strike-slip components with horizontal displacements of dozens, or even hundreds of kilometers. Pre-Mesozoic faults, in part reactivated during the Mesozoic, had an important role in controlling the distribution of Jurassic-Cretaceous organic-rich shales and porous clastics. Wrench faults that developed during the Late Cretaceous–Tertiary mark the limit of the major petroleum provinces of west Siberia: the oil-rich Mid-Ob province, the less-prolific southern basin, the northern province (the world's leading gas region), the as yet little-drilled Khatanga trough, plus several other less-explored areas. Furthermore, most of the low-closure hydrocarbon-bearing structures seem to be of the drag type, being directly related to wrenching.

The relationship between strike-slip faults and the comparatively much smaller petroleum accumulations within the Paleozoic of the basin's southern part is more difficult to understand.

Future exploratory drilling to Mesozoic targets, including the deep-seated Jurassic in northern regions, and the Cretaceous in little-explored, low-accessibility parts of central-southern regions, should result in considerable new reserves of oil being found, probably exceeding the amount already found. A comprehensive wrench-tectonical approach may help find these undiscovered resources.

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Vega Field and Potential of Ragusa Basin, Offshore Sicily

Vega, the largest single oil field in the Mediterranean Sea, is located between the southeastern coast of Sicily and the Island of Malta. The field lies entirely in Italian waters. Its discovery in October 1980 was based on interpretation of a very poor-quality seismic survey which, nevertheless, roughly outlined a relatively small structure. A limestone and dolomite fractured reservoir of the Inici, or Siracusa Formation, of Late Jurassic age, may contain in excess of 1 billion bbl of heavy crude (15.5 API) within a productive area of approximately 10,000 acres (4,000 ha.). Reservoir properties are excellent, with permeabilities in darcys. The field extends northwest-southeast for 8.5 mi (14 km) and averages 1.7 mi (3 km) in width, according to the 3D seismic survey (2,000 km) shot soon after the discovery well was drilled. The gross oil column reaches approximately 820 ft (250 m). The southeasternmost part of the Vega structure is not yet completely defined, and an additional 3D seismic survey is in progress. Should the new seismic results confirm expectations, the Vega structure could extend over 10 mi (17 km).

The deepest formation reached by wells in the Ragusa basin is the Taormina Formation (dolomite of Middle to Late Triassic age) to which the Ragusa, Gela, Ponte Dirillo, and Piano Lupo oil fields are linked. The overlying Streppenosa Formation (Late Triassic to Early Jurassic age) is represented by bituminous shale with limestone development at the bottom (basal Streppenosa or Noto Member), which produces in the Mila and Irminio fields.

The overlying Inici reservoir consists of dolomite and underlain by limestone in the southwestern part of the basin, and entirely of limestone in the northwestern portion of the basin. The Inici Formation represents the platform facies of the open-sea Villagonia and Giardini sediments. The Cammarata-Pozzillo (discovered in 1959), Perla (1979), Vega (1980), and Prezioso (1983) heavy crude oil fields are related to this formation.

The Vega structure lies across the edge of the Inici carbonate platform. The northeastern flank appears to be controlled mainly by the facies variation between the Inici and Villagonia Formations. The southwestern flank seems, rather, to be controlled by dip.

The potential for discovery of other fields similar to Vega in the Ragusa basin is excellent.

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Antarctica—Geology and Hydrocarbon Potential

Antarctica covers approximately 14 million km^2 (5.4 million mi^2) and hosts an estimated 90% of the world's ice. About 98% of the continent is covered by glacial ice with an average thickness of 2,000 m (6,500 ft). Temperatures range from slightly below freezing along the coast in January to -88°C (-126°F) in the interior in August.

Seven nations lay claim to parts of Antarctica. However, some claims overlap and none are accepted or recognized by most nations, including the United States and the USSR. The 1959 Antarctic Treaty, which expires in June 1991, did not annul, but froze, the existing claims for the duration of the treaty. International meetings to determine jurisdictional and exploitative rights have been and are continuing to be held.

The first impression of the hydrocarbon potential of Antarctica is generally negative. The environment is hostile and only 2% of the continent is seen through the ice. Careful study of the surprisingly ample volume of published data available on the geology and geophysics of Antarctica, coupled with the application of the principles and mechanics of plate tectonics relative to the oceans and adjacent land masses, gives a different and very positive attitude toward the hydrocarbon potential of this vast unexplored frontier area.

On the basis of limited data, 21 sedimentary basins are identified for Antarctica and immediately adjacent areas. These include six onshore subglacial basins and 15 offshore basins. Excluding 11 basins considered to have little or no potential, the other 10 basins contain an estimated 16.9 million km^3 (4.05 million mi^3) of sediment having a potential hydrocarbon yield of 203 billion bbl oil equivalent.

The problems associated with hydrocarbon exploration in Antarctica are formidable. Technology is adequate for seismic surveys and exploratory drilling of the Antarctic continental shelf, as concluded from current operations in the Arctic and from operating requirements of drilling rigs under construction. However, a working relationship among involved nations must first be evolved and production, storage, and transportation problems solved.

