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Petroleum Geology of the Nemaha Uplift, Central Mid-Continent

by

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INTRODUCTION

The Nemaha uplift is a regional paleostructural feature extending from southeast Nebraska to central Oklahoma (fig. 1). It is narrow, being little more than 80 miles at its widest in the north, and approximately 500 miles in length. Structurally, the uplift separates the Cherokee platform of northeastern Oklahoma and the Forest City basin of Kansas and Missouri from the Anadarko, Sedgwick and Salina basins to the west. To the south, it extends obliquely across the broad arch or platform separating the Arkoma and Anadarko basins and bounds the eastern end of the Anadarko basin. It has been productive of oil and gas from rocks ranging in age from Cambrian to Permian. Resources discovered total more than 2.8 billion barrels of oil and a relatively small amount of gas. The provincial area covered by this report is indicated by figure 2, and encompasses approximately 17,000 square miles. This report provides a brief summary of the geologic framework used in the assessment of oil and gas resources for this area, reported in USGS/MMS Open-File Report 88-373 (1988).

STRUCTURE

Although a cohesive structural element, the Nemaha uplift is actually a composite and complex feature, containing many separate fault blocks that produce structural culminations along its great length (fig. 3). Its surface expression is one of gentle anticlinal folding over more pronounced basement highs (fig. 4). Plunging to the south, the uplift is bounded on the east by a major fault system, the Humboldt fault zone (Jewett, 1951; Berendsen and Blair, 1986), and by collateral faults, which impinge the Thurman-Redfield fault zone of the Mid-Continent rift to the north and the Pauls Valley uplift (fig. 5) and Arbuckle Mountains uplift to the south (fig. 1). Along the abrupt eastern margin defined by the Humboldt fault zone, faults are typically interpreted as high-angle (Wells, 1971; Carlson, 1971) and, in some instances, reverse (Cary, 1955; Cronenwett, 1958). Major faulting, downthrown to the west, is noted primarily along the margin of the uplift along the Central Oklahoma fault zone, adjoining the Anadarko basin (Jordan, 1962; Tarr and others, 1965; Amsden, 1975; Anderson and others, 1982).

Precambrian basement rocks lie at depths of less than 600 feet in crestal blocks at the north end of the Nemaha uplift, but lie at depths exceeding 10,000 feet at its southern extremity. Vertical relief across the arch on the Precambrian basement locally exceeds 3000 feet, particularly adjacent to the Forest City basin in Kansas, and generally diminishes to the south, as shown by Anderson and others (1982a). In contrast, only very gentle structure and relief is expressed in younger rocks, where Permian and Pennsylvanian strata exposed at the surface and drilled in the shallow subsurface show gentle anticlines, domes, and arches as expressions of a much stronger deformation at depth in older rocks. Typically, vertical relief in these younger beds is on the order of 100 to 400 feet, reaching a maximum of about 900 feet in the north (Anderson and others, 1982b).

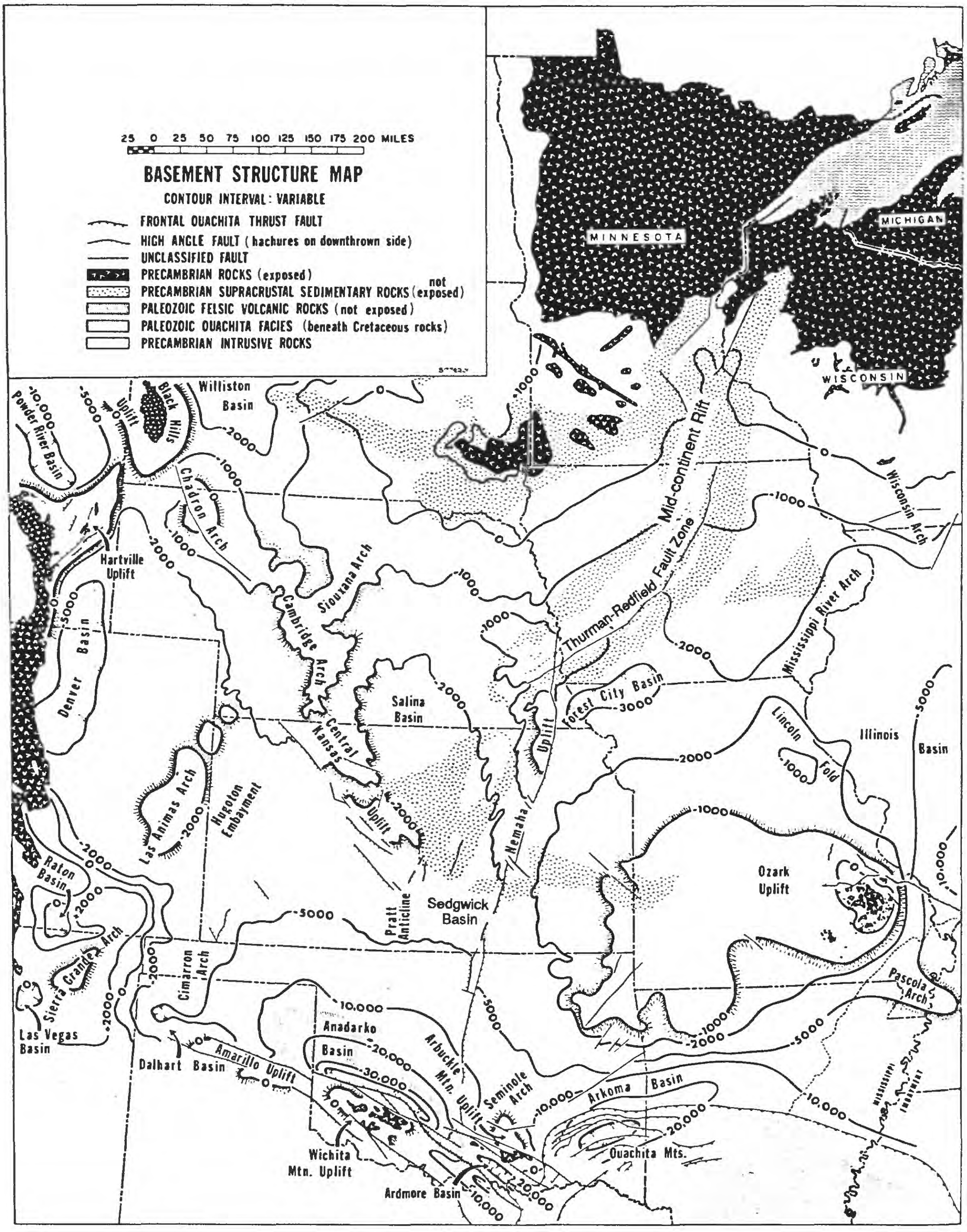

Figure 1.--Index map of Mid-continent region showing major structural elements (modified after Adler and others, 1971, reprinted by permission of American Association of Petroleum Geologists).

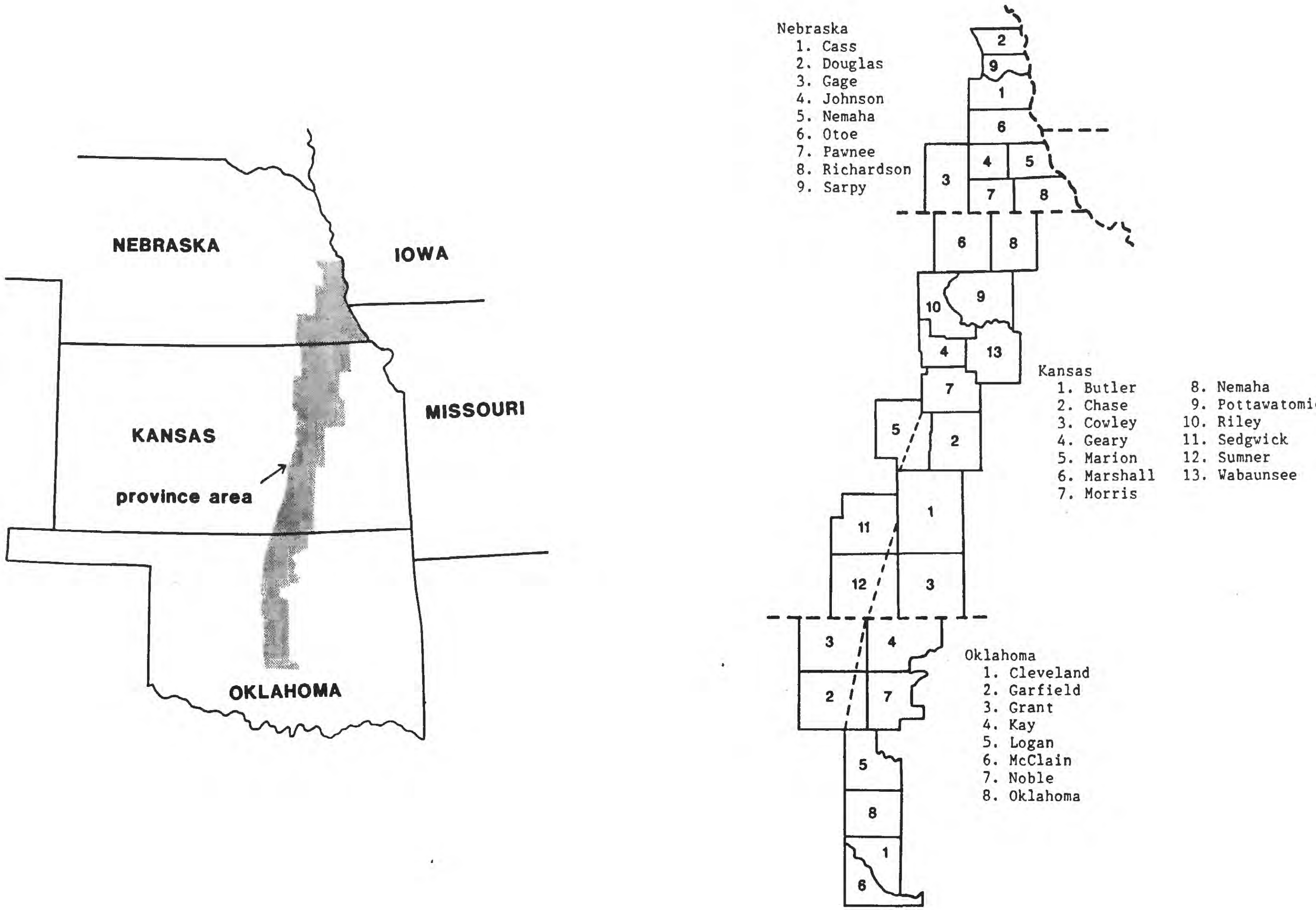

Figure 2.--Province area, Nemaha uplift, showing involved counties.

