organic metamorphism; under ideal conditions, LOM is nearly linear with maximum burial depth. Comparison of reflectance data of vitrinite obtained from coal-bearing with other strata provides the most satisfactory method of describing the progression of organic metamorphism through a major segment of the coal-rank scale. Vitrinite reflectance studies in noncoal-bearing sequences are commonly complicated by the presence of higher reflectance vitrinite, which may result from the physical incorporation of vitrinite from older rocks or from oxidation caused by winnowing action or bioturbation. Interpretation of the reflectance data strongly hinges on a sequence of samples, a knowledge of the lithology, and knowledge of the depositional environment.

Geochemical maturity parameters, such as the *n*-paraffin ratio and the naphthene-ring index, indicate that the generation of petroleum is at a maximum for a source rock with a thermal history corresponding to a high-volatile *B* to medium-volatile bituminous coal rank (LOM 9 to 11.5), which falls within a vitrinite reflectance (*Ro*) of 0.72 to 1.20%. Studies in California and Alaska Tertiary basins show that the onset of geochemical maturity occurs at LOMs of 9-11. The depths to this zone range from 10,000 to 17,000 ft; the differences depend chiefly on variations in geothermal gradient.

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PROGRESS IN ARCTIC OCEAN SEDIMENT STUDIES

A few years ago the only information available on the deep Arctic Ocean sediments and history was based on a few short cores taken incidentally from floating ice islands by Americans and Russians. Summer work in the Beaufort, Chukchi, Laptev, Kara, and Barents Seas provided additional information but only for the marginal parts of the Arctic Ocean. Beginning in 1963, a systematic coring program was initiated from ice-island T-3 by Lachenbruch and Marshall of the U.S. Geological Survey. To date, 550 cores have been taken along the drift course of T-3, covering almost 1 million sq km of the central Arctic Ocean. Such coverage of an ocean from an iceberg is unique.

Because these cores represent the only record for such a large part of this important ocean, study has been designed to yield maximum data concerning mineralogy, petrology, paleontology, sedimentary structures, glacial erratics, paleomagnetism, and heat flow. Paleomagnetism has provided a stratigraphic framework for all of the studies. The objective of a paleoecologic interpretation of the Arctic Ocean has led to a variety of data, including information on the permanence of the ice pack and identification of the oldest sediment (Cretaceous) known in the central Arctic Ocean. Also, studies on paleomagnetism, sediments, silicoflagellates, and Foraminifera have combined in a unique manner to help establish a time reference for plate tectonics of the Arctic Ocean.

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GENERATION OF LIGHT HYDROCARBON GASES IN DEEP-SEA SEDIMENTS

Several hundred analyses have been made both on board the *Glomar Challenger* and in the laboratory on gas samples returned from the Deep-Sea Drilling Project (JOIDES). Methane was the dominant gas in all samples, commonly amounting to more than 99% of the total. Small quantities of ethane or propane were observed in areas of high heat flow, or over a possible petroleum reservoir.

Significant quantities (40 X 10^9 cu ft/cu km) of methane can be generated in the interstitial water of deep-ocean sediment where reducing conditions are initiated by rapid burial of organic matter. Comparison of carbon isotope (C^{13}/C^{12}) ratios of coexisting methane and dissolved carbonate indicates that the methane originates by bacterial CO_2 reduction. This mechanism does not involve the formation of ethane or higher hydrocarbons, or require the rupture of carbon-carbon bonds. Therefore, bacterial methane is chemically and (usually) isotopically distinct from hydrocarbon gases derived from thermocatalytic maturation of organic matter. Bacterial methane production generally begins when all sulfate is reduced, and continues with increasing depth of burial in the sediment, as long as symbiotic bacteria provide the required substrates, carbon dioxide, and hydrogen.

At some depth in the sediment column, depending on temperature and concentration, methane can exceed solubility in the interstitial water, migrate upward as a gas, and reach saturation at shallower depths. If the height of the overlying water column is greater than about 1.5 km, the gaseous methane may be converted to the solid clathrate hydrate within the uppermost (about 500 m thick) layer of sediment, where temperatures are below 20-25°C.

