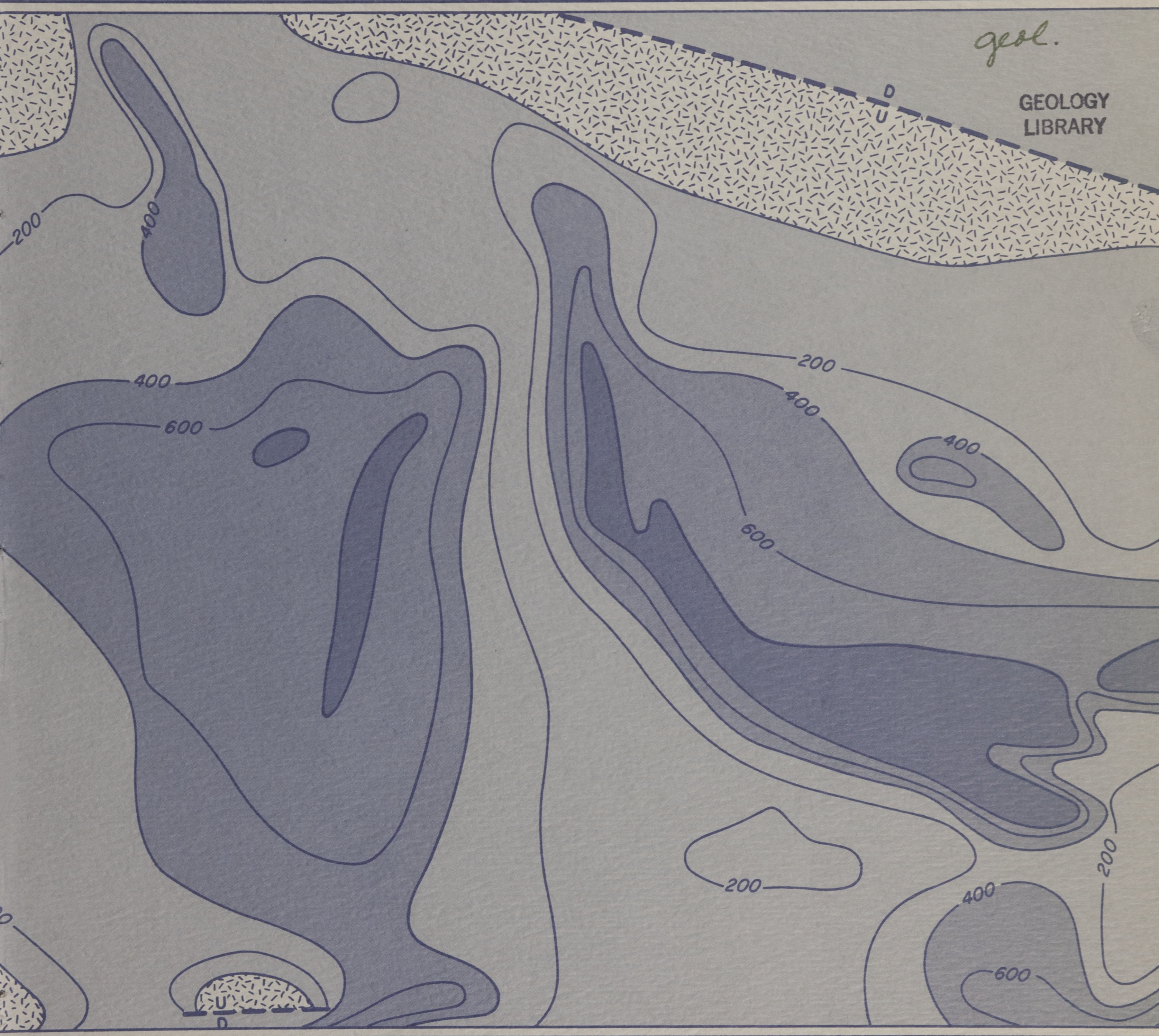
Report of Investigations No. 123

Petroleum Potential of the Palo Duro Basin, Texas Panhandle

Shirley P. Dutton, Arthur G. Goldstein, and Stephen C. Ruppel



Bureau of Economic Geology · W. L. Fisher, Director
The University of Texas at Austin · Austin, Texas 78712
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Funded by the U.S. Department of Energy under contract number DE-AC97-80ET46615

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CONTENTS

Figures

Tables

Plates

ABSTRACT

The Palo Duro Basin seemingly has all the elements necessary for hydrocarbon generation and accumulation: reservoirs, traps, source rocks, and sufficient thermal maturity. Porous facies in pre-Pennsylvanian, Pennsylvanian, and Permian strata are potential hydrocarbon reservoirs. Within the pre-Pennsylvanian section, shallow-marine carbonates of both Ordovician (Ellenburger Group) and Mississippian age have sufficient porosity and permeability for hydrocarbon accumulation. Three main exploration targets of Pennsylvanian and Wolfcampian age are (1) granite-wash sandstones, (2) shelf-margin carbonates, and (3) elongate-delta sandstones. Granite wash was deposited in fan deltas adjacent to fault-bounded, basement uplifts around the basin margins. Porous facies are braided-channel, fan-plain, and distal-fan deposits. Porous carbonates developed through time along the different positions of the shelf margins. Organic-rich basinal shales are juxtaposed against the porous shelf-margin facies. High-constructive, elongate-delta deposits in the southeastern part of the basin retain high porosity in bar-finger (channel-mouth bar) sandstones. In younger strata, dolomites in the Clear Fork (Leonardian) and the San Andres (Guadalupian) Formations are reservoirs along the Matador Arch. However, porosity in these units apparently pinches out to the north.

Both stratigraphic and structural traps occur in the basin. Porosity pinch-outs form the primary stratigraphic traps. Major faults are associated with the Amarillo Uplift; smaller faults have been identified in the deeper parts of the basin. Most faults are thought to have existed before the Pennsylvanian and to have been reactivated by a northwest maximum principal compression. Fracturing adjacent to some faults may have created fractured reservoirs.

The Palo Duro Basin contains source rocks of sufficient quality to generate hydrocarbons. Pennsylvanian and Wolfcampian shales contain up to 2.4 percent total organic carbon (TOC) and are fair to very good source rocks. Lipid-rich organic matter occurs primarily in basinal shales.

Kerogen color and vitrinite reflectance, which measure thermal maturity, indicate that temperatures were sufficiently high to begin to generate hydrocarbons from lipid-rich organic matter. Pennsylvanian and Wolfcampian kerogen is yellow orange to orange. Average reflectance in Pennsylvanian vitrinite is 0.52 percent; in Wolfcampian samples the average reflectance is 0.48 percent. Recent oil discoveries in the Palo Duro Basin confirm that oil was generated.

INTRODUCTION

Although the Palo Duro Basin in the Texas Panhandle (fig. 1) is located between two prolific hydrocarbon-producing basins, the Midland and the Anadarko, it remains an exploration frontier. There is substantial production along the margins of the Palo Duro Basin, but few discoveries have been made within the central part of the basin. Historically, there have been several episodes of exploration and drilling in this area, but in some counties fewer than 25 wells have been drilled (fig. 2). The poor discovery record in the basin could be due either to the low level of drilling or to an actual lack of hydrocarbons.

The Bureau of Economic Geology has been conducting research on the Palo Duro Basin since 1977 to evaluate the potential of the basin for isolation of high-level nuclear wastes in Permian salt strata (Dutton and others, 1979; Gustavson and others, 1980 and 1981). Although our investigations have been primarily regional, much of our work has implications for the local explorationist. This report summarizes some of the results of Bureau research, funded by the U.S. Department of Energy, on oil and gas potential of Paleozoic rocks (table 1) in the Palo Duro Basin. It presents stratigraphic, tectonic, structural, and geochemical interpretations useful in evaluating the basin. Detailed stratigraphic analyses delineate potential hydrocarbon reservoir facies and identify potential stratigraphic trapping configurations. An understanding of the diagenetic history of the sediments aids in prediction of porosity distribution. Structural studies define the timing of fault movement and locate possible structural traps. Analyses of source-rock quality and thermal history of the Palo Duro Basin provide important evidence on whether hydrocarbons could have been generated within the basin. All these studies can help focus exploration efforts in this frontier area.

Subsurface information, particularly geophysical well logs and sample logs (pl. I), provided most of the data for this study. In the central part of the basin, the data base consists of all commercially available well logs (fig. 2). In counties along the Matador Arch where hydrocarbons are produced, data from all wildcat wells and from selected field wells are used (fig. 2). The operator, well name, and BEG number of all wells that were available for this study are listed in the Appendix. Wells outside the Palo Duro Basin that were used in structural and stratigraphic cross sections in this report (fig. 3) are also listed in the Appendix.

Table 1. Stratigraphic chart and general lithology of the Palo Duro Basin (after Handford and Dutton, 1980).

System	Series	Group/ Formation	General lithology and depositional setting
Quaternary		Undifferentiated	Fluvial and lacustrine clastics
Tertiary	Pliocene Miocene	Ogallala	
Triassic	Upper	Dockum	Fluvial-deltaic and lacustrine clastics
Permian	Ochoa	Absent	Sabkha salt, anhydrite, red beds, and peritidal dolomite
	Guadalupe	Artesia	
		Pease River	
	Leonard	Clear Fork	
		Wichita	
	Wolfcamp	Undifferentiated	Shelf and shelf-margin carbonate, basinal shale, and deltaic sandstone
Pennsylvanian	Virgil	Cisco	
	Missouri	Canyon	
	Desmoines	Strawn	
	Atoka	Bend	
	Morrow		
Mississippian	Chester	Undifferentiated	Shelf carbonate and chert
	Meramec		
	Osage		
Ordovician	Canadian	Ellenburger	Shelf dolomite
Cambrian	?	Undifferentiated	Shallow marine (?) sandstone
Precambrian			Igneous and metamorphic

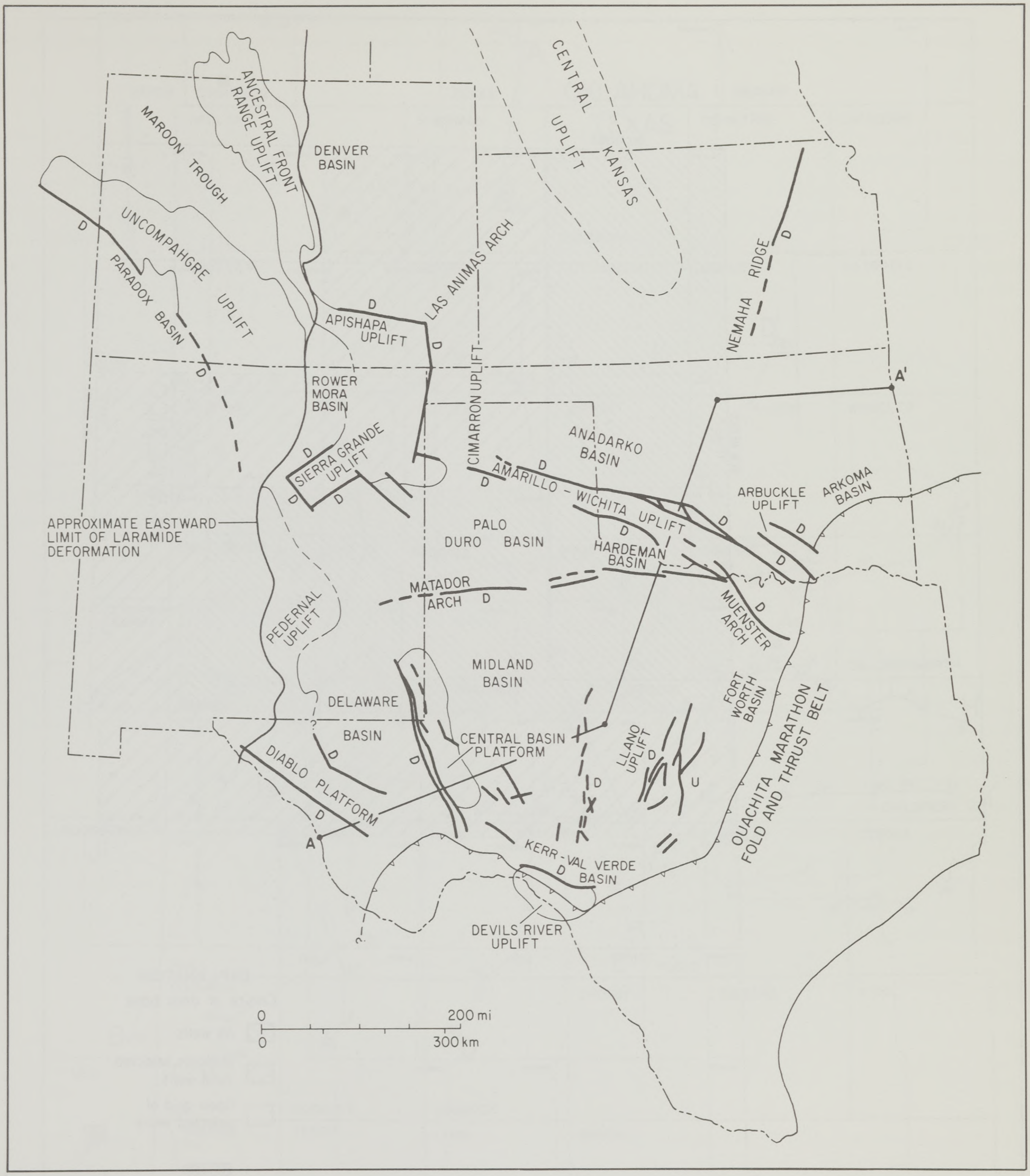


Figure 1. Late Paleozoic basins and uplifts of the southern Midcontinent region (Ancestral Rockies) showing location and tectonic setting of the Palo Duro Basin.

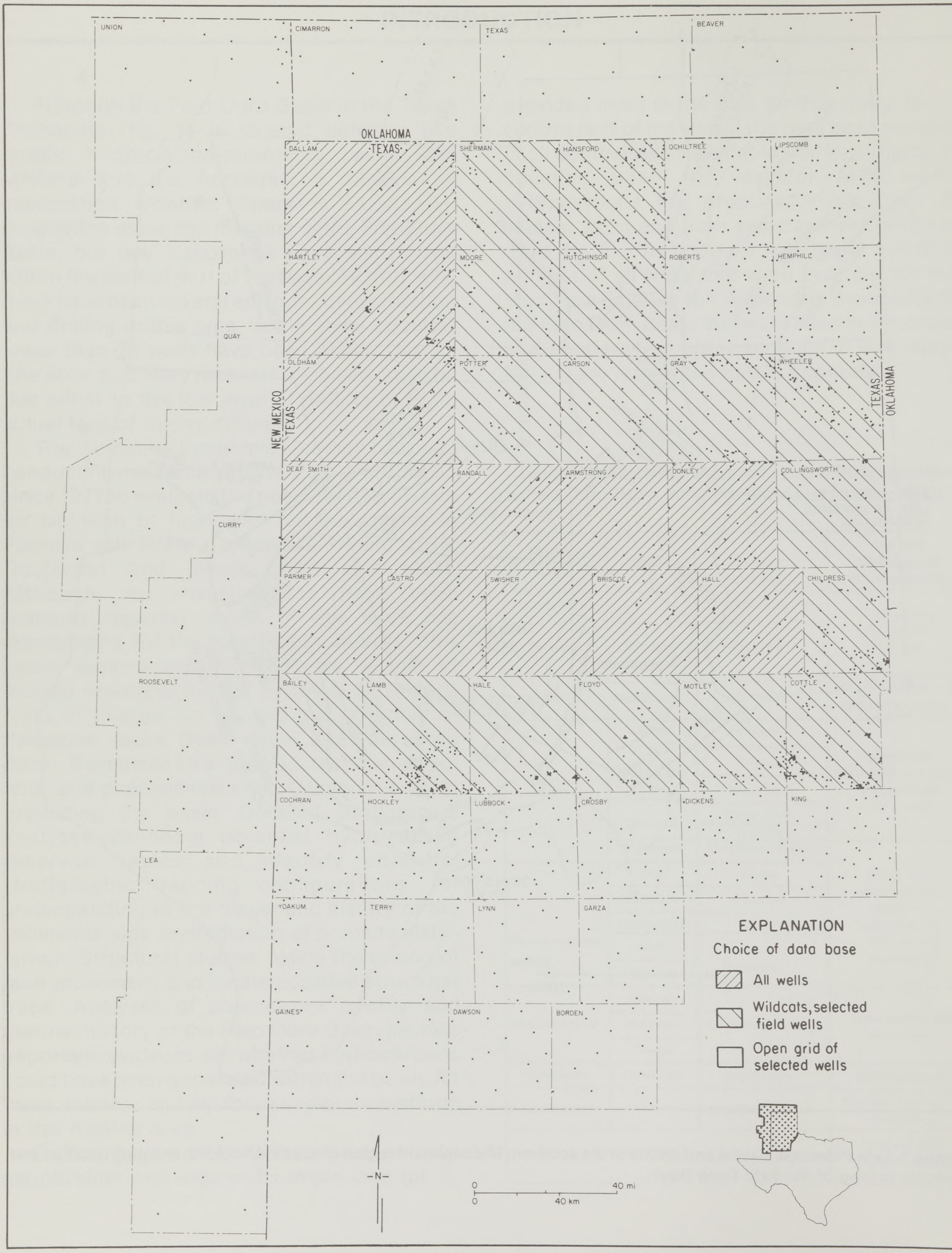


Figure 2. Data base showing areas where the selectivity of data points (wells) varied. Names and operators of wells used on maps and cross sections in this report are listed in Appendix.

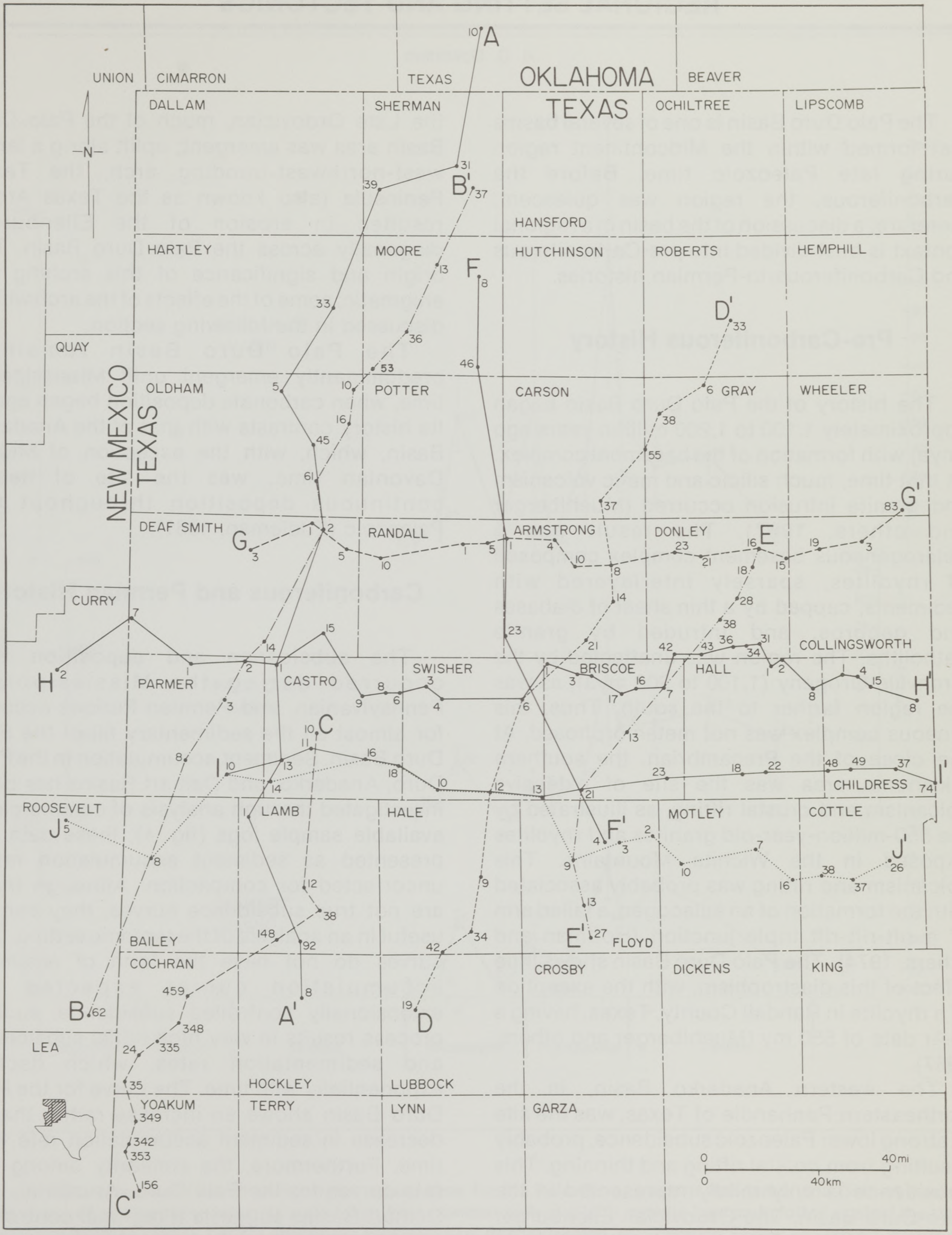


Figure 3. Location map of cross sections used in this report. Names and operators of all wells on cross sections are listed in Appendix.

REGIONAL SETTING AND TECTONICS

A. G. Goldstein

The Palo Duro Basin is one of several basins that formed within the Midcontinent region during late Paleozoic time. Before the Carboniferous, the region was quiescent; therefore, a discussion of the basin in a regional context is best divided into pre-Carboniferous and Carboniferous-to-Permian histories.

Pre-Carboniferous History

The history of the Palo Duro Basin began approximately 1,100 to 1,200 million years ago (mya) with formation of the basement complex. At that time, much silicic and mafic volcanism and granite intrusion occurred (Muehlberger and others, 1967). The result was a heterogeneous basement complex composed of rhyolites, sparsely interlayered with sediments, capped by a thin sheet of diabases and gabbros, and intruded by granite batholiths. The region was unaffected by the Grenville Orogeny (1,100 to 900 mya), as was the region farther to the south. Thus, this igneous complex was not metamorphosed. At the close of the Precambrian, the southern Oklahoma area was the site of extensive volcanism and crustal rifting, as illustrated by the 550-million-year-old granites and rhyolites exposed in the Wichita Mountains. This volcanism and rifting was probably associated with the formation of an aulacogen, a failed arm of a rift-rift-rift triple junction (Hoffman and others, 1974). The Palo Duro Basin shows little effect of this diastrophism, with the exception of a rhyolite in Randall County, Texas, having a K-Ar date of 550 my (Muehlberger and others, 1967).

The western Anadarko Basin, in the northeastern Panhandle of Texas, was the site of strong lower Paleozoic subsidence, probably resulting from crustal rifting and thinning. This subsidence is only mildly represented in the Palo Duro Basin. The Ordovician Ellenburger Group is commonly thin, locally thickening to 1,000 ft (300 m). Consequently, the Palo Duro Basin was not subjected to major crustal thinning associated with the aulacogen. During the Late Ordovician, much of the Palo Duro Basin area was emergent; uplift along a large, west-northwest-trending arch, the Texas Peninsula (also known as the Texas Arch), resulted in erosion of the Ellenburger diagonally across the Palo Duro Basin. The origin and significance of this arching are enigmatic; some of the effects of the arch will be discussed in the following section.

The Palo Duro Basin remained predominantly emergent until Mississippian time, when carbonate deposition began again. Its history contrasts with that of the Anadarko Basin, which, with the exception of Middle Devonian time, was the site of nearly continuous deposition throughout the Paleozoic (Eddleman, 1961).

Carboniferous and Permian History

The subsidence and deposition that occurred during the Mississippian, Pennsylvanian, and Permian Periods account for almost all the sedimentary fill of the Palo Duro Basin. Sediment accumulation in the Palo Duro, Anadarko, and Dalhart Basins has been investigated through analysis of commercially available sample logs (fig. 4); these data are presented as sediment accumulation rates, uncorrected for compaction. Although these are not true subsidence curves, they can be useful in an analysis of the tectonic setting. The curves do not have the form of sediment accumulation curves expected for extensionally controlled subsidence; such a process results in very high initial subsidence and sedimentation rates, which decline exponentially with time. The curve for the Palo Duro Basin shows an increase rather than a decrease in sediment accumulation rate with time. Furthermore, the similarity among the rate curves for the Palo Duro, Anadarko, and Dalhart Basins suggests a regional control on subsidence. Thus, subsidence caused by wrenching (pull-apart basins) is not considered to be a valid mechanism. Wrenching-related subsidence would occur at changes in the

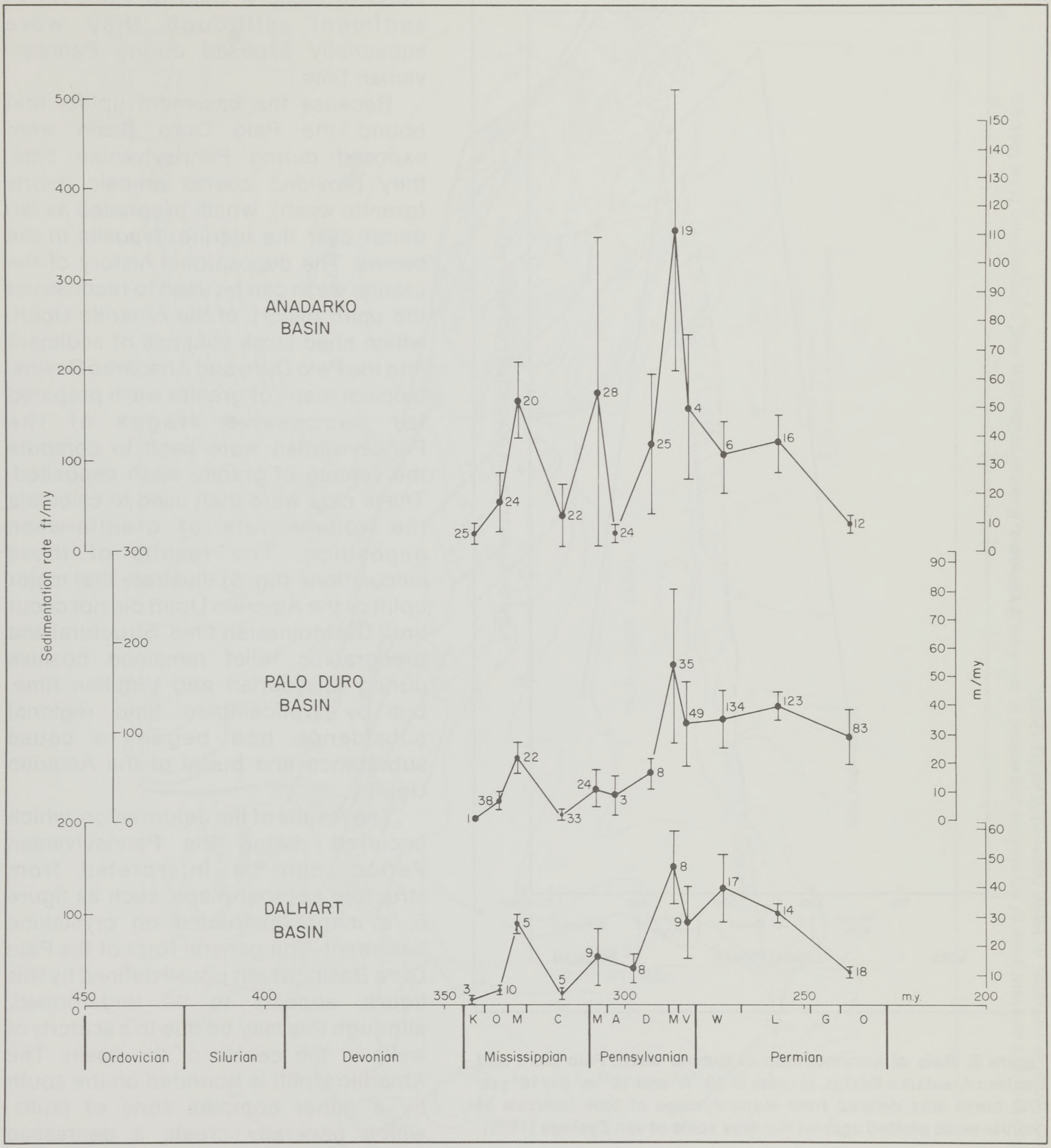


Figure 4. Plot of sediment accumulation rates versus time for the Palo Duro, western Anadarko, and Dalhart Basins. Thicknesses of stratigraphic intervals were taken from commercially available sample logs and plotted against the time scale of van Eysinga (1975). Letters abbreviate Mississippian, Pennsylvanian, and Permian Series; see table 1. Points on the curves are mean values; error bars are ± one standard deviation, and the number of values is noted next to the mean values.

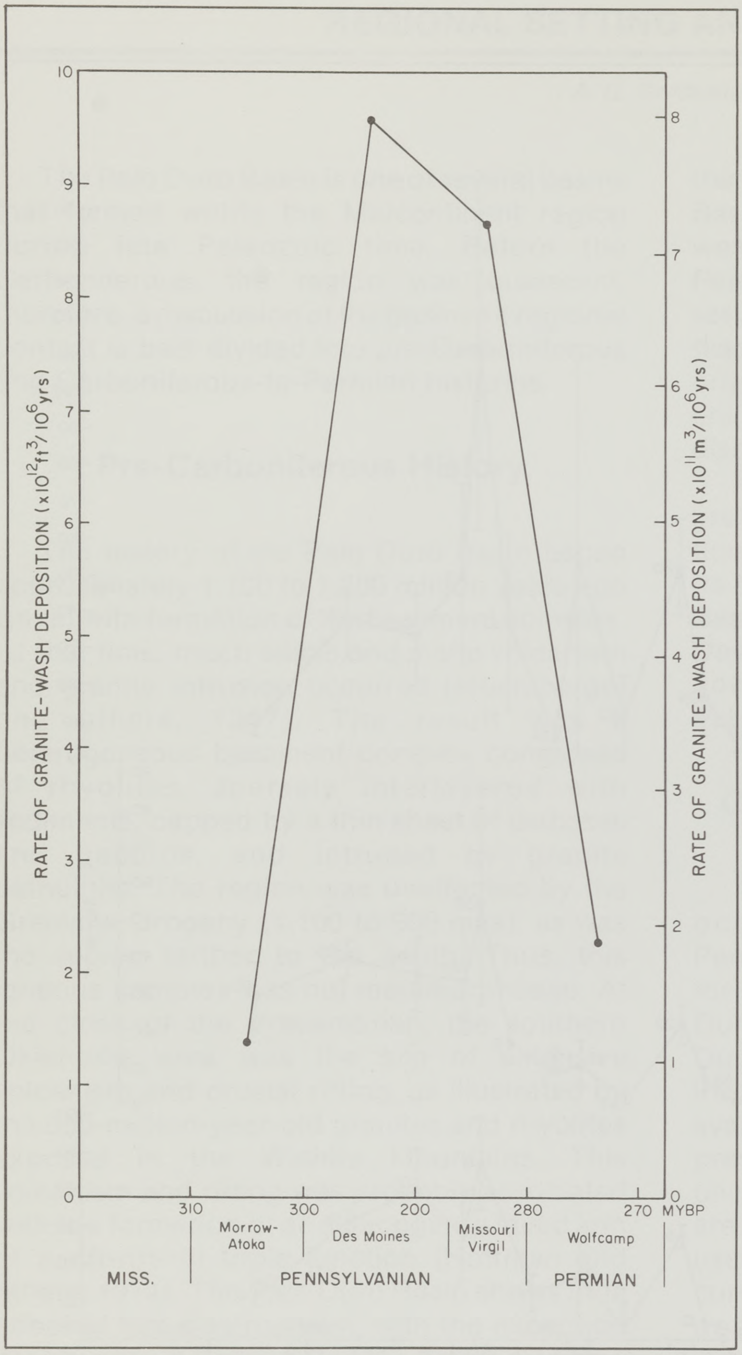


Figure 5. Rate of accumulation of granite wash, Palo Duro and western Anadarko Basins, in units of $10^{12}ft^3$ and $10^{11}m^3$ per 10^6 yrs. The curve was derived from isopach maps of time intervals of granite wash plotted against the time scale of van Eysinga (1975).

strike of a major wrench fault and would be both local and due to crustal thinning. Regional subsidence is also suggested by the burial of the bounding uplifts (pl. II). Both the Amarillo Uplift, which bounds the Palo Duro Basin on the north, and the Matador Arch, which limits the basin on the south, are buried by 2,000 to 6,000 ft (600 to 1,800 m) of sediment, although they were subaerially exposed during Pennsylvanian time.

Because the basement uplifts that bound the Palo Duro Basin were exposed during Pennsylvanian time, they provided coarse arkosic debris (granite wash), which prograded as fan deltas over the marine deposits in the basins. The depositional history of the granite wash can be used to reconstruct the uplift history of the Amarillo Uplift, which shed large volumes of sediment into the Palo Duro and Anadarko Basins. Isopach maps of granite wash prepared for successive stages of the Pennsylvanian were used to compute the volume of granite wash deposited. These data were then used to calculate the volume rate of granite-wash deposition. The results of these calculations (fig. 5) illustrate that major uplift of the Amarillo Uplift did not occur until Desmoinesian time. Structural and topographic relief remained positive during Missourian and Virgilian time, but by Wolfcampian time regional subsidence had begun to cause subsidence and burial of the Amarillo Uplift.

The results of the deformation, which occurred during the Pennsylvanian Period, can be interpreted from structure contour maps, such as figure 6, a map constructed on crystalline basement. The general form of the Palo Duro Basin, which is well defined by this figure, appears to be undeformed, although this may be due to a scarcity of wells in the center of the basin. The Amarillo Uplift is bounded on the south by a rather complex zone of faults, which generally create a depressed region between the basin and the uplift. The deepest part of the basin lies adjacent to the Amarillo Uplift; the implications of this will be discussed later in this report. The southern margin of the basin is formed by the Matador Arch (Red River and Electra Arch), which is a narrow basement uplift with several small peaks (fig. 1).

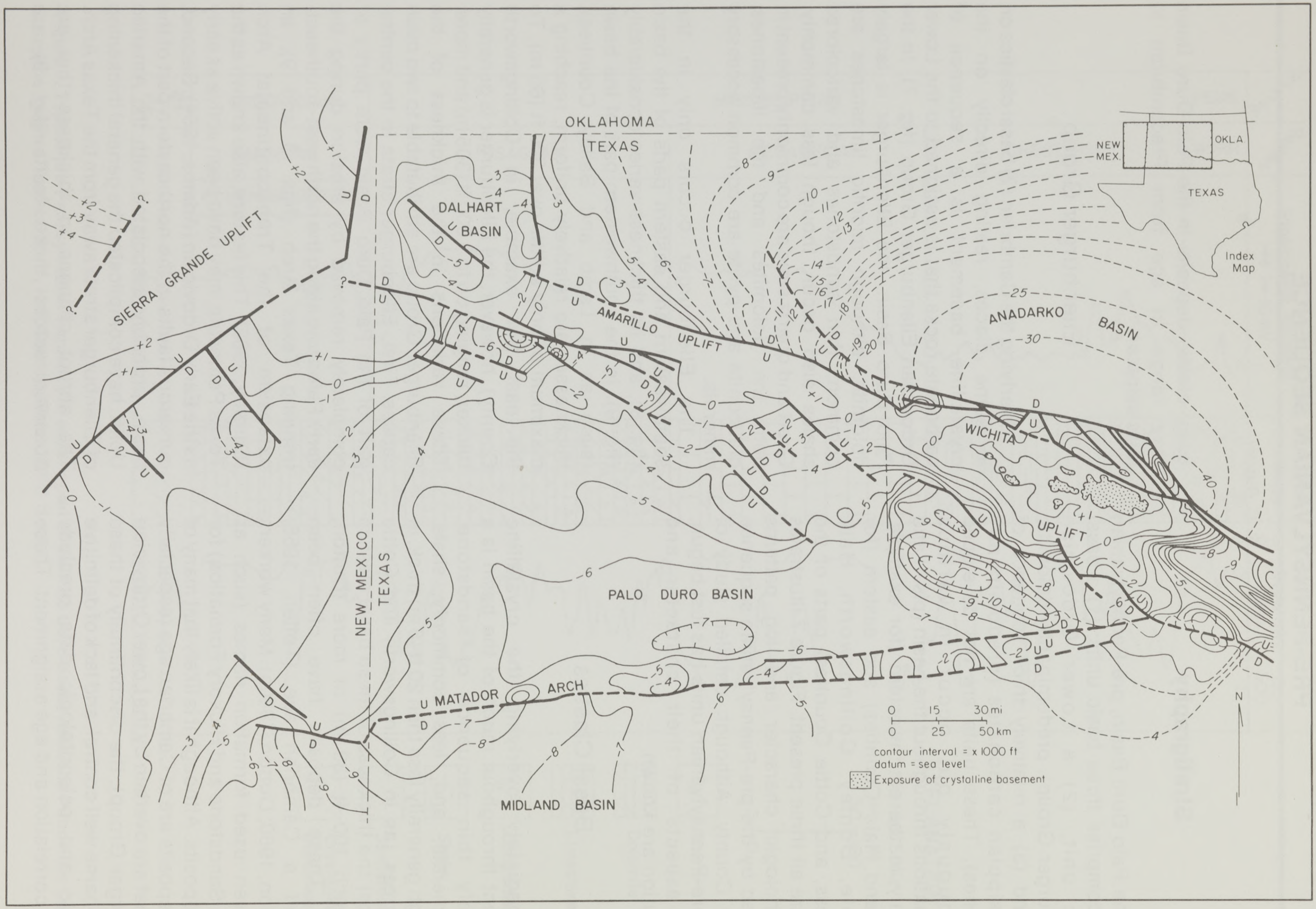


Figure 6. Structure contour map of crystalline basement in western Oklahoma, Texas Panhandle, and northeastern New Mexico. Contour interval is variable, notably north of Wichita Uplift.

PRE-PENNSYLVANIAN SEQUENCE

S. C. Ruppel

Stratigraphy

In the Palo Duro Basin, pre-Pennsylvanian strata comprise three basic units: (1) a basal clastic unit, (2) a Lower Ordovician (Ellenburger Group), predominantly dolomitic unit, and (3) a relatively thick sequence of Mississippian carbonates (predominantly limestones). These units are not developed continuously but occur in various combinations throughout the basin (pls. II and III). Only in the southwestern (for example, Lamb and Hale Counties) and eastern (for example, Donley, Collingsworth, Hall, Childress, and Cottle Counties) parts of the basin are all three present. Figure 7 illustrates the lithologic character and log patterns exhibited by the pre-Pennsylvanian sequence in Hall County. Although detailed study of these pre-Pennsylvanian units has just begun, some aspects of their character and distribution are known.

Basal Clastics

Immediately overlying the crystalline basement throughout much of the basin is a relatively thin sequence of sandstone, conglomerate, and, less commonly, shale. Although generally less than 20 ft (6 m) thick, in some areas (as in Collingsworth and Cottle Counties) the thickness of these basal clastics may reach 100 ft (30 m) or more (Dutton, 1980a). These deposits have often been assigned a Cambrian age (Totten, 1956; Nicholson, 1960; Dutton, 1980a). Many workers have even used formation names (such as Reagan Sandstone and Hickory Formation) for these deposits. Although it is likely that many of these deposits are of Cambrian age (especially those that are overlain by the Lower Ordovician Ellenburger Group), the discontinuity of these rocks, sparse well control, and lack of definitive lithologic and paleontologic data preclude precise correlation and age assignment. These basal clastic deposits in the Palo Duro Basin may range in age from Precambrian to Mississippian.

Ellenburger Group

Overlying the Cambrian (?) basal clastics or, in some places, resting directly on the crystalline basement is a sequence of carbonate rocks that is assigned to the Lower Ordovician Ellenburger Group (fig. 7). In the Palo Duro Basin, the Ellenburger is largely dolomite, although micritic limestones are common; thin sandstones and varicolored shales also occur, though less commonly. Chert and quartz sand are commonly present in both the dolomites and the limestones; glauconite and pyrite are common accessory minerals.

The Ellenburger occurs only in the southwestern and eastern parts of the basin (fig. 8), and its thickness varies considerably (fig. 9). In the southwestern part of the basin (such as in Lamb and Bailey Counties), thicknesses are relatively uniform, reaching a maximum of only a little over 200 ft (60 m). To the east (for example, in Collingsworth County), however, the Ellenburger is generally thicker, ranging up to 1,000 ft (305 m) and more. These variations in the thickness of the Ellenburger Group are attributable to two main causes. First, Ellenburger strata in the central part of the Palo Duro Basin were partly or completely removed by erosion during the early Paleozoic along the northwest-southeast-trending Texas Arch (figs. 8 and 9), an extension of the Transcontinental Arch (Eardley, 1962). This feature, also known as the Texas Peninsula, may have been active as early as the Early Ordovician (Adams, 1954). Second, numerous faults in the northeastern part of the basin, probably associated with the Amarillo Uplift, have complicated the general thickening of Ellenburger strata away from the Texas Arch. The abrupt changes in thickness that are observed across these faults (fig. 9) are

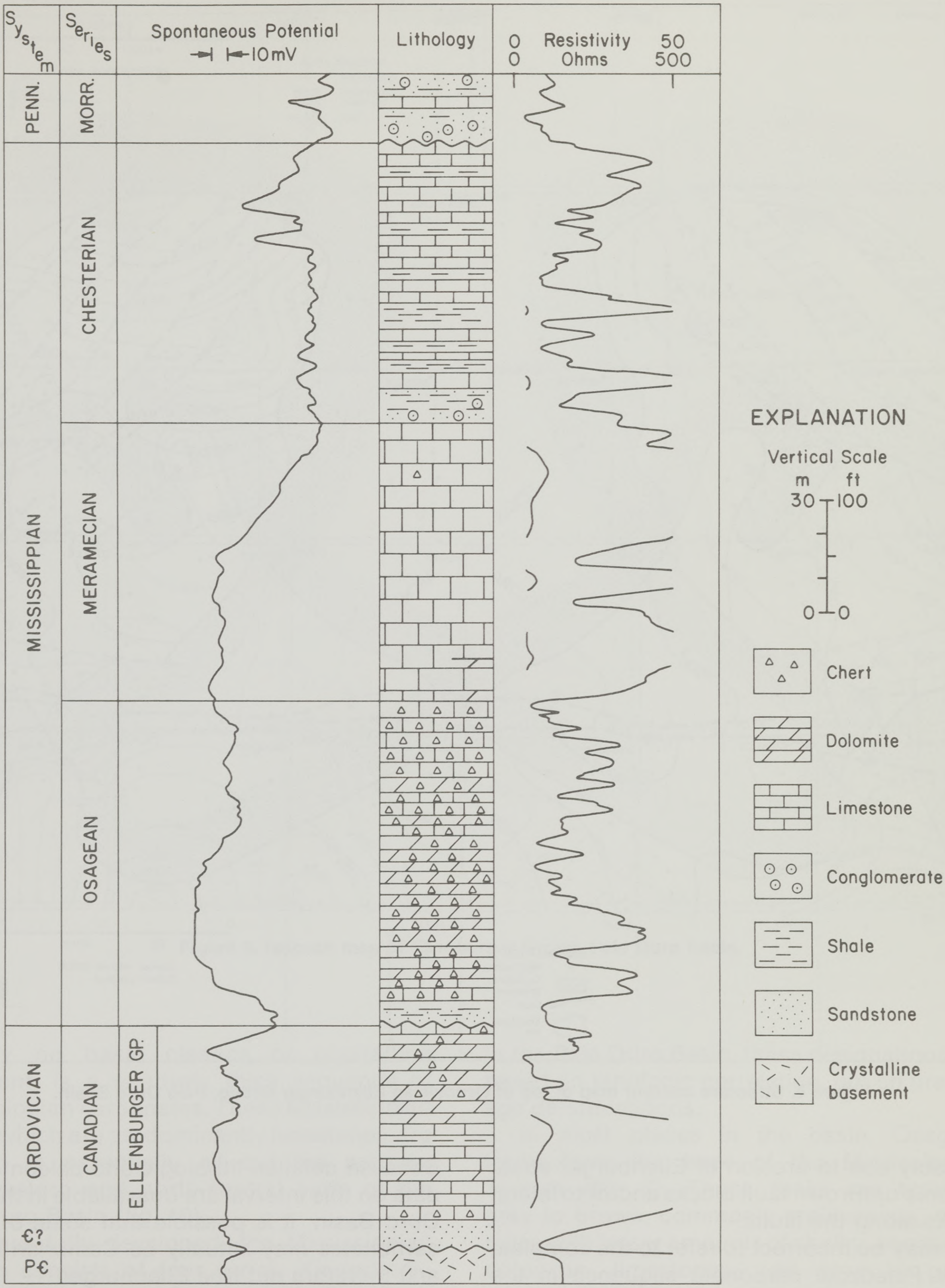


Figure 7. Typical pre-Pennsylvanian sequence in eastern part of the Palo Duro Basin. Amerada Petroleum Corporation, Lafayette Hughes Trustee No. 1, Hall County, Texas (BEG No. 18).

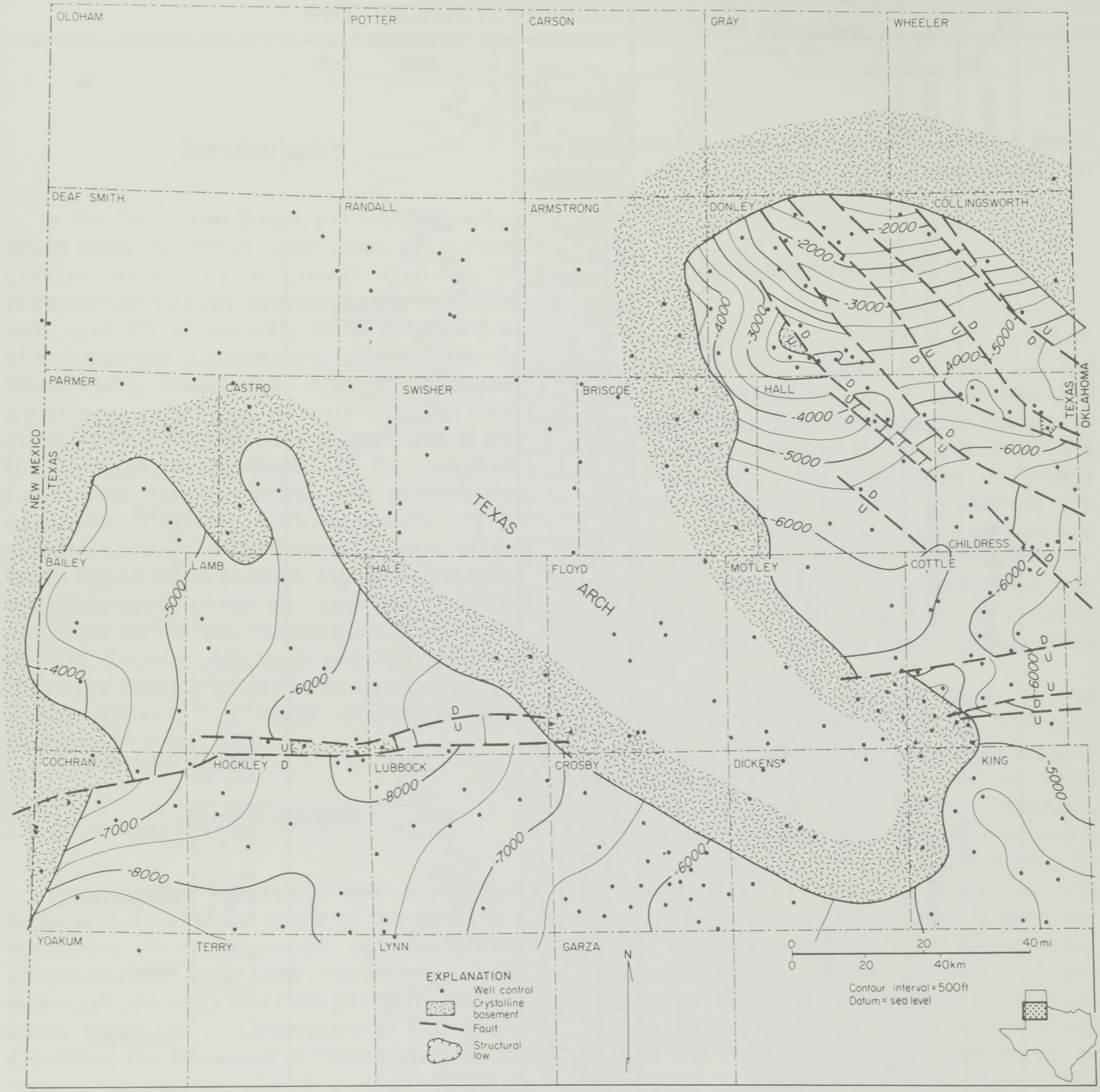


Figure 8. Structure contour map of top of Ordovician Ellenburger Group, Palo Duro Basin.

probably due to erosion of Ellenburger strata on some upthrown fault blocks and/or to lateral offsets along the faults.

It may be incorrect to refer to the complete lower Paleozoic carbonate sequence in the Palo Duro Basin as Ellenburger. In the type area in Central Texas and elsewhere (Cloud and Barnes, 1946), Ellenburger carbonates are underlain by similar dolomites and limestones of Cambrian age (Wilberns Formation). Because detailed lithologic and paleontologic data on this interval are unavailable in the Palo Duro Basin, it is possible that some of these carbonates may actually be Cambrian in age and therefore not true Ellenburger.

