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Review of the geology of the southern Oklahoma fold belt province as a basis for estimates of undiscovered hydrocarbon resources

by

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CONTENTS

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INTRODUCTION

The purpose of this report is to review the geology of the southern Oklahoma fold belt province to aid in estimating the amounts of undiscovered hydrocarbons in this province. The term province, as used in this report, refers to a geographic area that commonly, but not always, contains a sedimentary basin.

The method used in this assessment is play analysis. A play is defined as a group of prospects and/or discovered fields [or accumulations] having common characteristics such as source rock,trapping mechanism, structural history, etc., which may contain gas and/or oil (Procter and others, 1982).

Present estimates of undiscovered hydrocarbons are limited to accumulations with expected ultimate recovery volumes greater than 1 million barrels of oil (MMBO) or 6 billion cubic feet of gas (BCFG). Production and geologic data were collected from the literature and from magnetically stored information such as Petroleum Data Systems (PDS) where available.

Computer generated drill intensity maps were made from PDS[1] data to aid in visualization of producing trends. These maps supplemented geological data and aided in play definition in more thoroughly explored areas by showing locations of dry holes and shows from tested wells.

GEOLOGIC SETTING

General

The southern Oklahoma fold belt province is located within eleven counties in south-central Oklahoma (Fig. 1) and covers about 8000 square miles (20,500 square km).

Sedimentary rocks in the province range in age from Cambrian to Quaternary with the Paleozoic rocks comprising the bulk of the stratigraphic section (Table 1). Many of the units present contain high-quality reservoir rocks and high-quality source rocks.

[1]The use of trade names or products is for descriptive purposes only and does not constitute an endorsement by the U. S. Geological Survey.

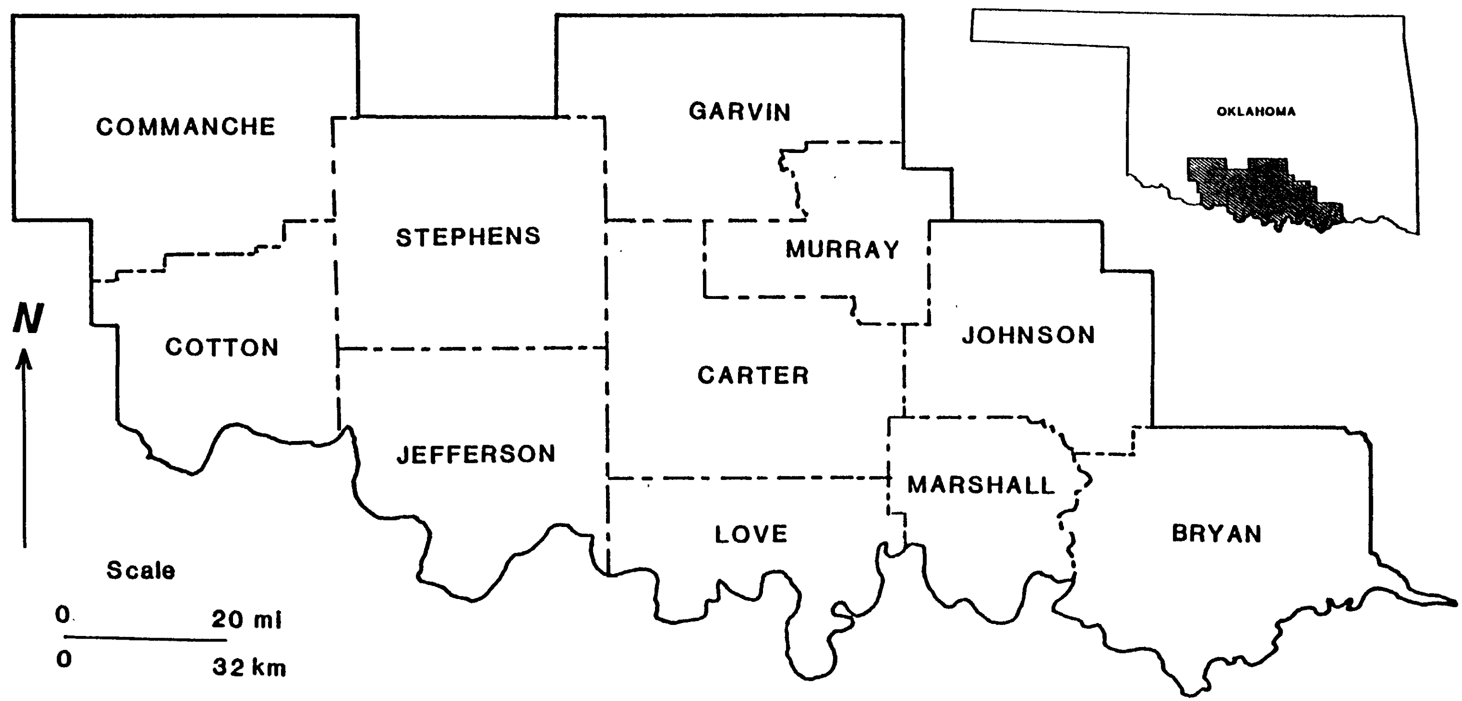

Fig. 1. Location map showing counties within the southern Oklahoma fold belt province.

