Pessimistic views regarding the liquid hydrocarbon potential in the basin stem from the following common observations. (1) The only exploitable hydrocarbon discoveries to date have been gas. (2) The only known source rocks are of post-Jurassic age and predominantly contain land-derived organic carbon, and hence are considered as gas prone. (3) Today's inferred geothermal gradient is such that the oil window is at least 5,000 m (16,000 ft) deep, and below the "acoustic basement," implying that existing hydrocarbons result from biodegradational processes not conducive to oil generation. (4) Old seismic data did not reveal well-developed structural traps.

However, the recent comprehensive interpretation affords the following conclusions. (1) Significant oil shows accompanying wet gas discoveries suggest that the South Mozambique basin is a mature province, as the hydrocarbon associations imply thermogenic processes. Hence, the geothermal history must have been more favorable than is generally inferred from present-day gradients. (2) Super-Karroo marine Jurassic sequences have been encountered in the Nhamura-1 well onshore, and Triassic marine sequences have been interpreted offshore from the application of seismic stratigraphy and well correlation. Furthermore, extrapolation of the continental character of the older Karroo from intracratonic locations to paleocontinental margins may not be valid, as exemplified by the basinward increase in marine character of the Sakemena and Ecca formations in Madagascar and Natal, respectively. Accordingly, the local presence of oil-prone source rocks is likely. (3) Steeply dipping reflectors truncated by the pre-Cretaceous unconformity testify to significant tectonic activity preceding the breakup of Gondwanaland. Hence, preconceived ideas about the depth of the economic basement and the absence of mature source rocks of pre-Cretaceous age should be revised. (4) Wildcats in the vicinity of ample structural closures have not been, in retrospect, optimally positioned nor drilled to sufficient depth to test the viability of prospects mapped along a major offshore extension of the East African rift system delineated by this new survey.

DEWEY, JOHN F., and G. D. KARNER, Univ. Durham, England, and W. C. PITTMAN, III, Lamont-Doherty Geological Observatory, Palisades, NY

Thermo-Mechanical Properties and Evolution of Pull-Apart Basins

Pull-apart basins are generally characterized by two component subsidence; an initial essentially instantaneous isostatic subsidence (S_1) dependent on the ratio of crustal to lithospheric thickness (C_z/l_z) and the stretching factor β, followed by a slower exponentially decaying thermal subsidence (S_t) controlled by the thermo-elastic properties of the continental lithosphere which, in turn, can be characterized by a thermal time constant τ. Rapid short-lived subsidence (Ridge basin) is indicative of either (1) inhomogeneous crustal stretching without major sublithospheric involvement, or (2) extremely small lithospheric diffusivities. The former implies a thin-skinned origin for pull-apart basins and suggests that the spatial and temporal distribution of bounding faults and splays typical of pull-apart basins result from inhomogeneous brittle failure of the upper crust. Crustal, extensional or shear-strength profiles for various geothermal gradients and degrees of wetness adequately explain two-layer extension with intra-crustal decollement. However, the effects of lateral heat flow decrease the thermal time constant by allowing a basin to subside more quickly because of both lateral and vertical cooling. The size of this effect is dependent on the width of the stretched lithosphere. The effective τ of a 100 km (60 mi) wide rift is 36 m.y. and for a 25 km (15 mi) rift is 6 m.y., whereas the actual thermal time constant in both cases is 62.8 m.y. Lateral heat flow amplified rift subsidence while producing complementary uplift in adjacent unstretched regions. However, the flexural rigidity of the lithosphere severely attenuates the deformation caused by the lateral flow of heat. Although the deformation is highly dependent on the mechanical properties of the lithosphere, τ is independent. Diachronous rift shoulders or peripheral uplifts may produce important hydrocarbon gradients and result from various combinations of lateral heat flow, flexural arching, and normal-fault decoupling.