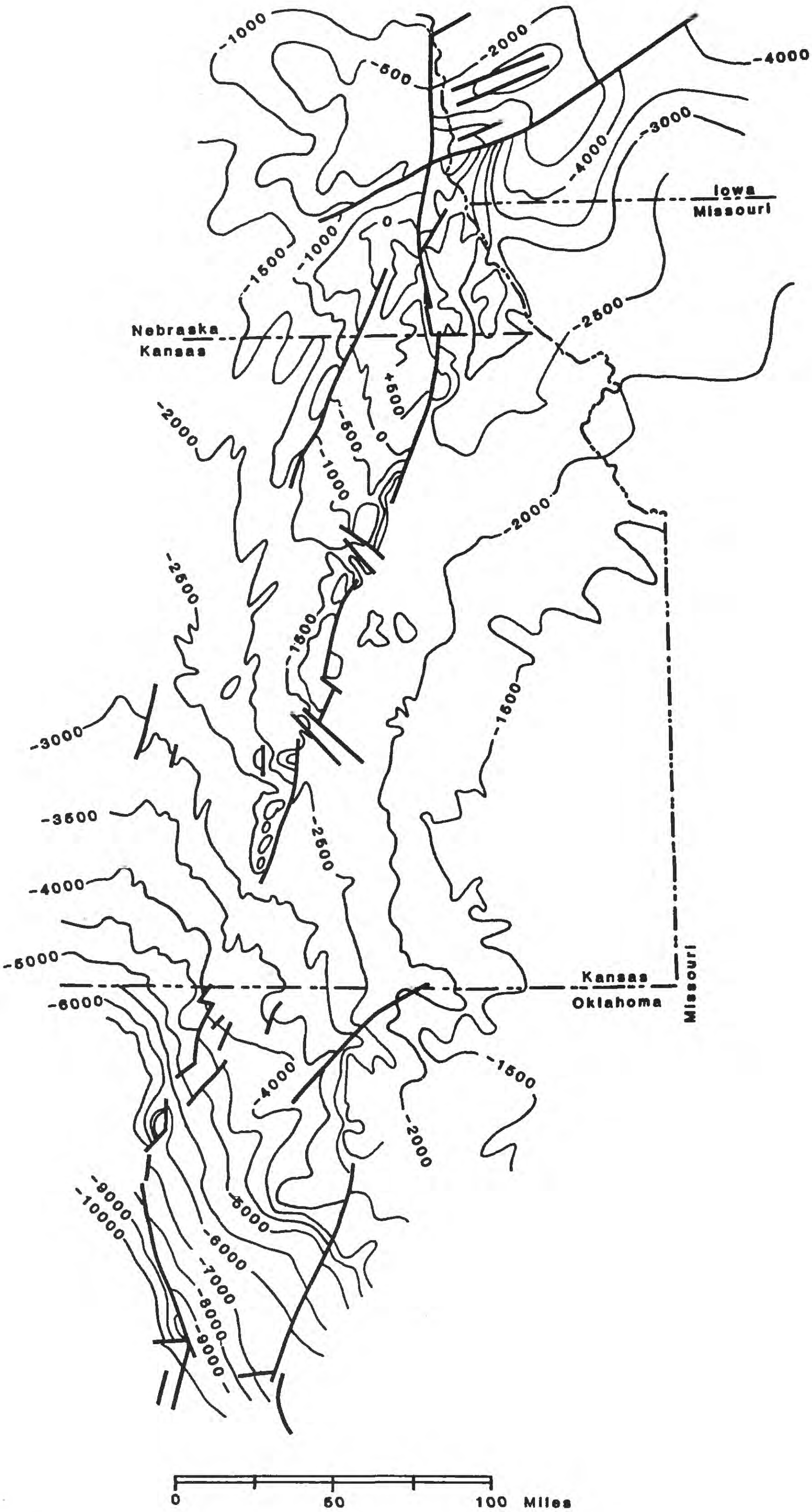

Figure 3.--Basement structure map, Nemaha uplift (modified after Anderson and others, 1982a; Burchett and others, 1983).

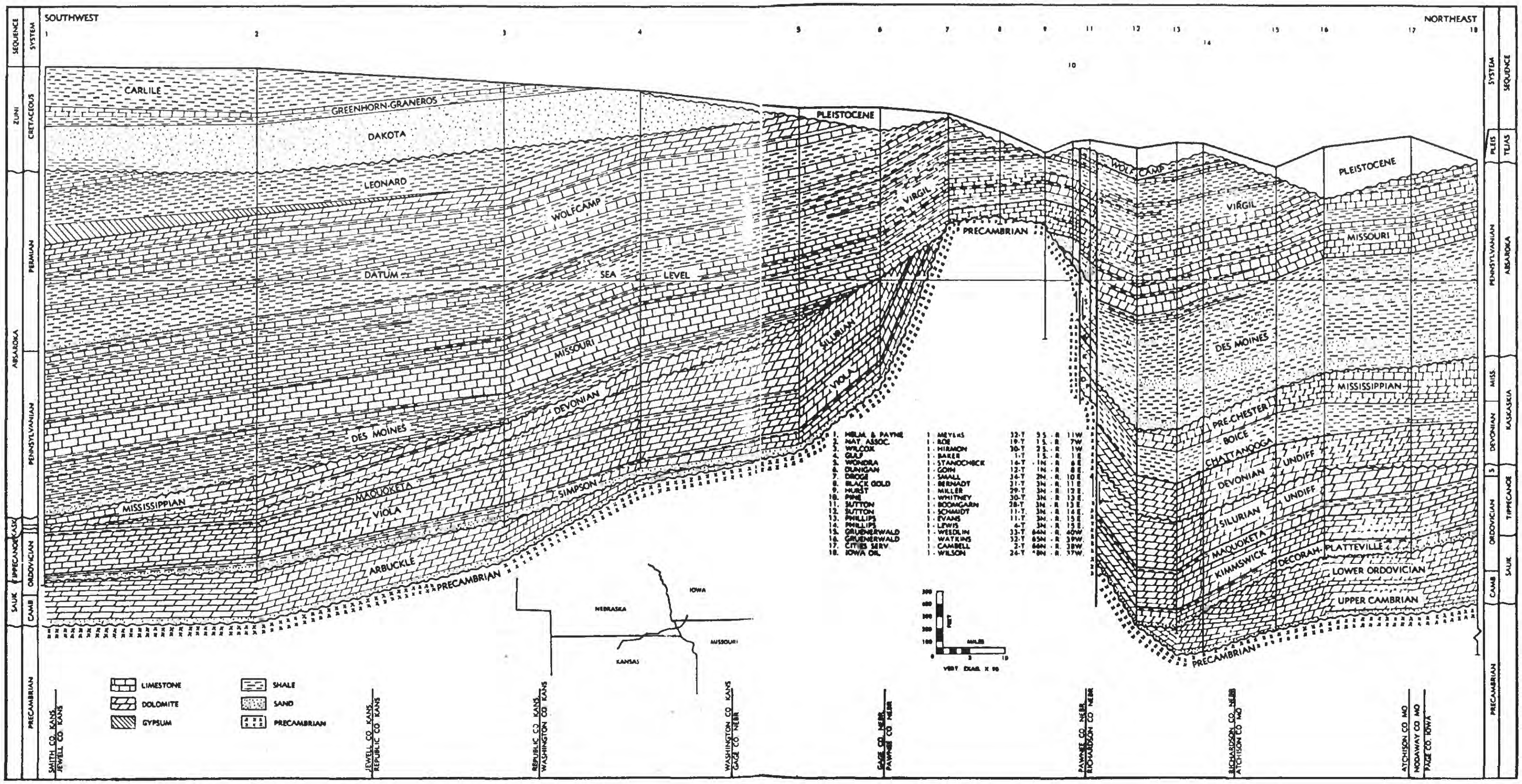

Figure 4.--Cross section of Nemaha uplift (after Carlson, 1971, reprinted by permission of American Association of Petroleum Geologists).

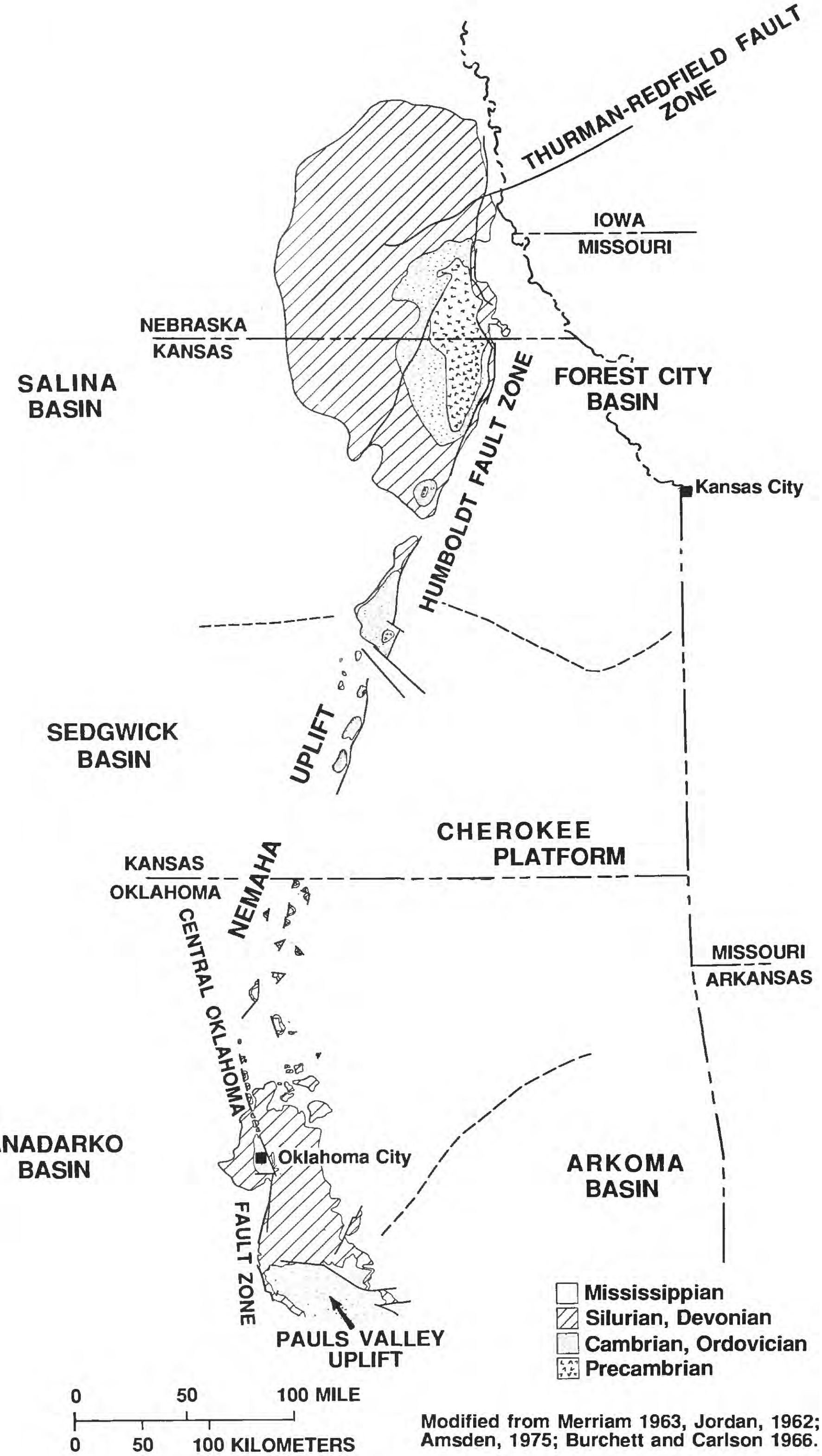

Figure 5.--Pre-Pennsylvanian subcrop map showing distribution of older Paleozoics beneath the Late Mississippian-Early Pennsylvanian unconformity (modified from Jordan, 1962; Merriam, 1963; Burchett and Carlson, 1966; Amsden, 1975).

