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 nearshore marine (delta-front and inner-shelf) sandstones disconformably overlain by crossbedded (active) to deformed (abandoned) distributary-channel sandstones and conglomerates. The sequence is capped by delta-plain mudstones and silty sandstones.

Tight-gas sandstone reservoir facies are nonhomogenous and include crevasse splay, abandoned and active distributary channel, shoreface, foreshore, and inner shelf sandstones. Distributary-channel facies represent 80% of perforated intervals in wells in the southern part of the Moxa area, but only 50% to the north. Channel sandstone bodies are occasionally stacked, occur on the same stratigraphic horizon, and are laterally discontinuous with numerous permeability barriers. Percentage of perforated intervals in upper shoreface and foreshore facies increases from 20% in the south to 50% in the north. These sandstones thicken to the north and east and are more laterally continuous than channel facies. The lower Frontier contains strike-oriented shoreface (delta front) and dip-oriented distributary channel sand bodies in approximately equivalent amounts. Delta-plain mudstones thin to the north and east and are an important stratigraphic seal. Highest gas production rates are from distributary-channel sandstones closer to the axis of Moxa arch. However, there appears to be little correlation between the thickness of any reservoir facies and net production.

MOSMANN, RAUL, PETROBRÁS, Rio de Janeiro, Brazil, and WILLIAM L. FISHER, Univ. Texas, Austin, TX

Geology and Major Oil Plays, Coastal Margin Basins, Brazil

Six major tectonic-depositional sequences, reflecting rift and passive margin evolution, variously characterize the filling of Brazilian coastal margin basins: (1) Late Jurassic prerift, (2) Early Cretaceous tectonic rift, (3) Early Cretaceous quiescent stage (evaporitic or calcilutitic), (4) middle Cretaceous initial drift carbonate platform, (5) Late Cretaceous platform/deltaic progradational and deep marine retrogradation, and (6) Tertiary main passive margin progradation.

Habitat of oil discovered to date meets two regional geologic conditions: (1) in tectonic rifts known to have basin core of starved, lacustrine shales, and (2) in basins which developed a quiescent phase during the transition from tectonic rift to passive margin.

Two major plays characterize the central core rifts, including (I) underlying prerift sediments in fault contact with the central core, and (II) sublacustrine fans overlying the central core. These plays, typified in the Recôncavo basin, constitute about half the recoverable oil found to date.

A structurally related variation of type II play and a third regional play exist where the quiescent condition occurred, including reservoirs of the rift below evaporitic or calcilutitic regional seals and carbonate platform and turbidite reservoirs in the passive margin above the quiescent episode. The subevaporitic-calcilutitic subplay is prominent where overlying regional seals are structurally unmodified, contains about 15% of the discovered oil, and has typical development in the Sergipe (evaporitic) and Potiguar (calcilutitic) basins. Where regional seals of the quiescent phase have been mobilized, structurally modified, or cut by subsequent submarine canyons, carbonate platform and turbidite reservoirs of the overlying passive-margin fills are the prominent play (type III). This play, with typical development in Campos basin, in Mosqueiro low in Sergipe basin, and onshore Espirito Santo basin accounts for 35% of the discovered oil.

Exploration implications of the established plays are: (1) source is from tectonic or quiescent stage fill (Aptian or older); (2) structural integrity of the quiescent stage seals is critical to oil migration; and (3) tectonic rifts are productive when a core of deep lacustrine shales was developed.

MOWATT, THOMAS C., Reservoirs, Inc., Denver, CO

Diagenetic Relationships and Hydrocarbon Resource Implications, Nanushuk Group and Torok/Topagoruk Formation, National Petroleum Reserve, Alaska

Petrographic, X-ray diffraction, and scanning electron microscope investigations of Nanushuk Group and Torok/Topagoruk formation (Brookian) sandstones and siltstones from 9 wells in the National Petroleum Reserve in Alaska resulted in recognition of features of interest regarding the diagenetic development of these rocks. Several kinds of labile materials are present, and secondary dissolution porosity has been developed to various degrees. Mineralogic, geochemical, and textural characteristics indicate the potential for development of appreciable porosity of this type in equivalent horizons and/or similar materials within the northern Alaska Cretaceous basin.