Continental lithospheric rigidities appear to increase with age following an orogenic or thermal event, suggesting that the long-term mechanical behavior of the continental lithosphere is similar to that of the oceanic lithosphere. However, high rigidities (10^{32} dyne-cm) associated with Archean or Proterozoic terranes and modeling of plate deformation suggest that the long-term thermal behavior of continental lithosphere is governed by a cooling plate model with a 200-250 km (124-155 mi) lithospheric thickness, nearly twice the 125 km (78 mi) estimated for the oldest oceanic lithosphere. This has important implications for the evolution of sedimentary basins. A doubling of the lithospheric thickness implies a quadrupling of τ, yet basin subsidence models have assumed that τ for the oceanic and continental lithospheres are similar. A large τ allows basin subsidence to continue over significantly longer times, but lateral heat flow, in addition to vertical, must be included in basin models to obtain accurate subsidence and temperature estimates. In particular, S_1 is highly dependent on the age of the underlying basement.

DOLAN, P., JEBCO, Surrey, England

Deep Water (200-800 m) Hydrocarbon Potential of United States Gulf of Mexico

Recent active Outer Continental Shelf (OCS) lease sales in the offshore Texas and Louisiana portions of the United States Gulf Coast have emphasized that this will be an arena of vigorous exploration for at least the next decade. Much of the principal prospective acreage on the shelf area (water depth less than 200 m or 660 ft) has been awarded for exploration. As a consequence, there is now a well-established trend toward assessment of deeper water acreage (200-800 m or 660-2,625 ft). For example OCS sale 72, in May 1983, included the award of leases in water depths of over 1,000 m (3,280 ft). This trend is likely to make the United States portion of the Gulf of Mexico the first intensively explored deep-water area in the world.

Geophysical and geologic data have been acquired on a generally ad hoc basis by various research and governmental institutions over the last 15 years. More recently, individual oil companies and geophysical contractors have started more methodical data acquisition programs. This move toward a more systematic evaluation has culminated in extensive regional seismic programs being acquired to evaluate leases available in the April and July 1984 OCS sales 81 and 84.

Acquisition, processing, and interpretation problems can be expected by those attempting to evaluate prospects in the deep water portions of the Gulf of Mexico.

From the geophysical evidence available, broad conclusions can be made concerning the likely hydrocarbon potential of the area.

FAERSETH, R. B., K. A. OPPENBØEN, and A. SAEBØE, Norsk Hydro, Oslo, Norway

Trapping Styles and Associated Hydrocarbon Potential in Norwegian North Sea

The exploration effort in the Norwegian North Sea is only 15-20 years old. The activity has resulted in several major oil and gas finds. Well data and significant amounts of seismic data have implied a thorough geologic understanding.

In the North Sea basin, the hydrocarbon discoveries to date can be assigned to four main forms of traps.

(1) The extensional structures are characterized by tilted fault blocks, or less commonly, rollover anticlines on the downthrown side of faults. The hydrocarbons occur in sub-unconformity, sandy reservoirs of Triassic to Late Jurassic age. (2) Salt-supported structures generally have fractured Upper Cretaceous-lower Tertiary chalk or Jurassic sandstones as a reservoir. (3) Stratigraphic traps are accentuated by drape, compaction, or late structural movements. Sands of Paleocene-Eocene age represent the main reservoir. (4) Anticlinal closures are related to a late phase of wrench movements. Discoveries of this type occur in the southern part of the basin and represent only a minor part of the proven reserves.

FITZGERALD, THOMAS A., The World Bank, Washington, D.C., and M. N. V. KUMAR, Oil and Natural Gas Commission, Madras, India

Hydrocarbon Potential of East Coast of India

The east coast of India is considered to be a divergent margin formed during the fragmentation of Gondwanaland during the late Mesozoic. The four sedimentary basins located along this coast—Cauvery, Palar, Krishna-Godavari, and Mahanadi (from south to north)—have their seaward extensions into the Bay of Bengal where some of them have built a 5-6 km (16,000-20,000 ft) thick late Mesozoic to Holocene sedimentary section.