The present Nemaha uplift had its first period of significant growth in late Mississippian or early Pennsylvanian time during the Ouachita orogeny when pre-Pennsylvanian rocks were folded, faulted, uplifted, and deeply eroded. Their truncated surfaces were onlapped by Desmoinesian strata and completely buried by Missourian time. Distribution of the pre-Pennsylvanian rocks, as shown in figure 5, is largely dependent upon the level of this stratigraphic truncation and, in places, the oldest sedimentary rocks have been entirely stripped from old high-standing basement blocks. Beneath the unconformity, dips of some of the older strata exceed 5 degrees. This early period of growth accounts for much of the presently observed basement relief.

Recurrent movement and differential compaction is demonstrated by mild deformation and faulting of the overlying Pennsylvanian and Permian strata. Growth over older features includes additional folding of anticlines and domes and renewed faulting, at least along the deep-seated, east-bounding fault system of the old Nemaha ridge. Dips in younger rocks are typically less than one degree and structural relief generally low.

The origin of the Nemaha uplift has been attributed by Berendsen and Blair (1986) to left-lateral wrench fault movement as a crustal response within the craton to plate collision along the continental margin. Amsden (1975) has suggested similar strike-slip movement on the Central Oklahoma fault zone. Earlier workers, such as Fath (1920, 1921), generally attributed the uplift to vertical movement on a pre-existing Precambrian zone of weakness.

STRATIGRAPHY

The Nemaha uplift involves sedimentary rocks of virtually all Paleozoic periods (fig. 6). Where the full stratigraphic section is present, it may exceed 10,000 feet in thickness, but because of paleostructural growth, parts of the older Paleozoic succession are locally absent by truncation, and some of the younger Paleozoic sequence by non-deposition, particularly on crestal elements of the uplift where Late Pennsylvanian strata may rest directly on Precambrian crystalline basement. The younger Paleozoics are everywhere present at the surface, except to the north, where they are covered by thin Pleistocene deposits.

The stratigraphic succession can be treated in two parts: an older Paleozoic rock package consisting primarily of dolomites and limestones, with subordinate clastics (the Sauk, Tippecanoe and Kaskaskia Sequences of Sloss, 1963); and a younger Paleozoic package (the Absaroka Sequence), which is largely terriginous, though containing abundant limestones. These two units are separated by a major unconformity of late Misssissippian or early Pennsylvanian age. Regional stratigraphy and distribution of the older Paleozoic rocks have been well-summarized by Huffman (1959) and Adler and others (1971), and of the Pennsylvanian series by Rascoe (1983), and are only briefly described in this report.

Precambrian crystalline rocks everywhere underlie the Paleozoic sedimentary succession, except to the extreme north in areas adjoining the Mid-Continent rift where the crystalline basement has been covered by a

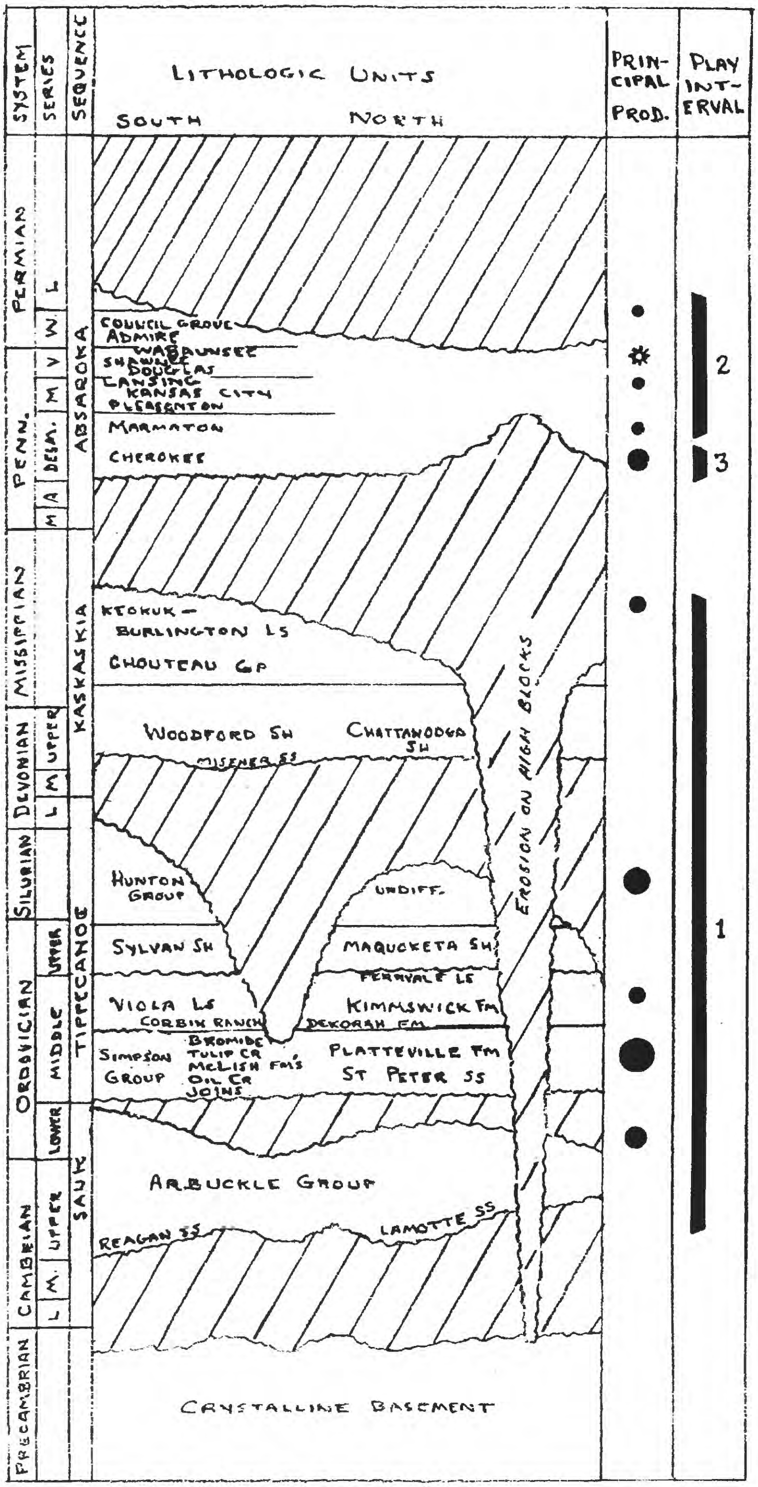

Figure 6.--Generalized correlation chart, Nemaha uplift. Major petroleum productive intervals indicated. Diagonal lines represent hiatuses. Rock intervals of assessed plays shown by numbered brackets.

Precambrian sedimentary and volcanic sequence. The crystalline basement consists of granite and metamorphics (Muehlberger and Bayley, 1968; Denison and others, 1984; Chenoweth, 1987; Sims, 1987) and, according to Denison, is dated at 1350 to 1500 Ma.

OLDER PALEOZOICS

Cambrian and Lower Ordovician

A thin, Late Cambrian sequence of arenaceous rocks, termed Reagan or Lamotte Sandstone, onlaps a granitic basement of some relief. Where not removed by erosion, the Reagan is conformably overlain by dolomites and limestones of the Arbuckle Formation, one of the major petroleum reservoir rocks of the Nemaha uplift. The Arbuckle thickens southward from generally less than 500 feet in Kansas to over 3000 feet in central Oklahoma. These rocks are unconformably overlain by younger Ordovician rocks and are locally truncated by early Pennsylvanian erosion and absent from many of the structural highs of the Nemaha uplift, particularly at its northern extremity.

Middle and Upper Ordovician, Silurian, and Lower Devonian

Resting unconformably on the Arbuckle Group, is a Middle and Upper Ordovician and Silurian sequence of mixed carbonates and clastics. Distribution of these rocks was influenced by the old Central Kansas uplift, or Ellis arch of Adler and others (1971), and combined with the Chautauqua arch to separate the Iowa basin of Adler or North Kansas basin of Rich (1931, 1933) from a larger, Oklahoma basin to the south (fig. 7). This arch was the site of both erosion and nondeposition of post-Arbuckle rocks (Huffman, 1959; Adler and others, 1971; Merriam, 1963; Witzke, 1980).

The Simpson Group forms the basal part of this sequence and is one of the most important hydrocarbon reservoir units of the Mid-Continent. It rests directly on Arbuckle and in the north contains the St. Peter Sandstone and the limestone Platteville Formation. On the Nemaha uplift south of the Central Kansas uplift, the Simpson Group thickens and assumes the more traditional formational breakdown recognized in southern Oklahoma, including, in ascending order, the Joins (dominantly carbonate), Oil Creek (shale and sandstone), McLish (shale, sandstone, and minor carbonate), Tulip Creek (shale) and the Bromide (dominantly sandstone, sometimes being called "Wilcox") and, according to some workers, the Corbin Ranch or "Simpson dense" (limestone and dolomite) (Schramm, 1964).

The Simpson Group in the north is overlain by the Decorah Shale, followed by the Kimmswick Formation (dolomite), Fernvale Limestone and the succeeding, often siliceous and dolomitic, Maquoketa Shale; in the south it is overlain by their equivalents, the Corbin Ranch Limestone and dolomite, the Viola Limestone, Fernvale Limestone and Sylvan Shale (Ireland, 1966). Shales of the Simpson and Decorah appear to contain petroleum source rocks (Newell and others, 1986). Conformably overlying the Maquoketa and equivalents is the Hunton Group, consisting primarily of limestones and dolomites. The Hunton is an important reservoir and is Silurian to Lower Devonian in age on the southern Nemaha and Silurian in