Mississippian System

Unconformably overlying the Ellenburger Group or, in some parts of the basin, resting

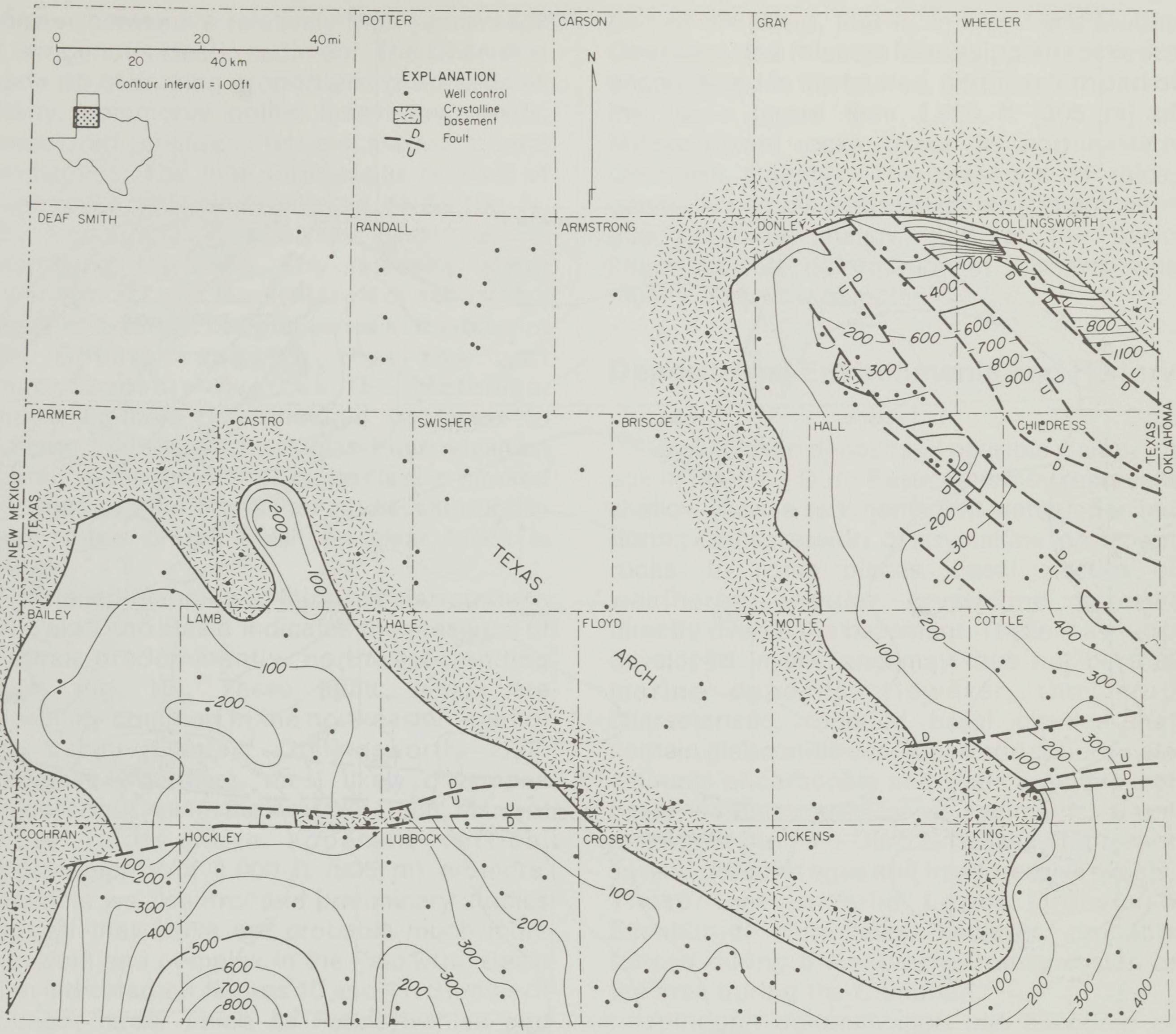


Figure 9. Isopach map of Ellenburger Group, Palo Duro Basin.

directly on basal clastics or crystalline basement, is a relatively thick sequence of Mississippian carbonates. These Mississippian rocks, which are predominantly limestones, are present in essentially all but the extreme northwestern and north-central parts of the Palo Duro Basin (fig. 10).

Where fully developed, the Mississippian System consists of four series: Kinderhook, Osage, Meramec, and Chester. In the Palo Duro Basin, however, the presence of Kinderhookian sediments has not yet been documented. Further, although the Mississippian is typically subdivided into Osage, Meramec, and Chester in the Palo Duro Basin, these designations are based on lithologic correlation, not on precise age determinations.

In most places in the basin, Osagean rocks form the base of the Mississippian System (fig. 7). These rocks are typically gray to brown, commonly argillaceous, dolomites with lesser amounts of chalky, commonly dolomitic, limestones, and gray to green shales. Chert is ubiquitous throughout the carbonates; quartz sand, glauconite, and pyrite are common accessories.

The overlying Meramecian deposits are usually readily distinguishable from the Osage

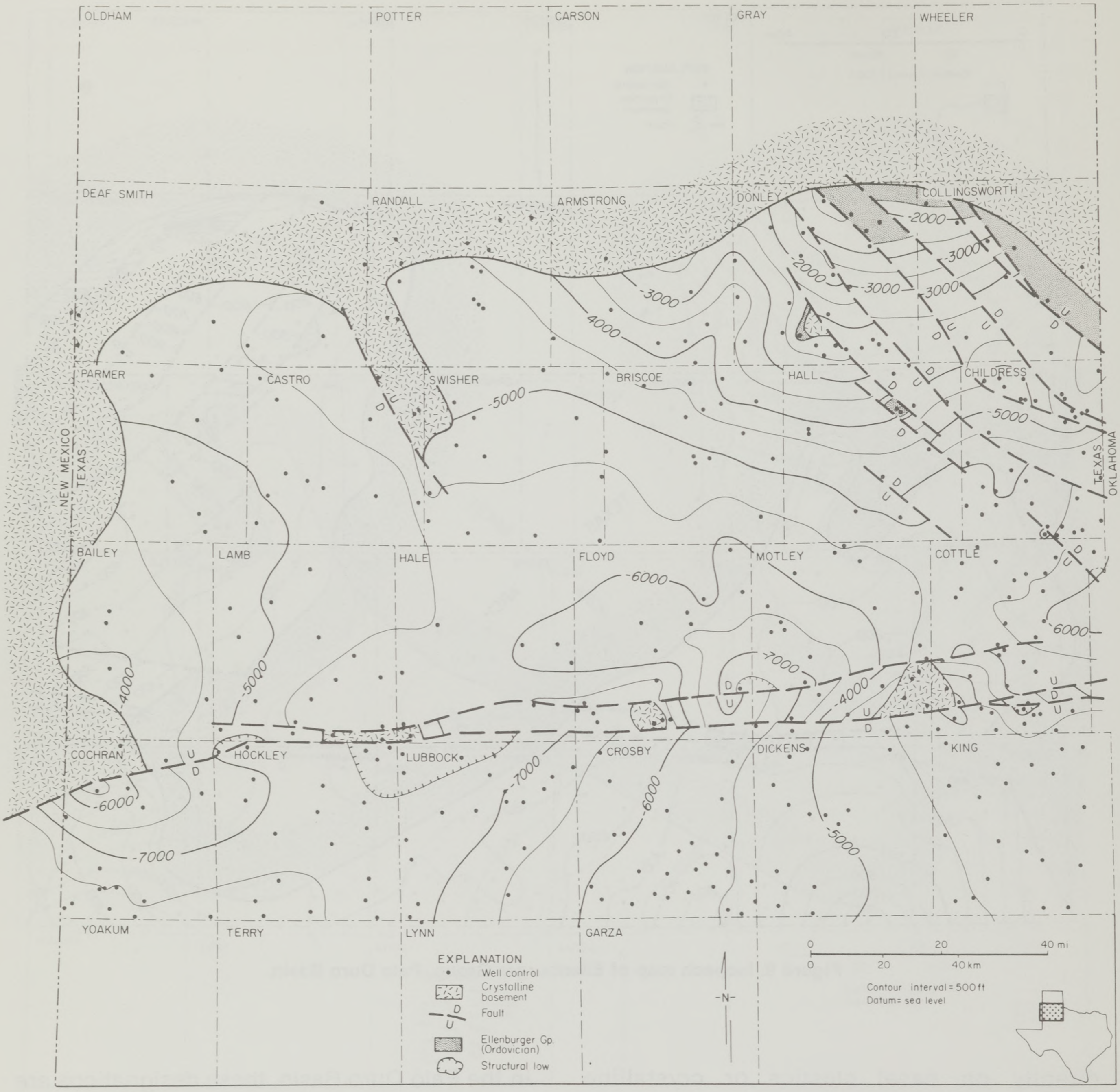


Figure 10. Structure contour map of top of Mississippian System, Palo Duro Basin.

both in core and on logs (fig. 7). Although dolomites and dolomitic limestones are frequently encountered in this unit, the predominant lithology is coarse-grained, commonly oolitic, generally non-argillaceous limestone. Chert occurs in the Meramec but is generally much rarer than in the Osage, as is shale. The Meramec is usually easily recognized on geophysical logs by its resistivity, which is generally much higher than any of the other Mississippian units (fig. 7). Meramecian deposits appear to conformably overlie Osagean rocks in the Palo Duro Basin.

Chesterian rocks, where present in the Palo Duro Basin, frequently resemble the overlying Pennsylvanian strata in lithology and log response more than older Mississippian rocks. Unlike either the Osage or the Meramec, the

Chester contains a relatively high percentage of terrigenous clastic sediment. The Chester is made up of varying proportions of sometimes cherty, commonly oolitic limestones, marls, varicolored shales, and calcareous quartz sandstones. The high terrigenous content of these rocks typically results in a low SP (fig. 7), which generally distinguishes them from the underlying Meramec. The relatively sharp lower contact and the presence of sandstone, shale, and, rarely, conglomerate at the base of the Chester suggest that the unit unconformably overlies the Meramec. Similarly, there is lithologic evidence to indicate that the Mississippian/Pennsylvanian contact at the top of the Chester is also marked by a hiatus in the Texas Panhandle, although in some parts of the basin no clear break is evident.

Detailed mapping of Mississippian strata in the Palo Duro Basin indicates the presence of several predominantly northwest-trending faults (fig. 10). These faults, which are especially common in the northeastern part of the basin (Donley, Collingsworth, Hall, Childress Counties), most likely developed synchronously with the Amarillo Uplift. Many of these faults have apparent vertical displacements of 1,000 ft (305 m) or more. Available well control and preliminary studies suggest that faults are probably much more prevalent and complex in the Palo Duro Basin than indicated on figures 10 and 11. Studies of younger strata (such as Pennsylvanian and Permian) not only support these conclusions but also suggest that many of the faults may have been active well into the Permian Period (R. T. Budnik, personal communication, 1982).

Mississippian strata thin and pinch out in the western and northwestern parts of the basin (Bailey, Parmer, and Deaf Smith Counties) owing to non-deposition and/or erosion along the Transcontinental Arch. In the northeastern part of the basin, Mississippian strata have been partly to completely removed by erosion on upthrown fault blocks. Erosion has similarly removed Mississippian deposits from along isolated, probably fault-bounded highs along the Matador Arch. Although thickness variations in the central part of the basin correlate closely with structure (thicknesses of more than 800 ft [245 m] occur in the deepest part of the basin, that is, in Floyd and Motley Counties), the thickest Mississippian rocks are encountered in the faulted, northeastern part of the basin (more than 1,000 ft [305 m] of Mississippian rocks occur in northeastern Childress County). The presence of thick, generally complete Mississippian sequences in this relatively shallow part of the basin illustrates that deformation in this area was mostly post-Mississippian.

Depositional Environments and History

Basal clastic deposits of possible Cambrian age in the Palo Duro Basin generally represent shallow-marine sediments that were deposited during transgression of crystalline basement rocks. In some places, basal clastics of weathered, angular, crystalline material directly overlie the basement. These may have developed in situ and may thus not be true marine deposits. However, the more characteristic, rounded basal clastics that contain glauconitic sandstone and subordinate amounts of carbonate and shale are typical of basal marine transgressive sediments. Basal clastics in the Palo Duro Basin may represent several different ages and transgressive events. Those that underlie Lower Ordovician Ellenburger carbonates, however, probably formed during the extensive transgression of the area during the Cambrian.

Although dolomitization has obscured or destroyed many original sedimentary textures in the Ellenburger Group, some environmental indicators remain. Ellenburger limestones are commonly very fine grained to aphanitic and contain bird's eyes, ooids, and gastropods. These features, combined with the glauconitic quartz-sand that occurs sporadically throughout the sequence, strongly suggest that the Ellenburger also represents shallow-water deposition. In fact, in at least some parts of the basin, the sequence of basal clastics and Ellenburger carbonates may represent a single transgressive event.

The Mississippian carbonate sequence in the Palo Duro Basin likewise is indicative of shallow-marine deposition. Following one or more periods of middle Paleozoic erosion, during which time some Ellenburger and all

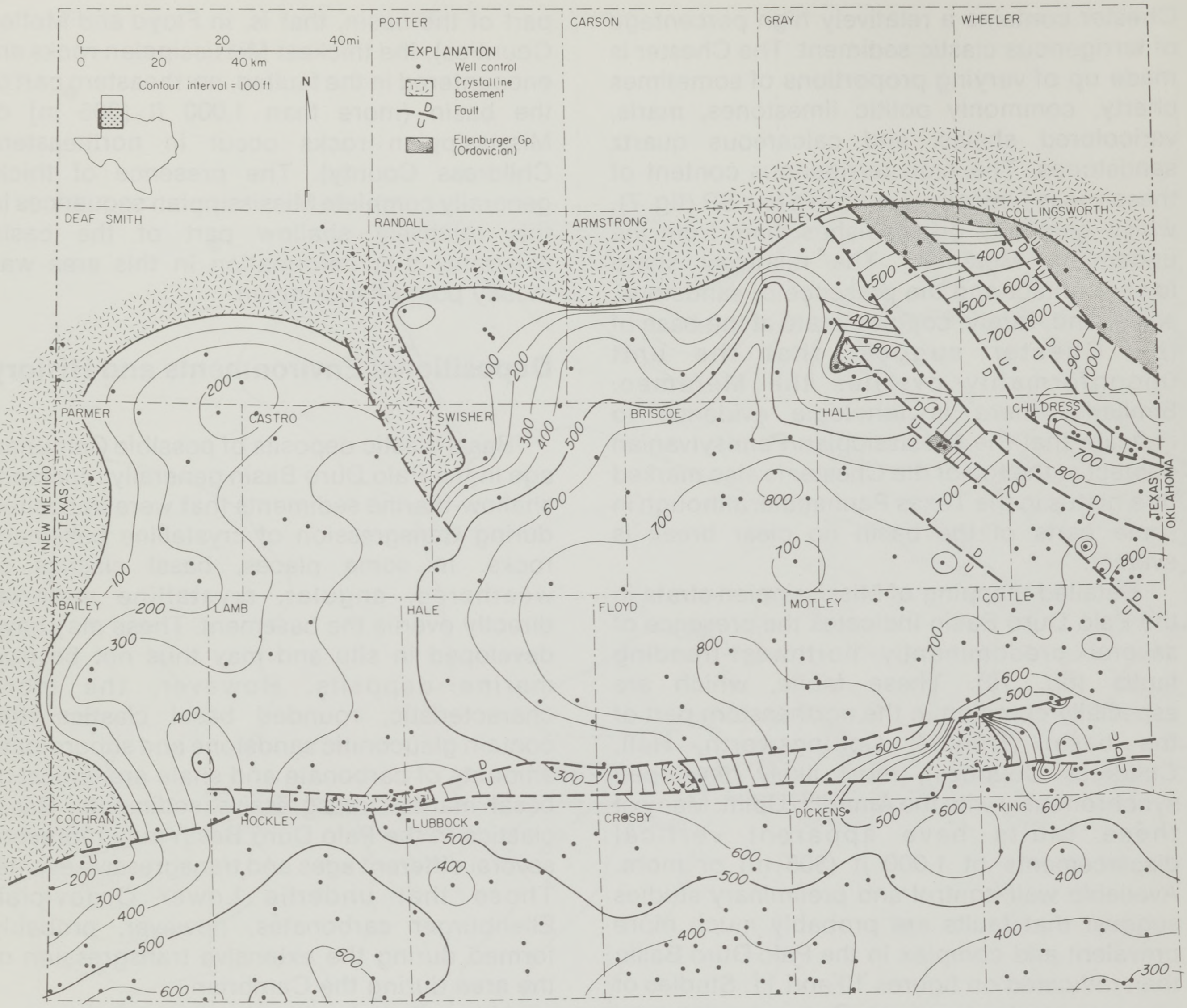


Figure 11. Isopach map of Mississippian System, Palo Duro Basin.

younger rocks were removed, another major marine transgression covered most, if not all, of the Texas Panhandle. Early Osagean deposits, whether they overlie the Ellenburger or rest directly on crystalline basement, commonly contain basal clastics (sandstones, conglomerates, shales; see fig. 7) that are representative of this inundation. Although platform margin and deeper water Mississippian sediments are known north of the Amarillo Uplift and south of the Matador Arch (in the Midland Basin), all Mississippian deposits in the Palo Duro Basin are representative of shallow carbonate platform deposition. The Osage and Meramec, as well as the Chester, contain typical open-marine faunas, ooids, and crossbeds, all typical of open-marine conditions. Terrigenous clastics are rare in the Osage and Meramec but commonly occur intermixed with carbonates in the Chester. A general upward increase in terrigenous sediment through the Chester probably reflects a shallowing trend and the early phases of tectonic activity that led to the formation of the Palo Duro Basin.

The pre-Pennsylvanian history of the Palo Duro Basin area can be summarized as follows. (1) A Middle to Late Cambrian marine transgression, which covered much of Texas, deposited Cambro-Ordovician carbonates and clastics in the Texas Panhandle. Erosion and non-deposition associated with the Texas Arch as early as Early Ordovician time (Adams, 1954) precluded preservation of lower Paleozoic rocks in the central part of the Texas Panhandle. (2) Subsequent periods of erosion removed all but Lower Ordovician and older rocks throughout the entire Palo Duro Basin area. (3) During the Early Mississippian, much of Texas was once again submerged. Shallow-water platform carbonates formed throughout the Panhandle area. (4) Finally, during the Late Mississippian (Chesterian), the first pulses of movement along what later became the Amarillo Uplift produced a general shallowing trend and an overall increase in terrigenous clastics being shed into the Palo Duro Basin. During this last phase, periods of erosion and non-deposition became increasingly prevalent, especially in the northern and northwestern parts of the basin.

Porosity and Hydrocarbon Potential

Zones of good porosity and permeability occur in all three pre-Pennsylvanian units in the Palo Duro Basin area. The sandstones and conglomerates that compose the basal clastic deposits generally show significant intergranular porosity, as is usually indicated on well logs (fig. 7). Hydrocarbon stains or shows, however, have not been reported from these deposits.

Porous zones are also common in the Ellenburger Group. Intergranular porosity occurs in many sucrosic dolomites; however, much of the porosity is due to the presence of molds, vugs, and fractures. In all cases, Ellenburger porosity exhibits wide lateral and vertical variations. Hydrocarbon shows in the Ellenburger are rare in the Palo Duro Basin. A slight oil stain was reported from coarsely crystalline dolomite in Donley County (Donley No. 26). Although no Ellenburger production has yet come from the Palo Duro Basin, the unit is productive in nearby Hardeman County, in the Midland Basin, and on the north side of the Amarillo Uplift in the Anadarko Basin. In these areas, Ellenburger reservoirs are typically developed on small structures. Reservoir extent is generally limited by porosity and permeability trends.

Like the Ellenburger, Mississippian carbonates in the Palo Duro Basin area contain numerous porous zones, constituting all types of porosity (fracture, vugular, cavernous, and intergranular). As in the Ellenburger, however, these porous zones are irregularly distributed and discontinuous. Hydrocarbon shows have been noted in Mississippian strata in nine Palo Duro Basin counties (Randall, Armstrong, Donley, Swisher, Childress, Lamb, Hale, Floyd, and Cottle), but no production has been reported. A single-well field produces from Mississippian strata in southeastern Floyd County, but this well is in the southern part of the faulted Matador Arch complex and is probably part of the Midland Basin. Mississippian rocks are also productive farther south in the Midland Basin, as well as in the Hardeman and Anadarko Basins. As in the Ellenburger, production in Mississippian strata is generally associated with small structures, although reservoir size is typically controlled by porosity trends. In some cases, reservoirs are developed in weathered (chert) zones at the top of the Mississippian sequence.

Although no pre-Pennsylvanian hydrocarbon reservoirs have yet been discovered in the Palo Duro Basin, numerous oil shows and nearby production suggest that conditions necessary for hydrocarbon formation may have been met, particularly in the Mississippian sequence. Downdip Pennsylvanian shales are potential source rocks, as are the Mississippian carbonates themselves. Erosion surfaces within and at the top of the Mississippian sequence are potential stratigraphic traps. It is likely, however, that any Mississippian reservoirs that exist in the basin will be small, like those in surrounding basins. Exploration success in Mississippian strata will require much more detailed mapping and seismic study.

Chances for hydrocarbon discoveries in the Ellenburger Group and underlying clastic sediments appear much less likely. Although sufficient porosity exists, the relative absence of shows is discouraging. However, given the limited number of pre-Pennsylvanian tests, exploration in these units should not yet be abandoned. Pennsylvanian shales could serve as sources of hydrocarbons in the Ellenburger, especially where the Mississippian has been removed by erosion.

PENNSYLVANIAN AND LOWER PERMIAN STRATA

S. P. Dutton

General Stratigraphy

The Palo Duro Basin is filled primarily with deposits of Pennsylvanian and Permian age (table 1). The Pennsylvanian section, composed of carbonate and terrigenous clastic rocks, records the initial development of the present Palo Duro structural and sedimentary basin (figs. 12, 13, and pl. III). Marine transgression occurred throughout this period as the basin subsided. Lower Permian carbonate, terrigenous clastic, and evaporite strata mark the transition from maximum transgression to basin filling (figs. 12, 13, and pl. III). Within both the Pennsylvanian and the lower Permian sections, several facies are important potential hydrocarbon reservoirs.

Pennsylvanian System

The style of sedimentation in the Palo Duro Basin changed throughout Pennsylvanian time in response to changing basin depth and source areas. Both sedimentation patterns and total sediment thickness were strongly influenced by regional subsidence. Precambrian basement highlands remained exposed throughout the Pennsylvanian, and strata thin onto these positive elements (fig. 14). The area of thickest Pennsylvanian rocks in the center of the Palo Duro Basin (2,000 ft, or 610 m) defines the northwest-trending basin axis (fig. 14). Present structural relief on the top of Pennsylvanian strata (fig. 15) exhibits a gentle southwest dip over most of the Palo Duro Basin and a more complex, faulted structure near the uplifts.

Pennsylvanian rocks in the Palo Duro Basin include, from oldest to youngest, the following groups (table 1): Bend (Morrow and Atoka Series), Strawn (Desmoines Series), Canyon (Missouri Series), and Cisco (Virgil Series). No widespread unconformities or regional marker beds are recognized within the Pennsylvanian System. There is, however, a noticeable vertical change in facies between the lower and the upper parts of the Pennsylvanian System. Across much of the basin, lower Pennsylvanian strata are composed of terrigenous clastics and thin, interbedded limestones (figs. 12, 13, and pl. III). In the upper part of the Pennsylvanian, thick limestone buildups are common, whereas clastics are relatively less important. The approximate stratigraphic level of this vertical lithologic change permits the subdivision of the Pennsylvanian section into a lower sequence (45 percent of the section) and an upper sequence (55 percent). The top of the Strawn Group coincides approximately with the boundary between the two sequences. Consequently, the lower sequence generally includes the Bend and Strawn Groups, and the upper sequence contains the Canyon and Cisco Groups. This subdivision has been used throughout this report as a convenient, as well as genetically meaningful, informal way to subdivide the Pennsylvanian System.

Pennsylvanian - Permian Boundary

Depositional conditions were generally similar during the late Pennsylvanian into the Permian; therefore, the system boundary is difficult to place. Combined paleontological (fusulinid) and lithological data were used to estimate the top of the Pennsylvanian System. A thin, widespread limestone unit was deposited near the end of the Pennsylvanian Period over much of what had formerly been the deep basin (figs. 12 and 13). The top of this limestone serves as an operational marker for the top of the Pennsylvanian System. Where the limestone was not deposited, the boundary is conventionally placed at the top of a widespread shale (fig. 13). Where shelf-margin limestone deposition continued into the Permian without a break, as in the western part of the basin (fig. 13, Castro No. 18), the systemic boundary is projected into the thick

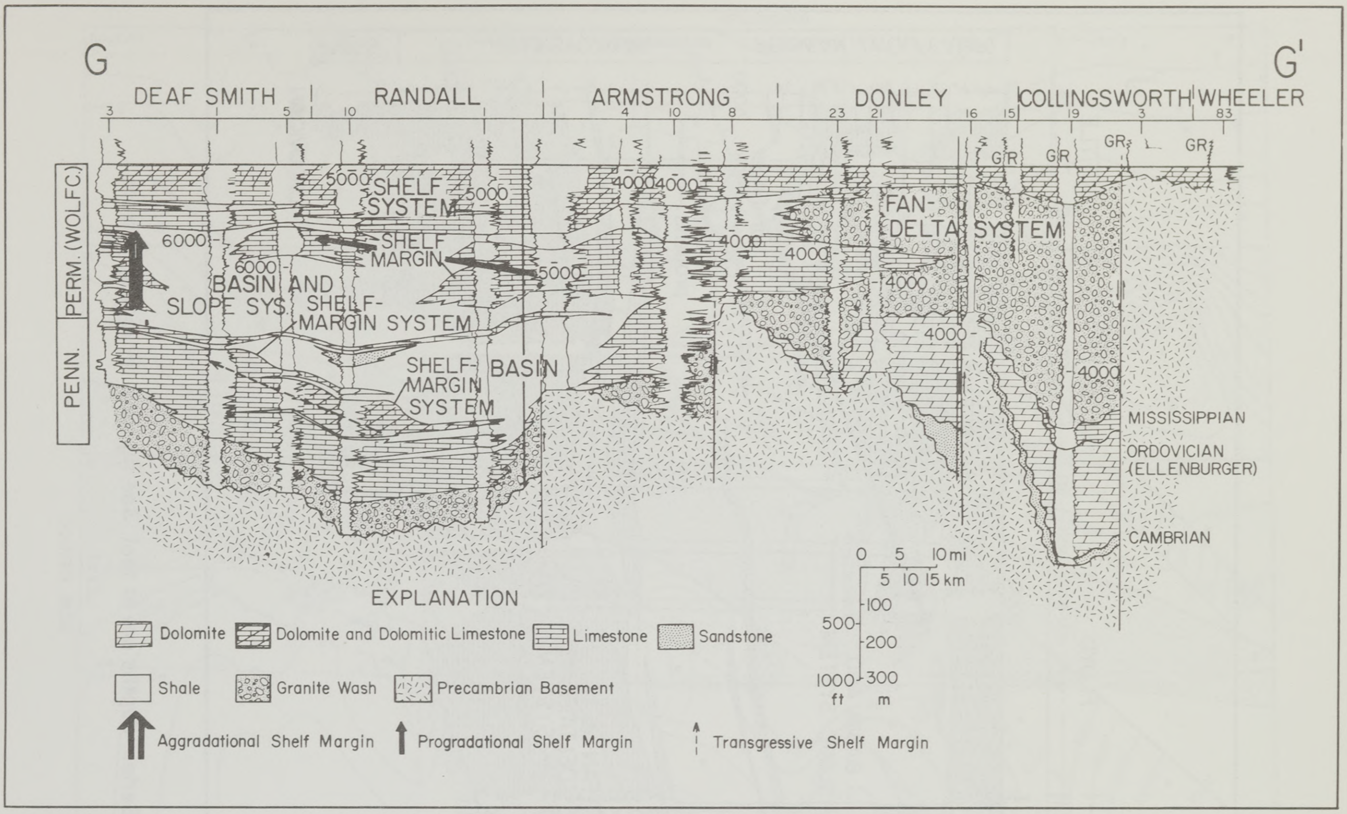


Figure 12. East-west cross section G-G′ showing stratigraphic framework and depositional systems composing Pennsylvanian - lower Permian strata. Datum is top of Wolfcampian Series; depths are in feet. GR are gamma-ray logs; other logs are SP and resistivity. See figure 3 for location (from Handford and Dutton, 1980).

carbonate sequence from the nearest wells where it can be recognized.

Lower Permian: Wolfcampian Series

Wolfcampian rocks record the transition of the Palo Duro area from a relatively deep basin to a restricted carbonate platform. Precambrian basement uplifts remained emergent throughout most of the early Permian but where finally covered by shallow-marine deposits at the end of Wolfcampian time. Wolfcampian strata thin over these buried uplifts (fig. 16). The axis of thickest Wolfcampian deposits trends north-northwest; this represents a shift from the northwest trend of the Pennsylvanian basin axis.

Lower Permian rocks have not been subdivided into formal stratigraphic units in the Palo Duro Basin. An informal division of the Wolfcampian Series into lower, middle, and upper sections has been used to delineate facies changes during early Permian time (Handford, 1980). The top of the Wolfcampian Series as used in the Texas Panhandle is not a time-stratigraphic boundary. The top is generally picked at the boundary between the Brown Dolomite, a porous, coarsely crystalline, buff dolomite, and the overlying anhydritic dolomite of the Wichita Group (B. Cunningham, personal communication, 1982). Because Wolfcamp strata were deposited during a marine regression, the top of the Wolfcampian Series is actually a time-transgressive boundary that is older in the northern part of the Palo Duro Basin than in the south.

Depositional Systems

A depositional system is an informal rock-stratigraphic unit consisting of an assemblage of process-related facies (Fisher and

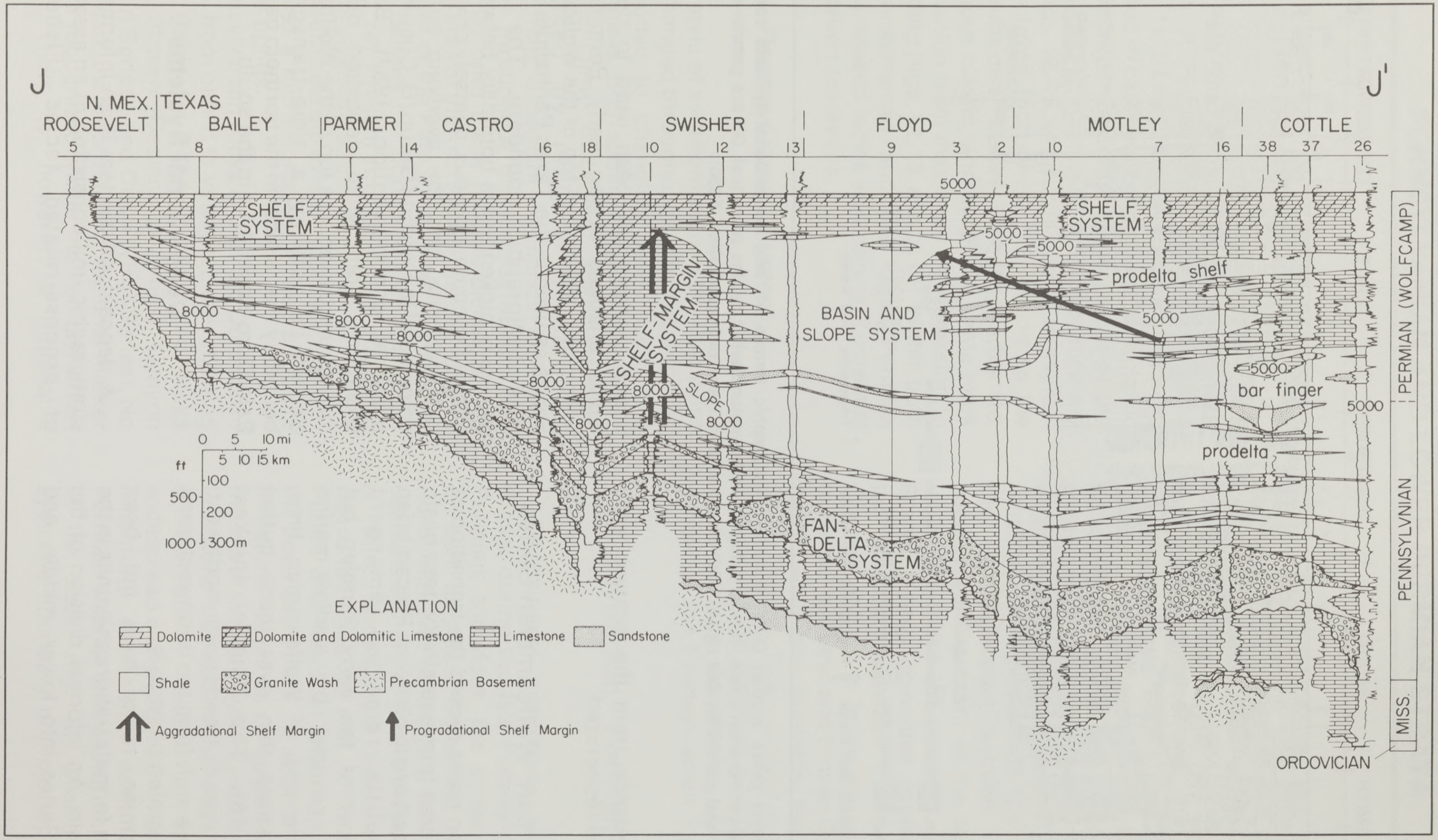


Figure 13. East-west cross section J-J′. Datum is top of Wolfcampian Series; depths are in feet. See figure 3 for location (from Handford and Dutton, 1980).

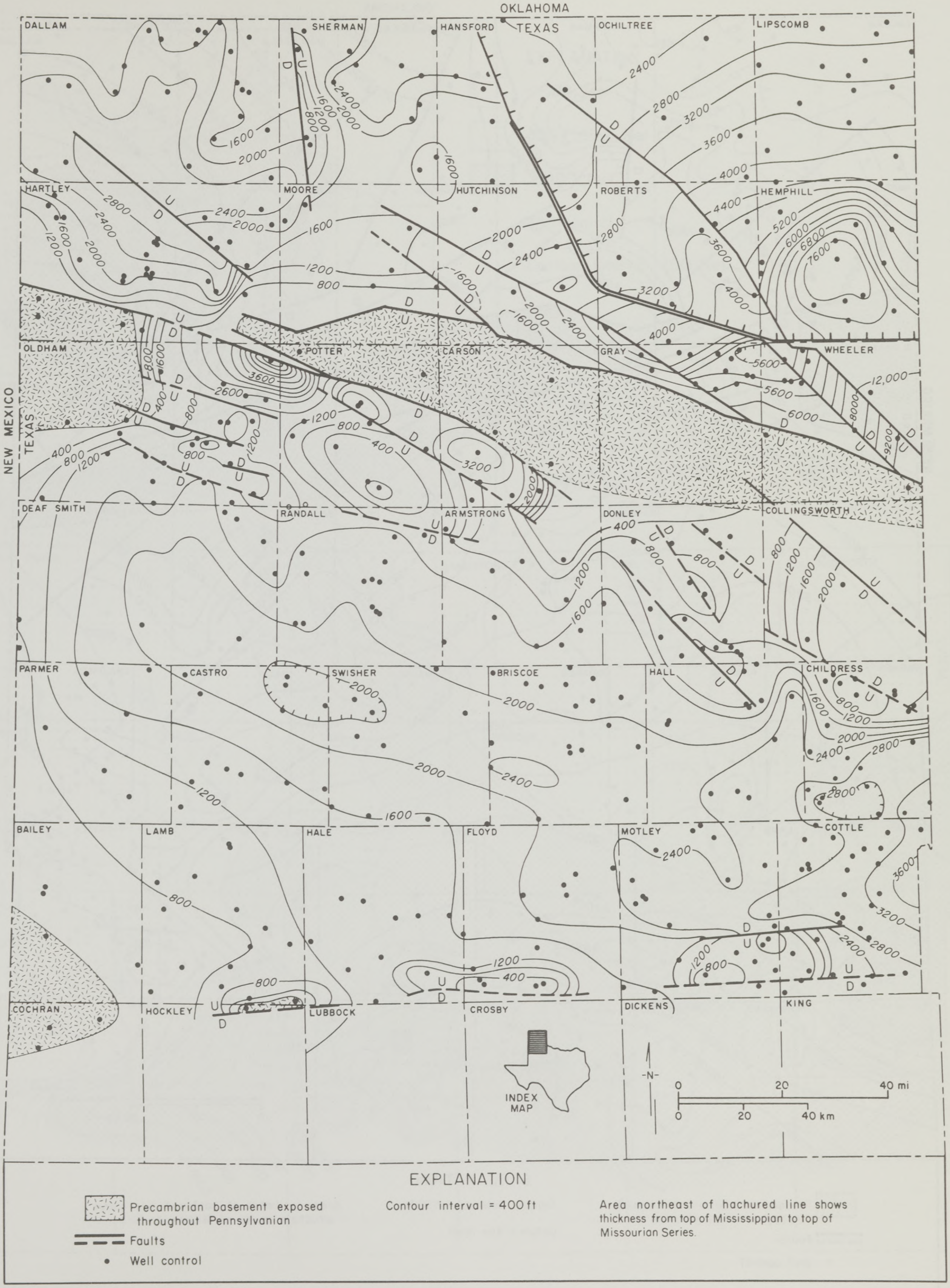


Figure 14. Isopach map of Pennsylvanian System, Texas Panhandle. Sediments thin onto uplifts that were exposed during Pennsylvanian Period.

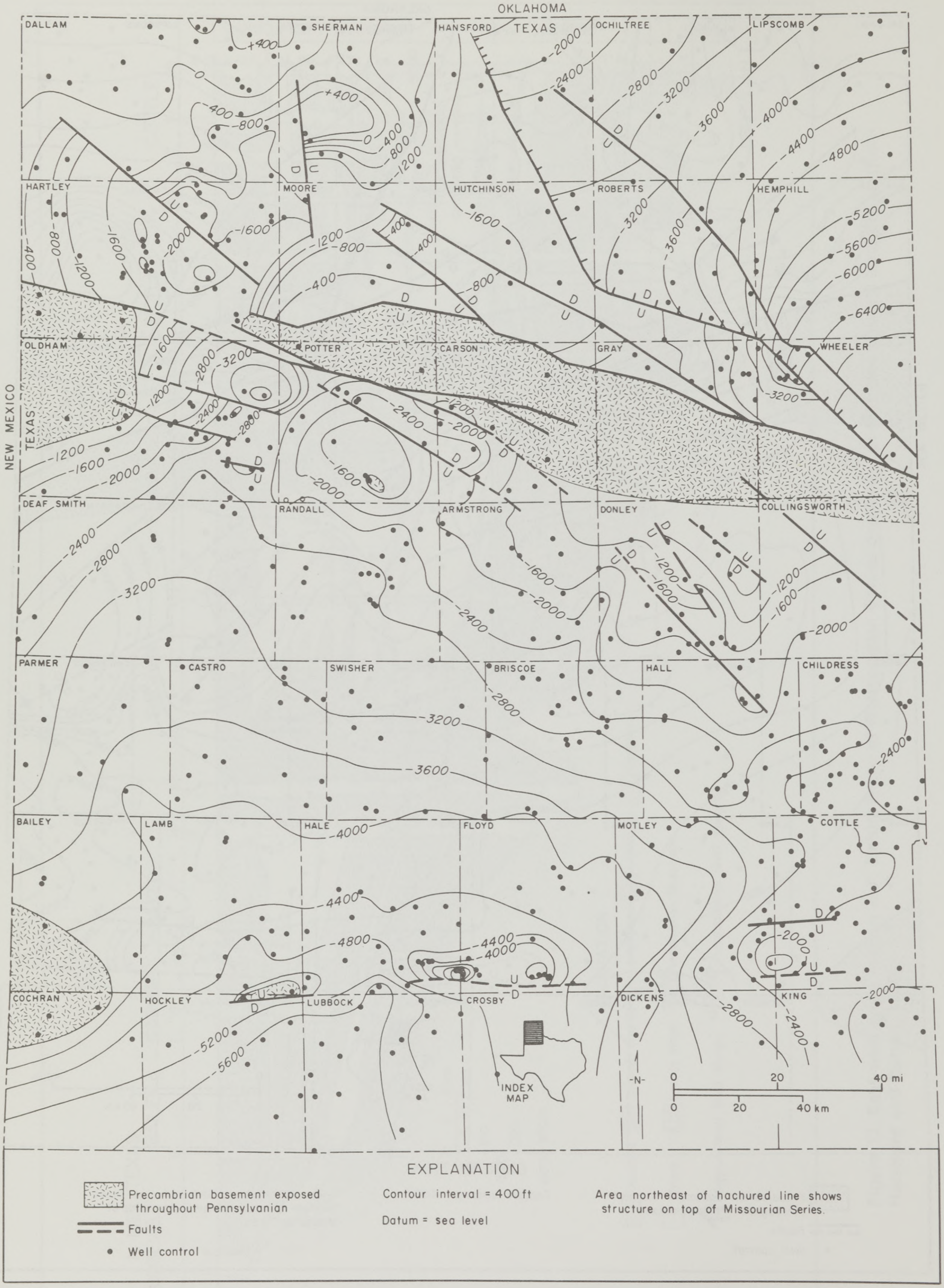


Figure 15. Structure contour map of top of Pennsylvanian System, Texas Panhandle.

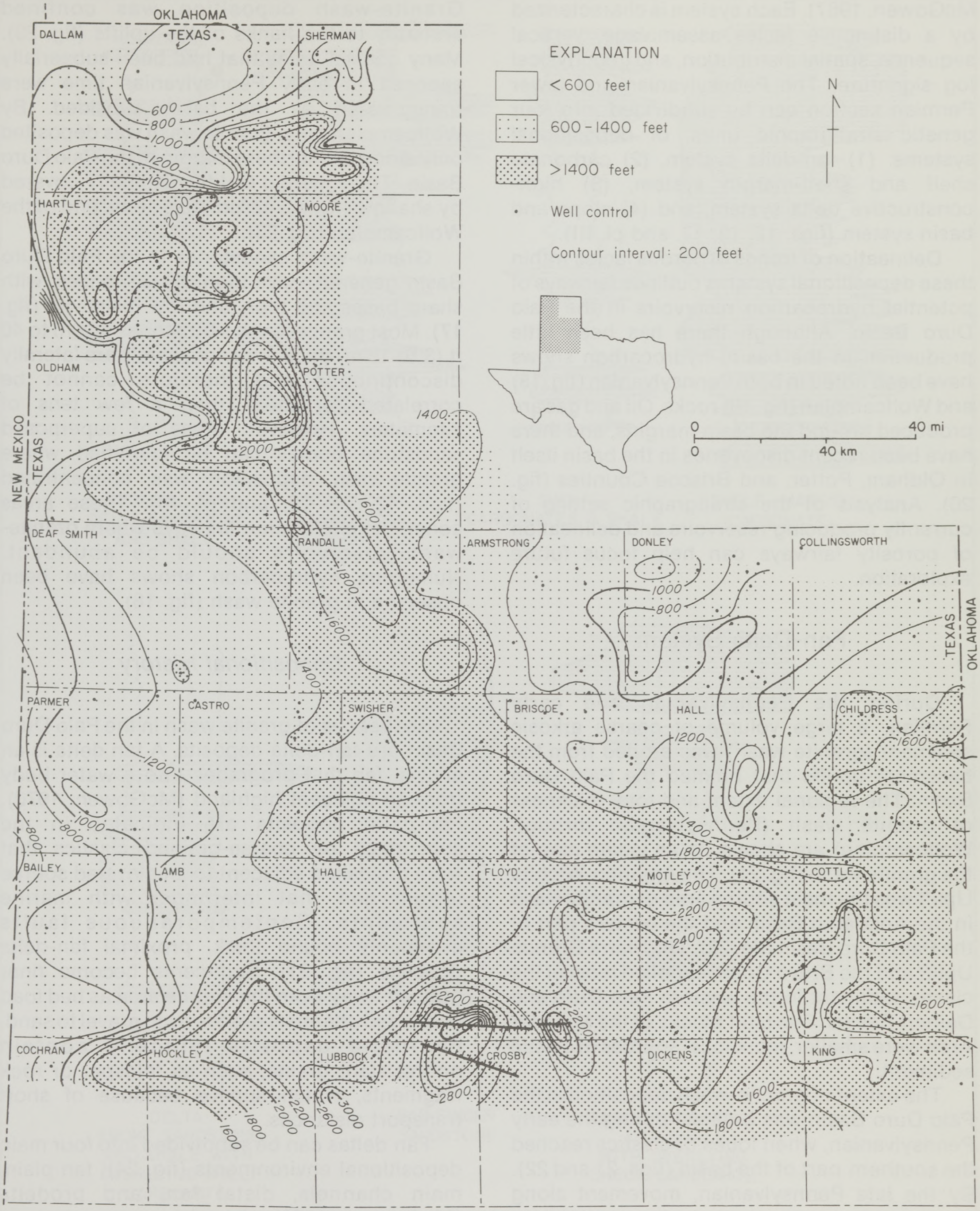


Figure 16. Isopach map of Wolfcampian Series, Palo Duro Basin (Handford, unpublished data).

McGowen, 1967). Each system is characterized by a distinctive facies assemblage, vertical sequence, spatial distribution, and geophysical log signature. The Pennsylvanian and lower Permian section can be subdivided into four genetic stratigraphic units, or depositional systems: (1) fan-delta system, (2) carbonate shelf and shelf-margin system, (3) high-constructive delta system, and (4) slope and basin system (figs. 12, 13, 17, and pl. III).

Delineation of trends of porous facies within these depositional systems outlines fairways of potential hydrocarbon reservoirs in the Palo Duro Basin. Although there has been little production in the basin, hydrocarbon shows have been noted in both Pennsylvanian (fig. 18) and Wolfcampian (fig. 19) rocks. Oil and gas are produced around the basin margins, and there have been recent discoveries in the basin itself in Oldham, Potter, and Briscoe Counties (fig. 20). Analysis of the stratigraphic setting of currently producing reservoirs and delineation of porosity fairways can help focus future exploration.

Fan-Delta System

During the Pennsylvanian and early Permian, a large volume of coarse arkosic sediment (granite wash) was eroded from the basement uplifts that rimmed the Palo Duro Basin. The regional extent and total thickness of granite wash (Pennsylvanian through Wolfcampian) are shown on an isolith map of the granite wash (fig. 21). The Amarillo-Wichita Uplift was the main source area of granite wash in the Anadarko Basin and the eastern part of the Palo Duro Basin (fig. 22). The Sierra Grande Uplift and the Bravo Dome supplied most of the clastic sediment in the western Palo Duro and Dalhart Basins. The fault blocks of the Matador Arch were smaller, more local sources of clastic sediment.

The extent of granite-wash deposition in the Palo Duro Basin was greatest during the early Pennsylvanian, when lobes of clastics reached the southern part of the basin (figs. 21 and 22). By the late Pennsylvanian, movement along faults in the uplifts had declined. Highland areas were eroded extensively and no longer supplied as much clastic sediment to the basin. Granite-wash deposition was confined primarily to the flanks of the uplifts (fig. 23). Many coastal areas that had been subaerially exposed in early Pennsylvanian time were transgressed as the basin subsided. By Wolfcampian time, granite wash was deposited only along the northern margin of the Palo Duro Basin. The Amarillo Uplift was finally covered by shallow-marine carbonates at the end of the Wolfcampian (fig. 23).

Granite-wash sandstones in the Palo Duro Basin generally give high SP responses, with sharp bases and tops, and low resistivity (fig. 17). Most granite-wash sandstones are 10 to 40 ft (3 to 15 m) thick. Individual beds are laterally discontinuous and therefore cannot be correlated for more than a few tens of kilometers. However, areas of superposed sandstone bodies can be identified where granite-wash deposition was concentrated (figs. 12, 21, 22, and pl. III). These areas constitute exploration fairways where granite-wash reservoirs should be abundant. Numerous hydrocarbon shows have been observed in granite wash (fig. 18).

Depositional History

Sequences of granite wash in the Palo Duro Basin are fan-delta deposits. A fan delta is an alluvial fan that progrades into a water body from an adjacent highland (McGowen, 1970). Fan-delta deposits are indicated in the subsurface by coarse-grained clastics that were deposited adjacent to an elevated source terrain and that interfinger with marine sediments. Contemporaneous faults commonly bound thick, proximal fan-delta deposits (fig. 21). Sediments become finer grained away from the source area as bed load in braided channels grades from gravel to sand. Fan-delta deposits typically contain nonresistant grains, such as feldspar or rock fragments, which survive because of short transport distances.

