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 equivalents of Palo Duro basin rocks, ranging from the Ordovician to the Permian, produce in fringing areas or in nearby basins.

The region has had a complex geologic history. Source beds, reservoir-quality rocks, and large structures are present, but it appears that most oil to be found will be largely in stratigraphic traps.

12. FRANK E. KOTTLOWSKI, New Mexico State Bureau of Mines and Mineral Resources, Socorro, N.M.

SEDIMENTATIONAL INFLUENCE OF PEDERNAL UPLIFT

Depositional and erosional features outline the late Paleozoic Pedernal uplift as a narrow northward-elongated landmass, connected southward with the Diablo platform and northeastward with the Sierra Grand arch and Amarillo-Wichita uplift. During pre-Pennsylvanian Paleozoic time, north-central and central New Mexico was periodically uplifted epeirogenically, but this "massif" bears little resemblance to late Paleozoic Pedernal uplift. Pedernal should not be applied to the massif in east-central New Mexico (southern part of Sierra Grande arch).

Ordovician, Silurian, and Mississippian strata probably were deposited in most of New Mexico and adjoining areas, and Devonian beds in most of southern and western New Mexico, but were removed from large areas during subsequent erosion periods. Early Ordovician El Paso-Manitou was eroded in Middle Ordovician time; later Ordovician Cable Canyon-Harding and Montoya-Fremont as well as Silurian Fusselman Dolomite were partly removed during Late Silurian-Early Devonian time; and only a remnant of Mississippian was left in central New Mexico by erosion during Late Mississippian-Early Pennsylvanian time. Erosional and sedimentational patterns trend east-west for earlier Paleozoic strata, with a positive-trending feature in north-central New Mexico, contrasting with Pennsylvanian and early Permian northward trends related to the Pedernal uplift and its adjoining basins, Orogrande and Estancia on the west, and Delaware on the southeast.

The northern New Mexico massif supplied some Cambrian sands, some Middle Ordovician Simpson sand and silt, and Late Devonian and Early Mississippian silt and clay. The Pedernal uplift area in south-central New Mexico was covered by early and middle Paleozoic seas, and did not become a detritus-source upland until Early Pennsylvanian time. During Pennsylvanian and early Wolfcampian time it provided much sediment to flanking basins; most of the uplift was worn down and was buried by floods of northern redbed material during late Wolfcampian time. Only remnant hills remained in the sandy seas of Leonardian time.

13. ARTHUR S. RITCHIE, The University of Georgia, Athens, Ga. (on sabbatical leave from University of Newcastle, N.S.W., Australia)

NATURAL CHROMATOGRAPHY—A FACTOR IN PETROLEUM MIGRATION

The essential elements of chromatography are defined as (1) a mixture which becomes separated, (2) the stationary phase (a medium, usually fine-grained, with large surface area), and (3) the mobile phase (a fluid that carries the mixture with it over or through the stationary phase during separation). One or more of such specific processes as ion-exchange, partition, diffusion, and absorption may participate in a chromatographic separation, which, however, is more complex than any one of them.

The permeability of rock involved in petroleum migration ranges from a maximum in uncemented uniformly graded sandstone to a minimum in shaly rocks. At the lower limits of permeability, the petroleum must flow past or through fine-grained rocks of great surface area. Within more permeable strata some fine-grained material is encountered. Petroleum colloids probably also act as chromatographic stationary phases.

In the laboratory, when mixed hydrocarbons are passed over fine-grained materials, the paraffins always advance at a greater rate than the cycloparaffins which, in turn, move faster than the aromatics. In addition trace metals are retained selectively in a certain order on the stationary phases.

In natural occurrences of petroleum in multiple pools, it is commonly reported that the upper pools are paraffin-rich, the intermediate pools cycloparaffin-rich, and the lower pools are richer in aromatics. In these cases chromatographic separation during migration is offered as an alternative to hypotheses of separate origins for the pools. Chromatographic separation of trace metals in petroleum fields is reviewed.

14. WILLIAM V. TROLLINGER, Consulting Geologist, Denver, Colo.

SURFACE EVIDENCE OF DEEP STRUCTURE IN ANADARKO BASIN

Surface geology has been neglected largely in the search for oil and gas in the Anadarko basin. This is understandable because the surface is composed essentially of upper Permian strata laid down after the major mountain-building activities in the region. In places the Permian rocks are mantled by moderately indurated Tertiary continental beds and unconsolidated Quaternary deposits.

A recently completed detailed photogeologic-geomorphic evaluation study revealed considerable evidence that the surface offers numerous clues to subsurface geologic conditions. The study involved comprehensive stratigraphic and structural mapping by conventional photogeologic techniques supplemented by detailed geomorphic structural analysis.

This phase, or "applied geomorphology," deals with determining the degree of influence that structure and lithology have had on the morphologic development of the region. Basic geologic-geomorphic relations are established and "interruptions" to the regional geomorphic "norm" are interpreted commonly as diagnostic clues to anomalous subsurface geologic conditions. The results in the Anadarko basin indicate that many deep-seated structural anomalies are reflected at the surface in the *drainage*, *landform*, *erosional*, *photo-tonal*, and (or) *fracture patterns*.

The study was enhanced by the use of a special-purpose aerial photography, taken with the Wild RC-9 camera. This photography has many advantages over conventional aerial photography and is especially well suited to low-dip areas. As a result of its 6.5 × exaggeration factor, an actual dip of 1° is exaggerated in the stereoscopic view to about 6.5°. This permitted reliable mapping of very low-relief features in the Andarko basin, where the dip exceeds 1° in very few places.

Four producing areas, with subsurface control used for comparative purposes, are examined as ex-