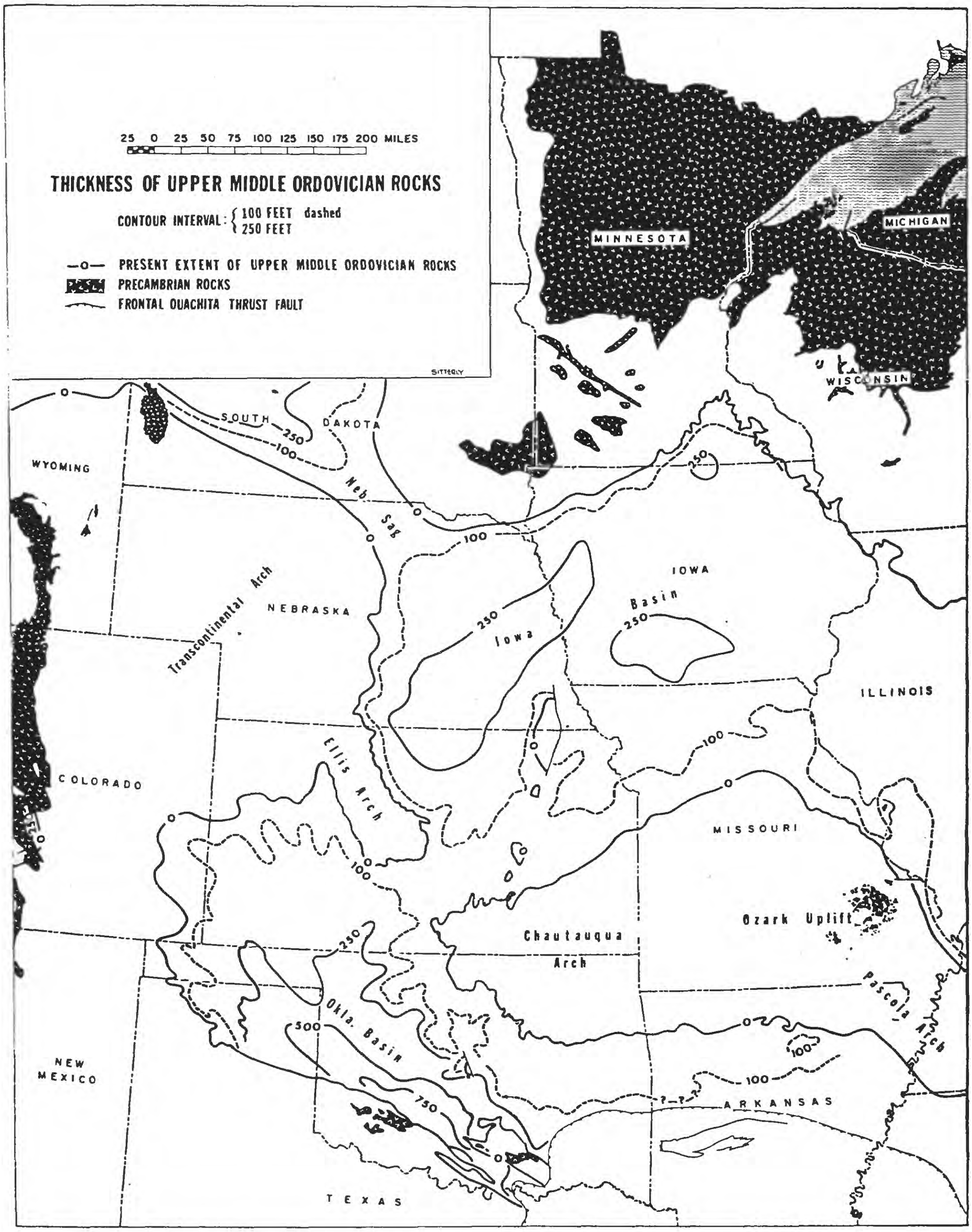

Figure 7.--Thickness map of upper Middle Ordovician rocks in Mid-Continent showing paleostructural elements. (modified from Adler and others, 1971, reprinted by permission of American Association of Petroleum Geologists).

the north. The total succession of Upper Ordovician, Silurian, and Lower Devonian strata (Tippecanoe Sequence) consists of up to 1600 feet of rock, bounded by major unconformities.

Upper Devonian and Mississippian

Where not removed by late Mississippian and early Pennsylvanian truncation of the Nemaha uplift, the Tippecanoe Sequence is overlain by the late Devonian-early Mississippian Woodford Shale of the Kaskaskia Sequence and its equivalent, the Chattanooga Shale. This dark, organic rich and cherty shale rests on a surface of modest paleotopographic relief, as well-documented in the adjoining Anadarko basin. On the old Central Kansas uplift and Chautauqua arch in the vicinity of the present Nemaha uplift, Late Devonian erosion has removed parts of the upper Tippecanoe Sequence so that Woodford rests on rocks as old as Simpson. On much of the Nemaha, it rests directly upon an eroded surface of Hunton rocks and at its base sometimes has a sandstone (Misener Sandstone) which is oil productive. The Woodford represents one of the major source rocks of the Mid-Continent (Cardott and Lambert, 1985; Comer and Hinch, 1981).

Post-Woodford rocks of the Kaskaskia sequence are generally limited to the Kinderhookian Chouteau Group, the Osagian Keokuk and Burlington Limestones. The sequence is primarily limestone with subordinate shale members. As a result of truncation these rocks are largely limited to flank areas of the Nemaha uplift. Residual or bedded chert zones, "Mississippi chat", are often found at the Mississippian surface beneath Pennsylvanian rocks.

YOUNGER PALEOZOICS

Pennsylvanian

Pennsylvanian rocks are everywhere present. Sedimentation in the area begins with Desmoinesian rocks and includes all succeeding Pennsylvanian series. It is a strongly cyclothemic sequence, typical of the Mid-Continent, dominantly clastic through the Desmoinesian, and more heavily carbonate in the Missourian and Virgilian.

Deposition of the Pennsylvanian rocks followed the major uplift of the Nemaha. Because of onlap, only the younger Pennsylvanian series are present over axial parts of the uplift and, on some of the highest blocks, Missourian rocks rest directly on eroded Precambrian. Desmoinesian rocks show great variations in thickness and sedimentation patterns. They clearly reflect the uplift and onlap of the old high areas of the Nemaha, and reach great thicknesses in areas flanking the uplift, such as in the Forest City basin. They override the uplift at its southern extremity in Oklahoma. Missourian and Virgilian rocks, however, extend across the Nemaha uplift with virtually no expression of structural growth or uplift in their thickness or depositional patterns and complete the burial of the uplift. Total thickness of Pennsylvanian rocks ranges from 750 to over 6000 feet, generally thickening southward.

The Pennsylvanian succession is a classic cyclothemic sequence, with ordered sequences of shales, coals, clays, sandstones, siltstones and limestones. A great number of local and informal names have been given these beds, and sandstones, mostly in the Desmoinesian, have been major reservoirs for oil and gas, particularly the "Bartlesville" and "shoestring" sandstones of northeastern Oklahoma and southeastern Kansas (Bass, 1937; Weirich, 1968). Occasional carbonates of late Pennsylvanian age are also productive as oil and gas reservoirs. Major stratigraphic groups are widely recognized and in ascending order are Cherokee, Marmaton, Pleasanton, Kansas City, Lansing, Douglas, Shawnee and Wabaunsee Groups and their equivalents.

Permian

Permian rocks on the Nemaha uplift range in age from Wolfcampian to Leonardian. Also cyclic, they consist primarily of terrigenous red beds, mostly shales, thin dense limestone beds, sandstones, and some evaporites. The Wolfcampian includes, in ascending order, the Admire, Council Grove and Chase Groups. Small amounts of oil and gas have been produced from Permian sandstone reservoirs. Permian rocks on the Nemaha range in thickness from 0 to 1500 feet.

STRUCTURAL HISTORY

The Nemaha uplift has seen a long history. Located on the craton, the area has seen repeated periods of regional warping, uplift, and erosion separated by periods of marine shelf sedimentation. The most significant of the upwarps prior to actual development of the Nemaha uplift appear to be of Middle Ordovician (post Arbuckle-pre Simpson) and Late Silurian-Early Devonian age, the latter involving movements on the ancestral Central Kansas uplift and Chautauqua arch, which separated the Iowa or North Kansas basin from the Oklahoma basin to the south (Adler and others, 1971; Rich, 1933; Lee, 1943) (fig. 7). Lesser unconformities bound several other early Paleozoic formations.

Development of the Nemaha uplift, as generally recognized, probably first began in late Mississippian or early Pennsylvanian time, although Wells (1971) suggests that during deposition of Kinderhookian clastic sediments, the first movements of the uplift occurred. In Late Mississippian or Early Pennsylvanian time, activity along the Nemaha structure divided the shelf and old North Kansas basin into the Forest City and Salina basins and produce a high standing block or series of uplifts, which extended south across the shelf to the Arbuckle Mountains uplift. Wells (1971) summarizes ...."rapid downwarping and faulting on the east side of the Nemaha ridge resulted in an east facing scarp and the formation of an asymmetric basin that was deepest near the Nemaha uplift" and that "the Nemaha uplift remained exposed and the transgressive overlap of Cherokee, Marmaton, and Pleasanton sedimentation continued until early in the Kansas City deposition when the scarp finally was inundated and deposition became linked in the areas east and west of the uplift."

After deposition of the Permian and prior to mid-Cretaceous, the Nemaha uplift was subject to a second cycle of growth, causing additional folding of strata over older structures and renewed faulting along some of the bounding faults. Structural relief and magnitude of faulting is modest, but sufficient to provide domal closures and anticlines for hydrocarbon accumulation in Pennsylvanian and Permian beds. Some of this structure is probably the result of differential compaction of Pennsylvanian rocks and draping over old basement high blocks.

SOURCE ROCKS AND THERMAL HISTORY

Source rocks significant to hydrocarbon accumulation on the Nemaha uplift have been variously identified as Ordovician Simpson and Decorah shales, the Devonian-Mississippian Woodford Shale, and the dark shales of the Cherokee sequence. Their potential contribution, however, must be examined in light of the burial history of the Nemaha uplift and surrounding areas.

Evidence to-date suggests that although higher thermal histories are recorded east of the ridge and along the eastern Kansas-Oklahoma border (Hatch, 1988, pers. comm.), only on deeply buried elements of the uplift or in adjoining basinal areas have organic-rich rocks been sufficiently buried to have reached temperatures adequate to mature as petroleum sources. This suggests that much of the oil on the uplift, especially in the north, may be derived through lateral migration out of adjoining basins, such as the Forest City, Arkoma and Anadarko basins.

Ordovician source rocks and reservoired oils have been examined in some detail in the vicinity of the adjoining Forest City basin (Newell and others, 1986, 1987; Longman and Palmer, 1987). There, organic geochemistry and thermal modeling indicates that organic-rich shales of the Simpson Group have contributed hydrocarbons to older Paleozoic reservoirs and that maturation was achieved in Late Pennsylvanian or Permian time. These organic-rich rocks, immature on northern elements of the northern Nemaha uplift itself, are mature in the axis of the Forest City basin, probably allowing migration into reservoirs on the Nemaha uplift. Organic-rich rocks of Ordovician age, including Simpson, Decorah, and perhaps Sylvan, appear mature on some of the deeper elements of the Nemaha uplift to the south and are mature in the Anadarko and Arkoma basins. Newell and others (1986) also suggest their maturity in the Salina basin, west of the Nemaha.

Gatewood (1970) and Webb (1976) present physical evidence that oil had migrated prior to mid-Pennsylvanian into some structures of the Nemaha uplift, such as Oklahoma City field, and was lost through surface leakage of exposed reservoirs before reburial and sealing by Pennsylvanian shales and a second phased accumulation. Ordovician and Devonian rocks have been suggested as sources for this oil, however, considerations of thermal and burial history suggest that hydrocarbons on the ridge prior to Late Pennsylvanian require lateral migration out of the adjoining Anadarko or Arkoma basin.

The Woodford Shale is often considered to be a primary source for much of the oil found in Paleozoic rocks of the region (Cardott and Lambert, 1985; Comer and Hinch, 1981) and, by inference, of the Nemaha uplift. Cardott and Lambert indicate that the Woodford Shale is at or within the upper part of the oil generation window at several points along the southern Nemaha uplift, a view concurred with by Davis (1984). It is clearly mature and has generated oil in the deeper parts of the adjoining Anadarko and Arkoma basins (Cardott and Lambert, 1985; Comer and Hinch, 1981; Schmoker, 1987). However, as one progresses northward into Kansas, Woodford and younger organic-rich rocks are not generally within the oil generation window on the uplift, and lateral migration from areas of thermal maturity, such as the Forest City, Anadarko and Arkoma basins, is probably required to provide for the abundant oil. Such migration appears generally important on the Nemaha and speculations concerning its mechanisms have long been proposed (Rich, 1931, and others).

Workers such as Adler (1971), suggest that although the Woodford was a probable source of oil in reservoirs which are overlain by the unit, and Simpson oils were from Simpson shales, the thick, dark, organic-rich shales of the Pennsylvanian were the principal source rocks for many of the older Paleozoic-reservoired oils, noting that Woodford Shale is often absent on anticlines of the uplift, due to Late Mississippian-Early Pennsylvanian erosion, and generally absent along the eastern Kansas-Oklahoma border, due to emergence during Late Devonian.