Fan deltas can be subdivided into four main depositional environments (fig. 24): fan plain, main channels, distal fan, and prodelta (McGowen, 1970). Distal-fan deposits are commonly reworked after deposition by longshore currents and breaking waves

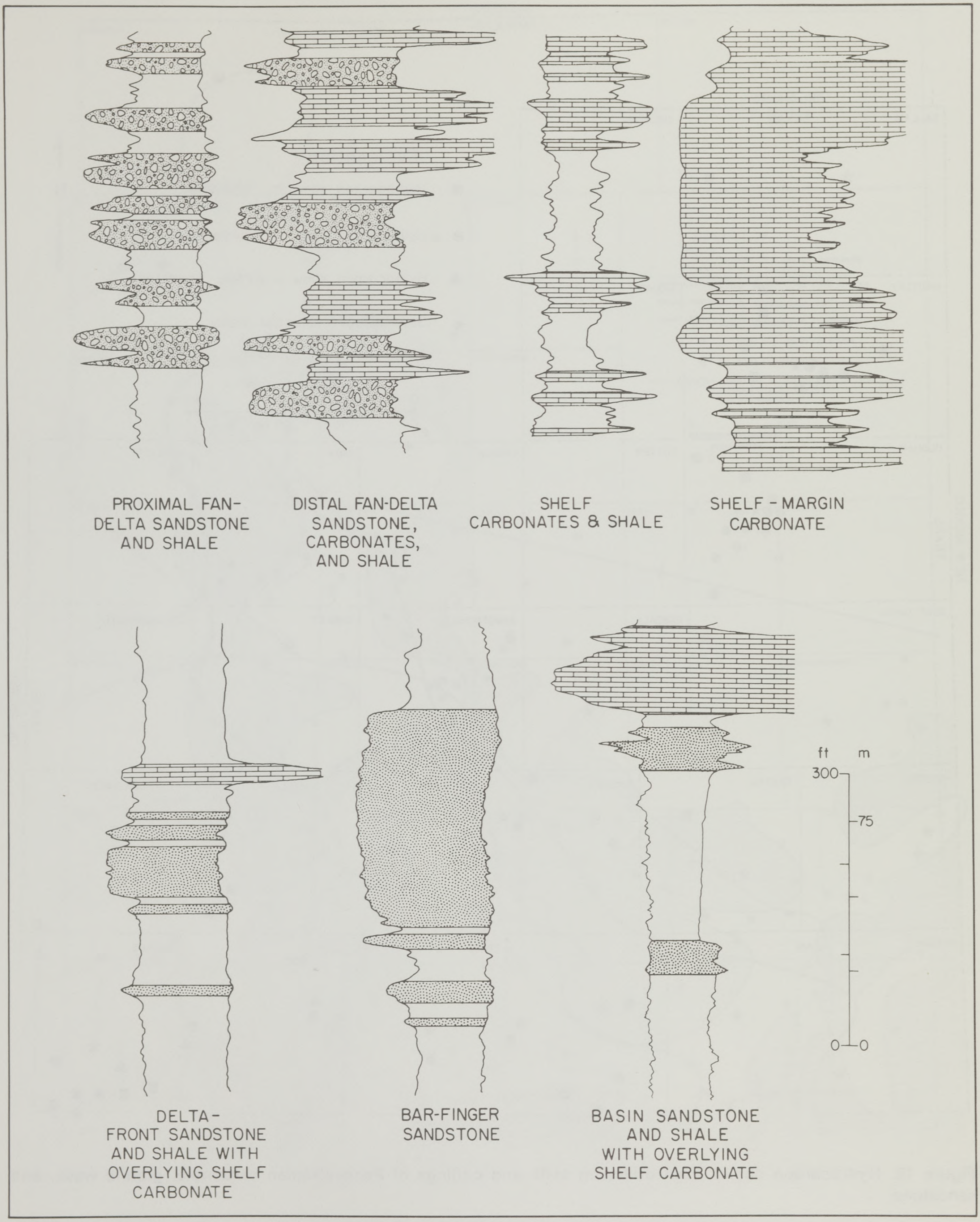


Figure 17. Typical electric log patterns of fan-delta, shelf and shelf-margin, delta, and basin facies. Spontaneous potential and resistivity curves are shown.

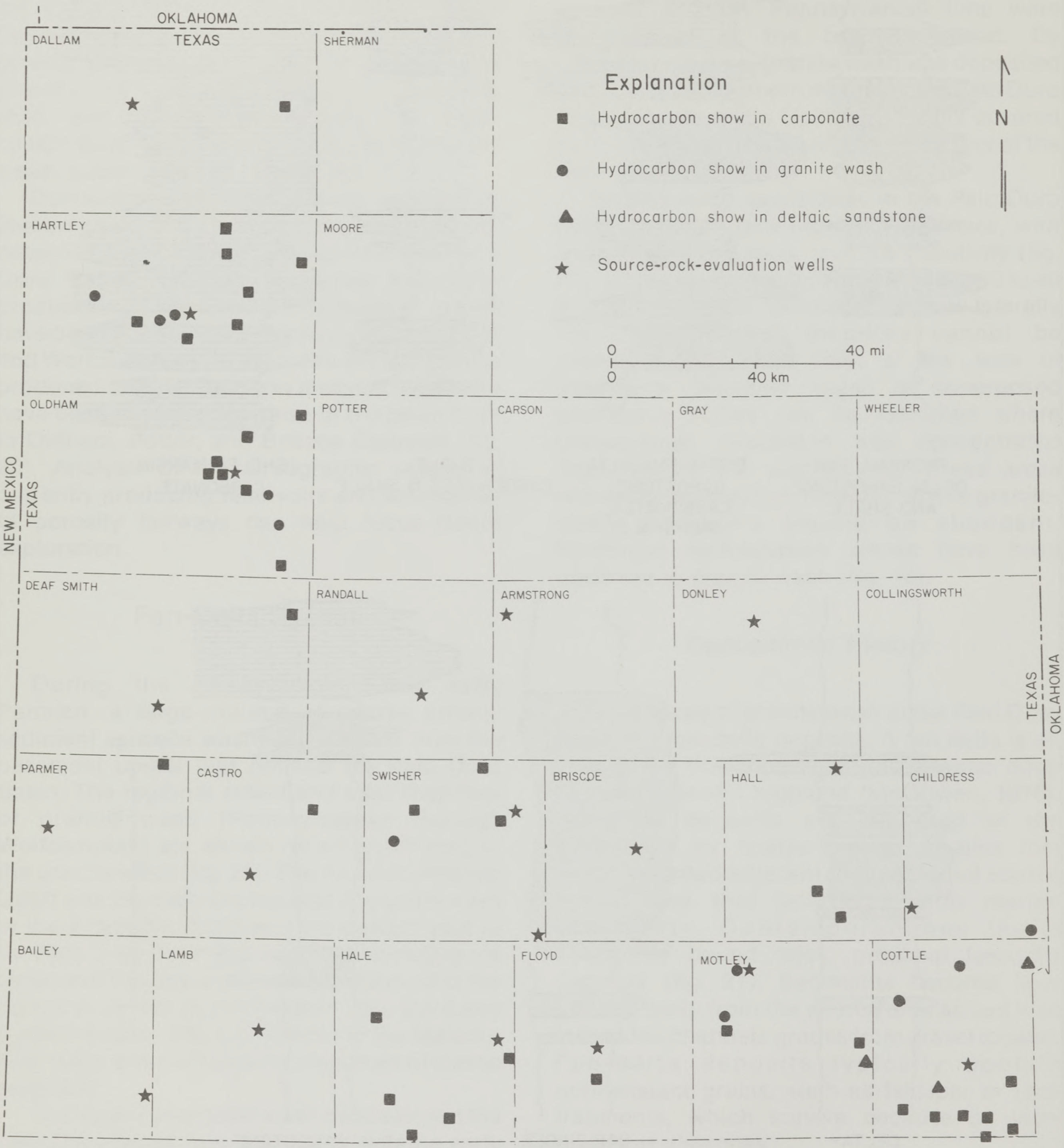


Figure 18. Hydrocarbon shows from drill-stem tests and cuttings of Pennsylvanian carbonate, granite wash, and sandstone.

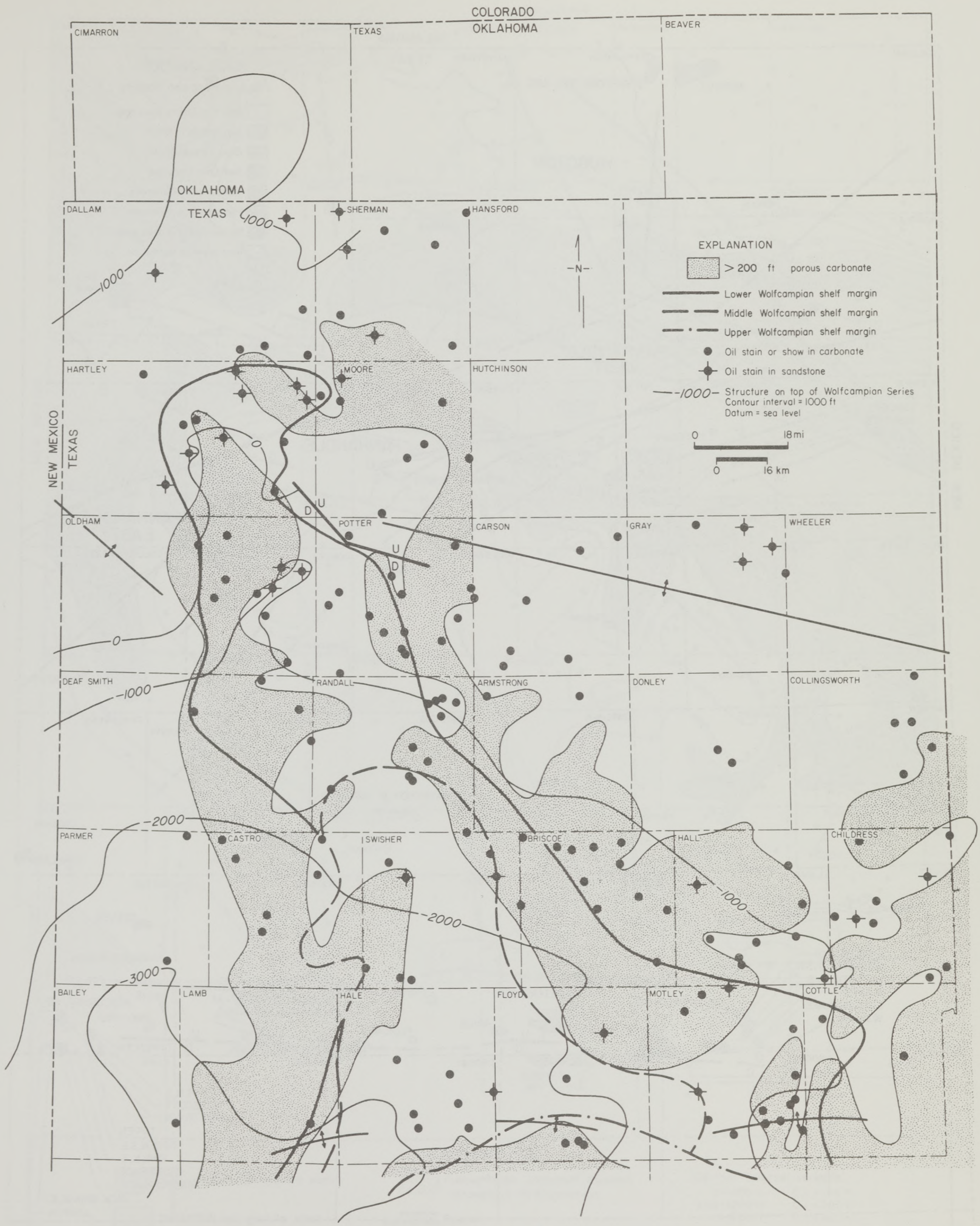


Figure 19. Distribution of oil stains and shows, as reported on sample logs, in relation to Wolfcamp structure, porous carbonate fairways, and lithology of host rock. Hydrocarbon shows are most common in shelf-margin carbonates and deltaic sandstones (from Handford, 1980).

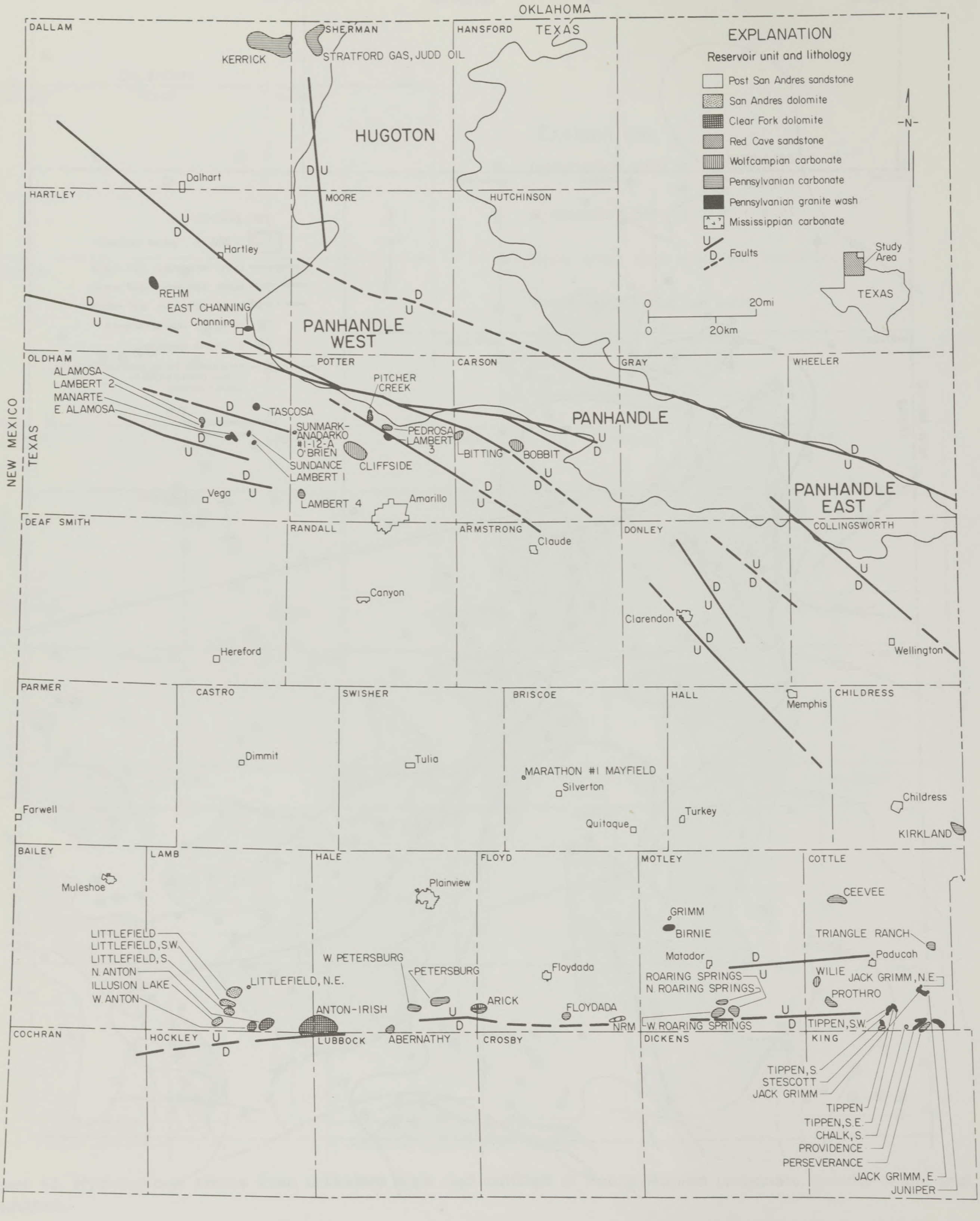


Figure 20. Location of oil and gas fields in the Palo Duro Basin and surrounding areas. Age and lithology of reservoirs are indicated.

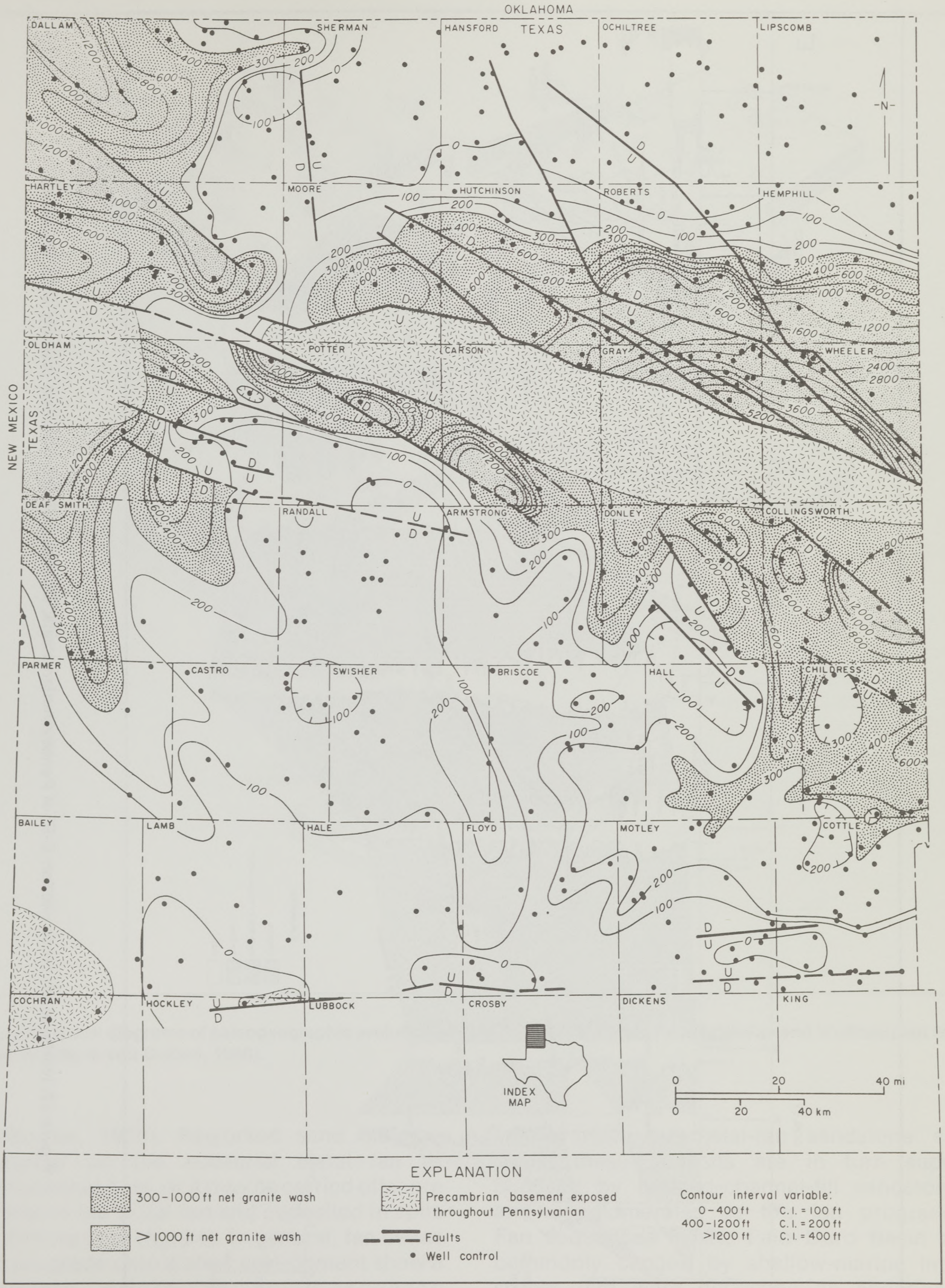


Figure 21. Isolith map of Pennsylvanian and Wolfcampian granite wash in the Texas Panhandle.

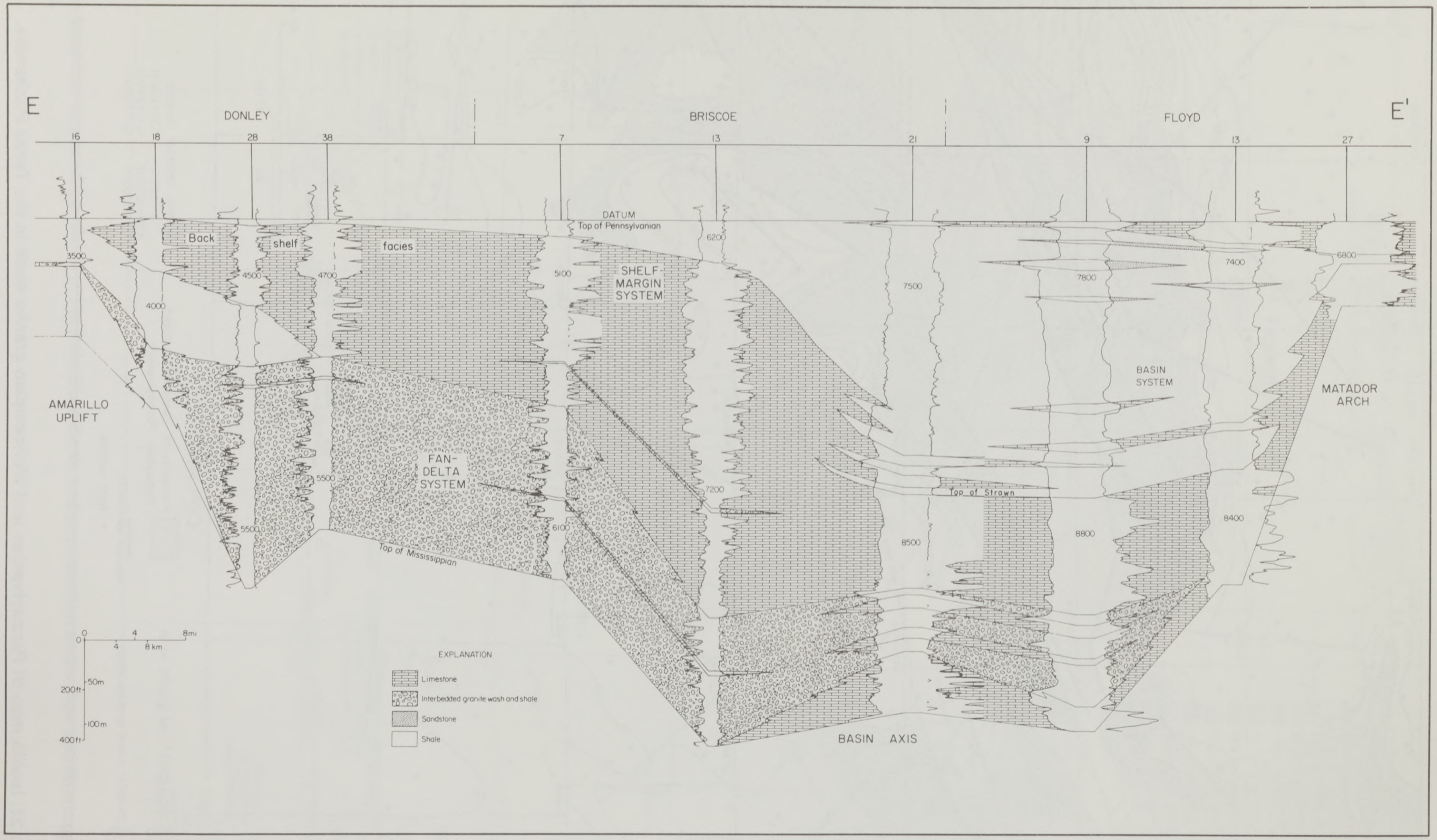


Figure 22. North-south cross section E-E′ of Pennsylvanian strata, Donley to Floyd Counties (see fig. 3 for location).

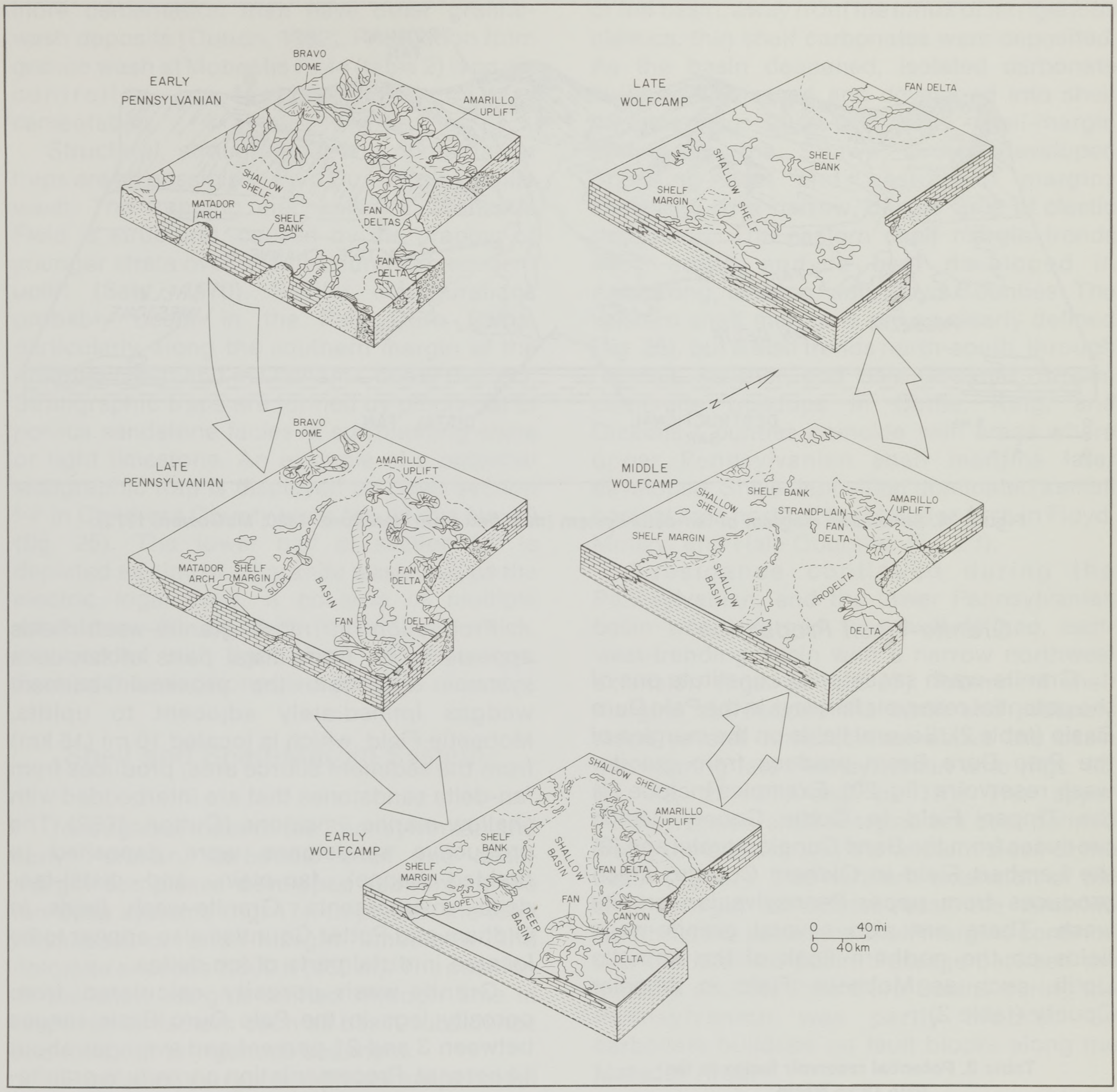


Figure 23. Block diagrams of paleogeographic evolution of Palo Duro Basin during Pennsylvanian and Wolfcampian time (from Handford and Dutton, 1980).

(McGowen, 1970). Reworked sand may be deposited on the subaerial distal fan as destructional bars, or it may be carried offshore parallel to the distal fan and deposited in spits or offshore bars (fig. 24). In general, fan deltas that prograde onto a shelf environment show a complete upward-coarsening sequence (Wescott and Ethridge, 1980; Brown, 1979). In a typical sequence, prodelta shale and siltstone are overlain by distal-fan sandstone and shale; these deposits are in turn superimposed by braided-channel-fill sandstones and conglomerates as the fan progrades. Fan sequences in the Palo Duro Basin are commonly capped by shallow-marine limestones that were deposited on abandoned fan surfaces following compaction and subsidence (fig. 17).

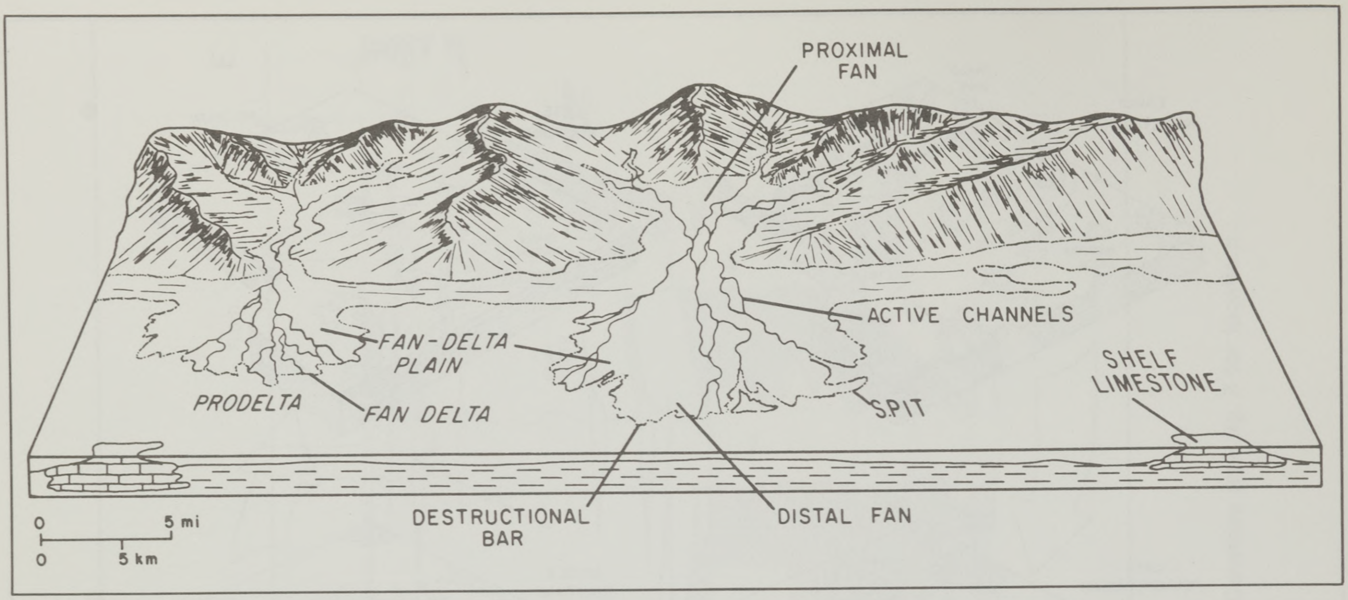


Figure 24. Schematic diagram of fan-delta system (modified from Handford, 1980; McGowen, 1970).

Granite-Wash Production

Granite-wash sandstones constitute one of the potential reservoir fairways in the Palo Duro Basin (table 2). Several fields on the margins of the Palo Duro Basin produce from granite-wash reservoirs (fig. 20). Examples include (1) the Tippen Field in Cottle County, which produces from the Bend Conglomerate, and (2) the Lambert Field in Oldham County, which produces from upper Pennsylvanian granite wash. There are also several granite-wash fields on the northern flank of the Amarillo Uplift, such as Mobeetie Field in Wheeler County (table 2).

Table 2. Potential reservoir facies in the Palo Duro Basin.

Reservoir	Porosity	Trap	Producing analog
Shelf-margin carbonate	8-10%	Stratigraphic Combination Structural	Empire-Abo Field, Eddy County, New Mexico, Leonardian dolomite
Fan-delta granite wash	13-15%	Structural Combination Stratigraphic	Mobeetie Field, Wheeler County, Texas, Missourian fan-delta granite wash
High-constructive delta sandstone	12-14%	Stratigraphic Combination Structural	Morris Buie - Blaco Fields, Shackelford County, Texas, Virgilian deltaic sandstone

Production in most granite-wash fields appears to be from distal parts of fan-delta systems, not from the proximal sediment wedges immediately adjacent to uplifts. Mobeetie Field, which is located 10 mi (16 km) from the sediment source area, produces from fan-delta sandstones that are interbedded with shallow-marine limestone (Dutton, 1982). The productive sandstones were deposited in braided-channel, fan-plain, and distal-fan-delta environments. Granite-wash fields in Oldham and Potter Counties also appear to be located in distal parts of fan deltas.

Granite-wash porosity calculated from porosity logs in the Palo Duro Basin ranges between 3 and 21 percent and averages about 14 percent. Precementation porosity in granite-wash facies was higher, but it has been reduced by precipitation of authigenic cements (Dutton, 1979). Total porosity has been enhanced by generation of secondary porosity resulting from leaching of feldspars and rock fragments. Distribution of porous granite wash (porosity $\geq$ 10 percent) closely follows total granite-wash distribution (fig. 21), indicating that, on a large scale, original porosity distribution, cementation, and leaching occurred uniformly throughout the facies. On a smaller scale, granite wash from certain environments, such as reworked distal fan, probably has undergone more cementation than have other granite-wash deposits (Dutton, 1982). Production from granite wash at Mobeetie Field (table 2) is partly controlled by facies-related calcite cementation.

Structural, stratigraphic, and combination traps are all possible in Palo Duro Basin granite wash. The trapping mechanism at Mobeetie Field is structural, caused by the draping of younger strata over a fault-bounded basement uplift (Sahl, 1970). Similar configurations probably occur in the Palo Duro Basin, particularly along the southern margin of the Amarillo Uplift and in Oldham County (fig. 21). Stratigraphic traps are formed by pinch-out of porous sandstone facies in surrounding shale or tight limestone. An example of a potential statigraphic trap is displayed on cross section I-I′ in Childress County wells No. 48 and No. 49 (fig. 25). The lower half of section I-I′ is depicted as almost all granite wash; but, as the electric logs show, it consists of multiple sandstones 20 to 40 ft (6 to 12 m) thick, interbedded with tight shale and limestone. Each of the sandstones is a possible reservoir.

Shelf and Shelf-Margin System

Throughout most of the Pennsylvanian and early Permian, carbonate shelf and shelf-margin complexes developed seaward of the fan-delta systems (fig. 17). In places, the total thickness of shelf-margin limestone and dolomite exceeds 2,800 ft (850 m). The position of the shelf margins shifted through time in response to factors such as basin subsidence and influx of terrigenous sediment.

These shelf-margin complexes are potential hydrocarbon reservoirs. There is some production from shelf-margin carbonates in and around the Palo Duro Basin (fig. 20), and numerous hydrocarbon shows have been observed along shelf-margin trends (figs. 18 and 19).

Distribution Through Time

During initial subsidence of the Palo Duro Basin in the early Pennsylvanian, the area was covered by a shallow sea. In the southern part of the basin, away from the influx of terrigenous clastics, thin shelf carbonates were deposited. As the basin deepened, isolated carbonate buildups coalesced and developed into shelf margins (fig. 26). This early shelf-margin system in the Strawn Group developed opposing east and west shelf margins separated by a narrow, deeper area of clastic deposition. The eastern shelf margin trends north-south and is best developed in Armstrong, Briscoe, and Floyd Counties. The western shelf margin is not as clearly defined (fig. 26), but it also trends north-south, through Randall, Swisher, and Hale Counties. Strawn carbonate buildups in Cottle, King, and Dickens Counties coincide with areas where upper Pennsylvanian shelf margins later developed. Shale deposition dominated a small basinal area north of the Matador Arch in Floyd, Motley, and Hale Counties (fig. 23).

Subsidence continued during the Pennsylvanian, and the lower Pennsylvanian basin was enlarged to a well-defined, east-west-trending basin with a narrow northwest extension (figs. 23 and 27). Prominent shelf margins surrounded the basin and probably stood several hundred feet above the basin floor during late Pennsylvanian time (figs. 12, 13, 22, 25, 27, and pl. III). The upper Pennsylvanian shelf margins are best defined along the eastern and the western sides of the basin (fig. 27). The northern extension of the shelf margin terminates near the Amarillo Uplift. To the south, the shelf margins continue into the Midland Basin. Passage between the Midland and the Palo Duro Basins during the Pennsylvanian was partly blocked by carbonate buildups on fault blocks along the Matador Arch.

Along the eastern and southwestern sides of the basin, the position of the shelf margin was stationary through late Pennsylvanian time. Shelf-margin carbonate banks built vertically and kept pace with subsidence. However, two different shelf margins are recognized in the northern part of the western shelf (figs. 12 and 27). The younger shelf margin retreated as much as 18 mi (30 km) west, or landward, of the older shelf margin. The two shelf margins merged in central Swisher County. Retreat of this part of the shelf margin probably resulted from the combined effects of subsidence and

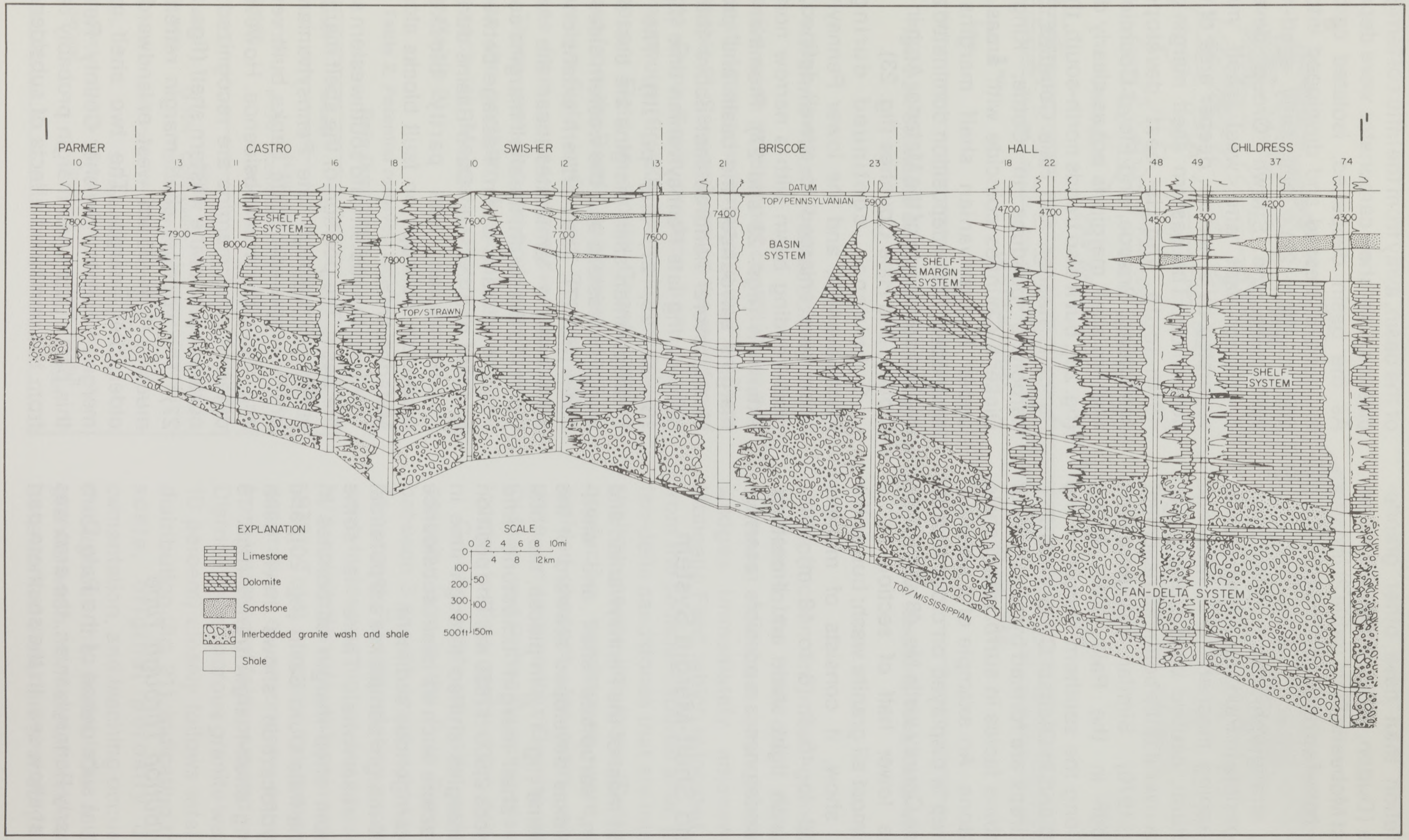


Figure 25. East-west cross section I-I′ of Pennsylvanian strata, Parmer to Childress Counties (see fig. 3 for location).

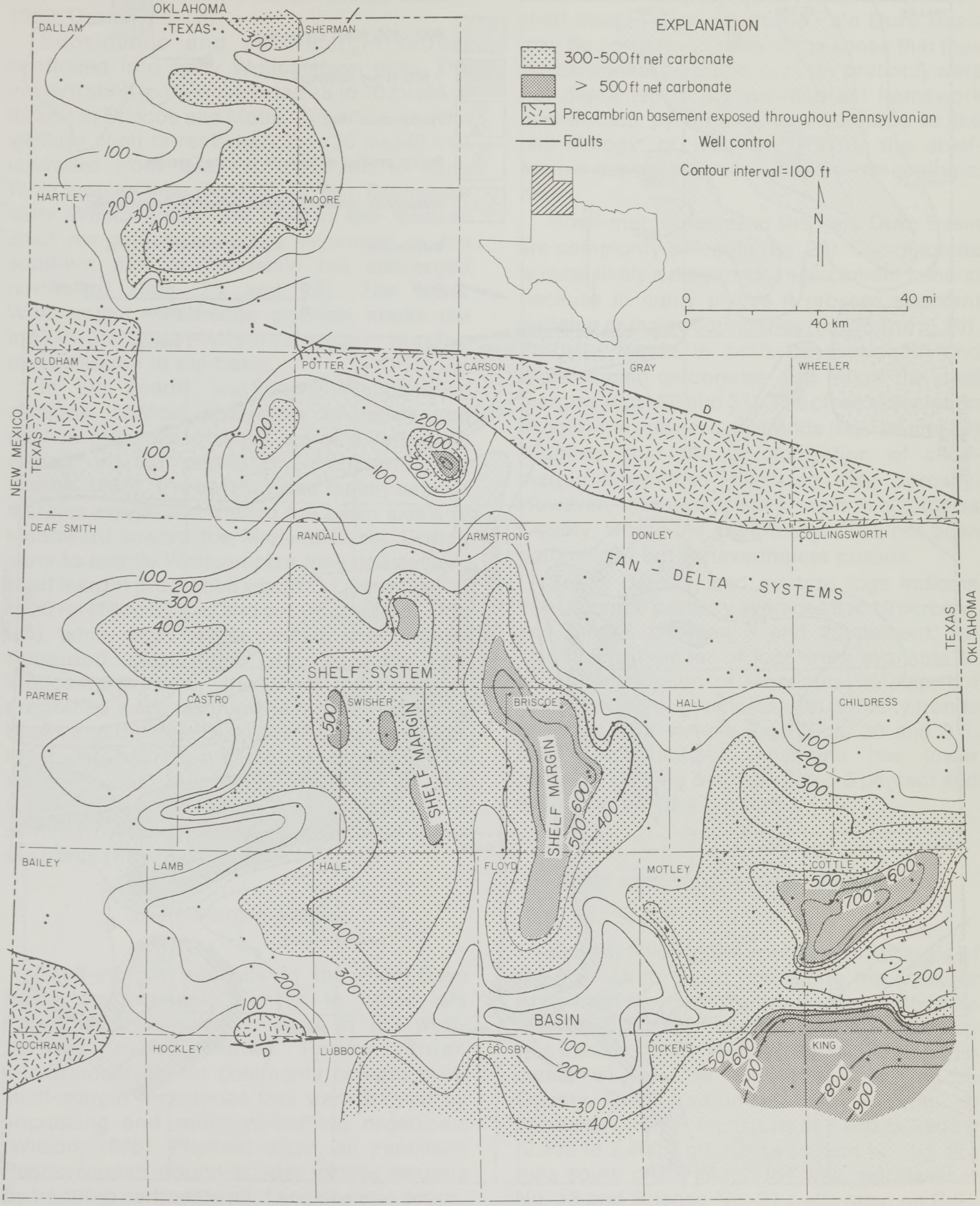


Figure 26. Net-carbonate map of lower part of Pennsylvanian System.

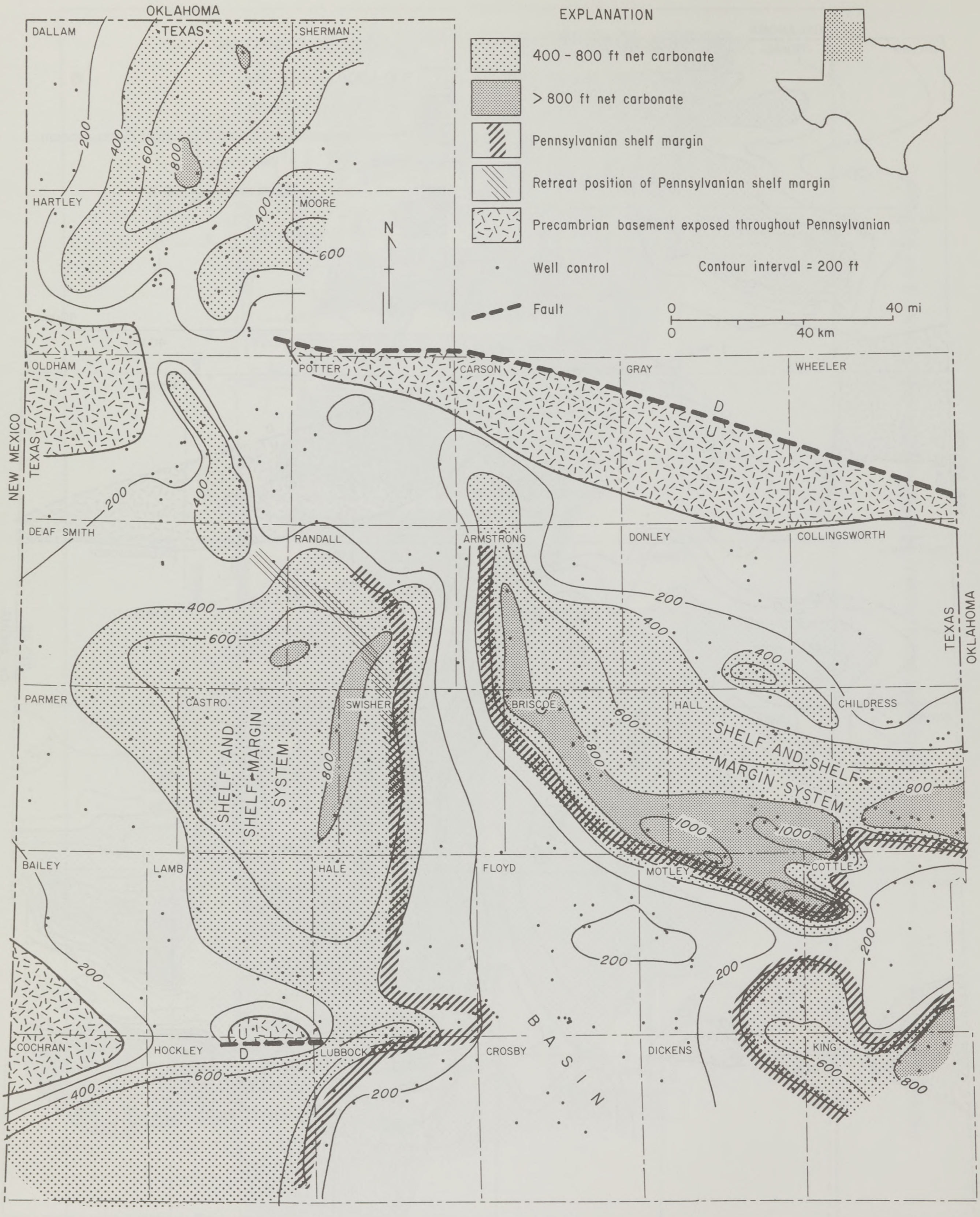


Figure 27. Net-carbonate map of upper part of Pennsylvanian System. Position of older shelf margin is shown by dark hachured lines, and younger (retreated) position is shown by lighter hachures.

clastic sedimentation (Handford and Dutton, 1980; Dutton, 1980a).

Subsidence and shelf-margin retreat continued into early Wolfcampian time. The eastern shelf margin retreated 15 to 20 mi (24 to 32 km) in Briscoe and Motley Counties, and the western shelf retreated another 30 mi (48 km) landward from late Pennsylvanian to early Wolfcampian time (figs. 27 and 28). During the early Wolfcampian, the eastern and western shelf margins were widely separated in the southern part of the basin but converged northward (figs. 23 and 28). The lower Wolfcampian shelf-edge position marks the maximum post-Mississippian marine transgression in the basin.

In the middle and upper Wolfcampian sections, vertical sequences of facies and relative positions of shelf margins reflect an overall marine regression (Handford and Dutton, 1980). The basin closed rapidly as shelf margins prograded toward the basin axis and southward toward the Midland Basin. During early to middle Wolfcampian time, the eastern shelf margin prograded westward (seaward) 10 to 30 mi (16 to 50 km) and southward 80 mi (130 km), while most of the western shelf margin remained stationary (fig. 28). By late Wolfcampian time, the shelf margins had prograded seaward into the northern Midland Basin, and the Palo Duro Basin became a wide, low-relief, restricted carbonate platform. The evolution of the shelf margins in the Pennsylvanian and Wolfcampian is summarized by a series of schematic block diagrams (fig. 23).

Shelf-Margin Facies

Shelf-margin deposits in the Palo Duro Basin are probably similar to other late Paleozoic shelf-edge buildups in the west-central United States. Pennsylvanian intracratonic basins commonly contain thick shelf-margin limestones that were formed by encrusting and sediment-baffling organisms (Wilson, 1975). Phylloid algae, an important Pennsylvanian mound-builder, formed mounds by trapping carbonate mud and skeletal debris. Fusulinids, red and blue-green algae, sponges, crinoids, brachiopods, and bryozoans existed alongside the green algae and contributed to mound development (Erxleben, 1975). Thus, shelf-margin deposits in the Palo Duro Basin may be considered reefs in the sense that they are carbonate buildups, but they probably were not deposited in a wave-resistant framework constructed by organisms. According to the terminology of Dunham (1970), the shelf-margin deposits are stratigraphic, not ecologic, reefs.

