Cluster analysis was used to delineate lithofacies in the Twin Creek Limestone of Middle Jurassic age in the Tunp, Salt River, and Wyoming Ranges in southwestern Wyoming. Subjective appraisal of the petrographic data produced lithofacies similar to that created by cluster analysis. Modern carbonate environments and their ancient analogs were compared with information obtained from field study and petrographic analysis of samples of the Twin Creek Limestone to delineate environments of deposition, paleogeography, and diagenetic history.

Six major lithofacies were recognized: (1) carbonate mudstone, (2) packstone-grainstone, (3) fossiliferous wackestone, (4) terrigenous mudstone, (5) sandstone, and (6) carbonate mudstone breccia. These lithofacies were deposited in a variety of environments, including outer shelf platforms (carbonate mudstone and fossiliferous wackestone), oolitic sand belts (packstone-grainstone), open to restricted lagoons (carbonate mudstone, fossiliferous wackestone, and terrigenous mudstone), tidal flats, and supratidal environments (terrigenous mudstone, sandstone, and carbonate mudstone breccia). The Twin Creek epeiric seaway experienced two major transgressions (early Bajocian and late Bathonian–early Callovian) and two regressions (early Bathonian and middle Callovian). Lateral migration of the adjacent facies occurred in response to these changes in sea level.

Eogenetic diagenetic features include minor compaction, micritization, coarse fibrous rim cementation, granular cementation, syntaxial rim cementation, and silicification of carbonates. These features were produced in environments ranging from freshwater phreatic to marine phreatic. Mesogenetic diagenesis was characterized by pressure-solution features and neomorphism. Telogenetic features are limited to calcite vein fillings and oxidation coating on carbonate and detrital grains.

RAY, PULAK K., DONALD R. NEWSOM, GREGORY KLOCEK, and TAYLOR BLOOD, Minerals Management Service, Metairie, LA

Subsurface Geology and Paleodepositional Environments of Pleistocene Trend; South High Island and South Galveston Area—a Regional Evaluation

The Pliocene-Pleistocene producing trend of South Galveston and South High Island areas represents a matured province with excellent data control. Four biostratigraphic working units (upper Pleistocene-*Trimosina A*, middle Pleistocene-*Angulogerina B*, lower Pleistocene-*Lenticulina I*, and upper Pliocene-*Valvularia H*) were regionally established and interpreted using all nonconfidential electric well logs. These correlations were verified with seismic data. Geophysical verification was possible in the upper and middle Pleistocene, but limited to local areas in the lower Pleistocene. Three major growth-fault systems, which become larger southward and attain as much as 4,000-5,000 ft of growth, were recognized. Salt piercement structures are sparse north of Federal Block HI-495 but increase in number southward. Paleoecological data and lithological information obtained from SP logs indicate that sedimentary sequences steadily prograded south from the Pliocene through Pleistocene, reaching the most southward position during the time of *Trimosina A*. Deposition of Pliocene-Pleistocene sand sequences occurred primarily in low-energy deltaic and associated environments. Occasional intraslope basinal and deep-water submarine fan type sand bodies were also recognized. The morphology and occurrence of deltas were significantly influenced by paleotopography and salt tectonics.

RAYNOLDS, ROBERT G. H., Amoco International, Houston, TX, and GARY D. JOHNSON, Dartmouth College, Hanover, NH

Structural Control on Molasse Sedimentation: Example of Siwalik Group of Northern Pakistan

Molasse sediments accumulate in elongate foredeeps during orogenic episodes induced by plate collision. These sediments are typically fluvial, but may grade distally into marine sediments. Molasse lithofacies exhibit a variety of syndepositional structural controls. Structural controls can be subdivided conveniently into 3 scale-dependent categories: (a) regional (basin-wide) control in which the fundamental asymmetric basin architecture is established by the collision process, (b) subregional in which structural control on the location of river systems influences facies distribution and preservation, and (c) local control in which developing folds and faults influence the character of the rock record. New data derived from paleomagnetic stratigraphy and fission-track dating has permitted refinement of lithofacies correlation in the Siwalik molasse sediments of northern Pakistan. A suite of 8 dated sections illustrates the structural controls on molasse facies distribution in the Himalayan foredeep between 3.4 and 1.6 m.y. Subregional and local structural controls are critical factors defining the facies of the proximal molasse sequence. Variable rates of sediment accumulation, differing efficiency of sediment preservation, structurally controlled unconformities, and abrupt time-transgressive lithofacies transitions are documented. Facies patterns preserved in the rock record are compared to analogous modern environments in India. The observed patterns indicate profound structural control on the distribution and interconnectedness of reservoir facies in fluvial-dominated foredeep settings.

