structures in cover rocks, and in part may be a cause of polyphase, break-back thrust development.

Basement faults are of three types: (1) normal faults of Precambrian and Cambrian age that are related to Precambrian continental rifting, (2) normal faults that were reactivated or initiated during Late Mississippian, and (3) Alleghanian thrust faults.

A basement fault system that moved during Cambrian and Mississippian-Pennsylvanian defines the northwest border of a basement low referred to as the Birmingham trough. The trough is a narrow, northeast-trending structure as much as 135 mi (215 km) long, up to 25 mi (40 km) wide, and has more than 7,000 ft (2,100 m) of displacement along the faulted northwest border. The southeast edge of the trough is bounded by Alleghanian basement thrust faults that exhibit as much as 2 mi (3 km) of shortening. The southwest-plunging trough loses relief to the southwest beneath the Gulf Coastal Plain onlap. On the northeast in northwestern Georgia, the trough is bordered by shallow basement.

The basement normal faults exerted significant control on the configuration of Alleghanian structures as well as on sedimentation during the Paleozoic. Basement faults control the magnitude of duplexes, thrust ramps, and associated ramp anticlines to varying degrees, depending upon local basement structural relief. Break-back thrusts in the Alabama Appalachians may be a result of buttressing of large-scale thrust sheets against the high-relief basement fault system at the northwest border of the Birmingham trough.

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Thermal History of Otway Basin, Australia—Case Study of Fission-Track Analysis in Petroleum Exploration

Annealing of fission tracks in minerals, like the generation and maturation of hydrocarbons, is a function of temperature and time, the temperature zone of fission track annealing in apatite (70-125°C, 158-257°F, for heating times of $10^6$-$10^8$ years) coinciding closely with the oil-generation window. Patterns of fission-track age, track length, and length distribution can thus give an important record of the thermal evolution of a sedimentary basin.

The early Cretaceous Otway Formation in southeastern Australia is a 3-km (10,000-ft) thick sequence of volcanogenic sediments in the late Jurassic-Tertiary Otway basin. Fission-track ages on detrital apatite, sphene, and zircon in outcropping sandstones from this formation are concordant, indicating a contemporaneous volcanic source. This concordance also indicates that the outcrop samples have not been heated above about 70°C (158°F) since deposition.

Apparent apatite ages from deep wells in the subsurface section of the Otway Formation decrease with depth, reaching zero at subsurface temperatures of about 125°C (257°F). Wells in different parts of the basin show a variety of thermal histories. In some wells, the rocks are experiencing their maximum temperatures now, whereas others show evidence of higher temperatures in the past. The extreme example, at the eastern end of the basin, experienced maximum temperatures prior to a period of rapid uplift about 95 Ma. The apatite data show that hydrocarbon generation in this area occurred less than 30 m.y. after deposition and prior to this structuring event. The fission-track evidence also requires that the early Cretaceous geothermal gradient was substantially higher than at present.

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Methods for Evaluating Occurrence and Origin of Radionuclide Concentrations in Texas Lignites

The association of tuffaceous formations with radionuclide-bearing lignites is well established in Texas and elsewhere in the United States. Radionuclides in or near minable lignite horizons are important due to public and governmental concern over the human and environmental effect of low-level radioactivity.

The primary lignite-bearing formations of Texas include the Eocene Calvert Bluff, Yegua, and Manning Formations. A study of the formations adjacent to these lignite formations reveals that the Manning Formation is the likeliest to contain radionuclide zones in or near the lignite horizons. The overlying tuffaceous Catahoula and Whitsett Formations are the probable source of the radionuclides. The reduced carbonaceous zones of the Manning Formation provided a favorable environment for radionuclide precipitation.

The occurrence of radionuclide zones within oxidized carbonaceous horizons are modeled for the Manning Formation using geophysical logs, cross sections and areal occurrence maps. In-situ borehole assays confirmed a wide range of gamma radiation log responses, and quantification of them revealed the concentrations and specific types of radionuclides present.

Specific exploration techniques are used to model this phenomenon during lignite exploration activities. These techniques include calibrated gamma probes, in-situ borehole assays using advanced high-resolution gamma-ray spectroscopy logging tools, mapping of lignite weathering profiles using close-spaced drilling techniques, geologic interpretation using cross sections, and mapping of the radionuclide zones and sands. The resulting geologic model can be used for environmental impact studies and mine planning.

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Paleohydraulic Analysis of Hummocky Cross-Stratified Sands Indicates Equivalence with Wave-Formed Flat Bed: Pleistocene Lake Bonneville Deposits, Northern Utah

Hummocky cross-stratification (HCS) has been reported from over 100 ancient units, but has never been unequivocally recognized in recent sediments. Consequently, little is known about hydraulic conditions under which HCS forms.

