shale, sandstone, siltstone, and limestone of the Spraberry Formation.

The basin sediments appear to be ideal petroleum source rocks and limited fracture development restricts the occurrence of basin oil to rock of Permian age. Shelf or platform oil may be mixed Permian and pre-Permian due to structural deformation, faulting, fracturing, and deposition across truncated surfaces.

Correlations of oil analyses with reservoir rock types suggest that differences in the chemical composition of basin and shelf oils may be related to the amount of evaporites in the reservoir rocks.

Oil groupings can be explained geologically through differences in sources, environment, paths of migration, or mixing of oils.

6. N. A. SAX, Humble Oil & Refining Co., Midland, Tex., AND WILLIAM K. STENZEL, Marathon Oil Co., Findlay, Ohio

OILS FROM ABO RESERVOIRS OF NORTHWESTERN SHELF

Twenty-five crude-oil samples collected along strike, up- and downdip, and stratigraphically high and low along the 75-mi Abo reef trend in southeast New Mexico were analyzed chemically and isotopically. It was hoped that these analyses would show significant relationships with geologic phenomena and that conclusions might be made regarding source, migration, and accumulation.

Geologically the Abo reef trend is a narrow east-west belt of middle Permian reef and bank-edge dolomitized carbonates approximately 70 mi long and 1-3 mi wide. These rocks form the reservoirs in significant Abo fields such as Empire, Vacuum, Lovington, *etc.* Dolomite of the Abo overlies Wolfcamp limestone. This dolomite-limestone interface is used commonly to separate rocks of Wolfcamp age from those of Leonard age; however, present evidence indicates that at least part of the subsurface Abo is Wolfcamp in age. The intertonguing relations of back-reef, reef, forereef, and basinal facies exist throughout the extent of the east-west "reef" belt. Generally, it can be stated that Abo petroleum originated in the basinal facies, migrated to the forereef and reef facies, and was restricted from further updip migration by anhydrite cementation. This cementation was caused by seepage refluxion on the shelf at the shelf-reef interface; anhydrite cementation decreases into the reef.

The analyses showed that the crude samples taken from Permian Wolfcamp, Abo, and Yeso reservoirs could be separated into three major source groups: Abo-Wolfcamp basinal rocks, Yeso basinal rocks, and pre-Pennsylvanian rocks. It has been demonstrated that crude-oil analyses and carbon-isotope analyses are excellent tools that can be used to determine the age of the source rocks of the Abo oil and enable the geologist to make significant conclusions regarding origin, migration, and accumulation.

7. B. B. COESTER, Atlantic-Richfield Co., Midland, Tex., AND JACOB L. WILLIAMS, Phillips Petroleum Co., Midland, Tex.

RELATIONSHIPS OF OIL COMPOSITION AND STRATIGRAPHY IN MULTIPAY FIELDS

Oil and water samples were collected and analyzed from five fields in West Texas and New Mexico. Two of the fields, Harper and Midland Farms, were "protected"; *i.e.,* the producing formations are not connected by known faults or unconformities and the oils from separate formations are different. Both protected fields are uncomplicated anticlinal traps.

Oil samples from Harper field from the Ellenburger (Lower Ordovician), Devonian, Pennsylvanian, and San Andres (upper Permian) are distinct. Simpson (Lower Ordovician) oil is identical with Ellenburger oil, showing a common source or migration *via* small faults.

At Midland Farms, Ellenburger and San Andres oils are distinct. Devonian and Silurian oils are similar to each other, because of a similar source, but are different from other oils. Pennsylvanian and Wolfcamp (lower Permian) oils also are similar to each other for the same reason, but are different from other oils.

Justis and Embar fields are "unprotected"; *i.e.*, some of the producing formations are connected by faults or unconformities and the oils in the different formations are similar. In both fields lower Permian rocks overlie lower Paleozoic strata unconformably. Both fields are faulted on the east flank.

At Justis, Ellenburger and Simpson oils are similar but not identical, possibly due to mixing from two sources. Montoya (Upper Ordovician), Silurian, and Clearfork (Leonard-Permian) oils are almost identical. This similarity may be due to a common source. It may also be due to migration, *via* faults, from pre-existing Montoya-Fusselman pools to the Clearfork. Seven Rivers-Queen (upper Permian) oils are different from others in the field.

At Embar there are several transverse faults. At Block 11 field, 2 mi west of Embar, lower Permian rocks overlie the Devonian. The Devonian is absent on the crest of Embar, but is present and productive in downthrown blocks on the east flank. Ellenburger, Silurian, Devonian, and Clearfork oils at Embar are very similar due to migration from a common source or to migration *via* faults. Devonian oils at Block 11 are similar to but slightly different from oils at Embar.

8. JOHN E. GALLEY, Shell Oil Co. (Retired), Kerrville, Tex.

SOME TECTONIC PRINCIPLES IN PERMIAN BASIN OF TEXAS AND NEW MEXICO

The Permian basin of Texas and New Mexico is primarily a depositional feature. It occupies the site of a structural depression in the relatively stable continental interior of North America. All tectonic events that created the Permian basin and its internal elements took place during the Paleozoic.

The Central Basin platform is the most prominent tectonic element within the basin. Smaller uplifts associated with the Central Basin platform cluster on and around it. They include most of the oil- and gas-producing anticlines of this prolific province.

The Central Basin platform and many of its satellite anticlines are bounded by faults along their steeper flanks. Some of the faults are "normal," where categorized by the absence of expected strata in a well bore; others are categorized as "reverse" where a stratigraphic section is repeated in a boring. All known faults in the province are vertical or nearly so. There is no evidence of low-angle thrust faults north of the Ouachita-Marathon tectonic belt. There is no evidence that vertical movements on the faults were caused by lateral compressive forces of regional scope.