Table 1. Generalized stratigraphic column, southern Oklahoma fold belt province. (Summarized from Merritt, 1978 and Harleton, 1960)

SYSTEM	GROUP	FORMATION
Quaternary		
Tertiary		
Cretaceous		
Permian		Cloud Chief
	Whitehorse	
	Pease River	
	Clearfork	
	Wichita	
	Pontotoc	
Pennsylvanian	Cisco	
	Hoxbar	
	Deese	
	Dornick Hills	upper part
		lower part
Mississippian		Springer
		Goddard Shale
		Caney Shale
		Sycamore Limestone
		Woodford Shale
Devonian	Hunton	Frisco Limestone
		Bois d' Arc Limestone
		Haragan Shale
Silurian		Henryhouse
		Chimneyhill Limestone
Ordovician		Sylvan Shale
		Fernvale Limestone
		Viola Limestone
	Simpson	Bromide
		Tulip Creek
		McLish
		Oil Creek
		Joins
	Arbuckle	West Spring Creek
		Kindblade
		Cool Creek
		McKenzie Hill
Cambrian		Signal Mountain
		Fort Sill
	Timbered Hills	Honey Creek
		Reagan

Structural Setting

This province lies in the eastern portion of the southern Oklahoma aulacogen and much of its importance in oil and gas production is realted to its tectonic history. The aulacogen formed in late Precambrian time as the result of an aborted rift in the earth's crust (Feinstein, 1981). The major structural elements of the area were formed during late Paleozoic time (mostly Pennsylvanian) by breakup of the Anadarko basin into smaller basins and highs (Fig. 2). This later movement probably occurred along earlier zones of weakness (Feinstein, 1981).

Structural complexity of the province is shown in a cross-section by Hicks (1971). This drawing (Fig. 3) shows that the thickness of sedimentary rocks in the area reaches over 20,000 feet (6060 m).

Large scale faulting placed rocks as young as Pennsylvanian in contact with rocks as old as Cambrian and provided avenues for petroleum migration. Folding has produced local highs that were partially eroded and leached, increasing their porosity and permeability. Folding has also produced many anticlinal features suitable for the trapping of hydrocarbons.

STRATIGRAPHY

PALEOZOIC

Cambrian System

Much of the information regarding the stratigraphy of this province is taken from Merritt (1978) unless otherwise noted. The work done by Merritt was conducted in the eastern part of the area in Marshall County, Oklahoma.

Early Paleozoic sedimentation began with the deposition of a few hundred feet of Upper Cambrian Reagan Sandstone (Hicks, 1971). This unit is a coarse, dark brown, feldspathic sandstone in the Arbuckle Mountains and ranges from 75 to 450 feet (23 to 136 m).

The Honey Creek Limestone (Upper Cambrian) forms a thin unit above the Reagan Sandstone. It is a coarsely crystalline glauconitic limestone and attains a thickness of 188 feet (57 m).

Cambrian to Ordovician Systems

The Arbuckle Group (Upper Cambrian and Lower Ordovician) consists of the Upper Cambrian Fort Sill and Signal Mountain Formations and the Lower Ordovician McKenzie Hill, Cool Creek, Kindblade and West Spring Creek Formations (Cardwell, 1977). This group of rocks is predominantly composed of dolomitized lime mudstones, stromatolitic boundstones, oolitic grainstones, some skeletal packstones and grainstones. The Arbuckle Group

