age that are rich in organic carbon (C-org) are common in the deep seas and in shallow interior and shelf basins of the world. High concentrations of C-org and the presence of fine laminations suggest that these strata accumulated in environments that were anoxic or nearly anoxic at and possibly above the seafloor. Many organic-rich sequences display a marked cyclicity in amount of C-org and, if deposition was near or above the carbonate compensation depth, in $CaCO_3$ as well. These cyclic C-org and $CaCO_3$ variations result in interbedded lighter and darker shale, marlstone, and limestone that have cycle periods ranging from 20,000 to 100,000 years. Variations in degree of bioturbation parallel changes in C-org and $CaCO_3$ because burrowing organisms were most active at times of deposition of relatively low C-org and high $CaCO_3$ sediments.

Such cycles are best developed in sediments deposited during episodes of lower dissolved oxygen concentration (so-called "oceanic anoxic events"), but similar cycles of C-org and $CaCO_3$ variation having periods of tens of thousands of years occur in strata of almost every geologic age. The periodicities are similar to those in pelagic sediments of Pleistocene age that are known to be climatically induced. Studies of geochemistry, stable isotopes, and mineralogy show that older organic cycles are also related to climatic changes that produced fluctuations in the amount of wind- and river-borne clastic sediment and terrigenous organic matter delivered to the oceans, and to coincident variations in surface-water salinity, productivity, and mid- to deep-water oxygen concentration. Regional paleogeography and paleodepth determined the amount and type of organic matter preserved within the sediments.

AULT, CURTIS H., and DONALD D. CARR, Indiana Geol. Survey, Bloomington, IN

New Exploration and Evaluation of Coal Resources in Complexly Faulted Area Containing Old Petroleum Production

The use of standard core-drilling methods to evaluate commercial possibilities of deep Pennsylvanian coals in southwestern Indiana is difficult if not prohibitively expensive owing to complex faulting and the presence of numerous alluvial channels.

In Posey County, where complex faulting is common, more than 5,000 oil tests have been drilled, most having electric logs or other geophysical logs run more than 20 years ago. Correlation of these logs with nearby coal-test cores, lithologic strip logs of well cuttings, and sparse outcrop information has resulted in: (1) mapping of zones of closely spaced normal faults (as many as four individual faults in a single well) with vertical displacements of 20 to more than 300 ft (6.1 to >91.4 m) and horizontal lengths of as much as 20 mi (32 km); (2) rapid mapping of coal thicknesses to an accuracy of about 1 ft from old geophysical logs; (3) delimiting of channels that are contemporaneous with peat deposition (related to thickness and sulfur content of coals); and (4) correlating for the first time several lithologic units in rocks of Pennsylvanian age. Through study of modern mining techniques in an area of closely spaced drilling in Indiana and Illinois we are able to consider the potential for underground mining in highly drilled areas of old petroleum production. Data integration from these diverse sources facilitates rapid outlining of prospective areas of minable deep coals that would not be possible otherwise.

AVBOVBO, A. A., and E. O. AYOOLA, Nigerian National Petroleum Corp., Lagos, Nigeria

Petroleum Prospects of Anambra Basin, Southern Nigeria

The Anambra basin occupies an area of about 40,000 sq km in southern Nigeria. Twenty-one exploratory wells have been drilled in the basin between 1952 and 1974. None tested formations older than lower Turonian. Five of the exploratory wells discovered gas while only one well encountered oil. These discoveries indicate that the basin is dominantly a gas-condensate basin. Because of plans to build an LNG plant in the neighboring Niger delta, an intensive exploration must be carried out in the basin to determine the gas reserves which can be tied into the proposed Niger delta LNG.

About 5,000 m of sediments ranging in age from Aptian(?) to Miocene are exposed in the basin. The sediment distribution consists of shales and limestones in the central part of the basin which grade into coarse-grained sandstones in the northwestern and eastern flanks of the basin.

Evaluation of wells drilled shows that the basin is most prospective where peripheral sandstones interfinger with or are overlain by shale units. Future exploration efforts should be concentrated on Turonian and Maestrichtian objectives which show good sand development beneath the zone of freshwater flushing.

AVIS, LOREN E., and D. R. BOOTH, Texas Oil & Gas Corp., Denver, CO

Promising Morrow Sandstone Discoveries in Southeastern Colorado

Eight new Morrow oil and gas fields have been discovered in southeastern Colorado during the past two years. The latest discovery resulted in a well flowing oil from a Morrow sandstone at an initial rate of 700 bbl of oil per day and 750 Mcf of gas per day. The trapping mechanism in this well, as in most, is a stratigraphic and structural combination.

The depositional history of Morrow sandstones in southeastern Colorado was strongly influenced by regional tilt into the Anadarko basin, established at the close of Mississippian time. Mississippian rocks were subject to truncation in the area of the Las Animas arch and development of karst topography on the erosion surface. Transgression of the sea from the southeast in Morrowan time resulted in the deposition of a sandstone and shale sequence.

