oklahoma the Duncan Sandstone ranges widely in composition, with quartzarenites, arkoses, sublitharenites, and feldspathic

TABLE 2.--COMPOSITION OF PERMIAN SANDSTONES

Stratigraphic Unit	Number of Samples	Location	Classification	Feldspar %	Reference
GUADALUPIAN-OCHOAN					
Quartermaster	5	Washita Co.	Subarkose	10-24	Spencer (1930)
Rush Springs	-	Caddo Co.	Subarkose	10-15	Olmsted (1975)
Rush Springs-Marlow	11	Grady-Caddo Co.	Arkose	25-37	Spencer (1930)
	24		Subarkose	13-24	
Marlow	6	Woods Co.	Subarkose	6-11	Fay (1965)
LEONARDIAN					
Dog Creek	12	Woods Co.	Subarkose	8-23	Fay (1965)
Flowerpot	9	Woods Co.	Subarkose	5-10	Fay (1965)
Duncan	30	Grady-Stephens-Garvin-McLain Co.	Quartzarenite	2-4	Self (1966)
	-	Garvin Co.	Arkose	-	Brown (1937)
	-	Grady Co.	Arkosic Congl.	-	Green (1936)
	1	Stephens Co.	Sublitharenite	4	Self (1966)
	1		Felspathic Lith.	10	Self (1966)
	11	Cleveland-McClain Co.	Subarkose	10-20	Spencer (1930)
	1	Grady Co.	Arkose	29	Spencer (1930)
Hennessey	-	Kiowa-Greer Co.	Arkose	-	Merritt (1958)
	-		Quartzarenite	1-4	Stith (1968)
	-	McClain Co.	Quartzarenite	-	Self (1966)
	4	Cleveland Co.	Subarkose	12-14	Spencer (1930)
	-	Kiowa Co.	Arkosic Congl.	-	Merritt (1958)
	-		Granite Congl.	-	
Post Oak Congl.	-	Comanche Co.	Arkose	-	Olmsted (1975)

TABLE 2 CONTINUED

Stratigraphic Unit	Number of Samples	Location	Classification	Feldspar %	Reference
Garber	6	Cleveland-Garvin Co.	Subarkose	11-21	Spencer (1930)
	9	Cleveland - Pottawatomie Co.	Quartzarenite	1-5	Baker (1965)
Wellington	16	Noble Co.	Subarkose	5-9	Shelton (1976)
	1	Payne Co.	Subarkose	5	Garden (1973)
	1		Arkose	25	
	5	Garvin-Cleveland-Pottawatomie Co.	Subarkose	15-23	Spencer (1930)
WOLFCAMPIAN					
Council Grove	1	Lincoln Co.	Quartzarenite	-	Morgan (1958)
	1		Subarkose	5	Ross (1972)
Council Grove-Chase	4	Pottawatomie Co.	Subarkose	8-18	Spencer (1930)
Chase	3	Payne Co.	Quartzarenite	3-5	Ross (1972)

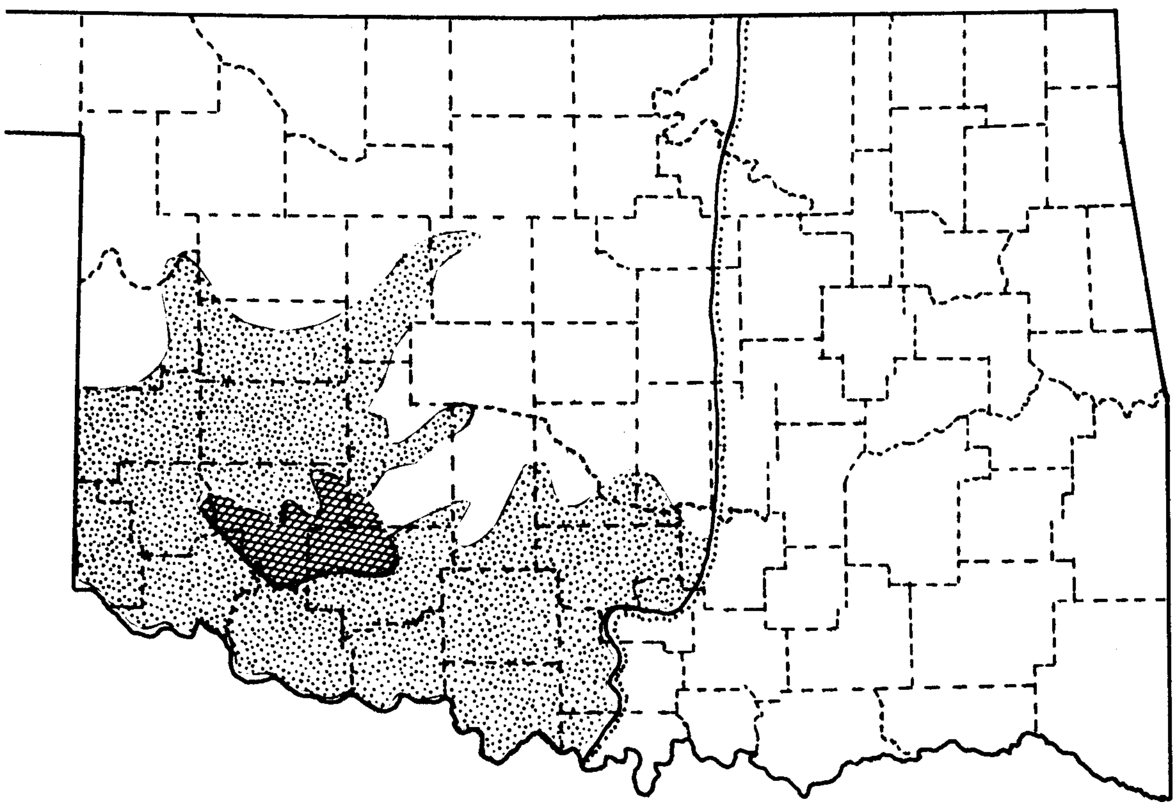


Fig. 35.--Distribution of arkose, Wolfcampian Series. After MacLachlan (1967).

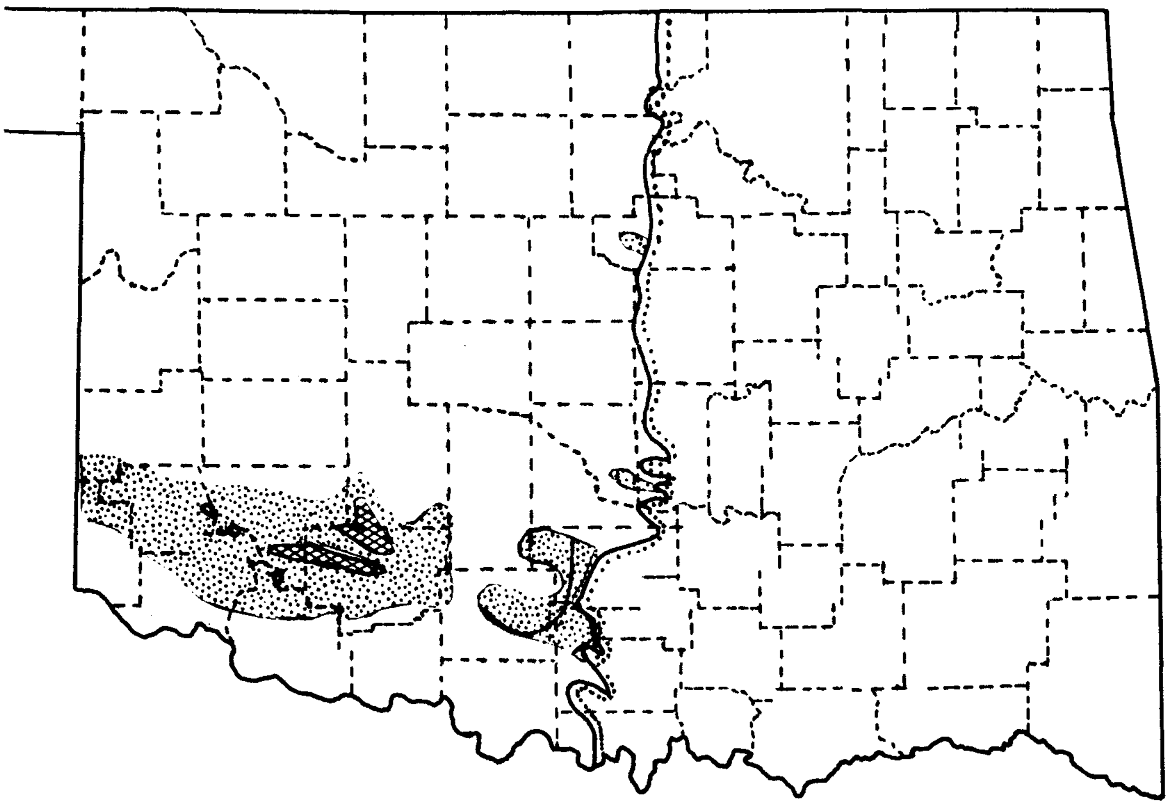


Fig. 36.--Distribution of arkose, Leonardian Series.

litharenites being present (Table 2). Quartzarenite is the predominant sandstone type. In central Oklahoma, subarkose is the dominant sandstone type in the Duncan (Table 2; Spencer, 1930). In northwestern Oklahoma the Flowerpot is primarily subarkosic siltstones, with five to 10 percent feldspar (Table 2; Fay, 1965). The Dog Creek in the same area contains eight to 23 percent feldspar.

The Guadalupian-Ochoan Marlow Formation is characteristically a subarkose in northwestern Oklahoma (Table 2; Fay, 1965); the Marlow-Rush Springs interval in western Oklahoma is subarkosic to arkosic (Table 2; Spencer, 1930). Units in the area fringing the Wichita uplift are arkosic (Fig. 37). The Quartermaster Group in western Oklahoma is subarkosic, with 10 to 24 percent feldspar (Table 2; Spencer, 1930).

The dominant source areas during the Permian were the Ouachita, Arbuckle, and Wichita uplifts. Feldspar was derived in large part from the Wichita uplift, with the Arbuckle uplift being a secondary source. The Sierra Grande-Apishapa uplift to the northwest may have been the source of some feldspar, especially that in northwestern Oklahoma. The specific role of each source area is not known precisely, primarily because of the sparsity of paleocurrent data. Apparently during much of the Permian, the Wichita uplift supplied sediments primarily to the Anadarko basin and secondarily to the area south of the uplift, where influence of the Ouachita uplift was dominant. Possibly the Wichita uplift may have contributed some clastics even during deposition of the youngest unit preserved in the Anadarko basin.

Mudrocks

X-ray diffraction analysis of Upper Mississippian-Lower Pennsylvanian shales from the Ardmore and Anadarko basins (Weaver, 1958) indicates that the Caney shales are characterized by the abundance of illite and the scarcity of chlorite and kaolinite, the Springer shales by the presence of montmorillonite and the absence of illite, the Morrowan shales by an abundant illite content, and the Atokan shales by the relative abundance of mixed-layer clay. The interval between typical

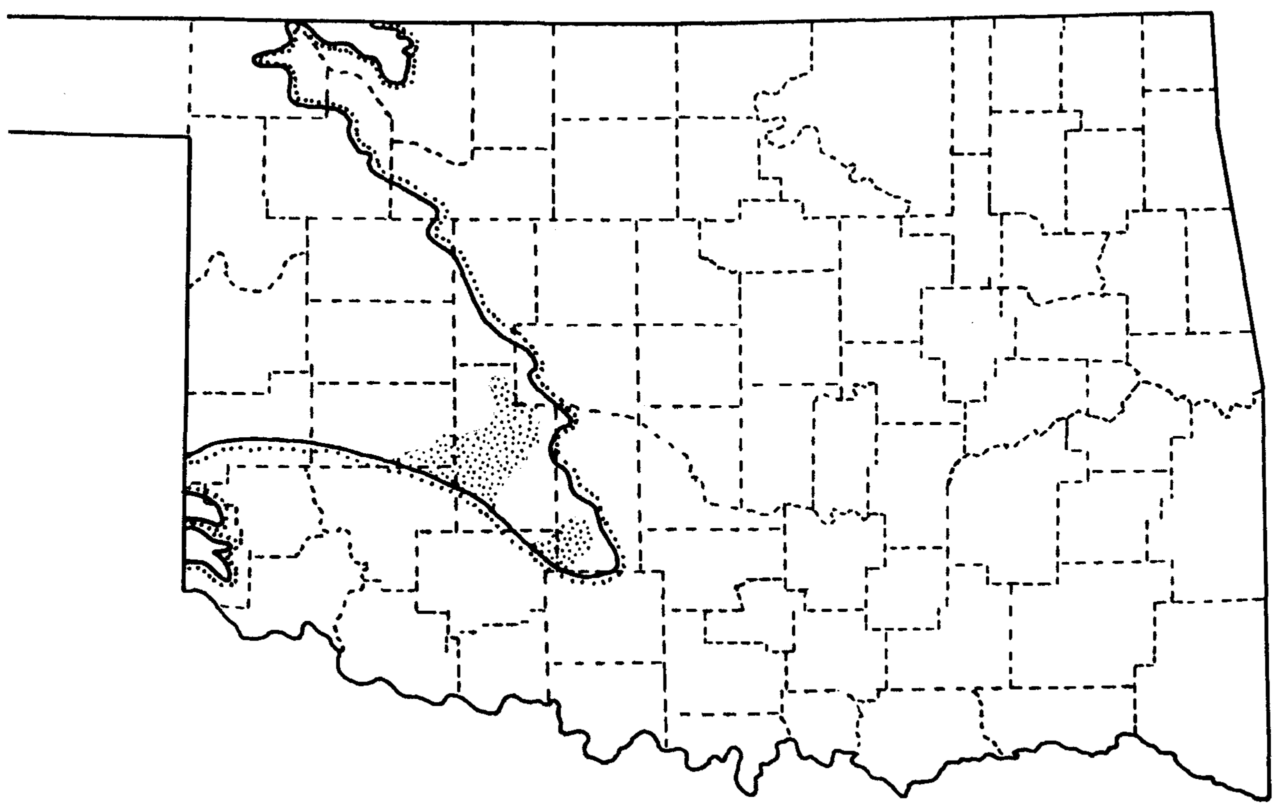


Fig. 37.--Distribution of arkose, Gaudalupian-Ochoan Series.

Springer suites and typical Caney suites is designated by Weaver as "Chester shales." Those mudrock units contain illite and montmorillonite. Weaver (1958) divided the Caney and Springer on the basis of the development of the "Chester shales."

In the Ouachita geosyncline the Mississippian Stanley Shale is characterized by the presence of illite, chlorite, and feldspar. The Pennsylvanian Jackfork and Johns Valley shales are distinguishable by the presence of mixed-layer clay and the relative scarcity of kaolinite and chlorite.

In northwestern Oklahoma the Cherokee Excello Shale, a black shale between the Oologah and Oswego Limestones, contains about 50 percent illite. Kaolinite is significant near the upper and lower contacts and in phosphatic nodules. The "Hot Shale" associated with the Missourian Marchand Sandstone in the subsurface of the Anadarko basin primarily contains well crystallized illite and chlorite.

On outcrop shale in the upper part of the Vamoosa Formation contains mixed-layer montmorillonite-vermiculite (or swelling chlorite), kaolinite, and small percentages of illite. The upper shale unit of the Ada Formation is predominantly montmorillonite in Pontotoc County (Iranpanah, 1966). In the more northerly areas the suite consists mainly of illite and chlorite. In a vertical sequence Iranpanah (1966) noted that the basal unit of the shale consists of Ca montmorillonite and some kaolinite, with a trace of illite. The overlying unit consists of illite and kaolinite, with poorly crystalline Na montmorillonite. Illite and chlorite, with some kaolinite and mixed-layer illite-montmorillonite, are dominant in the lower part of the upper shale section. The uppermost unit consists of mixed-layer illite-montmorillonite and chlorite, with some kaolinite.

The dominant clay mineral in conglomerates, sandstones, and shales of the Vanoss is a moderately well-crystalline kaolinite (Thomas, 1973). Lesser amounts of montmorillonite, illite, and mixed-layer illite-montmorillonite are also present. Montmorillonite is more characteristically present in shales or poorly sorted, fine-grained sandstones. Illite, which occurs sporadically throughout the outcrop area, is more common northward. North of Seminole County, the crystallinity of the illite increases while the crystallinity of the kaolinite decreases.

Wolfcampian units on outcrop in north-central Oklahoma are characterized by illite, chlorite, and kaolinite (Heine, 1975). Chlorite, which consists of both swelling and non-swelling types, is of progressively higher percentages in older units.

The Matfield Shale of the Wolfcampian Chase Group and the underlying Eskridge Shale of the Council Grove Group in Pawnee County contain 30-58 percent kaolinite, 27-33 percent mixed-layer illite-montmorillonite, 7-25 percent mixed-layer chlorite, and 7-16 percent illite (Cullers and others, 1975). The kaolinite and montmorillonite decrease northward, and illite and mixed-layer chlorite with chlorite show corresponding increases.