Shelf-margin facies in the Palo Duro Basin are commonly dolomite (fig. 29). The dolomite is most likely a diagenetic replacement mineral because in many places it crosses apparent bedding or facies boundaries (fig. 25 and pl. III). Porosity trends in both Pennsylvanian and Wolfcampian carbonates also follow the shelf margins (figs. 30 and 31). The close association of dolomite and porosity trends (figs. 29 and 30) suggests that the dolomitization of shelf-margin limestones increased their porosity. However, there are places, such as Childress County, where the shelf margin has not been dolomitized but is nevertheless porous.

Sonic, density, and neutron logs indicate that dolomite porosity averages 8 to 10 percent, and ranges between 5 and 25 percent. An insufficient number of logs were available to allow construction of a quantitative map, but calculated values coincide with porosity trends delineated by sample logs (figs. 30 and 31). Most undolomitized limestone has lower porosity, ranging between 3 and 8 percent and averaging about 4 percent.

Shelf and Shelf-Margin Production

Several fields in the southeastern margin of the Palo Duro Basin and along the Matador Arch produce from Pennsylvanian carbonate reservoirs (fig. 20). In addition, a 1982 discovery was made in Pennsylvanian limestone from the center of the Palo Duro Basin in Briscoe County. The Marathon No. 1 Mayfield (fig. 20) produces oil from limestone at 7,880 to 7,906 ft (2,402 to 2,409.7 m). Cross section I-I′ (fig. 25) runs south of the Marathon well, but Swisher No. 13 and Briscoe No. 21 wells (also on E-E′; fig. 22) penetrate a similar section. Production in the No. 1 Mayfield well apparently is from upper Strawn (or basal Canyon) limestone,

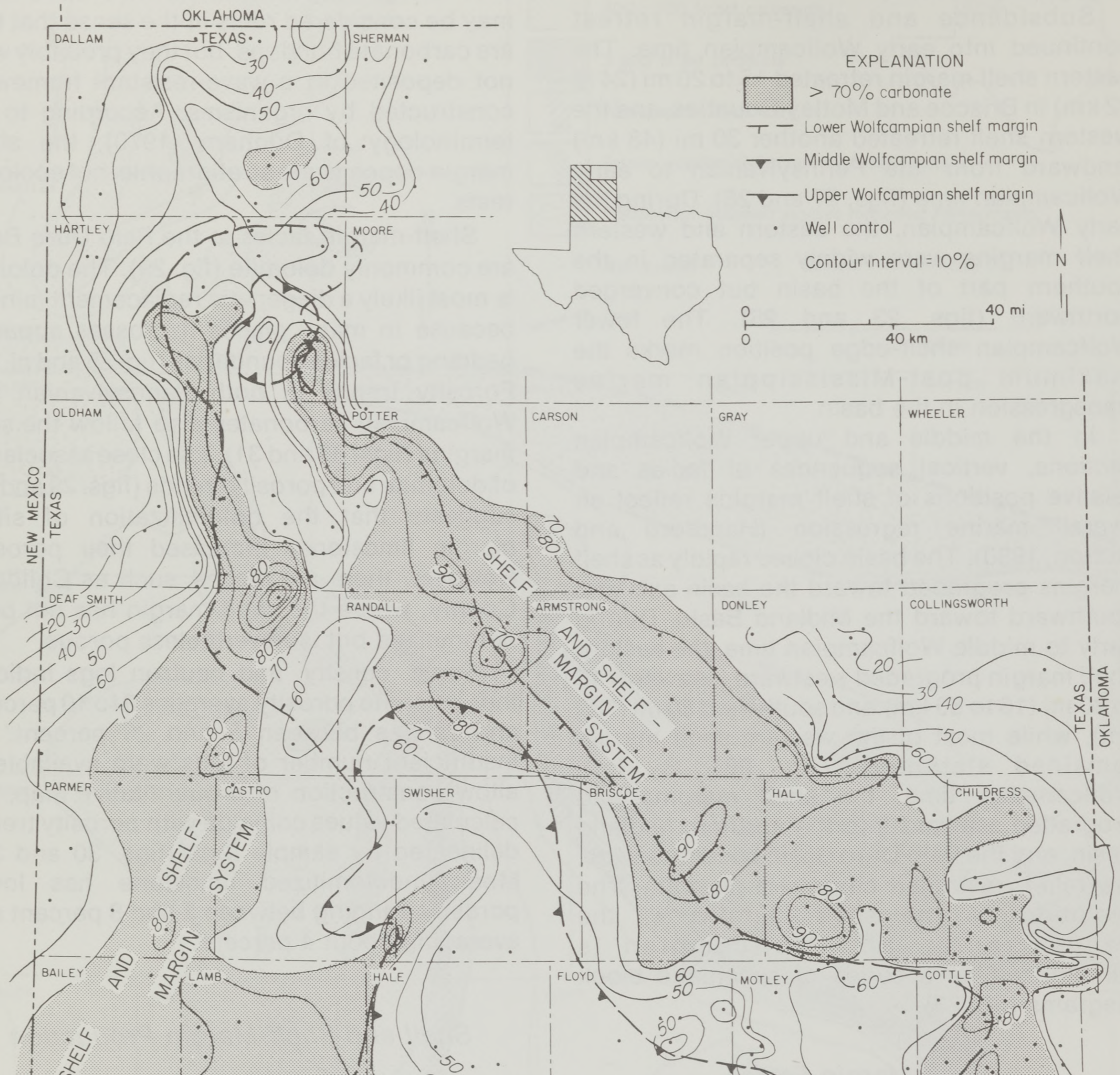


Figure 28. Percent-carbonate map of lower Permian strata in the Palo Duro Basin. Lines defining lower, middle, and upper Wolfcampian shelf-margin positions illustrate shelf-margin progradation through time (from Handford, 1980).

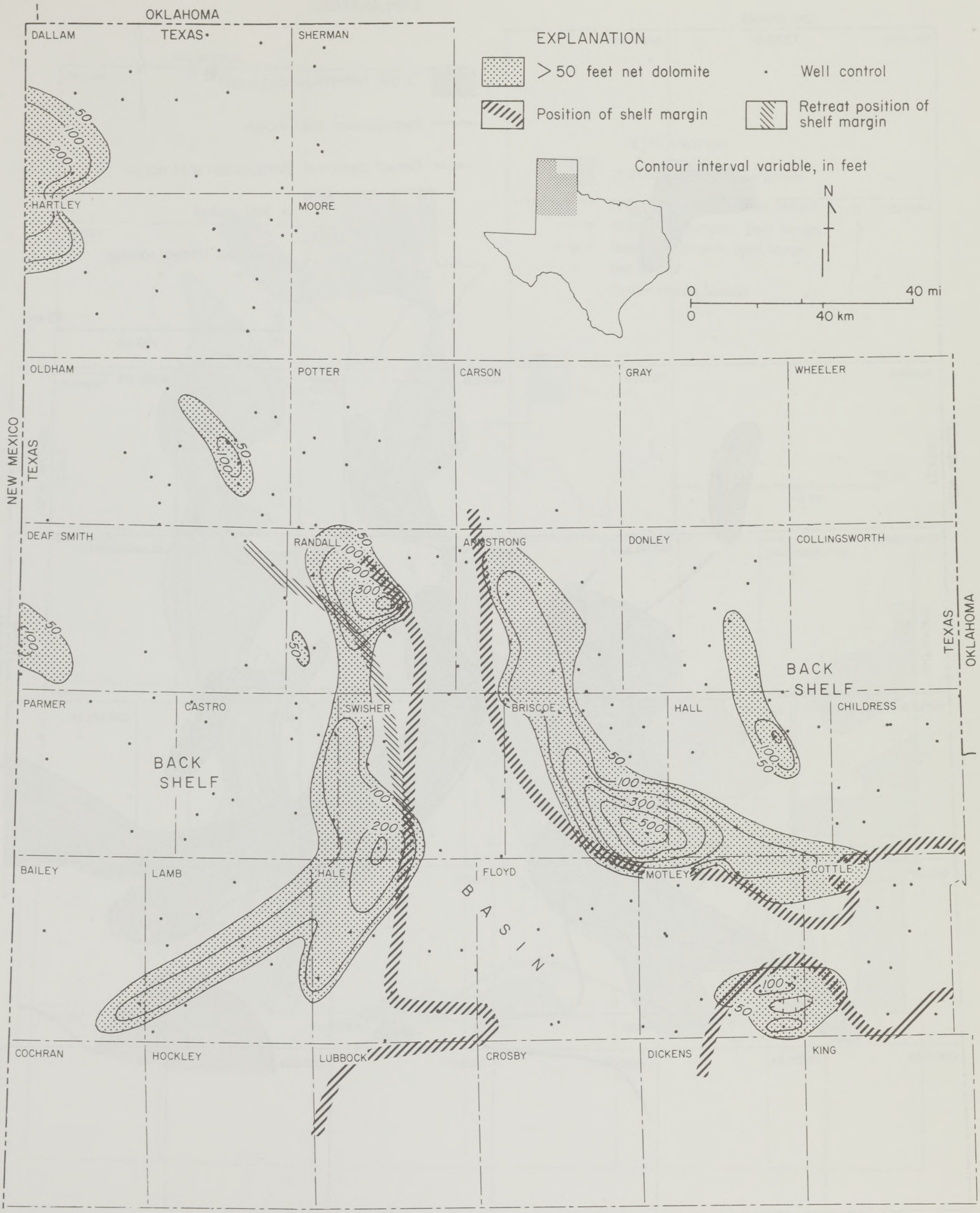


Figure 29. Isopach map, based on sample log information, of upper Pennsylvanian dolomite. Excellent correlation exists between porosity (fig. 30) and dolomite occurrence.

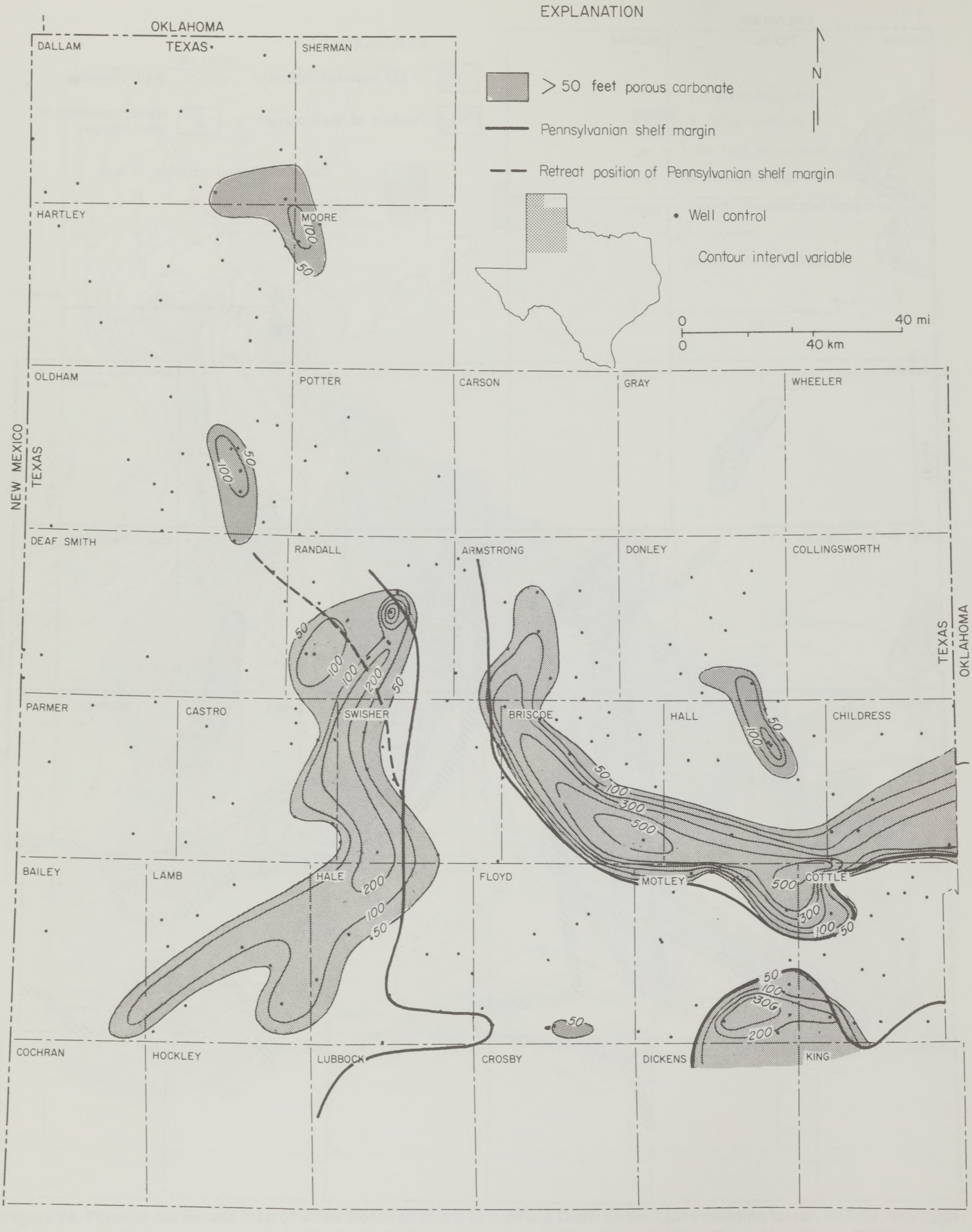


Figure 30. Isopach map of porous carbonate strata in upper part of the Pennsylvanian System. Map is made on the basis of qualitative sample log descriptions, so actual porosity values are unknown.

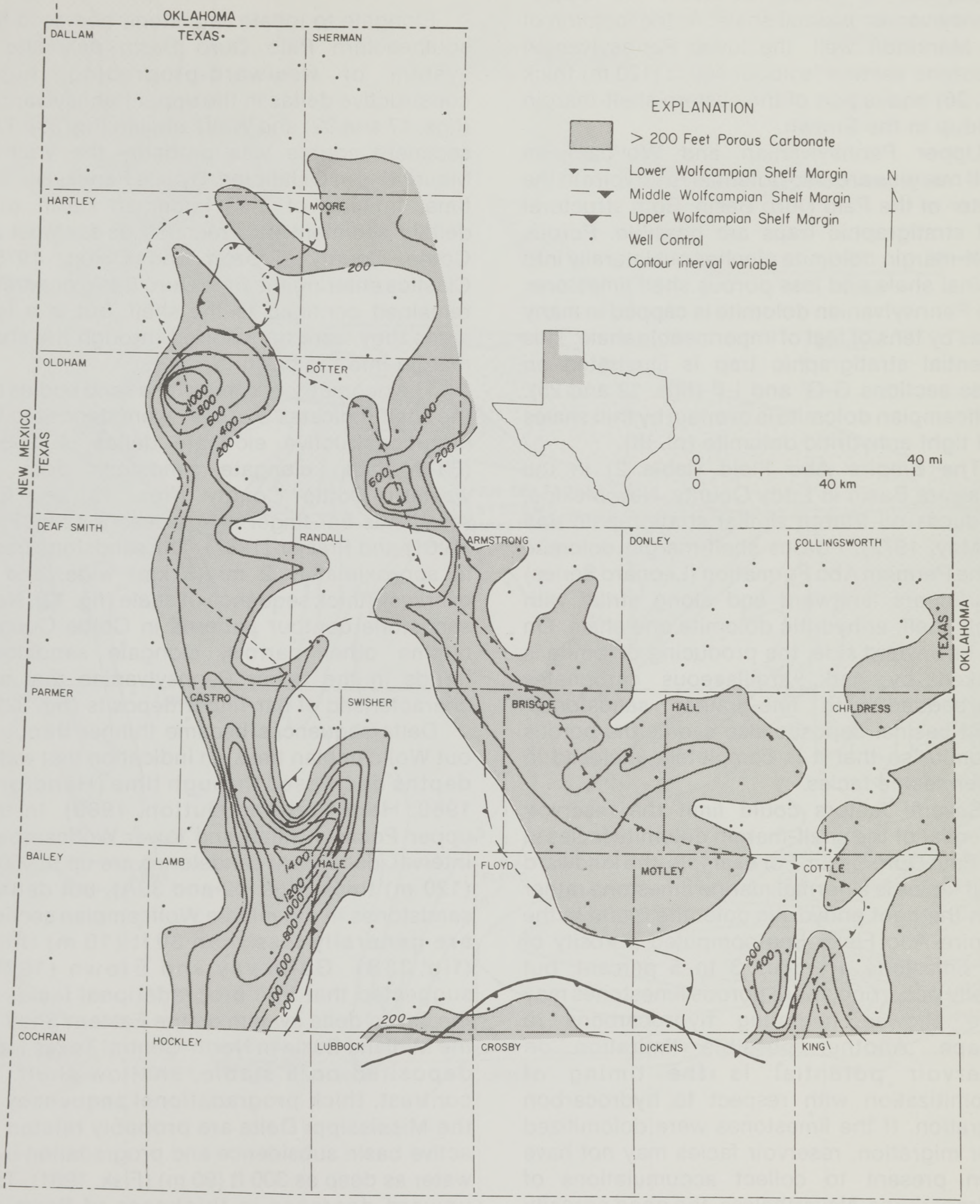


Figure 31. Isopach map of porous carbonate strata in Wolfcampian Series. Map is made on the basis of qualitative sample log descriptions, so actual porosity values are unknown (from Handford and Dutton, 1980).

which overlies an interval of granite wash and underlies a thick section of upper Pennsylvanian basinal shale. At the location of the Marathon well, the lower Pennsylvanian limestone section is about 400 ft (120 m) thick (fig. 26) and is part of the eastern shelf-margin buildup in the Strawn.

Upper Pennsylvanian and Wolfcampian shelf margins are also potential reservoirs in the center of the Palo Duro Basin. Both structural and stratigraphic traps are possible. Porous shelf-margin dolomite pinches out laterally into basinal shale and less porous shelf limestone. The Pennsylvanian dolomite is capped in many areas by tens of feet of impermeable shale. This potential stratigraphic trap is illustrated on cross sections G-G′ and I-I′ (figs. 12 and 25). Wolfcampian dolomite is overlain by thin shales and tight anhydritic dolomite (pl. III).

The Empire Abo Field (table 2) in the Delaware Basin in Eddy County, New Mexico, produces oil from a similar stratigraphic trap (LeMay, 1972). Porous shelf-margin dolomite of the Permian Abo Formation (Leonard Series) interfingers landward and along strike with tight, shelf, anhydritic dolomite and shale. On the basinward side, the producing dolomite is flanked by dark, argillaceous carbonates interbedded with fine-grained sandstones. Tight basinal deposits also overlie the porous dolomite so that it is completely enclosed in impermeable facies.

Several factors could limit the reservoir potential of the shelf-margin dolomite facies in the Palo Duro Basin. For example, the landward shelf facies is a normal marine limestone rather than the tight anhydritic dolomite found in the Empire Abo Field. Log-computed porosity of the limestone averages 3 to 5 percent, but locally occurring, more porous limestones may have allowed migrating hydrocarbons to escape. Another possible limitation on reservoir potential is the timing of dolomitization with respect to hydrocarbon migration. If the limestones were dolomitized after migration, reservoir facies may not have been present to collect accumulations of hydrocarbons. Nevertheless, the good porosity in shelf-margin facies and the juxtaposition of dolomite with organic-rich basinal shale suggest that the shelf margins are potential reservoir fairways.

High-Constructive Delta System

Elongate to lobate sandstone bodies in the southeastern Palo Duro Basin delineate a system of westward-prograding, high-constructive deltas in the upper Pennsylvanian (figs. 17 and 32) and Wolfcampian (fig. 33). The sediment source was probably the Wichita Mountains in Oklahoma. By late Pennsylvanian time, infilling of the Hardeman Basin with deltaic sediment had reached as far west as Cottle County (Frezon and Dixon, 1975). Clastics entering the Palo Duro Basin generally remained confined to the shelf, but in a few areas they were transported through the shelf margin into the basin (fig. 23).

The geometry of some of the sand bodies on the shelf indicates that they were deposited by high-constructive elongate deltas. A 200-ft (60-m)-thick, elongate sandstone body in western Cottle County (figs. 13 and 32) resembles bar-finger sands described by Fisk (1961) and Frazier (1967). The sandstone body is approximately 2 mi (3 km) wide, and it overlies a thick sequence of shale (fig. 13). Net-sandstone contour patterns in Cottle County outline other narrow, elongate sandstone trends in the upper Pennsylvanian that are characteristic of bar-finger deposits (fig. 32).

Delta sequences became thinner throughout Wolfcampian time, an indication that water depths decreased through time (Handford, 1980; Handford and Dutton, 1980). In the upper Pennsylvanian and lower Wolfcampian interval, delta-front sandstones are up to 400 ft (120 m) thick (figs. 32 and 33A), but deltaic sandstones in the middle Wolfcampian section are generally less than 30 ft (10 m) thick (fig. 33B). Galloway and Brown (1972) suggested that thin progradational facies in the Cisco delta system on the Eastern Shelf of the Midland Basin in North-Central Texas were deposited on a stable, shallow shelf. In contrast, thick progradational sequences in the Mississippi Delta are probably related to active basin subsidence and progradation into water as deep as 300 ft (90 m) (Fisk, 1961). The upward decrease in thickness of Permian deltaic sequences in the Palo Duro Basin indicates a shallowing trend in water depths that may have been related to slower subsidence rates (Handford and Dutton, 1980).

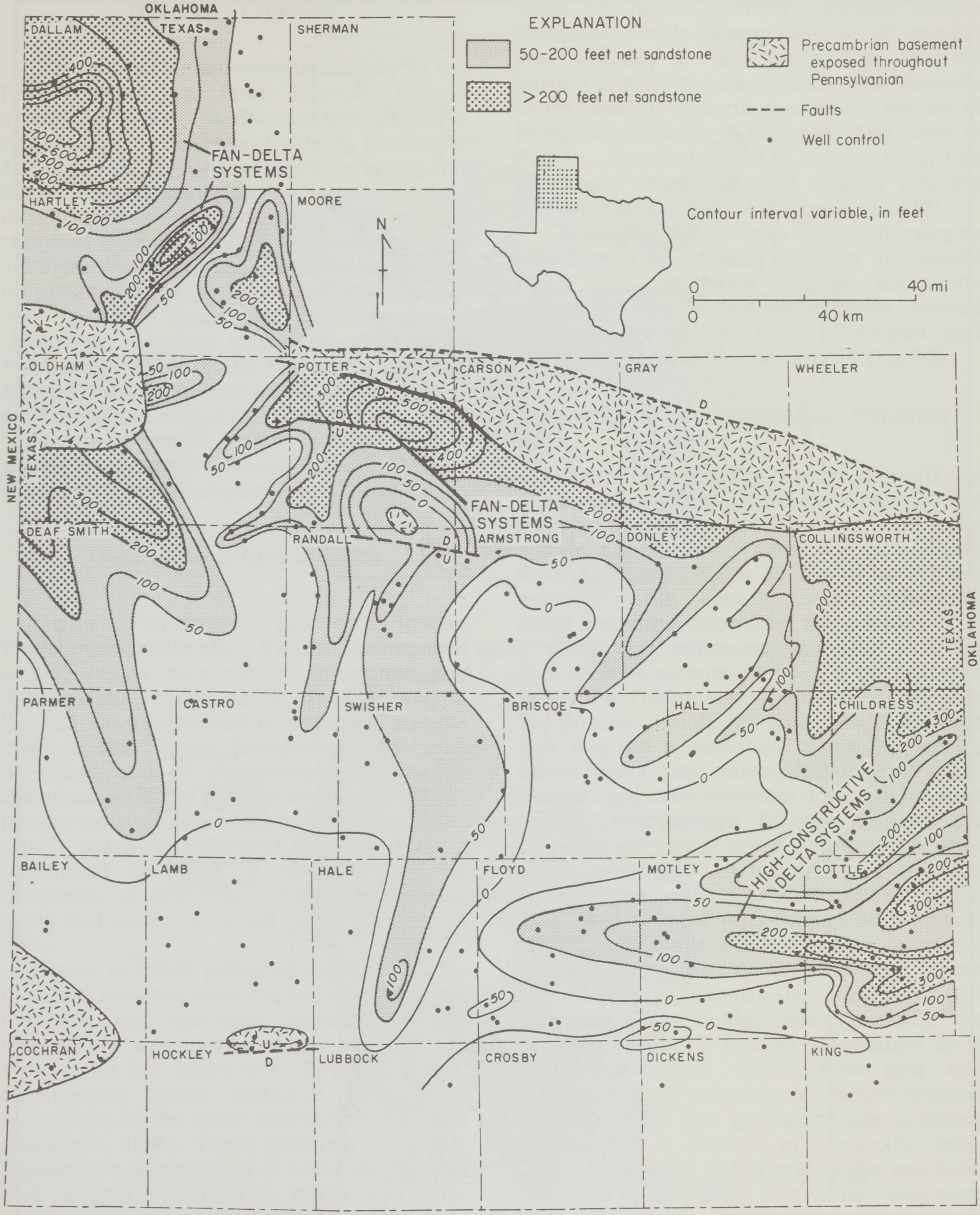


Figure 32. Net-sandstone map of upper part of the Pennsylvanian System, including both granite wash and nonarkosic sandstone.

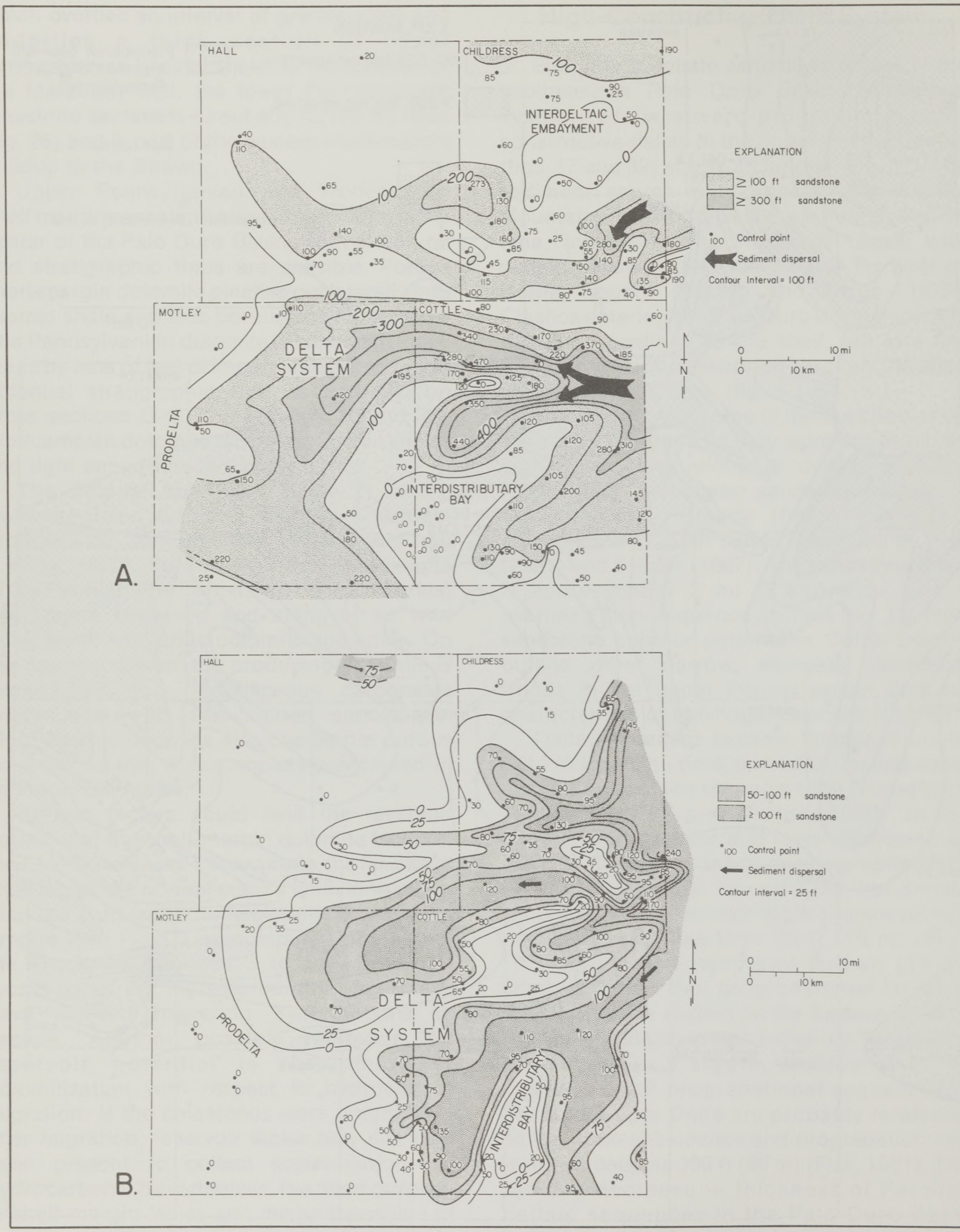


Figure 33. Isolith maps of Wolfcampian deltaic sandstones in southeastern Palo Duro Basin (from Handford, 1980): A. lower Wolfcamp Series. B. middle Wolfcamp Series.

Reservoir Potential

The third potential reservoir fairway in the Pennsylvanian and lower Permian section consists of deltaic sandstones located in the eastern part of the basin (table 2). Bar-finger sandstone bodies are enclosed by prodelta and delta-flank shale and may be sealed updip by mud plugs deposited after distributary channels were abandoned. Possible reservoirs are those deltaic sandstones that have porosity up to 12 to 14 percent, as in Cottle No. 38 (fig. 13). Bar-finger sandstones are reservoirs in Upper Pennsylvanian (Cisco Group) strata of the Eastern Shelf of the Midland Basin. The Morris Buie - Blaco Field in Shackelford County produces from a 50-ft (15-m)-thick, bar-finger sandstone reservoir (table 2). The trap is primarily stratigraphic, combined with a subtle structural hinge (Galloway and Brown, 1972).

Basin and Slope System

Upper Pennsylvanian and lower Wolfcampian rocks along the basin axis consist of silty shales, dark micritic limestones, and thin sandstones (figs. 12, 13, 17, 22, 25, and pl. III) that were deposited in slope and basinal environments. These fine-grained sediments are basinward of shelf-margin carbonates. Sediment probably entered the basin through passes between carbonate buildups along the shelf margins. Carbonate deposition terminated in areas of clastic input, but production of carbonate sediment continued in areas that were unaffected by the terrigenous influx.

Clastic sediment probably entered the basin in pulses; between these depositional episodes the basin was essentially starved. Sediment most likely was carried down the slope in submarine-fan channels. Several offset, superposed feeder channels have been recognized in the lower Wolfcampian section (Handford, 1980). These channels occur just beyond the progradational limits of fan-delta and high-constructive delta systems. Thickness trends indicate that the channels carried sediment from deltas on the shelf, across the shelf margin, and downslope into the basin. The narrow opening in the shelf margin in western Cottle County (figs. 23, 27, and 32) was probably a main passageway into the eastern arm of the deep basin. The Amarillo Uplift was an important northern source of terrigenous clastics in the basin. Fan deltas in Potter, Randall, and Carson Counties introduced sand and mud directly into the narrow northern arm of the basin (fig. 32).

Carbonate debris from the shelf margins was carried by turbidity currents and debris flows into the basin through submarine channels. The carbonate deposits formed aprons around the toes of slopes and submarine fans on the basin floor (fig. 25).

Basin and Slope Reservoir Potential

Many of the basin and slope deposits are enveloped by potential source rocks and are possible reservoir facies. However, most basin and slope sandstones are thin, fine grained, and tight, and they do not appear to have good reservoir quality. Lack of porosity, therefore, could limit production from these rocks.

Carbonate sediments deposited in slope and basin environments could be potential reservoirs. The productive limestone interval in the Briscoe County Marathon No. 1 Mayfield well may be a carbonate apron formed by debris flows that transported eroded shelf-margin carbonate sediment down the slope. A well in northeastern Swisher County, the Standard of Texas No. 1 Johnson (Swisher No. 6), penetrated a carbonate debris flow; core from the carbonate interval at 7,824 to 7,829 ft (2,384.8 to 2,386.3 m) contains both matrix-supported conglomerate and skeletal grainstone. The conglomerate is an impermeable carbonate mudstone-to-wackestone containing mudstone clasts. The sediment probably moved downslope as a matrix-supported debris flow and was deposited in an upper fan or feeder channel (Walker, 1978). The grainstone was probably deposited in a channel of a suprafan lobe. Original porosity in the grainstone has been occluded by carbonate cement that destroyed its reservoir quality. It is possible, however, that other slope grainstones were not cemented and could be potential reservoirs.

UPPER PERMIAN STRATA

S. P. Dutton

Transition to Evaporite Deposition

By late Wolfcampian time, the shelf margins had migrated to the southern edge of the Palo Duro Basin (figs. 23 and 28). The entire Palo Duro area became an extensive, low-relief, back-shelf environment. Post-Wolfcampian Permian strata (table 3 and pl. IV) are composed almost entirely of evaporites and red beds that record deposition on an extensive sabkha plain. To the south, the sabkha system in the Palo Duro Basin interfingered with a shallow-marine shelf and shelf-margin system in the northern Midland Basin.

The post-Wolfcampian evaporite section can be divided into five major genetic units (table 3): (1) the Wichita and Red Cave, (2) the lower Clear Fork and Tubb, (3) the upper Clear Fork and Glorieta, (4) the San Andres, and (5) the post-San Andres (Presley, 1980). Each genetic unit records a major basinward (southerly) facies shift (pl. IV). These genetic sequences can be subdivided into secondary cycles that record more localized episodes of transgression and regression.

Wichita - Red Cave Genetic Unit

Strata in the Wichita Group were deposited in a coastal sabkha that was bordered on the south by the deep Midland Basin and elsewhere by an alluvial fan plain (Handford, 1979). Dolomite and anhydrite were deposited in the Texas Panhandle; bedded salt was deposited farther landward (updip) in Oklahoma and Kansas. The Wichita Group is overlain by three clastic (red bed) lobes of the Red Cave Formation, which were deposited along the distal edges of coalescing alluvial fans and on landward fringes of sabkha mud flats (Handford, 1979).

Lower Clear Fork - Tubb Genetic Unit

Lower Clear Fork strata were deposited in coastal evaporite and carbonate environments similar to Wichita environments. However, because of a southerly shift of the environments following deposition of the Wichita Group, upper-sabkha, bedded salt was deposited in the northern Palo Duro Basin (fig. 34 and pl. IV). The overlying Tubb red beds record a basinward migration of siliciclastic mud-flat environments similar to the Red Cave Formation (Presley, 1980).

Upper Clear Fork - Glorieta Genetic Unit

This genetic unit resembles the underlying lower Clear Fork-Tubb cycle. Deposition of upper Clear Fork carbonates and evaporites in coastal sabkhas was terminated by progradation of Glorieta mud flats (pl. IV). Continental sabkhas (terrestrial salt flats) developed during Glorieta time in updip areas of the northern Panhandle (Presley, 1980 and 1981b).

San Andres Genetic Unit

The San Andres Formation marks the return to coastal evaporite and carbonate environments in the Palo Duro Basin (Presley and Ramondetta, 1981). Relatively open marine shelf environments (burrowed and fossiliferous dolomites) graded landward into coastal sabkhas (laminated dolomite with nodular anhydrite), which in turn graded into supratidal brine pans (massive salt, laminated anhydrite) (figs. 35, 36, and pl. IV). San Andres deposits in the Palo Duro Basin contain little terrigenous sand or mud compared with other upper Permian formations.

Post-San Andres Genetic Unit

Post-San Andres strata are composed predominantly of terrigenous clastic sediments and salt that were deposited in mud-flat and continental sabkha environments (Presley, 1980). In the Seven Rivers and Salado Formations (pl. IV), mudstones interfinger basinward with massive deposits of salt. Post-San Andres formations accumulated during the last stages of the regional Permian regression

Table 3. Stratigraphic chart of Permian System in Palo Duro and Dalhart Basins (modified from McGillis and Presley, 1981).

System	Series	Palo Duro Basin		Dalhart Basin		Series
PERMIAN	Ochoa	Post-San Andres interval	Dewey Lake Formation	Post-Blaine red beds	Dewey Lake Formation	Ochoa
			Alibates Formation		Alibates Formation	
			Salado Formation		Undifferentiated	
			Tansill Formation			
	Guadalupe		Yates Formation Seven Rivers Formation			Guadalupe
			Queen/Grayburg Formation			
		San Andres Formation			Blaine Formation	
	Leonard	Clear Fork Group	Glorieta Formation		Glorieta Sandstone	Leonard
			upper Clear Fork Formation		Clear Fork Formation	
			Tubb Formation		Undifferentiated Tubb-Wichita red beds	
			lower Clear Fork Formation			
			Red Cave Formation			
		Wichita Group				
	Wolf-camp	Wolfcamp (undifferentiated)				Wolf-camp

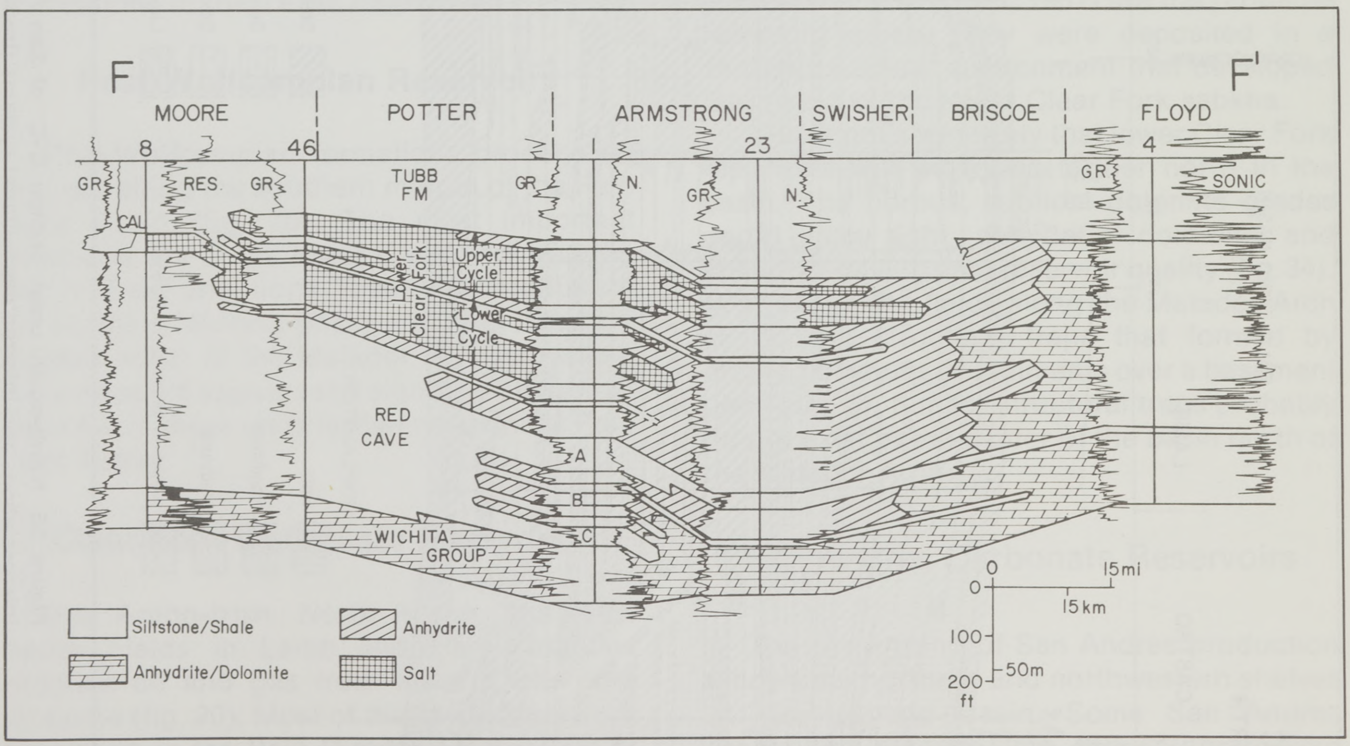


Figure 34. North-south cross section F-F′ of lower Clear Fork Formation. See figure 3 for location (from Handford, 1981).

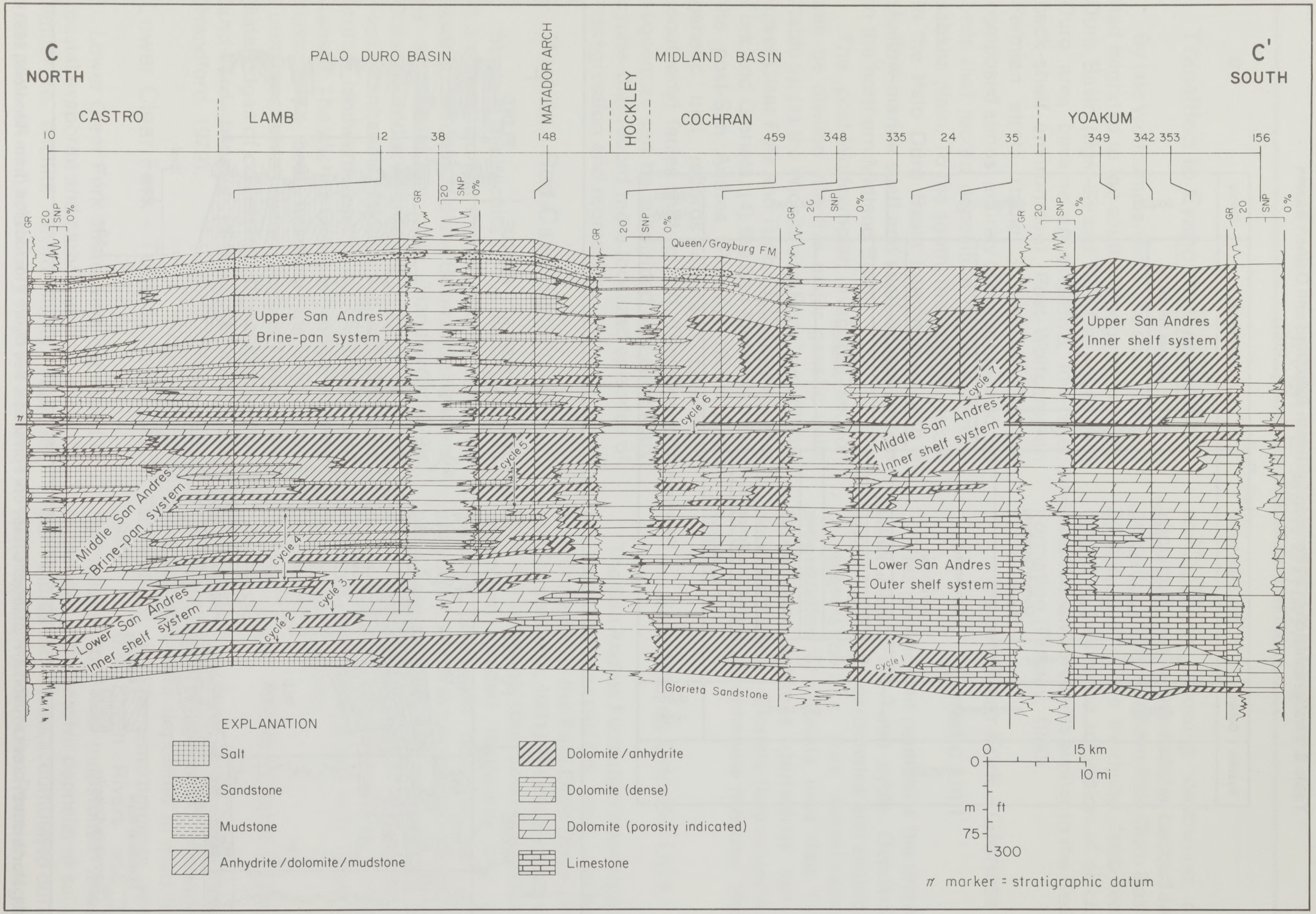


Figure 35. North-south cross section C-C′ of San Andres Formation in areas of production, showing generalized lithic interpretations and inferred depositional systems (from Presley and Ramondetta, 1981). See figure 3 for location.

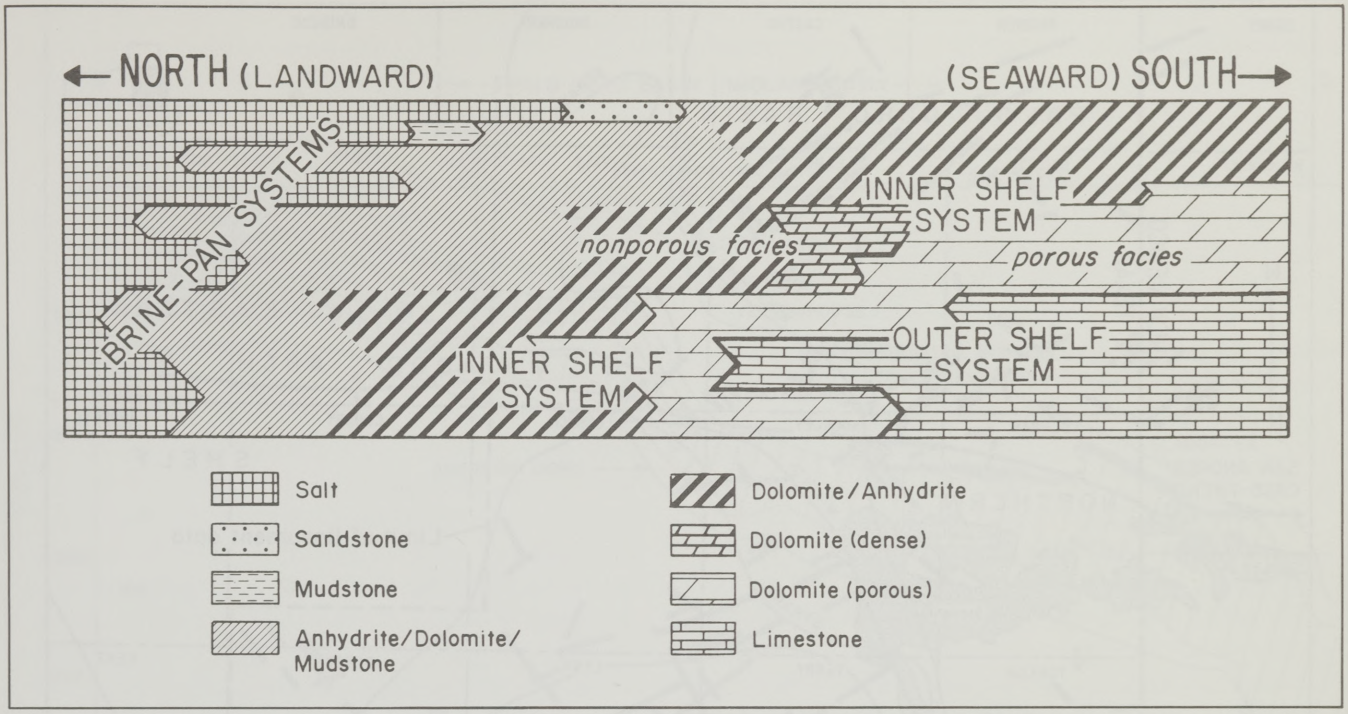


Figure 36. Diagrammatic cross section of San Andres rocks in hydrocarbon-producing areas, illustrating distribution of facies and depositional systems (from Presley and Ramondetta, 1981). This section simplifies relations in figure 35.

(McGillis and Presley, 1981) and record the final Paleozoic marine incursions and regressions in the Texas Panhandle.

Post-Wolfcampian Reservoirs

Post-Wolfcampian formations produce oil and gas along the southern margin of the Palo Duro Basin (fig. 20). The most important reservoirs are in the lower Clear Fork and the San Andres Formations. These units produce in the northern Midland Basin, and a few fields are located north of the Matador Arch. However, there does not appear to be significant reservoir potential in these units farther north in the Palo Duro Basin.

Clear Fork Carbonate Reservoirs

The Anton-Irish, North Anton, and West Anton Fields in Lamb and Hale Counties produce oil and gas from lower Clear Fork dolomite (fig. 20). Most of the lower Clear Fork Formation in the Palo Duro Basin consists of anhydrite and salt, but dolomite occurs along the southern margin of the basin (fig. 34). Cross-laminated dolomite packstones and grainstones (Handford, 1981) are the probable reservoir facies. They were deposited in a shallow, subtidal environment that developed basinward of the lower Clear Fork sabkha.

It does not seem likely that lower Clear Fork reservoirs will be found farther north in the basin. The porous, subtidal dolomite grades updip into tight anhydritic dolomite and anhydrite having poor reservoir quality (fig. 34). In addition, the fields along the Matador Arch all contain structural traps that formed by draping of younger sediments over a basement uplift (fig. 6). Similar structural traps probably do not exist in the center of the basin north of the Matador Arch.

San Andres Carbonate Reservoirs

The main trend of San Andres production follows the northern and northwestern shelves of the Midland Basin. Some San Andres production extends into the southern Palo Duro Basin in Lamb County (figs. 20 and 37).

