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THE ANADARKO BASIN
(OF PARTS OF OKLAHOMA ,
TEXAS , KANSAS , AND
COLORADO)

By M. E. MacLachlan

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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This report is preliminary and
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THE ANADARKO BASIN
(OF PARTS OF OKLAHOMA, TEXAS, KANSAS, AND COLORADO)

By M. E. MacLachlan

ABSTRACT

This report is a synthesis of published and unpublished data on the rocks of the Anadarko basin. The Anadarko is an asymmetrical syncline situated in parts of four States and occupying an area of about 45,000 square miles. As defined for this report it consists of: a deep trough at the south side in which there may be 33,000 feet of sedimentary rocks; an embayment area to the northwest where the section is about 9,500 feet thick in the deepest part; and a platform between these 2 features. The basin is outlined by positive elements on the east, south, and west sides, but the north limit is approximately located.

The Anadarko was formed by tectonic movements that began late in Mississippian to early in Pennsylvanian time. Recurrent movements continued into the Early Permian. There is no record of subsequent major orogenic movement except for slight modifications in post-Pliocene time when the embayment area was tilted east.

The Precambrian is exposed at the south edge in the Wichita Mountains. Elsewhere in the Anadarko basin it is a subsurface unit. The Precambrian surface has been covered in the basin since Late Cambrian time, and rocks belonging to the Cambrian through Quaternary Systems are represented.

The major economic resources found in the Anadarko area are water, oil, and gas.

INTRODUCTION

This report synthesizes the areal extent and lithologic content of the rocks of each system. As scores of units have been named and described, the stratigraphic discussions are, of necessity, generalized, and repetition is minimal to be compatible with the objective of the report.

The area discussed covers approximately 45,000 square miles and includes parts of four States; all or parts of 30 counties in northwestern Oklahoma, including the Panhandle area, 13 counties in the northeastern part of the Texas Panhandle, 26 counties in southeastern Kansas, and 4 in southwestern Colorado.

Most of the data used in the text and for the construction of isopach maps of Triassic and older rocks, are subsurface information obtained from wells drilled for oil and gas. The unpublished maps of the Permian System, for example, are based on lithologic description of well cuttings, which were identified by the American Stratigraphic Co., Kansas Sample Log Service, Texas Sample Log Service, and Ware and Kapner Co. The Colorado and Kansas areas shown in figures 15, 16, 17, 18, and 19 were prepared by M. R. Mudge as part of a forthcoming U.S. Geological Survey publication on the Permian System. Data on the Cretaceous, Tertiary, and Quaternary Systems are largely from published reports on ground water resources by the U.S. Geological Survey and reports published by the Kansas Geological Survey.

GEOGRAPHIC SETTING

The Anadarko basin lies in part of a broad highland belt that slopes gently eastward from the Rocky Mountains to the Central Lowland. At the eastern margin the elevation is 1,200 to 2,000 feet above sea level and at the western margin the elevation has increased to more than 4,000 feet above sea level. The major physiographic subdivisions from east to west include parts of the Central Lowland and the Great Plains (Fenneman, 1931). Each subdivision will be related to the geologic map (fig. 1).

The Central Lowland is east of an escarpment formed along a north-south line extending across western Kansas southward into Oklahoma, and generally coincides with the Permian-Tertiary contact. Near the escarpment are depressions due to solution of salt and gypsum formerly contained in Permian rocks. Some of these are permanent lakes. At the southern edge of the Central Lowland are the Wichita Mountains which disrupt an area of low relief. There, Precambrian, Cambrian and Ordovician rocks are exposed and have a general northerly dip.

The Great Plains province includes the High Plains and Colorado Piedmont. The High Plains lies in the central part of the Anadarko west of the Permian-Tertiary contact, and for the most part east of the Cretaceous-Tertiary contact of southeast Colorado. Tertiary rocks are exposed except for areas near the drainages where Quaternary and Mesozoic rocks crop out. The Colorado Piedmont includes the southern counties in Colorado where Cretaceous rocks outcrop and where the elevation is more than 4,000 feet above sea level.

Figure 1.--Generalized geologic map of the Anadarko basin. Geology modified from: Stose and others (1935), Colorado; Moore and Landes (1937), Kansas; Darton and others (1937), Texas; Miser (1954), Oklahoma.

The Anadarko is a grassland area and the climate is continental. Trees are found in lower elevations near the south edge. Grazing and irrigated farming are the major surface land uses. At the eastern margin rainfall averages slightly more than 20 inches and at the western margin the rainfall averages approximately 10 inches. Four major streams traverse the area, rising in the Rocky Mountains and flowing in a southeasterly direction across the basin. They all have wide beds, and are identifiable by the Quaternary pattern. Sand dunes present in belts as much as 15 miles wide are commonly along the northeast sides of the rivers and have been mapped locally with rocks of Tertiary age (Miser, 1954).

Few cities of size are located in the Anadarko basin. In Oklahoma, two have more than 10,000 and two more than 25,000 persons. Texas has two cities of more than 10,000. In Kansas, three have more than 10,000 but none more than 25,000 persons. In Colorado, there is no city of more than 10,000 people.

Major road and railroad systems cross the area from east to west, but north-south travel is by secondary routes.

TECTONIC FRAMEWORK

The Anadarko basin (fig. 2) is an elongate, asymmetrical syncline. Its trend is northwest from south-central Oklahoma and northeast Texas Panhandle to southwest Kansas and southeast Colorado, and it extends over an area of approximately 45,000 square miles.

Many definitions of the limits of the Anadarko are in the literature. Some have confined it to Oklahoma and Texas south of the -3,500-foot structure contour line shown on figure 3. Some have called the entire

Figure 2.--Tectonic framework of the Anadarko basin.

embayment area Hugoton (Worden, 1960, p. 5); others have called the northeast lobe **Dodge City** (Huffman, 1959, p. 5). The west side of the Anadarko has been extended as far as the Sierra Grande uplift to include the Dalhart basin (Adkison, 1960, Sheet 2).

As defined for this report the Anadarko basin is the entire area interior to the uplifts on figure 2. It includes a deep trough near the south side and an embayment area to the northwest. A platform, a wide transverse structure, is located between these two features.

A structure contour map (fig. 3) drawn on the upper surface of the Mississippian System delineates the basin. The -6,000-foot contour line is the approximate north limit of the trough. South of it Mississippian rocks lie at depths greater than 11,000 feet below sea level. The platform is approximately between the -6,000- and -3,000-foot contour lines. The north edge of the embayment area is approximately located at the -1,500-foot contour line.

In a northwest-trending belt, north of the Wichita Mountains, rocks of pre-Pontotoc age (Pennsylvanian and Permian) are intensely folded, faulted, and thrust (fig. 4), and dip steeply north toward the trough. In the deep trough several miles north of the Wichita Mountains an estimated 33,000 feet of Paleozoic sedimentary rocks are thought to overlie rocks of Precambrian age (Ham, Merritt, and Frederickson, 1957, p. 58). Except for the oldest part near the Wichita and Amarillo uplifts, Permian rocks have not been affected by faulting as have those of the preceding systems. On the platform Paleozoic rocks are thinner and dip gently south. In the embayment area

Figure 3.--Structure contour map of the Anadarko basin showing structure on top of the Mississippian System.

Figure 4.--Cross-section of pre-Triassic rocks in the Anadarko basin drawn from the Wichita Mountains, Oklahoma, northwest to southeast Colorado.

a section as much as 9,500 feet thick rests on the Precambrian (Merriam and Geobel, 1956, p. 144), and dips gently south and southeast.

Evidence for two pre-Mississippian diastrophic events--one pre-Late Cambrian and the other Middle Ordovician--in the Anadarko basin are noted by Harleton (1963, p. 1578-1579). The Reagan Sandstone of Late Cambrian age lies unconformably on, but is not intruded by rhyolite, in the Wichita Mountain area where rhyolite and metasedimentary rocks previously assigned a Precambrian age have been reassigned to the Cambrian. The presence of thin bentonitic beds and a facies change from limestone and shale to sandstone suggest tectonic activity during Simpson or Middle Ordovician time.

Several positive elements outline the basin (fig. 2). At the northeast the Central Kansas uplift which trends northwest is a post-Mississippian structure where Ordovician and older rocks lie directly beneath sedimentary rocks of Pennsylvanian age. The Pratt anticline to the south is a minor structural element in south-central Kansas that trends northeast. The Nemaha ridge is a post-Mississippian structure, forming the east edge of the basin in Oklahoma and having a northeast trend. On its western side pre-Pennsylvanian rocks are upturned, truncated, and overstepped by younger rocks, and locally, Mississippian rocks are absent (fig. 3). The Precambrian lies at approximately 4,000 feet near the Oklahoma-Kansas State line. The Nemaha is the only positive element in this area that is still active as may be demonstrated by recent earthquakes.

