Neither will it be possible to achieve comparable production capacities.

In both the United States and the rest of the world, given the required drilling effort, small fields will be found far into the future. They probably will not be able to offset the eventual decline of the world's large fields but will sustain a viable industry well into the 21st century.

MIALL, ANDREW D., Univ. Toronto, Toronto, Ontario, Canada

Sedimentation and Tectonics of Diffuse Plate Boundary: Canadian Arctic Islands from 80 Ma to Present

Use of a revised magnetic-anomaly time scale provides a more accurate chronology of sea-floor spreading events in the Labrador Sea and Baffin Bay. New stratigraphic data from the Meighen and Remus basins in the eastern Arctic Islands show that sedimentary and tectonic events there can be correlated with relative movements of Greenland between 80 and 36 Ma caused by Labrador Sea–Baffin Bay spreading. Within the eastern Arctic Islands these movements generated the Eurekan orogeny across the diffuse Greenland-Canada plate boundary.

Three discrete phases of movement have been recognized: (1) oblique compression, culminating in late Paleocene thrust faulting and fanglomerate progradation; (2) transcurrent movement from late Paleocene to mid Eocene; (3) near-orthogonal compression during the major deformation phase of the orogeny in the late Eocene to early Oligocene. Clastic depositional systems show numerous lateral facies changes reflecting the various movement styles.

From the Oligocene to mid Miocene, the Arctic Islands were affected by uplift and erosion. Extensional faulting and renewed clastic sedimentation occurred between 15 Ma and the present, and during this final phase the Arctic Islands area was fragmented into its present physiography of mainly fault-bounded islands.

MIALL, ANDREW D., Univ. Toronto, Toronto, Ontario, Canada

Sedimentation on an Early Proterozoic Continental Margin: Gowganda Formation (Huronian), Elliot Lake Area, Ontario, Canada

Eight continuous cores up to 150 m (500 ft) long and spaced an average of 200 m (650 ft) apart plus nearby outcrops, yield a detailed insight into the composition and architecture of an ancient continental-margin sequence.

Continental glaciers provided an abundant supply of coarse debris but, apart from rainout deposits from floating ice, played little or no part in Gowganda sedimentation. The basal 50 m (165 ft) of the Gowganda Formation represents a continental-slope depositional system. It consists mainly of gravelly and sandy sediment gravity flow deposits, interbedded with minor rain-out units of diamictite, and argillite containing dropstones. Ten types of sediment gravity flow are distinguished. An overlying submarine-channel depositional system, 10–50 m (30–165 ft) thick, consists of pelagic argillites containing dropstones and showing deformation structures. These are interbedded with well-sorted channel-fill sandstones. A submarine point bar 4.5 m (15 ft) thick demonstrates a meandering channel geometry. This channel-fill sequence probably formed during a period of high sea level and reduced sediment supply, possibly reflecting retreat of the ice. The subsurface sequence is completed by a blanket of massive rain-out diamictites up to 55 m (180 ft) thick, and a younger slope sequence of sediment gravity flow diamictites and sandstones.

The complex architecture of this formation reflects the interplay of numerous depositional and erosional processes that are now known to occur on continental margins. The traditional submarine-fan models may have no relevance to this type of continental margin, with its numerous sediment sources and frequent changes in sea level.

MILLER, BRUCE C., Exxon Co., USA, Kingsville, TX

Physical Stratigraphy and Facies Analysis, Lower Cretaceous, Maverick Basin and Devils River Trend, Uvalde and Real Counties, Texas

The formations of the Fredericksburg and lower Washita Groups in Uvalde and Real Counties, Texas, were deposited on a broad platform behind the Stuart City reef trend. Nine distinct lithofacies and corresponding depositional environments occur within this lower Cretaceous depositional regime: (1) nodular and burrowed mollusk lime wackestone lithofacies representing an open-marine platform, low wave-energy environment; (2) rudist, shell fragment, miliolid wackestone to packstone lithofacies representing a partially restricted to open-marine platform, low to moderate wave- and current-energy environment; (3) rudist, shell fragment, miliolid, grainstone to wackestone lithofacies representing an open-marine platform and bank, moderate to high wave- and current-energy environment; (4) evaporite collapse breccia lithofacies representing a hypersaline platform interior environment; (5) miliolid, shell fragment wackestone and *Texigryphaea* bed lithofacies representing a platform interior, shallow subtidal to intertidal transitional environment; (6) alternating thin evaporite collapse breccia with laminated mudstone and pellet packstone lithofacies representing an evaporite-dominated tidal mud flat environment; (7) carbonaceous lime mudstone lithofacies representing a platform interior euxenic lagoonal environment; (8) pellet intraclast lime wackestone to packstone lithofacies representing a restricted platform interior environment; and (9) pelagic lime mudstone to wackestone lithofacies representing a deep, open to slightly restricted platform interior environment.