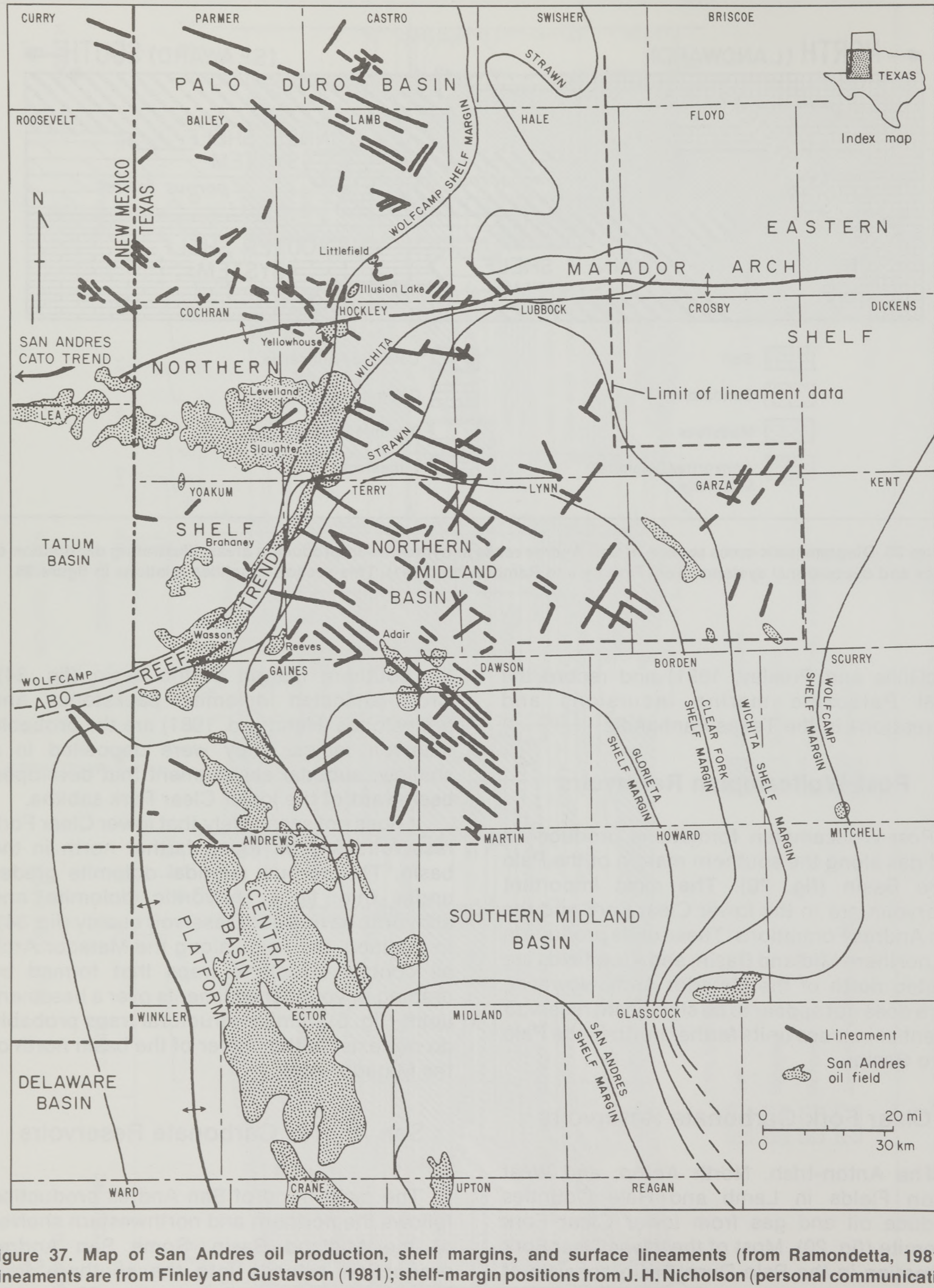


Figure 37. Map of San Andres oil production, shelf margins, and surface lineaments (from Ramondetta, 1981a). Lineaments are from Finley and Gustavson (1981); shelf-margin positions from J. H. Nicholson (personal communication, 1980).

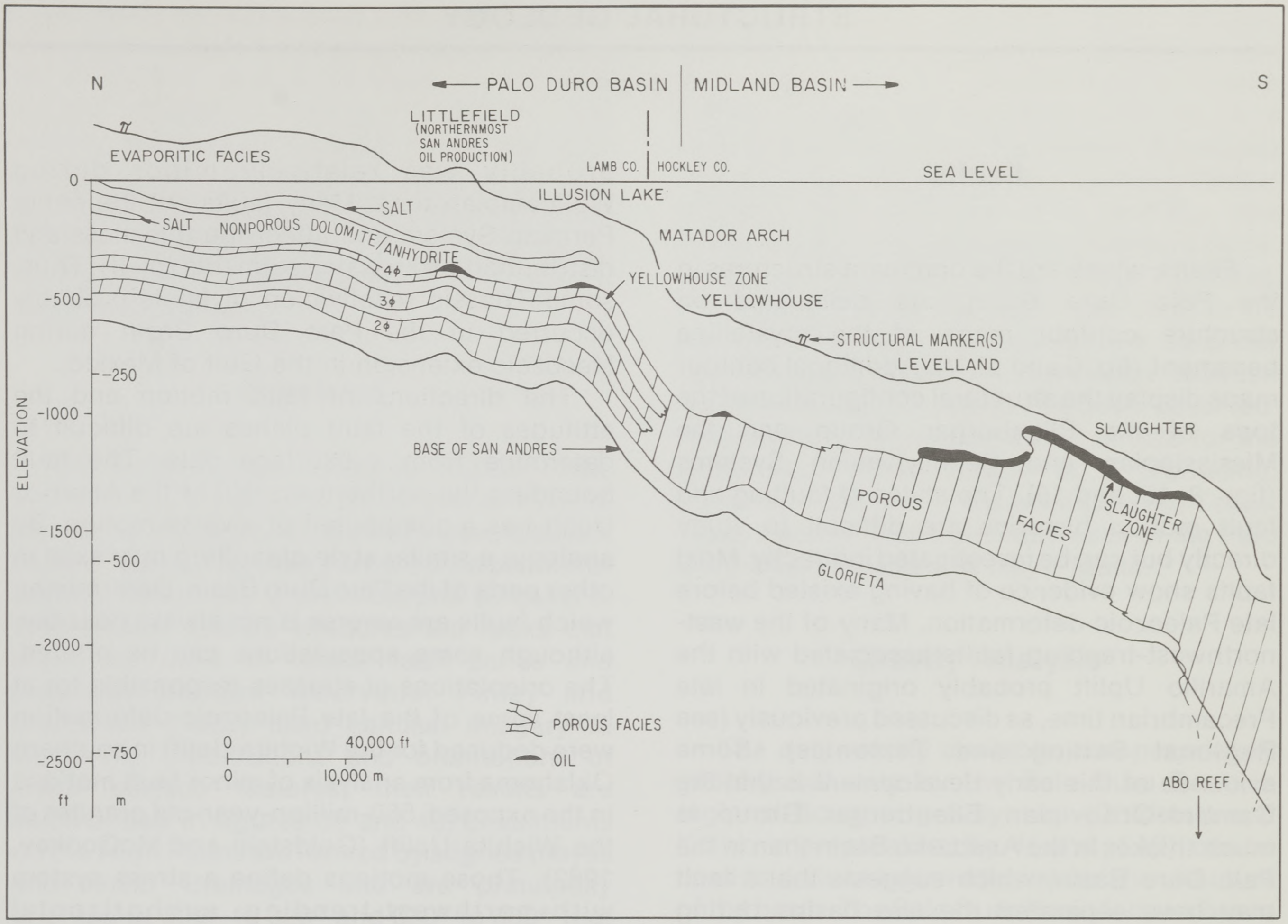


Figure 38. Cross section across Northern Shelf of the Midland Basin, lower San Andres Formation, showing porosity relationships (from Ramondetta, 1981a).

The reservoir facies is a porous dolomite (figs. 35 and 36), most commonly a highly bioturbated biomicrite that was deposited in a subtidal environment (Presley and Ramondetta, 1981).

Oil is trapped in San Andres fields by either structural closure or porosity pinch-out. Porous dolomite is thickest near Wasson Field, Yoakum County (fig. 35), and thins northward in a series of steps (figs. 35, 36, and 38; Ramondetta, in press). This regional, dip-oriented porosity pinch-out is the trapping mechanism in the Levelland-Slaughter-Cato trend. Porosity decreases to the north because of replacement of the carbonates by secondary anhydrite and occlusion of pores by halite (Dunlap, 1967). The decrease in porosity northward occurs in progressively older intervals, reflecting the southerly progradation of evaporite conditions (Ramondetta, 1981a).

Reservoir quality of the San Andres across most of the Palo Duro Basin appears poor. Porous dolomite beds pinch out north of the Matador Arch, where they interfinger with anhydritic dolomite, anhydrite, and salt (pl. IV). Therefore, hydrocarbon potential of the San Andres in most of the Palo Duro Basin is probably low (Ramondetta, 1981a).

Post-San Andres Reservoirs

Reservoir potential of the post-San Andres section is poor. A small amount of gas has been produced from post-San Andres sandstones at about 550 ft (168 m) in Motley County (fig. 20), but it is unlikely that post-San Andres beds in general are reservoirs in the Palo Duro Basin.

A. G. Goldstein

Faults

Faults, which are the dominant structures in the Palo Duro Basin, are delineated on structure contour maps of the crystalline basement (fig. 6 and pl. V). Additional contour maps display the structural configuration of the tops of the Ellenburger Group and the Mississippian and Pennsylvanian Systems (figs. 8, 10, and 15). The styles of faulting and fault motion histories are difficult to study directly but can be investigated indirectly. Most faults show evidence of having existed before late Paleozoic deformation. Many of the west-northwest-trending faults associated with the Amarillo Uplift probably originated in late Precambrian time, as discussed previously (see Regional Setting and Tectonics). Some evidence of this early development is that the Cambro-Ordovician Ellenburger Group is much thicker in the Anadarko Basin than in the Palo Duro Basin, which suggests that a fault may have separated the two basins during deposition. It appears that Ellenburger was thin over the Amarillo Uplift; only small amounts of carbonate debris have been recognized in the lower sections of the flanking granite wash. In addition to possible inheritance of late Precambrian structure, there may be some inheritance from late Ordovician deformation. The Texas Arch was a broad northwest-trending positive feature along which the Ellenburger Group was eroded (fig. 8). The nature of this uplift is unknown, but several faults in Donley, Hall, and Collingsworth Counties parallel the trend of the old arch. An inferred fault in Deaf Smith, Castro, and Swisher Counties (fig. 6) also parallels the trend (fig. 10). Thus, more northwest-trending faults may occur in the central part of the Palo Duro Basin.

The history of late Paleozoic faulting is fairly simple. As indicated by depositional rates for granite wash, fault movement was relatively limited during Morrowan and Atokan time; it was much greater during Desmoinesian, Missourian, and Virgilian times and most probably was relatively minor during Wolfcampian time. Many faults cut the entire Permian System and affect the thickness and distribution of Triassic sediments (pl. II). Thus, some Triassic reactivation of faults probably occurred in the Palo Duro Basin during Mesozoic extension in the Gulf of Mexico.

The directions of fault motion and the attitudes of the fault planes are difficult to determine from subsurface data. The fault bounding the northern margin of the Amarillo Uplift has a component of reverse motion. By analogy, a similar style of faulting may exist in other parts of the Palo Duro Basin. Determining which faults are reverse is not always possible, although some speculations can be offered. The orientations of stresses responsible for at least some of the late Paleozoic deformation were deduced for the Wichita Uplift in southern Oklahoma from analysis of minor fault motions in the exposed, 550-million-year-old granites of the Wichita Uplift (Goldstein and McGookey, 1982). Those motions define a stress system with northwest-trending, subhorizontal maximum principal compression, subvertical intermediate principal compression, and southwest-trending, subhorizontal minimum principal compression.

There is no unequivocal evidence that stress orientations were the same in the Palo Duro Basin as in the Wichita Uplift, but assuming that they were the same, we can deduce something about possible fault motions. The faults in Donley, Hall, and Childress Counties, and those in Deaf Smith, Castro, and Swisher Counties are probably normal faults, as they are roughly perpendicular to the direction of minimum compression. Similarly, the west-northwest-trending faults associated with the Amarillo Uplift must have a right-lateral component of motion. None of the major characteristics of wrench faults, however, have been recognized, so transcurrent motion was probably subordinate to vertical motion. Thus, most of those faults are viewed as high-angle reverse faults having a right-lateral component of motion. (Evidence of high-angle faulting will be discussed under Gravity Analysis.) That some faults are associated with deeply down-dropped blocks is evidence of reverse faulting. Although this cannot be taken as proof of reverse motion, it strongly suggests local loading adjacent to the fault. Structural traps associated with reverse faults (overhangs) may be present, particularly in Oldham, Potter, and Carson Counties. At the time of this writing, no seismic reflection data are available to confirm these speculations.

Fractures

Other structures of potential interest in the search for hydrocarbons are fractures. Much of the land surface above the Palo Duro Basin is covered by the Ogallala Formation, a blanket of Tertiary sands and gravels capped by caliche. This alluvial system obscures the rocks that might be used to locate fault zones and potential fracture reservoirs. Finley and Gustavson (1982) used Landsat imagery to study the distributions and orientations of linear surface features; their results are summarized in figures 39 and 40. Lineaments on the High Plains are formed by aligned playas and linear drainages and are principally oriented at 300° to 320° and 030° to 050° (fig. 39). In some areas, particularly just south of the Canadian River, greater diversity in lineament orientations has been attributed to the dissolution of middle and upper Permian salt by circulating ground water. For the Rolling Plains east of the High Plains, a greater scatter in lineament orientation was noted than for the High Plains. Dominant trends in the Rolling Plains are roughly north-south to 010° to 040°, 320°, and 180° (fig. 39). Finley and Gustavson (1981) have noted reasonable correlation between lineament and joint orientations (fig. 40), and they suggest that the lineaments, even those developed on the calichified Tertiary deposits, are fracture controlled.

To test the possibility of fracture porosity traps, fracture intensity indices (FII) (Pirson, 1977) were calculated for the Wolfcampian dolomite for approximately 250 wells in the Palo Duro Basin using the following relationship:

$$FII = \frac{1/R_d - 1/R_s}{1/R_w - 1/R_{mf}}$$

where R_d = deep resistivity, R_s = shallow resistivity, R_{mf} = resistivity of mud filtrate, and R_w = resistivity of formation water. Pirson (1977) thought the resulting value to be a quantitative measure of the percent of porosity that is fracture controlled. Because of potential errors in the calculation of R_w and R_{mf}, this index is taken only as a semiquantitative value. Rarely did FII values exceed .01, or 1 percent. The highest value recorded was .110, or 11 percent; the values between .03 and .02 occur near mapped faults. No correlation between lineaments and FII values has been observed. Pirson (1977) calculated an FII of .028 for the Cretaceous Austin Chalk in a producing, fractured reservoir in Caldwell County, Texas. Thus, fracture reservoirs may exist in the Palo Duro Basin adjacent to major faults.

Gravity Analysis

The only readily available, non-proprietary geophysical data for the Palo Duro Basin, a regional Bouguer gravity map (Goldstein and Keller, in preparation; fig. 41 and pl. VI), can be used to deduce information about the structure of the basin. The Palo Duro Basin forms a broad gravity low, whereas both the Amarillo Uplift and the Oldham "nose" are marked by gravity highs. Two-dimensional modeling was used to infer the sources of the observed anomalies. Lithologic cross sections (pl. II) were simplified, and density values were assigned to rock types on the basis of density log analysis and published values. For the two models discussed here (A-A′ and B-B′; derived from cross sections D-D′ and B-B′, respectively), the gravity field calculated for the sedimentary rocks does not reproduce the observed gravity field. Major geological unknowns that can justify changing the models are the depths of lithologic provinces. Muehlberger and others (1967) used core samples and cuttings to define the lithology of basement rocks (fig. 42). They found that the Panhandle contains three major basement lithologic provinces: (1) granites and granitic gneisses, notably along the Amarillo Uplift, eastern Palo Duro Basin, and Oldham "nose"; (2) rhyolites containing minor basaltic flows and sediments in the Dalhart Basin and the northern and southern Palo Duro Basin;

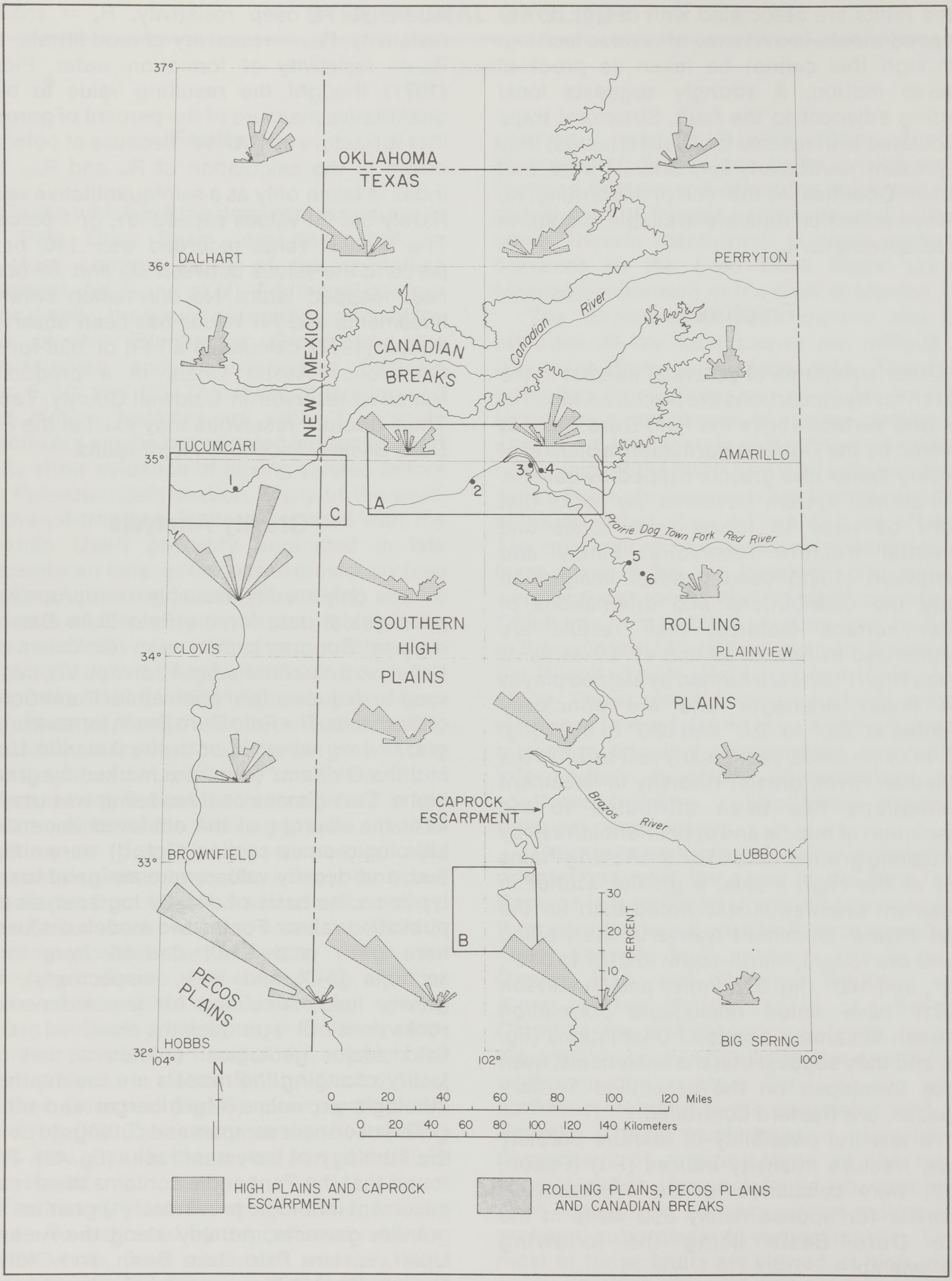


Figure 39. Summary of lineament length by 10° azimuth category within each named 1° x 2° National Map Series sheet. Localities 1 through 6 are sources of joint data for figure 40 (from Finley and Gustavson, 1981).

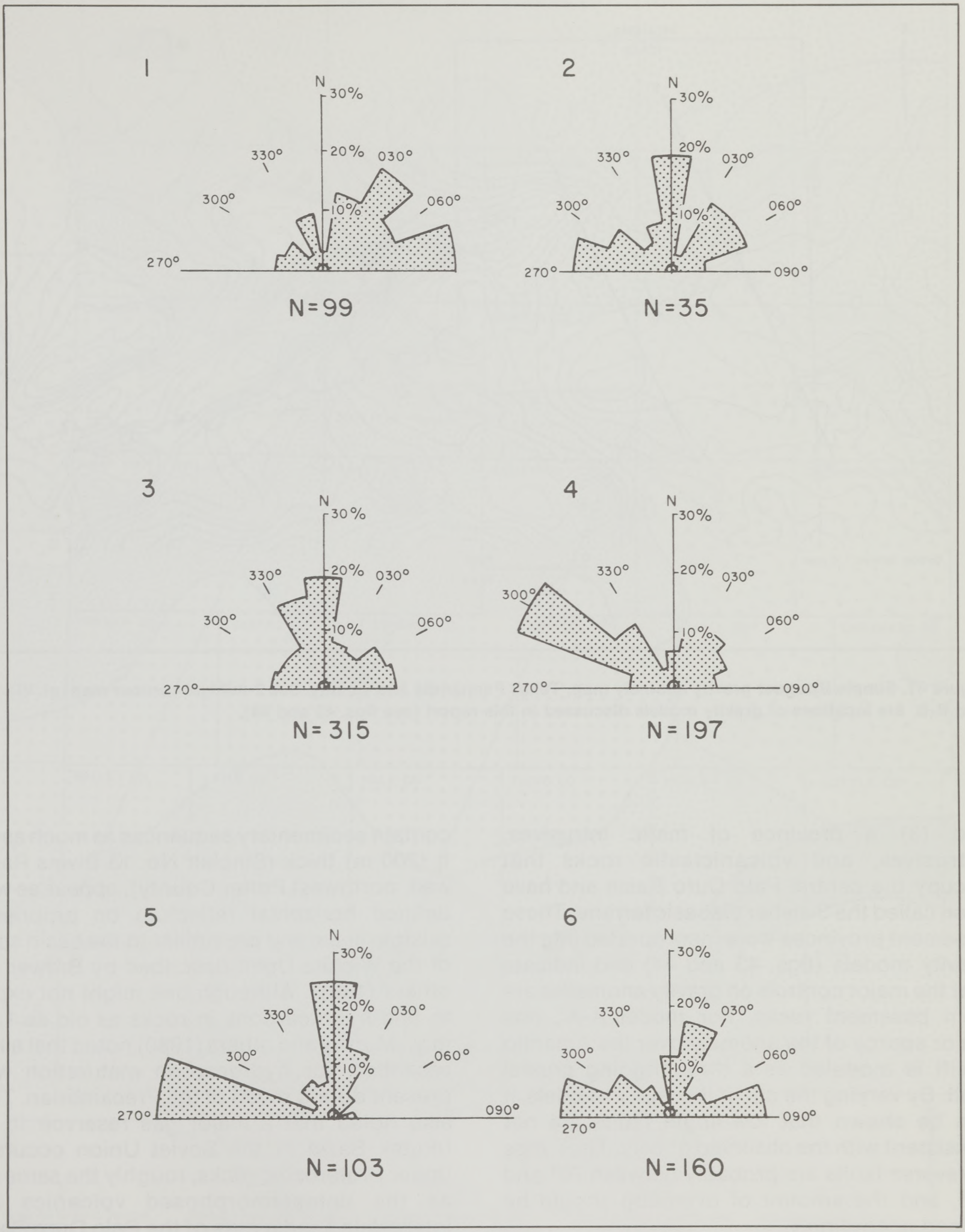


Figure 40. Joint orientations from localities in the Texas Panhandle and eastern New Mexico. Localities 1 and 2 are within the Clovis sheet, and localities 3 through 6 are within the Plainview sheet (see fig. 39) (from Finley and Gustavson, 1981).

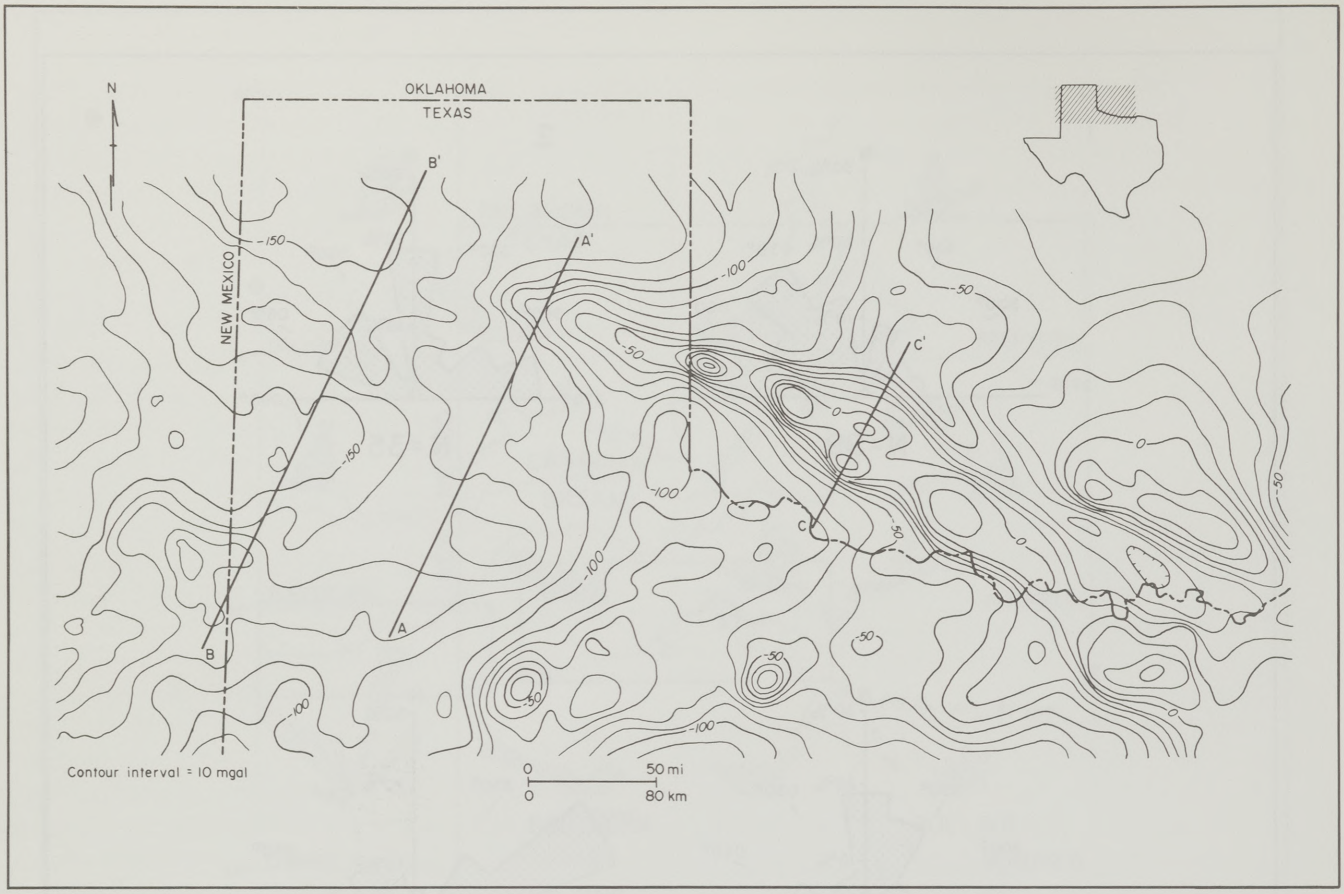


Figure 41. Simple Bouguer gravity anomaly map, Texas Panhandle and vicinity. See 2-milligal contour map (pl. VI). A-A′ and B-B′ are locations of gravity models discussed in this report (see figs. 43 and 44).

and (3) a province of mafic intrusives, extrusives, and volcaniclastic rocks that occupy the central Palo Duro Basin and have been called the Swisher diabasic terrane. These basement provinces were incorporated into the gravity models (figs. 43 and 44) and indicate that the major controls on gravity anomalies are from basement rocks. For model A-A′, one major source of the anomaly over the Amarillo Uplift is modeled as a throughgoing crustal fault. By varying the dip of the fault in models, it can be shown that low-angle faults are not consistent with the observed gravity. Thus, dips of reverse faults are probably between 70° and 85°, and the amount of overhang should be judged accordingly.

Secondly, both models indicate a fairly deep body of rhyolite either on the northern margin of the basin (A-A′) or in the basin center (B-B′). Locally these precursor basins are known to contain sedimentary sequences as much as 600 ft (200 m) thick (Sinclair No. 13 Bivins Ranch well, northwest Potter County), appear as well-defined horizontal reflectors on proprietary seismic lines, and are similar to the basin south of the Wichita Uplift described by Brewer and others (1981). Although one might not expect to find hydrocarbons in rocks as old as 1,300 m.y., Murray and others (1980) noted that all the essentials for hydrocarbon maturation were present during much of the Precambrian. They also noted that a major gas reservoir in the Irkutsk Basin in the Soviet Union occurs in upper Proterozoic rocks, roughly the same age as the unmetamorphosed volcanics and intercalated sediments of the Palo Duro Basin. Because the Precambrian rocks of the Palo Duro Basin have not been metamorphosed, there is no reason to exclude them from a comprehensive exploration program.

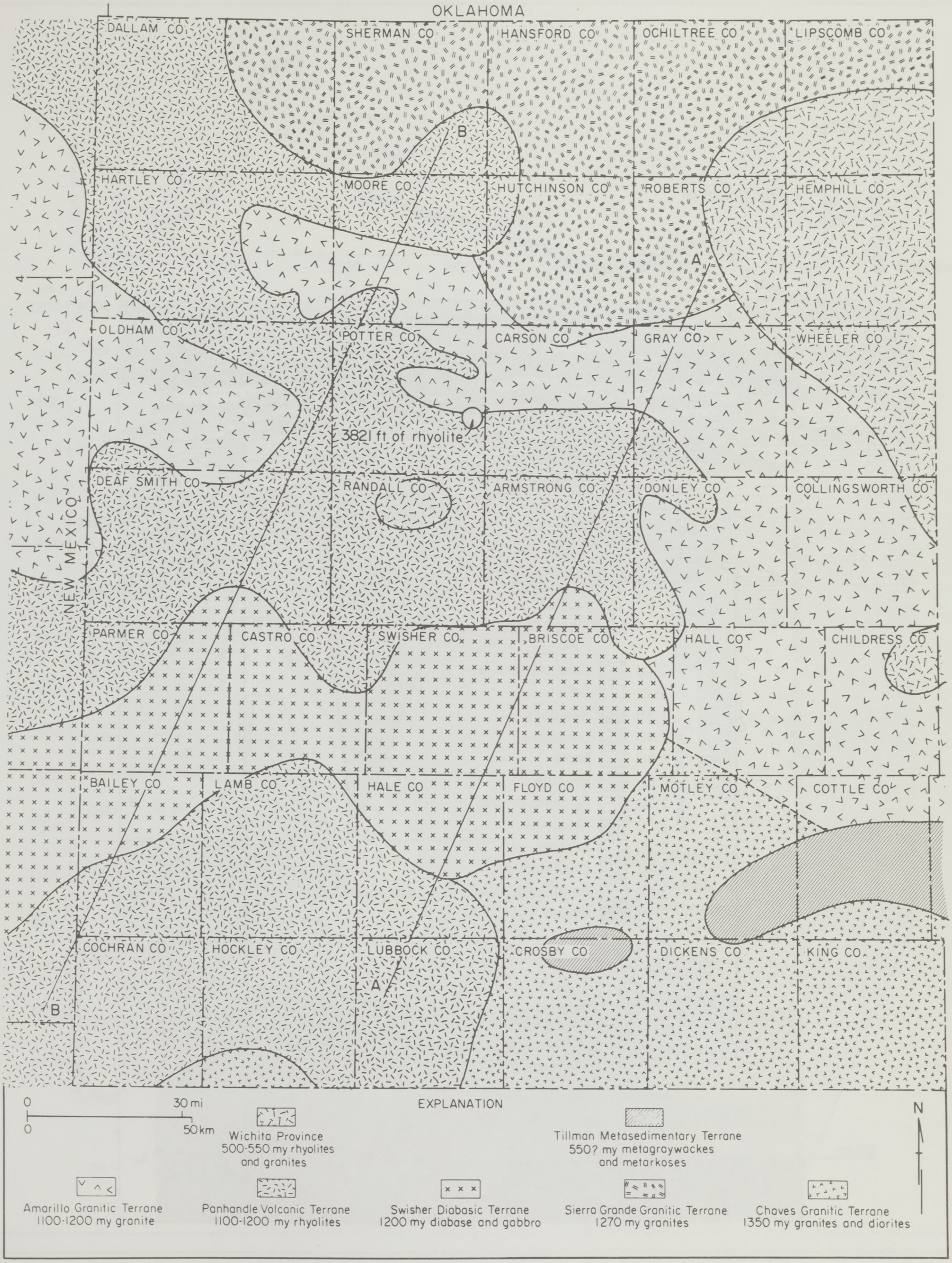


Figure 42. Basement lithologic provinces in the Texas Panhandle (from Muehlberger and others, 1967). A-A′ and B-B′ are locations of gravity models discussed in this report (see figs. 43 and 44).

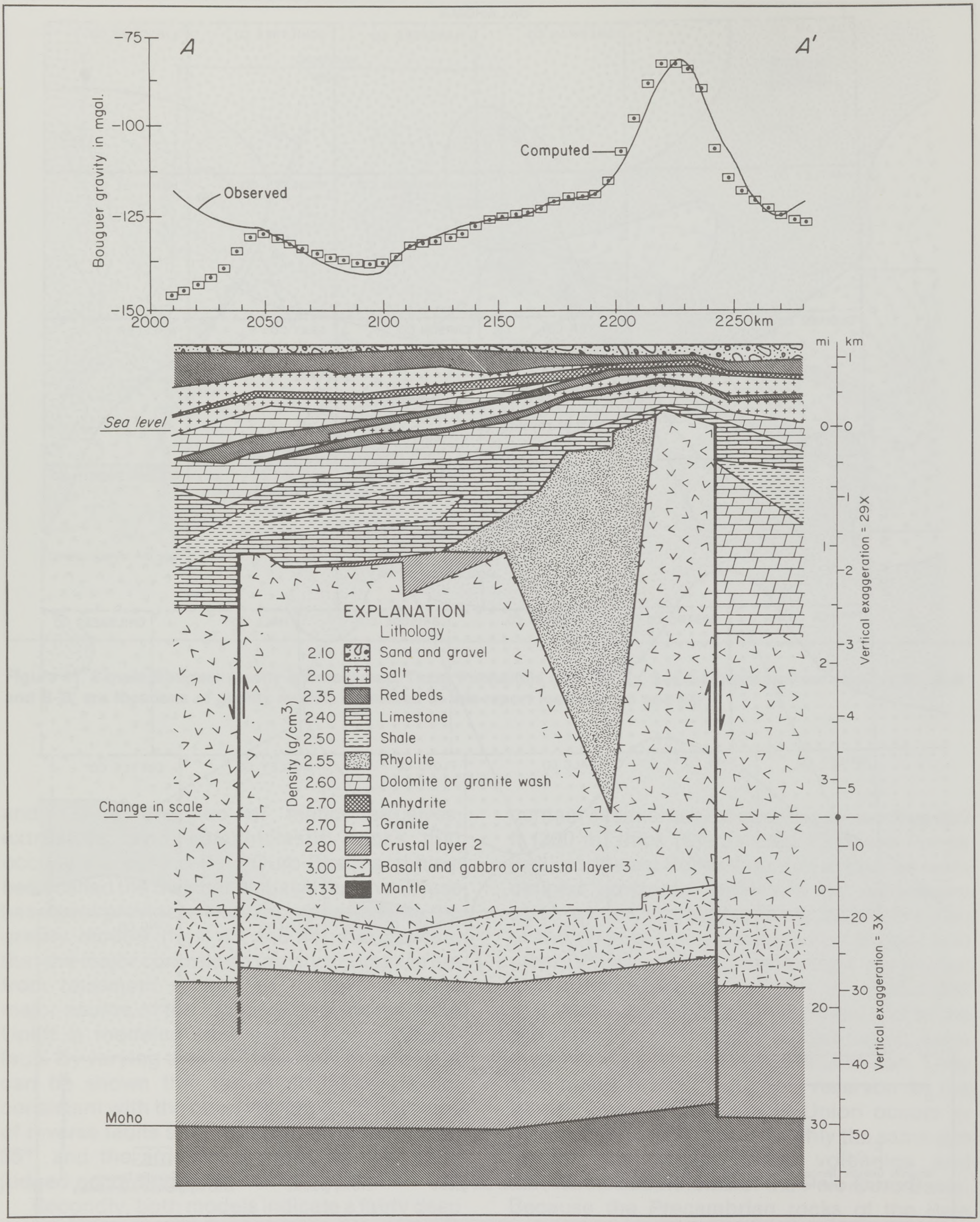


Figure 43. Gravity model A-A′. Cover-rock geometry is simplified from cross section D-D′; crustal layering and depth to Moho are taken from Stewart and Pakiser (1962), and the basement lithology is taken from Muehlberger and others (1967). See figure 42 for location.

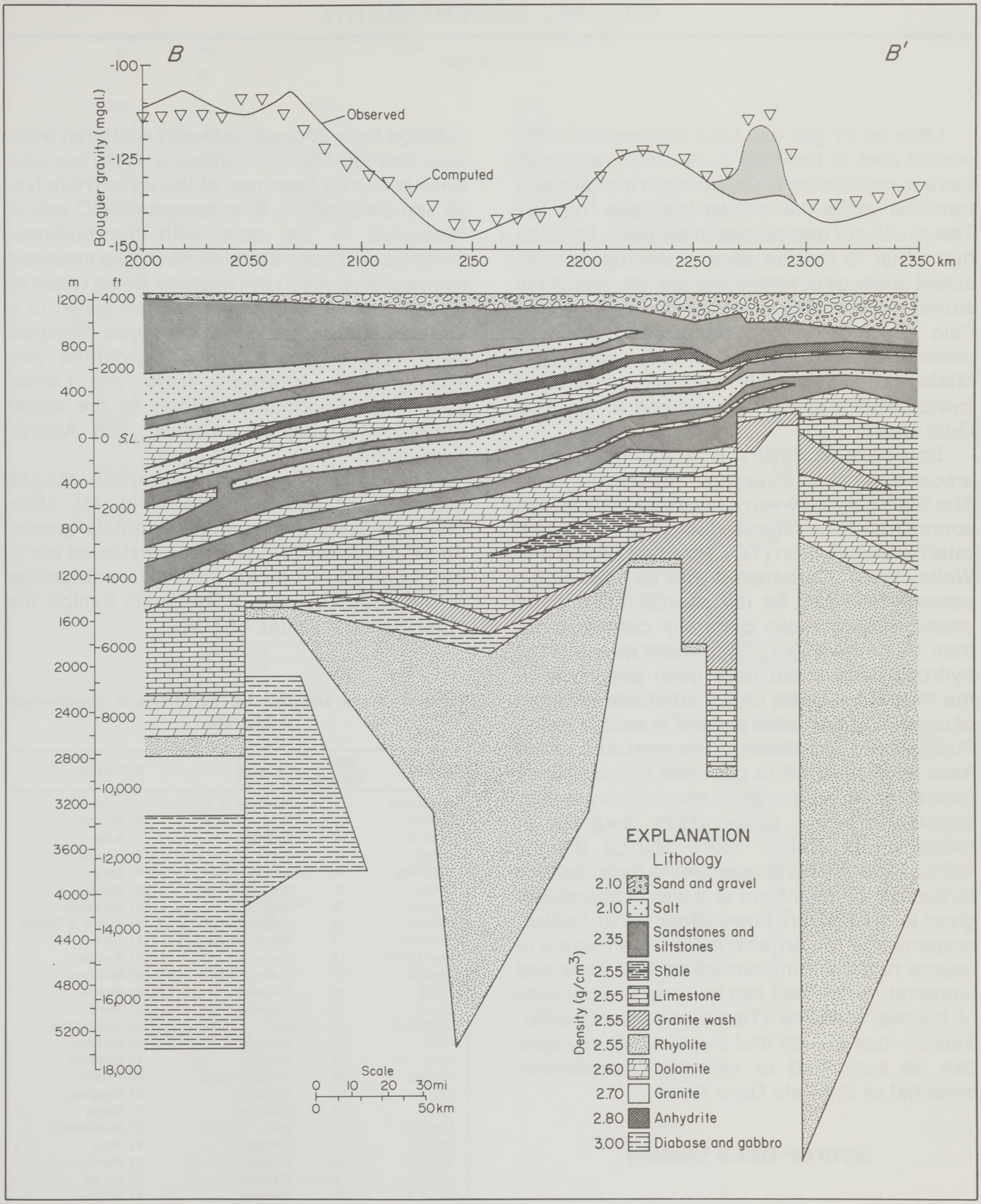


Figure 44. Gravity model B-B′, modified from cross section B-B′. Shaded area on computed curve is a positive anomaly predicted from the model, which does not appear in the observed gravity. This requires that granites in this region be thin sills intruded into a deep rhyolite basin. See figure 42 for location.

ORGANIC GEOCHEMISTRY

S. P. Dutton

Little oil or gas has been discovered in the central part of the Palo Duro Basin, although there is production from the basin margins and from the uplifts that border the basin (fig. 20). The paucity of discoveries in the basin could be due either to the low level of drilling or to an actual absence of hydrocarbons. Studies of the source-rock quality and thermal history of the Palo Duro Basin and comparison of these parameters with those of the productive Midland Basin provide evidence of whether hydrocarbons could have formed in the Palo Duro Basin.

Source-rock quality is a function of the amount and type of organic matter in a rock. The boundary between a fair and a poor clastic source rock is commonly defined at 0.5 percent total organic carbon (TOC) content (Tissot and Welte, 1978). Carbonates with as little as 0.3 percent TOC can be fair source rocks; good clastic source rocks generally contain more than 1.0 percent TOC. Significant quantities of hydrocarbons could have been generated in the Palo Duro Basin only if adequate amounts of organic matter were present in source rocks. Furthermore, sufficient temperatures must have been reached to generate hydrocarbons from disseminated organic material. In general, significant oil generation begins at temperatures around 150°F (60°C) (Pusey, 1973). Time is also an element in hydrocarbon formation; oil may form at lower temperatures given long exposure times (Dow, 1978). Optical properties of the organic material remaining in source rocks are influenced by both time and temperature, so they can be used as indicators of thermal maturity (Tissot and Welte, 1978). Source-rock quality and thermal maturity data can be combined to evaluate hydrocarbon potential of the Palo Duro Basin.

Source-Rock Quality

To determine whether sediments in the Palo Duro Basin contained sufficient organic matter to generate hydrocarbons, 341 samples of cuttings from 20 geographically scattered wells were analyzed for TOC (table 4). Core samples were analyzed from two of the wells (Hale No. 10 and Swisher No. 6) to compare TOC values measured in the core with the cuttings. Cuttings and core samples were also analyzed from seven wells in the Midland Basin (table 4) to compare TOC in the Palo Duro Basin to a known hydrocarbon-producing area. Samples were taken from a range of depths and stratigraphic intervals from the Lower Ordovician Ellenburger Group to the upper Permian (Guadalupian Series) San Andres Formation.

Total organic carbon content ranges between 0.01 and 6.9 percent (fig. 45). More than one third of the samples contain greater than 0.5 percent TOC and are considered fair to very good source rocks. San Andres dolomites in the southern part of the basin exhibit the highest single values of TOC.

Table 4. Wells sampled for geochemical source-rock analyses.