The Oklahoma City uplift to the south is probably a post-Morrow development that is associated with the Nemaha. On the crest, Middle Pennsylvanian rocks rest on truncated beds as old as Cambrian and Ordovician age.

The Wichita Mountains in Oklahoma where Precambrian, Cambrian and Ordovician rocks are exposed, form the abrupt southern edge. Some have estimated that these mountains rose about 19,000 feet above the basin, and that compressive forces initiated in Late Mississippian time, and recurrent in Pennsylvanian and early in Permian time produced a faulted north front, parallel to the mountains. Wheeler and Wallace (1950, p. 21) have estimated that 15,000 feet of pre-Des Moines rocks were beveled as a result of this orogeny. Associated with the Wichita Mountains is the buried Amarillo uplift, probably a subsurface western extension in Texas of the Wichita Mountains. Permian, Tertiary and Quaternary strata have buried it, and older rocks have been eroded from the crest.

On the west side the Cimarron uplift in Texas and the Keyes dome in the Oklahoma Panhandle which trend north-south may be considered as parts of the Amarillo uplift. Probably formed late in the Paleozoic, they separate the Anadarko from the Dalhart basin to the west. The Las Animas arch on the northwest side is a gentle upwarp that trends northeast extending into the area from central southern Colorado. This feature which separates the Anadarko from the Denver basin to the northwest was initiated early in Paleozoic time, and continued as a prominent structural feature through the Mesozoic Era.

The Freezeout Creek fault forms a sharp western boundary between

the shelf of the Anadarko and an uplift to the west. The fault was probably active in Late Pennsylvanian and Permian time.

PRECAMBRIAN SYSTEM

The composition and structural attitudes of Precambrian rocks in the Anadarko basin are poorly known. Precambrian rocks are exposed only in the Wichita Mountains at the southeast periphery of the basin, but have been reached by drill on and near the other major uplifts, and in part of the embayment. The Precambrian surface ranges from 1,000 feet above sea level (Cohee and others, 1961) on the Amarillo uplift at the southwest edge of the basin in the subsurface, to unknown depths, but certainly in excess of 20,000 feet below sea level, in the southeast part of the trough in Oklahoma. One of the deepest wells in the trough was abandoned in rocks of Springer age at 17,823 feet about 1,000 feet above the top of the Mississippian (Wheeler and Wallace, 1950, p. 18-19).

Wells that have reached the Precambrian have drilled intrusive and extrusive igneous, and metamorphic rocks such as granite, syenite, rhyolite, diabase, diorite, gabbro, quartzite, phyllite, schist, and gneiss. Granite is most commonly found because the uplifts which are at relatively shallow depths are predominantly of this rock type.

Certain regional generalizations have been made. It was thought that igneous rocks occur on the uplifts and metamorphic rocks underlie the basin. An earlier intrusion caused local metamorphism, and a later intrusion produced regional metamorphism with associated dikes and sills. A recent study by Merriam, Cole, and Hambleton (1961, p. 2018) has shown that igneous rocks are present in the embayment as well as on the uplifts.

Flawn (1956, p. 50) believes the igneous rocks are of late Precambrian age. Erosion prior to deposition of Upper Cambrian rocks peneplaned the area but irregularities are known to exist locally on this surface (Farquhar, 1957, p. 107). A weathered zone that is present at the top of the Precambrian at some localities has been mistaken for younger units that were derived from Precambrian rocks. Since Late Cambrian time the Precambrian surface has been covered except for areas on some of the uplifts that were exposed principally at the end of the Mississippian, during the Pennsylvanian and early in Permian time.

SEDIMENTARY ROCKS

Introduction

Rocks of all systems from Precambrian to Quaternary are represented in some part of the Anadarko basin (figs. 1 and 4, table 1). Permian rocks crop out in Oklahoma, Kansas, and Texas; Triassic and Jurassic rocks are represented by small isolated outcrops in the Panhandles of Oklahoma and Texas, and in Kansas; and Cretaceous, Tertiary, and Quaternary rocks are present in parts of all four States. Many small outliers are exaggerated, combined with others, or omitted because of small map scale. Other than exposures of Precambrian, Cambrian, and Ordovician rocks in the Wichita Mountains, all pre-Permian rocks are known only in the subsurface.

Rocks of Cambrian to Permian age attenuate northwestward from the trough toward the Hugoton embayment. Except for ground-water possibilities, there has been little interest in some of the younger subsurface units. As a result, samples are rarely collected

from strata above the Wellington Formation of Permian age (table 1). Units above the Triassic System are discussed in the text, but are not depicted on isopach maps.

Occurrences of some lithologic types in the Paleozoic are noteworthy. Strata of Mississippian and older age (table 2) are predominantly carbonate. New source areas of high relief at the Anadarko's south side changed the lithologic aspect of Pennsylvanian and Permian rocks. Deposition of clastic rocks interbedded with limestone (Middle Pennsylvanian to Early Permian) was succeeded by that of clastic rocks interbedded with evaporites (Early to late Permian).

In the southeast part of the trough in Oklahoma there are thick sequences of black claystone in the Upper Mississippian, Lower and Middle Pennsylvanian. Stratigraphic detail is lacking because these rocks lie at considerable depth and occur in a complexly deformed area. Thin limestone beds common to the Missouri, Virgil, and Lower Permian are vugular and porous. They extend over wide areas on the platform and in the embayment, but change to a clastic lithology southward in the trough toward source areas in the Wichita and Amarillo uplifts. Sandstones of variable genetic character were laid down as beds and as discontinuous bodies such as channel and bar deposits. The extent of sandstone in the lower Paleozoic in the trough is not well known because few wells have penetrated the sequence; the location of channel and bar deposits is difficult to predict. Salt-bearing rocks of Permian age are found in a large part of the Anadarko area. The areal extent was greatest in Wellington time and smallest in Blaine time.

TABLE 1.--Generalized list of stratigraphic units of the Anadarko basin

SYSTEM		SERIES	EMBAYMENT (KANSAS)		PLATFORM AND TROUGH (OKLAHOMA)		
			GROUP	FORMATION	GROUP	FORMATION	
Quaternary	Recent			Alluvium and dune sand		Alluvium and dune sand and terrace gravel	
	Pleistocene			Bignell Loess			
				Peorian Loess			
				Loveland Loess			
				Crete Formation		Missing	
				Sappa Formation			
				Grand Island Formation			
Tertiary	Pliocene			Ogallala Formation		Ogallala Formation	
Cretaceous	Upper			Niobrara Formation		Missing	
				Carlile Shale			
				Greenhorn Limestone		Greenhorn and Graneros equivalents	
				Graneros Shale			
	Lower			Dakota Sandstone		Dakota Sandstone	
				Kiowa Shale		Purgatoire Formation (locally Kiowa Shale is recognized)	
			Cheyenne Sandstone				
Jurassic	Upper			Morrison Formation		Morrison Formation	
				Middle unit		Middle unit	
				Entrada Sandstone		Exeter Sandstone	
Triassic	Upper	Dockum		Sloan Canyon Formation of Stovall (1943)	Dockum		
				Unnamed unit			
Permian				Taloga Formation of Cragin (1897)		Quartermaster Formation	
				Day Creek Dolomite		Cloud Chief Formation	
			Whitehorse equivalent		Whitehorse	Rush Springs Sandstone	
						Marlow Formation	
			Nippewalla of Jewett (1959)	Dog Creek Shale	El Reno	Dog Creek Shale	Chickasha Formation
				Blaine Formation		Blaine Gypsum	
				Flowerpot Shale		Flowerpot Shale	
				Cedar Hills Sandstone			
				Salt Plain Formation			
				Harper Siltstone			
			Sumner	Stone Corral Formation		Stone Corral Formation	Duncan Sandstone
				Ninnescah Shale		Hennessey Shale	
				Wellington Formation		Garber Sandstone ? Wellington Formation	
			Chase		Chase		Wichita Formation
			Council Grove		Council Grove		
			Admire		Admire		
Carboniferous	Pennsylvanian	Virgil					
		Missouri					
		Des Moines					
		Atoka				Dornick Hills Formation	
		Morrow					
	Mississippian	Chester				Springer Formation	
		Meramec					
		Osage					
		Kinderhook		Chattanooga Shale		Woodford Shale	
Devonian							
Silurian			Missing	Hunton			
Ordovician	Upper			Missing		Sylvan Shale	
				Viola Limestone		Viola Limestone	
	Middle		Simpson		Simpson		
Lower							
	Arbuckle		Arbuckle				
Cambrian	Upper		Timbered Hills		Timbered Hills		
Precambrian				Metamorphic and igneous rocks		Metamorphic and igneous rocks	