READ, J. FRED, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA

Evolution of Cambrian-Ordovician Carbonate Shelf, United States Appalachians

Cross sections and isopach maps (palinspastic) of the Cambrian-Ordovician continental shelf, United States Appalachians, show that thickness and facies trends are controlled by the Adirondack, New Jersey, and Virginia highs and depocenters in Tennessee, Pennsylvania, and by the Rome trough. Carbonate sedimentation was initiated with drowning of Early Cambrian clastics, deposition of carbonate ramp and rimmed shelf facies followed by drowning, then regional regression and deposition of Early to Middle Cambrian red beds and platform margin rimmed shelf facies. During subsequent regional transgression, the Conasauga intrashelf shale basin formed, bounded toward the shelf edge and along depositional strike by Middle to Upper Cambrian oolitic ramp facies and cyclic peritidal carbonates. Intrashelf basin filling and regional regression caused progradation of Late Cambrian cyclic carbonates and clastics across the shelf. By this time, the margin had a relief of 2.5 km. During the Early Ordovician, incipient drowning of the shelf formed subtidal carbonates and bioherms that passed up into cyclic carbonate as sea level oscillations decreased in magnitude. Numerous unconformities interrupt this sequence in the northern Appalachians. The earlier high relief rimmed shelf was converted into a ramp, owing to uplift in the basin, heralding approaching collision. Subsidence rates on the margin were low (4 cm/1,000 yr) and typical of a mature passive margin. Shelf sedimentation in the southern Appalachians ceased with arc-continent collision and development of the Knox unconformity, which dies out into the Pennsylvania depocenter. Major exploration targets are in the Late Cambrian-Early Ordovician Knox Group.

REECKMANN, S. A., Exxon Production Research Co., Houston, TX, and I. R. DUDDY and A. J. GLEADOW, Univ. Melbourne, Melbourne, Victoria, Australia

Igneous Intrusions in Porous Sandstone Sequences—Widespread Thermal Effects Measured by Fission Track Annealing and Vitrinite Reflectance

Current literature suggests that igneous bodies have only minor thermal effects on intruded sedimentary rocks, increasing the maturity of a thickness of adjacent strata approximately twice the width of the intrusion. This study shows that this is not always true. In the Canning basin of Western Australia, Permian dikes, sills, and laccoliths have intruded porous and permeable Carboniferous and Permian sandstones. Efficient vertical and lateral heat transfer has occurred by movement of hot waters through the sedimentary rocks over large distances away from the igneous bodies. This heat transfer is recorded by the resetting of fission tracks in detrital Precambrian apatites, which now have apparent ages similar to those of the igneous intrusions. In some instances, a significant increase in vitrinite reflectance within the sediments is also evident, but vitrinite appears to be less sensitive to heat pulses of short duration, even though temperatures greater than 110°C have developed. Fission-track studies suggest that temperatures of at least 110°C to 130°C have occurred up to 3 km from thin doleritic dikes and sills in porous sandstones where pre-intrusion temperatures were around 40°C. Some evidence of increased temperature is also apparent 26 km from the nearest mapped intrusion, although this has not been sufficient to totally anneal fission tracks.

Vitrinite reflectance readings are significantly higher in wells that penetrated thin intrusions, and this increase in vitrinite reflectance to values of around 1% is evident in one well at least 500 m above a 156-m thick doleritic dike where fission tracks have also been reset. The intrusions have thus heated a considerable volume of regionally immature rocks to temperatures equating to the oil window for a short period of time. Whether this relatively short-lived temperature increase has led to significant generation of hydrocarbons is unknown; however, oil recovered from one well that penetrated a doleritic dike had a sterane:aromatic sterane ratio suggestive of generation during a rapidly cooling heat pulse.

REEL, CHRISTOPHER L., RPI/Colorado, Boulder, CO, and CLARENCE V. CAMPBELL, RPI/Canada Ltd., Calgary, Alberta, Canada

Chin Coulee Field—a Stratigraphic Trap in Lower Cretaceous Fluvial Valley-Fill Sandstones

Hydrocarbons, stratigraphically trapped in fluvial valley-fill sandstones, constitute some of the more important oil fields in North America. The Chin Coulee field in southeastern Alberta, Canada, has produced over 4.4 million bbl of oil since its discovery in 1960, with an estimated 1 million bbl still to be produced via secondary recovery. The field covers approximately 80 km^2 with an average net pay thickness of 3 m. The hydrocarbons are stratigraphically trapped in the fluvial Sunburst Sandstone, which records the Early Cretaceous transgression of the Boreal Sea.

These lower Mannville aggradational sequences accumulated in an incised drainage system in Jurassic marine shales, which provide the bottom seal for the reservoir sandstones. Following deposition of the Sunburst Sandstone, an accelerated rise in base level led to the accumulation of argillaceous limestones and calcareous shales commonly referred to as the "ostracod zone." These fine-grained strata provide an effective seal above the porous sandstones.

Postdepositional tilting of the strata to the west, due to subsidence in the foreland basin east of a rising orogene (Nelson uplift), resulted in migration of hydrocarbons in an easterly updip direction. Stratigraphic trapping of these hydrocarbons occurred in sandstones pinching out in the upper reaches of tributary valleys to the east of the main drainage system (Chin Coulee and Taber Southeast fields).