The thick Cherokee shale section traditionally has been cited as a source bed for the Pennsylvanian oil pools (Baker, 1962; Goebel, 1971; Adler, 1971; and others), and occasionally for the older Paleozoic pools (Cardwell, 1977; Adler, 1971). Pennsylvanian shales contain abundant organic matter, particularly humic material (Wenger and Baker, 1986), and are largely gas prone. Other than in eastern Oklahoma, they appear not to have seen sufficient thermal history to have matured near the Nemaha uplift (Hatch and others, 1984; Hatch, King and Daws, in press). However, in deep parts of the Anadarko and Arkoma basins, Pennsylvanian rocks do appear to have achieved thermal maturity (Schmoker, 1987) and long-distance lateral migration from these areas as proposed by Price (1980) may have occurred. Amounts of hydrocarbons so generated are unknown.

Vertical migration of oil and gas into Pennsylvanian and Permian reservoirs from underlying pre-Pennsylvanian rocks has also been suggested by early workers such as Rich (1931) and Gish and Carr (1929) and is supported by recent geochemical investigations of Hatch and others (1984; in press) and modeling by Davis (1984). These studies indicate that some oil in Pennsylvanian and Permian reservoirs originates in Devonian source beds. Avenues for vertical migration are independently suggested by the presence of helium in natural gas in shallow Pennsylvanian and Permian reservoirs on the Nemaha uplift and by erratic charging of those reservoirs.

HYDROCARBON OCCURRENCE

The Nemaha uplift is a prominent structural uplift on which folding and faulting fundamentally control the distribution of oil and gas. Structural growth is complex. Cambrian to Mississippian rocks, which were strongly uplifted, faulted and truncated during early Pennsylvanian time, provide reservoirs within anticlinal closures and truncation traps on high blocks that were buried during mid- to late Pennsylvanian. These are the principal petroleum reservoirs and traps on the Nemaha uplift. Structures were reactivated following deposition of Pennsylvanian and Permian strata, producing moderate folding and faulting of young rocks and additional deformation of older rocks (fig. 4). Late deformation, in part, may be due to differential compaction. This latest folding is expressed by the anticlinal configuration which is seen at the surface and in the shallow subsurface along the axis of the buried uplift, and it produces closures and sites for the accumulation of oil and gas in Pennsylvanian and younger rocks.

Oil and gas on the Nemaha uplift occurs in three basic settings, shown schematically in fig. 8:

1) older Paleozoic structural and truncation traps;
2) shallow structural traps in Permian-Pennsylvanian rocks; and
3) Cherokee sandstone stratigraphic traps.

Older Paleozoic structural and truncation traps:

Reservoir rocks ranging in age from Ordovician to Mississippian are productive in anticlinal traps and in truncation traps on high blocks beneath the Late Mississippian-Early Pennsylvanian unconformity. Eroded structures are, in some cases, "bald headed" anticlines or uplifts wherein beds of Late Pennsylvanian age lie on rocks as old as Precambrian (fig. 5). Anticlines preserving pre-Pennsylvanian rocks on their crests or such rocks in truncation traps on their flanks have produced large volumes of oil. Altogether, more than 125 oil fields greater than 1 million barrels have been found in these traps and they collectively have accounted for more than 2.4 billion barrels of discovered oil (fig. 11 and Appendix A).

El Dorado field (approximately 280 million barrels of recoverable oil) is an outstanding example of production from one of the ancient buried anticlines over which the younger rocks are less tightly folded. Here, a porous zone of beveled Ordovician strata lies immediately below Pennsylvanian beds. The productive zone ("Stapleton zone") includes weathered truncated edges of the Viola Limestone, St. Peter Sandstone and Arbuckle dolomite. In this field, as in some other fields, communication is seen between the producing formations.

The Arbuckle Group is the oldest of the major producing units in fields of the Nemaha uplift. Reservoirs are found where intercrystalline porosity developed and was enhanced by solution and weathering prior to the deposition of the overlying Pennsylvanian rocks. Goebel (1971) indicates that 40 percent of the total production on the Nemaha uplift in Kansas is from the Arbuckle.

According to Adler (1971), the Simpson has been the single most important reservoir on the Nemaha uplift. The Oklahoma City field, which was discovered in 1928, produces from Viola, Simpson and Arbuckle but has yielded over 600 million barrels of oil from the Simpson alone (Gatewood, 1970). As shown by Gatewood and summarized by Adler (1971), "in this field, as in others along the Nemaha ridge axis, oil is trapped on the flanks of structures, where Simpson rocks have been eroded from the crest of the anticline and sealed by Pennsylvanian strata."

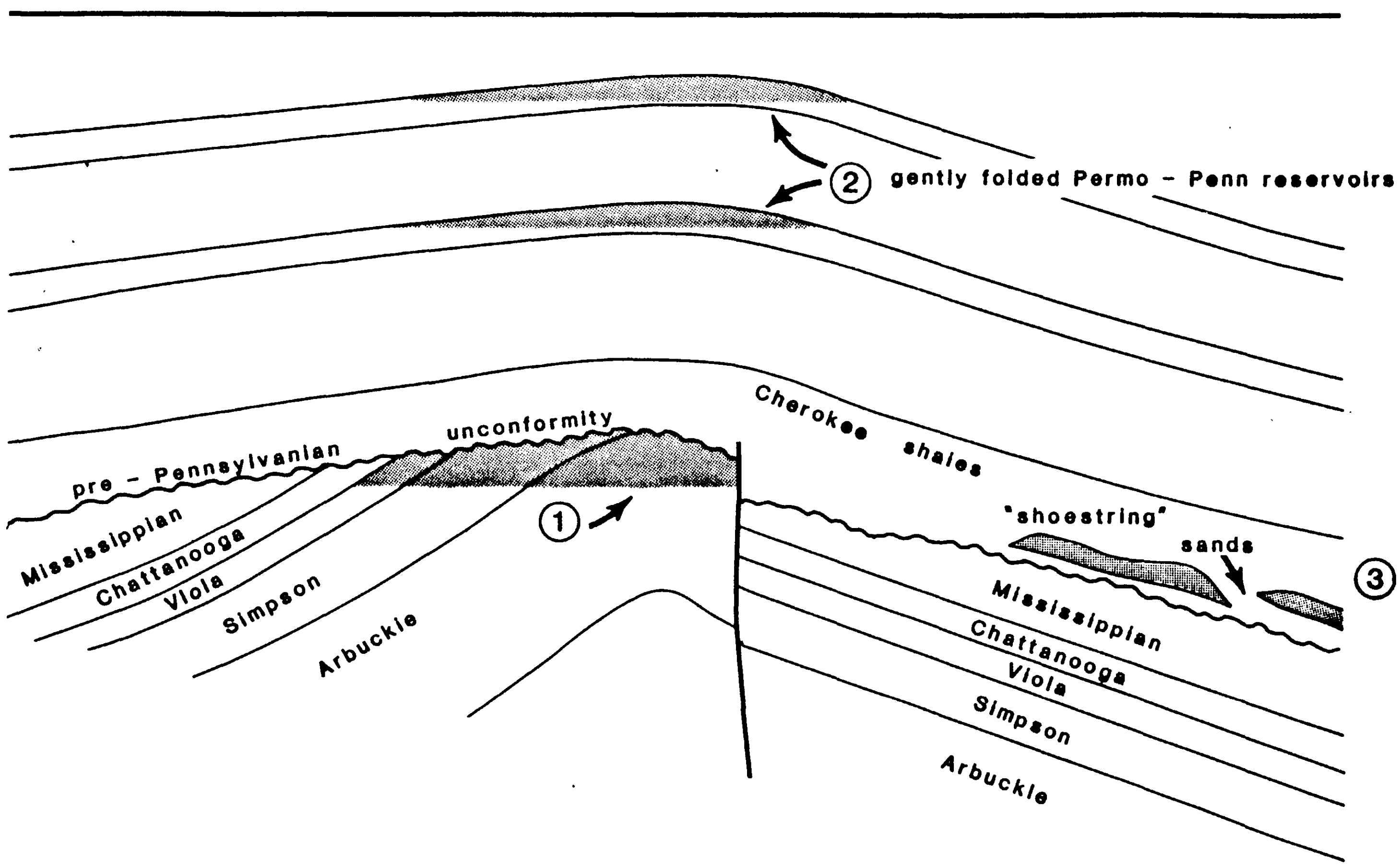

Figure 8.--Schematic representation of hydrocarbon plays, Nemaha uplift: Older Paleozoic (Pre-Pennsylvanian play); 2) Pennsylvanian-Permian structural play; 3) Cherokee sandstone stratigraphic play.

The Viola Limestone is generally a secondary reservoir in traps on the uplift and only infrequently produces alone. Production is from often vuggy, porous dolomite beneath Pennsylvanian rocks. Altogether, over 50 fields yield some oil from the Viola; production is primarily on structures that also produce from Simpson.

The Hunton carbonate section is an important reservoir, as demonstrated by West Edmund field, where dolomitization and fracturing provides a reservoir in a truncation trap beneath the Pennsylvanian unconformity and a container for over 180 million barrels of oil (Swesnik, 1948). Where still overlain by Woodford, the Hunton may also provide non-structural, paleotopographic stratigraphic trapping potential similar to that of the Anadarko basin (Maxwell, 1957; Harvey, 1968; Adler, 1971; Amsden 1975, 1983).

The locally productive Misener sandstone is a secondary objective in both structural and combination structural-stratigraphic traps.

The Mississippian sequence is the youngest of the pre-Pennsylvanian "structural" reservoirs. Many fields produce relatively small amounts of oil from the "chat", a weathered residual chert or bedded chert at the top of the Mississippian, and from porous zones within the carbonate section. Most of the reservoirs are controlled by the overlying basal Pennsylvanian unconformity.

Shallow structural traps:

The second major setting for major hydrocarbon occurrence involves structural traps in the gently folded Pennsylvanian and Permian sequence (fig. 8). Sandstones and carbonates of the post-Cherokee Pennsylvanian and Permian series are productive in small structural closures and combination traps of the Nemaha uplift; reservoirs are typically thin and often gas-bearing. They usually produce in association with deep, older Paleozoic reservoirs, that is, on common structures. Accumulations that exceed one million barrels oil (MMBO) or 6 BCF gas number only about 40. Their largest size is slightly over 20 million barrels and their average is much smaller. Approximately 180 million barrels of recoverable oil has been discovered in these accumulations.

Cherokee sandstone stratigraphic traps:

The third major setting for hydrocarbon occurrence involves stratigraphic traps in the Pennsylvanian Cherokee Group. These are traps formed by various lenticular sandstone bodies, particularly channel sandstones, strandline sandstones, and offshore bars of the Bartlesville Sandstone, often known as "shoestring sands" (Bass and others, 1937; Wells, 1971; Visher, 1971). Conglomerate and sandstone lenses in the basal Desmoinsian also have been productive in stratigraphic traps related to paleotopography at the unconformity. Several fields also result from structural combinations. Approximately 40 fields larger than 1 million barrels have been found in this association; the largest appears to be about 30 million barrels, and the average, far less. Approximately 200 million barrels have been discovered in the larger accumulations along the south end of the Nemaha uplift.

EXPLORATION HISTORY

Although some exploration drilling near oil seeps took place in the Forest City basin as early as 1860, with shows and small amounts of oil and gas encountered in Pennsylvanian sandstones, exploration of the nearby Nemaha uplift did not take place until the beginning of the 20th century, when drilling and exploration in the Forest City basin and flanks of the Ozark uplift spilled over onto the Nemaha uplift.