Table 2.--Relative abundance, in percent, of common sedimentary rocks
in the trough of the Anadarko basin

[Modified from Bokman, 1954]

	Upper Pennsylvanian	Middle Pennsylvanian	Lower Pennsylvanian and Upper Mississippian	Mississippian and Devonian (base of Springer to base of Woodford)
Sandstone--	22	15	8	8
Mudstone--	65	71	88	39
Limestone--	13	14	4	53

	Devonian and Silurian	Ordovician		
	Hunton Group	Sylvan Shale	Viola Limestone	Simpson Group
Sandstone--	-----	-----	-----	20
Mudstone---	20	100	-----	40
Limestone--	80	-----	100	40

	Carboniferous	Pre-Carboniferous and post-Arbuckle
Sandstone-----	17	12
Mudstone-----	66	34
Limestone-----	17	54

A map was constructed to show the areal distribution of geologic units at a depth of 6,000 feet (fig. 5). The youngest strata are of Wolfcamp age and are present in isolated areas near the south border of the trough. The oldest rocks, those of Precambrian age, are updip in the embayment. Intervening units of Pennsylvanian, Mississippian, Ordovician, and Cambrian age lie at this depth in the central part of the Anadarko.

Mesozoic rocks are present in the western part of the area. They probably were not deposited over the entire basin. Fay (1959, p. 12) believes that Cretaceous rocks did not extend beyond 99° because fragments of them have not been found east of that longitude. He believes Pleistocene stream patterns developed on Permian rocks. Subaerial erosion persisted from Cretaceous to Pliocene time, as there is no evidence of deposition or major orogenic movement in the Anadarko during the Tertiary Period. However, the embayment was modified in post-Pliocene time by slight eastward tilting. At the end of the Tertiary, Ogallala deposits were eroded as much as 500 feet at some localities. Ogallala sediments were reworked by Pleistocene streams thus making the Tertiary-Quaternary contact obscure particularly in the subsurface. Terrace deposits, dune sand, and alluvium were laid down in Quaternary time.

Most drillers attempt to penetrate rocks of Morrow age. Older rocks, particularly in the trough, lie at depths too deep to be explored for oil economically at the present time. Consequently, pre-Pennsylvanian units in Oklahoma are not as well known as those of younger ages, and thicknesses shown on figures 6, 7, 8, 9, 10, and 11

Figure 5.--Map showing rocks present at 6,000 feet below the surface.

are inferred in the trough from known thicknesses in the embayment, platform, and areas adjacent to the Amarillo and Wichita uplifts.

Data on depths at which specific horizons will be encountered in the trough are scarce. At the southeast edge of the trough 1 well drilled to 18,158 feet reached Springer rocks. About 18 miles east and slightly north another well reached Arbuckle rocks at 15,184 feet (Suffield, 1956, p. 173). Estimated depths to pre-Pennsylvanian units based on known thicknesses (Suffield, 1956, p. 179) are: Mississippian--18,300 feet; Hunton--21,500 feet; Viola--22,400 feet; Simpson--23,000 feet, and Arbuckle--24,600 feet.

Extremely thick sections are recorded from some wells at the southeast end of the trough. The reliability of them is suspect because of their proximity to the zone of complex folding and faulting (fig. 2) that resulted from the late Paleozoic orogeny. Some (Huffman, 1959, figs. 2-6, 7-12) presume that rocks of all systems are present in the trough as southward thickening units that butt abruptly against the Wichita-Amarillo uplifts. Actually parts of each pre-Pennsylvanian system may be represented at some localities in this zone in fault blocks rather than as rapidly southward thickening sections. At other localities steep dip, repetition of beds, or other structural complications caused by the faulting, folding, and thrusting may account for thick sequences. The thick Pennsylvanian section, estimated to include more than half of the 33,000-foot subsurface sedimentary section (Ham and others, 1957, p. 58), may also be somewhat excessive because of structural complications.

Most of the nomenclature of the Anadarko was established in Kansas and Oklahoma. Some units, however, were named for localities as far north as Nebraska. Although the northeast Texas Panhandle is included in the Anadarko, many local geologists have preferred to extend nomenclature from south of the Amarillo uplift into that part of the basin, using the Oklahoma-Texas State boundary as a dividing line for terminology, though sharp lithologic changes do not occur at that line. This artificial boundary has established names in Texas such as: Clear Fork Group rather than Hennessey or Ninnescah Shales; Wichita Group rather than Wellington Formation; "Blaine of Texas" to mean something more than the Blaine of its type locality; and Herington Limestone (a thin member of the Nolans Limestone of the Chase Group in Kansas) to include rocks which probably are equivalent to the entire Chase Group.

The Pennsylvanian System has been finely divided into scores of units in Kansas, but a discussion of such voluminous nomenclature was untenable for this type of report. These divisions though recognizable in parts of Kansas and Oklahoma have not been clearly established everywhere in the Anadarko basin.

Cambrian and Ordovician Systems

The basement complex is unconformably overlain by rocks of the Timbered Hills (Late Cambrian age) and Arbuckle (Late Cambrian and Early Ordovician age) Groups, undivided (fig. 6). The areas of maximum thickness are in the trough where these groups may be more than 4,000 feet thick. Timbered Hills and Arbuckle rocks have been removed from the Amarillo uplift and from parts of the Wichita Mountains.

Figure 6.--Isopach map of rocks of Timbered Hills and Arbuckle ages (Late Cambrian and Early Ordovician). Modified from Huffman (1959, p. 6).

Exposures 6,200 feet thick have been reported from the northeast side of the Wichita Mountains (Ham and others, 1957, unnumbered table). Depths to the top of the Arbuckle are less than 2,000 feet below sea level near the Central Kansas uplift and are more than 4,100 feet below sea level on the platform in Oklahoma.

The Reagan Sandstone at the base of the Timbered Hills is a coarse, white, arkosic, calcareous, dolomitic and glauconitic sandstone. Minor amounts of white to pink chert are present at the base. The Reagan may be 30 to 460 feet thick (Huffman, 1959, p. 9).

The upper part of the Timbered Hills and the overlying Arbuckle is a sequence of dolomite and dolomitic limestone which may be brown to brown gray, fine to coarsely crystalline, and sandy, silty, cherty, and oolitic. More limestone and chert is present in the Ordovician than in the Cambrian part.

The Simpson Group of Middle Ordovician age (fig. 7) unconformably overlies the Arbuckle Group in the trough, platform, and in part of the embayment. A section as much as 2,000 feet thick is postulated at the southeast end of the trough. The top of the Simpson lies at approximately 2,300 feet below sea level near the Central Kansas uplift, and at an unknown depth below sea level in the trough.

The Simpson Group is a sequence of alternating sandstone, shale, and limestone with minor amounts of gray, sandy to silty dolomite. Sandstone is gray, very fine to medium grained, and dolomitic. At the base and top the sandstone may be conglomeratic, poorly sorted and loosely cemented. Shale is gray to green, but may be black locally.

Figure 7.--Isopach map of rocks of Simpson age (Middle Ordovician).

Modified from Huffman (1959, p. 7).

Limestone usually gray, but brown at some localities is fine to medium crystalline, sandy, and dolomitic. Pyrite, glauconite, and phosphate pellets are important accessory constituents.

The Viola Limestone (fig. 8) of Middle and Late Ordovician age overlies the Simpson Group in the trough and in the southern part of the embayment. The Viola is thinner than the underlying Simpson, and extends over a slightly larger area. Hence, it overlies the Arbuckle Group at the west edge in the Oklahoma Panhandle and Colorado, at the central and north edge in Kansas, and locally at the east near the Central Kansas uplift and Nemaha ridge.

The maximum thickness exceeds 1,000 feet. The top of the Viola would be reached about 2,100 feet below sea level at the north end of embayment and an unknown depth below sea level in the deepest part of the trough.