The formative tectonics of these basins are generally similar and date from Late Jurassic–Early Cretaceous interior fracturing of the continental crust with northeast-northwest-trending horst-and-graben faulting along the ancient Precambrian grain. In Palar, it appears to have been initiated in the Permian.

The basins have two or more cycles of deposition. During the first (rift) cycle in the Early Cretaceous (stage 1), nonmarine to paralic sandstones and shales were deposited in the interior grabens. With continued subsidence and marine encroachment during middle to Late Cretaceous (stage 2), the horst areas also became the repositories of sandstones, shales, and limestones, and finer clastics filled the graben areas. However, the basins filled gradually, followed by uplift and truncation. Fissure eruptions connected with the Deccan volcanic episode of Peninsular India cover parts of Krishna-Godavari onshore.

The second cycle (coastal margin), during the Tertiary, which is well developed in all basins except Palar, was superimposed unconformably on the horst-graben morphology of the Cretaceous basins. Paralic to shallow marine clastics and carbonates were deposited during the Paleocene-Eocene. Eocene carbonate banks of considerable areal extent appear to have supported limited biohermal activity in the three basins. In the Krishna-Godavari and, to some extent, the Mahanadi basins, deltas prograded to the outer edge of the continental shelf during the Neogene, with deep-sea equivalents along the paleoslopes.

Although no commercial discoveries have been identified to date, significant oil and/or gas shows have been encountered in some of the tests, with definite but lesser shows in others. The strata with important shows range from Cretaceous sandstones and fractured basalts to poorly consolidated Pliocene sands; others include weathered and fractured basement rocks and Eocene carbonates. Source facies have been identified in Upper Cretaceous, Paleocene, and Miocene shales. All important shows observed to date are located on horsts and other structural highs, but stratigraphic controls are very likely to be associated with sub-Upper Cretaceous unconformities, between Cretaceous and Paleocene and between Miocene and Pliocene. Oil and gas plays in each sequence appear to be limited by the fault block in which the particular sequence is most completely developed and each appears to contain indigenous source rock providing hydrocarbons to the reservoirs in the sequence. The major faults, with the possible exception of the major growth faults, appear to be sealing. The important plays are in the normal to transitional pressure regimes with a few gas plays in the overpressured sequences.

FORREST, J. T., Texas Eastern Australia, Houston, TX, and E. L. HORSTMAN, Ameraust Consultants, Perth, Australia

Northwest Shelf of Australia as Major Future Petroleum Province

The Northwest shelf of Australia extends over 1,000 mi (1,600 km) in a northeast-southwest direction and averages more than 200 mi (320 km) in width; it can be divided, from southwest to northeast, into the Carnarvon basin, the offshore Canning basin, the Browse basin, and the Bonaparte basin. Each of these is further divided into subbasins based on stratigraphic and structural boundaries. Sedimentary thicknesses are probably in excess of 30,000 ft (9,000 m).

Structurally, the entire Northwest shelf is dominated by Early to mid-Jurassic rifting. Although the tensional tectonic style predominates, compressional features are present, probably resulting in part from rebound of the tensional stress and possibly from strike-slip movement in the basement. In the Bonaparte basin, salt movement has created both piercement and deep-seated salt structures.

Proven petroleum reservoirs of the Northwest shelf are Permian, Triassic, Jurassic, and Cretaceous sandstones. The major petroleum source is Upper Jurassic shale, which has generated both oil and gas in the Carnarvon and Browse basins. Gas in Permian sandstones in the Bonaparte basin probably has a source within the Permian.

By the end of 1983, approximately 200 exploratory wells had been drilled on the Northwest shelf, for a drilling density of less than one well per 1,000 mi^2 (2,600 km^2). Over 100 of those wells are in the Carnarvon basin, which covers less than 20% of the total area of the shelf. Significant discoveries have been made in the Carnarvon, Browse, and Bonaparte basins, but only the Carnarvon is currently producing; its proved reserves are estimated at 462 million bbl of oil and condensate, 155 million bbl of LPG and 11 tcf of gas (1982 statistics).