The first successful drilling near the Nemaha uplift occurred in Cowley County, Kansas, in 1903, with discovery of Dexter field, yielding gas from shallow Permian sandstones immediately east of the uplift axis. About 1905, gas was discovered at Ponca City field in Kay County, Oklahoma, in uppermost Pennsylvanian and Lower Permian sandstones, followed by Newkirk field in 1906 and Blackwell field in 1909. These shallow accumulations were recognized as being located on anticlinal features, which stimulated further exploration of such anticlines as could be mapped along the trend. Deeper drilling at Mervine and Blackwell in 1913 and 1914 resulted in discovery of additional oil and gas pays in the Pennsylvanian and generally encouraged exploration. Only later were several of these structures found to be productive in the pre-Pennsylvanian reservoirs as well.

In Cowley and Butler Counties, Kansas, additional gas was discovered in shallow Permian and Pennsylvanian sandstones by 1906. However, the discovery of large amounts of oil in the Ordovician at Augusta field in 1914 (52 million barrels) and in Ordovician and Silurian rocks of the "Stapleton zone" at El Dorado field in 1915 (280 million barrels) marked the beginning of large scale oil production in Kansas and the beginning of intensive exploration of the anticlines and domes of the Nemaha uplift in both Kansas and Oklahoma.

Other discoveries followed, including Garber anticline, Oklahoma, in 1916, and prolific new deep pays in several of the older producing areas. By 1945, a series of major oil and gas fields had been found along the Nemaha uplift, including the giant Oklahoma City field (approximately 750 million barrels). Altogether, more than 160 fields exceeding one million barrels of oil have been discovered and the total amount of oil found exceeds 2.8 billion barrels. Substantial gas also has been discovered, for which production figures are incomplete.

Today the area is in a mature stage of development. The last field discovery exceeding 10 million barrels of oil was in 1969 (S. Peckham), a field of approximately 13 million barrels. Prospects for additional large accumulations of oil and gas appear very limited although numerous small accumulations probably are undiscovered, and many new pool additions may be made to existing fields.

HYDROCARBON PLAYS

The hydrocarbon plays identified for resource assessment of this province are those associations discussed in previous sections and shown schematically in figure 8.

Older Paleozoics (Pre-Pennsylvanian) Play

This play describes the occurrence of oil and gas in older Paleozoic reservoirs beneath Middle or Late Pennsylvanian seals in structural and truncation traps on or associated with the Nemaha uplift. The general play area encompasses virtually the entire province area (fig. 9) and limited, geologically related contiguous areas. Reservoirs range in age from Cambrian to Mississippian. Principal objectives are the Arbuckle, Simpson, Viola and Hunton formations, which include both sandstone and carbonate reservoirs, although Simpson sandstone reservoirs are the most important in terms of past production. Secondary objectives include the Mississippian carbonates and "chat", and the Devonian Misener Sandstone.

Source rocks are believed to be Ordovician Simpson and Sylvan shales, and the Devonian-Mississippian Woodford Shale; in much of the area, long-distance lateral migration from these source rocks appears to have occurred.

Major fields have been found in this play, including the super-giant, Oklahoma City field (figs. 10, 11, and Appendix A); over 130 exceed 1 MMBOE. The mature state of exploration leaves opportunity mostly for subtle and smaller traps, primarily unconformity related traps involving local porosity development in subcropping units, and structural and combination traps beneath the unconformity, including downthrown blocks along reverse-faulted edges of larger uplifts. Drilling depths range from 2000 to 10,000 feet.

Permian-Pennsylvanian Structural Play

This play describes the occurrence of oil and gas in structural and combination traps involving shallow Permian and late Pennsylvanian reservoirs.

Reservoirs are typically sandstones but also include limestones of late Pennsylvanian and Permian age. They are productive either singly or in various combinations in simple, low relief closures over deeply buried basement blocks. Oil and gas typically appear to have migrated vertically, and not all available reservoirs are hydrocarbon bearing. Individual sandstones often display stratigraphic controls on distribution and many traps are therefore combination traps involving both structure and stratigraphy. Drilling depths range from a few hundred to about 5000 feet.

Between 1903 and 1983, over 40 fields containing more than 1 million barrels of oil or 6 billion cubic feet of gas have been discovered in this play, the last in 1960 (figs. 10, 12, and Appendix A). In addition, a great number of smaller oil and gas accumulations have been discovered.

This play was treated as essentially exhausted insofar as undiscovered accumulations larger than one million barrels or 6 billion cubic feet.

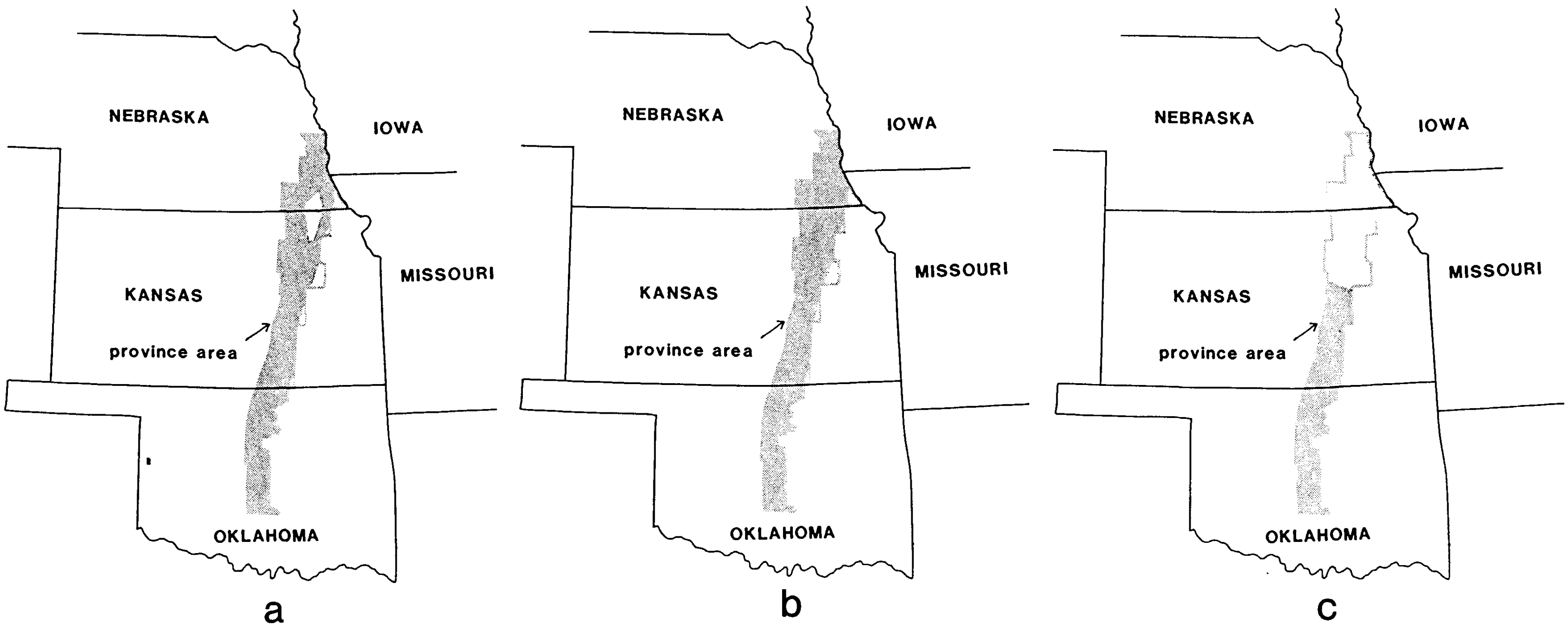

Figure 9.--Nemaha uplift play areas. Play areas occupy shaded areas of formal province and small geologically related areas peripheral to it. Play areas: a) Older Paleozoic (pre-Pennsylvanian play); b) Pennsylvanian-Permian structural play; and c) Cherokee sandstone stratigraphic play. All areas within a play are not equally prospective or productive.

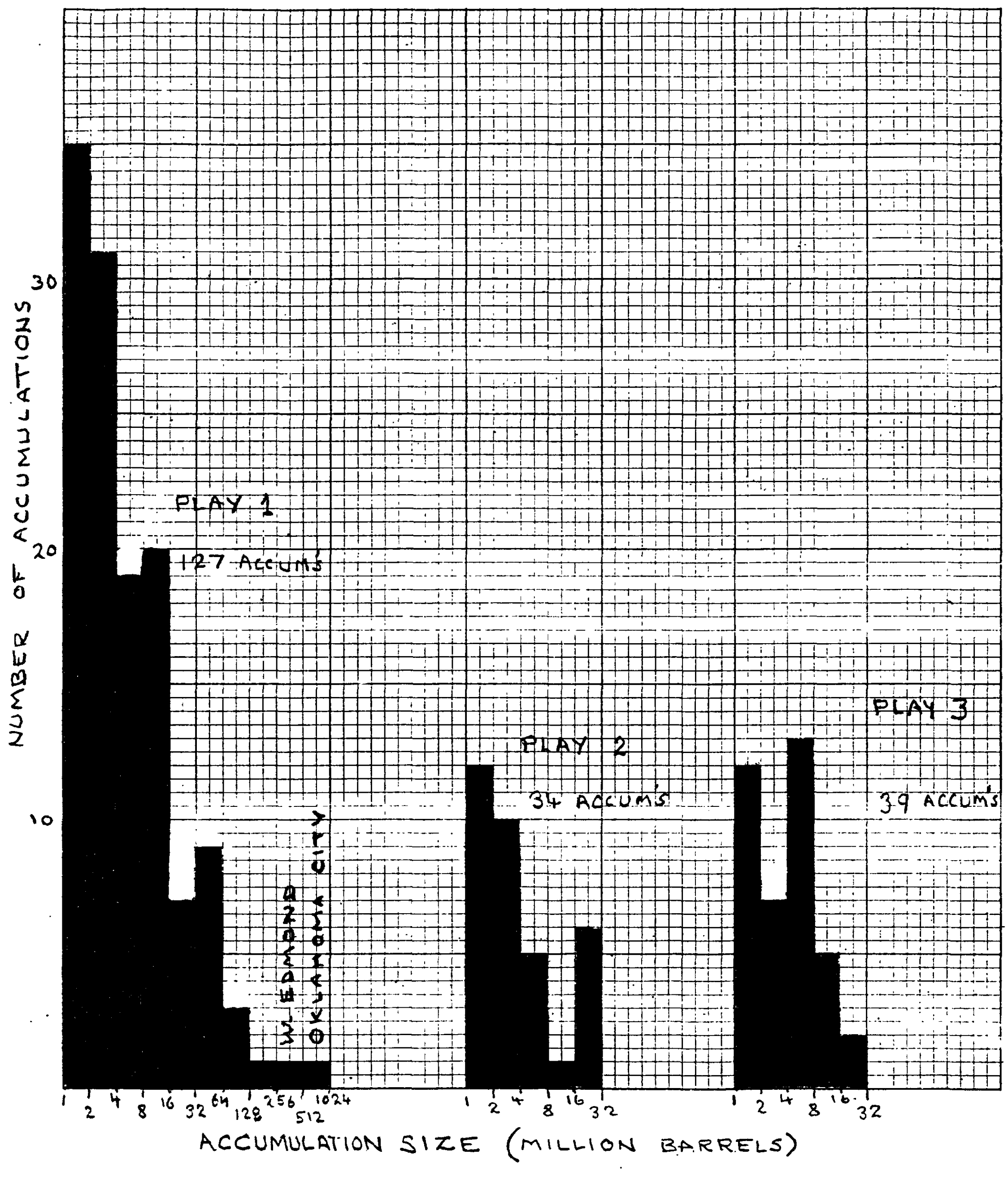

Figure 10.--Size distributions of known oil accumulations in the hydrocarbon plays of the Nemaha uplift (discovered 1903-1983).