The lower part of the Viola is buff, brown to gray, fine crystalline limestone. In the upper part it is more coarsely crystalline and crinoidal limestone. The Viola may be dolomitic, cherty, and fossiliferous. Dolomite and dolomitic limestone with brown and gray chert are the predominant facies in the embayment; limestone with dark-gray to black chert characterizes the trough; and alternating limestone and dolomite facies are common on the platform.

The Sylvan Shale of Late Ordovician age (fig. 9) overlies the Viola Limestone. The Sylvan is missing from about two-thirds of the Anadarko, thereby covering a smaller area than any of the pre-Triassic units. It is 0 to 100 feet thick on the platform and more than 500 feet thick in the trough.

Figure 8.--Isopach map of rocks of Viola age (Middle and Late Ordovician).
Modified from Huffman (1959, p. 8).

Figure 9.--Isopach map of rocks of Sylvan age (Late Ordovician).
Modified from Huffman (1959, p. 9).

The Sylvan is a green-gray, dark-gray to black, waxy shale with a satiny luster. Dolomite is present as beds and stringers near the base, and is a more common constituent in northern Oklahoma.

Silurian and Devonian Systems

The Hunton Group (fig. 10) of Silurian and Devonian age overlies the Sylvan Shale except for areas in the Texas and Oklahoma Panhandles where it rests on the Viola. It is more than 1,000 feet thick in the trough. The top of this group would be reached between 7,400 feet below sea level south of the platform in Oklahoma and an unknown depth below sea level in the deeper parts of the trough.

The Hunton is composed of limestone which may be gray to brown, coarsely crystalline, dolomitic, oolitic and glauconitic, and a few thin dolomite beds which are gray to brown. Some pink crinoidal limestone is present in the upper part. Locally, gray chert is abundant.

Devonian and Mississippian Systems

Upper Devonian and Lower Mississippian Series

One of the most distinctive units in the Anadarko basin is the deposit of Late Devonian and Early Mississippian age (fig. 11). In Oklahoma it is called Woodford Shale and overlies the Hunton Group, except at the north and west edges where it rests locally on the Sylvan and locally on the Viola. In Kansas, the temporal equivalent of the Woodford is the Chattanooga Shale which rests on the Viola. Rocks of Woodford age are more than 500 feet thick in the trough. Depths to the top of this formation are at about 4,700 feet below sea level on the Oklahoma platform to more than 7,300 feet below sea level directly south of it.

Figure 10.--Isopach map of rocks of Hunton age (Silurian and Devonian).
Modified from Huffman (1959, p. 10).

Figure 11.--Isopach map of rocks of Woodford age (Devonian and Mississippian). Modified from Huffman (1959, p. 14).

The Woodford is a green, dark-gray to black, radioactive shale. It is pyritic and contains black chert as lenses and beds. Buff to brown, crystalline limestone, which contains buff, gray and black chert, and a few thin dolomite beds are present. On the northeast part of the platform it has been described as a gray to black, bituminous, sporeaceous mudstone.

Locally, at the base, is a thin, very fine- to medium-grained, pyritic and glauconitic sandstone. It is known as the Misener sand of subsurface usage.

Mississippian System

Mississippian rocks above the Woodford (fig. 12) are the thickest and most widespread of any of the post-Arbuckle pre-Pennsylvanian units. The Mississippian overlaps progressively older rocks from the southeast part of the trough in Oklahoma to the northwest in the embayment, resting successively on the Woodford Shale, Hunton Group, Viola Limestone, and Arbuckle Group. The depth to the top of the Mississippian (fig. 3) ranges from 1,000 feet in the embayment to more than 11,000 feet below sea level in the trough.

More than 3,000 feet of Mississippian rocks are postulated to lie in the deepest parts of the Anadarko basin. An abnormal sequence, 4,567 feet thick, in one well, at the east end of the trough directly north of the Wichita Mountains, is thought to be the result of steep dip or repetition of beds by faulting (McDaniel, 1959, p. 16). The irregular thicknesses near the Nemaha ridge are due to post-Mississippian erosion. Mississippian rocks are missing from the Wichita Mountains and the Amarillo uplift, and from parts of the Nemaha ridge. Lower

Figure 12.--Isopach map of rocks of Mississippian age.

Mississippian rocks are present over the entire Anadarko area. Locally the Upper Mississippian is thin or absent.

Lower Mississippian Series

Gray and brown, fine crystalline to granular, cherty, partly silty limestone characterizes the Lower Mississippian (Kinderhook and Osage ages). In general, the rocks are darker (gray to black), siltier (silty limestone and limy siltstone and mudstone), and less cherty in the upper part. The trough facies is predominantly cream to dark-gray, silty, fossiliferous limestone and gray shale, whereas the embayment facies is predominantly buff to gray, glauconitic, very cherty limestone and dolomite.

Upper Mississippian Series

Rocks of Meramec age are composed of brown and gray, finely granular dolomite and dolomitic limestone. Some glauconite is present. Chert is abundant to the north where it is white to gray, but to the south it is less abundant and darker. The rocks also become siltier southward in the trough. Meramec rocks are divisible into three parts. The lower part is gray-buff dolomite and dolomitic limestone containing white chert. The middle part is buff to brown, oolitic, dense limestone with thin interbeds of cream dolomite and dolomitic limestone that contains tan chert. The upper part is a cream, sandy, oolitic limestone with orange to pink reworked chert.

Rocks of Chester age contrast with the carbonate sequence of the underlying Meramec and Osage in that they are lithologically more variable. Brown, gray-buff to dark-gray, medium crystalline, oolitic and crinoidal limestone, which may be silty and dolomitic in part, is interbedded with gray and gray-green shaly mudstone.

At the top of the Mississippian on the platform near the Nemaha ridge in Oklahoma is the Mississippi chat, an informal term. The chat is a residual chert zone that is composed of weathered, tan, tripolitic chert, probably derived from eroded rocks of Osage age, which was cemented in Pennsylvanian time. It overlies rocks of Osage age and underlies Pennsylvanian strata but the exact age of this unit is unknown.

In the southeast part of the trough in Oklahoma, the lithologic character and nomenclature differs from that used elsewhere in the Anadarko area. There, the strata are made up of gray, cherty, silty limestone at the base, that is overlain by a thick sequence of brown to black, gritty, calcareous, shaly mudstone. Where these lithologies are present, the Mississippian-Pennsylvanian contact is obscure.

Pennsylvanian System

Pennsylvanian rocks rest unconformably on those of Mississippian age. Depths to the top of the Pennsylvanian range from about 200 feet above sea level in the northern part of the embayment and about 700 feet above sea level near the Central Kansas uplift to more than 4,000 feet below sea level in the trough.

The development of the Anadarko basin and its bordering uplifts (fig. 2), initiated perhaps late in Mississippian time, affected the thickness and lithologic content of these strata. Thicknesses in excess of 18,000 feet may be present in the deep trough north of the Wichita Mountains. Clastic deposition prevailed (table 2). In Early and Middle Pennsylvanian time thick, dark claystone with some interbedded

sandstones was deposited. In Late Pennsylvanian time cyclic sedimentation prevailed. Alternating thin persistent limestones, claystones, and lenticular and local channel sandstones were laid down. Upper Pennsylvanian deposits contain thick wedges of arkosic materials near the Amarillo and Wichita uplifts. Some of these have been called granite wash by many subsurface geologists. However, these strata contain pebbles of limestone, dolomite, and chert as well as granitic material, in a matrix of poorly sorted arkose loosely cemented by calcium carbonate.

The Pennsylvanian is divided into two parts for the isopach maps (figs. 13 and 14), and into series in the text. This system has been divided locally into much smaller units as shown by Jewett (1959).

Lower Pennsylvanian Series

The lowest sequence of Pennsylvanian rocks is more than 8,000 feet thick in the trough, and is divisible into 2 parts.

The Springer Formation at the base belongs to the Mississippian and Pennsylvanian Systems (Chester and Morrow Series), but because an indeterminate part of it is of Chester age it is discussed with other units of Pennsylvanian age. The Springer is confined generally to the trough where thicknesses of 4,000 to nearly 6,000 feet have been reported in the southeast part (McDaniel, 1959, p. 17). These thicknesses may be excessive and due to steep dip or faulting. The presence of Springer in the Panhandle area is not certain (Totten, 1956, p. 1954). Therefore, the western as well as the northern limit is not precisely known.

The Springer is a dark-gray to black claystone, slightly sideritic

Figure 13.--Isopach map of rocks of Early and Middle Pennsylvanian age.