In Noble County analyses of Wolfcampian and lower Leonardian mudrocks indicate that illite, kaolinite, and chlorite are the most common clay minerals (Shelton, 1976). It is common for the illite to be degraded. Kaolinite is absent from a gray-green unit in the upper-middle part of the Wellington, which contains some vermiculite. Four of five samples containing mixed-layer illite-chlorite are reddish in color. Two samples with possibly some montmorillonite are also reddish.

Clay minerals in the Leonardian Flowerpot Shale in northwestern Oklahoma are mainly illite with some swelling chlorite and chlorite (Wu, 1969). The swelling chlorite in the uppermost part of the shale is thought by Wu to represent altered chlorite or incomplete formation of authigenic brucite layers. The absence of kaolinite in the upper Flowerpot is noteworthy. From petrologic data the main source areas were probably the Ouachita and Arbuckle uplifts.

Carbonates

Pennsylvanian carbonates, which are very prominent on the northern shelf, are characterized to a large extent by phylloid algal banks. The banks are an unusually thick sequence of carbonate mudstone built in large measure by the algae in an environment of low turbulence (Heckel and Cocke, 1969; Frost, 1975). The banks influenced sedimentation and distribution of fauna and flora; they were largely responsible for development of other associated environments. Common carbonate rock types on the shelf are skeletal and laminated mudstone, algal-bryozoan boundstone, and skeletal and oolitic grainstones. Although the thin Pennsylvanian and Permian limestones associated with transgressions are quite variable in texture, mud-supported rocks are most common.

Deeper water carbonates compose a small part of the sections in the Anadarko basin and part of the Wapanuka Limestone in the frontal zone of the Ouachita system. Slope units in the Wapanuka consist of cherty spiculites and wackestones, interbedded with shelf-derived oolitic grainstones.

Dolomites are associated with the northern edges of banks or platforms (where carbonate banks may have restricted circulation of water) and southward changes in carbonate sections; all of these carbonates were deposited on the shelf as intertidal deposits. Dolomites are present also as supratidal deposits in the redbed, evaporitic sequences, and possibly as caliche and lacustrine deposits. The dolomite probably did not form during deposition, but it may have formed penecontemporaneously more commonly than diagenetically.

URANIUM IN OKLAHOMA

Previous Investigations

Radioactive anomalies have been reported throughout Oklahoma in numerous geologic environments. Uranium has been discovered in marine black shales, asphaltic sandstones, bituminous nodules, Cambrian igneous rocks, and sandstones. In addition, the presence of helium and radon in some oil and gas wells (Pierce, Mytton, and Gott, 1956; Pierce, Gott, and Mytton, 1964) and the high uranium content of some petroleum ashes (Hyden, 1956; Hyden and Danilchik, 1962) are further indications of possible mineralization. Anomalous uranium concentrations also have been reported for ground and surface waters at several localities throughout the state (Landis, 1960; Scott and Barker, 1962).

Marine Shales

Middle Paleozoic marine black shales containing anomalous concentrations of uranium are present in much of Oklahoma. Landis (1958) and Swanson (1960) examined several radioactive samples from the Devonian Chattanooga Shale in northeastern Oklahoma. Uranium values for the shale range from 0.001 to 0.007 percent, with one locality in Cherokee County having 0.005 percent uranium in an interval 10 feet thick.

In the Arbuckle Mountains area the Woodford Shale, correlative of the Chattanooga Shale, and the Mississippian Delaware Creek (Caney) Shale are anomalously radioactive. The uranium content of several Woodford samples ranges from 0.001 to 0.014 percent, with a modal value of 0.001 percent uranium (Landis, 1958). Samples of the Delaware Creek Shale range from less than 0.001 to over 0.002 percent uranium (Patrick and Ham, 1969). Because the Woodford-Chattanooga Shale is uniformly radioactive, the most significant areas may be those where the shale subcrops below the Pennsylvanian (Plate 1), especially Pennsylvanian sandstones.

Hyden and Danilchick (1962) sampled several Pennsylvanian black shales in the Desmoinesian Series of northeastern Oklahoma. Most of those shales contain 0.001 percent uranium or less, with phosphatic shales having higher concentrations of uranium. The average content of sampled phosphatic shales is approximately 0.003 percent U_3O_8. The Excello Member of the Senora Formation, a phosphatic shale, which was sampled in detail, shows an equivalent uranium content of 0.003 to 0.004 percent.

Detailed analyses of phosphate nodules in seven Pennsylvanian shales of Kansas were made by Runnels and others (1953). The average uranium content was determined to be 0.017 percent U_3O_8.

Asphaltic Sandstones

Petroleum-impregnated rocks and asphaltic deposits at the surface and to a depth of 500 feet are known from 33 of the 77 counties of Oklahoma (Jordan, 1964). The principal area is in southern Oklahoma. Another area is in northeastern Oklahoma; it extends into eastern Kansas and western Missouri. Impregnated rocks include both sandstones and carbonates.

In southern Oklahoma asphalt deposits are in sandstones of Ordovician, Pennsylvanian, and Permian ages (Beroni, 1956). Although most of these asphaltic sandstones do not have anomalous concentrations of uranium, selected samples from the Sulphur, Cameron (T2N, R12W), and Ada areas contain between 0.002 and 0.22 percent uranium in the ash of the extracted oil (Hail, 1957).

In northeastern Oklahoma oil seeps and/or asphaltic rocks are in Sylamore Sandstone (Devonian), Mississippian limestones, and Atoka sandstones (Jordan, 1964). In the general area of Bartlesville Desmoinesian sandstones produce or have produced from depths of less than 500 feet. Upper Missourian sandstones produce or have produced from those depths in Osage County. These types of accumulations extend into eastern Kansas and western Missouri. Five samples of heavy oil from western Missouri were determined to contain 0.004 to 0.145 percent uranium in the ash of the extracted oil (Hail, 1957).

Bitiminous Nodules

Bitiminous nodules along the northern flanks of the Wichita uplift (Hill, 1957) were found to contain above-normal concentrations of uranium. Three nodules from the NE¼, Sec. 30, T6N, R14W, contain 2.36, 9.38, and 3.58 percent uranium, respectively, in the ash of the extracted oil. Five other samples from nearby areas, however, do not contain uranium content in excess of 0.002 percent. Most of the uraniferous nodules range from one to five millimeters in diameter and are associated with petroliferous rocks of Permian age.

Granitic Vein Deposit

A two-to three-inch wide vein containing traces of uranium and thorium is present on the north side of Osage Lake in the SE¼ Sec. 22, T3N, R14W (Dale and Beach, 1951; United States Atomic Energy Commission, 1968). The vein, which occurs in a Cambrian granite, contains 0.002 percent uranium with 0.17 percent thorium. The radioactive minerals are associated with zircon crystals.

Sandstone Deposits

Uranium was first discovered in a sandstone lens in Sec. 8, T22N, R4E, in Pawnee County (Beroni, 1956) (Plate 4). The uranium-bearing materials are in a Wolfcampian channel deposit. The radioactive minerals are associated with carbonaceous material, wood fragments, and logs. Pyrite, chalcopyrite, and chalcocite, in association with calcite, fluorite, and dolomite, are also present in the carbonaceous material. Secondary minerals in the deposit include uranophane [$Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$] and carnotite [$K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O$], along with malachite and azurite. Uranium content in selected samples ranges from 0.002 to over 1.00 percent U_3O_8 (Beroni, 1956). Curtis (1956) described uranium deposits in Sec. 19, T22N, R4E, and Secs. 23 and 24, T22N, R3E. These deposits are also associated with copper mineralization. In Secs. 23 and 24 both deposits are limestone conglomerates in the basal part of the Wolfcampian Matfield Shale above the Wreford Limestone. The deposit in Sec. 19 is associated with carbonized wood in a channel sandstone.

Several radioactive deposits were discovered in the 1950's in the Red River area of southwestern Oklahoma. The largest deposit is in Cotton County south of Randlett, Oklahoma in the SW¼ Sec. 30, T5S, R12W (Chase, 1954) (Plate 2). There small amounts of uraninite (UO_2), galena, pyrite, and chalcopyrite are associated with woody fragments in the lower two to four feet of a channel sandstone, 25 feet thick. The deposit, which is in the Permian Garber Sandstone, also contains torbernite [$Cu(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$], autunite [$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{-}12H_2O$], uranophane, carnotite, and bayleyite [$Mg_2(UO_2)(CO_3)_3 \cdot 18H_2O$], along with malachite and azurite. From analyses of selected samples the uranium content is from 0.014 to 2.140 percent eU (United States Atomic Energy Commission, 1968).

In western Jefferson County in the SE¼ Sec. 7, T5S, R8W (Plate 2), anomalous radioactivity in a 0.5- to 1.5-foot lens of reddish-brown sandstone lens was reported by Chase (1954). Anomalous radioactivity was noted a short distance away, in ferruginous sandstone "float" on blue-gray shales, with a sample containing 0.052 percent eU_3O_8 (United States Atomic Energy Commission, 1968). Sandstone "float" in the NE¼ Sec. 1, T5S, R9W, is also reported to show anomalous resistivity.

Other minor anomalies are in sandstone lenses interbedded with red shales and siltstones in Cotton and Jefferson counties. The radioactivity is generally three to four times normal background of 0.025 MR/HR. The anomalies are commonly in units with carbonaceous material or bituminous residue and secondary copper minerals (United States Atomic Energy Commission, 1968).

Two radioactive anomalies were reported east of Manitou in Sec. 34, T1N, R15W, and Sec. 1, T1S, R16W (Plate 2) (United States Atomic Energy Commission, 1968). The host rock is a Wichita (Hennessey) coarse-grained arkosic sandstone, five to 10 feet thick, stained with iron, manganese, and asphalt (Beroni, 1954).

Samples of the deposit contain up to 0.010 percent eU_3O_8.

The only uranium occurrence in Oklahoma to have been of commercial value is in the town of Cement. From July to September, 1956, approximately 26 tons of ore, 0.16 to 2.66 percent U_3O_8, were extracted from the deposit. All of the ore was produced from a trench 50 feet long, three feet wide, and four to five feet deep. In the deposit, carnotite [$K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2)$] and tyuyamunite [$Ca(UO_2)_2(VO_4)_2 \cdot nH_2O$] were disseminated in sandstone parallel to a N70^{o}W-trending fracture dipping 80^o to the southwest near the axis of the Cement anticline.

A second radioactive anomaly was reported in the Cement area shortly after the initial uranium discovery. The deposit, which is located in the NE¼ SE¼ Sec. 2, T5N, R9W (Plate 2), is interbedded sandstones and siltstones of the Rush Springs Formation. No visible uranium minerals were recognized; however, radioactive readings of 0.2 to 0.5 MR/HR were recorded along a 100-foot sandstone outcrop (United States Atomic Energy Commission, 1968).

Carnotite and tyuyamunite have been reported in the Upper Permian redbeds of western Oklahoma (United States Atomic Energy Commission, 1968). In Roger Mills, Custer, and Washita Counties these uranium minerals are in some one-to five-foot sandstone and siltstone lenses in the lower part of the Doxey Formation (Plate 3). Some of the uranium is on the flanks of minor folds produced by the slumping of sedimentary rocks due to collapse of beds overlying solution cavities developed in underlying evaporite units (Beroni, 1956).

Uranium Potential of Permian and Pennsylvanian Sandstones

Uranium-bearing sandstones and/or sandstones with radioactive anomalies are known to be present in the following geologic frameworks:

1. Oil-producing structural features in southern Oklahoma with altered Permian sandstones.
2. Lower Permian channel sandstones on gentle local structural features on the Waurika-Muenster arch.

3. Permian alluvial-fan deposits associated with Wichita and Arbuckle uplifts
4. Permian tidal-flat (possibly sabkha) sandstone-siltstones in western Oklahoma and north-central Oklahoma.
5. Oil-productive Pennsylvanian sandstones in northeastern Oklahoma.

Oil-Producing Structures

Radioactive anomalies in the Cement and Cox City areas appear to be associated with oil-producing anticlines with alteration of redbeds near the crests of the structures by seepage of hydrocarbons (Olmsted and Al-Shaieb, 1975). Several other anticlines in southern Oklahoma, including West Cement, Chickasha, Velma-Cruce, Eola, and Healdton, have similar surface alterations (Fig. 38) (Gouin, 1956). These structures require further evaluation which was not undertaken in this study.

<u>Cement Uranium Deposit</u>. Geologic Setting. Large quantities of hydrocarbons have been produced from the Cement anticline in southeastern Caddo County. The structure has also produced the only uranium deposit of commercial value in Oklahoma. The structure is a west-northwest-trending anticline that is slightly overturned toward the north. Unfaulted Permian strata, 2500 feet in thickness, unconformably overlie a faulted and tightly folded pre-Permian structure. A major south-dipping reverse fault intersects the pre-Permian unconformity along the north flank of the anticline (Fig. 39). The fault parallels the fold and also parallels a north-dipping normal fault system which has been truncated by the unconformity near the crest of the structure. Several minor, normal faults cut the anticline at an angle, resulting in the displacement of the pre-Permian fold axis.

Minor structural deformation which occurred sometime after deposition of the Cloud Chief Formation produced a gentle anticline in Permian units with an axis which nearly coincides with that of the earlier Paleozoic structure. As contoured on the top of the outcropping Rush Springs Formation, the Cement fold is approximately 11 miles long and two miles wide (Reeves, 1921). Its crest, expressed

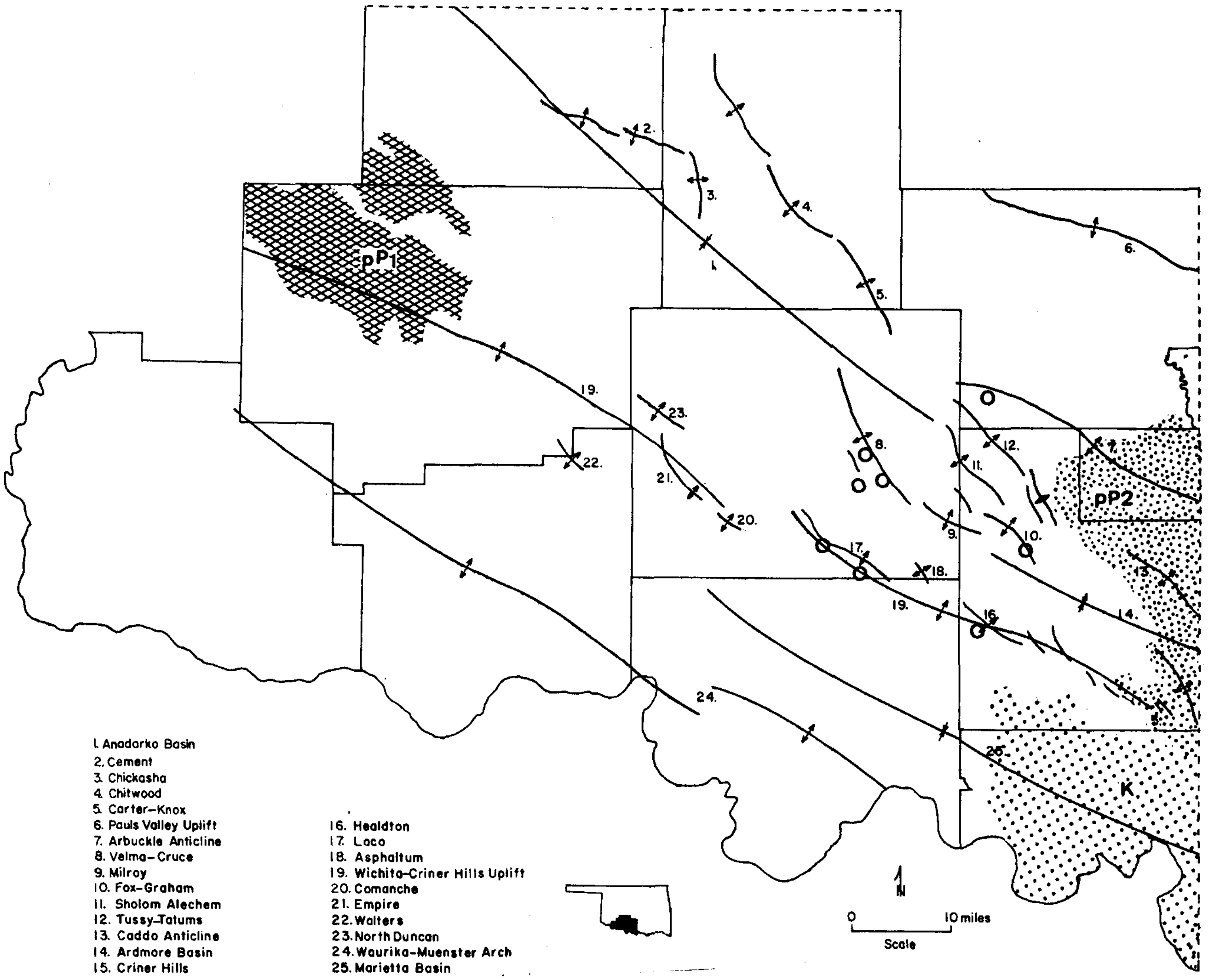


Fig. 38.--Major structural features of southern Oklahoma with deformation of Permian strata. K=Cretaceous, pP1=pre-Permian, Wichita Mountains, pP2= pre-Permian, Arbuckle Mountains, Ardmore basin, Criner Hills. Small circles indicate oil seeps.

