tems (Wolfcampian), Southeastern Palo Duro Basin, Texas

In Late Pennsylvanian and Early Permian time the Palo Duro basin was part of a relatively deep seaway that extended northward from the Midland basin into the Mid-Continent. Deep, central-basin areas were surrounded by massive, carbonate-shelf margins and shallow-shelf terrane.

In the southeastern Palo Duro basin, high-constructive, elongate delta systems deposited quartzose sand derived from eastern sources (Wichita Mountains). Late Pennsylvanian and early Wolfcampian delta-front sandstones (>200 ft or 60 m thick) are present on the basinward side of the shelf margin, suggesting that deltas prograded beyond the shelf margin and into deep water. Later, as terrigenous sediment supply was sharply reduced, the shelf margin prograded basinward over deep-water delta facies. During middle Wolfcampian time, clastic input was increased and high-constructive deltas once again prograded into the southeastern Palo Duro basin. However, progradation was not so extensive as earlier episodes and most delta-front sands were deposited in shallow-shelf environments. Consequently shallow-water conditions precluded formation of thick delta-front sequences in shelf environments.

Upper Pennsylvanian-Lower Permian deltaic sandstones in the southeastern Palo Duro basin are subarkoses. Porosity ranges from 0 to 13% and averages 4.8%. Both primary and secondary (leached feldspars) porosity are present. Cementation began with clay coats, followed by quartz overgrowths. Iron-rich dolomite replaced margins of framework grains and filled most remaining pores. Timing of feldspar leaching and kaolinite cement is unknown.

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Geochemical Prospecting for Stratigraphic Traps

Petroleum geochemistry has received considerable attention in recent years and has emerged as a useful tool in exploration efforts. Most of the methods currently being used find maximum benefit and application in frontier exploration areas. Such studies generally provide information on source-rock quality, maturity level, and migration history. Some techniques, however, are applicable to more mature petroleum provinces and are especially suited for stratigraphic-trap exploration efforts. One such method involves pyrolysis of samples (well cuttings) and measurement of the quantity of hydrocarbons that are volatilized. Detecting, quantifying, and mapping hydrocarbon content of samples from specific stratigraphic units help to assess proximity to oil accumulations.

As oil moves to a trap, small quantities of hydrocarbons are invariably left in the rocks which served as avenues of migration. Concentrations of these hydrocarbons are highest near an oil accumulation and become progressively lower at greater distances from an accumulation. Concentration gradients can be mapped and interpreted in much the same way as conventional subsurface data and thus can provide the exploration geologist with a quantitative tool. Data are rapidly obtained, and information derived from initial boreholes can be used to help position subsequent tests. Preliminary results from several Mid-Continent study areas have been encouraging.

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Investigation of Desmoinesian Rocks in Northeastern Oklahoma for Heavy-Oil Potential

Various estimates of the heavy-oil resources of the Tri-State area of Kansas, Oklahoma, and Missouri have ranged from 30 million to several billion bbl of oil in place. During 1977-78 the Oklahoma Geological Survey, in conjunction with the state geological surveys of Missouri and Kansas and the U.S. Department of Energy, conducted an 18-hole drilling and coring program to assess the heavy-oil potential of northeastern Oklahoma. Reported bituminous material in shallow wells and the presence of asphalt-bearing sandstone in mine shafts suggested that Craig and Ottawa Counties might hold the best potential for shallow heavy-oil accumulations.

The results of our 18-hole program show that the Lower Pennsylvanian sandstones in this area are somewhat discontinuous and vary considerably in reservoir quality. Seven of the boreholes indicated the presence of oil; however, 1-mi (1.6 km) offsets from these sites commonly demonstrated lack of continuity of specific sandstones and an absence of heavy oil where adequate-quality reservoirs exist. We feel that the Oklahoma part of the Tri-State area does not contain as much heavy oil as had been estimated.

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How Many Wildcats Must We Drill?

Decline of United States oil and gas reserves could be moderated by increased exploratory drilling. In 1978 U. S. production was 3.0×10^9 bbl crude oil, 0.7×10^9 bbl natural-gas liquids (NGL), and 19.3×10^{12} cu ft natural gas ($= 3.3 \times 10^9$ bbl oil equivalent-BOE), for a total of 7.0×10^9 BOE. To continue production at this rate until 1990 (12 years) would require discovery of 84×10^9 BOE.

Annual estimates of ultimate recovery (past production + reserves) are made for each year since 1920 by API and AGA. To each of these estimates must be added an estimate of reserve growth from revisions, extensions, new-pool discoveries, in-field drilling, and enhanced recovery. From the derived annual totals and AAPG estimates of footage drilled annually in new-field wildcat wells, the oil and natural gas discovered/foot were estimated. In the late 1940s the average discovery/foot was more than 350 BOE. By the late 1970s the average discovery/foot had dropped to 52 BOE. Projections of these decline curves determined the number of feet of new-field wildcats needed to find 2×10^9 BOE/yr, approximately the present rate of discovery in the U.S. Projected average drilling depth permits calculation of the number of needed wildcats/yr (12-yr total = 388,514 wells). Estimated discoveries are 7% oil and 8% gas.

