hydrocarbon reservoirs in North America were used to quantitatively study diagenetic alterations of pore systems. Results were most favorable for rocks in which no early cementation or secondary replacement occurred and for which the pore system could be characterized sedimentologically.

Geologic modeling of permeability/porosity crossplots may reveal secondary permeability that results from microstructural damage, fracturing, and/or directional dissolution. Secondary permeability type may be determined from examination of the core or porecasts. Analyses of permeability/porosity crossplots may establish the relative timing of the various diagenetic modifications.

OBRADOVICH, JOHN D., and CHARLES W. NAESER, U.S. Geol. Survey, Denver, CO

Geochronology Bearing on Age of Monterey Formation, California

The name Monterey Formation or Monterey Shale has been applied to lithologically similar pelitic marine rocks of Miocene age exposed in the coastal regions of California. These rocks, characterized by unusually high proportions of silica, have been variously termed diatomite, porcelanite, porcelaeous shale and mudstone, chert, and cherty shale. The type area for the Monterey Formation was designated near Monterey, California.

Although the Monterey Formation in general contains numerous ash, tuff, and bentonite beds, only a few of these volcanic units have been dated. It has been necessary to make use of both the isotopically dated horizons and Kleinpell's Miocene benthonic foraminiferal stages to construct a time-stratigraphic framework for the Monterey Formation at different locations. Ages for the various stage and zone boundaries, based on published and unpublished data, are as follows:

Repettian-Stratotype *B. oblique ("Delmontian"),* ca. 5 m.y.B.P.; Stratotype *B. oblique*-Mohnian, ca. 7 m.y.B.P.; Mohnian-Luisian, ca. 12 m.y.B.P.; Luisian-Relizian, 14.0 to 14.9 m.y.B.P.; Relizian-Saucesian, 15.7 m.y.B.P.

At the type area, an ash from the Canyon del Rey Diatomite Member, the uppermost member of the Monterey Formation, was dated at 11.3 ± 0.9 m.y. (F-T on zircon). Coupled with a Luisian age for the oldest strata, the type Monterey Formation spans, at most, the time interval from 15 to 10 m.y.B.P. In contrast, the Monterey Shale in the Palos Verde Hills encompasses the time interval from 15 to 5 m.y.B.P. based on isotopic data from the Altamira Shale, Valmonte Diatomite, and Malaga Mudstone Members, which contain foraminiferal assemblages characteristic of the Relizian, Luisian, and Mohnian Stages, and the *B. oblique* zone ("Delmontian").

At other localities where biostratigraphic and isotopic data are available, the rocks termed Monterey are not exact time equivalents of the type foramation, an observation made earlier by both Kleinpell and Bramlette.

ODDO, JOHN E., JOHN A. S. ADAMS, and M. B. THOMPSON, Rice Univ., Houston, TX

Novel Approach to Eh-pH Diagrams and Their Relation to Uranium In-Situ Leaching

When constructing Eh-pH diagrams, workers have previously assumed a fixed total concentration of a substance in solution, and calculations (assuming equilibrium) were made to predict mineral phases and aqueous species at various Eh-pH conditions. When dissolving a solid compound (as in in-situ leaching), it seems more plausible to assume a solid phase in solution at various Eh-pH conditions and allow the aqueous species the freedom to assume thier equilibrium concentrations.

The computer program EHPHUR was written to thermodynamically simulate the dissolution of a solid phase leading to diagrams which differ markedly from conventional Eh-pH diagrams. The name proposed for these new diagrams is dissolution diagrams. The assumptions include unit activity of uraninite, and fixed amounts of O_2, CO_2, and H_2S at 25°C and 1 atm. The parameters were chosen to simulate in-situ leaching systems currently in use.

Using these diagrams, thermodynamic arguments can be presented which are consistent with the results of kinetic experiments, for example: the first and zero order dependence of the uraninite dissolution rate on the carbonate concentration; the decrease in the dissolution rate as the pH approaches 6.0; and the dependence of the rate on the oxygen and hydrogen ion concentrations. Apparent optimum pH values for in-situ leaching are discussed.

OLDHAM, DAVID W., and D. KEITH MURRAY, Colorado School Mines Research Inst., Golden, CO

Methane from Coal Beds—an Exploration Approach

Vast amounts of methane are trapped in much of the unmined and unminable coal in the United States. This virtually untapped unconventional source of clean energy should become economically viable within the next few years. Consequently, it should be viewed as an important new exploration frontier.

An approach to coal-bed methane exploration involves a combination of coal and conventional gas exploration strategies. Because coal beds are both the source and the reservoir of the gas formed during the coalification process, the subsurface extents of the coal beds define the geologic dimensions of the resources of coal-bed methane. The amount of producible methane in a given coal bed is highly variable, being a function of the depth of burial, the rank of the coal, the degree of fracturing, and the permeability of the contiguous strata. Consequently, the successful search for producible quantities of coal-bed methane requires an understanding of the depositional and diagenetic history of coal.

O'LEARY, DENNIS W., U.S. Geol. Survey, Woods Hole, MA, and WILLIAM B. F. RYAN, Lamont-Doherty Geol. Observatory, Palisades, NY

Geomorphic Features of Shelf-Slope Revealed by Sidescan Sonar Images

Recently acquired sidescan sonar images reveal, for the first time, the landscape pattern and the detailed geomorphology of the North Atlantic shelf-slope break off the United States and other areas extending from the edge of the continental shelf to the upper slope. Long-range (GLORIA II) images that have swath widths of as much as 40 km show small-scale regional features; midrange images that have swath widths of as much as 5 km show features as small as 3 m across.