County	BEG number	Operator	Well name
Armstrong	1	Standard of Texas	#1A Palm
Bailey	20	Shell	#1 Nichols
Briscoe	13	Weaver	#1 Adair
Castro	11	Sun	#1 Herring
Childress	48	Griggs	#1 Smith
Cottle	41	Baria & Werner	#1 Mayes
Crosby	9	Gulf	#1 Niendorff
Dallam	22	Harrington	#1 Brown & Tovrea
Dawson	7	Pan American	#1 Jones
Deaf Smith	12	Honolulu	#1 Ponder
Donley	20	Doswell	#1 McMurty
Floyd	10	Sinclair	#1 Massie
Garza	1	Fairway	#1 Rains
Glasscock	—	Sun	#1 Hutchinson
Hale	10	Amerada	#1 Kurfees
Hall	1	Amarillo	#1 Cochran
Hartley	25	Phillips	#1A Cattle
Lamb	26	Stanolind	#1 Hopping
Lynn	7	Lone Star	#1 Bragg
Midland	—	Sun	#7 Hutchinson
Motley	1	Central	#1 Ross
Oldham	52	Stanolind	#1 Herring
Parmer	4	Stanolind	#1 Jarrell
Randall	18	Slessman	#1 Nance
Reagan	—	Sun	#1 Jolonick
Swisher	6	Standard	#1 Johnson
Swisher	13	Sinclair	#1 Savage

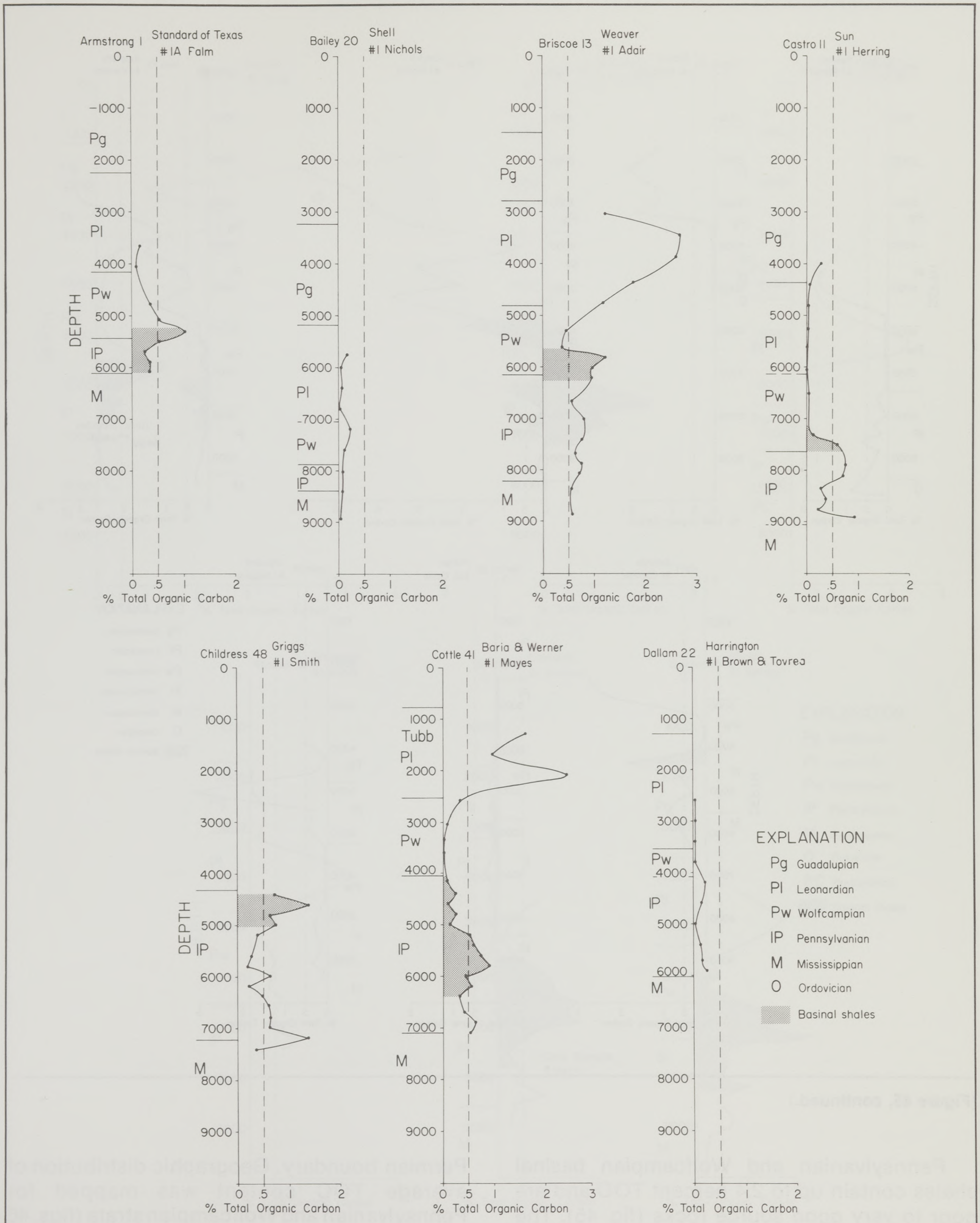
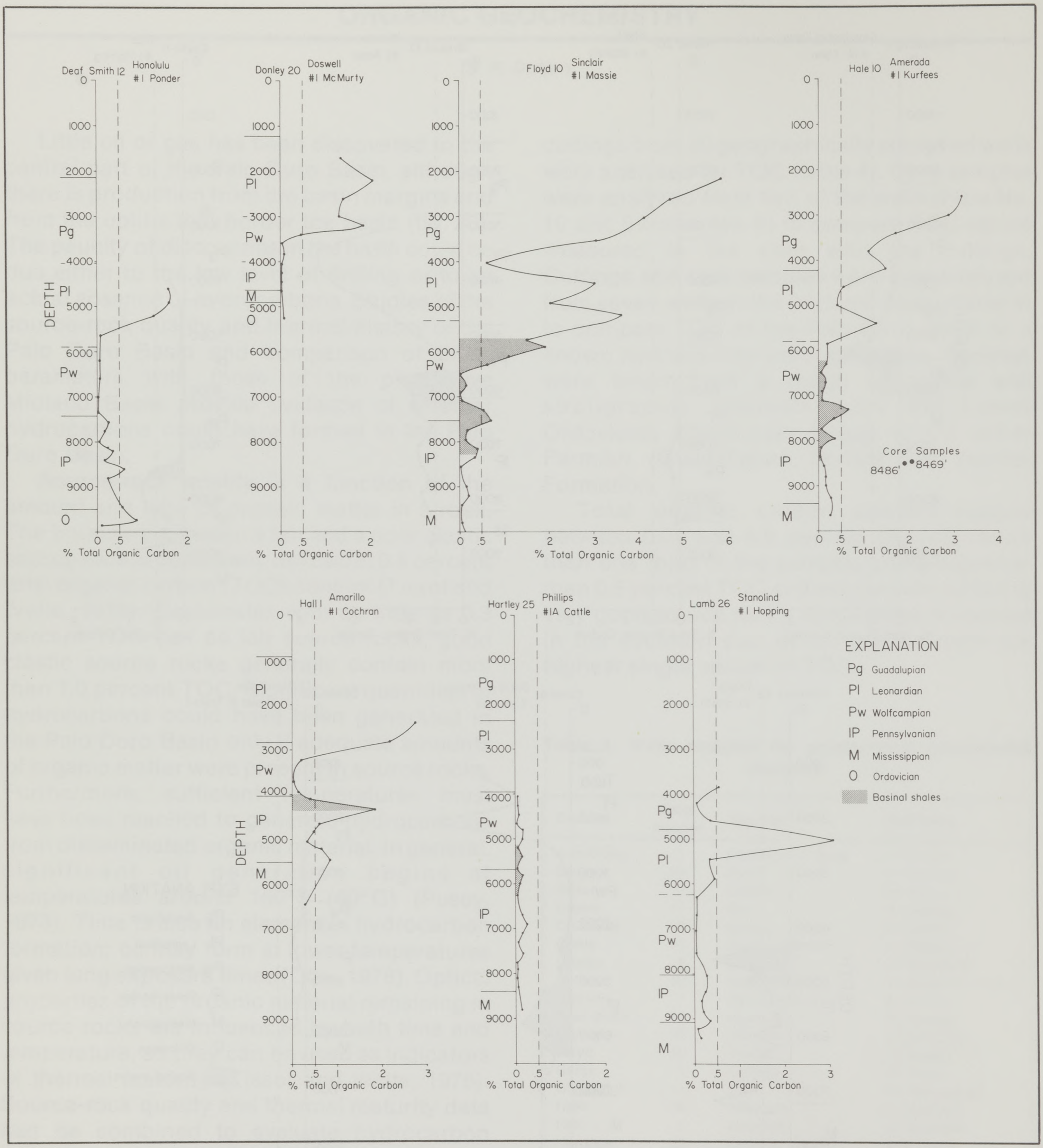
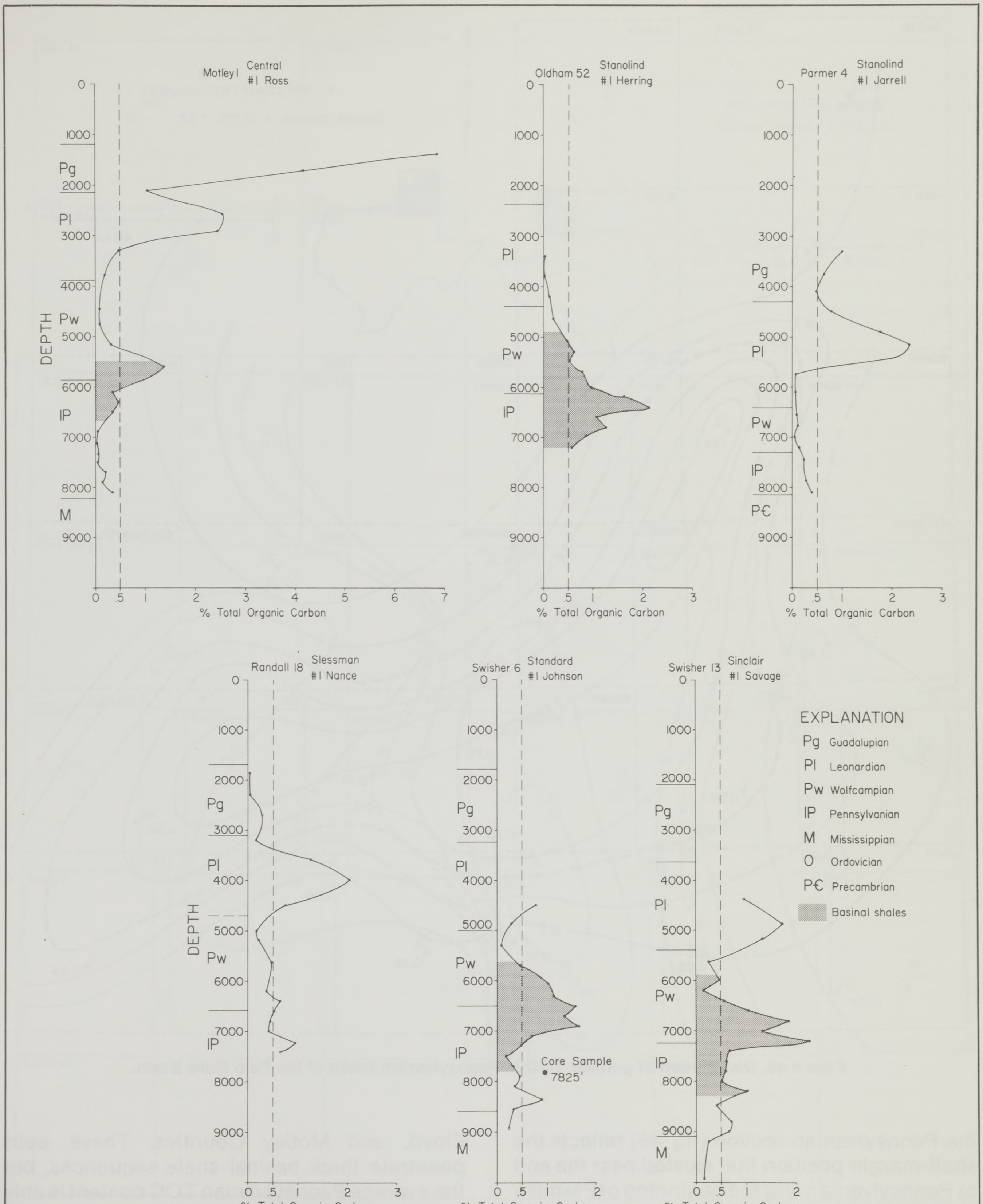


Figure 45. Plot of TOC versus depth below land surface for 20 wells in the Palo Duro and Dalhart Basins (continued on pages 62 and 63).



(**Figure 45, continued.**)

Pennsylvanian and Wolfcampian basinal shales contain up to 2.4 percent TOC and are poor to very good source rocks (fig. 45). The highest values of Pennsylvanian and Wolfcampian TOC occur in basinal shales stratigraphically near the Pennsylvanian-Permian boundary. Geographic distribution of average TOC content was mapped for Pennsylvanian and Wolfcampian strata (figs. 46 and 47). The 0.5-percent-TOC contour line delineates areas containing fair to good potential source rocks. Distribution of TOC in



(Figure 45, continued.)

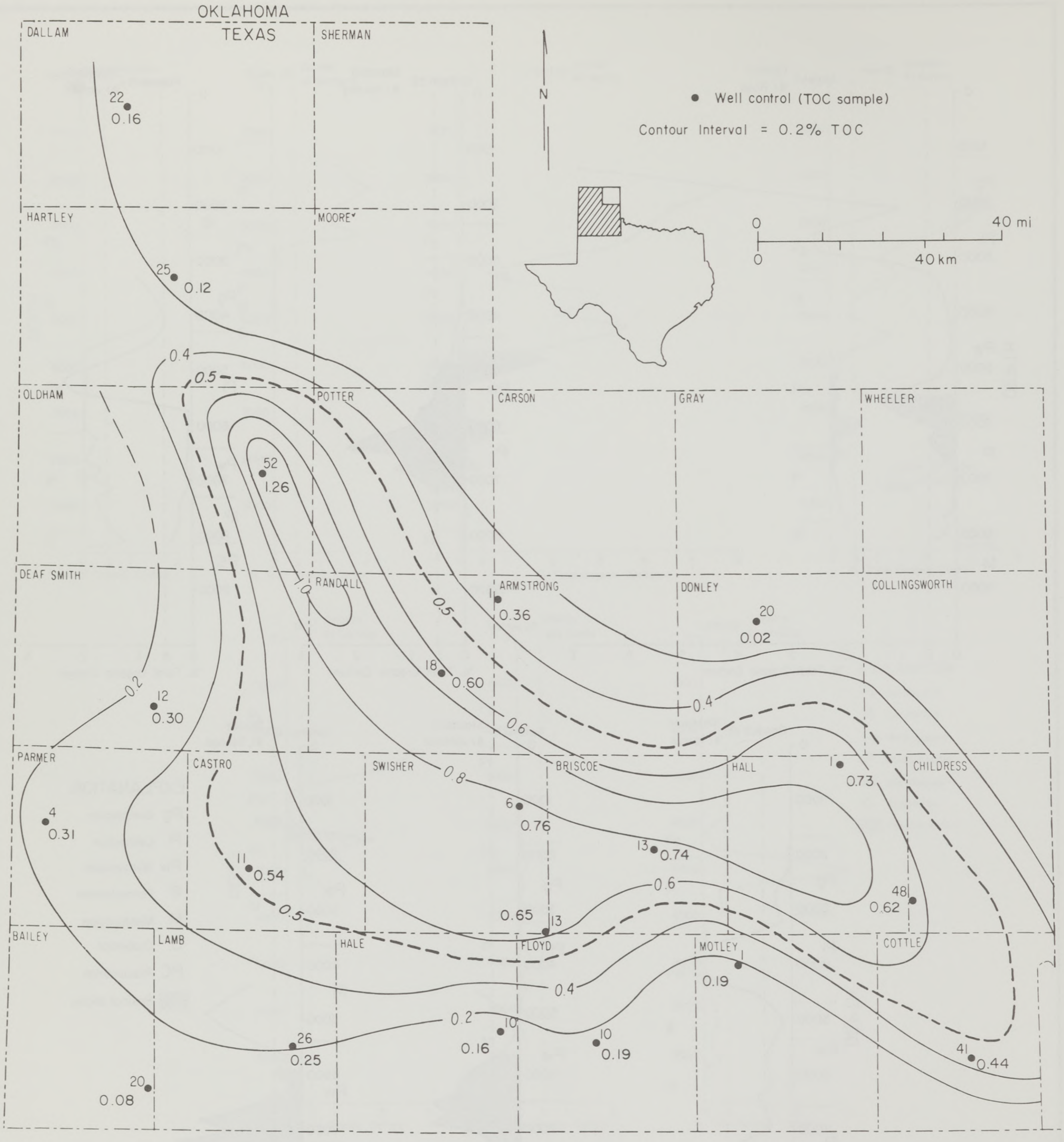


Figure 46. Distribution of percent TOC in Pennsylvanian rocks of the Palo Duro Basin.

the Pennsylvanian section (fig. 46) reflects the shelf-margin position that existed near the end of Pennsylvanian and the beginning of Permian (Wolfcampian) time (fig. 28); in general, basin-center facies have the highest TOC content. However, TOC content of Pennsylvanian shale is lower than expected in cuttings from Hale, Floyd, and Motley Counties. These wells penetrate thick basinal shale sequences, but the average Pennsylvanian TOC content is only 0.18 percent, substantially lower than the average TOC content in the northern arm of the basin. The southern part of the basin may have had a relatively high rate of clastic

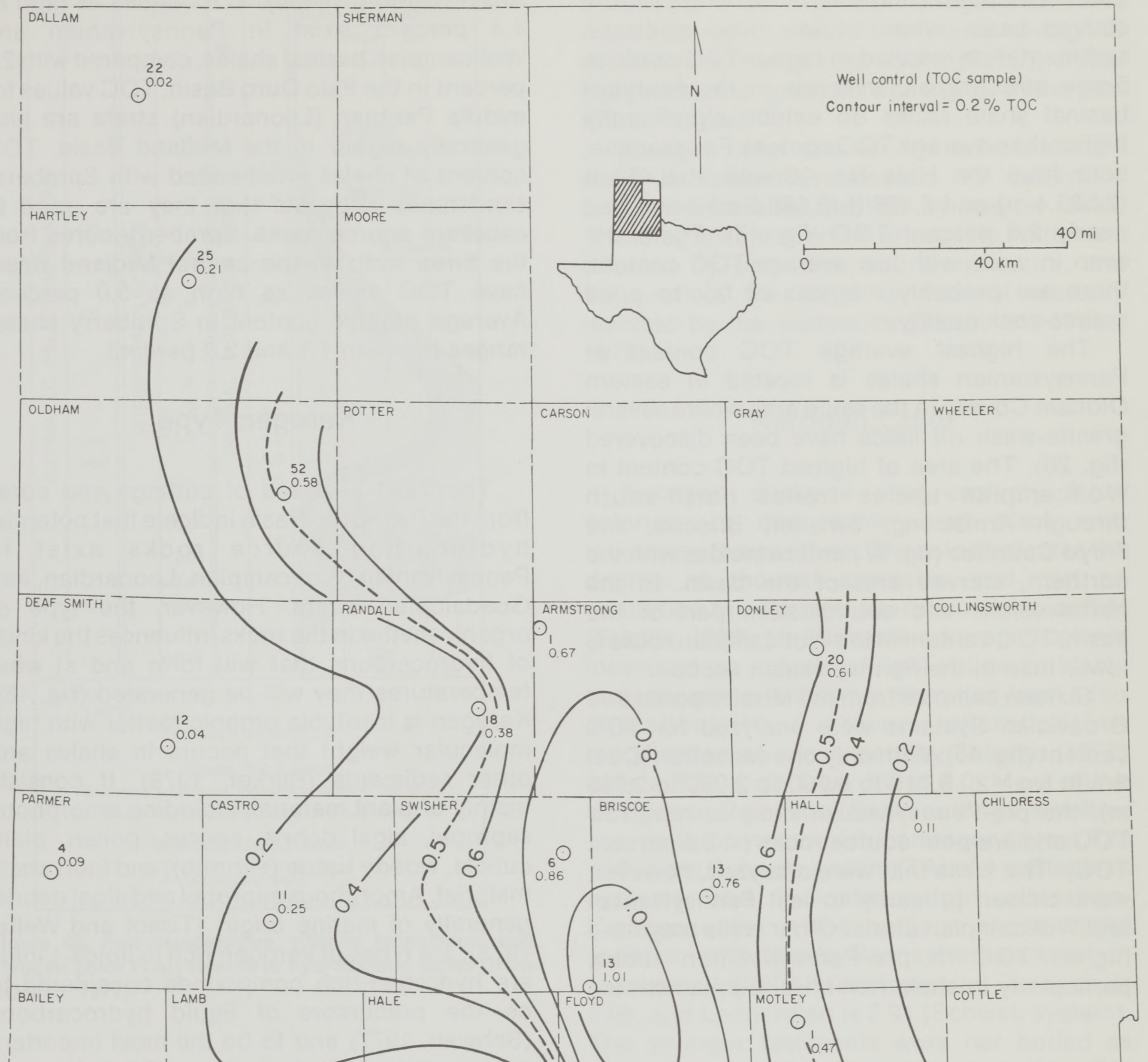


Figure 47. Distribution of percent TOC in Wolfcampian rocks of the Palo Duro Basin.

sedimentation that diluted the organic content. The northern arm may have constituted a more starved basin, where slower rates of clastic sedimentation resulted in higher TOC content. Some stratigraphic intervals in the southern basinal shale facies do exhibit significantly higher than average TOC content. For example, core from the Hale No. 10 well at 8,469 ft (2,583.4 m) and 8,486 ft (2,586.5 m) contained nearly 2.0 percent TOC (fig. 45). Therefore, even in wells with low average TOC content, there are probably intervals of fair to good source-rock quality.

The highest average TOC content in Pennsylvanian shales is located in eastern Oldham County in the same area where several granite-wash oil fields have been discovered (fig. 20). The area of highest TOC content in Wolfcampian shales trends north-south through Armstrong, Swisher, Briscoe, and Floyd Counties (fig. 47) and coincides with the northern, starved arm of the basin. In the northwestern and southeastern part of the basin, TOC content in the Wolfcampian rocks is lower than in the Pennsylvanian section.

Sixteen samples from the Mississippian and Ordovician Systems were analyzed for TOC content (fig. 45). With only one exception (Deaf Smith No. 12, 9,710 to 9,790 ft; 2,960 to 2,985 m), the pre-Pennsylvanian samples have low TOC and are poor source rocks ($<$ 0.5 percent TOC). The wells that were analyzed, however, were chosen primarily to test Pennsylvanian and Wolfcampian strata. Other wells may have higher TOC in pre-Pennsylvanian rocks, particularly in shale-rich Mississippian strata.

Midland Basin Samples

Total organic carbon was analyzed in seven wells from the northern and central Midland Basin. Cuttings from four northern Midland Basin wells (Crosby, Dawson, Garza, and Lynn Counties; table 4) were sampled from Permian, Pennsylvanian, Mississippian, and Ordovician strata. The three central Midland Basin wells (Glasscock, Midland, and Reagan Counties; table 4) were sampled from core within the oil-producing Spraberry Formation of Leonardian age. TOC content in the Midland Basin, a hydrocarbon-producing area, is generally greater than TOC content in the Palo Duro Basin (Dutton, 1980b). TOC values as high as 4.4 percent exist in Pennsylvanian and Wolfcampian basinal shales, compared with 2.4 percent in the Palo Duro Basin. TOC values for middle Permian (Leonardian) strata are also generally higher in the Midland Basin. TOC content of shales interbedded with Spraberry sandstones suggests that they are good to excellent source rocks. Spraberry cores from the three wells in the central Midland Basin have TOC values as high as 5.0 percent. Average organic content in Spraberry shales ranges between 1.1 and 2.8 percent.

Kerogen Type

The TOC analyses of cuttings and cores from the Palo Duro Basin indicate that potential hydrocarbon source rocks exist in Pennsylvanian, Wolfcampian, Leonardian, and Guadalupian strata. However, the type of organic matter in the rocks influences the kinds of hydrocarbons that will form and at what temperatures they will be generated (fig. 48). Kerogen is insoluble organic matter with high molecular weight that occurs in shales and other sediments (Barker, 1979). It consists mainly of plant material, including amorphous sapropel, algal debris, spores, pollen, plant cuticle, woody tissue (vitrinite), and inert coaly material. Amorphous sapropel and algal debris, generally of marine origin (Tissot and Welte, 1978), are types of kerogen rich in lipids. Lipids are hydrogen-rich compounds considered to be the precursors of liquid hydrocarbons (Schwab, 1977) and to be the most important source of liquid hydrocarbons. Other forms of kerogen have lower lipid content and originate mainly from terrestrial plants. Humic material forms dry gas at higher temperatures than are required to form oil from lipid-rich kerogen (Dow, 1978). For potential source beds to generate hydrocarbons, sufficient temperatures must be reached to mature the type of kerogen present.

Thermal Maturity

As organic matter is heated during burial, hydrocarbons are generated from kerogen

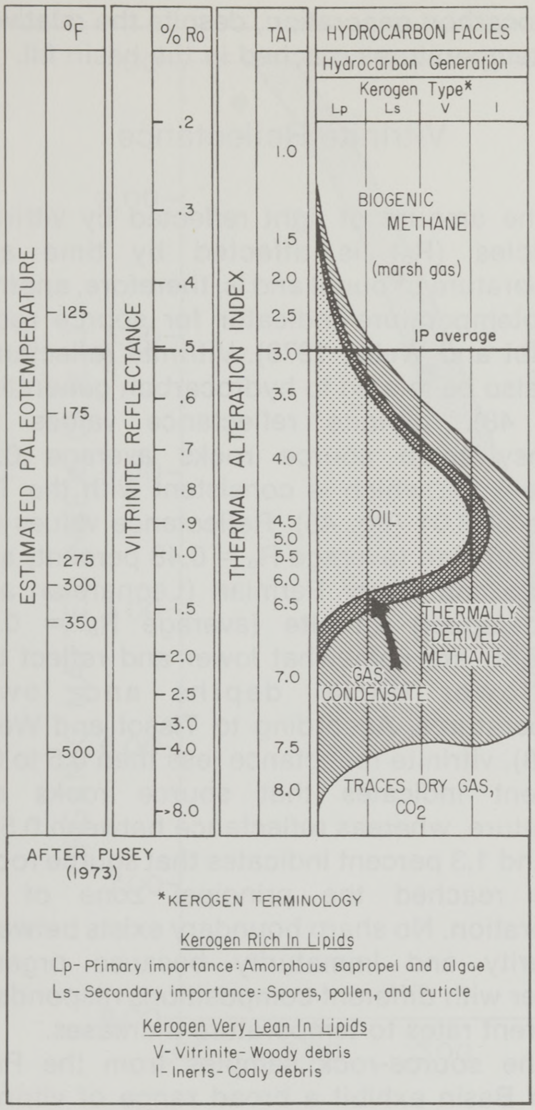


Figure 48. Paleotemperature, vitrinite reflectance, and kerogen color (TAI) related to hydrocarbon facies (from Schwab, 1977).

disseminated in the sediment (Dow, 1978). Temperatures of at least 150°F (65°C) are generally necessary to initiate significant oil generation (Pusey, 1973). The geothermal gradient in the Palo Duro Basin is 1.1°F per 100 ft (2.0°C per 100 m) (Dutton, 1980a), so temperatures of 150°F (65°C) are reached at about 7,200 ft (2,200 m). Present burial depths of Pennsylvanian strata are 5,000 to 9,000 ft (1,500 to 2,800 m); these rocks were probably buried even deeper in the past, before erosion of Triassic and upper Permian strata. Pennsylvanian sediments, therefore, should have reached temperatures near that required for oil generation. Lower Wolfcampian deposits also probably reached the temperature levels necessary to generate oil. Younger sediments most likely were never buried deep enough to reach temperatures near 150°F (65°C), unless the geothermal gradient was higher in the past than it is now.

Kerogen color and vitrinite reflectance are used as paleothermometers to determine paleotemperatures reached by source rocks. These optical properties of organic matter are affected by both time and temperature, and they reflect the stage of thermal maturity reached by the sediments (Tissot and Welte, 1978).

Kerogen Color

Kerogen darkens progressively from colorless to dark brown and black with increasing temperature. The color indicates the degree of thermal alteration and can be quantified as a thermal alteration index, or TAI (Staplin, 1969). By this system, kerogen color is measured on a scale of light yellow to black, corresponding to thermal alteration from 1 (no alteration) to 5 (severe alteration). A modification of this system by Schwab (1977) uses a TAI scale from 1.0 to 8.0. Most of the kerogen in Palo Duro Basin cuttings is yellow orange to orange, which corresponds to a TAI of 3 in the Schwab system (TAI of 2 in Staplin's system) and indicates slight alteration. Kerogen color in the cuttings shows slight variation with depth. Pennsylvanian kerogen averages 3.01 TAI; Wolfcampian kerogen is 2.95, and Leonardian is 2.91 (Schwab system). The younger sediments were not buried as deeply as were the older ones, and their TAI values reflect the lower burial temperatures. Average TAI values of Leonardian and Guadalupian kerogen are considerably lower in samples from the DOE/Gruy Federal core in northeastern Randall County (Randall No. 25) than in the cuttings. The TAI values in core samples average 2.49 (Schwab system), which corresponds to kerogen color of pale yellow to yellow. The higher TAI values in cuttings may be caused by oxidation of some of the kerogen during the grinding process that produces the cuttings. Kerogen color in cores is probably a more accurate measure of the true thermal maturity of the kerogen.

Table 5. Organic Matter Index values of different kerogen types (after Schwab, 1977).

	OMI number	Kerogen type
Lipid-rich	1	Algae: Lp
	2	Amorphous debris: Lp
	4	Spores - pollen: Ls
	4	Cuticle - membranous debris: Ls
	6	Vitrinite: V
Lipid-poor	8	Coal debris: I

Kerogen color (TAI) can be related to paleotemperature and zones of hydrocarbon generation (fig. 48). A TAI value of 3.0 corresponds to a temperature of about 145°F (62°C), which is slightly lower than the temperature of 150°F (65°C) given by Pusey (1973) as the temperature at which oil generation begins. However, only organic matter rich in lipids will begin to generate oil at 145°F (fig. 48); other types of kerogen require higher temperatures to form oil. Kerogen type can be quantified as an organic matter index (OMI) by assigning numerical values from 1 to 8 (table 5) to different forms of kerogen (Schwab, 1977). Lipid-rich organic matter has low OMI values, and values increase in more humic-rich kerogen.

If the relation between kerogen type and source-rock maturity is plotted using values of kerogen color (TAI) and kerogen type (OMI), Pennsylvanian source rocks fall in the transition or immature zones (fig. 49). Similarly, Wolfcampian source rocks are also generally in the transition zone between maturity and immaturity (fig. 49). This indicates that source rocks in the Palo Duro Basin probably did not reach the principal zone of oil generation. However, in those areas where lipid-rich kerogen was most abundant, a greater possibility exists that oil was generated. Figure 50 shows that the distribution of kerogen type in Pennsylvanian source rocks generally follows the outline of the Pennsylvanian basin, lipid-rich kerogen being more common in the deep-basin shale facies. Organic-matter-index values for Wolfcampian rocks are somewhat lower and thus indicate the abundance of lipid-rich kerogen in Wolfcampian basinal shales (fig. 51). Areas where lipid-rich kerogen is most abundant and where TOC values are sufficiently high are the most likely places for hydrocarbon generation, despite the relatively low temperatures reached in the basin fill.

Vitrinite Reflectance

The amount of light reflected by vitrinite particles (R_o) is affected by time and temperature of burial and is, therefore, another paleotemperature indicator for source rocks (Tissot and Welte, 1978). Vitrinite reflectance can also be related to hydrocarbon generation (fig. 48). Vitrinite reflectance values for Pennsylvanian source rocks average 0.52 percent R_o, which is consistent with the TAI value of 3.01 (fig. 48). Reflectance values for Wolfcampian (average $R_o = 0.48$ percent) and middle and upper Permian (Leonardian and Guadalupian) vitrinite (average $R_o = 0.49$ percent) are somewhat lower and reflect the shallower burial depths and lower temperatures. According to Tissot and Welte (1978), vitrinite reflectance less than 0.5 to 0.7 percent indicates that source rocks are immature, whereas reflectance between 0.5 to 0.7 and 1.3 percent indicates that source rocks have reached the principal zone of oil generation. No sharp boundary exists between maturity and immaturity because organic matter with different compositions responds at different rates to temperature increases.

The source-rock samples from the Palo Duro Basin exhibit a broad range of vitrinite reflectance values. Vitrinite populations with the lowest reflectance probably indicate the temperatures that were reached in the basin. Vitrinite with higher reflectance may have been reworked from older sediments (Tissot and Welte, 1978). Alternatively, some of the organic matter may have been oxidized during or shortly after deposition, which might affect vitrinite reflectance and give values of R_o that are too high (K. W. Schwab, personal communication, 1979). This seems the more probable explanation of vitrinite with high R_o in Pennsylvanian and Wolfcampian deposits in the Palo Duro Basin. The main source area was crystalline basement rocks, not older sediments, so recycled vitrinite probably is absent. R_o values vary less in core samples than they do in cutting samples, a suggestion that some high R_o values may be the result of the grinding process that produces the cuttings

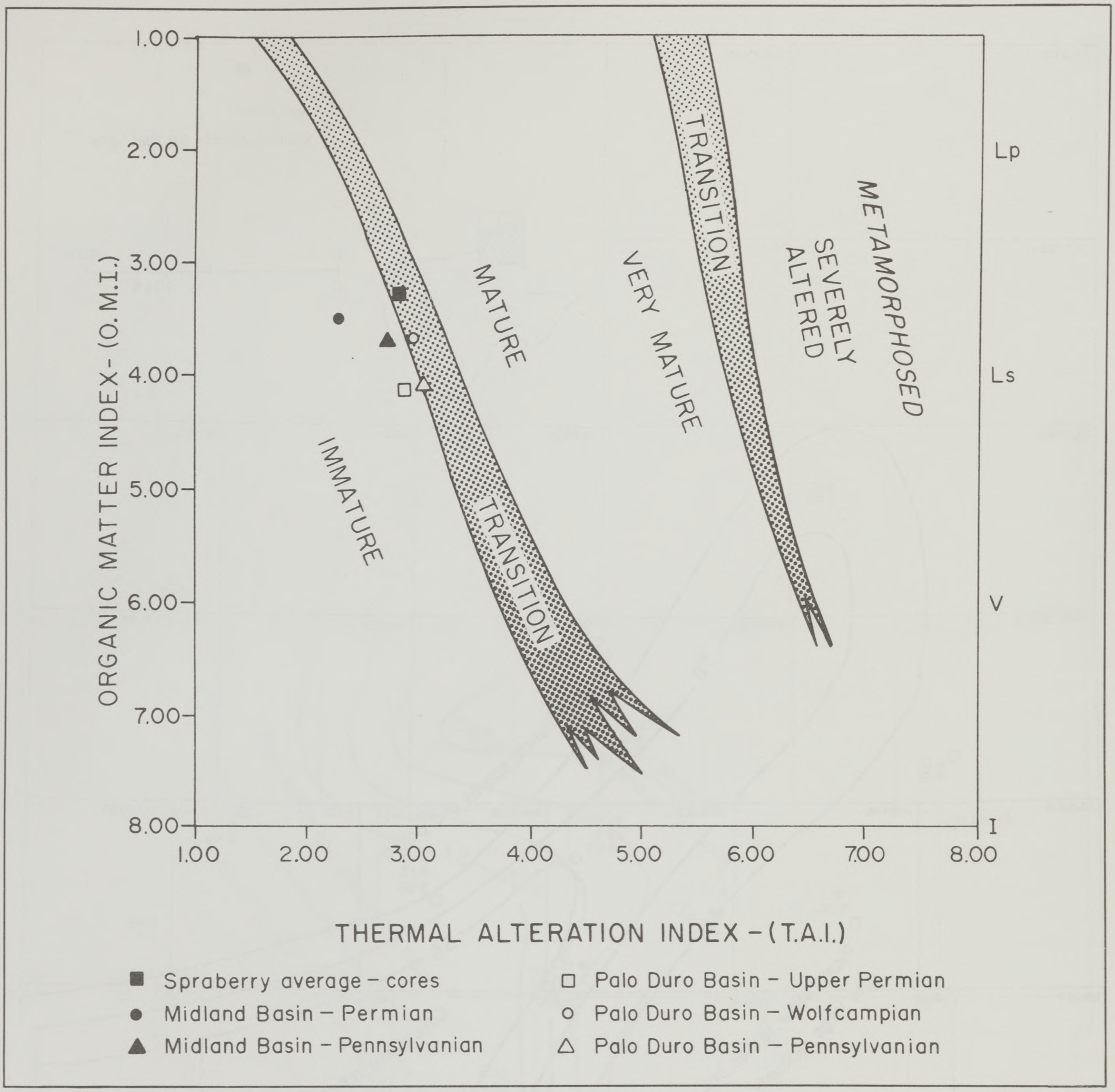


Figure 49. Thermal maturity of Midland and Palo Duro Basin samples based on kerogen color (TAI) and kerogen type (OMI).

(P. J. Ramondetta, personal communication, 1980).

Midland Basin Samples

Kerogen color and vitrinite reflectance were measured in samples from the Midland Basin to compare their thermal maturity with that of potential source rocks in the Palo Duro Basin. Vitrinite reflectance averages 0.63 percent in Pennsylvanian samples and 0.46 percent in Permian samples. Pennsylvanian samples exhibit a broad range of vitrinite reflectance values, and consequently an average value may not accurately reflect temperatures reached during burial. The highest R_o values may be from reworked sediments or oxidized cuttings.

Kerogen from the northern part of the Midland Basin is generally yellow.

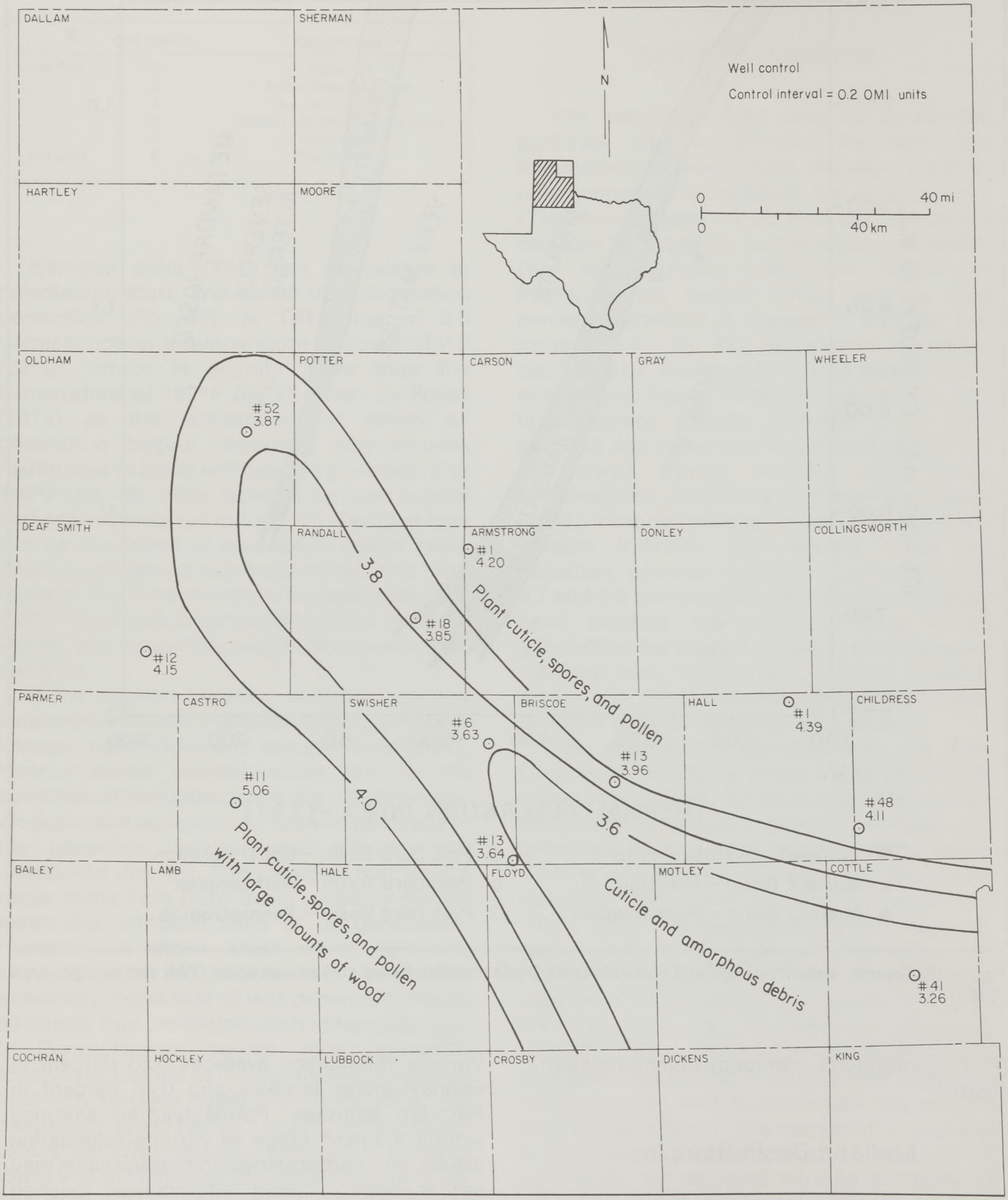


Figure 50. Distribution of kerogen type (OMI) in Pennsylvanian strata, Palo Duro Basin.

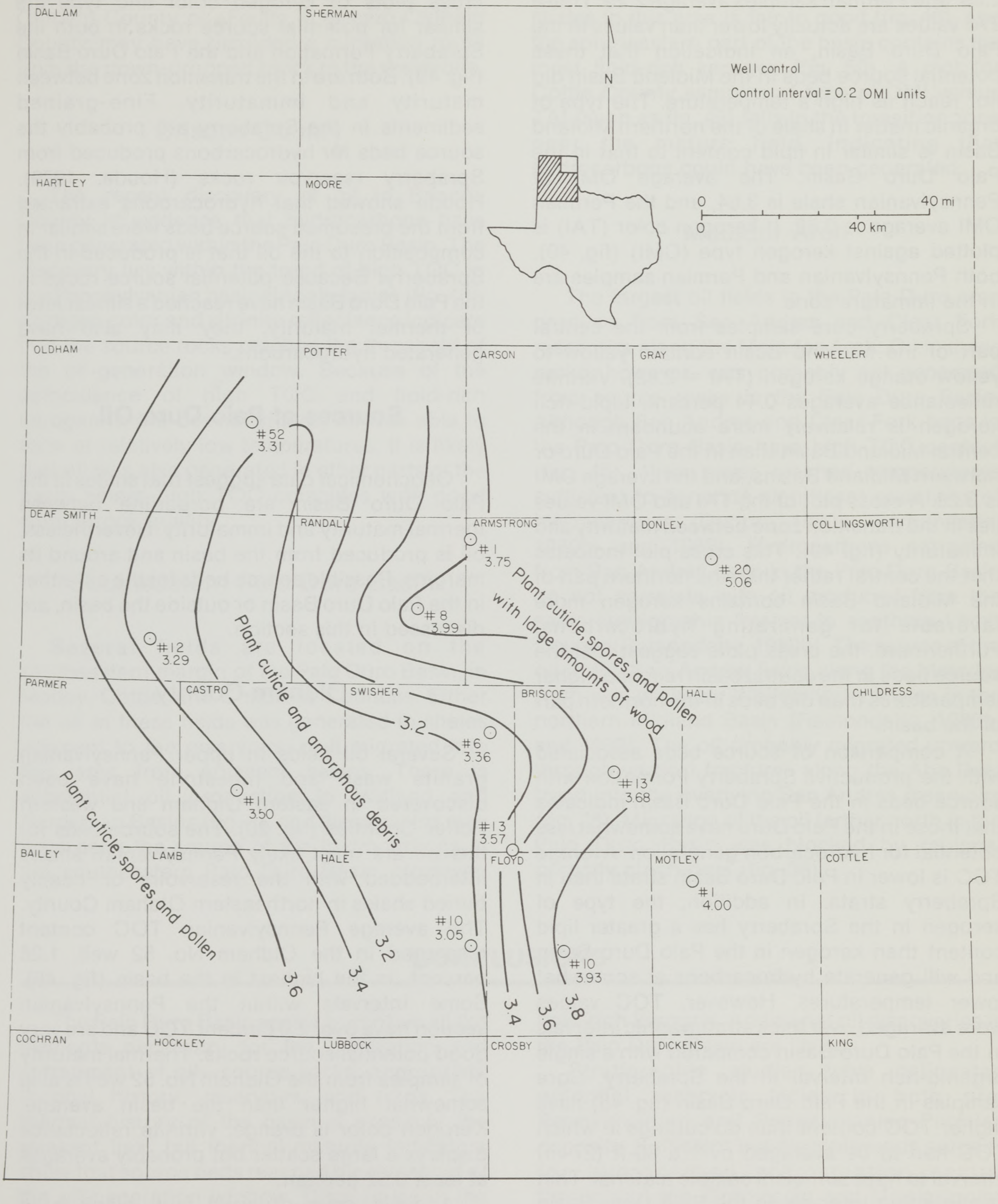


Figure 51. Distribution of kerogen type (OMI) in Wolfcampian strata, Palo Duro Basin.

Pennsylvanian samples have an average TAI of 2.69, and Permian samples average 2.29. These TAI values are actually lower than values in the Palo Duro Basin, an indication that these potential source beds in the Midland Basin did not reach as high a temperature. The type of organic matter in shale of the northern Midland Basin is similar in lipid content to that in the Palo Duro Basin. The average OMI of Pennsylvanian shale is 3.64, and the Permian OMI average is 3.52. If kerogen color (TAI) is plotted against kerogen type (OMI) (fig. 49), both Pennsylvanian and Permian samples are in the immature zone.

Spraberry core samples from the central part of the Midland Basin contain yellow to yellow-orange kerogen (TAI = 2.82). Vitrinite reflectance averages 0.44 percent. Lipid-rich kerogen is relatively more abundant in the central Midland Basin than in the Palo Duro or northern Midland Basins, and the average OMI is 3.28. A cross plot of the TAI and OMI values lies in the transition zone between maturity and immaturity (fig. 49). This cross plot indicates that the central rather than the northern part of the Midland Basin contains kerogen more favorable for generating hydrocarbons. Furthermore, the cross plots suggest that the source beds in the central basin reached higher temperatures than did beds in the northern part of the basin.

A comparison of source beds associated with the productive Spraberry Formation with source beds in the Palo Duro Basin indicates that those in the Palo Duro have somewhat less potential for hydrocarbon generation. Average TOC is lower in Palo Duro Basin strata than in Spraberry strata. In addition, the type of kerogen in the Spraberry has a greater lipid content than kerogen in the Palo Duro Basin and will generate hydrocarbons at somewhat lower temperatures. However, TOC values were averaged over thick stratigraphic intervals in the Palo Duro Basin compared with a single organic-rich interval in the Spraberry. Core samples in the Palo Duro Basin (fig. 45) have higher TOC content than do cuttings in which TOC had to be averaged over a 90-ft (27-m) interval to have sufficient sample material. Thin stratigraphic intervals in the Palo Duro Basin may be nearly as organic-rich as are the fine-grained Spraberry sediments.

Levels of thermal maturity determined by cross plots of kerogen color and type are similar for potential source rocks in both the Spraberry Formation and the Palo Duro Basin (fig. 49). Both are in the transition zone between maturity and immaturity. Fine-grained sediments in the Spraberry are probably the source beds for hydrocarbons produced from Spraberry reservoir rocks (Houde, 1979). Houde showed that hydrocarbons extracted from the presumed source beds were similar in composition to the oil that is produced in the Spraberry. Because potential source rocks in the Palo Duro Basin have reached a similar level of thermal maturity, they may also have generated hydrocarbons.

Sources of Palo Duro Oil

Geochemical data suggest that shales in the Palo Duro Basin are borderline between thermal maturity and immaturity. Nevertheless, oil is produced from the basin and around its margins. Possible source beds for the oil, either in the Palo Duro Basin or outside the basin, are discussed in this section.

Oldham County

Several oil fields in upper Pennsylvanian granite wash and limestone have been discovered in eastern Oldham and western Potter Counties (fig. 20). The source beds for this oil are most likely Pennsylvanian shales interbedded with the reservoirs or deeply buried shales in northeastern Oldham County. The average Pennsylvanian TOC content measured in the Oldham No. 52 well, 1.26 percent, is the highest in the basin (fig. 46). Some intervals within the Pennsylvanian section have over 2.0 percent TOC and are very good potential source rocks. Thermal maturity of samples from the Oldham No. 52 well is also somewhat higher than the basin average. Kerogen color is orange; vitrinite reflectance displays a large scatter but probably averages at least 0.52 percent.

A deep, down-dropped fault block is in northeastern Oldham County (figs. 6, 15, and pl. V). Shale in this area is several thousand feet deeper than in the rest of the Palo Duro Basin and could also have been the source of the Oldham County oil. Faults in eastern Oldham County may have provided a migration route from the down-dropped block to the reservoirs.

Briscoe County

The recent discovery of oil in Briscoe County is evidence that hydrocarbons have been generated within the Palo Duro Basin. The discovery lies within the trend of high TOC in the Pennsylvanian basinal shale facies (fig. 46). Kerogen color and vitrinite reflectance indicate that the source rocks reached the threshold of the oil-generation window. Because of the coincidence of high TOC and lipid-rich kerogen in the basinal shales, oil was able to form at relatively low temperatures. It is likely that oil was also generated in other parts of the basin where high TOC coincides with good source-rock quality.

Southeastern Palo Duro Basin

Several fields are located on the southeastern margin of the Palo Duro Basin, in Motley, Cottle, and Childress Counties. Either the oil in these fields was generated in shales adjacent to the reservoirs, or it migrated into this area from adjacent basins. There is substantial oil production in Midland and Hardeman Basins (fig. 1), and these basins may have been the source of the hydrocarbons in the southeastern Palo Duro Basin. However, the oil could have been generated in the Palo Duro Basin. TOC content of Pennsylvanian shales in this area is fair to good (fig. 46), and the southeastern part of the basin contains the most lipid-rich kerogen (fig. 50). A plot for Cottle County samples of type of OMI versus TAI (such as fig. 49) falls in the transition zone near the mature field, indicating that hydrocarbons could have been generated.

Matador Arch

The largest oil fields in the Palo Duro area produce from San Andres and Clear Fork reservoirs along the Matador Arch. Oil in these rocks, however, was probably not generated from source rocks in the Palo Duro Basin. Although San Andres and Clear Fork beds in the Palo Duro Basin have high TOC content (fig. 45), they never reached temperatures sufficient to generate significant quantities of hydrocarbons (Dutton, 1980b; Ramondetta, 1980b, and 1982). Hydrocarbons extracted from San Andres beds in the Palo Duro Basin do not correlate with oil produced from the same stratigraphic interval in southern Lamb County (Ramondetta, 1980b). The source of the oil in the San Andres fields along the Matador Arch was probably Wolfcampian shales in the northern Midland Basin (Ramondetta, 1980b, and 1982). The oil probably migrated upward through vertical fractures along the Abo Reef trend into the overlying San Andres reservoirs (fig. 28). Migration of the oil farther north in the Palo Duro Basin was blocked by regional porosity pinch-outs (fig. 38).

CONCLUSIONS

The Palo Duro Basin seems to contain all the elements necessary for the generation and entrapment of oil—source rocks, appropriate thermal history, reservoirs, and traps. The thermal history of the basin is probably the weakest link, but thermal-maturity indicators show that source beds reached the threshold of the oil-generation window. Discoveries in the basin provide evidence that oil actually was generated, probably in areas of high TOC and lipid-rich kerogen. Additional oil discoveries in the Palo Duro Basin are likely.

Stratigraphic studies have delineated potential reservoir facies in both pre-Pennsylvanian and Pennsylvanian-Permian deposits. Sufficient but discontinuous porosity for hydrocarbon accumulation occurs throughout the Ordovician and Mississippian carbonate strata. Erosional unconformities are common in these rocks. These, together with

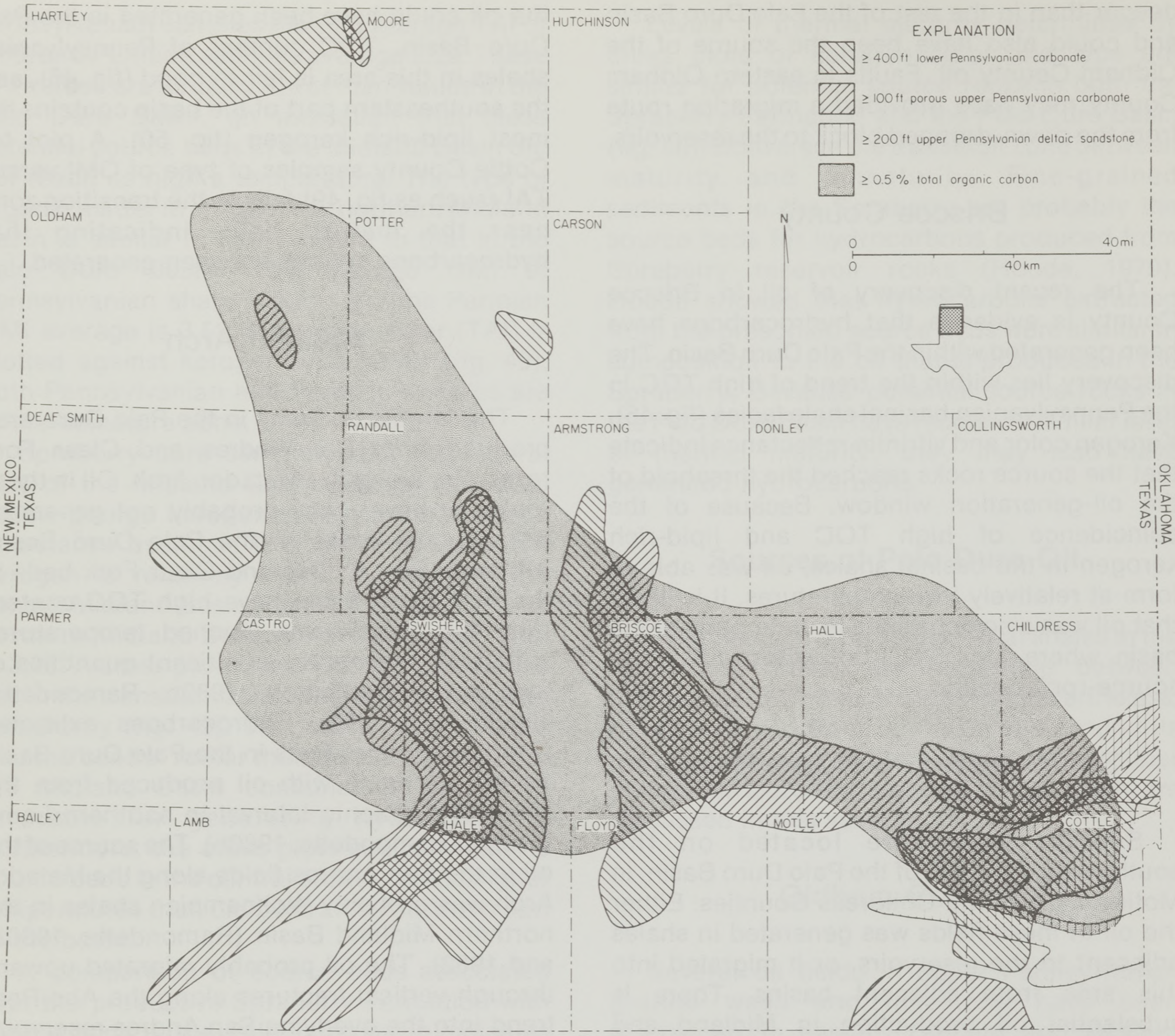


Figure 52. Pennsylvanian potential reservoir fairways. Carbonate buildups in lower Pennsylvanian and deltaic sandstones and porous shelf margins in upper Pennsylvanian are superimposed on the distribution of organic-rich (≥ 0.5 percent TOC) source rocks. Granite wash, also a potential reservoir, was not included because it is so extensive (fig. 22).

small structures that abound in the basin, are potential traps. Potential Pennsylvanian and lower Permian reservoirs include granite-wash and deltaic sandstones as well as shelf-margin carbonates. Regional fairway maps for Pennsylvanian (fig. 52) and Wolfcampian (fig. 53) strata outline areas where reservoirs should be concentrated. Granite-wash fairways are not included on the maps because they are so extensive. Many existing granite-wash fields are located in areas with less than 200 ft (60 m) of net granite wash (figs. 20 and 21). Additional fields in granite wash are most likely to be discovered near the trend of high TOC (fig. 46), and the fields will probably be structurally controlled.