Projected increases in drilling and completion costs (JAS) indicate a total cost of $179 billion. *Not included* are lease, geologic and geophysical, development-well, and overhead costs.

A projected increasing role of natural gas and NGL in the total energy mix results from the relatively large proportion of gas, on a Btu equivalent basis, being discovered/foot of new-field wildcat drilled. At present finding rates it is not possible to replace the 7.0×10^9 BOE annual production.

Projected costs are so large that attainment of these limited goals does not seem possible. Total cost of the necessary new-field wildcats ($179 billion), however, is in the same order of magnitude as President Carter's estimated federal income from the "windfall" profits tax for 1980 to 1990. In any case, estimates of available oil and gas resources indicate that it *is* possible to moderate the decline in reserves and production.

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Depositional Environment of Bartlesville Sandstone, Sallyards Field, Greenwood County, Kansas

A facies model of the subsurface Bartlesville Sandstone in Sallyards field, Greenwood County, Kansas, was developed from well-core descriptions, petrographic analysis, electric log examination, and construction of maps and cross sections.

Subsurface mapping indicates that the Bartlesville Sandstone is narrow and elongate in plan view and lenticular in cross section. It displays an asymmetric convex-down base, thickens at the expense of the underlying shales, and is a multistoried sandstone body. Self-potential logs usually show an abrupt basal contact and a blocky or an upright bell-shaped curve. A structure map at the top of the pre-Pennsylvanian surface indicates that deposition of the Bartlesville Sandstone was influenced by underlying structure.

The sandstones are mineralogically and texturally immature with abundant metamorphic rock fragments, micas, clays, angular tourmaline, and feldspar grains. The amounts of clays and micas increase and grain size decreases upward in the sandstone as shown by thin-section measurements. Biogenic material includes abundant wood fragments and organic matter in the conglomerate zones.

Core studies reveal a vertical sequence for the Bartlesville Sandstone consisting of a sharp basal contact, large-scale cross-bedding, massive bedding or conglomerate zones, unidirectional current ripples, and a gradational or sharp upper contact with overlying siltstone. The scale of sedimentary structures decreases upward. The laterally associated facies consist of dark-gray to black shale, greenish-gray shale, ironstone, underclay, coal, and limestone.

Comparison of the described facies model with process-response models of modern depositional environments indicates that the Bartlesville was deposited by a perennial, fine-grained, meandering, alluvial stream following lows on the eroded pre-Pennsylvanian surface. The associated facies were deposited in a delta-plain to shallow-marine environment. Enclosure of the sandstone bodies in oil-rich shale and later structural movement led to favorable conditions for the development of combination structural-stratigraphic traps.

Previous regional work, checked by log correlation across Kansas, suggests that the Bartlesville Sandstone in Sallyards field is laterally equivalent to the surface Bluejacket Sandstone.

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Environments and Diagenesis, Morrow Sandstones, Cimarron County, Oklahoma

Detailed investigations of Morrow Sandstones in Cimarron County, Oklahoma, provide a bird's-eye view of problems encountered during regional exploration, production, and completion practices over a wide area from New Mexico to Kansas. The generally poor lateral and vertical control of sand distribution can be improved through a detailed knowledge of environments of deposition. Frequent formation damage because of poor completion procedures can be largely prevented through an understanding of Morrow sandstone diagenesis.

Morrow sandstones in Cimarron County form two distinct reservoirs. Type 1 reservoirs are thick (10 to 50 ft or 3 to 15 m), porous (20 to 23%), permeable (47 to 236 md), and very coarse grained (0.83 mm). These reservoirs are fan-shaped, being less than 1 mi (1.6 km) wide at the apex (on the northwest) and 4 mi (6.4 km) wide at the southeastern edge. Sand thickness is greatest at the center of the body. These sands were deposited in the estuarine portions of a braided fluvial system.

Type 2 reservoirs are thin (generally less than 20 ft or 6 m), have relatively low porosities (4 to 20%) and permeabilities (3 to 100 md), and are fine grained (0.24 mm). These reservoirs are discontinuous, lenticular, elongate units which trend at approximately right angles (NE-SW) to the Type 1 reservoirs. Maximum width is 1 mi (1.6 km); maximum length is of the order of several miles. These sands were deposited in lower tidal-flat and shallow, offshore-marine environments, as beaches and bars.

Once the reservoir has been discovered, it is vital that completion practices be tailored to the specific rock composition. Failure to do this may result in serious formation damage, and the bypassing of potential production. Problems characteristic of these sands include: (1) a migration of fines, (2) extreme acid sensitivity, and (3) possible water sensitivity. The sand composition may often require a multistage acid job with KCl flushes. Hydrofluoric acid should not be used unless the detailed sand composition has been determined by thin-section analysis.

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Geochemistry of Small Lacustrine Delta, Great Salt Plains, Alfalfa County, Oklahoma

A shallow lacustrine delta is forming at the northern end of the Great Salt Plains reservoir in Alfalfa County, north-central Oklahoma. Although sediment is supplied solely by the river, organic matter may be derived from the land surface (and transported by the river) or de-