Stabilization of methane as a solid gas hydrate could be an important factor in the accumulation of natural gas deposits by (1) preventing loss of gaseous methane from the sediments; (2) allowing upward migration of gaseous methane at a pace controlled by the sedimentation rate; and (3) producing an enrichment of gaseous methane in the zone just below the lower limit of stability of the gas hydrate.

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SEDIMENTARY EVOLUTION OF NORTHERN APENNINES AS CONSEQUENCE OF EMBRYONIC TETHYAN SPREADING DURING LATE TRIASSIC-EARLY JURASSIC

Mesozoic Tethyan sedimentation may be explained tentatively by assuming a paleogeographic east-west-trending, narrow furrow dividing Europe from Africa. Along its northern margin are aligned the Carpathians, Northern Alps, Corsica-Sardinia, and Beticum; along the southern side are the Dinarides, Southern Alps, Apennines, Sicily, and the Atlas Mountains.

A slow transgression from Late Permian to early Lias is recognized from the Dolomites through Lombardy and Tuscany, and as far south as Sicily and the Atlas Mountains. The transgressive sequence overlying the continental facies is composed of clastic, shallow-marine deposits, evaporites, clayey or carbonate lagoon/tidal-flat deposits, shelf limestones, and cherty, pelagic limestones, or uninterrupted shelf sequences. The same facies sequence is recognized in the horizontal plane in two main directions along the main transgressive trend, and perpendicular to the isopach lines symmetrically disposed on both sides of the furrow. This situation is detected from Late Permian to Late Triassic, and is related to a slow downwarping. During early to middle Hettangian, a carbonate-shelf facies spread over the area, testifying to general marine conditons.

In late Hettangian time, a pelagic realm covered the region, and the facies distribution was controlled by faults parallel with or perpendicular to the main furrow. Thus, pelagic basins between small carbonate platforms were formed abruptly, attesting to the disintegration of the previous larger platform. However, tectonic control maintained the previous trend. In fact, the first pelagic facies are late Hettangian in Tuscany and Pliensbachian in Umbria. During Malm time, in the Ligurian region, continental crust broke up with extrusion of ophiolites which promoted jasper sedimentation, diminishing from Tuscany toward Umbria.

We conclude that the embryonic tectonic movements are detectable over great distances, through a slow shifting of facies in time and space. The rapid tectonic movements, instead,

account for the sudden appearance of pelagic facies which follow platform disintegration.

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CRETACEOUS SEDIMENT DISPERSAL PATTERNS IN THE METHOW-PASAYTEN GRABEN, NORTH CASCADES, WASHINGTON

Analysis of paleocurrent trends, thickness variations, and lithologic intervals recorded to Cretaceous clastic sediments of the Methow-Pasayten graben indicates a dominantly eastern source through most of the Cretaceous, but with a Late Cretaceous interval of westerly derived sediments.

Neocomian black shales, volcanic sandstones, and conglomerates of Barksdale's Buck Mountain Formation and the Upper Jurassic Dewdney Creek Group of Coates were derived from the east. These sediments are overlain unconformably by arkosic Aptian sediments of Barksdale's Goat Creek, Panther Creek, and Harts Pass Formations, and Coates' Hauterivian to lower Albian Jackass Mountain Group, all apparently derived from the crystalline rocks of the Okanogan Highlands on the east. These Late Jurassic, Neocomian, and Aptian sequences of volcanic rocks, volcanic sediments, and arkosic sediments record the destruction of the volcanic cover and erosion into the Okanogan Highlands crystalline rocks. In sharp contrast, the unconformably overlying chert-grain sandstones and chert-pebble conglomerates of Barksdale's Upper Cretaceous Virginian Ridge Formation contain paleocurrent structures and variations in clast size and formation thickness which indicate derivation from a western source. The most probable source terrain is the Paleozoic Hozomeen Group of the Cascade core.

Unconformities and chert sandstones and conglomerates correlate with the mid-Cretaceous deformational episode of Misch in the North Cascades. These sediments could reflect tectonic uplift during thrusting or rapid isostatic rebound following mid-Cretaceous deformation and metamorphism.

