occur where upper Minnelusa dune sands are encased in the overlying supratidal red Opeche Shale (Permian). The morphology of these sands suggests northwest-southeast-trending barchanoid sand ridges.

Thickness variations in the Opeche mirror the relief on the Minnelusa surface. Opeche isopahcous maps are one of the main methods used to explore for Minnelusa paleotopographic traps. Hand-contoured isopachous maps can be subject to ambiguous interpretations in areas of low-density control. This difficulty is partially overcome when the map is mathematically produced.

Observations from oil tests in the area indicate that Minnelusa paleotopography is cyclic with a wavelength of approximately 3 mi (5 km). Double Fourier transforms are appropriate in modeling this kind of cyclic data.

For a test township, the calculated double Fourier surfaces showed good correlation with the actual data values. This technique was then applied to a Minnelusa prospect in Campbell County, Wyoming.

Double Fourier surfaces were calculated for several structural datums and isopach intervals. Additionally, regional dip was determined from a polynomial fit, the section was restored to horizontal, and then was modeled to reveal paleotopography.

The paleotopographic-high axes and Opeche thin axes showed remarkable coincidence. This trend is believed to represent the trace of a paleo sand dune.

A test well sited using conventional geologic methods plus input from the double Fourier maps confirmed the accuracy of the calculated surface.

MASTERS, CHARLES D., U.S. Geol. Survey, Reston, VA

United States Assessment Procedures and World Energy Resources Program

Resource assessment is a people-oriented endeavor. At every stage of the exercise, good judgment is essential to satisfactory results. There is no single procedure that can guarantee an approximation of truth, but clearly there are procedures and techniques to be selected from within the context of the problem to be solved that serve to lessen subjectivity in the final outcome.

The U.S. Geological Survey has had the responsibility of determining petroleum potential, especially for basin size areas. This determination assists in the decision process relative to lease sales, wilderness areas, and international relations. Our requirement is basin understanding, not exploration well siting. Considering the dimension of the objectives, the time frame of need, and the resources available (both people and data), volumetric analysis at the level of the play (group of prospects) is rarely practical. Rather, as described in U.S. Geological Survey assessment documents, we have utilized a variety of volumetric/analogy techniques, sometimes comparing with Klemme classifications, with specific United States or foreign basins, or internally within the basin being assessed, which in effect is a degree of maturity analysis. The petroleum geology of the basin and the results of the various number-generating processes are then subjected to the Delphi process, as reported elsewhere, for the group assessment.

The assessment so determined is the hypothesis of the petroleum potential of the area. Because the hypothesis derives from an analysis of petroleum parameters such as source rock, reservoir rock, traps, and seals (which data are published), it is subject to testing as exploration proceeds or as new data are made available. The advantage of the assessment is only partly in the number. In addition, the organization of data permits the recognition of anomalies in the exploration process or in resource reports, thus permitting ongoing adjustments in the assessment or its analysis.

MATSON, ROGER M., McConathy Oil & Gas Co., Denver, CO

Geology and Petroleum Potential of Hanna Basin, Carbon County, Wyoming

The Hanna basin is one of the world's deeper intracratonic depressions. It contains exceptionally thick sequences of mature, hydrocarbon-rich Eocene through Paleozoic sediments, and has the requisite structural and depositional history to become a major petroleum province.

Stratigraphic traps exist within the deeper central parts of the basin in low permeability, possibly overpressured Eocene, Paleocene, and Upper Cretaceous rocks. The Eocene-Paleocene Hanna and Ferris Formations consist of up to 20,000 ft (6,100 m) of organically rich lacustrine shales, coals, and fluviatile sandstones. The Upper Cretaceous Medicine Bow, Lewis, and Mesaverde formations consist of up to 10,000 ft (3,050 m) of marine and nonmarine dark, organic-rich shales that enclose many stacked hydrocarbon-bearing sandstones.

Structural prospecting should be most fruitful around the edges of the basin where Laramide flank structures exist. Deformation of the Hanna basin sediment package into its 30-mi (50-km) wide by 8-mi (13-km) deep present configuration should have produced out-of-the-basin thrusts terminating in closed anticlines. Strata along the northern margin of the basin, located on the southward-displaced Emigrant Trail–Bradley Peak-Shirley thrust complex, were crumpled into anticlinal folds such as O'Brien Springs and Horseshoe Ridge. Oil and gas ranging in age from Pennsylvanian to Upper Cretaceous have been found in these structures.

Only 7 wells have been drilled in the deeper part of the Hanna basin. Two of these tested gas at commercial rates from Upper Cretaceous rocks at depths from 10,000–12,000 ft (3,050–3,660 m). Sparse drilling along the basin flanks has revealed structurally trapped oil and gas at depths from 3,000–7,000 ft (915–2,130 m). The encouragement from the few wells drilled indicates that a more concerted exploratory effort in the Hanna basin is justified.

MATTHEWS, TRUITT, Baylor Univ., Waco, TX

Petroleum Potential of Serpentine Plugs and Associated Rocks, Central and South Texas

During deposition of the Upper Cretaceous Austin Chalk and Taylor Marl, "serpentine plugs" formed by submarine volcanic activity along major fault zones in the ancient Gulf of Mexico. After eruption, palagonite-tuff mounds, formed by the hydration of basaltic glass, localized deposition of shoal-water carbonates on topographic highs.

The serpentine plugs occur along an arcuate belt extending approximately 250 mi (400 km) from Milam County southwestward to Zavala County, Texas

Hydrocarbon traps in and around serpentine plugs have yielded approximately 47 million bbl of oil and significant quantities of natural gas from altered volcanic tuff and associated shoal-water carbonates. Shallower production is from overlying sedimentary rocks structurally influenced by volcanic plugs.

Entrapment of hydrocarbons occurs as: (1) stratigraphic traps within porous zones of carbonate units; (2) stratigraphic traps within porous volcanic tuff (serpentine); (3) structural traps within overlying sands; and (4) traps within high-porosity fracture zones. Exploration for plugs should be concentrated along existing fault zones by either magnetic or seismic surveys.

Analysis of the plugs suggests that there are at least 3 distinctive groups: (1) a southern group characterized by well-developed and productive marginal sands; (2) a middle group characterized by hydrocarbon-saturated biocalcarenite and reworked volcaniclastic facies; and (3) a northern group in which the dominant hydrocarbon saturation is in the volcanics themselves. Each of these groups appears to reflect a somewhat different geologic history.

MAZZULLO, JAMES M., and GARY K. BURCH*, Texas A & M Univ., College Station, TX

Provenance and Diagenesis of Ivishak Sandstone, Northern Alaska

The Ivishak sandstone of northern Alaska is a regressive sequence of Lower Triassic fluvial and paralic deposits that constitutes an important hydrocarbon reservoir in the Prudhoe Bay area. A petrographic study of the formation, utilizing samples from wells from both reservoir and nonreservoir rocks, was undertaken to determine the provenance and diagenetic histories of the formation.

The Ivishak sandstone can be characterized as a low-rank or lithic graywacke. The major detrital species it contains include: (a) quartz (46%), dominantly reworked sedimentary and volcanic monocrystalline quartz and metamorphic polycrystalline quartz; (b) chert (22%), containing variable amounts of inclusions (clay and carbonate); (c) sedimentary rock fragments (10%), largely mudstones and silty mudstones; and (d) metamorphic 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.