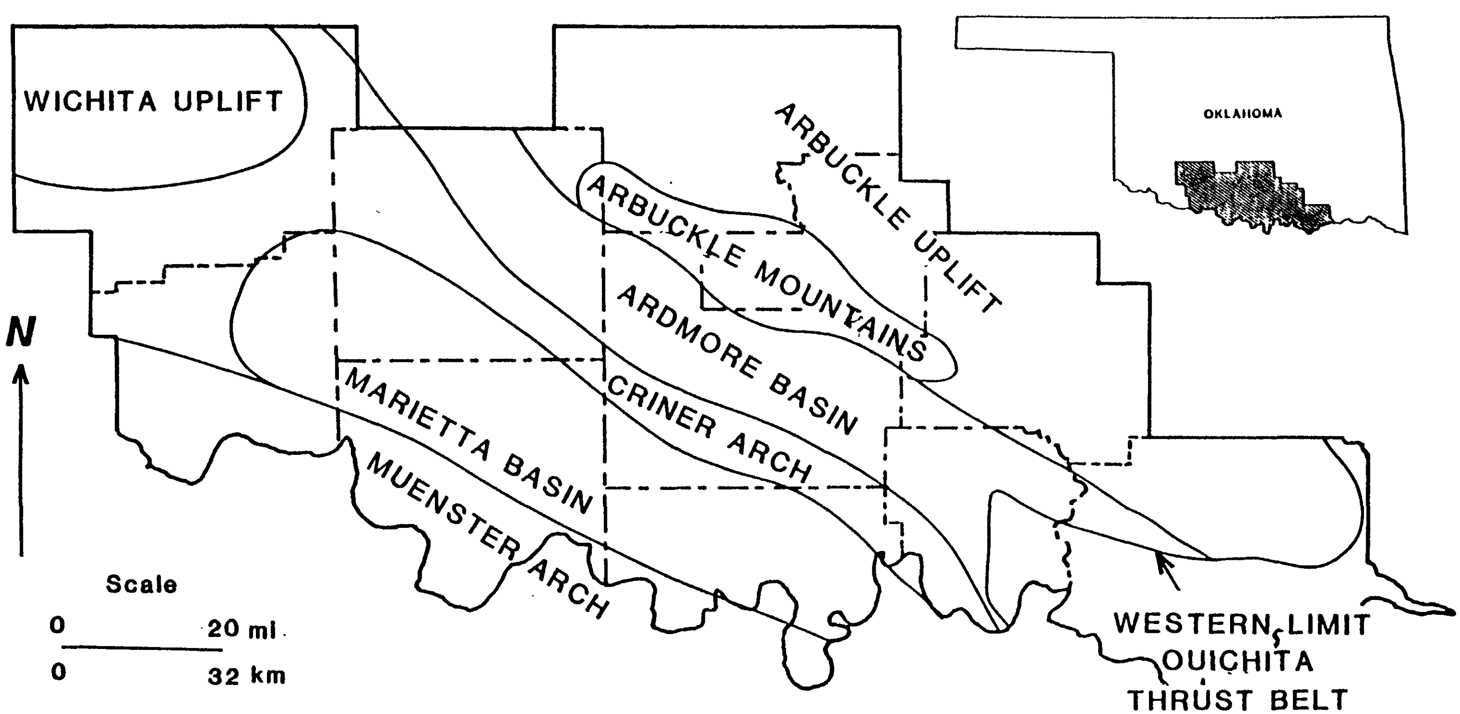

Fig. 2. Major structural features of the southern Oklahoma fold belt province. (Modified from Ferguson, 1979 and Hicks, 1971)

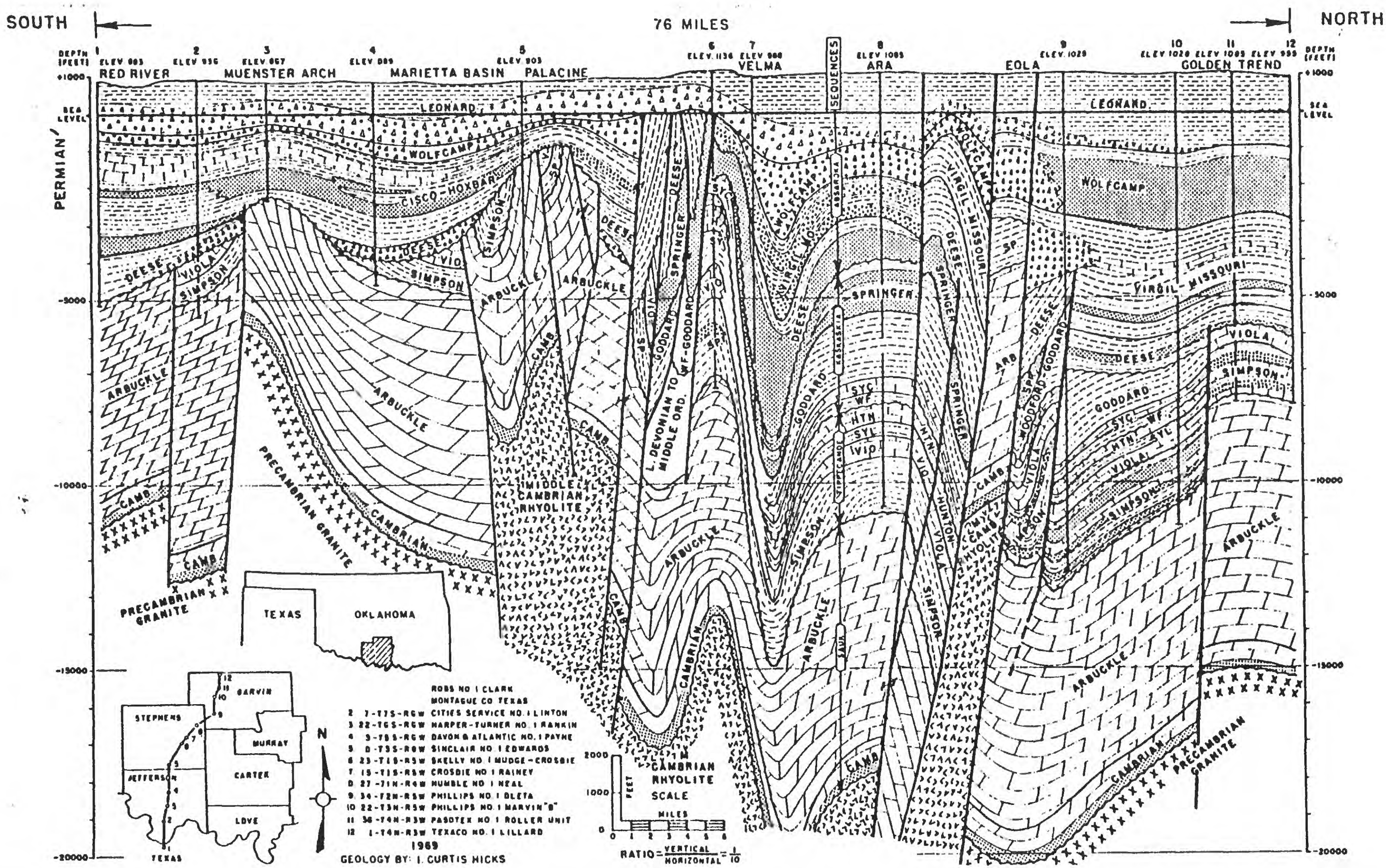

Fig. 3. Interpreted north-south cross-section of the central part of the southern Oklahoma fold belt province. (From Hicks, 1971).

attains a thickness of almost 7000 feet (2121 m) in this province.

Ordovician System

The Simpson Group (Middle Ordovician) is made up of the Joins, Oil Creek, McLish, Tulip Creek and Bromide Formations. The Joins Formation is primarily a finely crystalline, brown, dolomitic limestone. It attains a thickness of 221 feet (70 m) in the eastern part of the province.

The Oil Creek Formation is 900 feet (273 m) thick in the eastern part and may exceed 1000 feet (303 m) in other parts of the province. The unit is made up of medium to coarsely crystalline silty limestone, green waxy shale and interbedded sandstone.