Except for the Carnarvon basin, where well density is still low, the Northwest shelf is essentially unexplored. All of the basins are indicated to have most of the elements required for the generation and accumulation of petroleum. Recently announced discoveries in widely divergent areas of the shelf have generated renewed interest in this large unexplored offshore area and may stimulate the exploration activity necessary to make the Northwest shelf a major petroleum province of the future.

FUKUTA, OSAMU, Geological Survey of Japan, Ibaraki, Japan

Analogy Between Natural Gas Found in Lakes of Rift Valley System of East Africa and Its Allied Gas in Japan

The Afar triangle in northeastern Ethiopia is where the Red Sea rift, the Carlsberg Ridge of the Indian Ocean, and the Rift Valley system of east Africa meet. About 20 m.y. ago, the Arabian Peninsula and Africa were joined. Fit of shorelines of Arabia and Africa works out most successfully if the African coast is left intact and the Arabian coast is superposed in two separate sections. In this reconstruction, a corner of Arabia overlaps the Afar triangle, an area that now has some of the characteristics of an ocean floor.

In 1979, J. Welhan and H. Craig reported that hydrothermal vents at 21°N, on the East Pacific Rise, are discharging turbid waters. Mixtures of the plumes with ambient seawater contain significant amounts of dissolved H_2 and CH_4 as well as mantle-derived ^{3}He-rich helium. The $^3He/^4He$ ratios of rock samples obtained earlier by J. Lupton and H. Craig from the Mid-Oceanic Ridge, including the Mid-Atlantic Ridge and the East Pacific Rise, are extremely high at an almost constant value of $(1.3 \pm 0.2) \times 10^{-5}$, which they defined as the MOR-type helium. However, the deep brines of the Red Sea contain about 1,000 times more methane than normal seawater does, according to Gold and Soter in 1980.

Much evidence leads us to believe that large amounts of ^{3}He-rich helium-bearing natural gas have been gushing out in many places of the Rift Valley of east Africa for a long time. If waters of some lakes are charged with natural gas from the mantle of the earth, in due time, dissolved-gas deposits will form in the deeper zones of some lakes. If charging continues, the water throughout the lake becomes saturated and then oversaturated by gas. In 1980, Gold and Soter stated that Lake Kivu, which occupies part of the East African rift valley, contains 50 million tons of dissolved methane for which there is no adequate microbial source.

The Japanese Islands began to separate from the Asian continent during the early Miocene. The early Miocene was characterized by intensive volcanic activity that produced large amounts of pyroclastics and other volcanic rocks, generally called "green tuff" in Japan. It has been suggested that oil and gas in "green tuff" is derived from the upper mantle.

GALLAGHER, JOHN J., JR., Occidental Oil and Gas Co., Bakersfield, CA

Philippine Islands: a Tectonic Railroad Siding

In 1976, significant quantities of oil were discovered offshore northwest of Palawan Island by a Philippine-American consortium led by Philippines-Cities Service, Inc. This was the first commercial oil found in the Philippine Islands.

Other exploration companies had decided that there was no commercial oil in the Philippines. They fell prey to a situation Wallace E. Pratt, who began his career in 1909 in the Philippines, later described: "There are many instances where our knowledge, supported in come cases by elaborate and detailed studies...has convinced us that no petroleum resources were present in areas which subsequently became sites of important oil fields." As an example, he mentioned some of the world's best exploration companies who concluded, "There is no oil in Arabia," shortly before the first major Arabian discoveries. More recent examples are the North Sea and offshore eastern Canada. Wallace E. Pratt implied that an oil explorer's chances of success will improve if he or she uses exploration and scientific knowledge to discover what is unknown to others.

Some explorers are blinded by the negative implications of the same knowledge that successful explorers use to find important oil fields. The Palawan discoveries are examples of successful use of knowledge. Recognition that the Philippine Islands are a "tectonic railroad siding" may be the key to future exploration success. These islands are continental fragments, each with its own individual geologic characteristics, that have