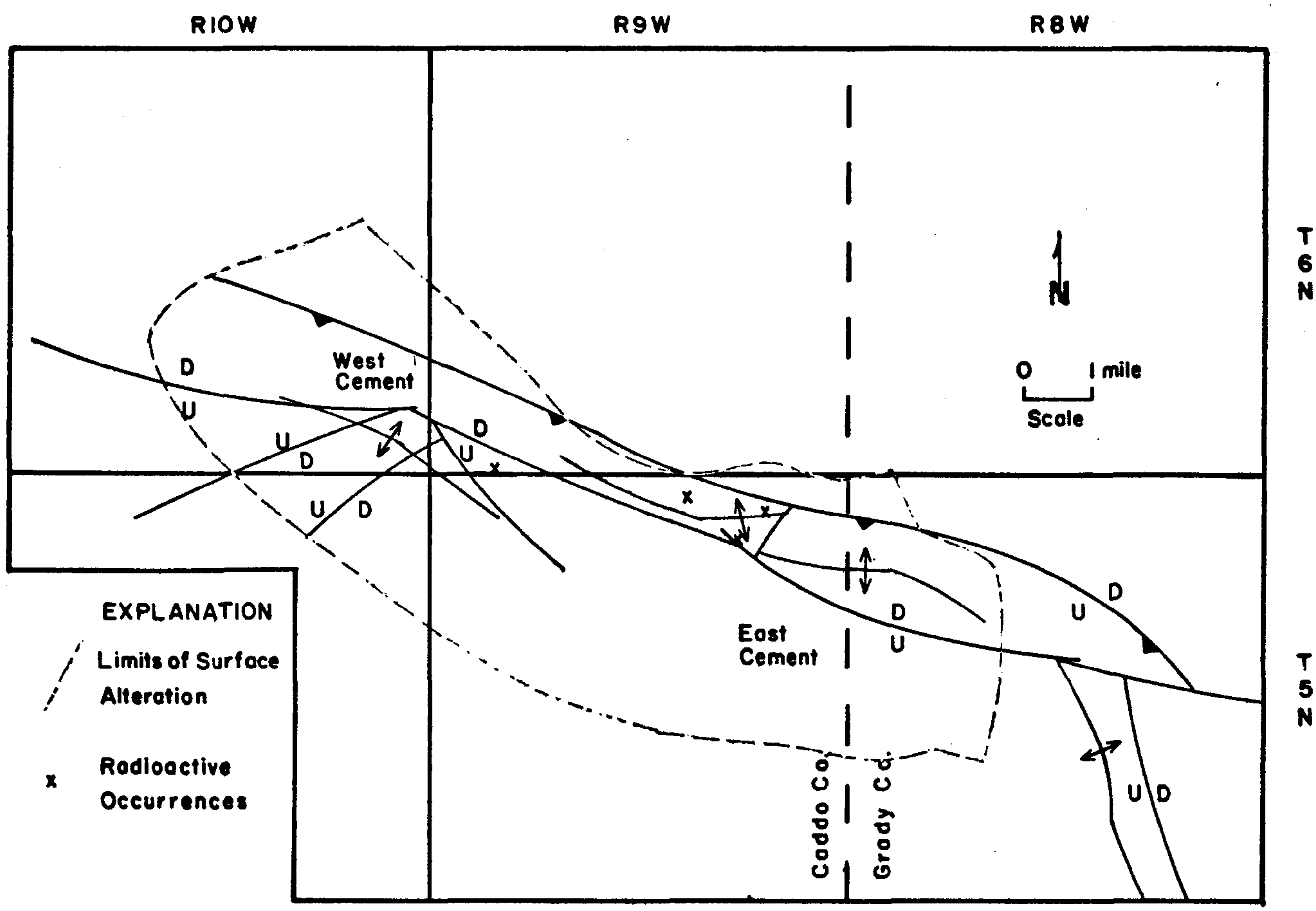


Fig. 39.--Structural sketch map of the Cement area, showing pre-Permian structural features, radioactive occurrences, and surface alteration. After Herrman (1961) and Donovan (1972).

topographically, is dominated by two domes. The East and West Cement domes are approximately four miles apart and are capped by the basal member of the Cloud Chief Formation. The town of Cement is located on the west side of East Cement dome.

The oldest rocks exposed on the Cement structure are sandstones of the Rush Springs Formation and the overlying Moccasin Creek Gypsum Member of the Cloud Chief Formation. The Rush Springs Formation is approximately 250 feet thick in the Cement area.

Petrology and Petrography. Near Cement the Rush Springs Formation is a fine- to very fine-grained subarkose composed of quartz, orthoclase, plagioclase, microcline, and chert. The sandstone consists of well to very well sorted, subangular to subrounded sand grains. The friable sandstone is cemented with hematite which occurs as rims on the sand grains and gives the sandstone its characteristic red color. Beds of very fine-grained silty sandstone were found in the Rush Springs Formation in Sec. 2, T5N, R9W.

In the vicinity of the Cement oil field the Rush Springs Formation is altered to colors of yellow, buff, or white along the flanks of the anticline. Near the crest of the structure the sandstone has a gray coloration. In these areas most of the sandstone are extremely hard and are indurated with carbonate cement.

Thin-section studies were conducted on each of the four types of sandstone in the Cement area. The samples include the yellow to white sandstone on the flanks of the structure, the gray, well-cemented sandstone near the crest of the fold, the silty sandstone in Sec. 2 and the red sandstone.

Quartz accounts for 50 to 60 percent of the total rock in each sample, excluding the silty sandstone. The grains show both straight and undulatory extinction; some quartz is of composite quartz grains with sutured contacts. Although a few quartz grains contain unaltered edges, most grains have irregular edges which show evidence of carbonate replacement. Orthoclase composes eight to 12 percent of the rock, with microcline and plagioclase each accounting for two to three percent. Most of the orthoclase grains show extensive surface alteration to clay and sericite. Although unaltered microcline and plagioclase grains are present, they are generally altered in part to sericite and/or carbonate. Chert pebbles constitute up to one percent of the rock. Biotite, chlorite, sericite, and zircon are present as accessories.

The yellow to white samples from the flanks of the structure are tightly cemented with carbonate, which accounts for 29 to 35 percent of each sample. The sand grains "float" in the carbonate cement, and most of them show some carbonate replacement. Although most of the hematite has been removed from the light colored sandstones on the flanks of the structure, several grains have iron oxide stains or rims of limonite. Small hematite concretions contain unaltered sand grains. Locally in some areas, the absence of carbonate cement results in porous units. One of the samples from the flanks of the structure is soft, friable and limonitic yellow in color. The sandstone, with no carbonate cement, commonly shows grains with limonite rims and in point contact.

Well-cemented sandstone near the crest of the anticline contains small amounts of pyrite and no visible traces of iron oxide. The sandstone, which is well cemented with carbonate, contains little pore space.

The silty sandstones contain 38 percent quartz, 16 percent orthoclase, and one percent each of chert, microcline, and plagioclase. A reddish-brown clay matrix, accounting for 30 to 40 percent of the sample, cements the detrital portion of the rocks.

The unaltered reddish-brown sandstone contains no carbonate cement. Hematite as grain coatings and pore filling is the primary cementing medium. The sand grains are generally well rounded and in point contact. Quartz overgrowths are present on a few quartz grains.

Surface Alteration. Unique features of the Cement anticline are the coloration and mineralogic changes which occur in the Permian sedimentary rocks over the structure (Fig. 39) (Donovan, 1972). Not only do the sandstones have gray coloration near the crest of the structure, where they are tightly bound with a carbonate cement, but also the Moccasin Creek Gypsum Member of the Cloud Chief Formation at the crest of the anticline is altered to a carbonate which is predominantly calcite.

Donovan (1972) attributed the alteration of the gypsum and sandstone to hydrocarbon leakage which was controlled by the distribution of faults and the pre-Permian unconformity. Oxidation of the migrating hydrocarbons by sulfates resulted in the formation of carbonate replacement of gypsum near the crest of the structure. Hydrogen sulfide released either as a by-product of the sulfate-hydrocarbon reactions or contained in the escaping hydrocarbons reduced the ferric oxides in the Rush Springs Formation (Donovan, 1972). The soluble ferrous compounds were then removed by water, producing the coloration change characteristic of the sandstone. Carbonate mineralization of sandstones in the underlying formations is reported to a depth of 2500 feet (Donovan, 1972).

Radioactive Anomalies. The ore body at Cement was in a west-northwest-trending fracture near the crest of the Cement anticline. Carnotite and tyuyamunite were confined to the upper side of the southwest-dipping fracture and occurred as a series of pods along the fracture. Radioactive readings on the deposit ranged from 0.05 to 0.80 MR/HR. The host for the ore is the sandstone in the upper Rush Springs Formation. In the ore zone the sandstone is white in color with dark-brown, yellow-brown, and red stain. McKay and Hyden (1956) generally found white sandstone parallel to the mineralized fracture. A halo of reddish-brown sandstones was observed to separate the ore zone from the barren portions of the host. Away from the fracture the sandstone is yellow with dark-brown stain. Although it contains several hard, carbonate concretions, the white sandstone was generally more friable than the iron-stained, yellow sandstone. McKay and Hyden (1956) found non-radioactive pyrite nodules, some up to six inches in diameter and with anhydrite veinlets, in the yellow rock.

The highest concentration of uranium in ground-water samples collected throughout the United States by Scott and Barker (1962) was in a sample taken from a well at Cement, Oklahoma. The well, located in Sec. 3, T5N, R9W, contained water with a concentration of 120 ppb uranium. A second sample collected nearby in Sec. 1, T5N, R10W, contained only 2.2 ppb uranium. The difference between the uranium contents of the two samples and the presence of a uranium ore body in the vicinity of the ground-water anomaly suggest that hydrogeochemical prospecting might be helpful in exploring for uranium in southern Oklahoma.

Forty-eight ground-water samples from an area around Cement show several ground-water anomalies in the vicinity of East Cement dome (Fig. 40). In the town of Cement water from three wells located near the former ore body contains anomalous concentrations of uranium, with that from the well approximately 200 feet northeast of the former deposit containing concentrations of 120 to 160 ppb uranium. The well is 165 feet deep and produces from the Rush Springs Formation, as do most wells in the area. The highest concentration of uranium of 465 to 860 ppb in ground water collected during this study was in a 85-foot well located about 700 feet north of the former ore body. Ranges in the uranium content in each well may be attributed to seasonal variations in rainfall. Two wells, 200 feet apart, contain 80 ppb uranium and less than two ppb uranium, respectively.

High concentrations of uranium were also present in water samples collected in Secs. 2, 4, and 11, T5N, R9W. The wells in Secs. 2 and 11 produce water from the Rush Springs Formation. A sample from a spring in the NE¼ SE¼ Sec. 2 contained 85 ppb uranium. Ground-water anomalies in Sec. 4 are from water in municipal wells 400 to 600 feet deep. A water sample obtained from the deepest well, which is in the center of Sec. 4, contained 38 ppb uranium. The aquifer in the well consists of a series of sandstones, the lowermost of which is 100 feet thick. The sandstones are probably in the upper Duncan Sandstone or lower Chickasha Formation.

In the SE¼ Sec. 2, T5N, R9W, anomalous radioactivity was detected in an outcrop two feet high along the west side of an old oilfield service road. The highest radioactivity recorded along the outcrop was 0.03 MR/HR, with a normal background

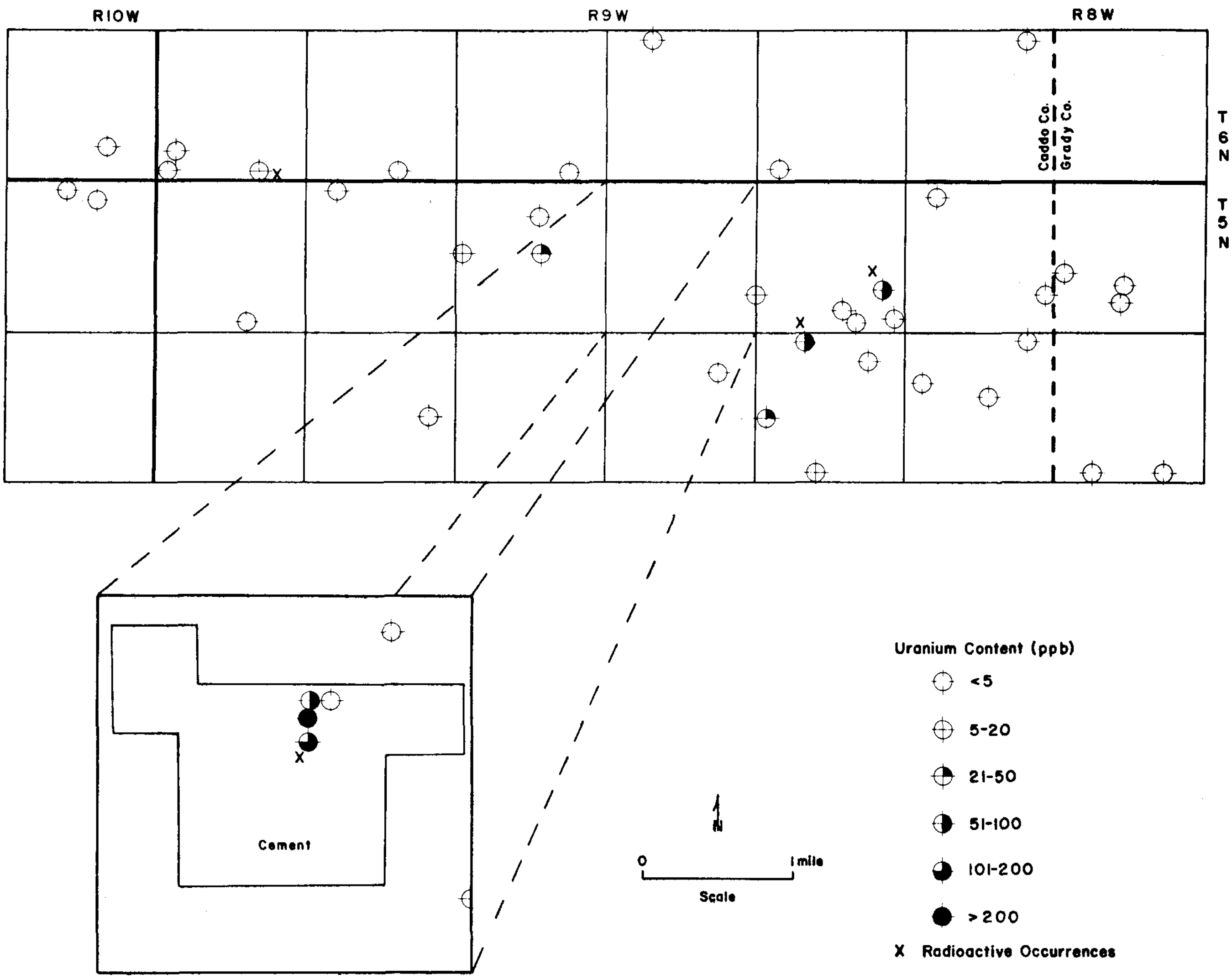


Fig. 40.--Ground-water anomalies and radioactive occurrences in the Cement area.

of 0.009 MR/HR. Anomalous radioactivity was recorded for two to three feet along the contact between a gray-green, thin-bedded, silty sandstone and an underlying massive, buff to gray, silty sandstone.

A second radioactive occurrence was discovered along the north side of the county road in the SE¼ SE¼ Sec. 31, T6N, R9W. The radioactivity occurred in a one-foot thick, reddish-brown sandstone, interbedded with a massive, buff colored sandstone. Asphaltic concretions, some measuring up to six inches in diameter, were the most radioactive. Radioactivity near the asphaltic sandstones averaged 0.07 MR/HR compared to a background of 0.009 MR/HR. The anomalous concretions were scattered along an outcrop approximately 15 feet in length.

Gamma ray logs show anomalous radioactivity at relatively shallow depths on the Cement structure. Mobil Oil Company's Surbeck No. 6, in the NW¼ SE¼ Sec. 3, T5N, R9W, shows several near-surface radioactive anomalies. The readings indicate that three anomalous zones exist 100 to 150 feet below the surface. The highest radioactivity is 130 feet below the surface in a zone five feet thick. Another anomalous interval in the Rush Springs Formation is present between 280 and 300 feet below the surface, and a third anomaly is in a sandstone of the Hennessey Shale at a depth of 1345 feet.

Subsurface anomalies were also found at several localities on West Cement dome in Secs. 34-36, T6N, R10W. Examination of gamma ray logs reveals several anomalous zones within 2900 feet of the surface. The shallowest mineralization was in Sec. 35 where anomalous radioactivity is at a depth of 10 to 20 feet.