Figure 14.--Isopach map of rocks of Late Pennsylvanian age.

and locally bituminous. Some sandstone and thin, dark-gray, silty to sandy limestone beds are also present.

Younger Morrow rocks overlie the Springer in the deep part of the trough and overlie Mississippian rocks updip. The relationship of the upper part of the Morrow to the Springer and the areal extent of both units are indeterminate.

In the southeast part of the trough the younger Morrow is more than 4,000 feet thick (McDaniel, 1959, p. 18). These rocks are thought to be absent from the northeast part of the platform and from parts of the embayment. Some suggest postdepositional erosion, others nondeposition. However, this unit, as well as the overlying rocks of Atoka age, may be thin, but not recognized, because of miscorrelation with units present east of the Anadarko basin.

In the Texas Panhandle at the base of the younger sequence of Morrow age is a gray to tan, fine- to coarse-grained, poorly sorted, subangular to subround, glauconitic, pyritic, calcareous sandstone. This sandstone, as much as 150 feet thick, is known locally as the Keyes sand. The sequence above the Keyes is composed of gray to black, carbonaceous, pyritic claystone and gray to brown siliceous and glauconitic sandstone. Gray to buff limestone is common. Limestone conglomerate is present locally north of the Amarillo uplift.

In Oklahoma the upper part of the Morrow is the lower part of the Dornick Hills Formation. It is a dark-gray claystone and siltstone, and gray, very fine- to medium-grained, glauconitic calcareous sandstone. Some interbeds of gray silty to sandy limestone are present.

Middle Pennsylvanian Series

Rocks of Atoka age have approximately the same areal extent as the underlying rocks of Morrow age (Huffman, 1959, figs. 11 and 12). One of the thickest sections is 5,000 feet thick and is in Oklahoma.

Dark-gray to black claystone with thin dark-gray to brown, dense, cherty limestone, and fine-grained, calcareous sandstone beds comprise this interval. At the north flank of the Amarillo uplift thin wedges of arkosic limestone conglomerate are present. In Oklahoma the Atoka is represented by the upper part of the Dornick Hills Formation. This unit is primarily a gray to black claystone with gray siltstone, gray, very fine- to medium-grained, calcareous sandstone, and gray to black limestone. Some of the sandstone is coarse grained. Some coal is present in the lower part.

Orogenic movements prior to Des Moines time did not affect Pennsylvanian deposition in the northwest part of the Anadarko, but they accounted for the thin to missing sections of Springer, Morrow, and Atoka ages in the east part of the basin. Des Moines rocks were the first Pennsylvanian deposits to cover a large part of the Anadarko, overlapping successively older strata--Atoka, Morrow, and Mississippian--northeastward (Boler, 1959, fig. 16). Rocks of Des Moines age thicken southward from Kansas to more than 2,300 feet in Oklahoma (Adkison, 1960). They are cyclical deposits that are predominantly gray to black claystone but may be reddish near the base. Gray, very fine grained sandstone and gray to black, dense to finely crystalline limestone beds are common. Some of the limestones are oolitic and contain black chert. Coal beds are present locally.

Upper Pennsylvanian Series

Rocks of Missouri age are more than 2,000 feet thick in the trough, and more variable lithologically than the older Pennsylvanian deposits. This sequence is composed of gray to black claystone and gray, fine crystalline limestone which may be oolitic and cherty. Coarse- to fine-grained, gray sandstone, some gray siltstone and several coal beds are common in the middle and upper parts. Glauconite and chert are important accessory constituents.

Rocks of Virgil age thicken to more than 3,000 feet in the trough, and are alternations of claystone, limestone, siltstone, and sandstone. A few coal beds are present near the base and at the top. Claystone is usually gray to black, but may be gray red to red brown. Limestone is brown to gray, generally finely crystalline, although individual beds are sandy to silty, and oolitic. The siltstone and sandstone are gray. Sandstone ranges from very fine to medium grained. Chert is an important accessory constituent.

During Missouri and Virgil times limestone was more predominant in the thinner section in the embayment. The mudstone and sandstone sequence in the trough is gradational on the platform with the embayment facies, and with the thick arkosic conglomerates near the Amarillo and Wichita uplifts.

Permian System

Permian strata are present over the entire Anadarko area. The top of the Permian is about 1,700 feet above sea level at the north end of the embayment and is about 2,500 feet above sea level in the trough. Permian rocks thicken from 1,500 feet at the north edge to 6,500 feet in the trough.

Beveling has exposed the Wellington Formation (table 1) at the east side and pre-Wellington deposits near the Wichita Mountains. The Wellington is buried by successively younger Permian formations westward to the Permian-Tertiary contact (fig. 1). Throughout the remainder of the Anadarko area, Permian deposits are in the subsurface.

The lower contact of the Permian is arbitrarily placed at many localities. On the platform and northward in the embayment the contact is at the top of the Brownville Limestone Member of the Wood Siding Formation (Late Pennsylvanian age). South toward the trough the systemic contact is obscured as the sequence becomes more clastic in both systems, and identification of individual limestone beds is arbitrary. The upper contact with Triassic rocks (fig. 20) is at the west edge of the Anadarko where Upper Triassic rocks are present in the subsurface and where they are exposed at scattered localities along major drainages (fig. 1). Elsewhere the upper contact is locally with Cretaceous and locally with Tertiary rocks.

The Permian is divided into three parts for this study. The oldest part (fig. 15) includes rocks of Wolfcamp age between the Pennsylvanian-Permian and Herington-Wellington contacts. In the middle part (fig. 16) are those units from the base of the Wellington to the top of the Dog Creek Shale which are considered of Leonard and early Guadalupe age. The youngest part (fig. 17) includes strata from the base of the Marlow to the top of the Quartermaster, generally considered to be of late Guadalupe age. Whether rocks of Ochoa age are represented by all or part of the Quartermaster and Cloud Chief, or their correlatives, is not resolvable at this time because the correlation of these units with

Figure 15.--Isopach map of rocks of Wolfcamp age, Kansas and Colorado, by M. R. Mudge.

Figure 16.--Isopach map of rocks of Leonard and early Guadalupe age,
Kansas and Colorado, by M. R. Mudge.

Figure 17.--Isopach map of rocks of late Guadalupe age, Kansas and Colorado, by M. R. Mudge.

those of known Ochoa age in southern Texas has not been established.

The Permian represents the final phase of the Anadarko as a depositional and structural basin. The Admire Group at the base of the lower part is a transitional deposit between cyclic deposition of thin beds of claystone, limestone, and sandstone of Late Pennsylvanian age to thick beds of marine limestone and mudstone of the Chase Group. The middle part is comprised of reddish mudstone, evaporite, and some sandstone, with dolomite beds scattered throughout the sequence. This restricted marine deposition is replaced in the upper part by that of mudstone and sandstone with minor anhydrite, gypsum, dolomite, and limestone, on perhaps what was part of a marine mudflat.

Lower part

Rocks of Wolfcamp age (fig. 15) are coextensive with those of Late Pennsylvanian age in the Anadarko basin, thickening southward from 600 feet in the embayment to more than 2,000 feet in the trough.

In the embayment and on the platform the lower part of the Permian has been divided into three groups which are, in ascending order, the Admire, Council Grove, and Chase. In the trough the section becomes more clastic, and limestones used to define the boundaries of each group are not easily identified. The name Wichita Formation (lower part) has been applied to the sequence in west-south-central Oklahoma, and the name Pontotoc Group (upper part) has been extended into the area for rocks in east-south-central Oklahoma. The nomenclature for Wolfcamp rocks in Texas is informal except for the application of the name Herington for rocks of Chase age (Totten, 1956, fig. 8).

Gray limestone and shale, and some dolomite comprise this interval in the embayment and on the platform. Carbonate rocks make up as much as 80 percent of the section. Limestones are commonly cherty, vugular, oolitic, and fossiliferous. Sandstone, generally fine grained to medium grained, is present as beds and channel fillings. At the northwest edge near the Las Animas arch and south of the platform, limestone beds pinch out. Red-brown mudstone and conglomerate occupy most of the section equivalent to the Admire and Council Grove Groups. Conglomeratic rocks derived from granite of Precambrian and limestone of Paleozoic ages are present as thick wedges near the Amarillo-Wichita uplifts thinning northward.