The McLish Formation consists of about 450 feet (136 m) of coarsely crystalline, brown, silty limestone. Interbedded sandstones are well developed at the base of the formation and these reach a thickness of over 100 feet (33 m).

The Tulip Creek and Bromide Formations are generaly considered together. They reach a combined thickness of over 600 feet (182 m) in the eastern part of the province. The Tulip Creek Formation is composed of shales, limestones and three relatively persistant interbedded sandstones, known locally as the "First, Second and Third Bromide Sand". The Tulip Creek Formation is approximately 350 feet (106 m) thick. The Bromide Formation consists of a basal sandstone, a medium green shale and an upper dense limestone (Hicks, 1971). The Bromide Formation attains a thickness of almost 350 feet (106 m) in the eastern part of the province.

The Viola Limestone (Upper Ordovician) is a fine to medium crystalline, off white to brown dolomitic limestone. It attains a thicknes of 550 feet (167 m) in the area.

Above the Viola Limestone rests the (Upper Ordovician) Fernvale Limestone. This formation ranges from 25 to 37 feet (8 to 11 m) thick and it consists of coarsely crystalline fossiliferous limestone.

The Sylvan Shale (Upper Ordovician) ranges from 280 to 330 feet (85 to 100 m) in thickness in the eastern part of the province. It is composed of light green soft shale with some dolomite in the lower part of the unit.

Silurian to Devonian Systems

The Hunton Group (Silurian and Devonian) is composed of four widely recognized formations, the Silurian Chimneyhill and Henryhouse Formations, the Lower Devonian Haragan Shale and the Lower Devonian Bois d'Arc Limestone. This group reaches 300 feet (91 m) in the eastern part of the province.

The Chimneyhill Formation is about 30 feet (9 m) thick in this area and is composed primarily of finely crystalline limestone. It also contains lenses of crinoidal, oolitic and pelmatozoan limestone.

The Henryhouse Formation is composed of gray argillaceous limestone. It is approximately 25 feet (8 m) thick in this area.

The Haragan Shale ranges from 100 to 145 feet (30 to 44 m) thick in this area. It is composed of green to gray argillaceous limestone.

The Bois d'Arc Limestone is a coarsely crystalline gray to white glauconitic limestone unit. It is approximately 100 feet (30 m) thick in this area.

Devonian to Mississippian Systems

The Woodford Shale (Upper Devonian and Lower Mississippian) is approximately 240 feet (73 m) thick in the area studiedd by Merritt (1978), however it varies considerably in thickness over this province (Amsden, 1975). It is generally a hard, dark brown to black shale with interbedded cherts. One sample of the Woodford Shale contained more than 8% organic carbon (Cardwell, 1977).

The Sycamore Limestone (Mississippian) attains a thickness of 300 feet (91 m) in this area. It is composed primarily of light brown, calcareous, micaceous, and slightly glauconitic siltstone with much shale and limestone occurring in some wells.

The Caney Shale (Upper Mississippian) is a brown to black, hard calcareous shale becoming silty toward the base. It ranges in thickness from 200 to 500 feet (61 to 152 m).

Mississippian to Pennsylvanian Systems

The Goddard Shale is about 2000 feet (606 m) thick. It is considered to be of Late Mississippian and/or Early Pennsylvanian or strictly Mississippian in age by various workers in this area. It is described as a dark gray, fine textured shale.

The Springer Formation (Upper Mississippian and Lower Pennsylvanian) contains from three to five distinct sandstone units in this province. The entire formation is described as a light gray fine textured shale with interbedded sideritic layers in the lower part. It ranges from 1200 to 3000 feet (364 to 909 m) in thickness in this area.

Information regarding Pennsylvanian and Permian rocks of this province was taken from Harlton (1960) unless otherwise noted. The work by Harlton describes rocks near the northwestern part of this province.

The Lower and Middle Pennsylvanian Dornick Hills Group is generally divided into two parts. The lower part of the Dornick Hills Group consists of about 3900 feet (1182 m) of medium to dark gray, hard, micaceous, calcareous sandstones and tan to brown, medium to coarse, fossiliferous limestones (Merritt, 1978). The upper part of the Dornick Hills consists of about 2100 feet (636 m) of fine to medium grained, compact to loose calcareous sandstone interbedded with medium to dark gray shale (Merritt, 1978).

The Deese Group (Middle Pennsylvanian)is primarily a fine to coarse grained, calcareous, glauconitic, loose to compact sandstone with red brown to medium gray shales (Hicks, 1971). Sandstone units within this formation are generally quartzitic and angular to sub-angular (Hicks, 1971). This group of rocks attains a thickness of over 2800 feet (848 m) in the central portion of this province.

The Hoxbar Group (Middle Pennsylvanian) is a complex and variable sequence that resulted from significant changes in depositional conditions. It is composed of sandstone, calcareous sandstone, and limestone. The Hoxbar Group attains a thickness of over 1000 feet (303 m) near the northwestern part of the province.

The Cisco Group (Upper Pennsylvanian) varies considerably in thickness in this province ranging from 1800 to 4100 feet (545 to 1242 m) near the northwestern part of the province. This sequence is predominantly shale, conglomerate, sandstones with carbonate zones and lignite beds in the lower part of the sequence.

Permian System

The Pontotoc Group (Upper Pennsylvanian and Permian) is about 1800 feet (545 m) thick near the northwestern edge of the province. It consists of maroon shales, cherty, arkosic, sandy conglomeratic limestones and fine to coarse grained sandstones.

The Wichita Group (Lower Permian) consists of about 700 to 1000 feet (212 to 303 m) of dark gray, maroon and brown shales. Very fine grained sandstone bodies and carbonate layers also occur within the lower part of this interval.