Cox City Deposit. Geologic Setting. In southeastern Grady County the village of Cox City is located near the crest of the Carter-Knox anticline (Figs. 5, 41). The fold trends northwest-southeast through T3N, R5W, and extends into the northeastern part of T2N, R5W. Two episodes of deformation were responsible for the present configuration of the anticline. During the Arbuckle orogeny folding associated with upthrust or strike-slip faulting at depth produced an northwest-trending disharmonic anticline. Southwest-dipping overthrust faults, displace the

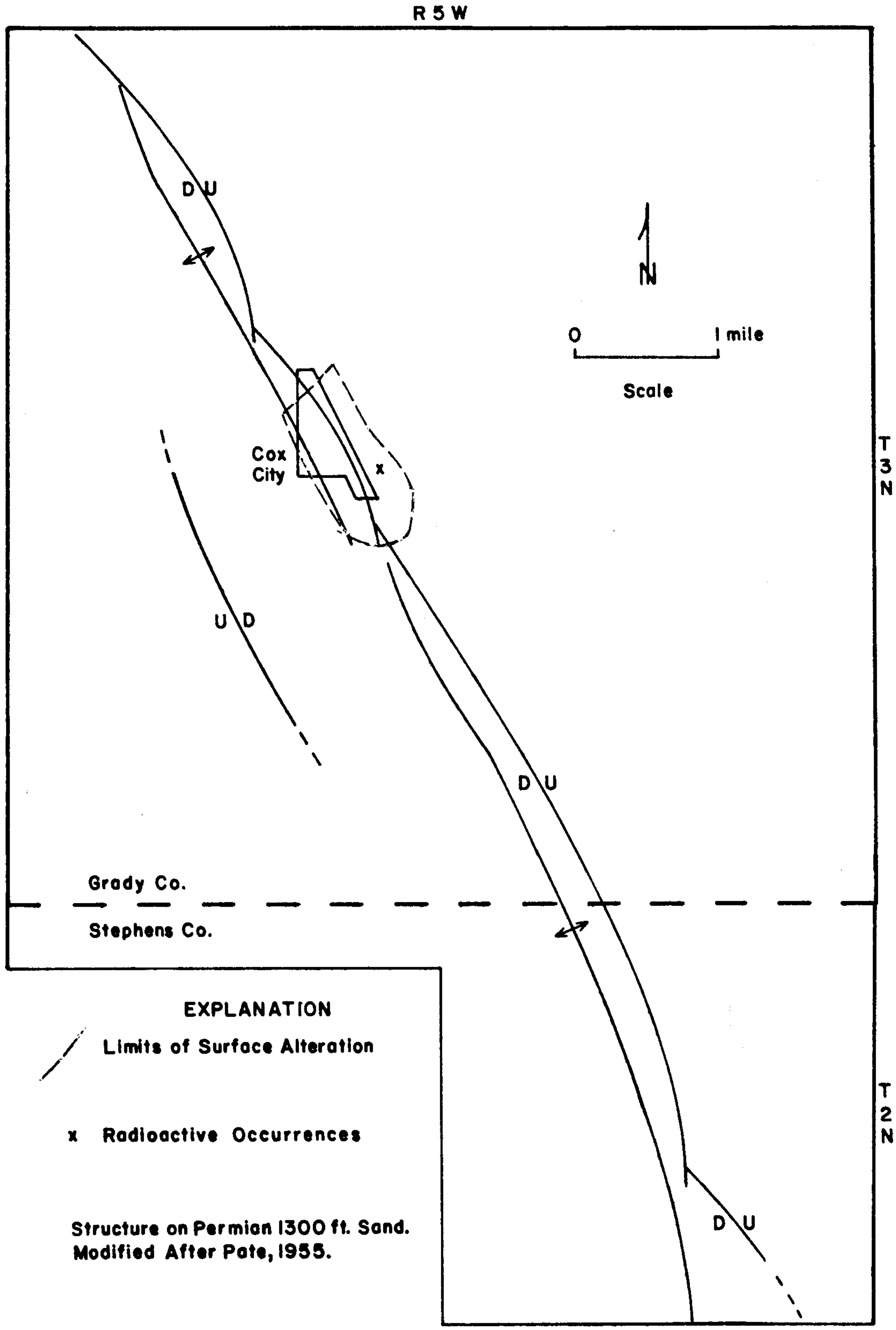


Fig. 41.--Structural sketch map of the Cox City area, showing radioactive occurrences and surface alteration.

north limb of the fold. The fault dies out in the ductile Springer shales (Reedy and Sykes, 1959).

Permian strata, which unconformably overlie Pennsylvanian units, are folded into a gentle anticline. A normal fault, which parallels the anticlinal axis and lies immediately east of it, shows displacement of 100 to 200 feet (Pate, 1955). One mile west of the anticlinal axis, a northeast-dipping normal fault forms the west boundary of a graben which parallels the fold. Both normal faults extend downward into underlying Pennsylvanian strata.

The Permian section on the Carter-Knox anticline is approximately 2100 feet thick. Formations at the surface include the Chickasha Formation and underlying Duncan Sandstone.

Petrology and Petrography. Units of the upper part of the Duncan Sandstone and lower part of the Chickasha Formation crop out near Cox City. The exposed rocks are fine- to very fine-grained sandstones with interbedded silty sandstones and a few carbonate, clay-pebble conglomerates. The sandstones which crop out near the crest of the structure generally are buff to yellow-brown in color, with some reddish-brown stain. In Cox City these sandstones are white and contain small brown concretions. The sandstones in this area are hard and contain carbonate cement.

The calcareous sandstone which crops out near the crest of the anticline at Cox City is similar to the carbonate-cemented sandstones at Cement. The fine- to very fine-grained sandstone contains 53 percent quartz, five percent orthoclase, and traces of chert, microcline, and plagioclase. Thirty-six percent of the rock is carbonate cement, and iron oxide accounts for six percent.

Most of the detrital grains are altered in part to either carbonate, sericite, or clay. The carbonate alteration occurs as replacements along grain boundaries; clay and sericite alteration is along the surfaces of the grains. Iron oxide rims are on several grains.

Silty sandstones and carbonate conglomerates are present on the flanks of the anticline. The sandstones are generally buff to yellow-brown; however, in several areas they are blue-gray. The buff-colored carbonate conglomerates contain both carbonate and clay pebbles in a detrital matrix. The conglomerates are well indurated by carbonate cement.

The silty sandstones are very fine-grained, poorly sorted, and contain up to 41 percent clay matrix. Hematite cubes (probably after pyrite) are common in the matrix of blue-gray sandstones. The cubes, which range in size from 0.03 to 0.10 millimeter, have iron oxide halos. Reaction rims of sericite and reddish-brown clay are present on most detrital grains. Quartz is the primary detrital constituent, accounting for 47 percent of the sample. A few composite quartz grains with sutured contacts are present, and several grains display undulatory extinction. Eight percent of the rock consists of orthoclase; plagioclase, microcline, chert, and sericite are present as accessories. The feldspars are in various stages of alteration to sericite and clay; however, plagioclase and microcline are also present as scattered unaltered grains. Several carbonate grains with detrital nuclei are also present in the sandstone.

The clay-pebble conglomerate contains clay pebbles which consist of reddish-brown calcareous mud with some very fine-grained quartz grains. Some of the pebbles contain very fine-grained carbonate rhombs and a few small hematite grains. The carbonate pebbles contain small grains of quartz which show evidence of replacement by the carbonate. Several of the pebbles have nuclei of fine-grained carbonate crystals which appear as "islands" in a carbonate, mud matrix. Many of the pebbles are rimmed by iron oxide and clay. The matrix of the rock consists primarily of quartz, with lesser amounts of orthoclase, plagioclase, microcline, and chert. Some quartz grains show replacement by carbonate cement. Most of the orthoclase is altered to clay, and a few of the feldspar grains show evidence of sericitic alteration. The scattered grains of microcline and plagioclase are generally less altered than the orthoclase.

The very fine-grained carbonate cement locally consists of very fine-grained rhombs which have small hematite grains at their centers.

Surface Alteration. A small area encompassing the axis of the Carter-Knox structure at Cox City was outlined by McKay and Hyden (1956) as showing evidence of surface alteration (Fig. 41). Units of the lower part of the Chickasha Formation and upper Duncan Sandstone, which generally are purple and reddish-brown, have been altered to shades of buff, gray, and white. Near the intersection of State Highway 17 and the county road in Cox City, the Duncan Sandstone is white in color and is well indurated with carbonate cement. A short distance south and east of the intersection, blue-gray siltstones and shales are found interbedded with yellow and buff sandstones.

Radioactive Anomalies. An intensified hydrogeochemical survey was conducted in the Cox City area for the purpose of locating areas of radioactive mineralization. Twenty water samples analyzed from wells in T3N, R5W, show a major anomaly in the SW¼ SW¼ Sec. 17, T3N, R5W, on the west edge of Cox City (Fig. 10). Ground water from the well at that location in June, 1974, contains 365 to 480 ppb uranium. The well, which is 225 feet deep, produces water from the Duncan Sandstone.

Anomalous readings were obtained on outcrop in a drainage ditch along the south side of a county road approximately 200 yards east of the intersection of Cox City. The highest readings averaged 0.02 MR/HR, compared to a normal background of 0.009 MR/HR.

The anomalies occurred in several blue-gray, argillaceous sandstones which are interbedded with yellow, limonitic sandstones and buff carbonate conglomerates. The anomalous radioactivity generally was present near the contacts between several conglomerate lenses and the blue-gray sandstones. Radioactivity could not be detected away from the road cut.

Gamma-ray logs from oil wells in the north half of Sec. 21, T3N, R5W, indicate the presence of radioactivity in the Cox City area (Fig. 42). Several near-surface anomalies are indicated in the NE¼ NW¼ Sec. 21 with the highest radioactivity occurring in a zone five-to seven-feet thick. The anomalies are located in a zone less than 100 feet below the surface in and near the northeast, longer normal fault.

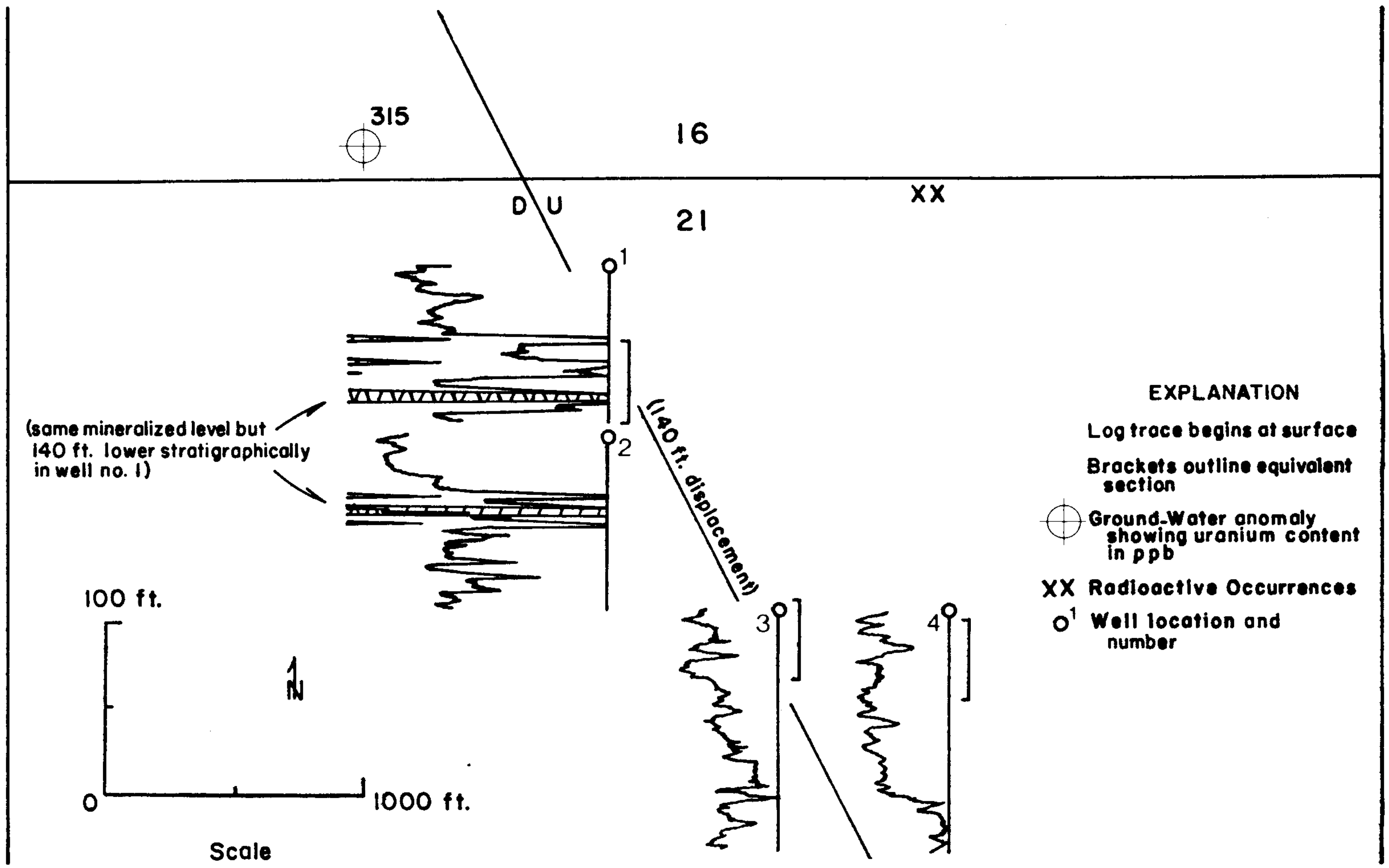


Fig. 42.--Gamma-ray log map of the Cox City area, showing subsurface radioactive occurrences.

Although the mineralized horizons are on both sides of the fault, they apparently do not extend continuously along its entire length. The strongest mineralization is 45 to 75 feet below the surface.

Other Geochemical Anomalies. Several wells in northern Cotton and southwestern Stephens Counties with high concentrations of uranium are from sandstone aquifers located on or near a subsurface structural feature. The anomalies in T2S, Rs7-10W, also are in areas underlain by pre-Permian structures, which include the oil-producing Comanche, Empire, West Duncan, and Walters anticlines. Uranium content of 18 ppb was determined for a water sample from a well in Sec. 25, T2S, R13W.

Channel Sandstones on Gentle Structures

Numerous, gentle structural features are present in Jefferson County (Bunn, 1930). Most are situated on or near the axis of the Waurika-Muenster arch or the Wichita-Criner uplift. The structures are generally characterized by gentle dips and little, if any, topographic relief. Present on outcrop are the Wolfcampian (or Oscar according to the Oklahoma Geological Survey), Wellington Formation, Garber Sandstone, and Hennessey Shale (Plate 2). They consist of reddish-brown to gray shales and siltstones with lenses of weakly indurated, friable sandstone. The sandstones generally are a buff to gray or reddish-brown and fine- to very fine-grained.

Silty sandstones interbedded with shale are in the lower parts of the sandstone channels. They generally are buff to yellow-brown and are very fine-grained.

Several conglomerate lenses are present, and they are buff to reddish-brown and are composed of carbonate and clay pebbles in a detrital matrix. The conglomerates are cemented with iron oxide and carbonate.

Composition. Quartz comprises approximately 60 percent of the channel sandstones. Most quartz grains are cloudy; several grains have overgrowths, and some composite grains have sutured contacts. Orthoclase constitutes from eight to 10 percent of the sandstone, with plagioclase comprising about two percent of the rock.

The orthoclase and plagioclase are extensively altered to clay and sericite. Hematite stain occurs on many of the grains, and iron oxide rims are common in the reddish-brown sandstone. Very little iron oxide is in the buff to gray samples. Chert pebbles account for about six percent of the rock, and the samples contain a clay matrix of illite with some kaolinite and vermiculite; the matrix constitutes about nine percent of the rock. The samples contain significant porosity; many of the grains are in point contact.

Quartz, the primary detrital constituent of the silty sandstones, accounts for approximately 50 percent of the rock. Several of the quartz grains have quartz overgrowths. Composite quartz grains with sutured contacts are also present. Orthoclase constitutes about six percent of the sample, and microcline and plagioclase are present as accessories. Most of the orthoclase is extensively altered to sericite and clay, and individual sericite grains are present as are unaltered and altered microcline and plagioclase grains. A clay matrix, primarily of kaolinite, illite, and vermiculite, constitutes up to 40 percent of the samples. Some fresh and slightly altered pyrite cubes occur locally in the clay. The pyrite is also altered to limonite and hematite, which in some cases is a cement. Chert pebbles comprise one to two percent of the sample. Several biotite and chlorite grains are present as accessories, along with a few heavy mineral grains. Flood (1964) identified the heavy minerals in the sandstones of western Jefferson County as zircon, tourmaline, and leucoxene.

A reddish-brown carbonate conglomerate interbedded with silty sandstones and shale is composed of large carbonate pebbles in a fine-grained quartz, feldspar, and clay matrix. Very fine-grained quartz grains showing evidence of replacement by carbonate are in the carbonate pebbles. The pebbles are rimmed by iron oxide and clay. Clay and iron oxide pebbles are also present in the rock.

Most of the rock is cemented by a very fine-grained carbonate; however, in places it is cemented by iron oxide.