The Morrow series consists of a basal transgressive sandstone member (Keyes sandstone) overlain by at least three sandstone units deposited during regressive pulses in an overall transgressive sequence. These Morrow sandstones generally trend from northwest to southeast toward the Anadarko basin; their source is inferred to have been the ancestral Rocky Mountain

uplift for the upper sequence and the Amarillo uplift for the basal Keyes member. The environment of deposition appears to have been fluvial delta plains and associated tidal channels which were alternately created and destroyed by regression and transgression of the Morrowan seas. Distribution of these elongate sandstones is generally erratic and meandering; individual sand bodies have an estimated width of up to 1 mi (1.6 km) and a maximum thickness of 42 ft (12.8 m).

The nature and distribution of these sandstones leave many areas essentially unexplored. Southeastern Colorado has had substantial Morrow discoveries which justify a closer look at the area.

BACHMANN, G. H., G. DOHR, M. MUELLER, et al, Preussag AG, Hannover, Germany

Exploration in Classic Thrust Belt and Its Foreland—Bavarian Alps, Germany

The Bavarian Alps are composed of a stack of thrust sheets, which have been transported northward onto the molasse of the Tertiary foredeep.

Exploration in the Unfolded Molasse zone and its Mesozoic substrata has resulted in the discovery of a considerable number of oil and gas fields. Most of these fields are related to monoclines, which are aligned along west-east–striking, reverse growth faults. In addition, other fields are related to facies traps which were successfully located by improved seismic methods.

The northern edge of the Alpine orogene is formed by the west-east–striking synclines of the Folded Molasse zone, which is thrust at least 20 km over the autochthonous Unfolded Molasse zone. Several wildcats reveal good porosities and oil and gas shows. Coalification studies have proved that even the deepest parts of the Molasse zones are within the oil window.

The Helveticum zone is thrust over the Folded Molasse zone, and it contains potential reservoir rocks with gas shows. The Helveticum zone is tectonically overlain by the Flysch zone, which has no reservoir properties.

The Kalkalpin zone (Cretaceous Alps) is the uppermost thrust complex. It was recently penetrated by the wildcat Vorderriss 1, which proved that the Kalkalpin consists of several nappes with a total thickness of 6,400 m. At Vorderriss the Flysch zone is not present and must have been tectonically removed; the Kalkalpin zone is thus underlain by allochthonous Helveticum zone. Minor oil and gas shows are present in the Vorderriss 1.

In the Alps, seismic data are of satisfactory to good quality and major thrust planes can be mapped. The seismic data indicate that the molasse and its substrata extend far to the south beneath the Kalkalpin zone and, furthermore, they apparently form domal structures at several locations.

At Vorderriss, seismic data indicate that the Helveticum zone, the molasse, and the Mesozoic substrata, which all underlie the Kalkalpin zone, have a total thickness of about 2,000 m. The crystalline basement is expected to be at a depth of 8,200 m. According to maturity studies this sedimentary complex is still within the oil window.

BACKUS, MILO M., Univ. Texas at Austin, Austin, TX

Geophysical Exploration is Just Beginning

What fraction of the yet undiscovered hydrocarbons will ultimately be found and produced? The answer depends on our success in developing and effectively applying the seismic method. Seismic reflection technology is in its infancy, and geophysical exploration is just beginning.

We are now going after a three-dimensional quantitative subsurface image, in terms of compressional wave impedance. We are beginning to seek additional elastic properties and Q. Inference of structure from lateral variations in reflection time is being supplemented by inference of fluid content and other rock properties from "lateral" variations in impedance.

Details of seismic images should be explained in terms of subsurface geology, unless proved otherwise. If well log data disagree with seismic data, well log data are probably wrong. We have a real need for improved "ground truth" if we are to effectively evaluate and interpret the seismic image.

There are many limitations to current image quality, highly variable from one prospect to the next, and for the most part amenable to foreseeable technology improvements. In most areas, the only fundamental limitations on our ultimate seismic image quality are high frequency loss, and geologic noises—and we do not understand either one.

BAKER, F. E., and G. W. FOCHT, Hudson's Bay Oil and Gas Co., Calgary, Alta.

Geophysical Case History of Two Hills Colony Gas Field of Alberta

Seismic waveform changes, which in their most obvious form are known as "bright spots," have been known for some years to give direct indications of hydrocarbons. An example of the successful application of waveform analysis and direct detection of gas in a shallow Lower Cretaceous formation of east-central Alberta, Canada, is detailed.

At a depth of approximately 2,000 ft (610 m), the Colony formation typically consists of only thin (10 ft; 3 m) blanket sands interbedded with shale. However, in 1976 Hudson's Bay Oil and Gas Co. investigated a 100-ft (31 m) thick occurrence of channel sand (with substantial gas pay) in this formation. After some hit and miss attempts at extending the channel trend on geologic interpretation, seismic methods were applied. A seismic line over the channel well revealed a classic "bright spot." Several other lines also showed bright spots in the Colony zone. The results of seismic modeling can be summarized as follows. The lateral consistency of the sediments above the Colony provided a stable boundary of modeling and permitted the detection of gas. The inconsistency and complexity of the sediments underlying the Colony resulted in interference patterns that prevented exact quantitative analysis of gas pays. Furthermore, other geologic phenomena provided waveform changes that were similar to that of