regarding the cost, risk and time that will be involved in developing production from those resources. Even from a national sense of supply security, the vast reserves of oil in the tar sands and in-situ recovery deposits of heavy oil in western Canada will provide a competitive ceiling that will limit future development of frontier basins to those where production costs are not significantly higher than those of the tar sands.

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Future Petroleum-Productive Regions of USSR and Mongolia

The potential for major discoveries of oil and gas is high in the USSR, but remote in Mongolia. Development of the USSR's potential is plagued by six factors: (1) remoteness of prospective basins from commercial markets, (2) lack of adequate infrastructure within prospective basins, (3) inadequate drilling technology for economic development below depths of 3,200-3,800 m (10,500-12,500 ft), (4) poor-quality indigenous equipment, (5) absence of offshore capabilities, not only in the warm Caspian and Black Seas, but also in the ice-plagued Arctic and Pacific Oceans, and (6) a chronic manpower shortage. Imports of foreign technology are alleviating the problems gradually, but they are far from solved.

European USSR.—The most important objectives of the future are: (1) Jurassic through Devonian in the Greater Barents basin and Svalbard platform, offshore Barents Sea, (2) deep Carboniferous-Ordovician of Timian-Pechora basin, (3) subthrust plays of western Urals, (4) pre-Kungurian salt section of the Pricaspian basin, (5) Devonian of the Dnepr-Donets graben, (6) Jurassic through Paleogene of the Black Sea shelf, (7) pre-Tertiary formations of the North Caucasus trough, and (8) deep Tertiary objectives near Baku in the central and southern Caspian Sea.

Asiatic USSR.—The most important targets are: (1) deep Mesozoic and Paleozoic (Carboniferous, Devonian, Silurian) carbonates of the Nyurol'ka, Frolovo, and other depressions in and below the West Siberian basin, including the Kara Sea, (2) late Paleozoic-Mesozoic of the Aral' Sea, the Ustyurt depression, the Chu-Sarysu basin, and the Turgay and Syrdar'ya syneclises, most of them unexplored, (3) the pre-Upper Jurassic of the central Asian basins, (4) the deep Tertiary of the Cheleken district, (5) the subthrust and pre-Tithonian salt section of the South Tadzhik basin, (6) the Proterozoic-Silurian marine sequences of the Tunguska, Lena, and Sukhana basins, and of the Nepa-Botuoba arch, (7) the Carboniferous-Lower Jurassic of the Vilyuy, Lena-Anabar, Khatanga, and Yenisey basins, with the associated subthrust plays of the Taymyr and Verkhoyansk ranges, and (8) the numerous late Paleozoic-Mesozoic offshore basins of the Arctic shelf plus the Tertiary basins of the Pacific, especially the Severny basin.

Mongolia.—Principal objectives are Jurassic and Cretaceous fluviatile and lacustrine sandstones in southeastern Mongolia, especially in the East Gobi basin and in the Hailar basin, which is shared with China. Similar basins in China have giant fields, such as Karamay in the Junggar basin and Daqing in the Songliao basin.

Resources.—Through 1983, the USSR had produced about 75 billion bbl of oil and condensate and 217 tcf of gas. Estimated proved plus probable liquids was 35-36 billion bbl and, of gas, about 800 tcf. Resource potential, above and beyond proved plus probable, is estimated at about 90 billion bbl and 1,000 tcf (these numbers will increase as offshore ice-pack technology is improved). In contrast, Mongolia's produced and proved oil is less than 2 million bbl, but the resource potential could be large.

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Oil and Gas Potential of Amazon Paleozoic Basins

The Paleozoic basins, covering an area of about 800,000 km^2 (309,000 mi^2) in the Amazon region, are elongate symmetrical intracratonic synclines filled with as much as 4,000 m (13,000 ft) of sediments, separated by basement uplifts or major arches and located in continental interior areas (as are the United States Illinois, Michigan, and Williston basins). These Amazon basins resulted from an initial crustal thinning followed by rifting with associated ultrabasic intrusions and, finally, cooling and subsidence. Gravity anomalies, coinciding with the axes of the synclines, support this genetic hypothesis.

These synclines were filled during the Silurian-Devonian with one cycle of continental alluvial sediments grading upward to deltaic marine clastics and minor periglacial deposits. A regional unconformity separates the Devonian from the Permo-Carboniferous cycle when, following fluviodeltaic sedimentation, highly restricted marine conditions developed a sequence of evaporite deposits.

Tectonics affected differentially these basins during the Triassic-Jurassic and Early Cretaceous, associated with widespread basic volcanism. A northeast-southwest thrust-fault system, branching southwest, characterizes a compressional orogenic province in the Upper Amazon basin. This compressional province, located in the Jurua River area, constitutes a major structural trend. Adjacent to those faults and extending for over 500 km (310 mi), large natural gas accumulations occur in several domal features. Sandstones of the Permian Monte Alegre Formation, sealed by evaporite strata, are the main reservoir rock. Geologic estimates of natural gas resources are presently rated at 120 billion m^3 (4.237 tcf) and exploration follows the productive trend toward the west-southwest.

The Middle Amazon basin, separated from the Upper Amazon by the Purus arch, was affected by lineament-block tectonics, also with associated volcanism and some local mild shearing. Minor domal features of Devonian periglacial Oriximina Formation sandstones comprise small subcommercial oil accumulations. In contrast with the Upper and Middle Amazon basins, the Lower Amazon basin has been the site of rifting since the Permo-Triassic. The rifting was associated with a nearby hot spot that uplifted the eastern part of the basin, forming the Gurupa arch. As a consequence of this uplift, a set of collapse grabens developed in the Lower Amazon basin. Potential reservoir rocks in Middle and Lower Amazon basins are Permian Monte Alegre and Devonian Oriximina sandstones. Major source rocks in all three basins are Devonian Barreirinha black shales. Organic geochemistry data indicate that both Upper and Lower Amazon basins are predominantly gas-prone, whereas the Middle Amazon basin shows potential for oil generation.

Forecasts for the major exploratory trends in the Upper Amazon indicate a good possibility of extending the already discovered natural gas province. In the Lower Amazon basin, further exploration will consist in drilling well-defined structural features identified for the first time by seismic methods, with a possibility of discovering another gas province. Prospects in the Middle Amazon basin are for both oil and gas, but the main problem is identification of adequate structures, as well as stratigraphic traps.

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Geology of Barents Sea

The Barents Sea is situated on the continental shelf between Norway, the Spitsbergen Islands, and Novaya Zemlya. The main structural framework of the area was formed during the Caledonian and Hercynian orogenies, whereas the western parts were reactivated by the Kimmerian and Alpine orogenies. Because of the complex opening of the Greenland-Norwegian Sea, important Tertiary reactivation of Mesozoic normal faults occurred along southwest-northeast-trending systems of wrench faults.

Owing to substantial erosion in the late Tertiary, the subsidence history and thermal development are more difficult to unravel in this area than in other places along the Norwegian Shelf. The erosion products were deposited in a huge sedimentary wedge extending onto the oceanic crust.

The hydrocarbon discoveries in the Troms area in the southern part of the Barents Sea are encouraging for further exploration. However, the petroleum potential for large areas is not well known at this stage.

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Wrench Faults as Factor Controlling Petroleum Occurrences in West Siberia

The morphology of west Siberia suggests the presence of huge wrench faults, which also can be seen on Landsat imagery. Many of these faults have been confirmed by geophysical surveys and subsurface data. However, Soviet geologists have not always recognized the importance of 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