ingly bimodal, recording deposition in low-relief coastal settings. Overlying nonmarine units are lithologically intermediate between typical Gannett Group lithologies which occur to the west and typical Morrison-Cloverly lithologies which occur to the east. These consist predominantly of numerous fining-upward sandstone channels isolated in variegated siltstone and mudstone. These were deposited in low-gradient meandering fluvial channel and related flood-plain settings, respectively. The Draney Limestone in the upper part of Gannett Group extends eastward across this area into the top of the "Lilac Beds" of the Cloverly Formation, demonstrating synchroniety of deposition across the foreland basin. Nonmarine units are overlain by rippled, crossbedded, and burrowed transgressive nearshore sands of the "Rusty Beds," which are in turn overlain by the normal marine dark shales of the Thermopolis Formation.

Paleoflow directions in nonmarine axial foreland basin units are predominantly to the north, ranging from northwest to northeast. As such, these fine-grained meanderbelt facies demonstrate that while synorogenic rivers of the tectonically active basin margin carried sediment of the Gannett Group eastward toward the basin axis, rates of axial basin subsidence exceeded rates of fluvial input, even during the earliest stages of deformation. Synorogenic rivers, bounded on the west by the rising orogen and the east by the stable craton were constrained to flow northward, parallel to the belt of orogenic deformation. As such, major fluvial systems of the Western Interior were analogous to those of other foreland basin settings such as the Paleozoic Michigan River system which paralleled and flowed to the west of the rising Appalachians, and the east-flowing Quaternary Indogangetic system south of and parallel with the rising Himalayas.

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Evidence for Post-Cementation Migration of High-Temperature, High-Pressure Fluids—Siluro-Devonian Helderberg Group, Central Appalachians

Fluid inclusion data and fracture-filling cements in carbonate and siliciclastic rocks of the Siluro-Devonian Helderberg Group, central Appalachians, indicate post-cementation, late Paleozoic migration of high-pressure, high-temperature fluids.

Void-filling quartz and calcite cements contain secondary, 2-phase fluid inclusions that give freezing temperatures of -20 to -25° C (-4 to -13°F) (salinity > 22 wt.% NaCl). Homogenization temperatures are 200 to 300 + °C (392 to 572°F) (temperatures calibrated and pressure corrected) and greatly exceed maximum paleotemperatures (120 to 160°C; 248 to 320°F) given by conodont color-alteration index values or calculated from known sedimentary overburden. High homogenization temperatures suggest rapid movement of metamorphic fluids so that ambient burial temperature was not raised for long enough periods of time to affect conodont CAI values. These fluids probably came from Blue Ridge-Piedmont thrust sheets that were undergoing metamorphism during late Paleozoic deformation. These fluids migrated more than 75 km (47 mi) during thrusting.

Well-cemented sandstone and limestone have multiple crosscutting trains of secondary hydrocarbon inclusions. Some trains crosscut cement-filled fractures. Hydrocarbons also occur as thin films along cement crystal boundaries and as secondary inclusions trapped along calcite deformation twins. These inclusions indicate geopressured fluids moved along intercrystalline boundaries and along deformation twin planes in calcite under deep burial conditions either during or after deformation.

Rare fractures contain transported skeletal grains, "exotic" clasts, recemented clasts of fracture-filling cement, and mud. Cement clasts contain included mud and skeletal grains, and indicate several episodes of particle transport, cementation, and refracturing prior to final fracture filling. Primary(?) 2-phase fluid inclusions in vein-filling calcite give homogenization temperatures of 120 to 150°C (248 to 302°F). Coarse-grained "clastic" fracture fills indicate migration of rapidly moving fluids capable of transporting clasts through fracture conduits under deep burial conditions.

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Paradox of Great Thicknesses of Carbonate Turbidites—Some Synergistic Observations from French Western Pyrenees and Upper West Florida Continental Slope

By the end of the Turonian, a westward-trending flysch trough was well established in what is now the western French Pyrenees. Over the next 22 m.y., to the end of the Maestrichtian, up to 5 km (16,000 ft) of carbonate flysch were deposited, uninterrupted by major silicoclastic sedimentation. Individual carbonate turbidites vary from a few centimeters to occasional massive deposits tens of meters thick. One carbonate megaturbidite can be traced 90 km (56 mi) and is still 10 m (33 ft) thick at its most distal exposure. Carbonate constituents lack shallow water indicators, suggesting that deposition and mass movement initiation occurred on continental slopes. Carbonate sediments were fed into the trough from both north and south.

Are there modern carbonate depositional environments we can turn to that will help us understand how such great thicknesses of carbonate flysch can build up without major clastic input? We believe that the west Florida upper continental slope is one such environment. It is part of a system which has been a carbonate depocenter since Jurassic time. A lime mud slope facies has accumulated at the rate of about 30 cm/1,000 years (12 in./1,000 years) for the last 25,000 years. At that rate (and allowing for a 50% reduction due to compaction) about 3.3 km (11,000 ft) of carbonate could accumulate in 22 m.y. A large variety of structures show that mass movement is continually displacing sediment downslope. If a second carbonate margin were close, accumulation of 5 km (16,000 ft) of carbonate flysch in 22 m.y. in a subsiding trough need not be extraordinary, even in an orogenically quiescent system.

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Shallow Structure and Carbonate Sedimentation of West Florida Upper Continental Slope

An extensive mini-sparker (3.5 kHz) and piston-coring survey of the continental slope above the West Florida Escarpment has revealed a Pleistocene sequence up to 160-msec (2-way travel time) thick overlying a second strong reflector of either Pliocene or Miocene age. South of 27°20′ N, the contact between the two is clearly erosional and includes a band of karst features. The Pleistocene drape thins to a minimum, in some places exposing the second layer, at about 525 m (1,725 ft) water depth, and then thickens dramatically downslope. We attribute this thinning to the north-south-flowing Loop Current blocking deposition and scouring the bottom. Present depth of the erosional surface suggests as much as 400 m (1,300 ft) of subsidence after its formation.

Two parallel reefs mark the upper slope from its southern limit to 26°40′ N. Sediments on the upper slope are a foraminifera-coccolith ooze, the compositional equivalent of a chalk deposit. Radiocarbon dating indicates that ooze below the erosional minimum accumulated at more than 60 cm/1,000 years (24 in./1,000 years) for at least the last 25,000 years, a surprisingly high rate. High sedimentation rates are also reflected in a wide variety of mass-wasting features from creep to massive slides to gravity-induced folds tens of kilometers long.

Fan deposits have formed at the foot of the continental slope off the southwestern corner of the west Florida margin. Orientation of sand-wave fields on the outermost shelf suggests that offbank transport combined with high slope sedimentation rates and subsequent mass wasting have provided material for these deposits.

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Basement Faults and Cover Tectonics in Southernmost Appalachians

Stratigraphic and seismic data indicate that basement faults occur beneath the Appalachian foreland fold and thrust belt in Alabama. Some of the high-relief basement faults control the locations of thrust-related 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_0). 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_0 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.