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Tectonic Development and Hydrocarbon Potential Offshore Troms, Northern Norway

The study area, offshore Troms, is located from 16 to 25°E long. and 70 to 72°N lat. The geologic border between continental and oceanic crust is defined by a dramatic increase in water depth in the western part of the area. The area with water depth less than 500 m (1,640 ft) covers approximately 6,000 km^2 (2,300 mi^2). In this area, several highs and basins are defined. The Troms and Hammerfest basins are situated between the Loppa high on the north and the Troms-Finnmark basement high on the south. The southwestern continuation of the Troms basin is a strongly faulted depression, the Harstad basin. Thinned continental crust under the Troms basin is covered with more than a 15 km (9.3 mi) thick sedimentary sequence of Paleozoic and younger rocks. Early Permian evaporites have formed a few large diapiric structures. The main rifting phase in the Troms basin occurred during Late Jurassic–Early Cretaceous. Several thousand meters of Cretaceous claystones were subsequently deposited. During early Tertiary, a second rifting phase resulted in sea floor spreading west of the studied area. During the cooling stage, the southwestern Barents Sea acquired a westward dip. Tertiary sediments onlap the Upper Cretaceous unconformity from the west. Quaternary sediments lie directly on Cretaceous sediments in the eastern part of the area.

The north-south–oriented Ringvassøy-Loppa fault complex separates the Troms from the Hammerfest basin. In the Hammerfest basin, the Permian is developed as a shallow shelf carbonate facies. Tertiary and Mesozoic sedimentation was dominated by clastics. The Harstad basin is dominantly filled with Jurassic and younger sediments, and Paleozoic sediments are thought to underlie. Minor amounts of diapirism are present. Several compressional structures, formed by mid-Cretaceous strike-slip forces, are associated with the Troms-Finnmark fault complex. The Loppa high is a triangular-shaped structure covered by relatively thin Jurassic to Quaternary sediments. The southeastern part is an inverted Triassic basin. Shallow shelf carbonates define a good seismic marker in the upper Paleozoic.

Seismic control of the area offshore Troms, at present, is generally a 2 by 4 and 2 by 2 km grid. More detailed surveys cover the licensed areas, totaling 2,200 km^2 (850 mi^2). The first exploratory well was spudded in spring 1980, and 15 wells, dominantly wildcats, have now been drilled. Five gas discoveries have been made in the western Hammerfest basin, two of them with recoverable reserves in the range of 50-100 × 10^9 Sm^3 (1.76-3.52 tcf) gas.

All discoveries have been made in Early to Middle Jurassic sandstones. Rocks of Triassic and Permian age will be increasingly important toward the east and north. In the Troms basin, these sub-Cretaceous rocks are deeply buried, so younger reservoir zones have been drilled. Jurassic and younger rocks will be the main targets in the virgin Harstad basin.

The gas has been generated from Lower Jurassic coals and shales. These, and Upper Jurassic shales with oil source potential, will probably also be the source for most hydrocarbons to be discovered in the future. Some deep Paleozoic structures will be dependent on older source rocks.

The hydrocarbon potential of the relatively well-known Troms and Hammerfest basins is considered low and moderate, respectively. More promising today are Paleozoic structures on the Loppa high and structures in the Harstad basin.

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Permian of Norwegian-Greenland Sea Margins—Future Exploration Target

Oil and gas exploration in the northern North Sea and the southern Norwegian shelf has mainly been concentrated on Jurassic and younger reservoirs with Late Jurassic black shale source rocks. New onshore investigations in Jameson Land, central East Greenland, suggest that the Permian of the Norwegian-Greenland Sea margins contains relatively thick sequences of potential oil source rocks interbedded with carbonate reefs.

The East Greenland, Upper Permian marine basin is exposed over a length of 400 km (250 mi) from Jameson Land in the south to Wollaston Forland in the north, parallel with the continental margin. The maximum width of the onshore part of the basin is 200 km (125 mi), and the maximum thickness of preserved sediments is about 300 m (1,000 ft). The Upper Permian lies unconformably on faulted, tilted, and peneplaned Lower Permian red beds or older rocks. The Upper Permian sediments are indicative of a transgressive sequence. Initial sedimentation in the marginal parts of the basin are characterized by evaporites and hypersaline carbonates, whereas normal marine carbonate and black shale prevail in the more offshore parts of the basin. Continued transgression led to the development of normal marine conditions throughout the basin and carbonate reefs were formed over structural highs. Black shale rich in organic matter was deposited under anaerobic to dysaerobic conditions between and around the reefs. Toward the end of the Permian, reef growth ceased and many reefs were draped by black shale that finally gave way to coarser grained, carbonaceous sandy shale, deposited under well-oxygenated normal marine conditions. A very short but marked regression took place at the Permian-Triassic boundary, so that along basin margins and over structural highs, the top of the Permian was eroded. Subsequently, the Early Triassic sea transgressed the area and deposition of marine sandstone and shale continued. The Triassic shale is reminiscent of the Upper Permian shale, but the organic content of the former is low and mainly of terrestrial origin (spores and pollen). Accordingly, the Triassic shale has no source rock potential. Following the Early Triassic marine interlude, a major regression took place. The remaining part of the Triassic was characterized by intermontane graben deposition of alluvial fan, fluvial, eolian, and lacustrine red beds.

