course of the Ob River in the central part of the basin, production is largely oil from Lower Cretaceous arkosic sandstones on anticlines. Samotlor, the largest oil field in the USSR, is in this area. In the northern part of the basin, mainly gas is produced from Upper Cretaceous clastic rocks on anticlinal traps. Urengoy, the world's largest gas field, is located in this area.

CLAYTON, J. L., U.S. Geol. Survey, Denver, Colo., and P. J. SWETLAND, Gulf Science and Technology Co., Pittsburgh, Pa.

Petroleum Generation and Migration in Denver Basin

Crude oils and shales from the northern Denver basin were analyzed using organic geochemical techniques to determine relations between oil and source beds. Hydrocarbon analyses (gasoline-range, $C_{15}+$ saturates, and C_{15} to C_{20} isoprenoids) and stable sulfur isotope ratios show that, in general, Cretaceous oils are compositionally similar throughout the basin and are dissimilar to oil produced from the Permian Lyons Sandstone.

Shales were evaluated for source-rock potential based on organic richness, thermal maturity, and geochemical correlation with crude oils. These analyses showed that most of the Cretaceous oils have been derived from Carlile Shale, Greenhorn Limestone, Graneros Shale, and Mowry Shale. These units have a maximum collective thickness of about 600 ft (180 m) and can be grouped together on the basis of similar geochemistry. The source bed for the Lyons oil has not been identified.

Analyses of samples from the Carlile-Greenhorn-Graneros-Mowry interval from throughout the basin show that the effective source beds are limited to the basin-axis area. Although shale samples from eastern Colorado and southwestern Nebraska are organic-rich, they are generally thermally immature ($\bar{R}_o$ values 0.32 to 0.49%) and contain hydrocarbon distributions unlike the Cretaceous oils. Samples from the basin-axis area of Colorado have $\bar{R}_o$ values of 0.60 to 0.85% and petroleumlike distributions of hydrocarbons. Rocks in southeastern Wyoming generally have intermediate reflectance values (0.48 to 0.62%) but large quantities of extractable, heavy ($C_{15}+$) hydrocarbons ($\sim$700 to 1,600 ppm), and have good source potential. However, geochemical correlations revealed that the Wyoming samples are compositionally somewhat different from the oils and are not considered a major petroleum source in the Denver basin.

The occurrence of petroleum on the east flank of the basin and the limited geographic distribution of effective source beds indicate that extensive (perhaps 100 mi; 160 km) lateral migration has occurred. This suggests that an understanding of lateral-migration pathways is important for petroleum exploration in the Denver basin.

Cretaceous oils in the Terry and Hygiene reservoirs have probably undergone extensive vertical migration (2,500 ft or 762 m in the Central Front Range area).

CLIFFORD, HAROLD J., ROGER GRUND, and HASSAN MUSRATI, Arabian Gulf Exploration Co., Benghazi, Libya

Geology of a Stratigraphic Giant—Messla Oil Field, Libya

The Messla oil field is the most recent addition to the imposing list of 20 giant fields which have been discovered within the prolific Sirte basin of Libya. The field, discovered in 1971, is located in the southeastern part of the Sirte basin, approximately 40 km north of the supergiant Sarir oil field. Although in an early stage of development the field is estimated to contain approximately 3 billion bbl of original oil in place. The essential trapping mechanism is the updip truncation of the Lower Cretaceous Sarir Sandstone on a broad structural flexure.

The average oil column of approximately 100 ft (30 m) is productive from an average depth of 8,800 ft (2,640 m) over a 200-sq-km area.

The Messla field is a seismically defined stratigraphic accumulation located on the east-dipping flank of an ancestral basement high. The productive unit is the Lower Cretaceous fluvial Sarir Sandstone which wedges out westward on the Precambrian basement and is truncated by a marked unconformity at the base of the capping Upper Cretaceous marine shales, which are considered to be the source rocks.

The reservoirs consist of two Sarir sandstones separated by a continuous shale bed. Porosity values average 16% and the permeability 450 md. Production as of early 1978 is in excess of 100,000 bbl/day of 40° API gravity oil with a cumulative production of 45 million bbl.

CLIFTON, H. EDWARD, KEITH A. KVENVOLDEN, and JOHN B. RAPP, U.S. Geol. Survey, Menlo Park, Calif.

Spilled Oil and Infaunal Activity—Modification of Burrowing Behavior and Redistribution of Oil

A series of experiments in Willapa Bay, Washington, indicates the degree to which the presence of spilled oil modifies the burrowing behavior of infauna and the extent to which they redistribute oil into the sediment. Small amounts of North Slope crude oil introduced at low tide directly into burrow openings (mostly made by the crustacean *Callianassa*) caused a limited and temporary reduction in the number of burrow openings. The presence of low concentrations of oil to depths of 30 cm shows that the fauna mixed this oil into the sediment. In contrast, a layer of oil-saturated sand <1 cm thick buried about 5 cm below the sediment surface sharply reduced the number of burrow openings. After a year a few new burrows penetrated only the margins of the experimental plot (even though chemical studies showed that the oil was biodegraded in 6 months). Cores showed a dramatic reduction in bioturbation under the buried oily sand layer.