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DIRECT DETECTION OF HYDROCARBONS

Because of the gas shortage in the United States, it is necessary to increase the nation's gas reserves. It is possible to utilize a very highly refined seismic technique for the direct detection of gaseous hydrocarbons in aquifers. This refinement is based on the increase in reflection coefficient caused by the addition or the replacement of the liquid in the pore space of an aquifer by the gas and an accompanying decrease in both the velocity and density of the aquifer. Refined data-acquisition techniques, including binary-gain amplifiers, accurately record the size of the reflections. Improved data-processing techniques with floating point processing, which preserves the amplitude of the reflections, make it possible to display a seismic section that the interpreter can use to find subsurface locations where the reflection coefficient is increased in amplitude ("hot spots"). Because this technique depends on the uniformity of source and surface conditions, it is particularly suitable for offshore areas and should come into extensive use in future offshore-gas exploration in the United States. This technique probably was responsible in part for the very high prices paid for some of the blocks in the recent offshore Louisiana sale.

Like almost all seismic techniques, it is not unambiguous and there are phenomena which can be confused with the increase in amplitude due to the presence of gas. This increase in amplitude can be caused by focusing, lithologic changes, phases of reflections caused by multiples, and nonuniformity of source and surface. It is important that the acquisition and processing be done carefully so that the interpreter is presented with a high-quality section for interpretation. This interpretation requires a more careful treatment than in the past.

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TAR SANDS DEVELOPMENT

Tar sands (also known as oil sands and bituminous sands) are sand deposits which are impregnated with dense viscous petroleum. Ultimate world reserves of bitumen in tar sands are about equal to ultimate reserves of crude oil in the United States. However, the only tar-sand deposit of present commercial importance is in the Athabasca area of Alberta, Canada. The pioneer venture to produce synthetic crude oil from tar sands began in 1967, operated by Great Canadian Oil Sands Limited (GCOS).

Tar sand is mined and transported to a processing plant where the bitumen is extracted, after which the sand is discharged into a tailings pond. At 10 weight percent bitumen saturation, two tons of processed tar sand produces 1 bbl of bitumen. Because tar sand is a relatively low-value ore, mining and transportation costs must be minimized. A key economic factor to be considered is the removal of overburden. The overburden ratio at GCOS (that is, the thickness of overburden which must be removed to expose a unit thickness of tar sands) is approximately 0.4.

The fact that large tar sands reserves are readily available in a friendly, stable country, and further that the material shipped is almost pollution free, should lend impetus to development.

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ORIGIN OF LATE CENOZOIC BASINS IN SOUTHERN CALIFORNIA

Several sedimentary basins in southern California, within and south of the Transverse Ranges, display a history suggestive of a rhombochasmic origin. Beginning in the early Miocene, segments of the continental margin at the soft and splintered border between the Pacific and Americas plates were apparently fragmented so that basins originated as irregular pull-aparts. Basin walls were formed by both transform faults and by crustal stretching and dip-slip faulting. Deep basin floors grew as a complex of volcanic rocks and sediments. As basins enlarged, high-standing blocks are pictured as separating laterally from terranes that were originally adjacent. Older rocks exposed around margins therefore cannot be extrapolated to depth within the basins.

Support for such a speculative model comes from accumulating understanding of the Salton trough. This narrow graben is being pulled apart obliquely, with faults of the San Andreas system serving as transforms. With widening, the walls sag and stretch, and margins are inundated by sedimentation that occurs simultaneously with deformation and volcanism in the basin floor. The Los Angeles basin apparently started to form as a rhombic hole in the middle Miocene, with basin-floor volcanism accompanied and followed by voluminous sedimentation. The Miocene "Topanga basin" in the western Santa Monica Mountains contains vast thicknesses of volcanic and sedimentary rocks that were laid down adjacent to high ground, from which sediments and huge detachment slabs were carried into a spreading hole. Other basins that perhaps reveal stages in the history of crustal stretching, culminating in pull-aparts and rhombochasms, are parts of Ventura basin, Ridge basin, and several offshore depressions, including the Santa Barbara Channel.

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MARINE MINERAL RESOURCE ECONOMICS

Analysis of future demand projections to the year 2,000 for 88 mineral commodities indicates that estimated land resources in the U.S. will not meet the demand for 31 of these, and world resources are inadequate for 20 of them.

Apparent mineral resources in the marine environment are in most cases equal to, or greater than, those of terrestrial occur-