<u>Near-Surface Alteration</u>. Core-drilling conducted by Bunn (1930) showed that

there is a pronounced color change in the formations over some of the structures in Jefferson County. He observed that brown colored shales generally contain a larger proportion of light-blue or gray color toward the crest of the structures. Drilling fluid and shale cutting chips from a well on a structure in Sec. 24, T7S, R6W, were characterized by a light-gray color to a depth of 1000 feet. According to Bunn these same units are red in a well drilled 3/4 mile downdip.

Radioactive Anomalies. The largest deposit and the one having the highest concentration of uranium is in the SW¼ Sec. 30, T5S, R12W, south of Randlett in Cotton County (Plate 2). At the time of discovery uraninite, torbernite, autunite, uranophane, carnotite, and bayleyite were in a sandstone channel, which is at least 600 feet long, 300 feet wide, and 25 feet thick. The trend of channel sandstone is N20^{O}E (Beroni, 1954). Mineralization is confined to the lower portion of the channel in an area 25 feet long and two to four feet thick. A high silt and clay content, along with abundant carbonaceous material, characterizes the sandstone in the mineralized zone. The host is a fine- to very fine-grained sandstone, with gray coloration due to the abundant clay content. The predominant clay mineral is kaolinite; smaller amounts of illite and vermiculite are present. The mineralized sandstone grades upward into a buff to gray, fine- to very fine-grained barren sandstone which contains no carbonaceous material and very little silt or clay.

Ground Water. A concentration of 18 ppb uranium was determined in a sample from a well, 75 feet deep, in the NE¼ NE¼ Sec. 11, T6S, R8W. The aquifer, Wolfcampian in age, is a lighter colored sandstone than most water-bearing zones in Jefferson County.

A well, 20 feet deep, in NE¼ SE¼ Sec. 35, T4S, R9W, contained water with 26 ppb uranium, and a well, 42 feet deep, in Sec. 33, T4S, R9W, had water containing 30 ppb uranium.

The highest concentration of uranium of 44 to 55 ppb is from a sample of unknown depth in a well at a service station in the SW¼ SW¼ Sec. 34, T4S, R10W.

Surface. The radioactivity is in a series of interbedded argillaceous sandstones and shales on outcrop along a county road between Secs. 17 and 19, T5S, R8W (Plate 2). The highest recorded radioactivity was 0.07 MR/HR compared to a normal background of 0.009 MR/HR. The anomalous readings were obtained from a reddish-brown and blue-gray mottled shale, six- to eight-inches thick, which is interbedded with buff, argillaceous sandstones.

An argillaceous sandstone, which is four- to six-inches thick and about two feet below the previously described shale, is also radioactive. The buff sandstone is mineralized along its contact with an underlying reddish-brown and blue-gray, mottled shale. The mineralized portion of the outcrop has a recorded radioactivity of 0.025 MR/HR.

A carbonate conglomerate, approximately eight inches thick, is not radioactive, but an overlying silty shale, 1.5-feet thick, has zones of anomalous radioactivity which average 0.025 MR/HR.

Alluvial-Fan Deposits

Associated with Wichita Uplift. Granite wash is a coarse clastic sediment composed primarily of felsic intrusive igneous rock fragments varying in size from silt to boulders with varying amounts of other detritals, commonly carbonates and cherts.

The Wichita Uplift was a positive area from Morrowan through Wolfcampian time during which time a series of granite washes derived from it was deposited both along the north and south flanks of the uplift. It was also topographically expressed during a significant part of the Leonardian, and it undoubtedly was a source area then as well.

The granite wash, which is as much as thousands of feet thick, is variable both laterally and vertically in the section, a feature which is due both to variations in orogenic activity in time and space and to areal sedimentologic variants. Study and correlation of the granite wash is difficult because of the similarity in lithology and the lack of fossils.

Surface Deposits. Granite wash, which crops out only near the exposed parts of the Wichita uplift, is much less extensive than in the subsurface. Chase (1954) concluded that these conglomerates, composing the Post Oak Conglomerate of the Wichita Formation, are equivalent to the Wellington Formation, the upper part of the Pontotoc Group, and the lowermost part of the Garber sandstone. It is now regarded by the Oklahoma Geological Survey to include equivalents of part of the Hennessey Shale.

Chase (1954) divided the Post Oak into four facies, designated as follows:

Ppo-1 limestone conglomerate

Ppo-2 granite boulder conglomerate

Ppo-3 rhyolite porphyry conglomerate

Ppo-4 granite gabbro conglomerate with zeolite-opal cement.

Distribution on outcrop of these facies is shown in Figure 43.

Ppo-1 consists of limestone cobbles derived from uplifted Arbuckle Limestone. It is present north of the Wichita Mountains.

Ppo-2 consists of granite boulders and cobbles in a matrix of arkose with a calcite, limonite, and clay cement. The conglomerate weathers to boulder beds of unconsolidated, well rounded boulders surrounded by a yellowish clay matrix. Near the mountains, the conglomerate consists of granite fragments ranging from six to 18 inches in diameter, interbedded with irregularly crossbedded lenses of arkose. North of the mountains, the conglomerate decreases in thickness away from the mountains and changes into limestone conglomerate and/or intertongues with shale. Six to eight miles south of the mountains the conglomerate grades into a coarse-grained, conglomeratic crossbedded arkose. Some of these arkoses grade into red shale, whereas others continue in the subsurface 20 to 30 miles south of the mountains and maintain a consistent thickness of about 400 feet.

Three large boulder fans are present south of the mountains. The two fans to the west are typical granite conglomerates, whereas the fan to the east (Ppo-3), in the Fort Sill area, is composed of rhyolite and limestone boulders as well as

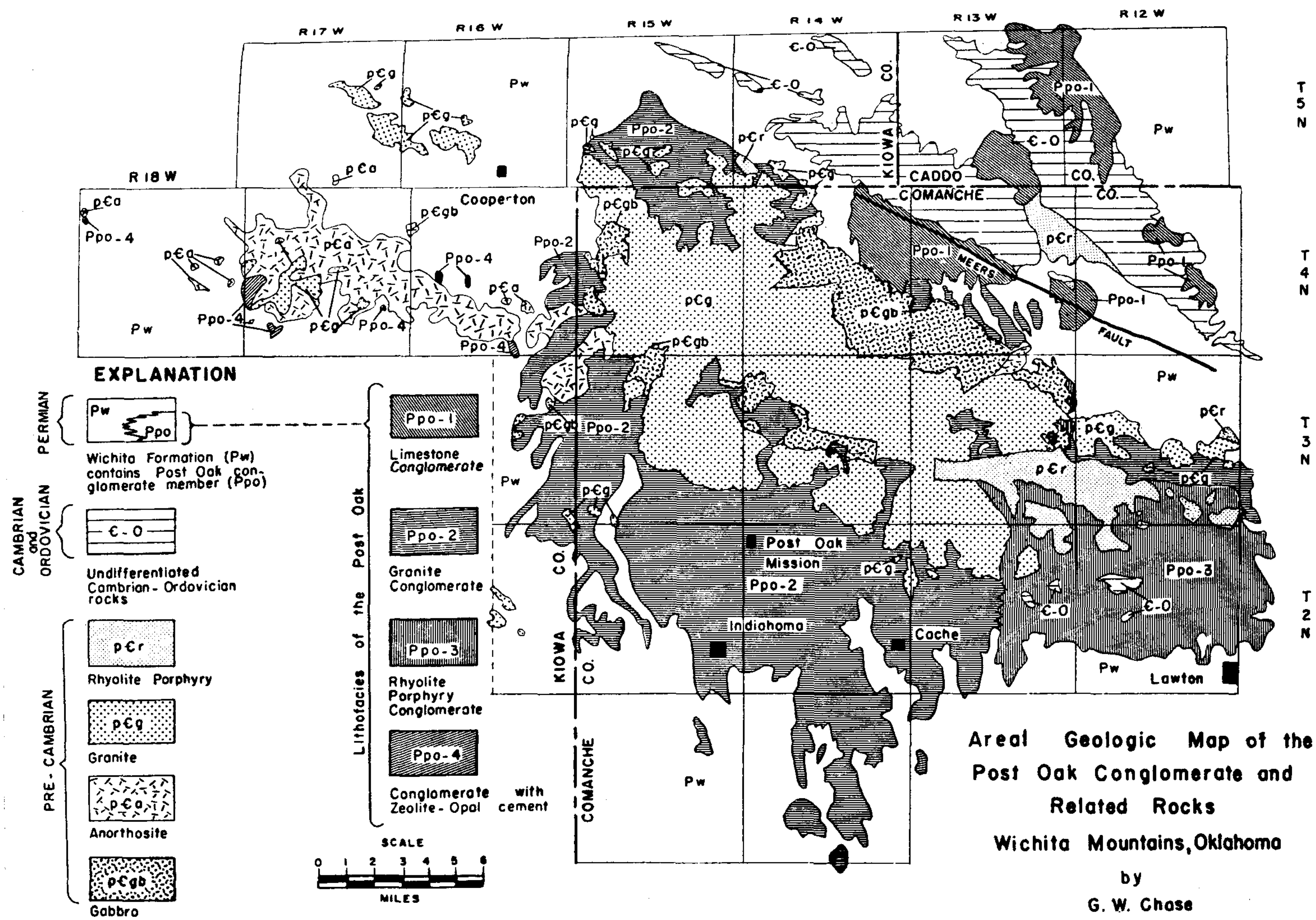


Fig. 43.--Geologic map of the Post Oak Conglomerate and related rocks, Wichita Mountains. From Chase (1954).

granite boulders. Rhyolite boulders predominate toward the east.

The facies designated as Ppo-4 by Chase, also described by Merritt and Ham (1941) and Mayes (1947), crops out around hills made of gabbro-anorthosite west of the other exposures, which are larger in areal extent. Ppo-4 contains rounded pebbles of anorthosite ranging in size from one to three inches. Generally, however, these pebbles are absent, and the rock appears as a dull brick red to light gray unit speckled with white. Detrital feldspar and ilmenite are present in minor amounts. The principal components of the rock are zeolites and opal. Natrolite is the major zeolite, and it is present as small needles and fibers, commonly replacing labradorite. It is also present in cavities, along with analcime. Opal is present throughout the facies; it varies from 12 to 40 percent. Calcite and dolomite also occur in variable amounts. Halloysite, hematite, and limonite are minor minerals.

Two radioactive anomalies reported by the United States Atomic Energy Commission (1968) are in a coarse-grained arkosic sandstone south of the Wichita Mountains in Sec. 34, T1N, R15W, and Sec. 1, T1S, R16W. The sandstone, as much as 10 feet in thickness, is in the Hennessey Shale, which is the basinal equivalent of the Post Oak.

Subsurface Deposits: Anadarko basin. More subsurface data are available north of the Wichita uplift in the Anadarko Basin (Fig. 44) than south of the mountains.

It should be noted that the thick sequence of granite wash in the Anadarko basin is not vertically continuous, as suggested in Figure 44, but is interbedded with shale, carbonates, and sandstones. Granite wash is, however, the dominant lithology. Pennsylvanian granite wash is commonly interbedded with and grades into beds of shale and sandstone. Thin marine limestones are present in the section, but they compose less than 10 percent of it. Fusulinids in these limestones are the principal means of dating these sediments.

Granite wash thickens northward from the Wichita uplift into the Anadarko Basin, where it is present at lower stratigraphic positions. It grades into the finer

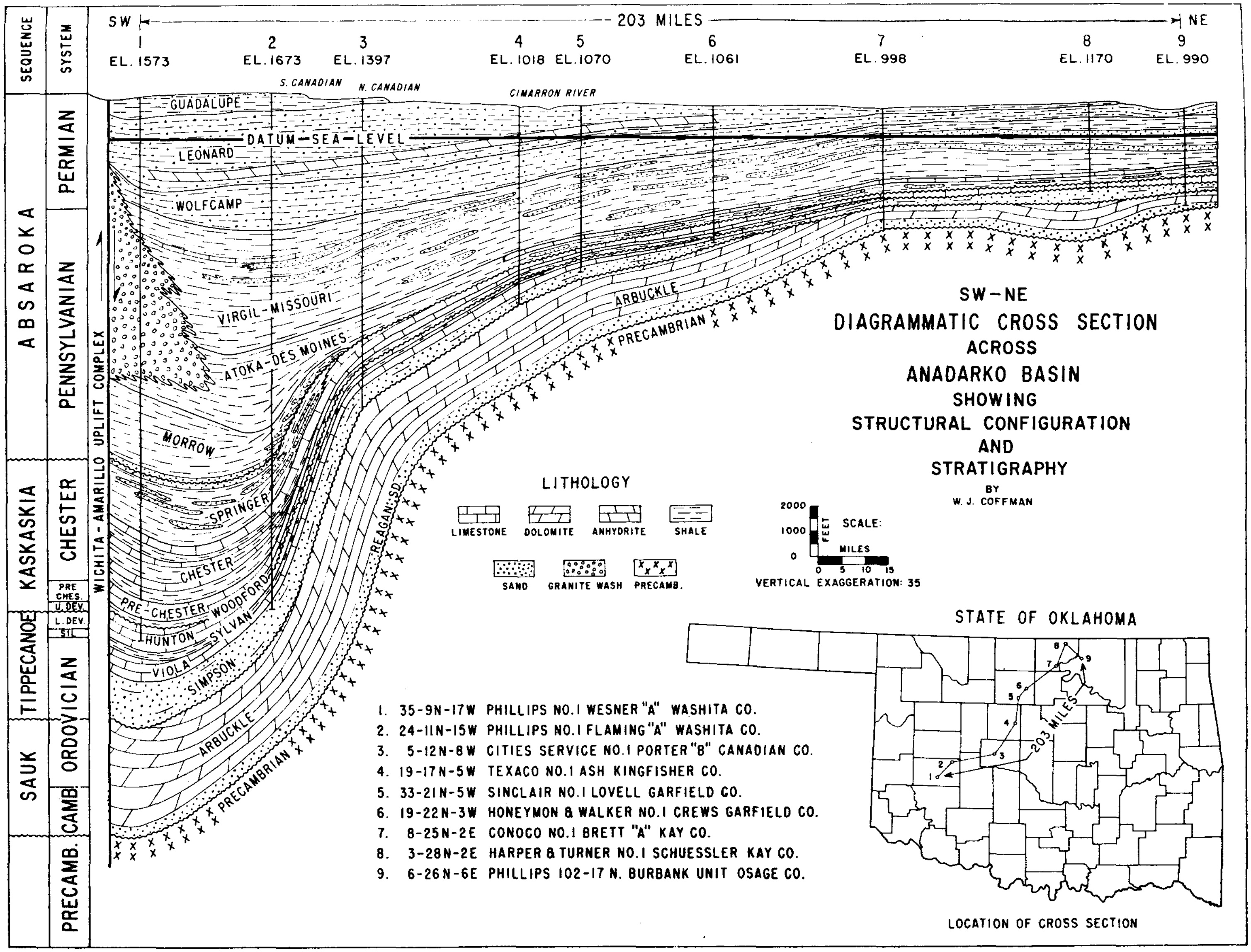


Fig. 44.--Cross section of Anadarko basin, showing granite-wash deposits near Wichita uplift. From Adler (1971).

clastics of the basin, which are white to light gray, fine, arkosic sandstones and gray, micaceous, silty shales. Red beds are generally restricted only to Permian and upper Virgilian sediments near the mountain front.

Granite wash changes to carbonate wash both in a direction parallel to the uplift and perpendicular to it. This change reflects to a large extent differences in provenance (Fig. 45).

In the western part of Beckham and Roger Mills Counties, the detritus present along the flanks of the uplift is granite wash, with no carbonate fragments. This granite wash is composed largely of feldspar in various stages of decomposition. It has low porosity due to the filling of interstitial spaces by kaolinite. An 8000-foot section of conglomerate, shale, and dark limestone is present in the Elk City field in Beckham County.

Major oil production is from coarse clastics in the Missourian, although oil and gas have been found both above and below the Missourian Series (Beams, 1952). Granite wash is present in the upper Desmoinesian, Missourian, and Virgilian sediments as well as in the Admire and Council Grove Groups of Wolfcampian age. The granite wash reservoirs, which are interbedded with shale and marine limestone, show irregularities in thickness and permeability. The dominant lithology generally is a coarse arkosic sand conglomerate, with rock types ranging from heterogeneous granite conglomerate to quartzarenite. Feldspar is the dominant constituent, with quartz and micrographic granite also being important (Edwards, 1959). Laterally the granite wash grades into fine clastics and marine carbonates, a relationship which commonly results in beds of coarse clastics being surrounded by impermeable material. However, some beds of porous, permeable material are continuously distributed over several square miles. The arkosic sand conglomerate reservoirs show a porosity decrease from 19.8 percent to 15.0 percent with depth. Porosity and permeability decrease markedly in a northward direction from the Elk City Field, primarily due to calcite filling pores and partially replacing quartz and feldspar grains.

