combination of slight structural closure and updip porosity pinch-out. Updip oil migration may have occurred through "breaks" in the Mexia-Talco fault system with oil entrapment in numerous updip small fault closures and possible porosity pinch-outs. Well control is inadequate for further definition of this trend. Flow rates over 1,000 BOPD have been reported in several of McFarlane's wells. Producing characteristics appear to be excellent with 48° gravity oil and under 1,100:1 GOR. Hydrogen sulfide is reported at 2% or under. In view of its possibly large area and shallow depth (9,000 ft or 2,743 m)—and a price of $40/bbl—this field could prove to be the most significant oil field discovered in east Texas in 20 years.

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Potential of Evaporitic Environment as Source of Petroleum

Examination of modern saline lakes, solar evaporation ponds, and lagoons shows that the evaporitic environment can be very productive of organic matter. Few species survive in the brines, but those that do commonly are in great profusion. In a marine evaporitic embayment, the flow of surface currents is persistently toward regions of highest salinity, so that there is a continual supply and concentration of nutrients. Prolific growth of phytoplankton may be similar to that in areas of upwelling in modern oceans. Only carbonates precipitate in the "mesosaline" part (4 to 12% salinity) of such an evaporitic environment and no great dilution of organic matter by clastic or biogenic sediments occurs. Because stratification of brine may occur and reducing conditions may be associated with the bottom waters, much of the organic matter produced can be preserved. Upon maturation, the result may be a rich carbonate source rock, frequently unrecognized in the geologic column. In the Middle East, mesosaline conditions have occurred many times from the Triassic to the Cretaceous and may be responsible for the vast reserves of petroleum in the area. Evaporitic conditions may also have played a part in the petroleum productivity of many other areas, including the Michigan and Paradox basins.

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Clastic Depositional Models

Depositional models of clastic rock sequences provide a valuable insight into many exploration and production problems in the energy business. The size, shape, lateral relations, and physical properties of sedimentary bodies have obvious and well-recognized relevance to searching for and developing petroleum, coal, and some ores. Acknowledgement of the value of depositional models by industry stimulated incisive research beginning more than 30 years ago and has sustained a very active and growing interest throughout the scientific community. As a result, today we face the blessing and the perlexity of a large and rapidly expanding fund of data.

No person can now really cope with assimilating the literature, past and present, on clastic depositional models, especially a person busy searching for mineral resources. My goal is to review some of the important advances that have happened, may be happening now, or should be promoted. These views are certainly personal and biased. As examples of my opinion, marine shelf and slope models are very poorly understood; knowledge of modern processes, Holocene deposits, and ancient examples has not led to unifying principles that can bolster exploration predictions in these general depositional environments. At the other end of the information spectrum, stream deposits are well known from many studies of modern and ancient examples and considerable experimental data. Yet embarrassing gaps in understanding remain because of accidents of geography, climate, or scale. Clastic depositional models from outcrop and subsurface provide case histories of fluvial, marine-shelf, and basin-slope environments that illustrate the state of the art and applications to practical oil exploration problems.

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Sedimentology and Petrology of Tar Sands

The two largest tar sand provinces of the world are those of the Orinoco petroleum belt in Venezuela (estimated in-place reserves of 1,000 to 2,000 × 10^9 bbl) and the Mannville Group oil sand deposits of Alberta (1,350 × 10^9 bbl estimated in-place reserves). Possible additions to these ranks are the Russian deposits of the Melekess depression and the Olenek area (reserve figures very erratic), and the bitumen-bearing Paleozoic rocks of the Carbonate Triangle in Alberta (reserves tentatively estimated to be more than 1,000 × 10^9 bbl). Other significant accumulations including those in the United States (principally Utah and California), Madagascar, Albania, Romania, the Caribbean, and the Canadian Arctic are all markedly smaller (reserves two or more orders of magnitude less).

Elements common to most of the major accumulations include: stable tectonic settings, usually in large foreland basins; thermally immature and only moderately compacted reservoir sediments, commonly uncemented, with very high porosities and permeabilities; far-reaching hydrocarbon migration networks with access to organic-rich source beds; near-surface settings, within the realm of pervasive oil degradation by water washing and bacterial action; and complicated, often enigmatic trapping configurations, involving both stratigraphic and structural factors, with bitumen plugs perhaps serving locally as updip seals. The deposits in which the reservoirs are dominantly hydrophyllic (water wet), including those of both Venezuela and Alberta, are the most amenable to exploitation in that they can be processed by the inexpensive and relatively efficient hot-water extraction method.

Athabasca is the largest of Alberta's oil sand deposits. It encompasses a total area of 32,000 sq km and is estimated to contain 870 billion bbl of oil in place. The Lower Cretaceous McMurray Formation reservoir is 35 to 70 m thick of uncemented, very fine to fine-grained, moderately sorted quartz sand and associated shale. The most important control on the grade of the oil sands is the distribution of primary porosity and permeability in the McMurray Formation sediments. Achieving a cogent understanding of the facies patterns thus leads directly to a predictive capability regarding the geometry and character of the oil-bearing zones.

Initial infilling of the McMurray depression appears to have developed in a wide variety of fluvial-deltaic environments, many of which are not yet fully understood. Subsequently, there developed a regime marked by the presence of deep channels, trending north and northwest, which locally incised the preexisting sedimentary sequences and deposited a characteristic, fining-upward cycle in many areas, particularly in the northern half of the deposit: trough cross-bedded channel-bottom sands at the base; giving way upward to solitary sets of epsilon cross-strata deposited on the sloping flanks of channel-margin bars; passing upward into argillaceous sands of flood-plain origin. The channels which produced this sequence were up to 45 m deep and many hundreds of meters wide. Where they eroded and reworked the preexisting sedimentary pile, apparently along discrete meander-belt trends, they left behind a sand-dominated sequence that today constitutes some of the thickest and richest oil pay zones in the entire deposit.