The Upper Permian black shale is relatively thick, widely distributed, has a high organic carbon content, and a favorable kerogen type. According to vitrinite reflectance and pyrolysis data, it is premature to slightly mature in the surface exposures along the basin margin. If buried under 2-3 km (6,500-9,800 ft) of younger sediments, as is expected in the onshore and offshore basins, the shale will most probably be developed as a mature source rock for oil. It is interbedded with and overlies carbonate reef and platform sequences that have undergone several periods of karstification in some areas. This karstification may have enhanced the reservoir potential considerably. The Upper Permian shale has a combined source rock and seal potential, and uppermost Permian and Lower Triassic coarse sandstone interbedded with the shale may also have reservoirs properties. The Lower Triassic also contains several tight shale and evaporite units that may function as seals. In the northern North Atlantic area, the Early to Middle Triassic was a period of rifting activity; thus, combined structural-stratigraphic traps are an obvious exploration target. Consequently, the possibilities for a Permian play in the northern part of the Norwegian shelf and along parts of the Norwegian-Greenland Sea margins are worth evaluating.

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Exploration History and Future Prospects of United States Atlantic Margin

The Atlantic Margin of the United States comprises four large basins that are, from north to south, Georges Bank basin, Baltimore Canyon Trough, Carolina Trough, and Blake Plateau basin (which includes the Georgia Embayment and Bahama Platform). Most exploratory drilling has focused on structures in the postrift basin depocenters, with eight Georges Bank wildcats having been drilled into structures formed by block faulting and salt movement. Target zones were Upper and Middle Jurassic sandstones and carbonates. All were dry holes with some minor gas shows. Twenty-nine exploratory wells have been drilled into four types of structures in Baltimore Canyon Trough: an intrusive dome, deep-seated diapirs, fault blocks, and most recently a Lower Cretaceous-Upper Jurassic shelf-edge "reef." Some hydrocarbons were associated with a deep-seated diapir structure, but the other wells were dry. Wells in the Southeast Georgia Embayment penetrated Lower Cretaceous-Upper Jurassic continental clastics and shallow Paleozoic basement rocks. All wells were dry. No exploratory wells have been drilled in the Carolina Trough or Blake Plateau.

Recent leasing in Georges Bank has been delayed because of litigation. In the Baltimore Canyon Trough, most recent leasing appears targeted at a prominent Lower Cretaceous-Upper Jurassic paleo-shelf edge, where it is hoped that synrift deposits rich in organic matter source porous shelf-edge carbonates and overlying clastics. Shell Oil, the largest leaseholder, is drilling a series of wells to test this structure. Between the Baltimore Canyon and Carolina Troughs, several leases have been taken over a large anticline possibly cored by salt. Another block of leases has been taken in the Carolina Trough immediately south of Cape Fear over a large grabenlike structure. Other, smaller groups of blocks appear to have lesser structures as targets. The Blake Plateau as yet has no active leases.

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Petroleum Potential of Western Desert of Egypt

The Western Desert of Egypt, despite many discouragements, has major potential as a petroleum province. Approximately 150 exploratory wells have discovered nine commercial oil and gas fields, with flows of oil or gas recorded from an additional 21 wells.

All discoveries have been in marine inner shelf sandstones and carbonates that range from Aptian to Turonian in age. Potential reservoir rocks are known in Paleozoic to Tertiary sedimentary rocks. Mature source rocks have been recognized in the Devonian and in Jurassic to Upper Cretaceous strata. Seals, mainly shale, but including carbonates and some evaporites, are present in most formations in most areas. Structural traps are abundant.

Despite these favorable factors, in-place reserves of only 800 million bbl of oil and condensate, and up to 1,185 bcf of natural gas have been found. Almost all exploration has been limited to the drilling of relatively small onshore structures and no giant fields have been found. All significant discoveries to date have been in anticlinal traps, commonly modified by faulting.

New investigations utilizing a broad regional tectonic framework provide a means both of recognizing the more prospective provinces of the Western Desert and for understanding the structural evolution in terms of the timing of growth folding and growth faulting. These new investigations have been based on an approximately 10 by 10 km (6 by 6 mi) seismic grid and have identified many structural prospects and leads in the onshore area. Most structures are in the Abu Gharadig, Kattaniya (Gindi basin), and northern province of the Western Desert. The Abu Gharadig basin is of particular interest, being recognized as a major rhombochasmic basin containing numerous localized "highs" provided by northeast-southwest-oriented, doubly plunging (periclinal) anticlines. There are, therefore, sufficient structures to warrant extensive additional exploration.

Particular attention should be given to testing the lower part of the Cretaceous and Jurassic. The Paleozoic section also warrants further attention as demonstrated by a review of drilling results and by indications from gravity data. The new investigations indicate a considerable potential within the Western Desert for discovery of small to moderate-size accumulations of oil and gas. In addition, possible reefal, carbonate