Evidence of strike-slip movement is inconclusive because it is difficult to detect and document. The presence of a cover of Mesozoic and Cenozoic strata in much of the Permian basin obscures many of the diagnostic phenomena that might otherwise be evident. Observations in other parts of the stable interior of the North American continent suggest that transcurrent movement probably occurred along some, if not many, of the faults in the Permian basin. Such movements presumably should be looked for especially in proximity to the Ouachita-Marathon belt where the tectonic patterns indicate the influence of strong compressive stresses.

The geometry of faulted anticlines in the Permian basin, and their similarity to mapped structures in outcrop areas where underlying concordant Precambrian basement structures can be observed, suggest strongly that they originated from stresses that were directed vertically upward in the basement complex. The folding in overlying strata, therefore, is related directly to basement faulting. No lateral compressive stresses can have created anticlines that are characterized by vertical faults. The concept of folding by compressive stress, followed by normal faulting as a result of "relaxation," is not acceptable because the angles of the fault planes more closely approximate 90° than 60°. The same origin for most of the faulted anticlinal uplifts, large and small, throughout the Mid-Continent region is suggested by similarity of shapes and geologic history.

9. GARY E. HENRY, Independent Geologist, Wichita Falls, Tex.

RECENT DEVELOPMENTS IN MARIETTA BASIN

During the past 10 years, a new search for significant reserves swept the Texas part of the Marietta basin and resulted in several important discoveries. The Ordovician Oil Creek Sandstone and numerous Strawn sandstones of Pennsylvanian age were the primary objectives.

The Marietta is primarily a Pennsylvanian basin, and oil occurrence is related closely to sedimentation and orogenies during this period. The presence of the southeast extension of the southern Oklahoma Criner Hills trend caused much deep exploration for Oil Creek gas-condensate production. The New Mag field was a significant result of this play. Much exploration remains to be done for fields of this type.

The 20-yr-old Handy field, also on the Criner trend, was extended considerably and new pay zones were found in this multipay Strawn field. Reserves were increased several times.

On the southwest side of the basin, the Bob K field in Cooke County was an important find. A combination of structural and stratigraphic entrapment created this very prolific multipay Strawn field.

Histories of development and geological interpretations of these and other areas are presented.

10. JOHN E. THORNTON, Geological Engineer, Wichita Falls, Tex.

CRITICAL EVALUATION OF HARDEMAN BASIN AND ITS ENVIRONS

Geologically the Hardeman basin is the easternmost extension of the elongate, east-west-trending geologic province known as the Palo Duro basin. Although the Hardeman basin apparently has not been subjected to the same violent structural unrest as other parts of North Texas (therefore, almost no structure is related to faulting), it is an area of prolific oil fields having traps of a peculiar type. Except for Conley, the largest Hardeman County oil field, oil traps here have almost no primary porosity. They seem to be either erosion remnants or small biohermal reefs with 100–200 ft of relief which have been vigorously and effectively leached by dolomitizing waters, leaving the limestone with secondary porosity values ranging from pin-point vugular to cavernous.

Since the 1959 discovery of Conley, it and 14 smaller fields have produced almost 10 million bbl of oil. This added to the 20 million bbl of oil produced from the Fargo and Odell fields of northwest Wilbarger County, raise the total for the Hardeman basin to 30 million bbl.

Seismic methods still provide the most reliable evidence of structure in the Hardeman basin, though increased drilling continually adds to the possibility of subsurface geological leads. As more fields are discovered, and more is understood of their structural form, there seems an increased demand for greater seismic accuracy which, because of the stratigraphic nature of the upper beds in the basin, is beyond the capacity of seismic tools. Most fields in the basin before discovery appeared on seismic maps as small low-relief closures or noses on positive structural trends. Many more such features are known, and must be explored.

Economically the Hardeman basin offers the highest return on investment of any area in North Texas. Because individual wells from various fields yield engineering reserve estimates as great as 1 million bbl of recoverable oil, a return as great as 30:1 is a reality. Such high returns normally are found, or anticipated, only in Gulf Coast exploration.

Though exploration costs are high in order to test the commonly cavernous Lower Mississippian "lime" at 8,500 ft (this is the prolific oil producer of Hardeman County), the Hardeman basin has a multiple-pay stratigraphic section to that depth, as shown by the presence of producing reservoirs in the Cisco-Canyon section (beginning at 3,900 ft), the Canyon limestones (normally Palo Pinto) below 5,000 ft, the Des Moines (Strawn) section of sandstone and conglomerate (from 6,000-7,300 ft), the Mississippian conglomerate (Holmes Sand) at 7,700 ft, the Mississippian limestones (Chappel and Osage) from 8,000 to 8,500 ft, and the Ellenberger dolomite below 8,500 ft (now producing only at Conley).

Exploration in the past has been aided by acreage and "dry-hole" support from major companies which control large blocks of leases. It is hoped this support will continue, but even without it exploration will continue in the Hardeman basin and westward into the Palo Duro basin, because positive exploration results in the Hardeman basin are already too great, and the promise for future successful exploration too strong, to discourage those men of vision who search for new oil.

11. GLEN S. SODERSTROM, Consulting Geologist, Amarillo, Tex.

STRATIGRAPHIC RELATIONS IN PALO DURO—HARDEMAN BASIN AREA

Low drilling density, variety and vintage of logs from wells drilled, and difficult regional correlations in Pennsylvanian rocks have contributed to poor oil-finding results in the Palo Duro basin. As a result the area has a "bad name" in industry. Stratigraphic