The Clear Fork Group (lower Permian) attains a thickness of about 1800 feet (545 m) near the northwestern edge of the province. It consists of dark red to maroon silty shale, gypsiferous siltstone, and sandstone.

The Pease River Group (Lower Permian) ranges in thickness from 500 to 675 feet (152 to 205 m) in the area. It is characterized by gypsiferous mudstone, shale, coarse sandstone and interlayers of fine to medium fine sandstone layers.

The Whitehorse Group (Permian) ranges from about 120 to 450 feet (36 to 136 m) in thickness near the northewstern part of the province. It is made up of white to red, fine to very fine grained, loosely bonded sandstone, some shale and dolomite.

The Cloud Chief Formation (Upper Permian) is represented by a gypsum facies. This is the basal unit of the formation and consists of about 10 feet of white and pink gypsum.

MESOZOIC

Crataceous System

Approximately 700 feet (212 m) of Cretaceous rocks occur in the eastern part of this province that lies in the Gulf Coastal Plain geographic province. These rocks are primarily limestones clay, shale and sandstone (Merritt, 1978).

CENOZOIC

Scattered exposures of Pleistocene and Holocene sand and gravel deposits along major drainages are present in this oil and gas province.

SOURCE ROCKS

Cardwell (1977) investigated the source rock potential of the Arbuckle Group and found it to be very poor. His work suggested that much of the organic matter was probably lost from Arbuckle rocks prior to burial (Cardwell, 1971). In many cases, oil now trapped in Arbuckle Group rocks is thought to have been sourced from Pennsylvanian rocks with which they are in fault contact. Geochemical fingerprinting also suggests that these oils now found in Arbuckle Group rocks came from Pennsylvanian source rocks (Cardwell, 1977).

Simpson Group reservoirs were probably sourced from interbedded shale units(Webster, 1980).

The Sylvan Shale does not appear, from descriptions in the literature, to be a high quality source rock. It is generally referred to as a light green, pale gray green and sometimes a brown shale (Merritt, 1978).

The Woodford Shale is a black shale believed by many workers to be an important source rock in this area. It is variable in thickness within this province, ranging from zero to over 900 feet (273m) (Amsden, 1975). Organic carbon content of one sample of the Woodford Shale was reported at greater than 8 wt. % (Cardwell, 1978).

The Caney Shale is a possible source rock in this province. It is described as brown to black by various authors (Merritt, 1978) and is present in thickness of from 200 to 500 feet (61 to 152 m) in the province.

The Goddard Shale is present in the province in considerable thickness but published descriptions do not indicate that is a high quality source rock (Merritt, 1978).

Springer Formation shales are likely source rocks for the vast quantities of Pennsylvanian-age reservoirs that exist in this province (Webster, 1980). These beds are in a favorable position to have charged overlying Pennsylvanian sandstone reservoirs and they are sometimes in a favorable position, due to faulting, to have charged older reservoir rocks (Hicks, 1971). The youngest potential source rocks (Pennsylvanian) have been buried to depths of 11,000 feet (3333 m) or more (Hicks, 1971). This depth, combined with an expected geothermal gradient of from 1.2 to 1.8 F per 100 feet is sufficient to have generated hydrocarbons from adequate source rocks.

HYDROCARBON OCCURRENCE

The area is well explored. Over 25,000 oil and gas wells have been drilled which gives an average drilling density of about three wells per square mile.

Hydrocarbons are found in each county in this province. Accumulations of the size considered for this report are found primarily in combination traps but structural traps are common and stratigraphic traps occur.

Oil and gas are produced primarily from upper Paleozoic rocks composed of sandstone reservoirs although rocks from virtually every system represented here contain hydrocarbons somewhere in this province and other reservoir rocks are common. Gas is abundant in this province but it is usually found associated with oil.

The province has produced, to date, about two billion barrels of oil and over two trillion cubic feet of gas from oil fields with an ultimate recovery of over 1 MMBO and gas fields with an ultimate recovery of over 6 (BCFG) combined. The ultimate recoveries from these fields are estimated to be over 2.3 billion barrels of oil and over 2.6 trillion cubic feet of gas.

PLAYS

Three plays are identified and described within this province. These plays are referred to as the older Paleozioc carbonate play, the Simpson play and the Pennsylvanian play. All of these plays produce hydrocarbons. However, primarily because of its poorly explored nature at greater depths in this area, the Simpson play probably represents the most promising play for hosting undiscovered hydrocarbons.

OLDER PALEOZOIC CARBONATE PLAY

This play consists of accumulations in carbonate rocks deposited during Cambrian through Devonian time (Fig 4.) These rocks include units in the Arbuckle Group, Viola Limestone and Hunton Group.

Arbuckle age carbonates are common producers in this province although not of major importance in terms of total volume. They produce from over 200 fields in the area (Gatewood, 1978). Reservoir rocks in the Arbuckle Group are dolomites and limestones that exhibit secondary porosity development related to solution along fractures. Accumulations