The Fredericksburg-early Washita depositional history is characterized by 2 distinct cycles of deposition. The first cycle is interpreted as an initial marine transgression over the partially eroded Glen Rose tidal flat deposits, followed by a period of regional shoaling, culminating with the deposition of the Kirschberg Evaporite within the Devils River formation and northward, and deposition of the lower McKnight evaporite-dominated tidal mud flat sediments to the south. The second cycle of deposition is interpreted as a gradual marine transgression culminating in the deposition of open-marine platform rudist bank facies (upper Devils River) and partially restricted to open deep platform interior deposits (Salmon Peak) prior to middle Washita emergence and erosion forming the pre-Del Rio unconformity.

MILLER, JACK E., General Electric Co., Lanham, MD

Landsat 4 Thematic Mapper Imagery: Improved Tool for Geologic Mapping in Eastern Overthrust

The central Appalachians were studied using Landsat 4 thematic mapper (TM) data to evaluate the improved spatial resolution (30 × 30 m, 100 × 100 ft) of TM for mapping capabilities. The TM bands 2, 3, and 4 were contrast stretched and edge enhanced using digital processing techniques. Photogeologic analysis of the 1:125,000-scale TM image examined drainage, landform, lineament, and structural features.

The study area comprises the junction of the central and southern Appalachians where fold axes change from N30°E to N60°E. Southeast-dipping thrust faults trend northeastward across the area. Cambrian through Devonian rocks are involved in and exposed by the thrust faults.

Recognition of drainage relationships (density and pattern) are important in identifying lithologies. Landforms reflect structure and lithology through characteristic topographic expression. Improved identification and delineation of drainage and landform characteristics on TM imagery support structural and lithologic interpretations.

Lineaments were identified by drainage, tonal, and topographic characteristics. Two major lineaments trending N83°E and N56°W, at the junction of the southern and central Appalachians, were identified. Identified structural features include fold axes, thrust faults, strike-slip faults, and thrust-faulted folds. Detailed lineament and structural mapping on TM imagery aids in unraveling complex surface geologic patterns in this critical area of the eastern overthrust.

Digitally enhanced Landsat 4 TM data proved advantageous for accurate mapping of drainage, landform. lineament, and structural features. Improved accuracy on a regional scale allows reliable geologic mapping and therefore subsurface interpretations, benefiting hydrocarbon exploration.

MINK, LELAND L., Morrison-Knudsen Mining Group, Boise, ID, and DAVID MCCLAIN, Morrison-Knudsen Power Group, Boise, ID

United States Geothermal Energy Overview—Current Status

Geothermal energy development and utilization in the United States date back to the pioneer days when thermal waters were developed and used for recreation and bathing purposes. In 1890 a district geothermal space-heating project was initiated in Boise, Idaho, and in 1925 the first electric generation using geothermal fluids was accomplished in The Geysers area of California.

Geothermal energy is being investigated in many areas of the United States with most of the development occurring in the western states. Most of this development is oriented toward small, nonelectric projects such as space heating, greenhouses, and aquaculture, although several larger heating and industrial projects are being considered.

Electric generation using geothermal fluids is being done in California, Utah, and Oregon, with most effort in The Geysers and Imperial Valley areas of California. Considerable exploration and drilling has been done in Nevada for electric-grade geothermal resources, although institutional and economic problems have limited development at this time.

MOIOLA, R. J., and G. SHANMUGAM, Mobil Research, Dallas, TX

Facies Analysis of Upper Jackfork Formation (Pennsylvanian), DeGray Dam, Arkansas

The DeGray Dam spillway cut displays perhaps the best exposed section of the upper Jackfork formation (Pennsylvanian) in the Ouachita Mountains of Arkansas and Oklahoma. Comprising more than 321 m (1,050 ft) of interbedded sandstone and shale, this deep-water succession was originally interpreted as a sequence of alternating proximal and distal turbidites, and subsequently as outer-fan depositional lobes. Recent detailed facies analysis, however, demonstrates that the succession represents a mid-fan association of channel and interchannel deposits.

Channelized intervals consist of stacked thinning-upward and/or amalgamated packages characterized by Mutti and Ricci Lucchi facies A, B, C, and G. Associated interchannel intervals consist of facies C, D, E, and G beds that are randomly interbedded or form thickening-upward packages that superficially resemble depositional lobes. These lobe-like packages, which are generally less than 4 m (13 ft) thick, are interpreted as crevasse-splay deposits. A similar association of channel and interchannel deposits can also be observed in nearby outcrops of the underlying lower Jackfork.

A longitudinal submarine fan system, analogous to the present-day Bengal fan, is visualized as the overall depositional setting for the Jackfork formation.

MOMPER, JAMES A., Consultant, Tulsa, OK

Petroleum Resources in Powder River Basin

This updated geochemical-geologic appraisal of Powder River basin resources appreciably increases earlier estimates of generated and expelled Cretaceous oil and gas. However, volumetric estimates of trapped and preserved petroleum were not significantly revised.