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Middle East—Stratigraphic Evolution and Oil Habitat

The post-Hercynian sequence of the Middle East is dominated by carbonate sedimentation on a stable platform flanked on the northeast by the Tethys ocean. Two principal types of depositional systems alternated in time: (1) ramp-type mixed carbonate-clastic units and (2) differentiated carbonate shelves. The first type was deposited during regressive conditions, when clastics were brought into the basin and resulted in "layer-cake" formations. The second type was formed during transgressive periods and is dominated by carbonate cycles separated by lithoclines, time-transgressive submarine lithified surfaces. Differentiation is marked, with starved euxinic basins separated by high-energy margins from carbonate-evaporite platforms.

The tectonic development of the Middle East can be divided into several stages. The first stage, which ended with the Turonian, was characterized by very stable platform conditions. Three types of positive elements were dominant: (1) broad regional paleohighs; (2) horsts and tilted fault blocks trending NNE-SSW; and (3) salt domes. All three influenced deposition through synsedimentary growth. The subsequent stage, from Turonian to Maestrichtian, was one of orogenic activity, with the formation of a foredeep along the Tethys margin and subsequent ophiolite-radiolarite nappe emplacement. From the Late Cretaceous to the Miocene, the platform regained its stability, only to lose it again at the close of the Tertiary, when the last Alpine orogenic phase affected the region, creating the Zagros anticlinal traps.

Source rocks were formed in the starved basins during the transgressive periods. Marginal mounds, rudist banks, oolite bars and sheets, and regressive sandstones form the main reservoirs. Supratidal evaporites and regressive shales are the regional seals. The spatial arrangement of these elements and the development of source maturity through time explain the observed distribution of the oil and gas fields.

The Middle Jurassic to Albian sequence in the central part of the Gulf, around the Qatar Peninsula, provides a well-studied example of the control on oil distribution by the distribution in space and time of mature source beds, effective regional seals, and reservoirs. Oil, tar, and extract typing as well as maturation studies show that the Upper Jurassic Hanifa bituminous limestone is the source for the oil and tar in the Jurassic as well as the Lower Cretaceous reservoirs, the latter reservoirs being only charged where the intervening regional Hith seal is either absent through nondeposition or is breached through faulting. Growth structures draining mature Hanifa kitchens contain sizable accumulations, whereas the Jurassic and Cretaceous reservoirs of the large Qatar dome contain only minor amounts of oil, which can be ascribed to insufficient source maturity and too late closure.

Geochemical and geologic evidence indicates that the tar mats present at the base of many oil accumulations are not the result of biodegradation or early, immature expulsion from the source, but probably the product of gas deasphalting of reservoired oil.

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Late Triassic-Jurassic Paleogeography and Origin of Gulf of Mexico

A step-by-step reconstruction of the paleogeography of the Gulf of Mexico and surrounding areas suggests that the basic structural and stratigraphic framework of the region was established by events during the Late Triassic and the Jurassic. Cretaceous and Tertiary events only accentuated and modified this framework. During the Late Triassic and Early Jurassic, continental conditions prevailed over most of the southern part of the North American plate. Marine deposition was restricted to parts of western and central Mexico that were covered by embayments of the Pacific Ocean. As the supercontinent of Pangea began to crack and break up in the Late Triassic and as the North American plate started to separate from the South American and African plates, tensional grabens began to form. They were filled with red beds and volcanic rocks.

It was not until late in the Middle Jurassic (Callovian) that Pacific marine waters began to reach the Gulf of Mexico area across central Mexico. These marine waters flooded intermittently the preexisting grabens and, between floods, evaporated to produce extensive salt deposits (Louann Salt). The salt varied markedly in thickness according to the rate of subsidence in the grabens. Little or no salt was formed in the intervening high areas. During the Late Jurassic, marine waters from the Pacific progressively covered an increasingly large part of the Gulf of Mexico and surrounding areas as a result of continued subsidence, sea-level rise, or both. Connection with the Atlantic, however, was not established until late Kimmeridgian or Tithonian time.

On the basis of these paleogeographic data, it is possible to speculate that in the Late Triassic and Early Jurassic the Yucatan continental block was located roughly 300 km north-northwest of its present position, and that it was a part of the large North American plate. As the North American plate began to drift northwestward, the Yucatan block seems to have been "left behind." The separation of the Yucatan block from the main North American plate probably started in the Late Triassic, continued slowly and sporadically during the Early and Middle Jurassic, and quickened after the formation of the extensive Callovian salt deposits. By the close of the Oxfordian the Yucatan block had reached essentially its present position, and the Gulf of Mexico had been born.

AAPG RESEARCH CONFERENCE

Temperature Environment of Oil and Gas

Santa Fe, New Mexico, September 13-17, 1981
WM. H. ROBERTS, III, and P. H. JONES, Conveners

Abstracts

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Shallow Geothermal Survey of Durkee Oil Field and Woodgate Fault, Harris County, Texas

This study was conducted northwest of Houston, Texas, in two areas of intensive investigation: Durkee oil field and a nearby segment of Woodgate fault. Temperature measurements made with thermistors at a depth of 2 m revealed temperature anomalies caused by sources at depth and in the near surface.