Granite wash in the West Sentinel oil field, in the extreme southwest part of

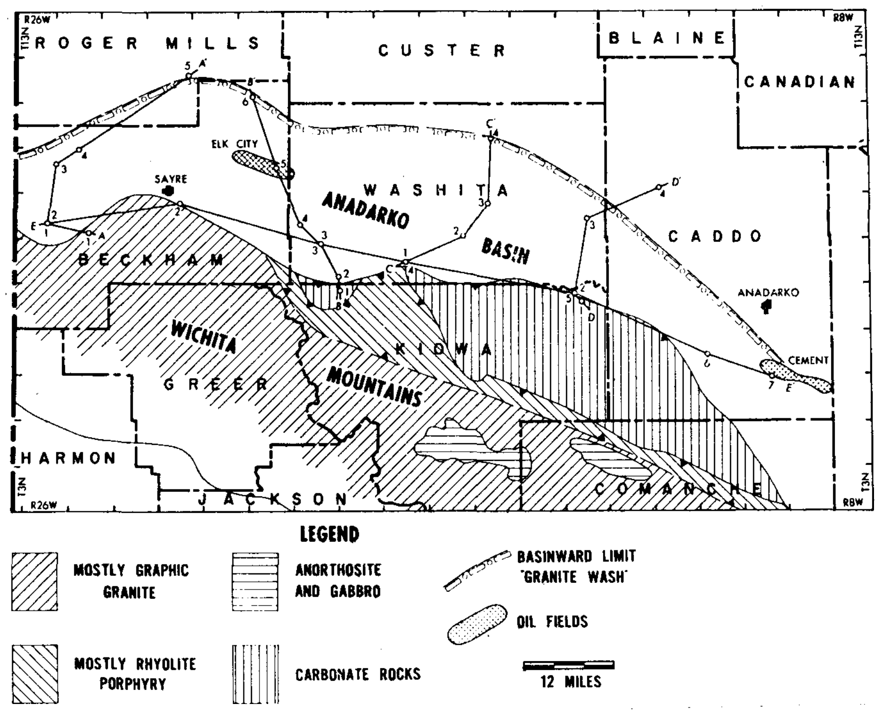


Fig. 45.--Distribution of rock types in the Wichita uplift. From Edwards (1959).

Washita County, contains strongly weathered fragments of basic igneous rocks, with magnetite, in the lower part of the Wellington Formation and in the upper part of the Virgilian Series (Gelphman, 1960). Coal beds and some bituminous shale also are present in the upper 300 feet of the Virgilian. Typical granite wash is present and in upper Desmoinesian to middle Virgilian strata. It is composed of fragments of relatively unweathered granite, dolomite or limestone, and chert in a matrix of poorly sorted arkose loosely cemented by calcium carbonate. Besides quartz and feldspar, the matrix also contains micas and both light and dark shales and some pyrite. The particles range in size from boulders to clay. Larger material is well rounded to subrounded, whereas the finer material is mostly angular. Silt and smaller particles do not exceed 17 percent (Gelphman, 1960). Individual granite-wash beds range from 10 to 100 feet in thickness. They are interbedded with shales, coal beds, and some thin limestones. In the upper Virgilian they include some beds of weathered basic igneous fragments.

In central Washita County, rhyolite fragments are a dominant constituent of the wash. Significant lenses of carbonate detritus also are present. Reduction of porosity is due to the presence of carbonate and the poor sorting of the sediments.

Carbonate detritus is more common in eastern Washita County and Caddo County. Granite wash containing much rhyolite is also present, but it is present in the lower part of the section and at some distance from the mountains. In central Caddo County, the section contains no coarse clastics. There in the area north of granite-wash deposits, shales, siltstones, and sandstones are the major sediments. Sandstones there are very fine grained, and they contain about 20 percent highly altered feldspars.

The increase in the amount of carbonate conglomerate to the east reflects a general shift from typical granite wash on the west to limestone conglomerate on the east. Granite wash is present along the flanks of the eastern part of the

Wichitas, but it does not extend as far north as it does in areas to the west.

For instance, although granite wash is found in northeast Comanche County, as described below, it is not present in the Cement Oil Field to the north, except in minor quantities in the Pontotoc. Several descriptions of Cement stratigraphy mention conglomerates (Herrmann, 1961; Harlton, 1960; Eisner, 1958), but these appear to be predominantly chert and carbonate conglomerates. Farther east in Grady and Stephens Counties this is also generally the case.

Granite wash in the subsurface of northeast Comanche County is present in the Wolfcampian Series as the Pontotoc Formation. The conglomerates become increasingly finer and less arkosic both upward and northeastward.

The granite wash was deposited in a series of alluvial fans and fan deltas extending into the Anadarko Basin and interdigitating with marine carbonates and fine clastics. In Beckham and Washita counties, greatest fan and delta development was in Desmoisnesian times, with two lobes of granite wash extending northward (McNeal, 1953). After that development, there was a progressive reduction in the northward extent of the granite-wash facies.

Granite wash in Beckham, Washita, Kiowa, and Comanche counties is not distributed uniformly through the section. For example, granite wash in one area is present in Atokan through Virgilian units, but it is present only in Virgilian and lower Wolfcampian rocks in another area 30 miles away in a direction parallel to the mountain front (Riggs, 1968).

Subsurface Deposits: Wichita Uplift. The South Erick Gas area, in Beckham and Greer Counties, is located on that part of the Wichita Uplift which was buried by Early Permian (Blazenko, 1964). Overlying the basement rocks of this area is a sequence of granite wash, shale, and some limestone, overlain by the "Brown" Dolomite, generally considered to be Wolfcampian.

The granite wash consists primarily of quartz and white to pink feldspar. Biotite, hornblende and/or augite are accessory minerals, and white chert fragments are also present. Some wash material is incorporated in brown shales, forming a rock consisting of sand grains in a clay matrix. Interbedded with the wash are green to red brown shales and white to pale gray limestones. The granite wash thickens into the Anadarko Basin.

The Panhandle gas field in Texas, which is a westerly extension of the South Erick gas area, contains uranium-bearing asphaltite as impregnations, fracture fillings, and nodules in both granite wash and underlying basement. The uranium content of the granite wash ranges from one to five ppm (Pierce and others, 1964).

Subsurface Deposits: Hollis Basin. Granite wash in the Hollis basin is present in lower Virgilian, Missourian, and Desmoisnesian beds, in association with limestone, shale, and sandstone (Sears, 1955). In Altus field, Jackson County, granite wash, which produces oil, is present in Pontotoc and Virgilian sediments. These beds were deposited on igneous basement rock. Granite wash in the Pontotoc is represented mainly by arkoses which have highly variable compositions. Some are composed of fresh igneous material, and others show varying degrees of feldspar alteration, with kaolinite and chlorite. In other arkose beds, quartz is a major element, and the beds are practically free of clay. Magnetite is present in some arkoses. In the lower part of the Pontotoc Group, dolomite and chert pebbles are present in some arkoses which are commonly porous. Shales interbedded with these arkoses are reddish brown and greenish gray. The latter may be carbonaceous. Gray and red-brown, fine, nodular limestones are also present in minor amounts. Virgilian arkose beds are associated with carbonaceous shales. In the lower part of the Virgilian, arkoses containing chert, granite pebbles, and rounded sand grains are interbedded with green and red-brown shales. Total thickness of sediments containing granite wash is apparently about 500 feet (Ryniker and others, 1959).

Apparently, granite wash is not present in Stephens County. Gouin (1930) mentions that Pennsylvanian conglomerates are composed of chert and limestone fragments. In South Palacine field, southeast Stephens County, Lower Permian sandstones/conglomerates contain chert and asphaltic stain (Atkinson, 1959). Also, presumably typical granite wash in the subsurface lies north of the Southwest Randlett field in southern Cotton County (Cipriani, 1959) and West Frederick field in southern Tillman County (Markey, 1959).

Associated with Arbuckle Uplift. Because the Vanoss Formation (or Group) on the north flank of the Arbuckle uplift is arkosic (Fig. 33; Thomas, 1973), it represents an analogous framework to that of the Post Oak Conglomerate. The Tishomingo Granite was the apparent source for the feldspar in the Vanoss, which ranges in thickness from approximately 1600 to 500 feet along the north-trending outcrop. The Vanoss is undifferentiated in the Arbuckle uplift area, but in north-central Oklahoma the equivalent section contains several thin limestones which pinch-out southward as well as shale units which interfinger with the coarse clastics to the south.

Tidal Flat (Sabkha) Sandstones-Siltstones

In western Oklahoma (Plate 3), carnotite and tyuyamunite are present in pink shales of the upper part of the Cloud Chief Formation and in siltstones in the overlying part of the Doxey Formation.

North of Foss in Washita County uranium is in a greenish-gray to maroon, calcite to gypsiferous siltstone in the lower part of the Doxey. The unit ranges up to five feet or more in thickness. Uranium content varies from zero to 0.006 percent, and vanadium varies from 0.002 to 0.044 percent.

High radioactivity is noted west of Cheyenne in Roger Mills County in thin beds of yellow to gray sandstone enclosed by red shale.

The occurrences in west-central Oklahoma differ from those in the southwestern part of the state in that they lack secondary copper minerals and carbonaceous material. The uranium may be more uniformly distributed through certain sandstone and siltstone lenses.

Similar depositional conditions to those in western Oklahoma, where uranium is present, existed in north-central Oklahoma during part of the Wolfcampian and Leonardian. An outstanding example of this type of depositional setting is the

Wellington Formation in Noble County. There it contains relatively thin, lenticular sandstones, interpreted as tidal-channel deposits, red claystones with one widespread green to gray shale, evaporites, and very thin carbonates (Shelton, 1976). The dominant mudrock section in the north grades into a sandstone-shale section in the south and southeast. Minor occurrences of secondary copper minerals are known from the Wellington in Noble County, and one radioactivity anomaly has been noted (Plate 4).

Cherokee Deltaic Sandstones in Northeastern Oklahoma

The lenticular Cherokee sandstones of northeastern Oklahoma, which are fluvial-deltaic in origin, contain abundant carbonaceous material and are common oil-producing reservoirs. Most Cherokee sandstones are very mature mineralogically, with only traces of feldspar and essentially no tuffaceous material. The Cherokee Group, however, includes some of the most radioactive shales in the Pennsylvanian-Permian section, and a number of radioactive anomalies in the Bartlesville Sandstone have been reported by Hyden and Danilchik (1962), Hail (1957), Hyden (1956) and Gott and Hill (1953). At several of the localities radioactive precipitates are associated with production of petroleum and formational water (Hyden and Danilchik, 1962). Precipitates from oil-field brine from the Nowata, Boston, and Cushing oil fields generally contain little uranium, although they are associated with high radioactivity (Hyden and Danilchik, 1962; United States Atomic Energy Commission, 1968). Water from one well in the Nowata oil field did contain 60 ppb uranium in water from the Bartlesville and .016 percent uranium in the oil ash (Hyden and Danilchik, 1962), and a nearby well contained 10 ppb uranium. However, almost all water samples from wells producing from the Bartlesville in Kay, Osage, Washington, Nowata, Payne, Tulsa, Creek, and Okmulgee Counties contained less than two ppb. Because Eh-pH values for the formational waters indicate that uranium would be unstable in solution, appreciable amounts of uranium in solution are not expected under those formational conditions. If fresh, oxygenated water is injected into the wells (as was done in the Nowata field project where the water contained significant uranium), it might cause the uranium to go into solution. Apparently the abnormal radioactivity of the precipitates is due primarily to the radium content of the brine.

Two of the highest uranium contents in petroleum from the western United States are from Bartlesville oil from Nowata field (Hyden, 1956). Many of the Cherokee sands have associated asphalt or heavy oil deposits (Jordan, 1964). Vanadium, which commonly is associated with uranium, is abundant in heavy oil-asphalt deposits (Hyden, 1956).

On outcrop most radioactive parts of the Bluejacket Sandstone commonly are the units with flaser bedding, or interlaminated sandstone and black shale. Also, the lower parts of sandstone lenses, where carbonaceous material is abundant, may be more radioactive than other parts of the sandstone.

Anomalous radioactivity has been noted on several gamma-ray logs of well drilled in eastern Oklahoma (Appendix D). Most of these record phosphatic shales in the Cherokee which are used as markers in correlation. One anomaly in Sec. 17, T18N, R7E, is apparently associated with the Ordovician Simpson and Arbuckle Groups unconformably below the Pennsylvanian. Another very prominent anomaly in the Cushing field area (in Sec. 9, T18N, R5E) is in the Woodford Shale.

The most significant radioactive anomalies in Pennsylvanian strata in northeastern Oklahoma are listed in Appendix D, and their locations are shown in Figure 46.

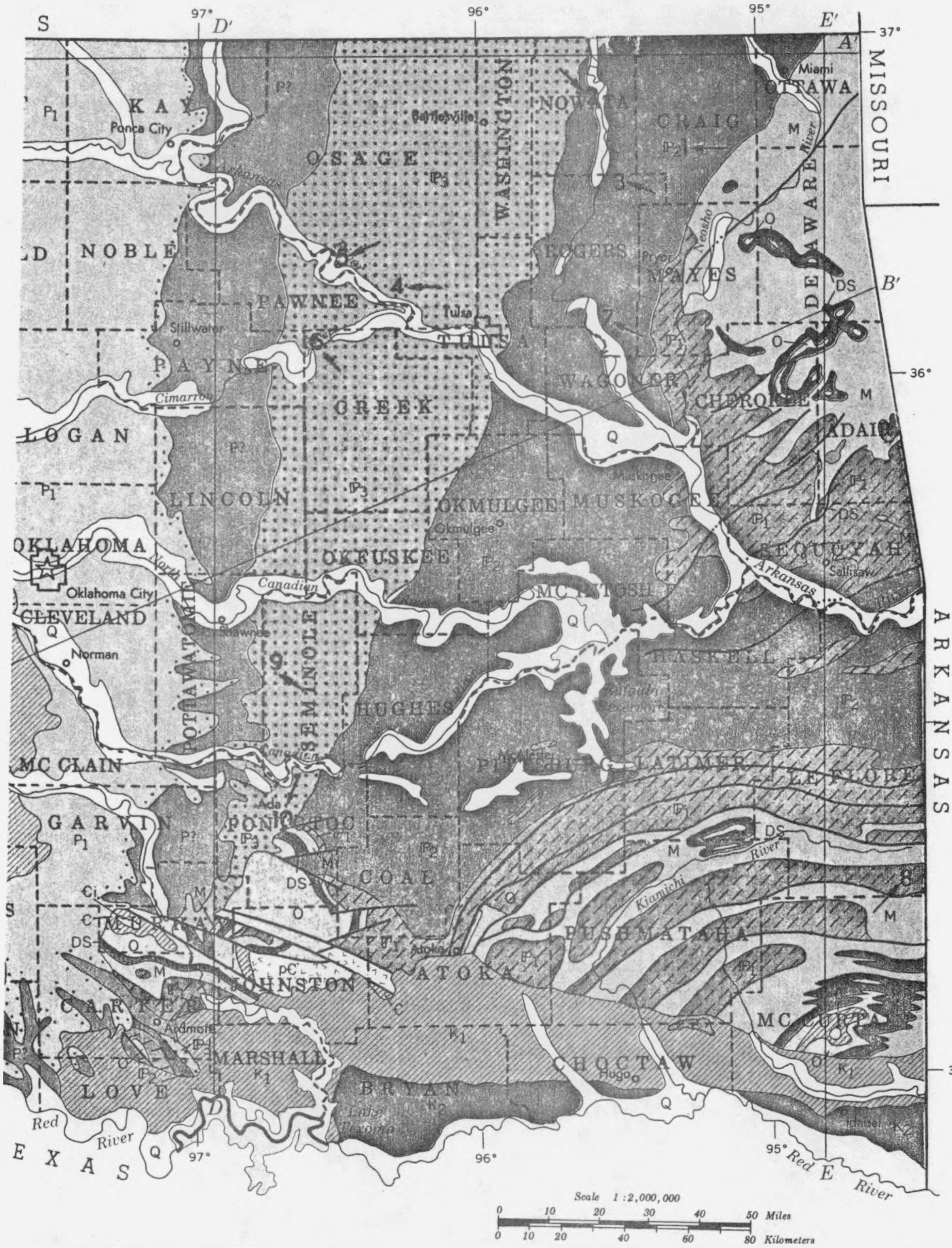


Fig. 46.--Significant radioactive anomalies in Pennsylvanian strata. Map after Branson and Johnson (1972). (See Appendix D for descriptions.)

SUMMARY

Uranium and radioactive anomalies in Pennsylvanian-Permian sandstones in Oklahoma are related to one or several of the following factors:

1. Relatively high feldspar content
2. Hydrocarbon seepage or production
3. Relatively common organic matter
4. Evaporitic depositional conditions

Several combinations of these factors are expressed in the following geologic frameworks in which anomalies have been noted:

1. Feldspathic Permian sandstones on oil-producing structures
2. Alluvial-fan deposits associated with Wichita and Arbuckle uplifts
3. Lenticular sandstones on the Muenster-Waurika arch
4. Tidal-flat (possibly sabkha) sandstones-siltstones in western Oklahoma and north-central Oklahoma
5. Deltaic-alluvial Cherokee sandstones (or oil and/or brine produced from them).

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APPENDIX A

Occurrences of Radioactive Anomalies on Plate 2

SE SE Sec. 31, T6N, R9W

Host: Rush Springs Formation--asphaltic nodules in reddish-brown sandstone one foot thick.

Radioactivity: 0.07 MR/HR near several of the nodules; background: 0.006 MR/HR.