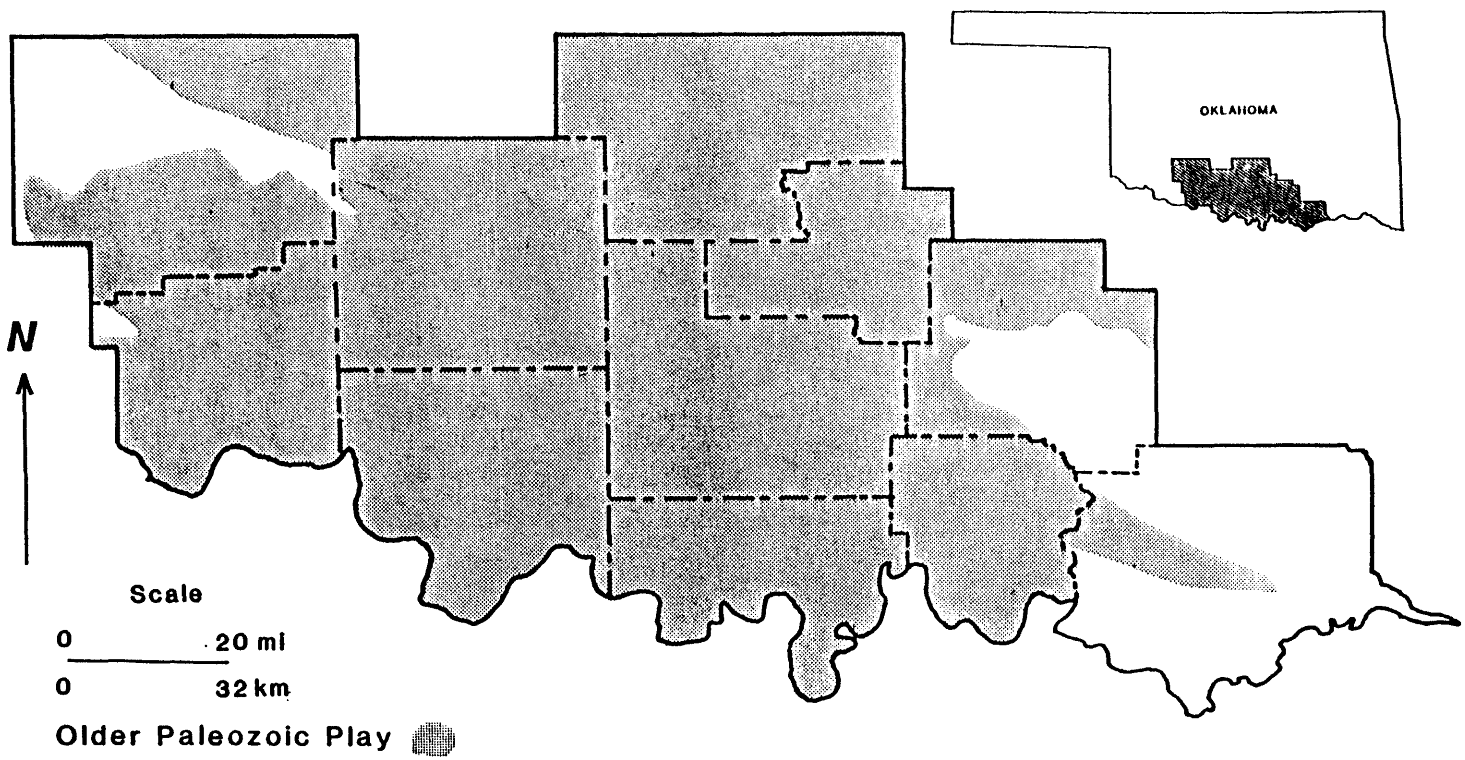

Fig. 4. Approximate area of the older Paleozoic carbonate play.

are usually restricted to the upper few hundred feet of the section (Cardwell, 1979), and are generally associated with structural highs (Gatewood, 1978) and faulting (Hicks, 1971). These porous zones are probably related to an unconformity of post-Arbuckle age known to exist over much of this area (Hicks, 1971).

The Viola Limestone is also productive in this province. Generally, production is from porous zones developed within a dolomite in the lower part of this unit.

The Hunton Group also contains carbonates that are productive in this province. These include the Chimneyhill, the Bois d'Arc and Frisco Limestones. Production from Hunton Group rocks is dependent on structure and secondary porosity development related to post-Hunton uplift and erosion and Morrowan exposure and weathering (Hicks, 1971).

Undiscovered traps are expected to be combination types; secondary porosity development related to lithology and structure and hydrocarbon localization related to structural highs. Seals for these traps are probably formed by 'tight' overlying beds; the Joins Formation in the case of Arbuckle reservoirs, the Sylvan Shale or tighter portions of the Viola Limestones itself for Viola resrevoirs, and the Woodford Shale, may form effective seals for reservoirs that may exist in rocks of the Hunton Group.

The most important source beds for this play are probably the dark Pennsylvanian shales, which are thought to be in fault contact with Arbuckle carbonates in several fields (Cardwell, 1977). Simpson units directly overlying Arbuckle reservoirs, or in fault contact with them, are possible source rocks. The Woodford Shale is also an attractive source rock for this play because of its organic richness. However, the Woodford Shale may be absent over much of the southern part of the province (Hicks, 1971).

Timing requirements necessary for hydrocarbon accumulation in this play have been met in many instances. Favorable reservoir conditions were formed and preserved in Arbuckle Group and Hunton Group rocks and the Viola Limestone. Hydrocarbons were probably generated from potential source rocks as early as 260 million years ago. Migration pathways were probably formed by numerous faults in the area, some of which may extend from the surface to depths greater than 20000 feet (6060 m) (Hicks, 1971).

Rocks in this play range in depth from about 2000 feet (606 m) to more than 20000 feet (6060 m) (Hicks, 1971) although the deeper parts of the Arbuckle Group, which were not subjected to erosion, may not exhibit favorable porosity development.