The experiments suggest that small amounts of oil temporarily stranded by tides have no long-range effect on burrowing behavior. The fauna, however, are capable of introducing measurable amounts of oil into the subsurface, where it is retained long after the stranded oil has moved elsewhere. A buried layer of oily sand greatly reduced infaunal activity, presumably because

the oil presents an impenetrable physical barrier that can persist after the oil itself is degraded by bacteria.

COHEN, A. S., Univ. California, Davis, Calif.

Environmental Significance of Fossil Root Casts from Koobi Fora Formation (Pliocene-Pleistocene), East Turkana, Kenya

Roots and fossil root casts at East Turkana, Kenya, are valuable as paleo-environmental indicators. Roots are preserved within the Koobi Fora Formation as calcified concentric and nodular casts in lithologies independently interpreted as fluviodeltaic or lacustrine-coastal plain. Five common root cast "types" are recognized: (1) horizontal, planar root mats; (2) vertical or vertically branching root structures; (3) horizontal or horizontally branching root structures; (4) diagonally branching root structures; and (5) root clusters or balls. Root mats are usually in blocky or laminated muds. Typically, the mats extend laterally over tens of square meters, although an individual mat will be only about 5 cm thick. They appear to have grown in quiet-water lagoons. Vertical root structures are best developed in coarse-grained sands interpreted as fluvial channel, and secondarily in fine-grained silts believed to be interdistributary overbank deposits. They are uncommon in blocky or laminated lagoonal muds. Comparison of root morphologies among living East Turkana plants supports interpretation of the fossil associations. In arid environments water availability is a dominant factor in root morphology. Plants growing along intermittent streams or flood plains must frequently rely on perched water bodies or underground seepage, and therefore send out long vertical tap roots to take advantage of this limiting resource. Plants living within shallow reed swamps have no such requirement, as their roots are nearly continually immersed in ground water; during floods the plant stalk itself is subaqueous. The roots of these plants tend to extend laterally in thin mats over much of the lagoon.

COLE, MARY LOU, Rice Univ., Houston, Tex.

Nearshore Glacial-Marine Sedimentation; Preliminary Modeling Based on Pliocene-Pleistocene Deposits of Puget Lowlands

Environmental interpretations based on combined sedimentologic and micropaleontologic analyses together with field relations have enabled preliminary modeling of processes of nearshore glacial-marine sedimentation in the Puget Sound region (Washington and British Columbia). Although these processes are active today in the Arctic and Antarctic, ice cover makes direct observations of them difficult. Therefore, uplifted Pliocene-Pleistocene deposits were examined, using various criteria for the recognition of similar deposits in the ancient record.

Forty-six whole or partial sections from the Puget Lowlands have been measured, described, and sampled, and over 200 samples have been analyzed for foraminiferal content. These data, in conjuction with detailed textural (settling tube) analyses and available radiocarbon dates from the area, have enabled the delineation of sedimentary environments and their associated facies.

Modeling is based on the interaction of such parameters as thermal regime of the ice sheet, eustatic sea-level fluctuations, circulation patterns as delineated by the microfaunas, and changes in bathymetry resulting from isostatic loading and rebound and from regional tectonics. Thermal regime of the ice appears to be the major controlling factor, determining both the kinds of sediments deposited and the extent to which marine processes are able to act on them. Microfaunas show strong evidence of the mixing of a restricted shallow-water ice-shelf fauna with mid-shelf and outer-shelf forms which must be explained by any subsequent models. Glaciotectonic structures appear to be an important consideration for interpreting these sequences and may possibly be used to explain some of the present problems with regional stratigraphic correlations.

COLEMAN, D. D., and W. F. MEENTS, Illinois Geol. Survey, Urbana, Ill.

Isotope Geochemistry of Natural Gas in Illinois Basin

Natural gas samples collected throughout the western half of the Illinois basin were analyzed chemically and isotopically to determine the origin and history of the gases. The samples were obtained from a variety of sources including groundwaters (fresh water and brines), cores, oil wells, and gas wells. Samples from shallow (50 to 500 ft; 15 to 150 m) groundwaters contain methane of bacterial origin; the δC^{13} values for methane from these waters are generally in the range of -65 to -90 parts per thousand. Samples from relatively deep (1,500 to 3,000 ft; 450 to 900 m) gas and oil accumulations contain thermogenic methane having δC^{13} values in the range of -46 to -56 parts per thousand. Gas accumulations that have isotopic compositions intermediate between those of the deep thermogenic gases and the shallow bacterial gases may be the result of mixing of gases from these two sources. There is also a general trend of increasing δC^{13} values southward, however, presumably reflecting increasing maturity of the source rocks in that direction as indicated by increasing coal rank. Therefore, some of the gases with δC^{13} values in the range of -56 to -65 parts per thousand may be "low grade" thermogenic gases. Additional C^{13}/C^{12} analyses and some D/H analyses are in progress to help resolve this question.

Most of the gas wells are on the margins of the basin. Gases from these wells are isotopically similar to solution gases from oil wells in the center of the basin, but often are depleted in the heavier hydrocarbons, some consisting almost entirely of methane. This chemical difference is believed to be at least partly a result of fractionation during migration of the gas toward the basin margins. Other available data are being assimilated to test this hypothesis.

COOGAN, ALAN H., Kent State Univ., Kent, Ohio