Known regional geologic, geochemical, and geophysical relationships are consistent with this view. Considerations of hydrocarbon resource potential should include concern for these relationships as integral to appreciation of the overall diagenetic evolution of the region.

Heretofore, the potential for the occurrence of significant reservoir rocks in these horizons has been considered to be rather low, based on primary petrologic characteristics. However, this should be reappraised in light of increased knowledge and understanding of the principles and realities regarding diagenetic events, inorganic and organic, including secondary porosity development, clay mineral relationships, and maturation of organic material.

MUEHLBERGER, W. R., and A. R. MOUSTAFA, Univ. Texas at Austin, Austin, TX

Late Cenozoic Pull-Apart Graben Development, Big Bend Region, Texas

The Big Bend region is a giant rhomb-shaped structure with the Presidio (west) and Black Gap (east) pull-apart grabens marking the north-northwest-trending ends and the north and south branches of the Texas lineament (TL) marking its west-northwest-trending strike-slip ends. This large rhomb is broken internally by many faults (west, west-northwest, and north-northwest trends) that have generated numerous small to large pull-apart grabens.

Black Gap graben is divided into segments by west-northwest faults that drop each segment deeper (250-1,050 m, 820-3,450 ft, structural relief) and southeastward in the United States part. The continuation into Mexico has not been studied.

Presidio graben also has a complex bounding fault pattern of north-northwest-, west-northwest-, and west-trending segments. Depth of the graben in unknown, although outcrop and well data give a minimum of 800 m (2,600 ft). The internal shape is poorly known because of widespread pediment gravel cover.

The Presidio and Black Gap grabens are the southeastern continuation of the Rio Grande graben system that terminates southward against the north-branch of the TL (that extends from El Paso to Valentine Black Gap across Texas). The south-branch of TL extends east-southeast from near Presidio across Mexico to the Gulf of Mexico near the mouth of the Rio Grande.

Right slip along the west-northwest trends is demonstrated in the Sierra del Carmen by slickensides and by a first-motion study of the Valentine earthquake. Strike-slip displacement is presumably modest across the region (under 10 km, 6 mi, ?), but actual slips are indeterminate with the present data set.

The Presidio graben lies along the eastern boundary of the Laramide Chihuahua overthrust belt. The Black Gap graben lies along the eastern boundary of the Laramide Rocky Mountain front.

MUNCEY, GERY, BILL EHNI, MARK KATTERJOHN, BETTY HARCLERODE-MOORE, and DAVE HALPIN, Geotronics Corp., Austin, TX

Magnetotelluric Sounding Method as Applied in Ouachita Thrust Belt, Central Texas: A Case History

A 25-station magnetotelluric (MT) traverse across central Texas has been recorded and analyzed. The 84 line-mi (135 line-km), northwest-southeast-trending traverse begins 13 mi (21 km) southeast of Lampasas and ends 6 mi (10 km) north-northeast of Lexington, Texas. Geologic elements crossed are the Ouachita foreland facies, frontal and interior zones, and the rimming gravity high described by Flawn et al, Nicholas and Rozendal, and others.

Interpretation of the MT data, supported by 1- and 2-dimensional modeling, borehole data, and previously published gravity data, suggests northwest transport on the order of 22 mi (35 km) for the allochthonous Ouachita frontal zone.

A shallow resistive zone in the Precambrian and the overlying autochthonous Ouachita foreland facies is traced southeast 46 mi (74 km) from the sites nearest Lampasas, but become indeterminate north of Taylor, Texas. Data from the Shell 1 Purcell (Williamson County) suggest the