SIMPSON PLAY

Simpson units occur over much of the province (Fig. 5) and contain excellent reservoir rocks, traps and possible source

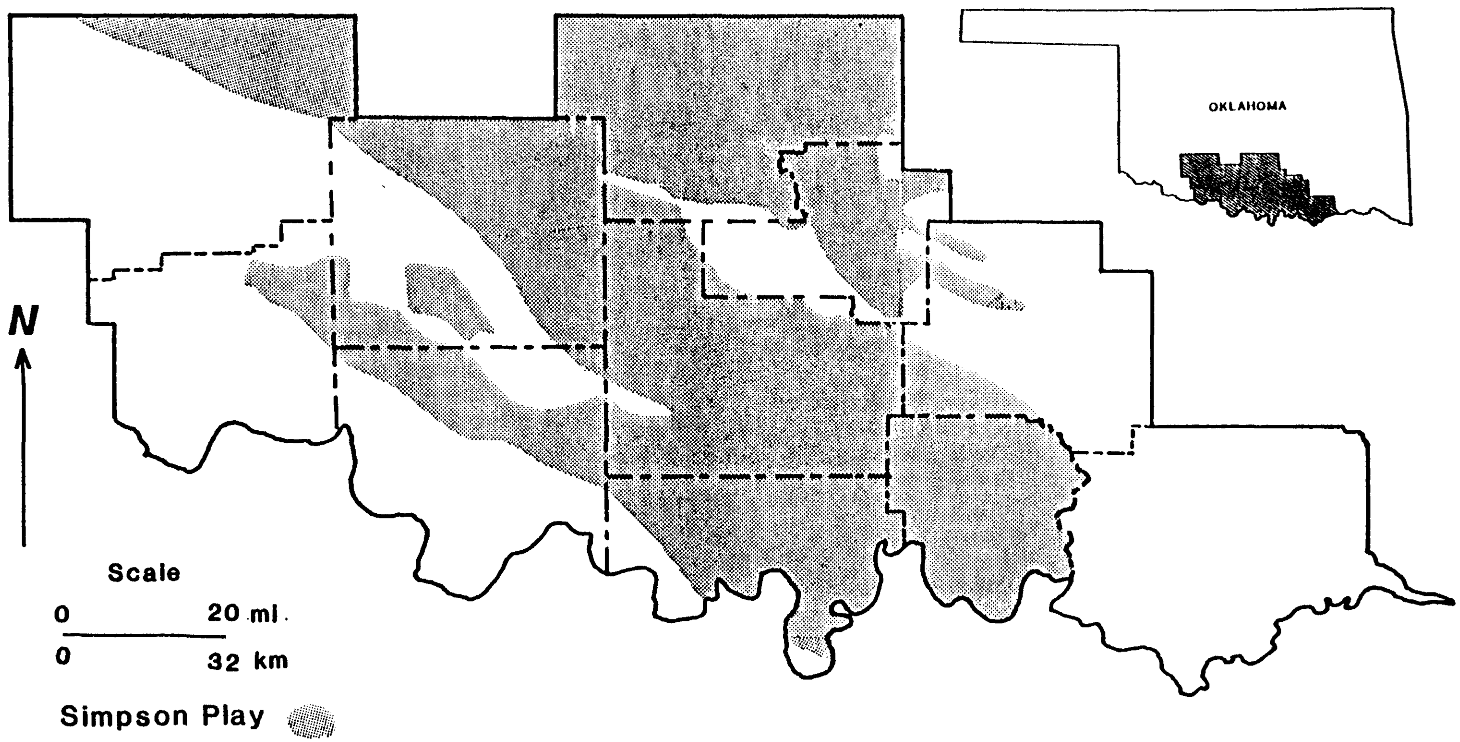

Fig. 5. Approximate area of the Simpson play. (Modified from Hicks, 1971).

beds. Reservoir rocks consist of four sandstone units and one limestone unit.

The Joins Formation (generally limestone) is not a significant producer.

The Oil Creek Formation is productive from a lower sandstone and upper limestone unit, which are separated by up to 800 feet (242 m) of green shale. The overall thickness of the Oil Creek Formation may be over 1000 feet (303 m) (Hicks, 1971).

The McLish Formation is more than fifty percent limestone and contains a lower and and an upper sandstone. The formation reaches a thickness of 500 feet (151 m) and is absent over major uplifts in the area (Hicks, 1971).

The Tulip Creek Formation is similar in distribution to the McLish Formation. The basal sandstone of the Tulip Creek reaches a thickness of 178 feet (54 m) in the area.

The Bromide Formation consists of lower sandstone, a green shale and an upper dense limestone. It reaches a thickness of 220 feet (67 m) in the area.

Over one-half of the traps (54%) found in Simpson strata are structural and almost 40% are combination traps. Seals are probably formed by interbedded shales and limestones overlying sandstone layers and by faults which have placed non porous beds in contact with reservoir rocks.

The Woodford Shale is often referred to as a primary source rock in this province and in some situations it could have charged Simpson reservoirs (fault contact between these source rocks and Simpson rocks) but it generally lies higher in the section (1500 feet [454 m]) and not in a favorable position for migration. Interbedded shale beds of the Simpson may have been the source of some of the hydrocarbons found in Simpson reservoirs (Webster, 1980).

Timing does not appear to be a limiting factor for this play. Oil generation probably began in Simpson rocks at about the same time it began in the Woodford Shale, after the end of major Pennsylvanian tectonic (trap forming) activity. Migration pathways may have been simply sand/shale contacts, if the Simpson oils were sourced from interbedded shales or from faults if younger source rocks were important.

Simpson rocks occur from less than 3000 feet (909 m) to over 16000 feet (4848 m) deep in the area and are poorly explored at greater depths (over 10000 feet). Oil and gas are both produced from this play. Because this play has historically been an excellent producer and because it is poorly known at greater depths, this play is expected to hold much of the undiscovered hydrocarbons in this province.