The midrange images show that the outer edge of the shelf, deeply embayed by submarine canyons, outlines a nearly flat surface marked by complex ripple patterns. In places, the slopes converging toward adjacent canyons are also complexly rippled; this feature suggests that the shelf surface and the upper canyon slopes are mutually stable under common hydrodynamic conditions. In general, canyons in the upper slope have relatively broad flat thalwegs distinguished by relatively bright surfaces; tonal gradations indicate that the thalweg surfaces lap smoothly onto sharply etched border terrane. Terrane bordering the canyons typically has a simple gully and ridge trellis pattern; one or both sides of this bordering terrane may be spectacularly etched and extended. Individual gullies typically extend up to faceted back slopes. The extent and pattern of etched terrane, as shown in the midrange images, varies considerably from canyon to canyon suggesting the influence of multiple erosional events involving different mechanisms, and a substratum of varied erosional resistance.

OMNES, GILDAS, Compagnie Generale de Geophysique, Denver, CO

What Can Elasticity Moduli Tell Us About Lithology and Diagenesis?

Because rocks have a certain rigidity, the displacement and velocity associated with pressure waves are not, for a given density, functions of the incompressibility alone, but also of the rigidity which links particles to each other.

In the shear waves, displacement occurs without volume change and the velocity is, for a given density, a function of rigidity alone.

For isotropic media:

$$V_p = \frac{(k + 4/3\mu)^{1/2}}{\varrho} \text{ and } V_s = (\mu/\varrho)^{1/2}$$

where V_p, V_s = velocities of pressure and shear waves; k = incompressibility modulus; μ = rigidity modulus; and ϱ = density.

The knowledge of V_p alone is not enough to separate the effects of changes of incompressibility and rigidity. Though seismic velocities are proportional to the reciprocal of the square root of the density, statistical evidence shows that pressure and shear-wave velocities increase with density.

This must be attributed mainly to the effect of cementation. Cementation fills pores with solid material, thus increasing incompressibility, and cements particles together, increasing rigidity. However, compaction, the process of volume reduction, has much less effect on the rigidity increase than on the incompressibility increase. Where cementation is not important, low shear-wave velocities can be expected. Lower shear-wave velocities can also be expected where fracturing decreases rigidity, or where the shaliness of a horizon increases. Compressibility changes can be detected in shaly intervals.

The velocity of pressure waves may remain fairly constant when ridigity increases and incompressibility decreases, as when voids occur where the matrix is better cemented than in contiguous formations. The knowledge of V_s might attract attention to such situations.

OREMLAND, RONALD S., U.S. Geol. Survey, Menlo Park, CA

Geochemical Prospecting for Oil and Gas: Microbiologist's Viewpoint

Microorganisms are important factors in the processes that govern the distribution of numerous chemical elements in the earth's crust. Carbon in particular undergoes an enormous variety of transformations as a consequence of microbial synthetic and degradative reactions. These reactions have importance in the study of organic geochemistry. Geochemical prospecting, however, has been limited by a lack of understanding of specific types of microbially mediated reactions and the extent to which they occur within the geosphere. Geochemical data interpretation for the purpose of finding oil and natural gas deposits would be enhanced by future research directed at: (1) defining the extent to which geochemically active microbes penetrate the earth's crust; (2) reinterpreting carbon isotope data in light of microbial reactions of formation, oxidation, and competition; (3) identifying novel microbial biomarkers; and (4) determining whether microbes can produce significant quantities of C_2+ gaseous hydrocarbons.

ORIFE, JAMES M., and AKPO A. AVBOVBO, Nigerian National Petroleum Corp., Lagos, Nigeria

Stratigraphic and Unconformity Traps in Niger Delta

Although hydrocarbons are dominantly trapped in rollover anticlines and fault closures in the Niger delta, some stratigraphic traps have also been recognized. Three types of stratigraphic accumulations are recognized in the Niger delta: (1) crestal accumulations below mature erosion surfaces; (2) canyon fill accumulations above unconformity surfaces; and (3) facies-change traps.

Several important oil discoveries in offshore southeastern Nigeria are associated with crestal accumulations below erosional surfaces. In addition, canyon fill accumulations have been observed in offshore southeastern Nigeria within the Qua Iboe Shale. Recent discoveries have also shown accumulations within the Opuama Clay in the western flank of the Niger delta. Facies-change traps have also been observed in the central part of the Niger delta. The various stratigraphic traps observed in the Niger delta are identified by interpretation of seismic data.

OSWALT, JACK M., Gulf Oil Exploration and Production Co., U.S., Midland, TX

Evaporites as Seals for Hydrocarbon Accumulations in Carbonate Provinces of North America: Case Histories

Evaporites are an important factor as the seal for hydrocarbon accumulations in carbonate provinces throughout North America. In the Silurian of the Michigan basin, dolomitized Niagaran pinnacle-reefs have been effectively sealed with evaporite cycles composed of anhydritic sabkha deposits of the Ruff Formation and cleaner evaporites of the Salina units. In the Williston basin of North Dakota and Saskatchewan, successive regressions of the Mississippian sea have resulted in the subsequent basinward migration of anhydritic sabkha deposits over algal-pelletal limestone banks that were formerly shoals at the seaward edge of the sabkhas. The anhydrite has halted the updip migration of hydrocarbons in these limestones. In the Permian of west Texas, over 731 million bbl of oil have been produced from the San Andres Formation against a porosity barrier along the eastern side of the Central Basin platform where anhydrite has plugged the porosity of the dolomite. The McElroy field is an excellent example of this important trend.

The environmental conditions that provide the typical setting for the formation of shallow-marine carbonates are also ideal for the formation of evaporites whenever marine waters become sufficiently restricted. The occurrence of excellent evaporite seals in close proximity to porous carbonate reservoirs can provide many opportunities for entrapment of