morphic rock fragments (4%), mostly slate and phyllite. Feldspars are conspicuously absent in the sandstone. This detrital suite, and the overall decrease to the southwest in the grain size of the sandstone, indicate that the sands of the formation were derived from a northern landmass, exposed in the Late Permian and Early Triassic, which consisted of Precambrian schists and quartzites overlain by early Paleozoic marine sandstones and deep-water cherts and argillites.

After deposition, the reservoir facies of the Ivishak sandstone underwent 4 consecutive diagenetic phases: (1) early carbonate cementation that prevented mechanical compaction, (2) dissolution of pore-filling carbonate and carbonate inclusions within chert grains, (3) precipitation of quartz as overgrowths, and (4) precipitation of authigenic kaolinite. At present, the intergranular porosity of the formation is high, averaging 11.5%, and is present in the forms of elongate and oversized secondary pores. Porosity also occurs as micropores associated with leached chert grains and with the kaolinite. In the more matrix-rich nonreservoir facies of the Ivishak, the clay matrix prevented complete carbonate cementation which allowed for greater mechanical compaction of the sandstones; in some places, this mechanical compaction, coupled with the precipitation of quartz overgrowths, reduced porosity to irreducible levels.

MCBRIDE, EARLE F., Univ. Texas, Austin, TX

Compaction in Sandstones—Influence on Reservoir Quality

Primary porosity that is lost during burial through cementation by carbonate, evaporite, and some clay minerals can be regenerated during the stage of secondary porosity development that is typical of most basins. However, primary porosity that is lost through compaction is forever lost and cannot be regenerated. Thus, it is desirable to be able to predict the amount of porosity loss expected in sandstones buried to given depths.

During progressive burial, terrigenous sandstones compact by (1) packing readjustments without changes in grain shape, (2) ductile deformation of clayey and micaceous grains, chiefly rip-up-clasts, fecal pellets, and fragments of shale, mudstone, slate, and schist, (3) bending of flexible micas, (4) pressure solution, and (5) fracturing of feldspar, quartz, and chert grains. Process 1 generally results in a 7-10% porosity loss and is independent of sandstone composition; processes 2, 3, and 4 are strongly dependent on framework composition and each by itself is responsible for producing tight sandstones; and process 5 is generally not important. Process 3 was modeled by Rittenhouse, who showed that sandstones with 35% ductile grains can compact to produce tight sandstones.

Pressure solution becomes important at depths greater than 8,000 ft (2,400 m). Pressure solution at quartz grain contacts is enhanced where thick illite or chlorite clay coats develop and is most common in quartz-rich sandstones that lack much quartz cement. Quartz dissolved from grains generally exits the formation instead of being precipitated as cement. Stylolites develop at mica-rich and clay-rich laminae and develop conspicuous vertical permeability barriers. Wholesale dissolution of quartz grains leaves a residue of clay, micas, organic matter, and feldspar.

MCCABE, PETER J., Alberta Research Council, Edmonton, Alberta, Canada

Influence of Strike-Slip Movement on Terrestrial Sedimentation in Upper Carboniferous of Nova Scotia and New Brunswick

Lower Pennsylvanian (Namurian and lower Westphalian) sediments of maritime Canada were deposited in alluvial and lacustrine environments. Thick (>3.5 km, 2.1 mi) sequences of these sediments accumulated within structural basins formed between strike-slip faults.

Movement of the faults during the Namurian caused uplift in compressional areas. These positive areas, consisting of crystalline rocks and older Carboniferous sediments, provided a local supply of coarse sediment to the basin. In some cases, the positive areas excluded the introduction of sediment from large rivers sourced well outside the depositional basin. Large lakes were common in the Namurian and were probably a result of the relatively small amount of sediment that entered the basins. This sediment-starvation is also indicated by sequences of stacked paleosols that provide evidence of slow rates of sedimentation.

A detailed study of the sediments indicates a progressive climatic change from arid conditions, with evaporites, in the lower Namurian to humid conditions, with coal deposits, in the Westphalian. This climatic change is reflected by an increase in the size of the extra-basinal river systems in younger formations. By the mid-Westphalian, the influx of sediment to the area was so great that the topographic basins were essentially infilled. Westphalian lakes were shallow and of limited lateral extent. Anomalously thick sequences of overbank sediments and stacked point-bar deposits are present, suggesting that tectonic movements were still sufficiently strong to influence the style of fluvial architecture.

MCGOOKEY, DOUGLAS A., Bur. Econ. Geology, Austin, TX

Cenozoic Epeirogenic Uplift of Palo Duro Basin, Texas, and Its Influence on Structure, Salt Dissolution, and Topography

Sufficient data are available to interpret a general history of Cenozoic epeirogenic uplift and its influence on structure, salt dissolution, and topography in the Palo Duro basin. Much of the structural warping and deformation of Middle and Upper Permian rocks in the Palo Duro basin occurred during Cenozoic epeirogenic uplift. Cretaceous marine strata in the Texas and Oklahoma Panhandles and eastern New Mexico were uplifted 3,000-4,000 ft (914-1,219 m). The "Tubb Sand" (Permian) exhibits about 4,000 ft (1,219 m) of structural relief over the Amarillo uplift and Bravo dome.