Middle part

Rocks of Leonard and early Guadalupe age (fig. 16) between the base of the Wellington and the top of the Dog Creek Shale (table 1), thicken from Kansas, where less than 1,000 feet are present, southward to more than 3,500 feet in the trough. Although the names Wellington and Dog Creek are used in much of the Anadarko area, nomenclature differs in part for some of the intervening stratigraphic units, and, locally for all the temporal equivalents (Totten, 1956, fig. 8). Successively younger formations are in this sequence to the west (Miser, 1954). Thicknesses at part of the east edge, for example, represent only the Wellington. Exposure of the Garber, Hennessey, Flowerpot, Blaine, and Dog Creek (table 1), successively overlap the Wellington westward. West and north of the Dog Creek-Marlow contact in Oklahoma, the middle part of the Permian is entirely a subsurface sequence.

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Fine-grained detrital rocks predominate in the middle part of the Permian. Coarse-grained rocks are generally confined to local areas north of the Amarillo and Wichita uplifts.

In the northwest corner of Oklahoma and adjacent part of the Texas and Oklahoma Panhandles evaporites occupy more than 20 percent of the interval. Salt is a common constituent of the middle part (figs. 18, 19). A salt section in the Wellington as much as 800 feet thick (Jewett, 1955, p. 91) represents the greatest extent of salt in Permian time. By Blaine time salt was deposited in small isolated areas.

The Wellington Formation is more than 1,000 feet thick in the trough, and is a red to gray-brown mudstone with thick beds of anhydrite and gypsum. Locally, particularly in the lower part, it contains salt as beds and casts. Gray to brown somewhat cherty dolomite is also present near the base.

The Garber Sandstone overlies the Wellington in Oklahoma. It is a very fine- to fine-grained sandstone with some siltstone and shale. The northern limit of the Garber is poorly defined, due in part to the increase in shale and in part to poor sampling of well cuttings.

The upper part of the Wichita Formation north of the Wichita Mountains may be the equivalent of the Wellington and Garber farther north.

The Hennessey Shale is red brown with some sandstone, siltstone, gypsum, and anhydrite. A conglomeratic facies of the Hennessey,

Figure 18.--Extent of salt in rocks of Wellington and Hennessey ages, Kansas and Colorado, by M. R. Mudge.

Figure 19.--Extent of salt in rocks of Stone Corral, Flowerpot, and Blaine ages, Kansas and Colorado, by M. R. Mudge.

in which boulders as much as 4 feet in diameter are found (Ham and others, 1957, p. 22), is present north of the Wichita Mountains. The correlative of the Hennessey in Kansas, at least in part, is the Ninnescah Shale.

An evaporite unit present above the Ninnescah in Kansas and for a short distance south on the platform above the Hennessey is in the Stone Corral Formation. It is composed of dolomite with anhydrite and gypsum locally.

In Oklahoma north and west of the Wichita Mountains the overlying sequence is in the El Reno Group, which includes in ascending order the Duncan Sandstone, Flowerpot Shale, Blaine Gypsum, and Dog Creek Shale. The Duncan is a gray, fine-grained, locally cross-laminated sandstone interbedded with gray-green claystone. The overlying Flowerpot is red-brown to gray-green mudstone. The gray green is commonly present as small spots, giving the mudstone a "polka-dot" aspect. Some very fine- to fine-grained sandstone, dolomite, gypsum, and anhydrite beds are present. Some beds of salt and salt casts are common. The Flowerpot-Blaine contact is gradational, marked by increased white massive gypsum beds upward into the Blaine. The Blaine is comprised of maroon gypsiferous claystone and gray to brown, fine to medium crystalline dolomite interbedded with gypsum. The Blaine-Dog Creek contact is also gradational. The Dog Creek is predominantly a brown-red to red-brown shale with thin beds of gypsum.

In the southeast part of the trough strata assigned to the El Reno Group are the Duncan Sandstone and Chickasha Formation.

The Chickasha is a crossbedded sandstone, mudstone, conglomerate, and shale unit. Both the Duncan and Chickasha become coarser grained to the southeast, and finer grained to the north and west. However, where gypsum beds occur in the El Reno Group, the names Flowerpot, Blaine, and Dog Creek are used.

In Kansas the sequence above the Stone Corral includes the Harper Siltstone, Salt Plain Formation, Cedar Hills Sandstone, Flowerpot Shale, Blaine Formation, and the Dog Creek Shale, all of the Nippewalla Group of Jewett (1959). These formations are thinner than those in the El Reno in Oklahoma, but contain the same rock types.

Upper part

The upper part of the Permian includes rocks of late Guadalupe age (fig. 17) that lie stratigraphically between the base of the Marlow Formation and the top of the Quartermaster Formation in Oklahoma, and rocks of equivalent age in the adjacent States (table 1). The eastern edge in Kansas and Oklahoma is the Dog Creek-Marlow contact. West of this contact the number of stratigraphic units increases with the addition of younger formations. Except for isolated exposures along some of the Panhandle drainages the upper part is covered by Tertiary and Cretaceous rocks (fig. 1), and locally by the Dockum Group of Late Triassic age (fig. 20). Where preserved, poor sampling of the upper part in most wells leaves the record incomplete, and the upper contact for this map cannot always be determined accurately.

The upper part of the Permian is more restricted areally than either of the underlying parts because it has been more extensively eroded.

Resultant thicknesses are variable; the thickest sections are northwest of the Wichita Mountains where more than 1,000 feet remain.

Formations of late Guadalupe age are primarily clastic, with some dolomite beds and local accumulations of anhydrite and gypsum that occupy more than 20 percent of the section at some places.

In Oklahoma the upper part of the Permian is a reddish sequence of sandstone and mudstone with interbeds of dolomite and gypsum. The Whitehorse Group at the base is divided in ascending order into the Marlow Formation and the Rush Springs Sandstone. The Marlow is an orange-red, friable, gypsiferous sandstone with thin beds of dolomite and gypsum. A thin clay-gall conglomerate, at the base locally, has been cited as evidence for an unconformable relationship with the Dog Creek beneath. The overlying Rush Spring is a pink to orange-red, fine-grained, feldspathic, gypsiferous, crossbedded sandstone. The Cloud Chief Formation above the Whitehorse is a red, gypsiferous mudstone with gypsum, anhydrite, and dolomite beds. The Cloud Chief contains more clastic deposits to the northwest, and more evaporitic deposits to the southeast (Ham and others, 1957, p. 57). The Quartermaster Formation at the top is a red-brown to white sandstone with discontinuous beds of brown-red mudstone at the base and red-brown siltstone at the top.

The upper part of the Permian is more clastic to the west in Texas and to the north in Kansas and Colorado. The temporal equivalents of the Whitehorse, Cloud Chief, and Quartermaster in Kansas are shown in table 1 and those in Texas in Totten (1956, fig. 8).

Triassic System

Upper Triassic rocks (fig. 20) assigned to the Dockum Group are at the west edge of the Anadarko basin. Except for scattered exposures which were included with those of Jurassic age on figure 1, the Dockum is a subsurface unit. The Dockum overlies successively older Permian rocks from west to east; it rests on the Taloga Formation of Cragin (1897) in the west, the Day Creek Dolomite in the central part of the Oklahoma Panhandle, and rocks of Whitehorse age in the east (Mudge, in McKee and others, 1959, pl. 2). The Dockum underlies successively younger rocks from west to east; it is beneath the Entrada Sandstone and its temporal equivalent the Exeter Sandstone of Jurassic age in the west, and the Ogallala Formation of Pliocene age in the east, except for local areas where it is overlain by Lower Cretaceous and Quaternary rocks (Mudge, in McKee and others, 1959, pl. 6).

The Dockum increases in thickness southwestward where maximum thicknesses of 600 feet are located. It lies at a depth of 305 feet near the Freezeout Creek fault.

The Dockum Group (Mudge, in McKee and others, 1959, p. 14) is divided into an unnamed unit at the base and the Sloan Canyon Formation of Stovall (1943) in Oklahoma and Colorado. A Dockum equivalent is recognized in southwest Kansas. The unnamed unit is composed of orange-red, fine- to medium-grained sandstone. Red and maroon siltstone and claystone are in the lower part. Locally conglomeratic beds of limestone and mudstone, and nodular limestone and dolomite are present. The Sloan Canyon is a variegated mudstone

Figure 20.--Isopach map of rocks of Late Triassic age, by M. R. Mudge,
in McKee and others (1959, pl. 4).

with interbeds of sandstone, sandy shale, marl limestone, and dolomite with some limestone and dolomite pebbles.

Post-Triassic erosion has caused the present limited extent of the Dockum. Triassic rocks, no doubt, covered a larger area than they do now, probably extending into the Anadarko basin as a thin deposit, but there is no evidence that the Anadarko influenced the character and extent of Upper Triassic rocks as it had those of the Pennsylvanian and Permian Systems.