NE SE Sec. 2, T5N, R9W[1]

Host: Rush Springs Formation--thin bedded, limonite stained, sandstone with some interbedded siltstone.

Radioactivity: 0.3 to 1.0 MR/HR on face of bulldozer cut; 0.2 to 0.5 MR/HR for 100 feet along white sandstone bed; background: 0.03 MR/HR.

SE SW Sec. 2, T5N, R9W

Host: Rush Springs Formation--buff to gray, thin bedded silty sandstone.

Radioactivity: 0.03 MR/HR for two to three feet along outcrop; background: 0.006 MR/HR.

SW NE Sec. 3, T5N, R9W[1]

Host: Rush Springs Formation--yellow-brown to white, calcareous sandstone; ore found along facture in the host.

Radioactivity: Selected samples show 1.18 to 2.046 percent eU_3O_8; average radioactivity: ten times background over mineralized fracture.

NW NE Sec. 21, T3N, R5W

Host: Duncan Sandstone--blue-gray, silty sandstone interbedded with carbonate pebble conglomerates.

Radioactivity: 0.02 MR/HR on blue-gray sandstone near contact with carbonate pebble conglomerates; background: 0.008 MR/HR.

---

[1]From United States Atomic Energy Commission (1968).

SW Sec. 9, T3N, R11W[1]

Host: Garber Sandstone--asphaltic sandstone and shale in channels one to two feet thick.

Radioactivity: 0.001 percent eU_3O_8; average radioactivity: 0.04 MR/HR; background: 0.03 MR/HR.

SE Sec. 22, T3N, R14W[1]

Host: Cambrian granite--ore occurs in branching veinlets two to three inches thick.

Radioactivity: 0.002 percent eU_3O_8; average radioactivity: 0.03 MR/HR; background: 0.03 MR/HR.

S½ Sec. 34, T1N, R15W[1]

Host: Post Oak Conglomerate--medium- to coarse-grained arkosic sandstone three to ten feet thick.

Radioactivity: 0.010 percent eU_3O_8; average radioactivity: 0.45 MR/HR; background: 0.04 MR/HR.

SE SE Sec. 1, T1S, R16W[1]

Host: Post Oak Conglomerate--medium- to coarse-grained arkosic sandstone.

Radioactivity: 0.06 to 0.11 eU_3O_8; average radioactivity: 0.035 MR/HR: background: 0.005 MR/HR.

SE Sec. 35, T2S, R6W[1]

Host: Garber Sandstone--coarse-grained asphaltic sandstone in channel two feet thick.

Radioactivity: Selected sample contained 0.001 percent eU_3O_8; average radioactivity: 0.03 MR/HR; background: 0.03 MR/HR.

SW Sec. 7, T4S, R12W[1]

Host: Garber Sandstone--fine-grained, pebbly sandstone and conglomerate containing plant remains and copper.

Radioactivity: 0.05 to 0.11 MR/HR; background: 0.030 MR/HR.

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[1]From United States Atomic Energy Commission (1968).

S½ Sec. 25, T5S, R6W[2]

Host: Oscar Group--arkosic conglomerate containing some copper minerals.

Radioactivity: Selected samples contained 0.008 and 0.022 percent eU_3O_8.

NW SW Sec. 7, T5S, R8W[1]

Host: Wellington Formation--highest radioactivity on dark-red sandstone which occurred as "float" material upon shale.

Radioactivity: 0.052 percent eU_3O_8; average radioactivity: 0.15 MR/HR; background: 0.03 MR/HR.

NW SW Sec. 17, T5S, R8W

Host: Oscar Group--interbedded silty sandstones and shales.

Radioactivity: 0.07 MR/HR in sandy shales; background: 0.008 MR/HR.

SW Sec. 30, T5S, R8W[2]

Host: Wellington Formation--ferruginous sandstone occurring as "float" material.

Radioactivity: Selected sample contained 0.052 eU_3O_8.

NE Sec. 1, T5S, R9W[1]

Host: Oscar Group--radioactivity on sandstone "float" material upon reddish brown shales.

Radioactivity: 0.040 MR/HR in sandstone; background: 0.015 MR/HR.

NE NE Sec. 3, T5S, R11W[1]

Host: Garber Sandstone--reddish brown sandstone and shale containing some azurite and malachite.

Radioactivity: 0.003 eU_3O_8.

NW SE Sec. 30, T5S, R12W[1]

Host: Garber Sandstone--buff colored channel sandstone 25 feet thick; ore in lower part of channel with copper minerals and plant material.

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[1]From United States Atomic Energy Commission (1968).

[2]From McKay (1957).

Radioactivity: 0.014 to 2.140 eU_3O_8; average radioactivity: 0.35 MR/HR; background: 0.01 MR/HR.

NW Sec. 4, T6S, R5W[1]

Host: Garber Sandstone--radioactivity associated with red and black concretions in sandstone.

Radioactivity: 0.20 MR/HR in concretions; background: 0.025 MR/HR.

NW NE Sec. 23, T6S, R5W[1]

Host: Wellington Formation--radioactivity associated with reddish colored concretions in rock.

Radioactivity: 0.08 MR/HR in concretions; background: 0.025 MR/HR.

SW Sec. 13, T7S, R6W[2]

Host: Wellington Formation--carbonaceous sandstone in channel one foot thick.

Radioactivity: Selected samples contained 0.004 and 0.029 eU_3O_8.

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[1] From United States Atomic Energy Commission (1968).

[2] From McKay (1957).

APPENDIX B

Occurrences of Radioactive Anomalies on Plate 3

	Location	Max. Counts/Sec.
1.	Sec. 14, T12N, R18W	410
2.	Sec. 30, T12N, R18W	2200
3.	Sec. 24, T12N, R19W	1000
4.	Sec. 14, T12N, R18W	620
5.	Sec. 29, T12N, R18W	1500
6.	Sec. 33, T12N, R17W	600
7.	Sec. 4, T11N, R17W	600
8.	Sec. 4, T11N, R17W	900
9.	Sec. 4, T11N, R17W	300
10.	Sec. 3, T11N, R17W	400
11.	Sec. 9, T10N, R17W	400
12.	Sec. 13, T9N, R18W	250
13.	Sec. 36, T9N, R19W	250
14.	Sec. 29, T9N, R20W	400
15.	Sec. 7, T9N, R20W	250
16.	Sec. 13, T9N, R22W	400
17.	Sec. 15, R9N, R22W	250
18.	Sec. 35, T10N, R23W	200
19.	Sec. 35, T10N, R23W	300
20.	Sec. 24, T10N, R23W	220
21.	Sec. 15, T10N, R23W	200
22.	Sec. 11, T13N, R25W	300
23.	Sec. 17, T13N, R20W	300

Background: 50-60 cps

APPENDIX C

Occurrences of Radioactive Anomalies on Plate 4

Location	Radioactivity of Anomaly
SE NE Sec. 23, T22N, R3E	
SE NW Sec. 24, T22W, R3E[1]	.002 - > 1 % U (Avg. .04%)
SW NE Sec. 8, T22N, R4E[1]	.043 % U
NE NW Sec. 19, T22N, R4E	
SW SW Sec. 28, T23N, R1W	120 counts/sec.; background 40 cps.

[1] From Curtis and others (1956).

APPENDIX D

Occurrences of Radioactive Anomalies in Figure 46

Location	Stratigraphic Unit	Description	Radioactivity of Anomaly
1. SW NW Sec. 10, T25N, R19E	Bluejacket	Siltstone on outcrop	.010 % eU
SW NW Sec. 15, T25N, R19E	Bluejacket	Sandstone on outcrop	.007 % eU
2. Sec. 35, T27N, R16E[1]	Bartlesville	Formational water	60 ppb U
3. Sec. 21, T25N, R17E	Bartlesville	Ash of oil	.045 % U in ash
Sec. 8, T24N, R17E	Bartlesville	Ash of oil	.040 % U in ash
4. Sec. 7, T21N, R9E[2]	Vamoosa	Sandstone and siltstone	.6 MR/HR
5. Sec. 1, T21N, R7E[2]	Bartlesville (and Simpson)	Formational water, ditch	.7 MR/HR, 5 MR/HR
6. NE Sec. 20, NW Sec. 21, T16N, R17E	Vamoosa	Sandstone on outcrop	.010 % eU
7. SW Sec. 12, T19N, R16E	Bluejacket	Flaser-bedded sandstone	.010 % eU
8. T3N, R26E[2]	Atoka	Siltstone on outcrop	Reported uranium mineralization
9. NE Sec. 14, T8N, R5E	Vanoss	Siltstone and black shale	.007 % eU
10. T4N, R6E[2]	Ada	Asphaltic sandstone	.5 MR/HR

[1]From Hyden and Danilchik (1962).

[2]From U.S. Atomic Energy Commission (1968).

APPENDIX E

Significant Radioactive Anomalies on Gamma-Ray Logs, Northeastern Oklahoma

Location	Interval (Depth)	Stratigraphic Unit	Lithology
SE Sec. 7, T18N, R4E	4000-4100	Cherokee	Shale
NE Sec. 9, T18N, R5E	3460-3500	Woodford (Devonian-Miss.)	Shale
Sec. 17, T18N, R7E	0-100	Virgilian	Shale and sandstone
	2070-2440	Cherokee	Shale and sandstone
	2440-2570	Simpson-Arbuckle (Ordovician)	Sandstone-carbonate
SW Sec. 17, T18N, R7E	2500-2590	Arbuckle (Ordovician)	Carbonate
SW Sec. 31, T20N, R11E	1450-1515	Cherokee	Shale
Sec. 34, T21N, R8E	2350-2400	Cherokee	Shale
Sec. 13, T21N, R14E	200-700	Cherokee	Shale
Sec. 34, T22N, R10E	1440-1490	Cherokee	Shale
SE Sec. 32, T26N, R15E	10-80	Coffeyville (Missourian)	Shale
	860-910	Cherokee	Shale
NE Sec. 2, T28N, R13E	900-1020	Senora (Cherokee)	Shale and limestone


GEOLOGIC MAP AND SECTION OF PRE-PENNSYLVANIAN ROCKS IN OKLAHOMA
SHOWING SURFACE AND SUBSURFACE DISTRIBUTION
by
LOUISE JORDAN
Assisted by William H. Bellis and Tommy L. Rowland
Prepared in collaboration with the oil companies and geologists of Oklahoma
1962
Surface geology modified from Geologic Map of Oklahoma, 1954, by Hugh D. Miser, and from other published sources. Small areas of complex structure are exaggerated and simplified.
EXPLANATION
NORTHERN OKLAHOMA
SOUTHERN OKLAHOMA
SOUTHEASTERN OKLAHOMA
Ouachita Mountain Province
NORTHEASTERN OKLAHOMA
Ozark Uplift
MISSISSIPPIAN
Chester Group
Meramec Group
Osage Group
Springer Formation, Goddard Formation, Caney Shale, Sycamore Formation, and Welden Limestone
Johns Valley Shale, Jackfork Group, and Stanley Group
Pitkin Limestone, Fayetteville Shale, Batesville Sandstone, and Hindsville Limestone, Chester Group; and Moorefield Formation, Meramec Group
Rocks principally of Osage Group. At top, in Ottawa County, includes beds equivalent to Moorefield Formation
NORTHERN AND SOUTHERN OKLAHOMA
DEVONIAN
Woodford Shale
Woodford Shale (Dev.) and Hunton Group (Dev. and Sil.)
Woodford Shale and Pinetop Formation
Arkansas Novaculite (Miss. and Dev.), Missouri Mountain Shale (Sil.?), and Blaylock Sandstone (Sil.)
Chattanooga Shale (Dev.), Sallisaw Formation (Dev.), Frisco Formation (Dev.), and "St. Clair" Formation (Sil.)
SILURIAN
Hunton Group
Woodford Shale (Dev.), Hunton Group (Dev. and Sil.), Sylvan Shale, "Fernvale" Limestone, and Viola Limestone (Ord.)
Arkansas Novaculite (Miss. and Dev.), Missouri Mountain Shale (Sil.?), Blaylock Sandstone (Sil.), Polk Creek Shale (Ord.), Bigfork Formation (Ord.), and Womble Formation (Ord.)
ORDOVICIAN
Sylvan Shale
Sylvan Shale, "Fernvale" Limestone, and Viola Limestone
Polk Creek Shale and Bigfork Formation
Sylvan Shale, "Fernvale" Limestone, Fite Limestone, Tyner Formation, and Burgen Sandstone
"Fernvale" Limestone and Viola Limestone
Simpson Group
Womble Formation, Mazarn Shale, Crystal Mountain Sandstone, Collier Shale, and Lukfata Sandstone
Cotter Dolomite
LATE CAMBRIAN
Arbuckle Group and Timbered Hills Group
EARLY-MIDDLE CAMBRIAN? AND PRECAMBRIAN
Basement complex
Stratigraphic contact in subsurface
Stratigraphic contact on surface
Outcrop trace of Pennsylvanian-Mississippian boundary
Unconformable outcrop trace of Mississippian or older rocks beneath Pennsylvanian, Permian, or Cretaceous strata
Fault in subsurface. Most minor faults and certain other faults not affecting distribution of pre-Pennsylvanian strata are not shown
Major fault mapped from outcrops
KEY TO WELLS SHOWN ON GEOLOGIC SECTION
INDEX MAP OF OKLAHOMA SHOWING LOCATION OF CONTROL WELLS AND GEOLOGIC SECTION
COLORADO
NEW MEXICO
KANSAS
MISSOURI
ARKANSAS
TEXAS
CIMARRON
TEXAS
BEAVER
HARPER
WOODS
ALFALFA
GRANT
KAY
OSAGE
WASHINGTON
NOWATA
CRAIG
OTTAWA
DELAWARE
MAYES
ROGERS
WOODWARD
MAJOR
GARFIELD
NOBLE
PAWNEE
ELLIS
PAYNE
TULSA
WAGONER
CHEROKEE
ADAIR
DEWEY
BLAINE
KINGFISHER
LOGAN
CREEK
ROGER MILLS
CUSTER
LINCOLN
OKMULGEE
MUSKOGEE
CANADIAN
OKLAHOMA
SEQUOYAH
OKFUSKEE
MCINTOSH
WASHITA
BECKHAM
CLEVELAND
SEMINOLE
HASKELL
CADDO
POTTAWATOMIE
MCCLAIN
HUGHES
GRADY
PITTSBURG
GREER
KIOWA
LATIMER
LE FLORE
HARMON
COMANCHE
COAL
JACKSON
STEPHENS
PUSHMATAHA
TILLMAN
COTTON
CARTER
JOHNSTON
ATOKA
JEFFERSON
LOVE
MARSHALL
BRYAN
CHOCTAW
MCCURTAIN
Area of Conformable M-IP Contact
Area of Desmoinesian-Pre-Pennsylvanian Contact
HOLLIS SYNCLINE
WICHITA MOUNTAIN UPLIFT
ANADARKO SYNCLINE
OKLAHOMA CITY UPLIFT
CUSHING UPLIFT
Harmon County
Jackson County
Kiowa County
Caddo County
Grady County
Cleveland County
Oklahoma County
Lincoln County
Payne County
Creek County
Tulsa County
Rogers County
Nowata County
Craig County
Permian-Pennsylvanian
Mississippian-Upper Cambrian
Basement complex
Vertical exaggeration approximately 5:1
GENERALIZED SOUTHWEST-NORTHEAST GEOLOGIC SECTION ACROSS OKLAHOMA