Fairways in shelf-margin carbonates occur both in Pennsylvanian (fig. 52) and in Wolfcampian (fig. 53) strata. The fairway containing lower Pennsylvanian carbonates is outlined by the 400-ft contour (fig. 52). Reservoirs may exist in lower Pennsylvanian carbonates outside this area, but the fairway delineates the trend of shelf-margin buildups where potential reservoirs should be concentrated.

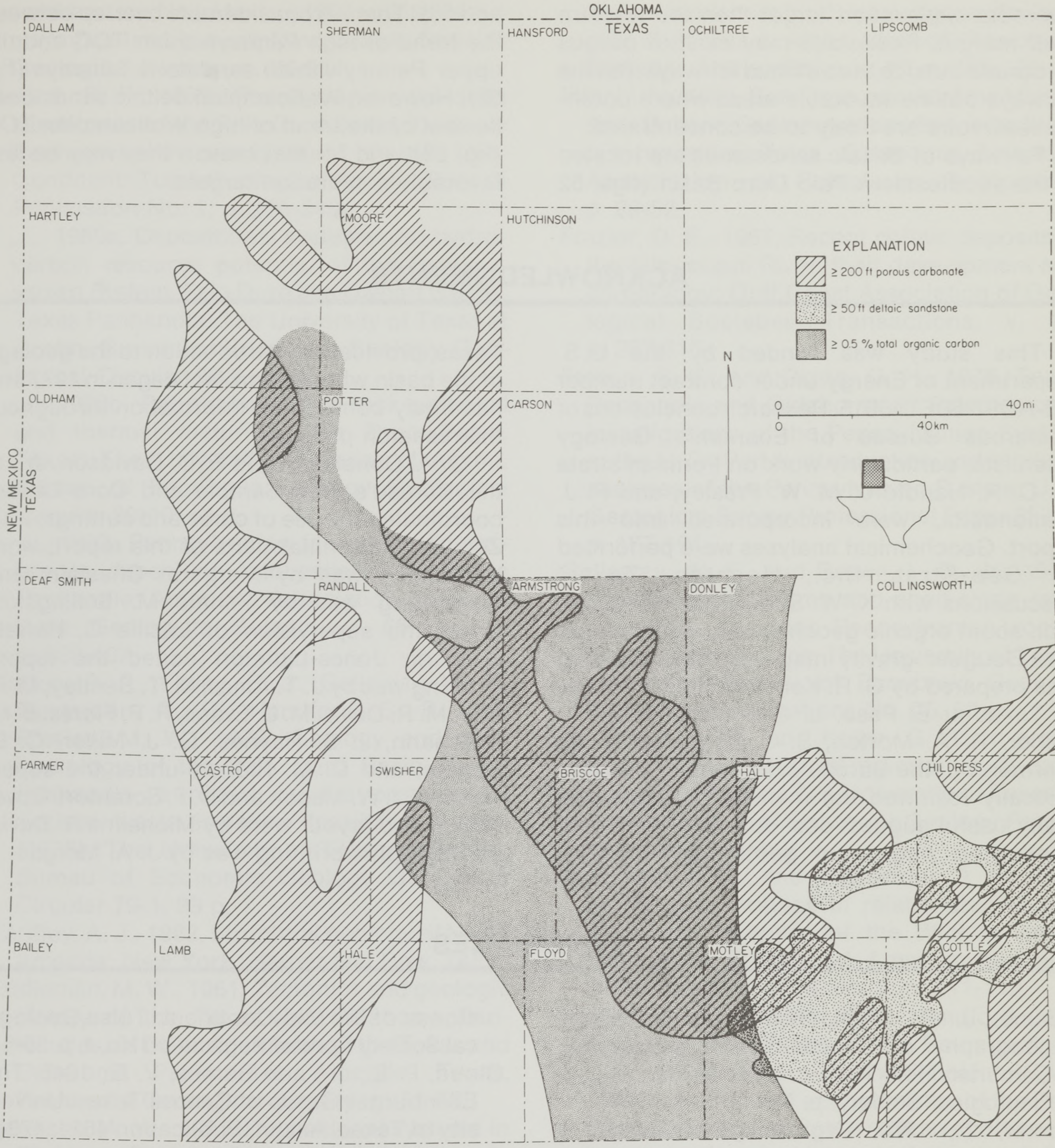


Figure 53. Wolfcampian (lower Permian) potential reservoir fairways. Positions of porous shelf margins and deltaic sandstones are superimposed on the distribution of organic-rich (≥ 0.5 percent TOC) Wolfcampian source rocks.

The upper Pennsylvanian shelf-margin fairway is delineated by the 100-ft contour of net porous carbonate (fig. 52). Both the lower and upper Pennsylvanian carbonate fairways coincide with the trend of high TOC in Pennsylvanian shales, particularly in the northern part of the basin (fig. 52). The juxtaposition of source rocks with porous shelf margins makes these attractive fairways.

The Wolfcampian shelf-margin fairway is defined by the 200-ft contour of net porous carbonate (fig. 53). High TOC in Wolfcampian shales overlaps only the eastern shelf margin. The eastern shelf, therefore, may be a more favorable exploration target than the western shelf margin. Reservoirs may exist in porous carbonate outside the outlined fairways, but the fairways outline favorable areas where potential reservoirs are likely to be concentrated.

Fairways of deltaic sandstones are located in the southeastern Palo Duro Basin (figs. 52 and 53). There is considerable overlap between the trend of high Pennsylvanian TOC and the upper Pennsylvanian sandstone fairways (fig. 52). However, Wolfcampian deltaic sandstones lie east of the trend of high Wolfcampian TOC (fig. 53), and for that reason they may be less favorable exploration targets.

ACKNOWLEDGMENTS

This study was funded by the U.S. Department of Energy under contract number DE-AC97-80ET46615. Research conclusions of numerous Bureau of Economic Geology scientists, particularly work on Permian strata by C. R. Handford, M. W. Presley, and P. J. Ramondetta, were incorporated into this report. Geochemical analyses were performed by Geo-Strat, Inc., Houston, Texas. Discussions with K. W. Schwab of Geo-Strat, Inc., about organic geochemistry were helpful. The Bouguer gravity map used for modeling was prepared by G. R. Keller of The University of Texas at El Paso. L. F. Brown, Jr., W. L. Fisher, R. A. Morton, S. J. Seni, and E. G. Wermund of the Bureau of Economic Geology critically reviewed the manuscript and made many useful suggestions. John H. Nicholson, consulting petroleum geologist, Amarillo, Texas, provided an introduction to the geology of the basin when the project began in 1977 and has freely contributed information throughout the research program.

G. A. Donaldson and E. D. Davidson, Jr., of the Bureau's Well Sample and Core Library coordinated the use of cores and cuttings. V. C. Zeikus typed initial parts of this report; word processing was by Margaret Chastain; and typesetting was by Fannie M. Sellingsloh, under the supervision of Lucille C. Harrell. R. Marie Jones-Littleton edited the report. Drafting was by J. T. Ames, M. T. Bentley, M. R. Day, M. R. Davis, M. L. Evans, R. P. Flores, B. M. Hartmann, J. S. Haynes, G. J. Miller, C. B. Rogers, and D. M. Ridner, under the supervision of J. W. Macon and D. F. Scranton. Cover design and layout were by Micheline R. Davis; photographic printing was by J. A. Morgan.

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APPENDIX. Wells used in this report.

BEG No.	Company	Well
	ARMSTRONG COUNTY	
1	Standard Oil Co. of Texas	#1-A Palm
2	Texas Crude Oil Co.	#1-142 Riley
3	Pelican Production	#1 Durett
4	Sunray Mid-Continent Oil Co.	#1 Cope
5	Texam-Green & Michaelson	#1 Bagwell
6	Nebo Oil Co.	#1 Thom. Bugbee
7	Cities Service Oil Co.	#1 Swift
8	Placid Oil Co.	#1 Matheson
9	Texaco, Inc.	#1 Troy Vance
10	Stanolind Oil & Gas	#1 A. Corbin
11	Ketal Oil Producing Co.	#1 F. B. Massie - M. S. Moore Est.
12	Geochemical Survey Co., Inc.	#1 Cobb
13	C. Andrade and C. C. Parks	#1 Bruce Cobb
14	Hassie Hunt Trust	#1 Helms
15	H. L. Hunt	#6 Ritchie
16	Hassie Hunt Trust	#1 J. A. Cattle Co.
17	Hassie Hunt Trust	#2 J. A. Cattle Co.
18	H. L. Hunt	#8 Ritchie
19	Texaco, Inc.	#1 Ritchie
20	H. L. Hunt	#7 Ritchie
21	H. L. Hunt	#4 Ritchie
22	W. V. Harlow	#1 Mattie Hedgecoke
23	Burdell Oil Co.	#1 McGehee Strat
24	Paragon Resources, Inc.	#1 J. A. Cattle Co.
	BAILEY COUNTY	
1	Hugh McMillan	#1-A Finley
2	W. P. Holloway	#1 St. Clair
3	Sinclair Oil & Gas Co.	#1 Couch
4	E. Puls	#1 Scoggins
5	W. A. Moncrief, Jr.	#1 Birdwell
6	W. A. Moncrief, Jr.	#2 Birdwell
7	El Paso Natural Gas Co.	#1 West Texas Mortgage & Loan Co.
8	Lion Oil Co.	#1 Birdwell
9	Broderick & Calvert	#1 Hayward
10	Coyote Lake Expl. Co.	#1 Ross
11	C. L. Craig & J. B. Smith	#1 A-3 Ross
12	C. L. Craig & J. B. Smith	#1 A Ross
13	Roy H. King	#1 Moore
14	W. A. Moncrief, Jr.	#1 Williams
15	W. A. Moncrief, Jr.	#1 Erickson
16	W. A. Moncrief, Jr.	#1 Crawford
17	Phillips Petroleum Co.	#1-A Stephens
18	First Fairway Corp.	#1 Rudd
19	W. A. Moncrief, Jr.	#1 Black
20	Shell Oil Co.	#1 Nichols
21	Cascade Petroleum Co.	#1 Newsom Trust
22	Geochemical Survey Co., Inc.	#1 Smith
23	W. A. Moncrief, Jr.	#1 McBee
24	Geochemical Survey Co., Inc., and W. A. Moncrief, Jr.	#1 Winkles
25	Great Western Producers, Inc.	#1 Lucas
26	Big Spring Expl. Co.	#1 Howell
27	Zenith Drilling Co.	#1 Moss
28	J. O. Whittington	#1 McCelvey
29	Delfern Oil Co.	#1 Newsome Est.
30	Merlin Roberts	#1 Roberts
31	Townsend Oil Co.	#1 St. Claire
	BRISCOE COUNTY	
1	Texaco Seaboard, Inc.	#1 Thelma Bivens Hall
2	I. W. Lovelady	#1 McMurty
3	Hassie Hunt Trust	#1 Owens
4	Tule Drilling Company	#1 Ritchie Cogdell
5	H. L. Hunt	#9 Ritchie
6	Smith & Collins	#2 Ritchie
7	H. L. Hunt	#3 Ritchie
8	Midstates Oil Corp.	#1 Hickock-Reynolds Royalty Co.
9	Luling Oil & Gas Co. and Royal Oil & Gas Corp.	#1 Edwards
10	H. L. Hunt	#10 Ritchie
11	Texaco, Inc.	#1 Glen Cleveland
12	Texaco, Inc.	#B-1-A Glen Cleveland
13	W. J. Weaver	#1 Adair
14	Bright & Schiff	#1 Burson
15	Humble Oil & Refining Co.	#1 Howard Ranch
16	Amarillo Oil Co.	#B-1 Bryant Edwards
17	H. L. Hunt	#1 Ritchie
18	Tule Drilling Co.	#1 Ritchie, Cogdell & Sons
19	D. M. Cogdell	#1 Ritchie, Cogdell & Sons
20	Gulf Oil Corp.	#D-1 Rodgers
21	Cockrell Corp.	#1 Allard
22	Phillips Petroleum Co.	#1 Montague
23	Amerada Petroleum Corp.	#1 Hamilton
24	D. M. Cogdell	#2 Ritchie, Cogdell & Sons
25	Exploration Unlimited	#1 Graham
	CARSON COUNTY	
11	Texaco, Inc.	#10 First State Bank of White Deer
16	E. H. Rice	#1 Chapman
17	Continental Oil Co.	#1 S. T. Bitting
18	Catherine C. Whittenburg	#1 W. J. Morris
20	Texas Gulf Producing Co.	#1 Bobbitt
29	Texas Gulf Producing Co.	#1 J. B. Horn
33	Roy H. King et al.	#1 Peacock
34	Pure Oil Co.	#1 Read
35	Texas Gulf Producing Co.	#1 Calliham
36	Phillips Petroleum Co.	#1 Ardis
37	J. M. Huber Corp.	#1 Newton
	CASTRO COUNTY	
1	Amarillo Oil Co.	#1 C. R. Veigel
2	Skelly Oil Co.	#1 M. S. Wilson
3	Pan American Petroleum Corp.	#1 M. L. Robbins
4	Texaco, Inc.	#1 Witkowski
5	Ashmun & Hilliard	#1 Witkowski
6	Ashmun & Hilliard	#1 Formwalt
7	Union Oil Co. of California	#1 Formwalt
8	I. A. Stephens	#1 Little
9	Ashmun & Hilliard	#1 Willis
10	Phillips Petroleum Corp.	#1-J Morris
11	Sun Oil Co.	#1 Herring
12	Austral Oil	#1 A. H. Ware
13	Amarillo Oil Co.	#1 L. C. Boothe
14	Sun Oil Co.	#1 Haberer
15	Sun Oil Co.	#1 Uselton
16	Ashmun & Hilliard	#1 J. L. Merritt
17	Standard Oil Co. of Texas	#1 Steakley
18	Anderson-Prichard Oil Corp.	#1 Fowler-McDaniel
19	Devore & Slade	#1 Dimiddie
20	A. P. Werner	#1 McFarland
21	Challenger Minerals, Inc.	#1 J. R. Matthews
	CHILDRESS COUNTY	
1	Seitz et al.	#1 Ray Albaugh
2	Ray Albaugh	#1-63 Ray Albaugh
3	The Texas Co.	#1 P. B. Smith
4	Russell Maguire	#1 Earl Vest
5	Russell Maguire	#1 Smith Land & Cattle
6	Skelly Oil Co.	#1 H. A. Painter
7	Barbre, Lancaster & Gogle	#1 Whiteside

8	Shell Oil Co.	#1 Mitchell
9	Stanolind Oil & Gas	#1 Steve Owens
10	Wes-Tex, Kewanee, and Coastal States Gas Producing Co.	#1-A Steve Owens
11	J. A. Murphy	#1 S. J. Clark
12	Sterling Oil Co.	#1 Clark
13	Jack Grace & M. M. Travis	#1 Johnson
14	Cherry Petroleum Co.	#1 Cliff Campbell
15	Skiles Oil Corp.	#1 Cliff Campbell
16	Corps of Engineers - Tulsa District	#1 Jonah Creek
17	Paul C. Teas	#1 T. R. Shields
18	G. E. Kadane & Sons	#1 Rocking Chair Ranch
19	Pure Oil Co.	#1 Gourd Land & Cattle Co.
20	Taubert, Steed & Gunn	#1 F. Wyatt
21	Gulf Oil Corp.	#1 Oliver McKee
22	Lamar Hunt Trust Estate	#1 Gourd Land & Cattle Co.
23	The Texas Co.	#1 F & M Trust
24	Armour Properties	#1 Gourd Land & Cattle Co.
25	Lamar Hunt Trust	#1 Rosetta Johns
26	Placid Oil Co.	#1 K. M. Waters
27	Bright & Schiff	#1 Felton
28	G. E. Kadane & Sons	#1 Newberry
29	Claud B. Hamill and Louisiana Land & Expl. Co.	#1 Kent McSpadden
30	Cheyenne Oil Corp.	#1 C. B. Boyd
31	British-American Oil Production Co.	#1 G. B. Howard
32	Taubert, Steed & Gunn	#1 Bird
33	J. W. Operating Co.	#1 Leslie McQuinn Estate
34	O. P. Leonard	#1 J. E. Turner
35	Taubert & Steed	#1 Furr - Coats
36	Centaur Petroleum Corp.	#1 H. G. Cliff
37	Perkins-Prothro	#1 Howard
38	R. L. Foree	#1 Kelly Estate
39	O. P. Leonard	#1 Reed Rhea
40	R. D. Gunn	#1 G. B. Dorsey
41	Corpening Enterprises	#1 Hander
42	Kay Kimbell, Swick & Ross	#1 J. Rhea
43	Armour Properties and R. D. Gunn	#1 Beryl Richardson
44	Brownlie, Wallace & Armstrong	#1 Frank Ehrle
45	T. F. Hodge	#1 City of Childress
46	Kimble, Swick & Gunn	#1 Hackler
47	R. D. Gunn	#1 Mitchie
48	U. H. Griggs	#1 Smith
49	Sinclair Oil & Gas Co.	#1 Willard Mullins
50	Texaco, Inc.	#1 Neva Rothwell
51	Humble Oil & Refining Co.	#1 Mollie Bennett
52	L. B. Taylor, Jr., and Kewanee Oil Co.	#1 E. B. Johnson
53	O. P. Leonard	#1 Jones
54	Blanco Oil Co.	#1 T. M. Russell
55	Cayman Corp.	#1 Coda Beavers
56	Pan American Petroleum Corp.	#1 Coda Beavers
57	Perkins-Prothro	#1 Reed
58	Ohio Oil	#1 L. A. Gibson
59	The Texas Co.	#1 Hughes
60	L. O. McMillan	#1 Furr
61	Tennessee Gas & Oil Co.	#1 A. L. Harp
62	W. L. Pickens	#1 Perkins
63	Lloyd H. Smith	#1 Boyd
64	Amerada Petroleum Corp.	#1 A. R. Middleton
65	L. H. Smith	#1 Pieratt
66	Texaco, Inc.	#1 J. A. Bierwirth
67	M. T. Halbouty	#1 Fowler
68	O. P. Leonard	#1 Oda Coats
69	British-American Oil Production Co.	#2-B Oda Coats
70	O. P. Leonard	#3 Coats
72	O. P. Leonard	#2-A Perkins
73	R. D. Gunn	#1-A Perkins
74	British-American Oil Production Co.	#1 E. V. Perkins
75	O. P. Leonard	#3-A Perkins
76	Wes-Tex Drilling	#1 Mitchell
77	T. B. Medders & Huber Corp.	#1 Gourd Land & Cattle Co.
78	Cosden Petroleum Corp.	#1 Maloy
79	O. P. Leonard	#1-B Perkins
80	O. P. Leonard	#1 Harp
81	Alma (Watchorn) Co.	#1 Lowe
82	Cambridge and Nail	#1 Sharp
83	Page Petroleum Inc.	#1-632 Seal
84	Meridian Oil Corp.	#1 Smith

COCHRAN COUNTY

24	Union Texas Petroleum Corp.	#2-E Frost
35	Pan American Petroleum Corp.	#1-B Paul Walker
335	W. A. Moncrief	#2 F. O. Masten
348	Julian Ard	#1 St. Claire
459	Julian Ard	#1 Elma Slaughter

COLLINGSWORTH COUNTY

1	Panoka Drilling Co.	#4-B H. E. Franks
2	Mayfield Drilling Corp. of LA., Inc., and T. T. Haley	#1 Franks
3	Steeple Oil & Gas and Petroleum Expl., Inc.	#1 Bryan
4	E. C. & R. C. Sidwell	#1 Knoll
5	E. C. & R. C. Sidwell	#2 Betenbrough
6	Texas Pacific Oil Co.	#7 Oscar Laycock
7	Eldorado Oil & Gas Co.	#5 Laycock
8	Hi-Plains Production, Inc.	#1 Williams
9	Hi-Plains Production, Inc.	#2 Williams
10	The Texas Co.	#1 A. M. Atkinson
11	King Resources Co.	#1 Geraldine Burrell
12	A. M. Park & Hammer	#1 Tindall
13	Elza P. Adams	#1 Boyd
14	Gulf Oil Corp.	#1 Boyd
15	Monsanto Chemical Co.	#1 Fain
16	Gulf Oil Corp.	#1 Ward
17	Lubbock Machine & Supply Co.	#1 Alexander
18	Tatum, Bennett & De Pauw	#1 A. F. Wischkaemper
19	Superior Oil Co.	#85-75 M. F. Brown
20	Roden Oil Co.	#1 Dwyer
21	E. A. Nesbitt	#1 Tarpley
22	Union Producing Co.	#1 Glenn
23	Bridgeport Oil, Inc.	#1 Hughes
24	Laan-Tex Oil Co.	#1 Bailey
25	Shell Oil Co.	#1 Shell-Cook
26	Concho Development Co.	#1 Hamilton-Deavers
27	Herbert Oil	#1 Coleman-Hess
28	B. B. Carter	#1 Hunter
29	El Paso Natural Gas Co.	#2 Christner
30	El Paso Natural Gas Co.	#3 Willoughby
31	Katex Oil & Mal-Cra. O.R.	#10 Bell
32	Texas Petrotech, Inc.	#1 J. E. Forbis
33	Humble Oil & Refining Co.	#1 Scruggs
34	Roadrunner Oil Co.	#1-114 Coleman-Montgomery

COTTLE COUNTY

1	Guest & Wolfson Co.	#1 McNeil-Johnson
2	Sun Oil Co.	#1 Smith
3	Alma Oil Co.	#1 Yarbrough
4	Skelly Oil Co.	#1 Harbison
5	Magnolia Petroleum Co.	#1 Alice Green
6	Falcon Seaboard Drilling Co.	#1 Yarbrough
7	Fisher-Webb, Inc.	#1-4 Yarbrough
8	L. T. Burns Estate	#1 Richards
9	Armour Properties	#1 Johnstone
10	Murphy Oil Corp.	#1 Timmons
11	Fain & McGaha	#1 Hoffman
12	Deep Rock Oil Corp.	#1 Portwood Ranch
13	Baria & Werner	#1 Della Nelson
14	Ohio Oil Co.	#1-A Yarbrough
15	T. J. Sivley	#1 Carter
16	Tom B. Medders	#1-A Portwood
17	Great Western Drilling Co.	#1 Portwood
18	Murphy Oil Corp.	#1 Boyle
19	Sun Oil Co.	#2 Hughes

20	Meeker & Gupton	#1 Carroll
21	The British-American Oil Production Co.	#1 Carroll
22	Sun Oil Co.	#1 Hughes
23	James H. Snowden et al.	#1 Hughes
24	Humble Oil & Refining Co.	#3-XJ Matador
25	Skelly Oil Co.	#1 Parrack
26	The Texas Co.	#1 Payne
27	Renwar Oil Corp.	#1 Anderson
28	A. V. Corpening	#B-1 Burnett
29	Pan American Petroleum Corp.	#1 Windfohr
30	Pan American Petroleum Corp.	#2-A Windfohr
31	Medders Petroleum Corp.	#1 Triangle Ranch
32	Medders Petroleum Corp.	#B-1 Triangle Ranch
33	Corpening Enterprises, North Central, and Smith	#1 Burnett Est.
34	Pan American Petroleum Corp.	#3-A Windfohr
35	Steve Gose	#1 Miller
36	Shell Oil Co.	#1 Williford
37	Humble Oil & Refining Co.	#J-1 Matador
38	Humble Oil & Refining Co.	#J-2 Matador
39	Humble Oil & Refining Co.	#J-3 Matador
40	Texas Pacific Oil Co.	#1 Kaines
41	Baria & Werner	#1 Mayes
42	Pan American Petroleum Corp.	#4 Windfohr
43	Pan American Petroleum Corp.	#2 Windfohr
44	Pan American Petroleum Corp.	#5 Windfohr
45	Texaco, Inc.	#36 Johnson
46	Texaco, Inc.	#34 Johnson
47	Janato, Inc.	#2 Johnson
48	Jack Grimm	#1 Worley
49	Stanolind Oil & Gas	#1 Richards
50	Jack Grimm & Hunt	#1 Richards
51	Perkins-Prothro	#1-L Swenson
52	Riley G. Maxwell Co.	#1 Clary
53	Jones & Stasney	#1 Wilie
54	Perkins-Prothro	#1 Wilie
55	Sequoia Oil Co., Inc.	#2 Wilie
56	General Crude Oil Co.	#39-1-B Swenson
57	Perkins-Prothro	#1 Swenson
58	General Crude Oil Co.	#39-2-B Swenson
59	General Crude Oil Co.	#39-3-B Swenson
60	Perkins-Prothro	#J-1 Swenson
61	General Crude Oil Co.	#277-1-B Swenson
62	Perkins-Prothro	#1-E Swenson
63	General Crude Oil Co.	#13-1-B Swenson
64	General Crude Oil Co.	#38-1-B Swenson
65	General Crude Oil Co.	#273-1-B Swenson
66	General Crude Oil Co.	#42-1-C Swenson
67	Frank Burger	#1-35 Swenson
68	General Crude Oil Co.	#35-1-C Swenson
69	Miami Oil Producers, Inc.	#1 Swenson
70	Perkins-Prothro	#1-D Swenson
71	General Crude Oil Co.	#33-1-C Swenson
72	Perkins-Prothro	#1-H Swenson
73	General Crude Oil Co.	#22-1-B Swenson
74	Perkins-Prothro	#2-G Swenson
75	Signal Oil & Gas Co. and Anderson-Prichard Oil Co.	#2 Swenson
76	Perkins-Prothro	#1-G Swenson
77	Perkins-Prothro	#1-C Swenson
78	General Crude Oil Co.	#29-1-C Swenson
79	Booker Oil Co.	#1 Swenson
80	Ramsey Petroleum Corp.	#1 Lynch
81	Sun Oil Co.	#1 Biddy
82	Robinson Brothers Oil Producers	#1 McGee
83	Robinson Brothers Oil Producers	#1 Harrison
84	Norman Oil Co.	#1 Richards
85	Robinson Brothers Oil Producers	#1 Richards
86	Hamilton & Rich	#1 Richards
87	Robinson Brothers Oil Producers	#1 Barron
88	Robinson Brothers Oil Producers	#2 Barron
89	Robinson Brothers Oil Producers	#1 Perkins
90	Robinson Brothers Oil Producers	#1 Owens
91	Robinson Brothers Oil Producers	#2 Tippen
92	Nueve Operating Co. of Texas and Imperial Oil Co.	#1 Gilbreath
93	Russell Maguire, et al.	#1 Johnson
94	Robinson Brothers Oil Producers	#1 Goodwin
95	Three Dollar Oil Co.	#1 Goodwin
96	Gus Edwards	#1-A Jamie Cate
97	Hovgard & Fitzgerald	#1 Thomas
98	Gus Edwards	#1 Etter
99	Hovgard & Fitzgerald	#1 Jamie Cate
100	Gus Edwards	#9 Gibson
101	Gus Edwards	#6 Gibson
102	Gus Edwards	#1 Etter
103	Gus Edwards	#4 Gibson
104	Gus Edwards	#7 Gibson
105	Gus Edwards	#8 Gibson
106	Gus Edwards	#5 Gibson
107	Fletcher Oil & Gas Drilling Corp.	#1-21-C Shamburger
108	E. B. Clark Drilling Co.	#1 Shamburger
109	Gulf Oil Corp.	#1-C Shamburger
110	O. P. Leonard	#1 Langford
111	Ad Oil Co.	#1 Monroe
112	Ab-Tex Production Co.	#1 Monroe
113	Gulf Oil Corp.	#1 Shamburger
114	States Oil Co.	#1 Gibson
115	States Oil Co.	#3 Johnson
116	Powel Briscoe, Inc.	#1 Glidewell
117	General Crude Oil Co.	#1 Jolly Meyers
118	Klabzuba & Schumacher	#1 Pierce-Langford
149	Trenco, Inc.	#1 Bostick
151	Northern Michigan Exploration Co.	#1 Irons-Marrs
154	Chalmers Operating Co., Inc.	#1 H. G. Russell

CURRY COUNTY, NEW MEXICO

2	Exxon Co., USA	#1 Brown

DEAF SMITH COUNTY

1	Frankfort Oil Co.	#1 J. F. Coffee
2	Frankfort Oil Co.	#1 Allison-Hayes
3	N. B. Hunt	#1 Overstreet
4	Texas Crude Oil Co.	#1-78 Rose
5	Frankfort Oil Co.	#1 Muse
6	Frankfort Oil Co.	#1 R. E. Gill
7	Humble Oil & Refining Co.	#1 R. J. Hyslop
8	Humble Oil & Refining Co.	#1 Stanbough
9	Humble Oil & Refining Co.	#1 Reinauer Brothers
10	Gardner Brothers Drilling Co.	#1 Collett
11	Gas Producing Enterprises, Inc.	#1 J. Garrett
12	Honolulu Oil Corp.	#1 Ponder
13	Lease & Royalty, Inc., of America	#1 Lindsey
14	La Mance Drilling Co.	#1 Western Realty
15	Ashmun & Hilliard	#1 Oppenheim
16	American Petrofina Co. of Texas	#1 J. G. McFarland
17	Voyager Petroleum, Inc.	#20-10 V. P. I. Reinauer
18	Buttes Resources Co.	#1 Brorman
19	American Petrofina	#1 Eva Brown
20	Stone and Webster Engineering Corp.	#1 Detten
21	Stone and Webster Engineering Corp.	#1 Friemel

DONLEY COUNTY

1	H. E. Bryan	#1 Hermesmyer
2	E. J. Dunigan, Jr.	#1 Steed
3	Service Drilling Co.	#1 Kathleen C. Griffin
4	Lefors Petroleum Co.	#1 Trew
5	Ambassador Oil Corp.	#1 Frank J. Hommell
6	Jake L. Hamon	#1 Hommell
7	James W. Witherspoon	#1 McMurty
9	El Paso Natural Gas Co.	#3 Lewis
10	El Paso Natural Gas Co.	#1 Saunders
11	El Paso Natural Gas Co.	#1 Brown
12	El Paso Natural Gas Co.	#1-A Baptist Foundation
13	El Paso Natural Gas Co.	#1 Baptist Foundation
14	El Paso Natural Gas Co.	#1 McMurtry

15	Roden Oil Co.	#1 Sitter
16	Stanolind Oil & Gas Co.	#1 W. J. Lewis
17	Texas Gulf Producing Co.	#1 Lewis
18	Magnolia Petroleum Co.	#1 W. J. Lewis
19	Texas Gulf Producing Co. and Sunray Midcontinent Oil Co.	#1 Lewis
20	Thomas Doswell et al.	#1 C. T. McMurtry
21	Humble Oil & Refining Co.	#1 Coleman-Huffman
22	G. B. Cree	#1 Robertson
23	Humble Oil & Refining Co.	#1 T. L. Roach
24	Russell Maguire and Sunray Midcontinent Oil Co.	#1 Ritchie
25	Placid Oil Co.	#1 W. R. Kelley
26	Rip Underwood and Corsica Oil Co.	#1 V. W. Carpenter
27	Centaur Petroleum Corp.	#1 H. L. Shaller
28	Alan Drilling Co.	#1 Sharret Myers
29	Robinson Brothers Oil Producers	#1 W. J. Lewis Estate
30	Stanolind Oil & Gas Co.	#1 Troy Broome
31	Shell Oil Co.	#1 Finch
32	Geochemical Surveys, Inc.	#1 Harrison
33	Robinson Brothers Oil Producers	#1 Kuteman
34	E. B. Clark and General Crude Oil Co.	#1 P. B. Gentry
35	Cauble Enterprises	#1 Charlotte Adams
36	Maynard Oil Co.	#1 Molesworth
37	General Crude Oil Co.	#1-140 Keystone Minerals
38	J. S. Micheal	#1 Thelma Clements
39	General Crude Oil Co.	#1-157 Keystone
40	Miami Petroleum Co.	#1 Lazy R. G. Ranch
41	H. L. Hunt	#5 Ritchie
42	J. F. Smith & J. W. Collins	#3 Ritchie
43	Miami Petroleum Co.	#1-162 Lazy R. G. Ranch
44	General Crude Oil	#1-30 Keystone Minerals
45	Lazy R. G. Ranch Co.	#1 Welch
47	Meridian Oil Exploration	#1 Craft
48	Sunco Co.	#7-34 Hermesmyer
49	Honolulu Oil Co.	#1 Ozier
50	Stone and Webster Engineering Corp.	#1 Sawyer

FLOYD COUNTY

1	Cockrell Corp.	#1 Daniel
2	E. B. Clark Drilling Co.	#1 Hall
3	Ralph J. Abbey et al.	#1 Howard
4	I. W. Lovelady	#1 Wells
5	Cockrell Corp.	#1 Wells
6	Houston Oil Co.	#1 Lackey
7	Humble Oil & Refining Co.	#1 Meriwether
8	Cockrell Corp.	#1 Mize
9	Cockrell Corp.	#1 Moss
10	Sinclair Oil & Gas Co.	#1 Massie
11	Pure Oil Co.	#1 Martin
12	Perry E. Larson	#1 Goins
13	Cockrell Corp.	#1 Karstetter
14	Cockrell Corp.	#1 Thomas
15	General American Oil Co.	#1 Strickler
18	Lario Oil & Gas Co.	#1 Mayo
19	General American Oil Co.	#1 Carmichael
20	W. W. West	#1 Carpenter
21	Poff-Brinsmere	#1 Krause
22	Livermore-Honolulu Oil Co.	#1 Krause
23	Texas Crude, Inc.	#1-4 Murray
24	Mills Bennett	#1 Montgomery
25	Standard Oil Co. of Texas	#1 Daniel
26	Glen Soderstrom	#1 Battey
27	Roy Furr	#1 Battey
28	Robinson Brothers Oil Producers	#1 Jones
29	Burdell Oil Co.	#1 Nichols
30	Standard Oil Co. of Texas	#1 Minnie Adams
31	Russell Maguire	#1 Bunch
32	Standard Oil Co. of Texas	#2 Minnie Adams
33	George P. Livermore, Inc.	#1 Alexander
34	Pan American Petroleum Corp.	#1-A Hammond
35	I. W. Lovelady	#1 Couch
36	Kern County Land Co.	#1 Ross
37	Argonaut	#1 Snodgrass
38	Exxon Corp., USA	#1 Bundy Campbell
39	Harken Oil and Gas, Inc.	#1 Pigg

GRAY COUNTY

6	Cabot Corporation	#1 Hobart - Fatheree
38	Mobil Oil Co.	#10 Heitholt
55	Cities Service Oil Co.	#1-C Dauer

HALE COUNTY

1	El Rey Petroleum, Inc.	#1 Whitten
2	DeKalb Agricultural Association, Inc.	#1 Pool
3	Ed Aylesworth	#2 Biers
4	Globe	#1 Downs
5	Mason & Walsh	#1 Harrell
6	Mobil Oil Co.	#1 Carl Laney
7	Honolulu Oil Corp.	#1 Alley
8	Permian Basin Oil Co.	#1 Shipp
9	Honolulu Oil Corp.	#1 Clements
10	Amerada Petroleum Corp.	#1 Kurfees
11	Standard Oil Co. of Texas	#1 Keliehor
12	Ray Albaugh	#1 Hormell
13	Ray Albaugh	#1 Robertson
14	Honolulu Oil Corp.	#1 Jones
15	Russell Maguire	#1 Wheeler
16	Southern Minerals Corp.	#1 Heard
17	General American Oil Co.	#1 Featherston
18	General American Oil Co.	#1-B Carmichael
19	General American Oil Co.	#2-B Carmichael
20	General American Oil Co.	#1 Byrd
21	General American Oil Co.	#5 Byrd
22	General American Oil Co.	#3 Byrd
23	General American Oil Co.	#4 Byrd
24	General American Oil Co.	#2 Byrd
25	Stanolind Oil & Gas Co.	#1 Hegi
26	Plymouth Oil Co.	#1 Daly & Hurlbert
27	Southland Royalty Co.	#1 Rosser
29	Stanolind Oil & Gas Co.	#2 Fisher
30	Stanolind Oil & Gas Co.	#1 Fisher
31	Standard Oil of Texas	#1 Sam Hunt
32	Stanolind Oil & Gas Co.	#1 Hale Co. State Bank
33	Walsh & Watts, Inc.	#1 Mitchell
34	Humble Oil & Refining Co.	#2 J. A. Lutrick
35	Humble Oil & Refining Co.	#1 J. A. Lutrick
36	Humble Oil & Refining Co.	#2 T. E. Lutrick
37	Humble Oil & Refining Co.	#1 T. E. Lutrick
38	Henderson & Erickson	#1 Overton
39	Barnsdall Oil Co.	#1 Camp
40	Southern Minerals Corp. and Seaboard Oil Co.	#1 Marsh
41	Chambers & Kennedy	#1 Hix
42	Honolulu Oil Corp.	#1 Schultz
43	Western Drilling Co.	#1 Jones
44	Western Drilling Co.	#1 Bickley
45	Pan American Petroleum Corp.	#6 Anton-Irish
46	Pure Oil Co.	#10 Preston
47	Pan American Petroleum Corp.	#31 Anton-Irish
48	Pan American Petroleum Corp.	#48 Anton-Irish
49	Pan American Petroleum Corp.	#9 Blackmon
50	Stanolind Oil & Gas Co.	#1-B Harroll-Townsend
51	Doric Exploration Co.	#1 Dyer
52	Sinclair Oil & Gas Co.	#1 Teague
53	Glenn J. Smith	#1 Durrett
54	Magnolia Petroleum Co.	#1 Garrett
55	Sinclair Oil & Gas Co.	#1 Teague
56	Robinson Brothers Oil Producers	#1 Fields
57	Dunigan Operating Co.	#1 Tooker
58	Davis Oil Co.	#1 Holler
59	Amoco Production Co.	#439 Anton-Irish Clearfork Unit
60	Amoco Production Co.	#441 Anton-Irish Clearfork Unit

HALL COUNTY

1	Amarillo Oil Co.	#1 Grace Cochran
2	Sun Oil Co.	#1 T. E. Spear
3	W. B. Hogan - Leonard Oil Co.	#1 Broome
4	Humble Oil & Refining Co.	#1 Moss
5	Humble Oil & Refining Co.	#1 Weaver
6	Honolulu Oil Corp.	#1 Noel
7	E. B. Colvin and Gulf Coast Royalty Co.	#1 Neeley
8	E. Constantin et al.	#1 Wilton
9	Edward Nepple	#1 Hutchins
10	J. O. Fox	#2 Davidson Core Hole
11	Texas Gulf Producing Co.	#1 House
12	J. B. Revier et al.	#1 Lewis
13	CRA, Inc., and Alex McCoy et al.	#1 Lewis Ranch
14	Alex McCoy Assoc.	#1-CH Lewis
15	Alex McCoy Assoc.	#2-CH Lewis
16	Sinclair Oil & Gas Co.	#1 Shannon
17	Tex-Oil & Land Corp.	#1 Deaver
18	Amerada Petroleum Corp.	#1 Hughes
19	Midwest Oil Corp.	#1 Hughes
20	Sinclair Oil & Gas Co.	#1 Hughes
21	Sinclair Oil & Gas Co.	#2 Hughes
22	R. D. Gunn	#1 T-Bar Ranch
23	Robinson Brothers Oil Producers	#1 Hughes
24	R. D. Gunn	#1 Williams
25	Rio Bravo	#1 Hughes
26	Perkins-Prothro and Powder River Oil Co.	#1 Ernest Rae
27	The Atlantic Refining Co.	#1 Garrison
28	Phillips Petroleum Co.	#1 Hughes
29	Gunn Oil Co.	#1 T-Bar
30	R. D. Gunn	#1 Timmons
29	Gunn Oil Co.	#1 T-Bar
30	Gunn Oil Co.	#1 E. M. Timmons
31	Gunn Oil Co. and Howell Corp.	#1 Johnson & Smith Unit
32	Gunn Oil Co.	#1 Crump-Ferrell
33	Louisiana Land and Exploration Co.	#1 O. C. Payne

HARTLEY COUNTY

33	Apache Oil Corp.	#1 Rose

HOCKLEY COUNTY

8	Stephen E. Collins and Sam H. Allen	#1 Noble Halliburton

LAMB COUNTY

1	Gulf Oil Corp.	#1-A L. E. Bartlett
2	Intex Oil Co.	#1 Gettys
3	Steve Gose	#1 J. E. Busby
4	John J. Christmann	#1 D. L. Givens
5	Belco Petroleum Corp.	#1 Halsell
6	National Associated Petroleum Co.	#1 Halsell
7	Honolulu Oil Corp.	#1 Halsell
8	Cactus-Broseco	#1 John Buth
9	H. L. Hunt Oil Co.	#1 Robertson
10	Chapman & Poland	#1 Harvey
11	Livermore Drilling Co.	#1 W. H. Grigsby
12	W. A. Moncrief	#1 Harmon
13	Sinclair Oil & Gas Co.	#1 Roy Gilbert
14	Sun Oil Co.	#1 Ed Sneely
15	William K. Young et al.	#1 F. R. Wilson
16	W. A. Stockard et al.	#1 Neil Wood
17	L. R. Hewitt	#1 Armstrong
18	Monsanto Chemical Co.	#1 Char
19	W. A. Moncrief, Jr.	#1 Bugs Roundtree
20	W. A. Moncrief, Jr.	#1 Kesey
21	Robinson Brothers Oil Producers	#1 Coen
22	Marathon Oil Co.	#1 W. L. Fritz
23	H. L. Cain	#1 Bundick
24	Felmont Oil Corp.	#1 Gray
25	C&H Oil Co.	#1 R. N. Nickolas
26	Stanolind Oil & Gas	#1 J. W. Hopping
27	Vaughn Petroleum, Inc.	#1 Eva Wells
28	R. H. Fulton & Co.	#1 Cowen
29	Atlantic Refining Co.	#1 W. M. Tyan
30	Texaco, Inc.	#1 H. C. Pickrell
31	Bethol Corp.	#1 Rollins
32	Delfern Oil Co.	#1 Truelack
33	The Texas Co.	#1 Chisholm
34	J. M. Welborn	#1 Martin
35	Shell Oil Co.	#1 Ivey & McCary
36	Pan American Petroleum Corp.	#1 Cecil Martin
37	H. L. Cain	#1 Gregg
38	Cherry Petroleum Co.	#1-A Pearl Pace
39	Tom Hewitt	#1 Calvert
40	Murchinson-Wayne	#1 Newenschwander
41	Greathouse, Pierce, & Davis	#3-1 Brantley
42	Jergins Oil Co.	#1 Ida May Harris
43	Pacific Western Oil Co.	#1-B D. L. Brown
44	J. S. Abercrombie Mineral Co., Inc.	#1 A. E. Fowler
45	Sohio Petroleum Co.	#1 Lewis
46	Cities Service Oil Co.	#1 Stanley
47	G. P. Livermore Drilling Co.	#1 Janes
48	Lario Oil & Gas Co.	#1 Coen
49	Amerada Petroleum Corp.	#1 Mary Hagler
50	The Texas Co.	#1 Brandt
51	G. P. Livermore Drilling Co.	#1 Hayhurst
52	G. P. Livermore Drilling Co.	#1 Lingnau
53	G. P. Livermore Drilling Co.	#1-106 Littlefield Townsite
54	Hall & Stewart	#2 Littlefield Unit
55	Hall & Stewart	#1 Stewart & Foley
56	L. C. Hewitt	#2 L. C. Hewitt
57	The Texas Co.	#4 Ida D. Hewitt
58	L. C. Hewitt	#1 Fee Ida Dalmont Hewitt
59	Humble Oil & Refining Co.	#1 Fowler
60	Shamrock Oil & Gas Corp.	#1 Bird
61	H. L. Hunt Oil Co.	#1 Foust
62	Big Spring Exploration Co.	#1 Sybert
63	Harding Oil Co.	#1 Beckum
64	Sharples Oil Corp.	#1 Heard
65	Cascade Petroleum Co.	#1 A. P. Duggan
66	G. P. Livermore Drilling Co.	#1-19 Grissom
67	R. E. & J. C. Williamson	#1 Lena H. Bullard
68	Western Drilling Co.	#1 Gray
69	DeKalb Agricultural Assoc.	#1 Melcher
70	W. A. Hover	#1 Alison Thompson
71	George P. Livermore Drilling Co.	#1 Lewey S. Aulse
72	Koch Ind.	#1 Hollowman
73	L. C. Hewitt Trustee	#1 Cunningham
74	Haskins & Knickerbocker	#1 Hulse
75	David Fasken	#7-1 Ruth Dodd
76	F. W. Holbrook	#1 J. E. Wuthrich
77	J. M. Welborn	#1 Fred Gerlach
78	J. M. Welborn	#1 Hilburn
79	Continental Oil Co.	#1 Reed
80	Cherry Brothers	#1 I. J. Rice
81	Shell Oil Co.	#1 Helen Thompson
82	Seaboard Oil Co.	#1 Jackson
83	David Fasken	#1-11 Clara Albus
84	Western Drilling Co.	#1 G. L. White
85	Drilling & Exploration Co.	#1 G. L. White
86	Norvel Douglas	#1 G. L. White
87	Johnson	#1 White Ranch
88	R. H. Fulton	#1 Keithley Estate
89	Hewitt	#1 V. M. Farr
90	DeKalb Agricultural Assoc.	#1 Stokes
91	DeKalb Agricultural Assoc.	#2 Albus
92	Depco., Inc.	#10 Young
93	DeKalb Agricultural Assoc.	#1 Locke
94	Sunray	#1 Gibson
95	Petroleum Exploration Inc. of Texas	#1-22 Price
96	R. H. King et al.	#1 J. Johnson
97	Shell Oil Co., Honolulu Oil Corp.	#1 C. R. Anderson

98	Jul-Tex Drilling Co.	#1-A J. T. Graham
99	Sohio Petroleum Co.	#1 R. C. Middlebrook
100	B. T. A. Oil Producers	#2 Anton 7112 JV-D
101	B. T. A. Oil Producers	#1 Anton 7112 JV-D
102	Cherry Petroleum Co.	#1 Middlebrook
103	San Juan Exploration Co.	#1 Jones
104	Mesa Petroleum Co.	#1-23 McCary
105	U. S. Signal Oil & Gas 71	#1 Reznik
106	J. W. Murchison	#1 H. Lisso
107	Jack W. Tranthan	#1 L. H. Porter
108	G. M. K. Wood	#1 McCurry
109	Midwest Oil Co.	#1 Duane Moser
110	The Texas Co.	#1 Kirk
111	H. L. Cain	#1 Moss
112	Joe M. Champlain	#1 Maynard
113	Joe M. Champlain	#1 Thomas James
114	Humble Oil & Refining Co.	#1 Branton
115	R. H. Fulton	#1 Pate
116	Gulf Oil Co.	#1-e D. R. Hopkins
117	Pan American Petroleum Corp.	#143 Anton-Irish
118	Pan American Petroleum Corp.	#142 Anton-Irish
119	Pan American Petroleum Corp.	#144 Anton-Irish
120	Pan American Petroleum Corp.	#146 AICFUW
121	Pan American Petroleum Corp.	#145 Anton-Irish Clear Fork Unit
122	W. M. & A. P. Fuller	#1 Troy Armes
123	Nash, Beck & Davis	#1 Halsell
124	Humble Oil & Refining Co.	#1 J. A. Jackson
126	Sun Oil Co.	#1 Halsell
148	Koch Exploration	#1 Yellowhouse Ranch
152	Jed Miller Co.	#1 Hinson Farm
157	Humble Oil & Refining Co.	#1 Bagwell
158	National Assoc. Petroleum Co.	#2 Halsell
159	Argo Petroleum Co.	#1 Thedford 19

LUBBOCK COUNTY

19	Bankline Oil Co.	#1-A Elliott

MOORE COUNTY

8	Continental Oil Co.	#1 Amis
13	Diamond Shamrock Oil and Gas Co.	#1 Robertson Storage
36	A. H. Rowland	#1-A Terry
46	Colorado Interstate Gas Co.	#36-A Masterson
53	Texas Gas Producing Co.	#1 Brown