Jurassic System

Strata of Late Jurassic age have a smaller areal extent than those of the preceding systems. They are for the most part (fig. 1) subsurface units and are underlain by the Dockum Group and overlain by Lower Cretaceous rocks assigned to the Purgatoire Formation in Colorado and the Oklahoma Panhandle, and to the Cheyenne Sandstone in Kansas.

The oldest unit of Jurassic age is the Entrada Sandstone in Colorado, and its temporal equivalent in Oklahoma is the Exeter Sandstone. Rocks of Entrada age are present in the westernmost Oklahoma Panhandle county and adjoining parts of southeast Colorado. This sequence is about 100 feet thick (Oriol, in McKee and others, 1956, pl. 5), and is composed of medium- to very fine-grained sandstone which may be gray, white, buff and salmon, medium to massively bedded and cross stratified.

The overlying unit was called the middle unit of Jurassic age by Oriol and Mudge (1956, p. 22). Locally more than 100 feet thick, it has approximately the same areal extent as the underlying Entrada.

Interbedded gypsum, anhydrite, and limestone with minor varicolored mudstone comprise the unit. Some conglomerate has been found in southeast Colorado and Oklahoma. The upper contact is controversial; it was placed at the top of a marker unit called the chalcedonic beds by Oriel and Mudge (1956, p. 22). In wells where these beds have not been identified the contact is obscure.

The Morrison Formation at the top is more extensive than either of the underlying Jurassic formations. The Morrison is approximately 100 feet thick locally, but thins irregularly to the east because of postdepositional erosion. The Morrison is characterized by variegated mudstone and marlstone with lenticular beds of conglomerate, sandstone, and limestone, and the proportion of coarse materials increases eastward (Oriel and Mudge, 1956, p. 23).

Cretaceous System

Except for scattered exposures in western Oklahoma and Kansas, Cretaceous rocks crop out in the northern and western part of the Anadarko area (fig. 1). They are in the subsurface in parts of Kansas and Colorado. The Cretaceous is about 1,500 feet thick in the embayment and the top is generally reached between 250 and 500 feet. The Cretaceous overlies successively older rocks from west to east of Jurassic, Triassic, and Permian ages. The Cretaceous underlies Pliocene and locally Pleistocene rocks.

Lower Cretaceous

The Cheyenne Sandstone is the oldest Cretaceous unit. It is considered a formation in most of the area but is the lower member of the Purgatoire Formation in Colorado. The Cheyenne is 0 to 150 feet thick

increasing to the northeast. A cliff-forming sandstone, it is white to light gray, fine to medium grained and friable containing beds of gray to black sandy claystone. Lenses of conglomerate which contain petrified logs, fragments of quartzite, and schist are present locally near the base.

The overlying Kiowa Shale is classified as the upper member of the Purgatoire in Colorado and as a formation elsewhere in the Anadarko area. The Kiowa is a dark-gray to black fissile claystone. Thinly laminated, calcareous, and sandy beds are more common in the lower part than in the upper part. The Kiowa may be as much as 90 feet thick in southeast Colorado (McLaughlin, 1954, p. 100).

Cliff-forming massive, crossbedded, buff sandstone characterizes the upper and lower parts of the overlying Dakota Sandstone. The middle part is even-bedded sandstone, sandy shale, and gray to black, occasionally variegated claystone. Some of the sandstone beds locally are conglomeratic, others porous and friable. Quartzite is present at many horizons as beds and lenses, grading abruptly into friable sandstone both vertically and horizontally.

The Dakota is not completely exposed. The thickness is variable due in part to erosion of the upper sandstone. Cobban (1956, p. 25) reported 100 feet in Colorado; Smith (1940, p. 35) thought it would exceed 350 feet in southwest Kansas.

Upper Cretaceous

The Graneros Shale overlies the Dakota Sandstone. A thickness of 65 feet has been reported in southwest Kansas (Smith, 1940, p. 35), and one of 86 feet has been reported in southeast Colorado (McLaughlin, 1954, p. 112). This formation thins eastward.

The Graneros is a dark-gray to black shale with many thin layers of bentonite which may be less than 1 inch to more than 12 inches thick. Some ferruginous sandy claystone and a prominent fossiliferous limestone bed are in the lower part. The limestone, approximately 5 feet thick, is dark gray to black, forming a prominent bench.

The Greenhorn Limestone has approximately the same areal extent as the Graneros beneath. It is 115 feet thick in southeast Colorado (McLaughlin, 1954, p. 119) thickening eastward to 132 feet in southwest Kansas (Smith, 1940, p. 35), as the Graneros thins.

The Greenhorn is composed of alternating beds of tan to white limestone, chalky limestone, and dark-gray to black calcareous shale. The limestones form prominent benches, and individual beds range from a few inches to 35 feet thick. Thin layers of bentonite are in the upper part.

The Carlile Shale above the Greenhorn thickens eastward from 85 feet in southeast Colorado (McLaughlin, 1954, p. 122) to more than 260 feet in southwest Kansas (Smith, 1940, p. 36). The lower part is chalky limestone and tan shale. The middle part is dark-gray to black shale with a zone of septarian concretions. The upper part is tan to rusty-brown, fine crystalline, very fossiliferous, ledge-forming limestone in Colorado, which eastward and northward becomes sandstone and is known as the Codell Sandstone Member.

The Niobrara Formation is 20 feet thick where only the Fort Hays Limestone Member is present in southeast Colorado. Where the Smoky Hill Marl Member is present the Niobrara may be several hundred feet thick.

The Niobrara is made up of gray, white to light-brown limestone with shale partings in the lower member, and gray, chalky shale and chalk in the upper member. Limonitic and pyritic concretions, gypsum veins, and thin bentonite beds are present as minor components.

Tertiary System

The Ogallala Formation of Pliocene age covers most of the west part of the Anadarko basin (Merrriam, 1955, p. 66; fig. 1, p. 67). The Ogallala is a series of valley fillings that overlap a surface of many ages. It was deposited by eastward-flowing streams on a surface of moderate relief (Merriam and Frye, 1954, p. 55). The oldest beds are in the lowest parts of pre-Pliocene valleys. Near the end of Ogallala time the upper beds merged across bedrock divides. On that surface the uppermost and most persistent Ogallala unit, the algal limestone, was laid down.

The Ogallala is as much as 600 feet thick in southwest Kansas. It is composed of unconsolidated to semiconsolidated deposits consisting of moderately well to poorly sorted sand and gravel, fine- to medium-grained sand, silt, bentonitic clay, diatomaceous marl, and volcanic ash. Some of the Ogallala is cemented by calcium carbonate and silica (Frye and Leonard, 1959, p. 12-13). The overall color of this formation is gray.

The Laverne and Rexroad Formations, also of Pliocene age and correlative with the Ogallala, are recognized locally in Kansas and Oklahoma. They contain the same types of clastic deposits but lack the distinctive algal limestone beds.

Quaternary System

Quaternary sediments occur as valley fillings and eolian deposits along all the major drainages in the Anadarko area. Some Quaternary deposits were locally derived from the Permian, for example, others were transported from the Rocky Mountain area.

In Oklahoma the older Quaternary sediments consist of gravel, sand, and volcanic ash, and the younger are channel and terrace deposits of gravel, sand, silt, and clay.

In Kansas Quaternary deposits have been divided into several formations. The Grand Island Formation at the base the overlying Sappa Formation (table 1) may be as much as 115 feet thick. Because of lithologic similarity, this poorly sorted clastic sequence is difficult to separate from the underlying Ogallala. Fragments derived from Precambrian granite, Greenhorn Limestone, and Dakota Sandstone are in the gravel. The Pearlette Ash Member at the top of the Grand Island is the most persistent marker unit of the Quaternary. The overlying formations are, in ascending order, the Crete, Loveland, Peorian, and locally the Bignell. These strata form an essentially continuous deposit that is as much as 65 feet thick. The Crete is an arkosic, poorly sorted sand and gravel. The Loveland, Peorian, and Bignell are loesses and are areally discontinuous. Individually they may be more than 50 feet thick.

The upper part of the Quaternary includes terrace deposits of late Pleistocene age, and dune sand and alluvium of Recent age. Dune sand may be 50 feet thick along the major rivers where particularly well developed. Alluvium present along all drainages is well sorted

along the major ones where as much as 75 feet remain, but poorly sorted along subsidiary ones.