Both hydrocarbon expulsion phases were evaluated in detail as follows. (1) *Oil-expulsion phase*—volumes of oil generated and expelled from each source rock, then trapped and preserved; also volumes of gas expelled with oil, then trapped and preserved, including gas generated with oil and minor quantities that resulted from incipient thermal cracking of oil. (2) *Gas-expulsion phase*—volumes of thermal gas generated, expelled, trapped and preserved after oil expulsions ceased, along with some gas formed from thermal cracking of unexpelled oil in effective gas source rocks which are fewer in number and areally much smaller than effective oil source rocks.

Gas derived from thermal cracking of oil in deep reservoirs, bacterial gas, and gas and oil generated beyond the geochemically defined limits of each effective source rock unit were not included in this appraisal. Volumes of biogenic gas and of gas formed by thermal cracking in reservoirs are minor, relative to gas expelled from source beds.

Expulsion efficiency appears to have averaged about 7% of generated oil. Most of the generated oil was retained in source beds, some of which was then expelled as gas. Although a high percentage of thermal gas was expelled, only a small quantity of expelled gas was preserved in traps.

MOORE, DARRELL, Texas Tech Univ., Lubbock, TX

Devonian and Mississippian Stratigraphy and Depositional Environments in Big Hatchet Mountains of Southwestern New Mexico

In the Big Hatchet Mountains the Upper Devonian Percha Shale rests unconformably on the Upper Ordovician Montoya Formation and is overlain by strata referred to the upper part of Sabin's Portal Formation. To date, this is the farthest east the Portal has been observed. Devonian rocks record a shallowing-up sequence from the lower Percha (Ready Pay-Box Members) deposited in quiet water to the Portal grainstone deposited at or above wave base. The Portal contains Upper Devonian (Famennian) conodonts indicative of Sandberg's shallow-water *polygnathid-icriodid* biofacies.

Mississippian strata, represented by the Escabrosa Group, contain Early Mississippian (Osagean) conodonts at the base. Lower Mississippian strata record 2 Osagean cycles of submergence and emergence. Encroachment began in the early Osagean (*isosticha*-upper *crenulata* Zone) when the basal oolitic grainstones of the Bugle member of the Keating Formation were deposited. A shallowing-up sequence followed, culminating in the deposition of high-energy grainstones of the upper Bugle. The end of Bugle deposition is marked by a second submergence (lower *typicus-Anchoralis latus* Zone) when argillaceous wackestones were deposited. This deepening continued during deposition of the basal Witch member. Regression began during deposition of the Witch, as suggested by the vertical sequence from fine-grained mudstones to high-energy grainstones. This shallowing sequence continues into the lower Hatchita Formation.

MOORE, GEORGE W., U.S. Geol. Survey, Menlo Park, CA

Results of Separation of Antarctica and Australia During Late Cretaceous

The U.S. Geological Survey research vessel *S.P. Lee* is investigating the area of continental breakup (90 m.y.B.P.) during which the Great Australian Bight separated from Wilkes Land, and Tasmania detached itself from the Ross Sea. Transform faults that formed along the Southeast Indian ridge are not perpendicular to the coast of Antarctica, but lie at an acute angle to it. This orientation indicates that the breakup followed a preexisting line of continental weakness. As new oceanic crust began to form after the breakup, the rift divided into a stairstep pattern of spreading axes and transform faults in harmony with the direction of separation. In places, the stairstep rifting created local basins of the continental-borderland type. Sediment flooded into the rifts from the two separated continents and lapped across stretched continental crust at the margins and onto newly formed and hot oceanic crust farther out. An optimistic scenario for petroleum formation in this area might be: (1) rapid sedimentation entrained organic petroleum precursors before they could decay at the sea floor, and (2) heat from the young oceanic crust below matured them. The favorable characteristics of rifted margins—silled grabens to reduce sea-floor oxidation, little reservoir-plugging volcanic ash, and rollover anticlines against curved growth faults—all make the area promising for exploration. Although petroleum is not known from the margin of Antarctica, analogous oil fields on the continental shelf near Tasmania suggest that the area has a resource potential.

MOSLOW, THOMAS F., Louisiana Geol. Survey, Baton Rouge, LA, and R. W. TILLMAN, Cities Service Research, Tulsa, OK

Sedimentology and Reservoir Characteristics of Tight Gas Sandstones, Frontier Formation, Southwestern Wyoming

The lower Frontier Formation, Moxa arch area, southwestern Wyoming, is one of the most prolific gas-producing formations in the Rocky Mountain region. Lower Frontier sediments were deposited as strandplains and coalescing wave-dominated deltas that prograded into the western margin of the Cretaceous interior seaway during the Cenomanian.

In this study, sedimentologic, petrologic, and stratigraphic analyses were conducted on cores and logs of Frontier wells from the Whiskey Buttes and Moxa fields. Twelve sedimentary facies have been identified. The most common sequence consists of burrowed to cross-bedded near-