Differential uplift of the margins of the basin caused draping, fracturing, and faulting, which increased the amounts and rates of erosion and salt dissolution coincident with fault-bounded structures. Structural control of topography around the southern high plains is indicated by the coincidence of the Caprock escarpment and structural highs in Permian rocks, as well as the coincidence of many stream segments and segments of the Caprock escarpment with subsurface fault trends.

MCGREGOR, B. A., U.S. Geol. Survey, Reston, VA

Role of Submarine Canyons in the United States Atlantic Continental Slope and Upper Continental Rise Development

Three areas of the United States Atlantic continental slope and rise (seaward of Georges Bank, Delaware Bay, and Pamlico Sound north of Cape Hatteras) have been studied using seismic reflection profiles and mid-range sidescan-sonar data. The continental slope in all three areas is dissected by numerous submarine canyons. The general sea floor gradient of the slope and the morphology of the rise, however, vary among the areas. Submarine canyons are dominant morphologic features on the slope and have an important function in sediment transport and distribution on the rise. In the study area north of Cape Hatteras, however, the low relief of the rise topography indicates that ocean currents flowing parallel to the margin may also affect sediment distribution on the rise. Morphology and sedimentation patterns suggest that differences in canyon ages exist both within each area and among the areas. Spatial and temporal variability of canyon activity is important in determining sediment sources for the construction of the rise. Although the United States Atlantic slope and rise are relatively sediment-starved at present, mid-range sidescan data and submersible observations and samples suggest that periodic sediment transport events occur within the canyons.

MCMAHON, JAMES PATRICK, Univ. Oklahoma, Norman, OK

Interpretive Seismic Modeling in Anadarko Basin

Seismic forward modeling is a powerful aid when interpreting seismic profiles of complex structure. Considered here is the frontal fault system that is the boundary between the Anadarko basin and the Wichita Mountains.

COCORP deep seismic reflection data collected across the basin may reveal new evidence of thrust faulting in the frontal fault system. North-south lines 2 and 2a of the COCORP survey are interpreted using AIMS™ (Advanced Interpretive Modeling System) installed on the University of Oklahoma's IBM 3081 computer. Line 2a stretches southward from the relatively undisturbed sedimentary rocks in the basin across the N85°W-trending frontal fault system to the south. The modeling begins at the north end of line 2a because of the relatively simple structural geometry and well control in that area.

The initial modeling began with an hypothesis based on well logs, COCORP data, and other geologic information. After the subsurface structures were defined, depth and velocity plots were produced. Normal incidence rays were then traced from each horizon to specified shot points. The ray-tracing plot gives a good indication of the quality of resolution one can expect from a particular subsurface geometry. The synthetic profile was produced by first applying a broad-band pulse, then applying a Ricker wavelet to each trace. A gain function was applied to enhance the section for interpretation. Forward seismic modeling in the Anadarko basin enhances interpretation by giving an idea of the seismic resolution one can expect and letting the interpreter test a geologic hypothesis against the seismic profiles.

MEGILL, ROBERT E., Retired, Houston, TX

Exploration—The Past is the Key to the Future

Contrary to conventional wisdom, the history of crude oil prices has been one of volatile swings. Natural gas prices, somewhat more stable, have nevertheless undergone large percentage changes from year to year. Such abrupt changes have caused fluctuations in cash flow and have necessitated the cycles of expenditure evident in the past.

In good times the petroleum industry reinvests almost all of its revenue in finding, developing, and producing oil and gas fields. The reinvestment percentage logically shrinks in poorer times. For exploration alone, the reinvestment rate has averaged 25% since 1944.

Gas discoveries are dominant in new discoveries, and revenue from gas fields is rising as a percent of total wellhead revenue. However, more than half of all revenue is still from oil fields. Revenue is the dominant factor affecting activity. Thus, the ability to forecast future prices determines the ability of the industry to foresee its future.

The petroleum industry's myopic record shows a lack of prescience in the ability to divine future price levels. Any forecast of future activity is limited to the accuracy of the assumptions about revenue.

Given these major uncertainties, a series of forecasts based on several scenarios appears prudent.

MEISTER, EGON MANFRED, PETROBRÁS, Rio de Janeiro, Brazil

Geology of Petroleum in Campos Basin, Brazil

A schematic model of oil generation, migration, accumulation, and alteration is presented for the Campos basin, a sedimentary province covering an area of nearly 31,000 km^2 (12,000 mi^2) offshore southeastern Brazil, where an estimated 1 billion m^3 (6.3 billion bbl) of oil in place has been discovered since 1974.