In Pleistocene lacustrine deposits of Lake Bonneville, both depth of formation and parameters of inferred generative waves may be defined accurately. HCS was formed in fine to medium-grained sand in water depths of 1.2-2.2 m (3.9-7.2 ft). The site of formation was exposed to a maximum fetch of 15 km (9 mi). Depths were great over this fetch, permitting calculation of conditions under which this example formed, assuming: (1) HCS is purely wave-formed; (2) HCS formed under maximum storm conditions; (3) maximum storm-generated wind speeds over Lake Bonneville were similar to speeds generated by continental storms today. Inferred wind-speed range is 16 m/sec (52 ft/sec, moderate gale force) to 34 m/sec (112 ft/sec, threshold hurricane force).

Resulting calculations indicate that HCS formed under waves with periods (T) of 3.8-5.7 sec and maximum orbital speeds ($U_m$) of 0.9-2.5 to ~2-4 m/sec (3.0-8.2 to 6.6-13.1 ft/sec), respectively. This range falls within the wave-formed flat-bed field for fine to medium-grained sand. Independent corroboration is provided by the equivalence of wavelength of hummocky laminae in outcrop and calculated wave-orbital diameter ($d_o$). HCS has wavelengths of 3.1-4.2 m (10.1-13.8 ft) in this example; the 3-m and 4-m (10-ft and 13-ft) isograds of $d_o$ run directly through the middle of the $U_m$-T field calculated above.

It is generally agreed that HCS probably is formed by oscillatory flow or oscillatory-dominant combined flow. Consequently, this analysis serves at least as a guide to conditions of formation of HCS and suggests that HCS and wave-formed flat bed are at least partly equivalent bed configurations.

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Abandoned Oil Fields of Texas Gulf Coast

One nonconventional oil target in Texas is the oil that remains in abandoned fields, defined as those fields that had no oil or gas production in 1977 and 1982. This target includes oil that has not been tapped by conventional field development because of reservoir heterogeneity and oil in reservoirs that have not been subjected to any secondary or tertiary recovery efforts. A total of 138 abandoned oil fields having individual cumulative production greater than 500,000 bbl are located in the Texas Gulf Coast (Railroad Commission of Texas Districts 2, 3, and 4). These 138 onshore fields produced 276 million barrels of oil before being abandoned. Nongiant fields in the Texas Gulf Coast average about 40% ultimate recovery, so these fields probably originally contained about 700 million bbl of oil in place. Therefore, about 424 million bbl of oil remain unrecovered.

Reservoirs in these abandoned fields are Tertiary sandstones. The 44 abandoned fields in the upper Texas Gulf Coast (District 3) produced from a wide range of plays; those plays with the largest number of abandoned fields are Yegua and Frio deep-seated domes, Eocene deltaic sandstone, and Frio barrier/strand-plain sandstone. The 19 abandoned fields in the middle Texas Gulf Coast (District 2) produced mainly from Wilcox and Frio fluvial/deltaic sandstones and from Frio and Jackson-Yegua barrier/strand-plain sandstones. The lower Texas Gulf Coast (District 4) contains 75 abandoned fields that produced from Frio fluvial/deltaic and barrier/strand-plain sandstones and from Jackson-Yegua barrier/strand-plain sandstones.

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Crustal Structure of South Florida Bank Derived from Ocean Bottom Seismometer Refraction Profiles

In March 1982, 6 seismic refraction lines, 70-90 km (43-56 mi) long, were shot in the southeastern Gulf of Mexico using the advanced University of Texas digital ocean bottom seismometers. Five lines were on the South Florida bank region in water depths of less than 1 km (3,300 ft) and one was in water depth of about 2.4 km (7,900 ft) off the northern coast of Cuba. After data reduction, first arrival picks were made and least squares lines were fitted to the picks to obtain the apparent velocities and intercept times for the layers. Using these values, flat layer crustal models have been initially computed. The 2 most dominant deep refractors have apparent velocities of 5.6-5.9 km/sec (3.5-3.7 mi/sec) and 6.2-6.6 km/sec (3.9-4.1 mi/sec). The top of these refractors varies in depth 2-6 km (6,600-13,000 ft) from the sea surface. They are interpreted to represent the crystalline basement. Basement rocks have been reached at a depth of 3.4 km (11,200 ft) in a well drilled in the Pinellas County arch. In the South Florida bank area, the deepest refractor observed has an apparent velocity of about 7.5 km/sec (4.6 mi/sec) at a depth of about 25 km (15 mi). Absence of any mantle velocity in these long profiles confirms the continental nature of this crust. The only possible mantle arrival (velocity = 8.4 km/sec, 5.2 mi/sec) was observed in the line off the northern coast of Cuba at a depth of about 26 km (16 mi). Similar crustal thickness has been observed in a refraction profile just northwest of this line. This deep crustal structure complements the shallow crustal structures for this area.