IGNEOUS ROCKS

Post-Paleozoic igneous rocks crop out at seven localities in Kansas. All are peridotite, except one, which is granite (Merriam and Geobel, 1956, p. 147).

Tertiary igneous rocks are present as scattered masses in the Anadarko area. They have also been found to intrude strata of Morrow age in one well in southeast Colorado.

A laccolithic mass known as Two Buttes is associated with many dikes and a few sills, that transect Permian and Jurassic rocks, and are truncated by the Ogallala (McLaughlin, 1954, p. 123). Some of the dikes are resistant to erosion and appear as narrow ridges above the surrounding terrain. Another intrusive mass west of Two Buttes and possibly related to it, uplifted and altered the Greenhorn Limestone (McLaughlin, 1954, p. 124).

The age of the intrusion is not known, though the youngest beds altered are in the Greenhorn (Late Cretaceous). The Ogallala (Pliocene) contains conglomerate derived from these intrusive rocks. A Miocene(?) age is suggested because of this relationship and because igneous activity took place elsewhere during the Tertiary.

Remnants of basaltic lava flows, locally more than 100 feet thick, are present in parts of southeast Colorado. These are considered to be of probable late Pliocene or Pleistocene age (McLaughlin, 1954, p. 131) because they overlies the Ogallala Formation, and because of the presence of scattered cobbles, remnants of eroded terraces, on top of them.

ECONOMIC GEOLOGY

The three primary economic resources obtained from rocks of the four States of the Anadarko area are water, oil, and gas (fig. 21). Lesser economic resources include: sand and gravel from Tertiary and Quaternary deposits in Oklahoma and Kansas; building stone, lime, and chalk from the Cretaceous in Kansas; building stone from the Precambrian, Cambrian, and Ordovician in Oklahoma; volcanic ash and bentonite from the Pliocene of Kansas; gypsum and salt from the Permian of Kansas and Oklahoma. Salt from the Permian is valuable because it can be dissolved and the resulting cavity used for liquefied petroleum gas storage. Salt is recovered from the brine and it is mined from the Wellington Formation of Permian age in Kansas east of the Anadarko area.

Water

There are five major types of aquifers in the Anadarko area. These are in carbonate and evaporitic rocks, sandstone, semiconsolidated clastic deposits, and alluvial deposits (Davis, 1958, p. 191).

Examples of carbonate and evaporite reservoirs include the Arbuckle and upper part of the El Reno Groups. The Arbuckle is an important aquifer locally along the north flank of the Wichita Mountains, where it lies at depths reasonable for development. High permeability of the Arbuckle is due to fractures, joints, and solution channels in limestone and dolomite. Water from the Arbuckle is used primarily for industrial and stock purposes because it is highly mineralized. Water in the Blaine Gypsum and Dog Creek Shale of the El Reno Group in Oklahoma is in solution channels and cracks which probably were formed as a result of alteration of anhydrite to gypsum and subsequently enlarged by solution (Davis, 1958, p. 200).

Figure 21.--Oil and gas fields in the Anadarko basin, by Coe and others (1955), and other published and unpublished maps.

Water in the Blaine and Dog Creek is highly mineralized but of sufficient quality and quantity for irrigation.

Limestone beds in the Greenhorn Limestone and Fort Hays Limestone Member of the Niobrara Formation supply limited quantities of highly mineralized water (McLaughlin, 1954, p. 120, 123).

Examples of sandstone aquifers include the Rush Springs, Garber, Wellington, and upper part of the Wichita Formations in Oklahoma which all contain fine-grained permeable sandstone and siltstone beds. The Duncan Sandstone yields small amounts for city and industrial uses. Local differences in grain size, silt content, and thickness limit the productivity of the Duncan as an aquifer (Davis, 1955, p. 94). Fine-grained sandy parts of the Chickasha and the Elk City Member of the Quartermaster are important aquifers in parts of Oklahoma.

The Dockum Group yields small quantities of water in southeast Colorado where it is largely sandstone (McLaughlin, 1954, p. 86). Some of the water in it may be due to seepage from the overlying Ogallala. Water from Triassic, and also from Permian rocks commonly contains too much chloride and sulfate to be potable.

Cretaceous rocks such as the Cheyenne Sandstone Member of the Purgatoire, the Dakota, and Codell Member of the Carlile are not considered valuable sandstone aquifers because of high mineral content.

Thousands of wells have tapped the Ogallala Formation--one of the most important aquifers of the High Plains area. It is an example of a widespread, semiconsolidated deposit.

Quaternary alluvial deposits of gravel and sand are the most important, permeable, and productive sources of water in the Anadarko area. More than 60 percent of the water supply of Kansas, for example, is contained in this type of reservoir (Frye and Leonard, 1952, p. 1). These sediments were deposited as flood plains and terraces along the major drainages (fig. 1). They are a few feet thick along the minor streams but may be as much as 130 feet thick along the Arkansas River valley in Colorado. The older terrace deposits yield water of better quality than the younger ones because of smaller mineral content (Davis, 1955, p. 79).

Dune sand of Quaternary age, though not an aquifer, serves as a catchment for rain and aids in recharge of underlying rocks (McLaughlin, 1954, p. 141).

Oil and Gas

The Hugoton embayment has been known for many years as an important area for natural gas and oil production. The first gas well near the embayment was drilled in 1918 north of the town of Amarillo on the south flank of the Amarillo uplift. Gas was discovered in southwest Kansas in 1919. An oil well was drilled in 1921 on the Amarillo uplift (Stevens, 1960, p. 2). By 1950, 20,000 oil and gas wells had been drilled in the embayment in an area 275 miles long and 25 miles wide (Stevens, 1960, p. 3).

Many horizons produce oil and gas. The most commonly penetrated are in Permian and Pennsylvanian rocks of the embayment, platform, and areas adjacent to the bordering uplifts of the basin. Important discoveries have been in the "Red Cave," an informal term for rocks of Hennessey age in the Texas Panhandle, the Chase and Council Grove

Groups, all of Permian age; the Marmaton and Cherokee Groups of Pennsylvanian age; and "granite wash" of Pennsylvanian and Permian ages. Productive lithologies include porous limestone beds and sandstone bodies.

Rocks of Mississippian, Hunton, Viola, Simpson, and Arbuckle ages are also important reservoirs. South of the platform in the trough these and other pre-Pennsylvanian rocks are untested because they lie at excessive depths.

The major occurrences of oil and gas are associated with stratigraphic traps on the platform and east part of the embayment area (fig. 21). One type of stratigraphic trap caused by lithologic changes accounts for production from Pennsylvanian rocks on the platform where, for example, rocks of Missouri age change from a carbonate to shale facies (Pate, 1959, fig. 5), and where many discontinuous sandstone bodies of Virgil age (Pate, 1959, figs. 14 and 15) are located. Another type of stratigraphic trap is that caused by updip limits where for example, rocks of Morrow, Chester, and Hunton age pinch out on the platform (Pate, 1959, figs. 9, 10, and 12).

Liquified petroleum gas storage

Salt is present in varying quantities as beds and as discontinuous bodies in rocks of Leonard and Guadalupe ages (figs. 18 and 19). Where burial is shallow, solution by ground water has partly removed it, and salt springs and sinkholes are common. Where salt is present beneath zones of ground water action, caverns may be artificially made.

Five Permian formations contain salt deposits of sufficient thickness and areal extent that they have been studied for possible oil and gas storage. These formations lie above the top of the Chase

Group and beneath the top of the Blaine Formation (fig. 22) whose upper surface is between 500 feet above sea level at the south edge of the trough near its exposed limits, and 3,500 feet above sea level at the northwest edge of the embayment. The thickest and most extensive salt-bearing unit is the Wellington Formation. Beds from 5 to 200 feet thick have been reported from the overlying formations.

Liquified petroleum gas is stored underground in artificial caverns formed by dissolving salt with hot water which is poured into a well hole and pumped back to the surface.

In Oklahoma there are two storage caverns in salt beds in the Blaine and Flowerpot (Jordan, 1959, p. 32; Jordan, 1961, p. 34). In Kansas there are 40 storage caverns. Thirty of these are east of the Anadarko in the Hutchinson Salt Member of the Wellington. In Texas there are 110 caverns.

Porous sandstone and limestone beds particularly those of Pennsylvanian and Early Permian ages may also be usable for storage of liquified petroleum gas.

Figure 22.--Structure contour map of the Anadarko basin showing structure on top of the Blaine Gypsum.

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