Source rocks for this oil belong to the Lower Cretaceous Lagoa Feia Formation; oil generation probably started in the Miocene. At that time, a series of local windows opened in the regional evaporite seal at the top of the Lagoa Feia Formation and focused the upward escape of hydrocarbons, mainly along halokinetic fault surfaces. Reservoirs of Albian, Late Cretaceous, and Tertiary age were charged and their porosities enhanced by natural fracturing, solution, and/or grain rearrangement. Original oil (postulated range of 30°-35° API gravity) underwent differentiation by migration, reflected in relative enrichment of aromatics and of the light ^{12}C stable carbon isotope. Alteration of oil by water occurs if one of the two fluids in contact is allochthonous; bacterial alteration is important in low-temperature regimes. Oil entrapment is helped by hydrodynamic conditions, with the intake area of the Paraiba do Sul river delta supposedly playing an important part.

Lopatin-type plots gave the first clue for establishing this model, which takes into account a large number of facts about the basin, such as well and seismic information, clay diagenesis, water and petroleum geochemistry, pressure data, and their geologic field relationships.

MELIM, LESLIE A., Western Washington Univ., Bellingham, WA

Sedimentary Petrology and Depositional Environment of Sandstones of Scow Bay, Indian and Marrowstone Islands, Northwestern Washington

The unnamed middle Eocene sandstones of Scow Bay that are well exposed on the beaches of Indian and Marrowstone Islands, northwestern Washington, document a previously unknown local basement high that shed sediment south onto a subsea fan from the San Juan Islands terranes. The sandstones are lithic arenites with a variety of lithic grains, predominantly volcanic and sedimentary (including chert). Rare quartz-plagioclase plutonic and low-grade metamorphic (mainly chlorite-rich) lithic grains are also present. Quartz and plagioclase comprise most of the nonlithic grains. Rare heavy minerals and potassium feldspar are also present. The San Juan Islands terranes were the source area. Paleocurrent directions obtained from flute casts support this interpretation.

The sandstones are thin to very thick-bedded with minor shale interbeds and at least two 20 to 30-m (65 to 100-ft) thick shale beds. The sandstone beds are commonly structureless, although dish structures, poorly developed parallel lamination, load casts, and shale rip-up clasts are abundant locally. Soft sediment deformation, including slumps, is locally evident. Amalgamation of thinner sandstone beds into very thick (3-5 m, 10-16 ft) beds is common but often difficult to recognize owing to their structureless nature. The exposure along the east coast of Indian Island reveals at least 11 thinning- and fining-upward sequences. The sandstones were deposited as channel-fill sequences on the midfan region of a subsea fan. The thick shale beds were deposited between active channels.

MELLO, MÁRCIO ROCHA, GUILHERME DE O. ESTRELLA, and PAULO CÉSAR GAGLIANONE, PETROBRÁS, Rio de Janeiro, Brazil

Hydrocarbon Source Potential in Brazilian Margin Basins

Twenty thousand samples from the Brazilian continental shelf basins were analyzed to characterize and evaluate the hydrocarbon source potential of the areas.

The geochemical evaluation of the rock and oil samples was performed by organic carbon determinations, Rock-Eval pyrolysis, vitrinite reflectance, thermal alteration index, liquid and gas chromatographies, gas chromatography-mass spectrometry, and carbon isotope analyses.

Three source rock systems have been identified: lower Neocomian shales deposited in a continental environment, upper Neocomian shales grading from continental to lagoonal environment, and Aptian shales related to evaporitic and lacustrine sequences.

Upper Cretaceous and Tertiary open marine slope sediments are not considered as source rocks. Locally, these sediments present high organic carbon content but show an extremely poor hydrocarbon yield. Anoxic depositional conditions, nevertheless, can be traced locally along some levels of the Santonian to Cenomanian shales and marls. These sediments are generally immature in the Brazilian margin basins and no oil was generated from this section.

Three oil families were distinguished through oil-to-oil and oil-to-source rock correlations: the lower Neocomian continental type, the upper Neocomian continental to lagoonal type, and the Aptian evaporitic to lacustrine related sequences.

The geochemical studies, together with geologic and geophysical data, provided the basis to display some models for the migration pathways and habitat of oils in the Brazilian margin basins.

MERIN, I. S., and J. R. EVERETT, Earth Satellite Corp., Chevy Chase, MD

Mapping Dikes from Thematic Mapper Imagery: Raton Basin

Analysis of 1:48,000-scale thematic mapper (TM) imagery of a portion of the Raton basin, supplemented with 1:80,000-scale black and white stereo aerial photographs and geologic and topographic maps, shows that many more dikes are present in the basin than are shown on previously published maps. In comparison with the geologic map, this study allowed mapping of a greater number of dikes, and extension, or connection, on refinement of the trend and/or location of many previously mapped dikes. Only a small number of dikes (or portions of dikes) were mapped in the field by previous investigators, for which no evidence was shown on TM imagery, aerial photography, or topographic maps.

Comparison of the TM imagery with the aerial photography reveals that TM imagery may be a better tool for locating dikes. Clearly, smaller objects can be identified and greater detail can be mapped using aerial photography as compared with TM imagery. For example, the photogra-