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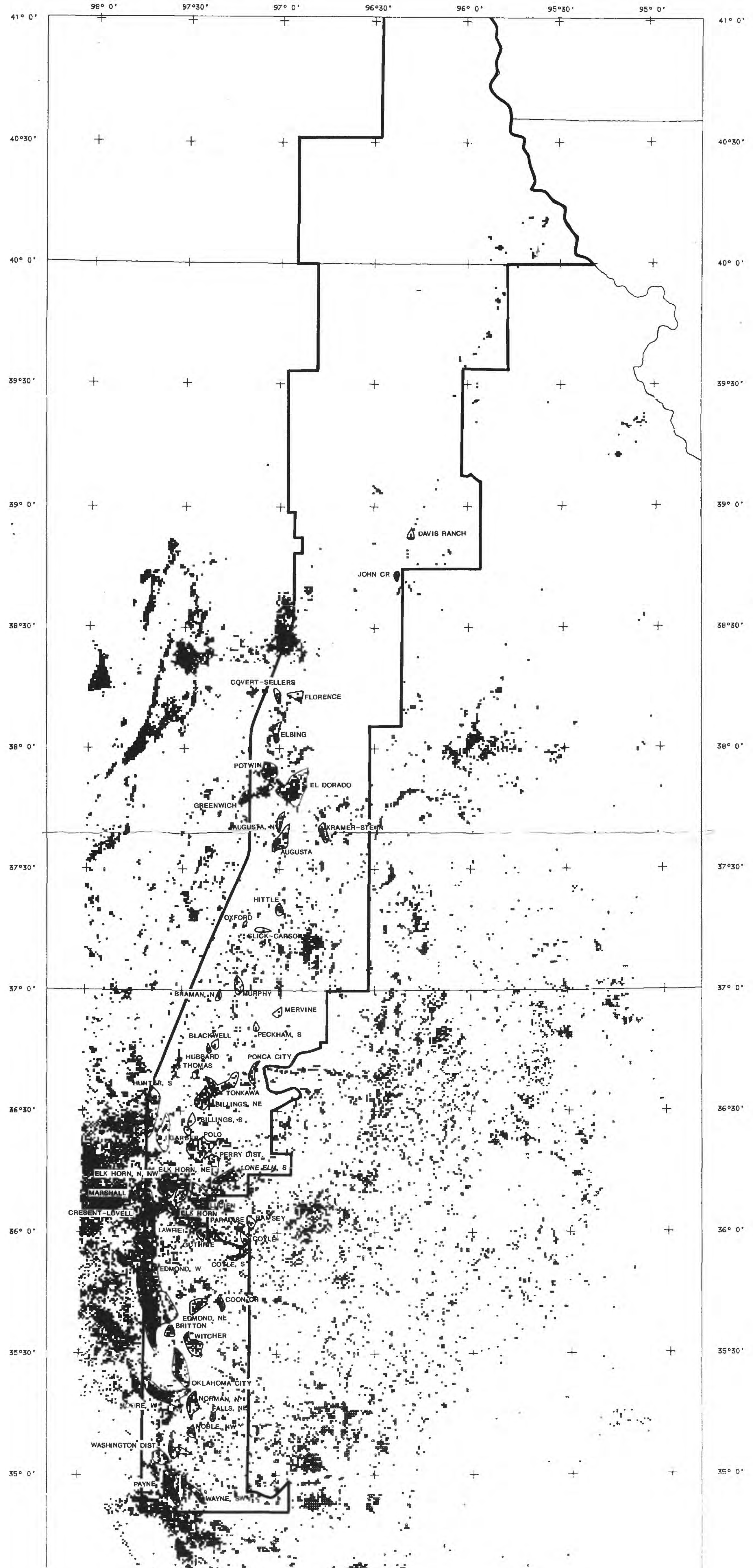

Fig 11 Map showing producing areas for the Older Paleozoics (Pre-Pennsylvanian) Play and locations and names of principal fields. Data from the WHCS computer data base, as of December, 1985. Nemaha uplift province outline indicated. Scale 1:2,000,000

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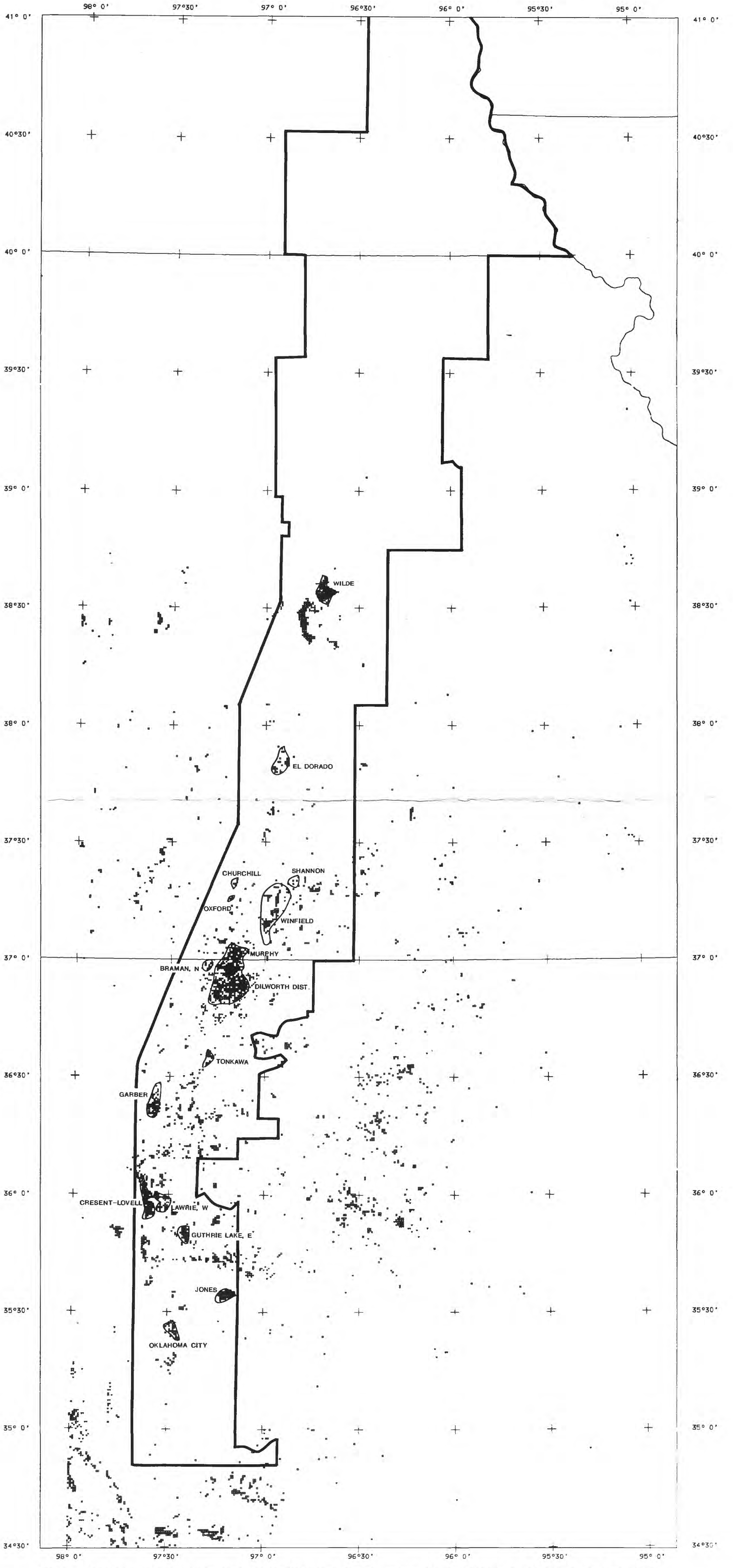

Fig 12 Map showing producing areas for the Permian-Pennsylvanian Structural Play and locations and names of principal fields. Data from the WHCS computer data base, as of December, 1985. Nemaha uplift province outline indicated. Scale 1:2,000,000

Cherokee Sandstone Stratigraphic Play

This play describes the occurrence of oil and gas in stratigraphic traps in the Pennsylvanian Cherokee Group sandstones. The play is principally confined to flank positions along the northern Nemaha uplift, but extends across the uplift at its southern end.

Traps are formed by various lenticular sandstone bodies, the most important being the "shoestring" and "Bartlesville" sandstones of southeastern Kansas and northeastern Oklahoma. Conglomerates and sandstone lenses in the Cherokee associated with the basal unconformity are also productive and are included within this play. Approximately 40 oil and gas fields larger than 1 million barrels have been discovered as of 1983. Drilling depths generally range from 750 to 10,000 feet. For purposes of assessment, this play was included with the Cherokee sandstones of the adjoining Cherokee platform where they are a major objective.

88-450-D

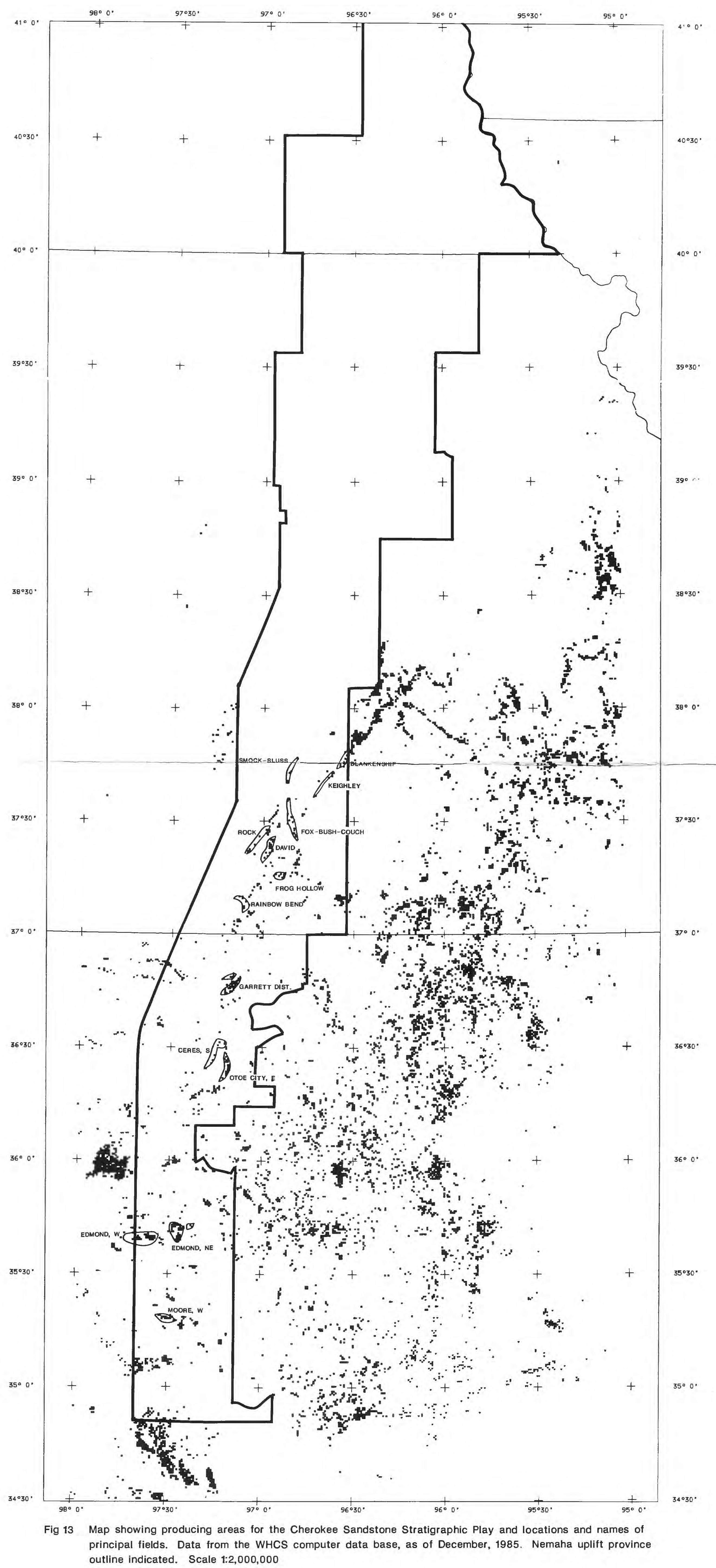

Fig 13 Map showing producing areas for the Cherokee Sandstone Stratigraphic Play and locations and names of principal fields. Data from the WHCS computer data base, as of December, 1985. Nemaha uplift province outline indicated. Scale 1:2,000,000

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Appendix A. Recognized accumulations >1 MMBO or >6 BCF Gas, Nemaha uplift, ranked in order of estimated size.

