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 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.

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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 H_2 and CH_4 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 $(1.3 \pm 0.2) \times 10^{-5}$, 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 ^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 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 moved from elsewhere to their present positions along a major strike-slip zone. Play concepts can be developed in the Philippines for continental fragments in each of the three major present-day tectono-stratigraphic systems that are dominated by strike-slip, but include subduction and extension tectonics, with both carbonate and clastic sediments.

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Continental Margin of Eastern Canada—Geologic Framework and Petroleum Potential

The Atlantic-type continental margin of eastern Canada is underlain by a series of Mesozoic-Cenozoic sedimentary basins separated by basement highs or areas of thinner sediments. Regional and/or salt tectonics have structured the Mesozoic sequence, which is masked by a less-deformed wedge of prograding uppermost Cretaceous and Cenozoic sediments. The basins have been targets of active hydrocarbon exploration for over 2 decades. Data from 138 exploratory wells and over 680,000 km (420,000 mi) of multichannel seismic coverage have indicated four major geologic/geochemical regions: Scotian Shelf, southern Grand Banks, northeastern Grand Banks, and Labrador–Southeast Baffin Shelf.

On the Scotian Shelf, 13 significant gas/condensate discoveries have been made out of 62 wildcats drilled since 1967. Five of the discoveries, including the Venture field, are in an overpressured zone that has been explored only since 1979. No commercial hydrocarbon accumulations have been found in the southern Grand Banks where 28 wildcats were drilled between 1966 and 1975. The northeastern Grand Banks region has been actively explored since 1971. The 22 wildcat wells drilled through late 1983 have yielded six significant light oil discoveries, including the giant Hibernia oil field. Labrador–Southeast Baffin Shelf exploration has yielded six gas/condensate discoveries in 26 exploratory wells drilled since 1971.

The Geological Survey of Canada has developed hydrocarbon-generation models to explain the regional variation in oil and gas occurrence and to assess future potential in terms of the nature and thermal maturity of the source rocks, type of organic material, and time of trap formation. These factors are related to the geologic history of the margin, which is characterized regionally by diachronism in major basin inception and in the resultant stratigraphic record. We predict an exciting future for this vast petroleum province.

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Circum-Arctic Petroleum Potential

The Arctic is one of the most climatically hostile and demanding areas in the world. However, to the petroleum explorationist it is one of the most exciting and promising hunting grounds that remains to be explored.

The low-lying areas and the shallow broad shelves of the circum-Arctic are underlain by many large sedimentary basin complexes. From the Late Devonian through the Tertiary, many types of sedimentary basins were formed and filled. Episodes of continental rifting have created large interior basins, passive continental margins, and new ocean basins. Major shear or transform faults have displaced continental segments hundreds of kilometers and formed sedimentary basins in the process. Convergent plate motion has resulted in thrust faulting, magmatism, subduction, and the accretion of exotic terranes to the continents. The processes of crustal contraction have formed sedimentary basins, and in some cases, inverted them.

Paleolatitudes have ranged from near the equator to the present polar portion and climates have fluctuated from tropical to arid to boreal.

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Basin Development and Hydrocarbon Occurrence Offshore Mid-Norway

The continental shelf offshore Mid-Norway was opened for exploration drilling in 1980. The area extends southward to the North Sea sedimentary basins and northward to the Barents Sea continental shelf. The central part is a proven petroleum province. By use of mainly seismic and well data, the tectonic evolution, sedimentary facies, reservoir potential, and hydrocarbon generation and distribution have been studied.

After peneplanation of the Caldeonides, a large epicontinental basin connected the region between Greenland and Norway during the late Paleozoic and Mesozoic. Pre-Triassic rocks have not yet been recorded in the wells and nothing is known about their exact composition. The main targets for the exploration drilling have been the Triassic-Jurassic succession. The Triassic consists mainly of continental red shales with sandstone and salt intervals of poor to no source or reservoir potential. During the Triassic, regional extension initiated the formation of half grabens.

A change in climate to more humid conditions toward the end of the Triassic led to coastal plain deposition that persisted into the Early Jurassic. These carbonaceous sediments are important source beds for gas and condensate. The reservoir potential is low because of expected lack of continuity of the channel sands and extensive kaolinite cementation.

A major transgression took place during the Early Jurassic, leading to deposition of a sequence of shallow marine sands, tidal-flat sands, and offshore muds of medium to low reservoir quality. A Middle Jurassic regression resulted in deposition of shallow marine sandstones presently representing the main reservoir in the area. Diagenesis has not been detrimental to the reservoir properties, and a similar porosity-depth trend as seen in the North Sea is present.

Normal and growth faulting during the Triassic to Early Jurassic culminated with the main Kimmerian (pre-Callovian) tectonic phase that resulted in extensive horst and graben development, with subsequent erosion of structural highs. The Upper Jurassic consists of marine shales, of which the upper part is an oil-prone shale of excellent source rock characteristics.

The base of the Cretaceous is developed as a regional unconformity (late Kimmerian) onlapped by Cretaceous marine shales, marls, and minor limestone with no reservoir potential. Differential subsidence created the main platforms and basins. The resulting Cretaceous thickness ranges between 0 and 3 km (9,800 ft), with the main depocenter at the outer part of the shelf.

The Tertiary represents a period of epeirogenic subsidence leading to rapid deposition of marine clastic sediments. The northward progress of the North Atlantic rift is seen in the sedimentary record as a series of tuffaceous layers within the upper Paleocene-lower Eocene. Along the margin, a volcanic high was formed. As the continental slope and shelf subsided, damming of glacial deposits landward of the outer high created the Voring Plateau. Reactivation of older fault zones took place, and there is evidence for strike-slip movements and folding, especially in the northern area.

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Basins and New Frontiers: an Overview

Although the global transition to alternate energy sources has begun, for the coming decades the world's chief reliance will be on oil and natural gas supplies. Therefore, petroleum exploration must be concentrated toward discovering the oil and gas that lie untapped in both the known petroleum producing areas of the world and in the frontier regions. These frontier areas—the deserts, ice-covered lands, deep waters, and remote continental interiors—are estimated to hold vast hydrocarbon accumulations. It is in these sectors where future oil and gas discoveries could make the difference between a proper energy transition or a global catastrophe.

Explorationists must reevaluate the mature and developing petroleum regions of the world. The vast ocean areas and the remote continental interiors must also be carefully and thoroughly appraised to ascertain their petroleum potential. In conjunction with these investigations, new and better uses of geology, geophysics, and petroleum engineering and technology must be employed so as to enhance not only exploration, but development and production.