

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.

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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 mi² (2,600 km²). 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.

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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 H₂ and CH₄ as well as mantle-derived ³He-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 $(1.3 \pm 0.2) \times 10^{-3}$, 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 ³He-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.

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Philippine Islands: a Tectonic Railroad Siding

In 1976, significant quantities of oil were discovered offshore north-west 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 some 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