MOTLEY COUNTY

1	West Central Drilling Co.	#1 W. T. Ross
2	Miami Operating Co., Inc.	#1-H Shoenail
3	Sunray DX Oil Co.	#1 Joan Louis Tatum
4	Dugger & Herring	#1 Russell
5	Lion Oil Co.	#1 Shoenail
6	Humble Oil & Refining Co.	#C-2 Matador Land & Cattle Co.
7	Humble Oil & Refining Co.	#C-1 Matador Land & Cattle Co.
8	A. Gutowsky, Inc.	#1 Mrs. Mattie Waybourne
9	General Crude Oil Co. et al	#1 I. F. Fish
10	Amerada Petroleum Corp.	#1 O. E. Birnie
11	General Crude Oil Co.	#1 F. M. Eiring
12	General Crude Oil Co.	#1 O. E. Birnie
13	General Crude Oil Co.	#1-A O. E. Birnie
14	Humble Oil & Refining Co.	#2 Matador Land & Cattle Co. "K"
15	Ray A. Albaugh Producing Co.	#1 Matador Land & Cattle Co.
16	Humble Oil & Refining Co.	#1 Matador Land & Cattle Co. "H"
17	Humble Oil & Refining Co.	#3 Matador Land & Cattle Co. "H"
18	Humble Oil & Refining Co.	#H-2 Matador Land & Cattle Co.
19	General Crude Oil Co.	#1 C. J. Soderstom
20	Perkins-Prothro	#1 Swenson "F"
21	Perkins-Prothro	#1 Swenson "B"
22	Kay Kimble et al.	#1 Swenson
23	Perkins-Prothro	#1 Swenson "A"
24	W. A. Moncrief & Sons	#1 Swenson
25	Five Resources, Inc.	#1 Westbrook
26	Atlantic Refining Co.	#1 Swenson Cattle Co.
27	Humble Oil & Refining Co.	#D-3 Matador
28	Humble Oil & Refining Co.	#4 Matador Land & Cattle Co. "D"
29	Humble Oil & Refining Co.	#2 Matador Land & Cattle Co. "D"
30	Humble Oil & Refining Co.	#1-D Matador
31	Ray Albaugh	#1-108 Matador Land & Cattle Co.
32	Perkins-Prothro	#2 Eva Thacker
33	Pan American Petroleum Corp.	#2 F. E. Brandon
34	Cosden Petroleum Corp.	#2 Ben Hawley
35	Cotten Petroleum Corp.	#1 Anna Webb
36	General Crude Oil Co.	#1 Hunsucker
37	Humble Oil & Refining Co.	B-2 Matador Land & Cattle Co.
38	Humble Oil & Refining Co.	#B-4 Matador
39	Humble Oil & Refining Co.	#B-7 Matador Land & Cattle Co.
40	Sun Oil Co.	#1 Matador Land & Cattle Co.
41	Humble Oil & Refining Co.	#6 Matador Land & Cattle Co. "B"
42	Humble Oil & Refining Co.	#B-1 Matador
43	Moss-Gordon Co., Ltd.	#1 M. S. Thacker
44	E. E. Moss & Sons	#1 Ollie Scott
45	Perkins-Prothro	#A-1 Brooks
46	Cascade Petroleum Co.	#1 E. C. Stearns
47	Pierce & Dehlinger	#1 Campbell
48	Locke Purnell & Fortune Drilling Co.	#1 Heath M. Robinson
49	Kadane - Griffith Oil Co.	#1 C. M. Bird
50	Skelly Oil Co.	#1 Tom Windham
51	Louisiana Coastal Petroleum Corp.	#1-44 Swenson
52	General Crude Oil Co.	#43-1 Swenson Development Co. "E"
53	Perkins-Prothro	#K-1 Swenson
55	General Crude Oil Co.	#280-1 Swenson Development Co. "E"
56	J. C. Williamson	#1 Bird
57	General Crude Oil Co.	#5-1 Swenson Development Co. "A"
76	Perkins-Prothro	#1 Hamilton "H"
77	Transcontinental Oil Corp.	#1 Payne
78	Miami Operating Co., Inc.	#2 Shoenail "H"
79	Koch Exploration Corp.	#1 Bob Jameson

OLDHAM COUNTY

1	Colorado Interstate Gas Co.	#1 Shelton
2	Shell Oil Co.	#1-68 Strat Test
3	R. H. Fulton	#1 Fulton Ranch
4	Shell Oil Co. and Atlantic Refining Co.	#1-6 Fulton
5	Shell Oil Co. and Atlantic Refining Co.	#98-1 Fulton
6	Superior Oil Co.	#6 Matador
7	Shell Oil Co.	#1-B Bivins
8	Shell Oil Co.	#1 Tascosa
9	Pioneer Production Corp.	#D-13 Bivins
10	Shell Oil Co.	#1 Bivins Ranch
11	Amarillo Oil Co.	#D-10 Bivins
12	Amarillo Oil Co.	#D-12 Bivins
13	Colorado Interstate Gas Co.	#111 Bivins A
14	Bivins Interest	#1 Channing
15	Pioneer Production Corp.	#D-14 Bivins
16	Shell Oil Co.	#B-1 L. S. Ranch
17	Colorado Interstate Gas Co.	#1 Ware
18	Shell Oil Co.	#1 L. S. Ranch
19	Cities Service Oil Co.	#A-1 L. S. Ranch
20	Shell Oil Co.	#1-60 Alamosa
21	Shell Oil Co.	#C-1 Alamosa Ranch
22	Shell Oil Co.	#1A-84 Fulton Ranch

23	Shell Oil Co. and Atlantic Refining Co.	#1-80 Fulton
24	Shell Oil Co.	#1-51 Fulton Ranch
25	Shell Oil Co.	#2-68 Strat Test
26	Coastal States Gas Producing Co.	#1 Mansfield
27	Shell Oil Co.	#3-68 Strat Test
28	Superior Oil Co.	#3 Matador
29	Roy Albaugh	#1 Matador
30	Superior Oil Co.	#2 Matador
31	Superior Oil Co. & Lazard	#1-312 Matador
32	Stanolind Oil & Gas Co.	#1 W. H. Green
33	Prairie Oil & Gas	#1 Lanergin
34	Shell Oil Co.	#3 Alamosa "A"
35	Hunt Oil Co.	#1 Alamosa Ranch
36	Shell Oil Co.	#1 Alamosa Ranch
37	Shell Oil Co.	#2 Alamosa Ranch "A"
38	Shell Oil Co.	#6-58 Strat Test
39	Shell Oil Co.	#1-58 Strat Test
40	Shell Oil Co.	#2-58 Strat Test
41	Shell Oil Co.	#B-3 Alamosa Ranch
42	Shell Oil Co.	#1-B Alamosa
43	Shell Oil Co.	#B-2 Alamosa
44	Shell Oil Co.	#8 Alamosa
45	Shell Oil Co.	#315-4 Alamosa
46	Shell Oil Co.	#315-2 Alamosa
47	Shell Oil Co.	#315-7 Alamosa
48	Shell Oil Co.	#1-315 Alamosa
49	Shell Oil Co.	#315-9 Alamosa
50	Shell Oil Co.	#1 Green
51	Shell Oil Co.	#3-58 Strat Test
52	Stanolind Oil & Gas Co.	#1 C. T. & W. E. Herring
53	Shell Oil Co.	#4-58 Strat Test
54	Shell Oil Co.	#5-58 Strat Test
55	Superior Oil Co.	#54-9 Gray
56	Humble Oil & Refining Co.	#1 J. F. Binford
57	Chambers	#1 Herring
58	Shell Oil Co.	#1 Taylor
59	Shell Oil Co.	#1 Bravo
60	Humble Oil & Refining Co.	#1 Humble
61	Atapco	#1 J. Taylor
62	Skelly Oil Co.	#1 J. Taylor
63	Royal Resources Corp.	#1 Tom Green
64	Ray Albaugh	#3 Matador
65	Superior Oil Co.	#1 Matador
66	Superior Oil Co.	#4 Matador
67	Barnett Oil Co.	#1 Currie
68	G. P. Livermore Drilling Co.	#1 Moser
69	Pan American Petroleum Corp.	#1 D. Whaley
70	Superior Oil Co.	#1 Howard Estate
71	Humble Oil & Refining Co.	#1-B J. F. Binford
72	Amarillo Oil Co.	#3-D Bivins
73	British-American Oil Production Co.	#1 Shelton
75	Baker & Taylor Drilling Co.	#1 Gravel Pit
76	Alpar Resources, Inc.	#1-38 Billy's Creek
77	Alpar Resources, Inc.	#1-35 Middle Creek
78	Page Petroleum, Inc.	#1-35 Newbill
79	Alpar Resources, Inc.	#1-98 Ranch Creek
80	Page Petroleum, Inc.	#1-11 Scott
81	Wagner & Brown - C & K Petroleum, Inc.	#1-15 Ware Ranch
82	Hoover & Bracken	#1 Gray Ranch
83	Baker & Taylor Drilling Co.	#4-A Mansfield
84	Stone and Webster Engineering Corp.	#1 Mansfield

PARMER COUNTY

1	U. S. Smelting Refining & Mining Co.	#A-1 S. H. Osborn
2	Gulf Oil Corp.	#A-1 Keliehor
3	Ashmun & Hilliard	#1 P. L. London
4	Stanolind Oil & Gas Co.	#1 A. J. Jarrell
5	Shell Oil Co.	#30-69 Shell Strat
6	Oil Well Drilling Co.	#1 Tharp
7	Mobil Oil Co.	#1 Sorley-Williams
8	Texaco, Inc.	#1 Owen Patton
9	Texaco, Inc.	#1 Capitol Mineral Rights
10	Sunray Oil Corp.	#1 Kimbrough
11	Convest Energy Corp.	#1 O. L. Jarman
12	U. S. Petroleum Co.	#1 Jamison
13	U. S. Petroleum Co.	#1 Jamison

POTTER COUNTY

1	Sinclair Oil & Gas Co.	#13 Bivins Estate
2	Bivins Interests	#1 Exell-Shell
3	Sinclair Oil & Gas Co.	#16 Bivins Estate
4	Sinclair Oil & Gas Co.	#9 Bivins
5	Colorado Interstate Gas Co.	#2-R Bivins
6	Sinclair Oil & Gas Co.	#5 Bivins
7	Colorado Interstate Gas Co.	#33-R Masterson
8	Colorado Interstate Gas Co.	#34-R Masterson
9	Sinclair Oil & Gas Co.	#11 Bivins
10	Sinclair Oil & Gas Co.	#17 Bivins Estate
11	Barnett Oil Co.	#68-47-1 Masterson
12	Wm. Gruenerwald et al.	#2-1X Masterson
13	Sinclair Oil & Gas Co.	#4 Masterson
14	Humble Oil & Refining Co.	#1 Caroline Bush Emery
15	Humble Oil & Refining Co.	#1-B Bush Trust Estate
16	Nabob Production Co.	#1 Fuqua Unit
17	Bivins Interests	#1 Strip
18	Amarillo Oil Co.	#1 Frank Givens
19	Shell Oil Co.	#1-207 Bivins
20	Bivins Interests	#2 Pedrosa
21	Eason Oil Co.	#1-3 Bivins Ranch
22	Lee T. Bivins	#1 Pedrosa
23	Bivins Interests	#3 Pedrosa
24	Eason Oil Co.	#1-60 Bivins Ranch
25	Bivins Interests	#1 LX-Shell
26	E. H. Rice	#1 Williams
27	Catherine C. Whittenburg	#1 Masterson
28	James G. Brown & Associates	#1 Hill
29	Amarillo Oil Co. and Socony Mobil Oil Co.	#1 Wilkins
30	Grady L. Fox	#1 Abbott
31	U. S. Bureau of Mines	#6-A Bush
32	U. S. Bureau of Mines	#15-A Bivins
33	Sinclair-Prairie	#1 Bush
34	Standard Oil Co. of Texas	#1 Bush
35	Addison Warner	#1 Bush
36	Harrington & Marsh	#1-A Bush Estate
37	Harrington & Marsh	#1-A Higgs
38	Amarillo Oil Co.	#1 Lundegreen
39	Texaco, Inc.	#1 Bivins
40	Canadian River	#1 City of Amarillo
41	Asarco	#1-29 WDW
42	Iowa Beef Processors, Inc.	#1 Iowa Beef
43	Tesoro Petroleum Co.	#1 Paxton
44	Humble Oil & Refining Co.	#1 Gouldy
45	Colorado Interstate Gas Co.	#33-A Masterson
46	Colorado Interstate Gas Co.	#34 Masterson
47	Amarillo Oil Co.	#6-D Bivins

RANDALL COUNTY

1	Frankfort Oil Co.	#1 H. L. Erwin
2	Burdell Oil Co.	#1 Winters
3	Woolsey - Devore	#1 Oxnard
4	Burdell Oil Co.	#1-A Winters
5	Frankfort Oil Co.	#1 Rex White
6	T. W. Carter	#1 Currie
7	Big Bear Oil Co.	#1 Currie
8	Pan Eastern Exploration Co.	#1 Powers
9	Texaco, Inc.	#1 Stomm
10	Placid Oil Co.	#1 Greeley
11	Roy Furr	#1 Beckman
12	Amarillo Oil Co.	#1 Irene Hicks
13	Arkla Exploration Co.	#1-55 Skypala
14	Shell Oil Co.	#1 Nester
15	Arkla Exploration Co.	#1-83 Kuhlman
16	Texaco, Inc.	#1 G. H. Leseberg

17	Consolidated Gas & Equipment Co.	#1 Oliver
18	Slessman	#1 Nance
19	Frankfort Oil Co.	#1 Grogan
20	Hassie Hunt Trust Estate	#1 L. B. Carruth
21	Frankfort Oil Co.	#1 L. L. Hix
22	Frankfort Oil Co.	#1 Stinnett "B"
23	Frankfort Oil Co.	#1 Stinnett
24	Meridian Oil Corp.	#1 Winters
25	Gruy-Federal, Inc.	#1 Rex H. White

ROBERTS COUNTY

33	Phillips Petroleum Co.	#1-C Cowan

ROOSEVELT COUNTY, NEW MEXICO

5	Humble Oil & Refining Co.	#1 New Mexico "CT" State
62	Shell Oil Co.	#2 Bluitt Unit

SHERMAN COUNTY

31	Petroleum Exploration	#1 Bullington
39	Petro Associates, Inc.	#1-332 Pronger

SWISHER COUNTY

1	Frankfort Oil Co.	#1 Wesley
2	L. A. Helms	#1 Harris
3	Frankfort Oil Co.	#1 Culton
4	Frankfort Oil Co.	#1 Bradford
5	Devore & Slade	#1 Kleen
6	Standard Oil Co. of Texas	#1 Johnson
7	H. L. Hunt Oil Co.	#1 Bivins
8	Burdell Oil Co.	#1 Bradford
9	Humble Oil & Refining Co.	#1 Nanny
10	Consolidated Gas & Equipment Co.	#1 Patton
11	Consolidated Gas & Equipment Co.	#1 Thompson
12	Frankfort Oil Co.	#1 Sweatt
13	Sinclair Oil & Gas Co.	#1 Savage
14	Chambers and Kennedy et al.	#1 Rodgers
15	Herdon Oil and Gas Co.	#1 Fowler McDaniel
16	Stone and Webster Engineering Corp.	#1 Zeeck
17	Stone and Webster Engineering Corp.	#1 Grabbe

TEXAS COUNTY, OKLAHOMA

10	Cities Service Oil Co.	#83-A Stonebreaker

YOAKUM COUNTY

156	Major Giebel & Forster	#1 Johnson
342	Louisiana Coastal Petroleum	#1 Been
349	H. L. Brown, Jr.	#1 Arc
353	H. L. Brown, Jr.	#1 Weaver

WHEELER COUNTY

83	Eldorado Oil and Gas Co.	#1 Roberts

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PLATE I. BASE MAP OF WELL CONTROL.

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REPORT OF INVESTIGATIONS NO. 123
PLATE II

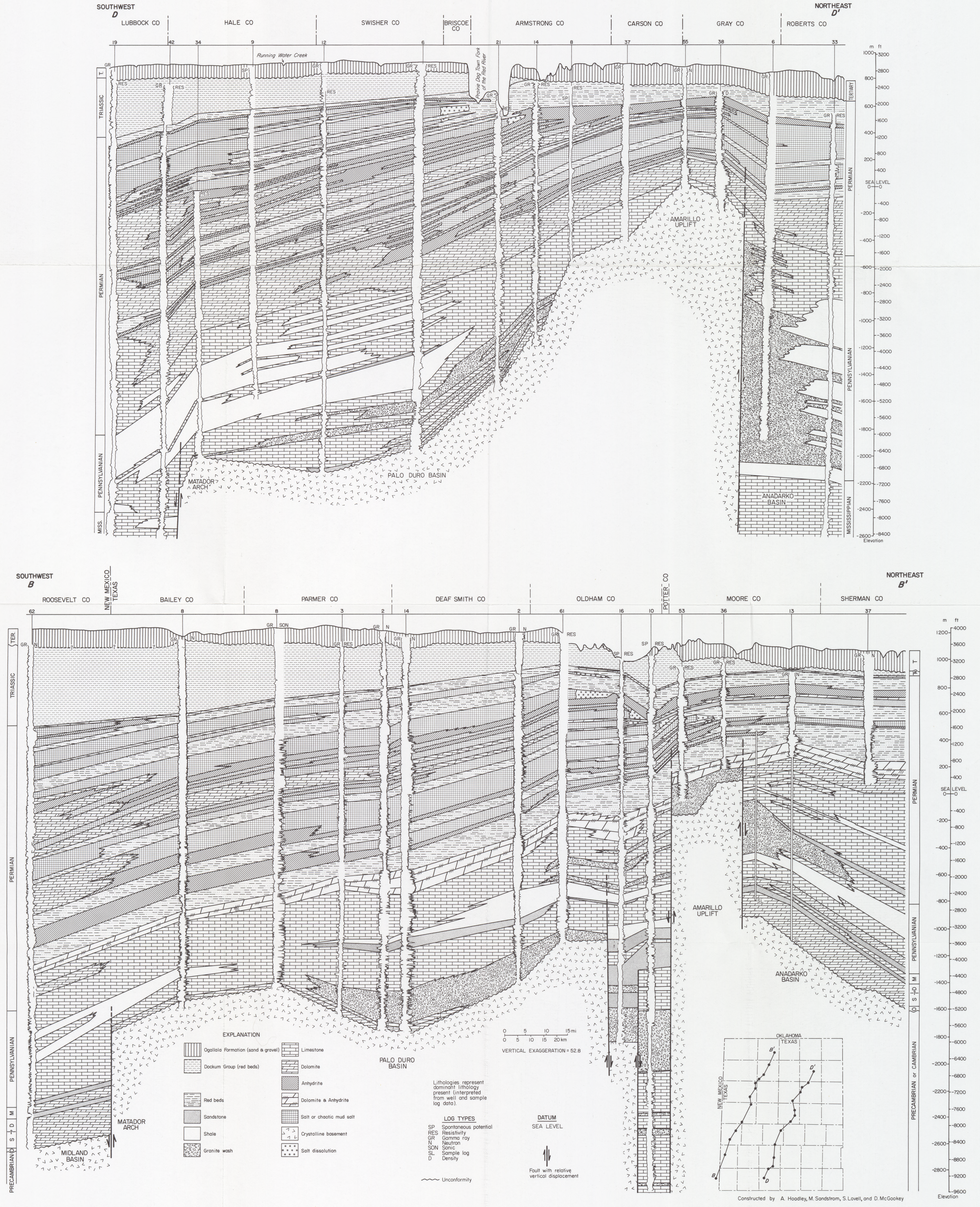

PLATE II. STRUCTURAL CROSS SECTIONS B-B' AND D-D' ACROSS THE PALO DURO BASIN, BASEMENT TO SURFACE.

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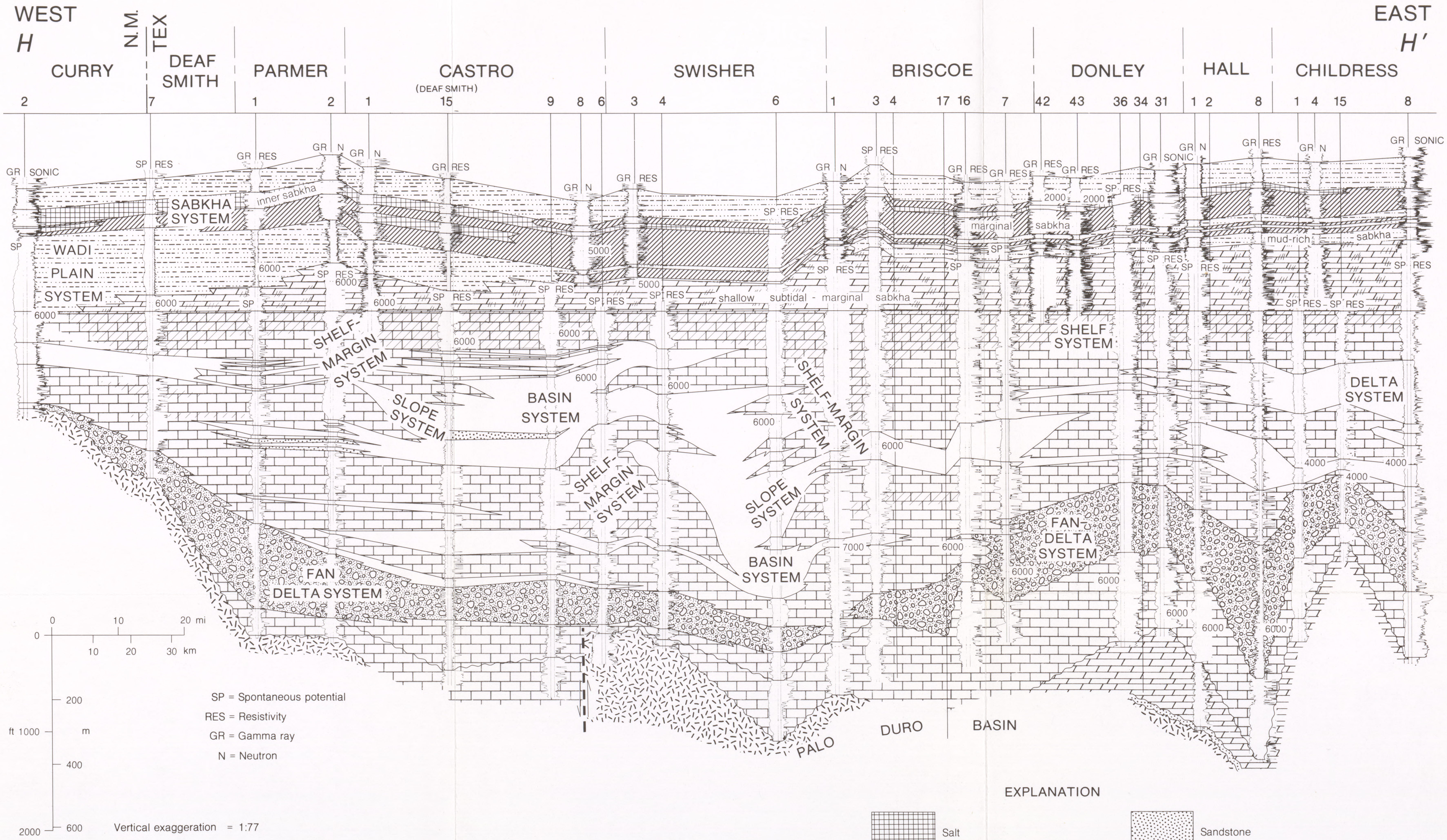
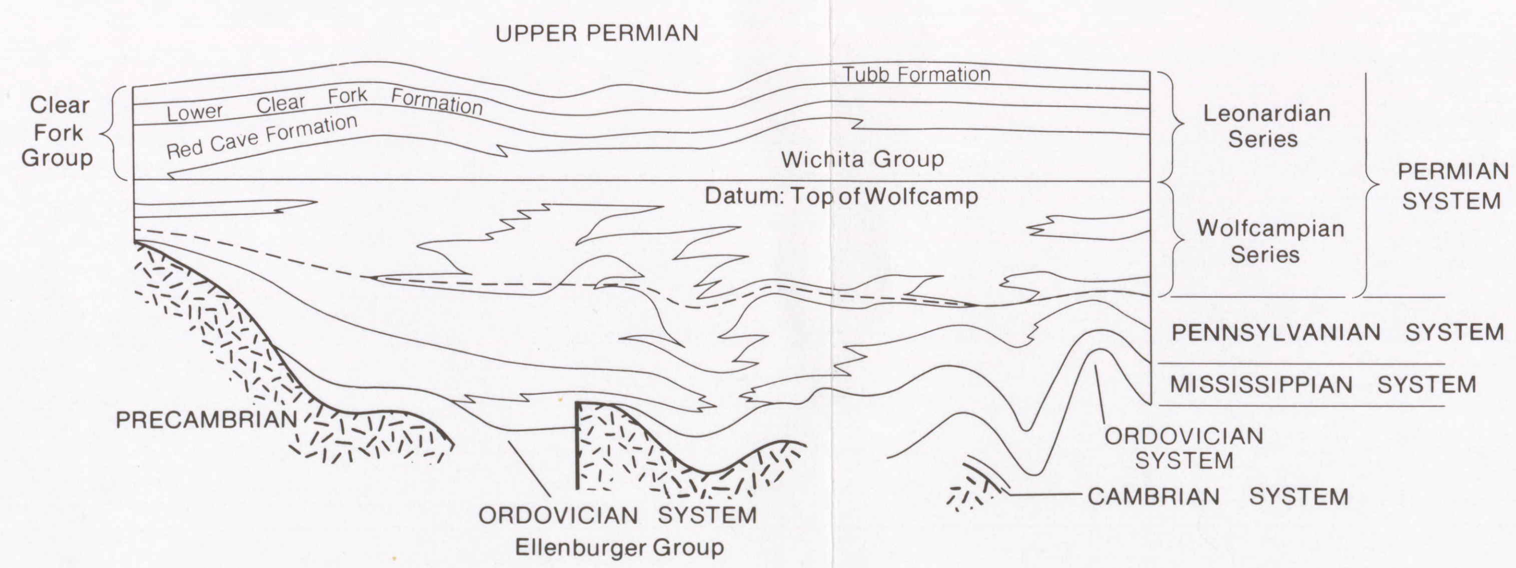
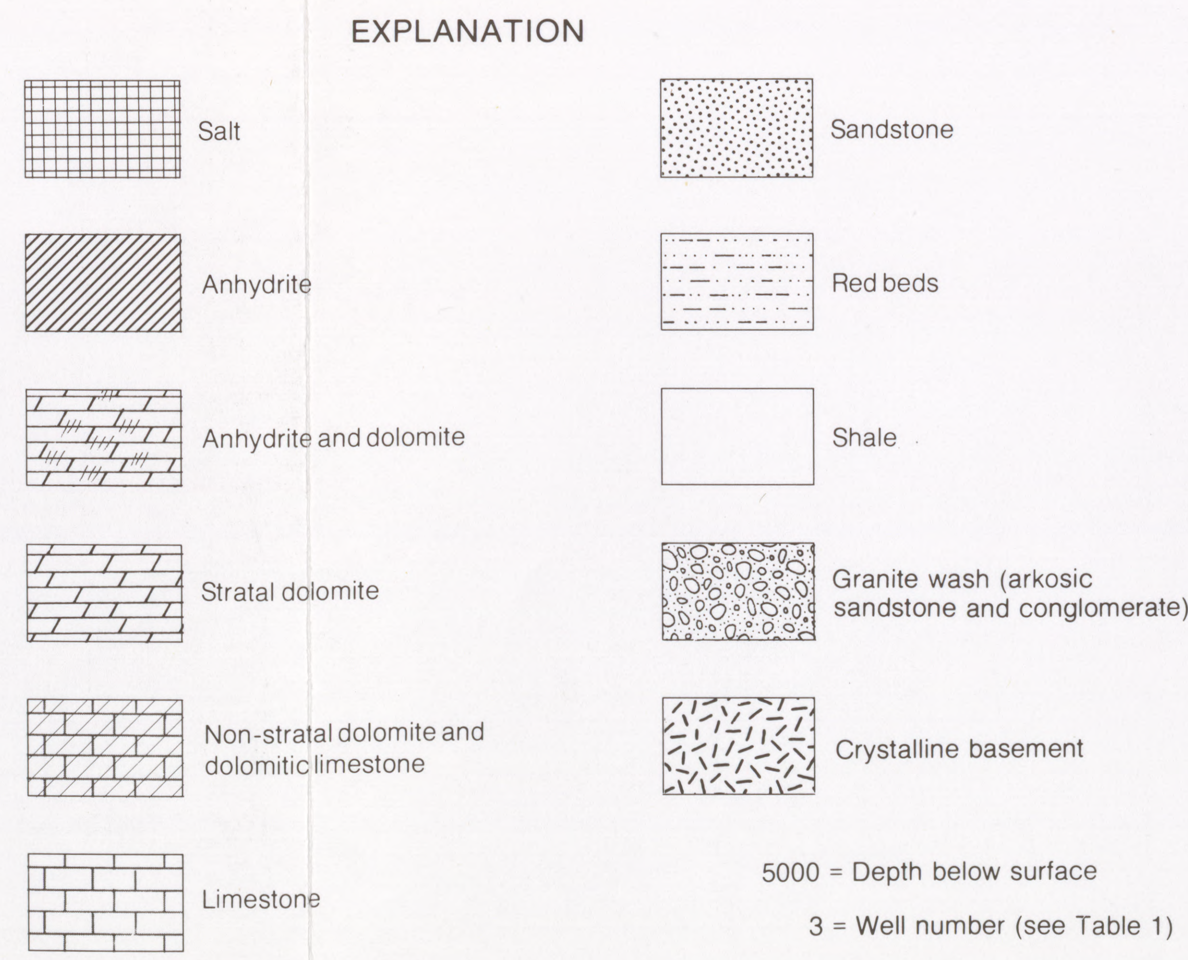
REPORT OF INVESTIGATIONS NO. 123
PLATE III







By C. Robertson Handford,
Shirley P. Dutton, and Paul E. Fredericks,
1981.

PLATE III. STRATIGRAPHIC CROSS SECTION H-H' OF BASEMENT TO MID-PERMIAN.

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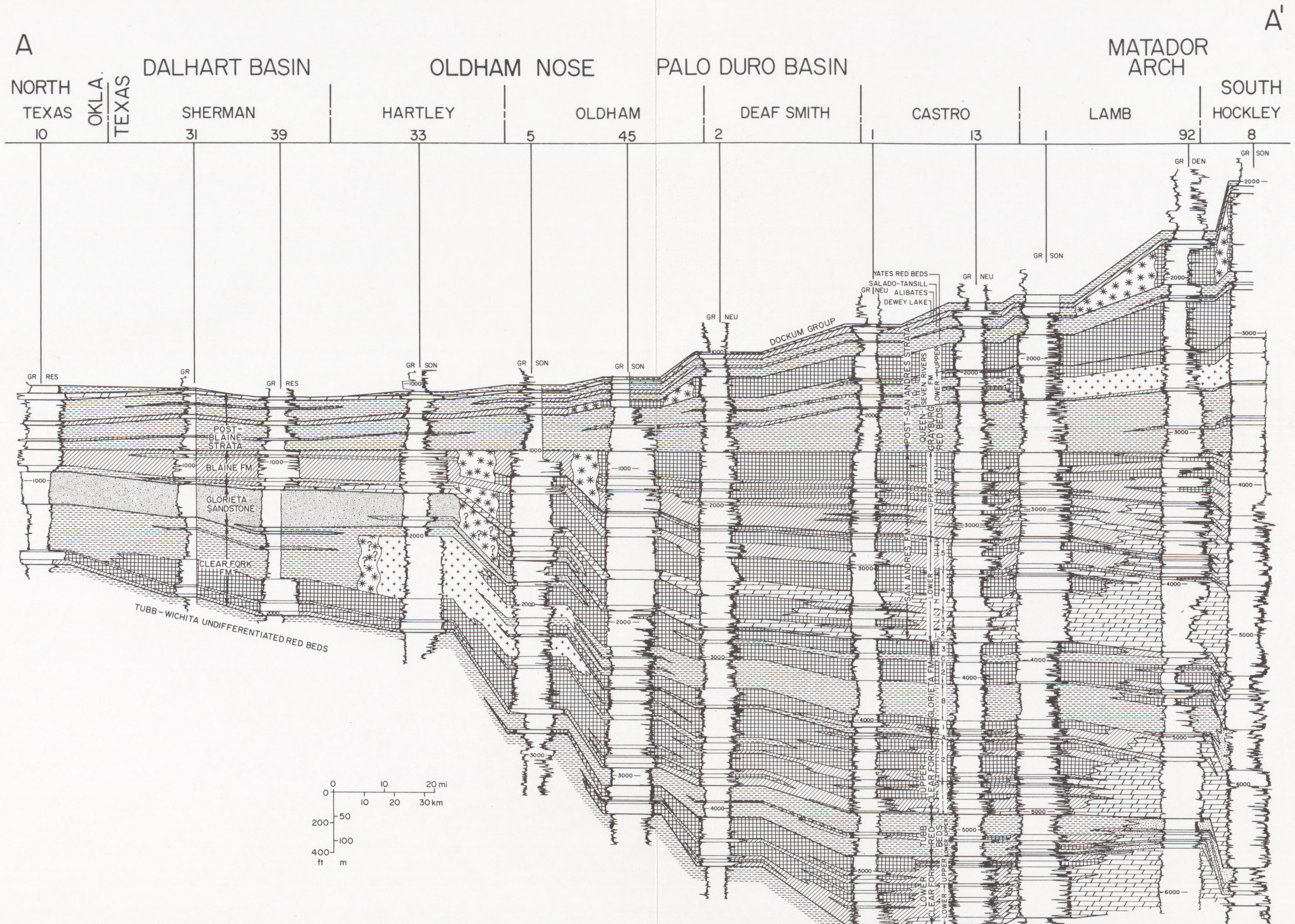
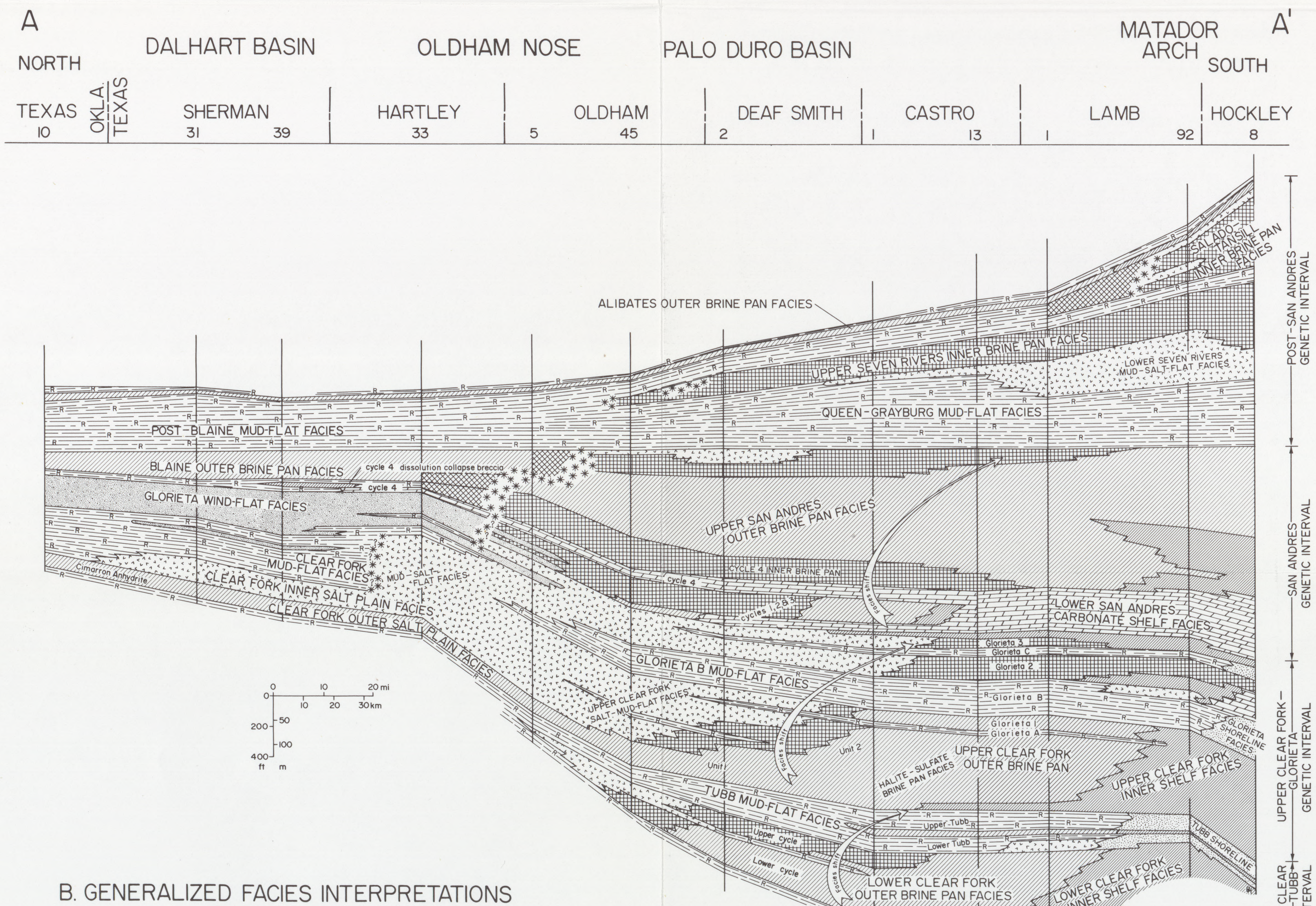
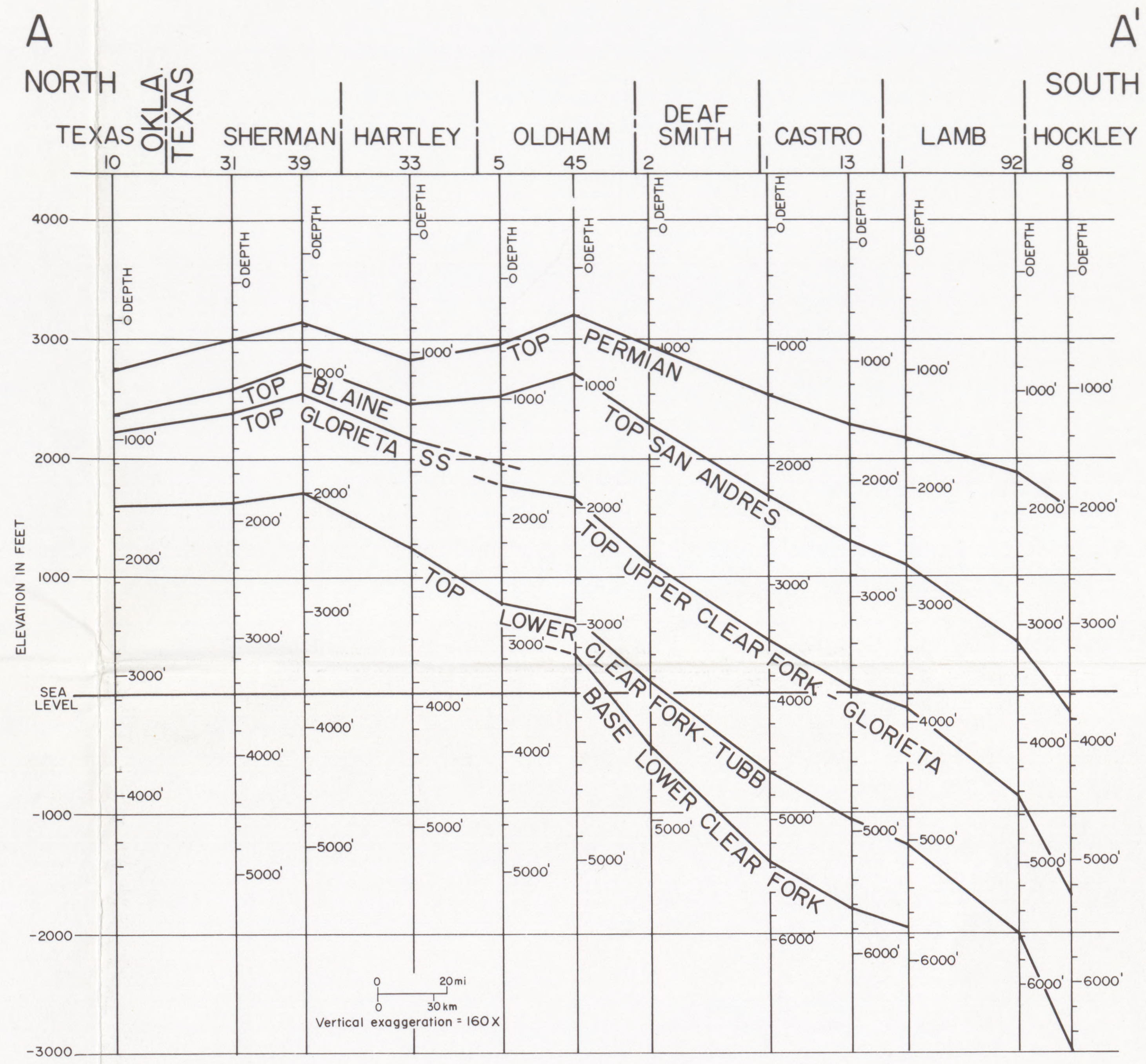


A. GENERALIZED LITHOLOGIC INTERPRETATIONS

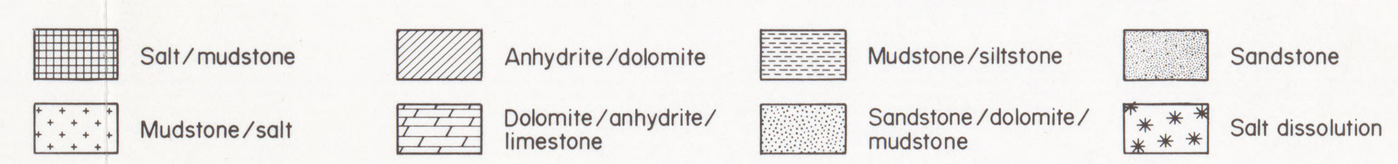


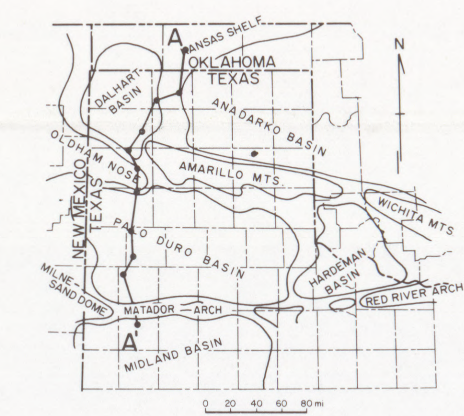
B. GENERALIZED FACIES INTERPRETATIONS



C. STRUCTURE ON MAJOR UNITS

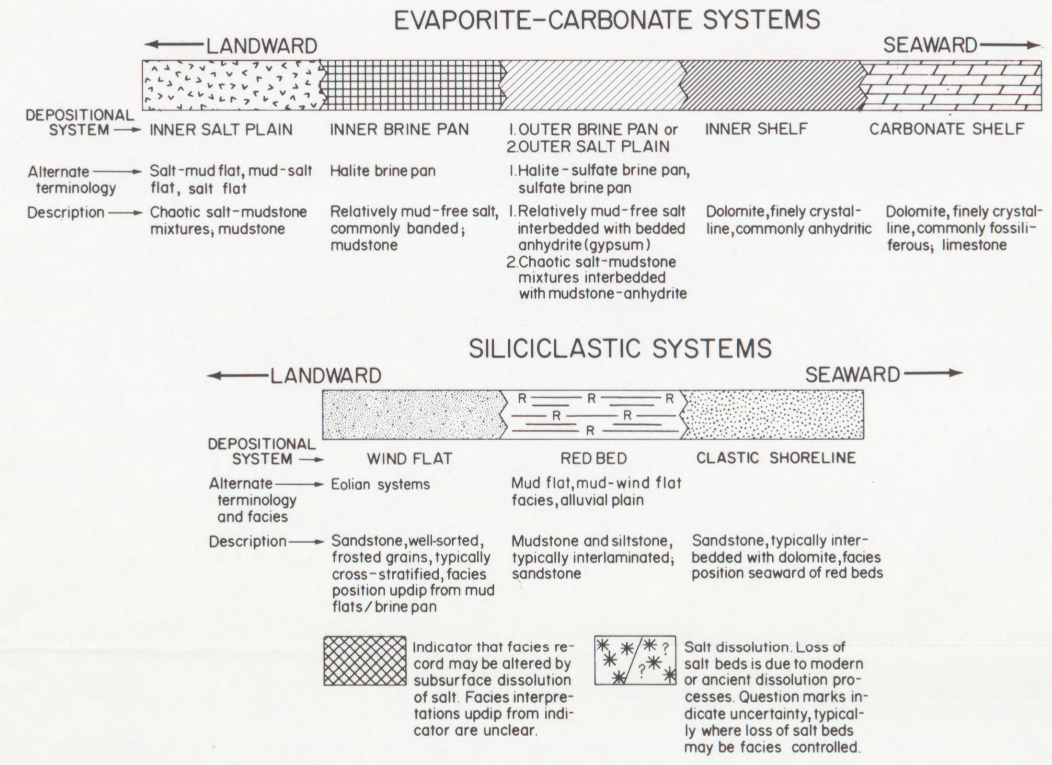
EXPLANATION - LITHOLOGIC INTERPRETATIONS





D. LOCATION MAP

EXPLANATION
FACIES INTERPRETATIONS



Mark W. Presley, 1981

PLATE IV. STRATIGRAPHIC CROSS SECTION A-A' THROUGH UPPER PERMIAN SALT-BEARING STRATA.

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REPORT OF INVESTIGATIONS NO. 123
PLATE V

PLATE V. STRUCTURE CONTOUR MAP ON TOP OF CRYSTALLINE BASEMENT, TEXAS PANHANDLE.

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REPORT OF INVESTIGATIONS NO. 123
PLATE VI

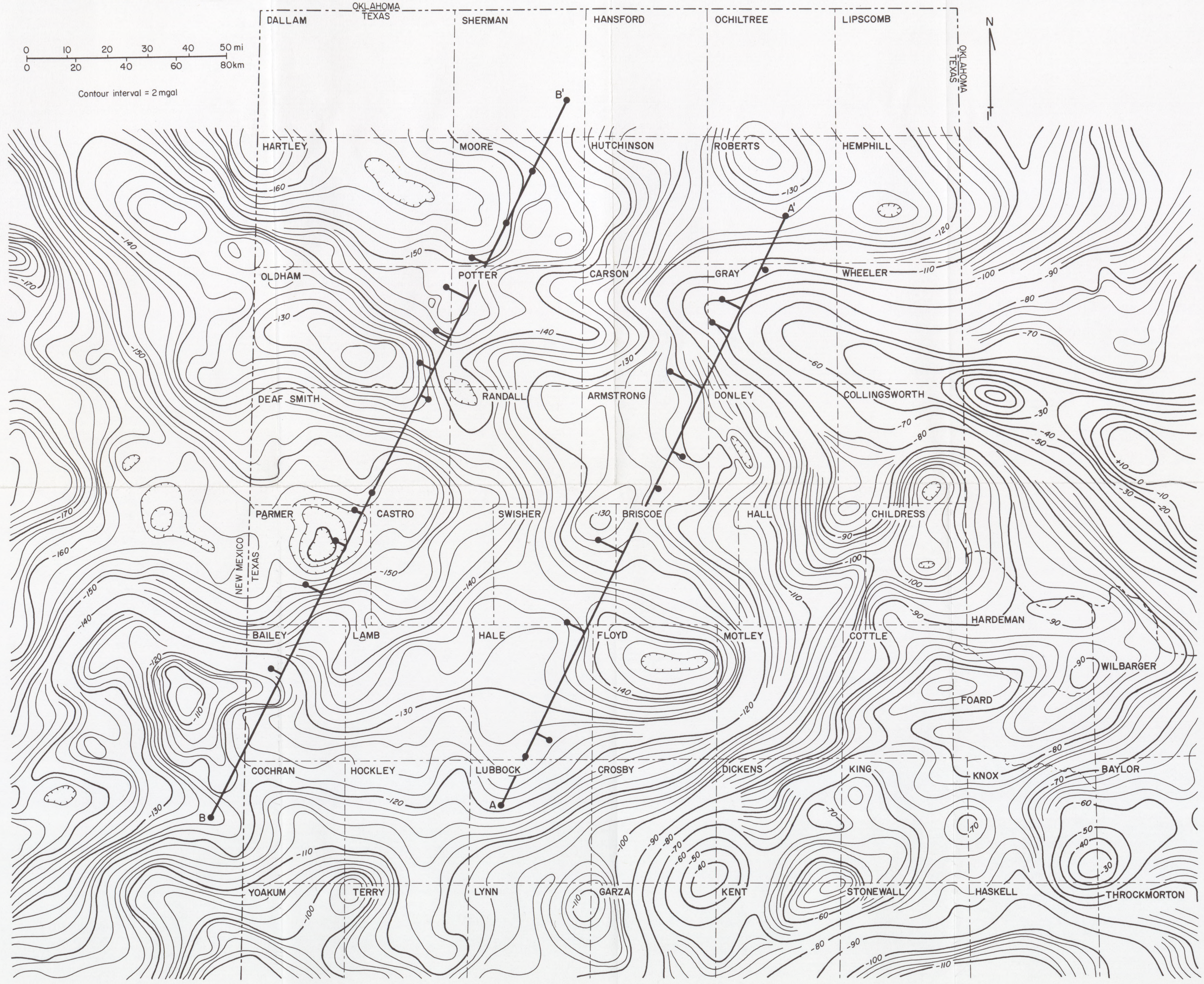

PLATE VI. BOUGUER GRAVITY MAP, TEXAS PANHANDLE.