Regional paleoenvironmental reconstructions suggest that the Sunburst Sandstone is equivalent to the Cut Bank Sandstone of the Cut Bank field area in northwestern Montana. The Cut Bank field lies along the same Late Jurassic drainage system (Fox Creek escarpment), and similar tributary valleys situated east of the escarpment may exist between these two producing field areas. This suggests the presence of additional untested hydrocarbon reservoirs exhibiting stratigraphic characteristics similar to those described in the Chin Coulee field.

REES, M. N., Univ. Kansas, Lawrence, KS

Processes of Sedimentation Associated with Fault-Controlled Trough Across a Shelf

Western North America was a rapidly subsiding, passive continental margin during the Cambrian. During the Middle Cambrian, a belt of carbonate deposition dominated the central shelf. It was bounded by fine-grained terrigenous sediments that accumulated in deep water to the west and in shallow water to the east. Movement along a high-angle fault that extended across the shelf produced a conspicuous embayment into the carbonate belt in Nevada and Utah during the middle Middle Cambrian. This fault movement controlled basin geometry and distribution of carbonate and shale lithofacies on the shelf for at least the next 40 m.y.

The embayment was an asymmetrical trough that deepened and widened as it extended some 400 km westward toward the edge of the continent. South of its abrupt southern margin, which marked the position of the fault, shallow subtidal and peritidal sediments accumulated throughout the Middle Cambrian. The northern flank of the embayment was a drowned platform that sloped gently southward into the trough axis. On this ramp, a carbonate platform was rapidly reestablished through vertical accretion and progradation. In the trough axis, which lay near the faulted margin, sediments representing anoxic and deep-water environments accumulated throughout the middle and late Middle Cambrian. Sedimentation rates in this axial region were inadequate to reestablish a shallow-water depositional setting because of reactivation of faulting and because the trough acted as a sediment bypass zone.

REITSEMA, R. H., Marathon Oil Co., Littleton, CO

Gas Compositions in a Well Column

An onsite mud-logging system was developed to avoid possible alterations in gas samples during shipment to laboratories. Compensation was made for the large gas contribution of the drilling mud entering the hole, for the rate of drilling, and for lag time of the drilling mud. Location of gas anomalies is more apparent with the modified system.

Several wells in the DJ basin were compared to establish a pattern of sediment gas vs. lithology or geologic formation. Gas content of the drilling mud throughout the hole showed that large changes occur in the absolute concentrations of methane through butanes and also showed an erratic pattern of the component ratios. These compositional changes should be taken into account in surface exploration for gas.

Other gases in the well column were also monitored. Hydrogen and helium were found in most wells. Their concentrations varied widely from well to well and in a single well. Carbon dioxide also showed large variations. Carbon isotope ratios of carbon dioxide did not correlate with the carbon isotope ratios of carbonate cements in the same samples.

REVETT, LOWELL W., Welex, Lafayette, LA, and BRIAN E. LOCK, Univ. Southwestern Louisiana, Lafayette, LA

Resistivity Curves from Complex Reservoirs: Under-Utilized Tools for Exploration and Production Geologists

Most geologists regard resistivity curves simply as sources of information concerning lithology and degree of water saturation of subsurface strata; however, other important geologic information can also be obtained. For example, water saturation is related both to pore characteristics and to the buoyancy pressures that lead to water expulsion from those pores by a hydrocarbon column. Thus, resistivity response is indirectly modified by a complex of factors including pore size, pore geometry, and grain-surface characteristics (including presence of clays). The combined effect of these pore characteristics is revealed most directly by capillary pressure curves. Because these same factors also determine permeability, resistivity itself can be regarded as responding to permeability.

This approach to resistivity interpretation has several important consequences. For example, true oil-water contacts encountered in the well bore display transitional resistivity values as upwardly increasing buoyancy pressures approach those necessary to produce irreducible water saturation. Complex reservoirs with inclined permeability barriers (such as shale drapes along lateral accretion cross-bedding in point-bar sands or shale interbeds in tilted turbidite sand sequences) may include false water levels where vertically adjacent but separated beds may have different fluid contents and may lack transition zones. Recognition of the distinction between these two types of oil-water contact may profoundly affect reserve calculations and help avoid passing over of viable reservoirs.

Correctly interpreted resistivity curves may also permit recognition of water production resulting from leading permeability barriers, may aid in distinguishing different types of oil show (leading, trailing, and residual) and may aid in explaining and predicting early water production, etc. Proper use of this readily available tool can have an important impact on successful exploration and production.

REYNOLDS, ROBERT C. JR., Dartmouth College, Hanover, NH

Thermal Transformation of Smectite to Illite

The diagenetic transformation of smectite to illite, with an intermediate series of mixed-layered compositions, has been documented by numerous studies of surface and subsurface rocks. Shales from typical Gulf Coast wells show compositions greater than 50% illite at approximately 100°C; the composition stabilizes at about 80% illite at the greatest depths sampled where the temperature is or has been as high as 130°C.

These findings are difficult to reconcile with data from oil (lower Paleozoic) rocks if it is assumed that illite-smectite compositions are equilibrium phases at specific temperatures. Potash bentonites (Ordovician)