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Ammonite Zonation in Condensed Zone, Middle Ozan Formation (Taylor Group, Upper Cretaceous) in Northeast Texas

Recognition of condensed zones is important because they may be marker horizons that are useful in exploration. Such a zone is demonstrated by the occurrence of ammonites belonging to 12 species and 9 genera from the middle Ozan Formation (lower Taylor Marl) in northeast Texas. The 1-foot (0.3-m) thick bed of bioturbated glauconitic biomicrite contains many specimens of disarticulated vertebrates, molluscs, remanié fossils (blackened phosphatic internal molds), and hiatus concretions. Four of 6 midcontinent ammonite range zones proposed by Cobban and others appear to be represented in the fauna, in ascending order, by *Baculites aquilaensis* Reeside, *Delawarella delawarensis* (Morton) (= zones of two unnamed species of *Baculites*), *Baculites obtusus* Meek, and *Trachyscaphites spiniger porchi* Adkins (= zones of *Baculites mclearni* and *B. asperiformis*). Young may be correct in assuming that the occurrence of *Delawarella delawarensis* and *Baculites aquilaensis* in the Ozan Formation may mean that rocks of the upper Austin Group and parts of the lower Taylor Group are the same age. If correlation with the midcontinent zonation is correct, then the sediments that formed the condensed zone slowly accumulated from 81 to 79 m.y. (mid early Campanian to early late Campanian). Several species of the fauna are preserved as both normal and remanié fossils, indicating that members of these species lived in the area for an extended period of time, perhaps as a relict fauna. The fauna includes a mixture of cosmopolitan and endemic species (indicating open shelf environment) with several types of heteromorphs (indicating moderate water depths).

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Subsurface Geological Data on a Microcomputer

Principal tasks in a subsurface geologic study include storing geologic data and selecting parameters such as depth, production, and total depth for posting on maps. These tasks can be carried out either with index cards, or with a system comprising a microcomputer, an off-the-shelf data-base program, a dot-matrix printer, and simple custom programs. The advantages of the latter approach are numerous, and include: (1) capacity to store thousands of pieces of information on just a few disks, (2) ability to sort and select data according to virtually any criterion (e.g., depth range, formation, etc), (3) capacity to combine selection criteria (e.g., depth of all penetrations of a particular formation in a certain area, that have certain production limits), and (4) removal of the possibility of introducing errors during the posting process. The system is limited either by the quantity and type of data that the geologist wishes to enter into the data base or by the quantity of money available to purchase the data in a form directly readable by the computer.

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Strong Transfer Function Links Thin-Section Data to Reservoir Physics

Thin sections carry considerable precise quantitative information concerning physical properties of the rock such as permeability, log response, and acoustic phenomena. This information is not obtained through conventional petrographic procedures such as point counting or simple linear measurements made with a graduated ocular. Instead, multispectral-image-analysis techniques are required. Critical parameters of such a system include: (1) selection of correct magnifications; (2) selection of proper spectral bands; (3) construction of a high precision digital filter able to define precisely grain and pore boundaries at the upper surface of the section; (4) identification of an algorithm to express in useful fashion the complex geometries of grain and pore as well as correctly identify minerals and mineral phases; and (5) development of software to analyze such data. Output data is copious—for example, more than 80 variables are used to describe pore size and geometry. The result, however, is precise estimation of such properties as permeability and identification of pore characteristics associated with enhanced or reduced permeability. The procedure at present requires minicomputer-level hardware for optimal data acquisition and processing.

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Pericollisional Strike-Slip Basins in Western Cordillera, Canada

The late Mesozoic-Paleogene evolution of the Canadian Cordillera was dominated by accretion of elongate crustal blocks against the North American craton. Geologic and paleomagnetic evidence suggest that these exotic terranes dispersed from volcanic arcs and oceanic platforms and approached North America along anastomosing right-lateral faults with great cumulative displacement. Obduction of oceanic allochthons was followed by transpressive thickening and regional metamorphism of the cratonic margin in the mid-Jurassic. Strike-slip motion and emplacement of plutonic rocks continued near relict sutures and reactivated deep faults. Sedimentary basins related to strike-slip faults formed by elongation of accreted terranes ("Stikinia" and "Wrangellia") and by shear within the deformed cratonic margin zone ("Rocky Mountain Trench"). Subsidence is reflected by northwest-southeast stretching along pull-apart structures, and by massive influx of turbidites from incipient collision zones and relict arc relief. It was interrupted and outlived by rotation of blocks, folding of basin sediments, and vigorous progradation of deltaic-fluvial clastics from rising collision belts. Transition from predominant transtension to prevailing transpression is diachronous from basin to basin. Near the Stikine-Wrangellia collision zone (Bowser basin), it occurred in the Late Jurassic; along the Stikine-Wrangellia border it occurred in the mid to Late Cretaceous. Only small nonmarine basins developed in the Rocky Mountain Trench system, which, in its southernmost part, was closed completely during Paleogene thrust faulting. The strike-slip basins of the western Canadian Cordillera were subject to high regional heat flow and also suffered from widespread intrusion of Paleogene granitoids. Therefore, they are generally poor oil and gas prospects.