Play 1. Older Paleozoic (pre-Pennsylvanian) play:

Field Name	State	Disc. Date Field (Play*)	Size Class[1]	Prod. Zones[2]
OIL:				
Oklahoma City	OK	1928	15	A,S,V
El Dorado	KS	1915	14	A,S,V
Edmond, W	OK	1943	13	S,H,M
Tonkawa	OK	1921 (1924)	12	A,S,V
Hunter, S	OK	1945	12	S,V,W,M
Garber	OK	1916 (1925)	12	A,S
Augusta	KS	1914	11	A,S
Lucien	OK	1932	11	S,W
Norman, N	OK	1935	11	A,S,V
Payne	OK	1956	11	A,S,V,H
Elbing	KS	1918	11	V,H,W,M
Crescent-Lovell	OK	1926 (1928)	11	S,H,M
Edmond, NE	OK	1944	11	S,H
Washington District	OK	1944	11	S,V
Moore, W	OK	1943	11	A,S,V,H
Billings	OK	1917 (1919)	10	A,S,M
Wayne, SW	OK	1946	10	S,H
Ramsey	OK	1938	10	S,H,W,M
Augusta, N	KS	1916	10	A,S
Coon Creek	OK	1944	10	S
Witcher	OK	1947	10	H
Polo	OK	1934	10	S,V,W,M
Marshall	OK	1927	9	S,M

* Pre-Pennsylvanian discovery date, where different from field discovery date.

Slick-Carson	KS	1924	9	A,S
Greenwich	KS	1929	9	A,S,V,H,M
Noble, NW	OK	1958	9	A,S,V
Ponca City	OK	1905 (1918)	9	S,M
Peckham, S	OK	1969	9	M
Blackwell	OK	1909 (1914)	9	S,M
Potwin	KS	1921	9	S,M
Thomas	OK	1924 (1925)	9	S
Falls, NE	OK	1955	9	S,V
Covert-Sellers	KS	1920	9	V,H
Kramer-Stern	KS	1926	9	A,S,V
Hittle	KS	1926 (1928)	9	A
Oxford	KS	1927 (a1930)	9	A,M
Jones	OK	1939 (1948)	9	W
Murphy	KS	1933	9	S,M
Coyle, S	OK	1947	9	S,H,W
Florence	KS	1920	9	V,H,W
Davis Ranch	KS	1949	9	V,H
John Creek	KS	1953	9	V
Orlando	OK	1929	8	S,W
Rich Valley	OK	1954	8	S,M
Padgett	KS	1924/25	8	S,M
Graham	KS	1924	8	A,S,M
Reynolds-Schaffer	KS	1924 (1926)	8	V,M
Falls City	NE	1939	8	H
Young	KS	1920	8	M
Lone Elm, S	OK	1952 (1957)	8	M
Noble, New	OK	1956	8	S
Lawrie, W	OK	1951	8	S
Britton	OK	1935	8	S
Towanda	KS	1948	8	V,M
Otoe City	OK	1929 (1941)	8	S
Alamo	OK	1957	8	S,V
Perry District	OK	1922	8	W,M

Noble, E	OK	1953	8	S,V
Wilson	KS	1938	8	A,M
Roulette Creek	OK	1950	8	S
Albright	KS	1956	8	M
Iconium, NW	OK	1947	7	S,H
Corn, S	OK	1960	7	S
Langston	OK	1934	7	S,H,W
Weathered	KS	1935	7	A,M
Barada	NE	1941	7	H
Blackwell, E	OK	1951	7	S,M
Paulson	KS	1958	7	M
Pierce	KS	1926	7	M
Hazlett	KS	1949	7	M
Guthrie	OK	1941	7	S.H
Guelph	KS	1951	7	A,S
Coyle, SE	OK	1951	7	S
Gibbon Spur, NE	OK	1959	7	S
Yaege	KS	1959	7	H
Curty, SW	OK	1969	7	S
Billings, E	OK	1919 (1956)	7	M
Brandt-Sensenbaugh	KS	1925	7	M
Maddix, N	KS	1957	7	M
Peabody	KS	1919	7	V,H,M
Deer Creek	OK	1920 (1927)	7	S
Lamont, E	OK	1956	7	M,W
Elk Horn, S	OK	1962	7	M
Snowden-McSweeney	KS	1930	7	M
Ferrell	KS	1939	7	M
Gibson	KS	1941	7	A,S,M
Shinn	KS	1946	7	M
Waterloo District, N	OK	1936 (1954)	7	S,V
Webb	OK	1921	7	S,M
Salter	KS	1946	7	S

State	KS	1926 (1929)	7	A,S,M
Oklahoma City, S	OK	1958	7	S,V
Asmusson	KS	1957	6	A,S,W
Flint Creek, W	OK	1959	6	S,H
Werner	KS	1956	6	M
Moore, SE	OK	1947	6	S,V
Curty, S	OK	1964	6	S
Dibble, SE	OK	1973	6	A
Elk Horn, NE	OK	1952	6	S,W,M
Orchard City	OK	1954	6	W
Criner, NE	OK	1958	6	H,S
Dawson	NE	1940	6	S,V,H
Polo, E	OK	1970	6	M
Geuda Springs	KS	1925	6	A,S,M
Helsel, W	OK	1953	6	S,V
Freeny, N	OK	1953	6	A
Luther	OK	1952	6	S,H
Autwine, W	OK	1956	6	S,M
Berndsen	KS	1958	6	S
Polo, SE	OK	1947	6	S.W
Dexter	KS	1903 (a1914)	6	M
Webb, N	OK	1948	6	S
Lucien, NE	OK	1942	6	S,V
McLain	KS	1982	6	S,V
Criner, SW	OK	1961	6	S
Norman, E	OK	1957	6	S
Langston, S	OK	1935	6	S,W
Oxford, W	KS	1926	6	A,M
Posey	KS	1956	6	M
Bethany	OK	1945	6	H
Hubbard	OK	1925 (1926)	6	S
White Rock, SE	OK	1952	6	S

Tonkawa, S	OK	1921	6	M
Denver, NE	OK	1961	6	S
Whitewater	KS	1949	6	V,M
Salt Fork, W	OK	1960	6	S,M
Garrett	OK	1949	6	S
GAS:				
Newcastle, S	OK	1954	7	S
Barnes, W	OK	1953	7	M
Red Rock	OK	1945	6	S
Moore, NW	OK	1964	6	S

Play 2. Permo-Pennsylvanian Structural Play:

Field Name			
OIL:			
Crescent-Lovell	OK	1926	10
Tonkawa	OK	1921	10
Braman, N	OK	1924	10
Churchill	KS	1926	10
Edmond, W	OK	1943	10
El Dorado	KS	1915	10
Oxford	KS	1927	9
Winfield	KS	1914	8
Shannon	KS	1960	8
Garber	OK	1916	8
Lawrie, W	OK	1951	8
Guthrie Lake, E	OK	1952	8
Sams	OK	1925	7
Biddle	KS	1921	7
Augusta	KS	1914	7
Guthrie	OK	1941	7
Captain Creek, W	OK	1959	7
School Creek, N	KS	1953	7

Ponca City, SW	OK	1940	7
Mervine	OK	1913	7
Lovell, SE	OK	1944	7
Elbing	KS	1918	7
Cabin Valley	KS	1952	6
Billings	OK	1916	6
Jones	OK	1939	6
Marshall	OK	1927	6
Blackwell	OK	1909	6
Falls City	NE	1939	6
Otoe City, E	OK	1943	6
Garber, E.	OK	1952	6
Augusta, N	KS	1916	6
Slick-Carson	KS	1924	6
Hubbard	OK	1924	6
Oklahoma City	OK	1928	6
GAS:			
Oklahoma City	OK	1928	10
Marshall	OK	1927	7
Dilworth District	OK	1917	7
Lawrie, W	OK	1951	7
Green Valley	OK	1951	6
Wilde	KS	1929	6
Winfield	KS	1914	6

Play 3. Cherokee Sandstone Stratigraphic Play:

Field Name			
OIL:			
Fox-Bush-Couch	KS	1917	10
Rainbow Bend	KS	1923	10
Rock	KS	1923	9
Ceres, S	OK	1947	9
Moore, W	OK	1943	9
Garrett Dist., NW	OK	1928	9
Edmond, NE	OK	1944	9
Keighley	KS	1925	8
David	KS	1935	8
Smock-Sluss	KS	1917	8
Blankenship	KS	1921	8
Frog Hollow	KS	1937	8
Edmond, W	OK	1943	8
Lucien	OK	1932	8
Haverhill	KS	1927	8
Witcher	OK	1947	8
Leon	KS	1925	8
Polo	OK	1934	8
Rahn	KS	1939	8
Burden	KS	1926	8
Eastman	KS	1924	7
Denver, SE	OK	1948	7
Autwine	KS	1957	7
Gibson	KS	1941	7
Evansville, NW	OK	1945	7
Harvey	KS	1952	7
Clear Brook, SW	OK	1953	7
Muddy Creek, SW	KS	1981	6
Salt Fork, SE	OK	1956	6
Webb, W	OK	1964	6

Geuda Springs	KS	1925	6
McKay	KS	1951	6
Combs	KS	1947	6
Hickory Creek	KS	1946	6
Otter Creek, E	OK	1982	6
Muddy Creek	KS	1950	6
Murphy	KS	1933	6
Kildare, NW	OK	1961	6
Smith-Shafer	KS	1917	6
Field Name			
GAS:			
Red Rock, W	OK	1956	6
Oklahoma City, SE	OK	1957	6

*1 **Size Classes:**

	Oil (MMBO)	Gas (BCFG)
6	1-2	6-12
7	2-4	12-24
8	4-8	24-48
9	8-16	48-96
10	16-32	96-192
11	32-64	192-384
12	64-128	384-768
13	128-256	768-1536
14	256-512	1536-3072
15	512-1024	3072-6144

*2 **Producing Zones:**

A = Arbuckle
S = Simpson
V = Viola
H = Hunton
W = Misener
M = Mississippian

Principal data sources include: International Oil Scouts Association, 1977, 1983, 1986; Paul and Beene, 1985; NRG Associates, 1986.