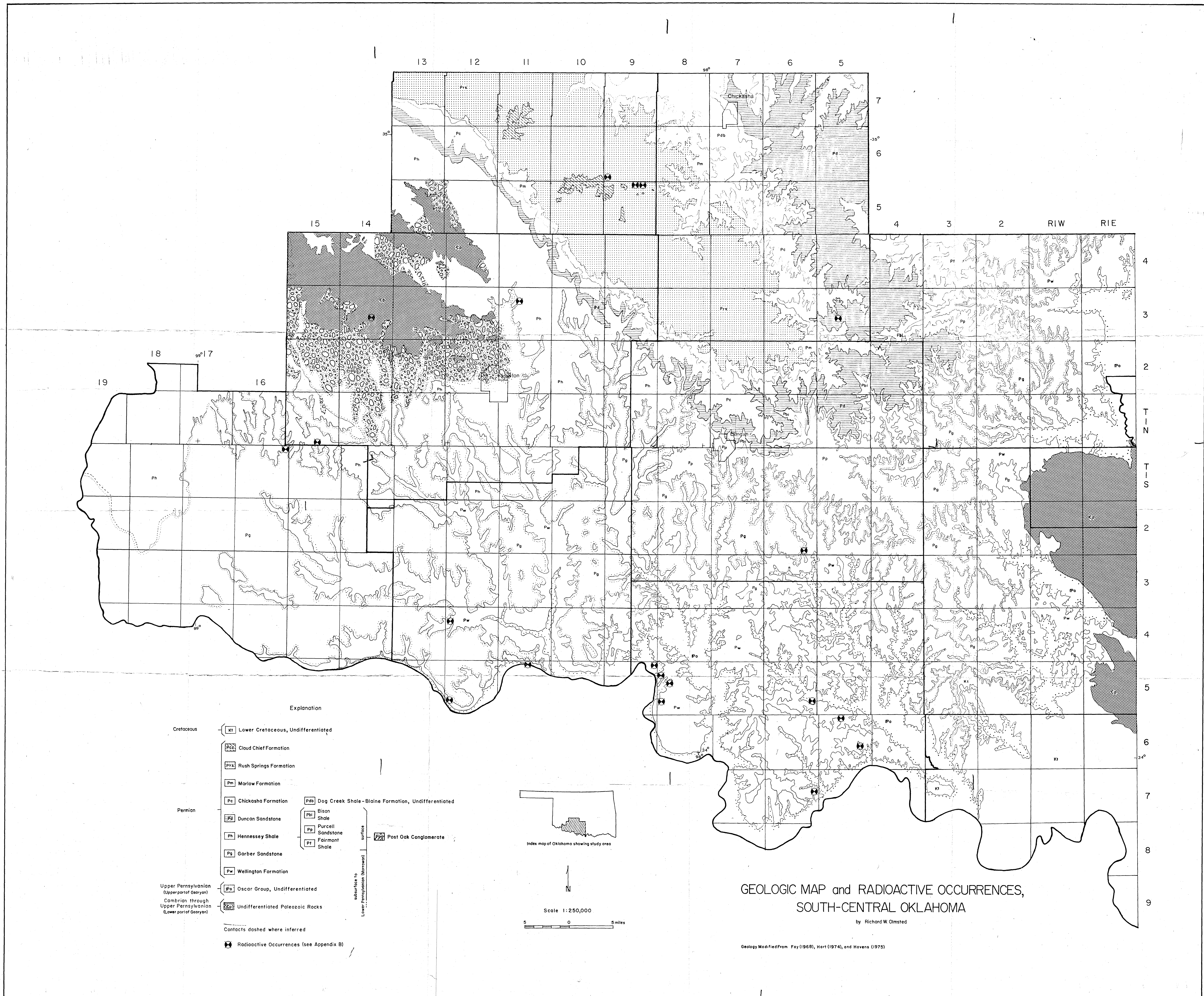
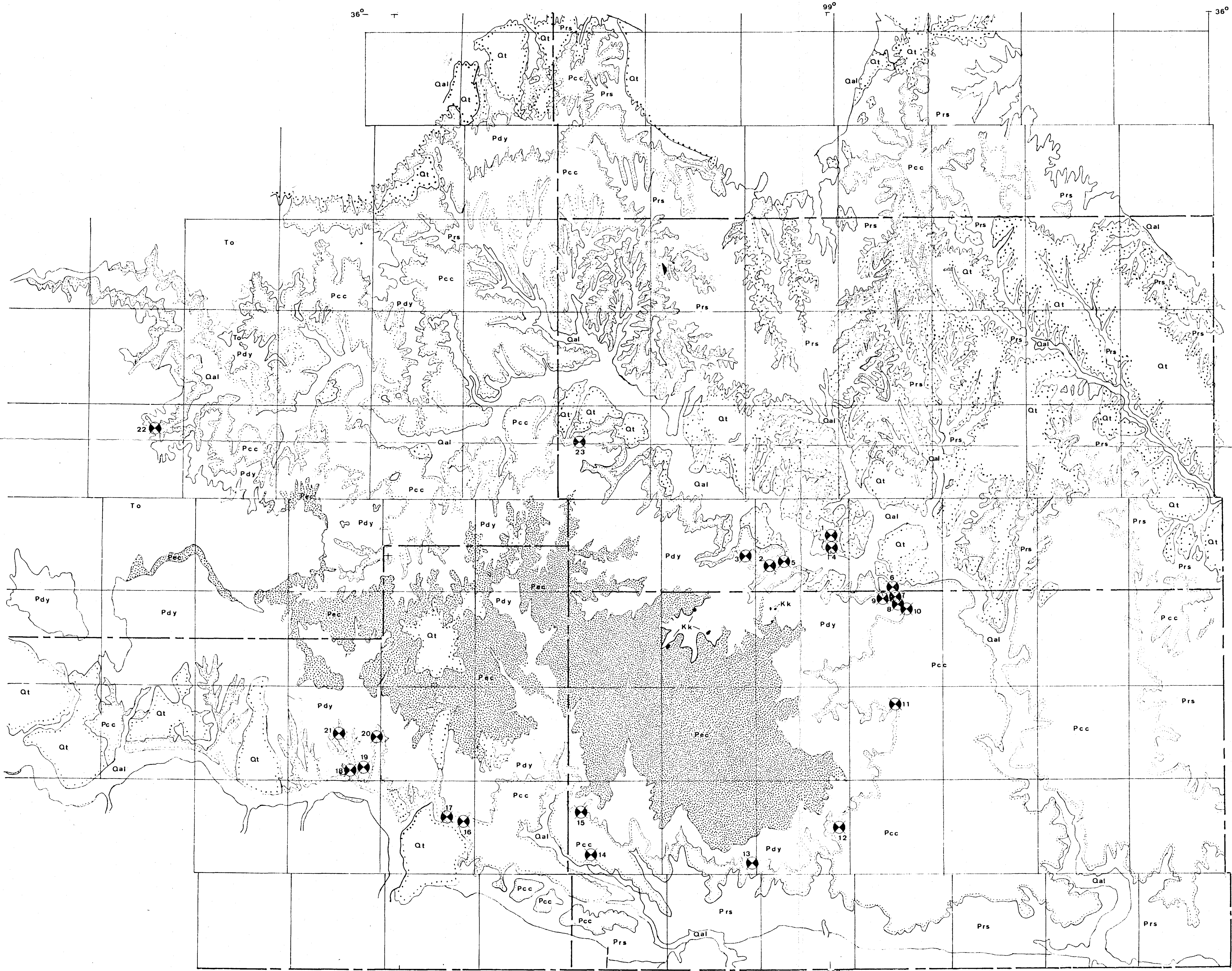

13
12
11
10
9
8
7
6
5
4
3
2
RIW
RIE
15
14
18
17
19
16
98°
99°
35°
34°
T1N
T1S
Chickasha
Prs
Pc
Ph
Pm
Pdb
Pd
Pf
Pw
Pp
Pbi
Pg
Kt
Explanation
Cretaceous
Kt Lower Cretaceous, Undifferentiated
Permian
Pcc Cloud Chief Formation
Prs Rush Springs Formation
Pm Marlow Formation
Pc Chickasha Formation
Pd Duncan Sandstone
Ph Hennessey Shale
Pg Garber Sandstone
Pw Wellington Formation
Pdb Dog Creek Shale-Blaine Formation, Undifferentiated
Pbi Bison Shale
Pp Purcell Sandstone
Pf Fairmont Shale
surface
subsurface to Lower Pennsylvanian (Morrowan)
Ppo Post Oak Conglomerate
Upper Pennsylvanian (Upper part of Gearyan)
IPo Oscar Group, Undifferentiated
Cambrian through Upper Pennsylvanian (Lower part of Gearyan)
Єp Undifferentiated Paleozoic Rocks
Contacts dashed where inferred
Radioactive Occurrences (see Appendix B)
Index map of Oklahoma showing study area
N
Scale 1:250,000
5
0
5 miles
GEOLOGIC MAP and RADIOACTIVE OCCURRENCES,
SOUTH-CENTRAL OKLAHOMA
by Richard W. Olmsted
Geology Modified From Fay (1968), Hart (1974), and Havens (1975)

Plate 3

Geology and Radioactive Occurrences, Western Oklahoma



EXPLANATION

Quaternary
- Qal — Alluvium
- Qt — Terrace Deposits

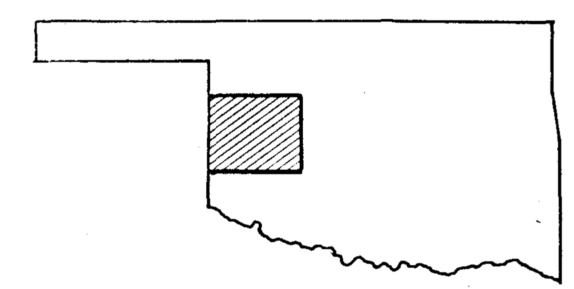
Tertiary
- To — Ogallala Formation

Cretaceous
- Kk — Kiowa Formation

Permian
- Pec — Elk City Formation
- Pdy — Doxey Formation
- Pcc — Cloud Chief Formation
- Prs — Rush Springs Formation

---- Contacts dashed where inferred

Radioactive Occurrence



Location Map

N

Scale 1:250,000

5 0 5

MILES

Geology modified after Carr and Bergman (1976)

Plate 4

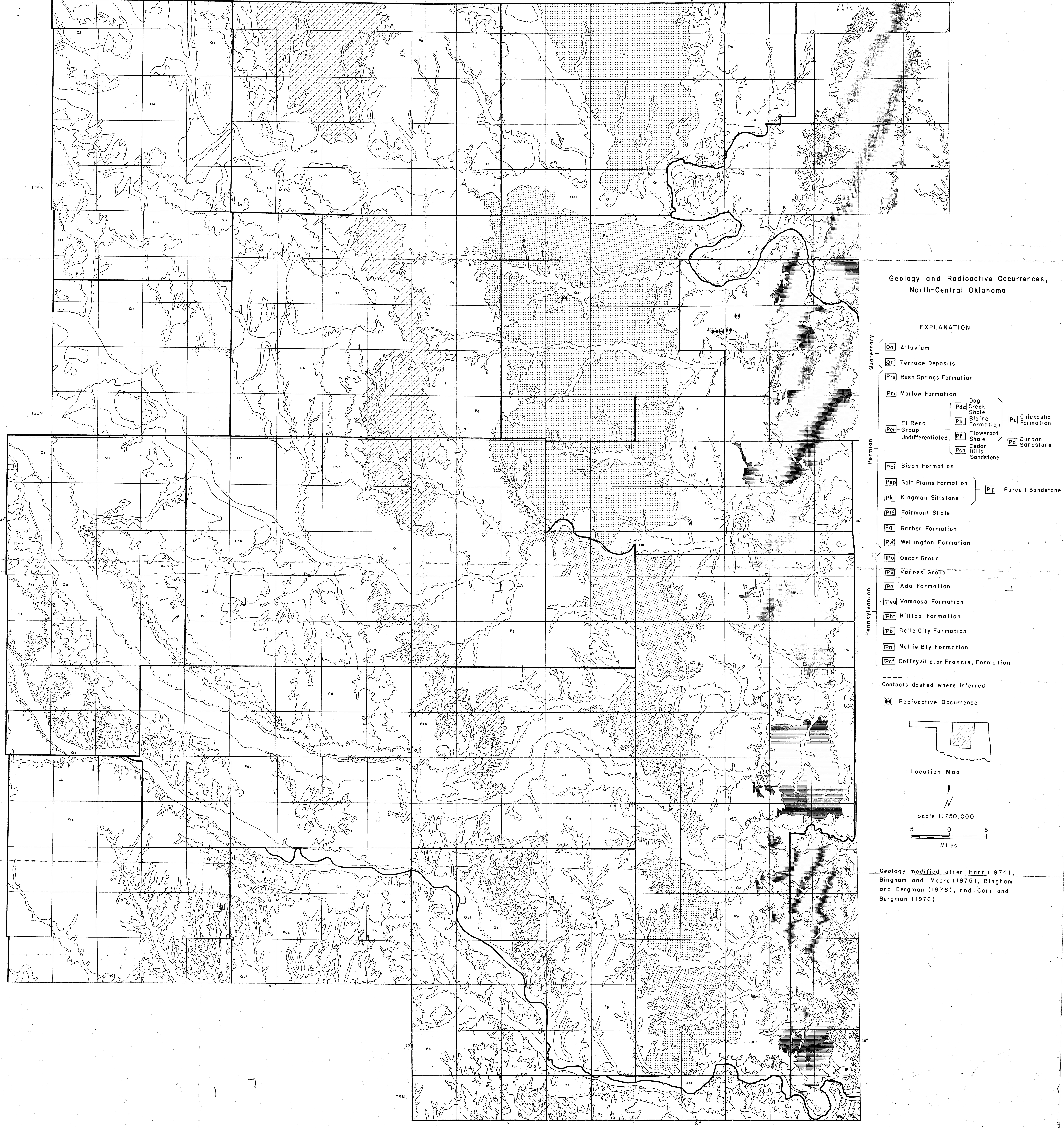
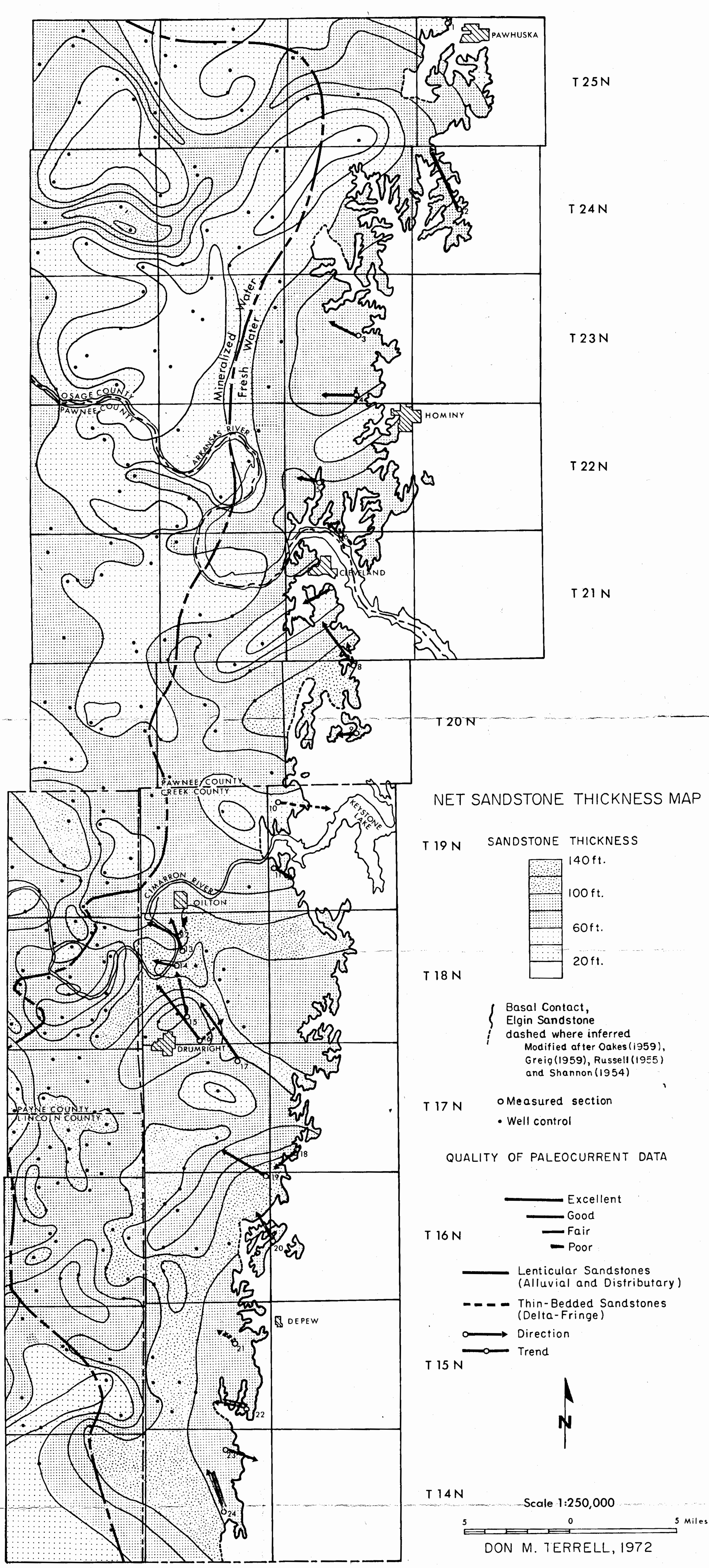

Geology and Radioactive Occurrences, North-Central Oklahoma
EXPLANATION
Quaternary
Qal Alluvium
Qt Terrace Deposits
Permian
Prs Rush Springs Formation
Pm Marlow Formation
Per El Reno Group Undifferentiated
Pdc Dog Creek Shale
Pb Blaine Formation
Pf Flowerpot Shale
Pch Cedar Hills Sandstone
Pc Chickasha Formation
Pd Duncan Sandstone
Pbi Bison Formation
Psp Salt Plains Formation
Pk Kingman Siltstone
Pp Purcell Sandstone
Pfa Fairmont Shale
Pg Garber Formation
Pw Wellington Formation
Pennsylvanian
IPo Oscar Group
IPv Vanoss Group
IPa Ada Formation
IPva Vamoosa Formation
IPht Hilltop Formation
IPb Belle City Formation
IPn Nellie Bly Formation
IPcf Coffeyville, or Francis, Formation
Contacts dashed where inferred
Radioactive Occurrence
Location Map
N
Scale 1:250,000
5 0 5
Miles
Geology modified after Hart (1974), Bingham and Moore (1975), Bingham and Bergman (1976), and Carr and Bergman (1976)
R10W
R5W
R1W
R1E
R5E
T25N
T20N
T15N
T10N
T5N
98°
97°
37°
36°
35°

Plate 5



NET SANDSTONE THICKNESS MAP

DON M. TERRELL, 1972