PENNSYLVANIAN PLAY

Pennsylvanian rocks account for most of the production and much of the estimated recoverable hydrocarbons in this province (Fig. 6). Petroleum is produced primarily from sandstones of

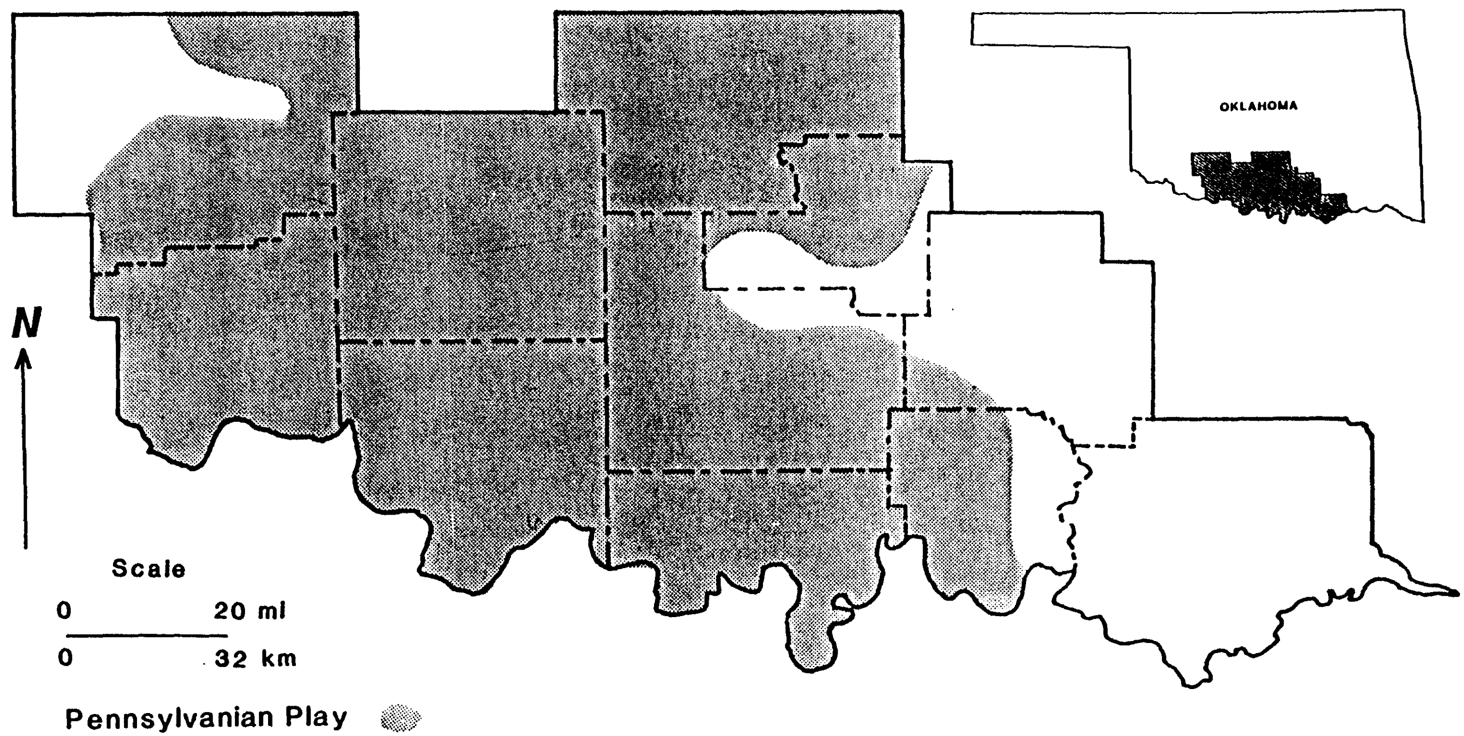

Fig. 6. Approximate area of the Pennsylvanian play.

the Springer Formation and Deese Group.

The Springer Formation contains three to five sandstone units composed of fine to medium size angular quartz grains which are relatively free of silt and other pore filling materials.

The Deese Group contains five sandstone units, all of which are productive. Reservoir rocks are composed of fine to medium size quartz grains. These grains are angular to sub-angular and are often relatively free of pore filling constituents. Some of the sandstones are graywacke and have poorer reservoir qualities than the cleaner sands (Hicks, 1971).

Traps in these formations are both anticlinal and stratigraphic. Stratigraphic traps caused by wedgeout or truncation of sandstone bodies are common. Seals are probably created by interbedded shales and/or fault contacts.

Source rocks for the tremendous Pennsylvanian hydrocarbon accumulations are probably the dark gray to black Pennsylvanian shales, the Woodford Shale and possibly shale in the Simpson Group, Caney Shale and Goddard Shale. The Goddard Shale also may serve as an effective barrier to vertical migration of petroleum from rich Woodford source rocks as much as 2000 feet (606 m) below, except where faulting has provided avenues for hydrocarbon migration. Due to the complexity of folding and faulting in this province these avenues are probably numerous. The Caney Shale may be a source rock in this province. It contains over 900 ppm extractable hydrocarbons (Hunt, 1961).

Probably the most important source beds for the Pennsylvanian reservoirs are the thick, dark gray to black Pennsylvanian shales (Webster, 1980; Merritt, 1978).

Timing is not a limiting factor for this play; traps were formed by Pennsylvanian tectonism simultaneously with or before probable source beds began to generate significant volumes of hydrocarbons. Probable migration pathways were faults and porous sandstone bodies.

Rocks in this play occur at depths of from about 1000 feet (303 m) to almost 11000 feet (3333 m) in the area.

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