

phy clearly shows that several dikes are right-laterally offset. These offsets appear on TM imagery only as subtle bends, rather than breaks in the dikes. However, because TM imagery reveals subtle spectral differences that aerial photography cannot, the imagery will display more information. This is demonstrated by nearly twice the number of dikes being mapped using TM imagery than with aerial photos.

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Computer Modeling and Graphic Representation of Development of Secondary Porosity and Cements in Reservoirs Rocks

We have developed a set of programs for analysis of surface and subsurface data that (1) organize the data to reduce its bulk without violating its integrity, (2) present 3-dimensional graphic representations of the data, and (3) use transport/reaction models to predict the evolution and spatial distribution of secondary porosity and cements. This evolution path and distribution arise through the interaction of flow, diffusion, dispersion, mineral dissolution, and cement precipitation.

These programs are applied to 2 types of reservoir rock: (1) a feldspathic arenite in which feldspar dissolves and calcite cement precipitates, and (2) a limestone undergoing dolomitization.

Knowledge of spatial distribution of porosity and cements derived from these models is valuable in choosing drill-hole sites.

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Use of Conodont Genus *Gondolella* in High-Resolution Biostratigraphic Zonation of Middle-Upper Pennsylvanian Rocks, Central North America

Several conodont taxa have been suggested for use as biostratigraphic tools in the Pennsylvanian, but each has its limitations. Some are severely restricted paleobiogeographically or paleoecologically. Others existed through a relatively short interval of time, leaving the bulk of the Pennsylvanian column unzoned. Frustratingly, the single most promising group, the *Idiognathodus-Streptognathodus* plexus, has eluded taxonomic treatment that is both phylogenetically sound and biostratigraphically useful.

Gondolella Stauffer and Plummer, 1932 (type-species *G. elegantula*, O.D.), is subject to many of these restrictions, especially geographically and paleoecologically, but offers a highly precise zonation in the rocks where it does occur that can serve as an interim standard for some (mostly Missourian) and a supplement for others (mostly Desmoinesian). Enough occurrences have been amassed to facilitate interregional, and in some cases, intercontinental correlations.

Desmoinesian gondolellids are known from 9 stratigraphic units in the Illinois basin and 5 from the Mid-Continent, and 5 zones are recognized. Distribution is relatively uniform, and zonation of this part of the column is almost total. This zonation is less detailed than the contemporary *Neognathodus* zonation, but it is a valuable supplement to it. The most dense concentration of *Gondolella*-bearing units is in the Mid-Continent Missourian where 15 units have produced gondolellids. These and the 6 Illinois basin units can be assigned to at least 6 zones, totally contiguous in the lower Missourian, less so upward. The Virgilian cannot be completely zoned, but the 2 productive Mid-Continent units are assigned to different zones.

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Environmental Significance of Pisoliths, Mississippian Madison Formation of the Williston Basin, Bottineau, Renville, and McHenry Counties, North Dakota

Pisoliths from the Mississippian Madison Formation of North Dakota originated in an agitated, shallow-water marine environment. Evidence for this interpretation includes: (1) association of pisoliths with oolites and marine fossils; (2) well-rounded clastic pisolith morphology; (3) vertical facies succession in core from open-marine facies through the pisolith-oolith facies band into lagoonal and intertidal facies featuring fenestral

fabrics and possible tepee structures; (4) upward-shallowing cycles with reverse grading, submarine hardgrounds, and desiccation features.

Madison pisolites (pisolith-rich carbonate) differ markedly from those set forth by Dunham as indicators of vadose, caliche soil conditions: (1) they lack fitted polygonal structure; (2) they have large amounts of primary pore space or cemented pore space; (3) they contain no peds (soil components); (4) no evidence of rooting is visible; (5) no classic "caliche" horizons are present; (6) only minor occurrence of vadose cements post-date pisolith initiation, development, and deposition; (7) no evidence for replacement of parent rock was observed.

Similar evidence was used by Esteban, and Esteban and Pray, to show that the "type" Capitan Formation pisoliths were not formed by caliche soil-forming processes. Pisoliths and pisolites should be viewed in relation to other carbonate allochems, sedimentary structures, and diagenetic fabrics to determine their origin and environmental significance.

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Regional Facies Distribution and Tectonic Evolution of Appalachian and Ouachita Thrust Belts

A series of 12 tectonic and lithofacies maps representing critical periods of the evolution of the Appalachian-Ouachita orogen were compiled from published sources and interpretation of seismic and subsurface data. The distribution of sediments supports the concept of multiple deformation that resulted from the collision and accretion of small plates or irregular margins of larger plates with North America.

During the Eocambrian and Early Cambrian, a series of rifts developed within the craton subparallel to the continental margin of the Iapetus Ocean. Ouachita sediments were deposited in this rift zone along the southern margin of the craton. However, the rift zone did not persist in the Appalachians, and the sediments in that belt were deposited along the continental margin.

In the Middle Ordovician, the extensional regime continued in the Ouachita belt while compression associated with plate collision began in the Appalachians. The northwest-southeast-trending boundary between these areas persisted throughout the evolution of the orogens. The sedimentary records indicate that the initial compressional deformation in the Ouachita belt began during the Late Mississippian, and the final phase of deformation in the Appalachians was initiated slightly later, during the Early Pennsylvanian.

Structural features associated with thrusting basin sediments over foreland areas were controlled to a great extent by the presence or absence of buttresses. The Ouachita Mountains area provides the best illustration of contrasting structural styles along the thrust belt. Elsewhere along the thrust belts the evidence is either covered by younger sediments or altered by a complex tectonic history.

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Resources of Small Oil and Gas Fields

In presently known small oil fields, a remaining recoverable reserve of about 3,100 million bbl appears evident. As much as 2,000 million bbl remain in place in abandoned small fields, of which at least 500 million eventually may be recovered through redevelopment or, in a few cases, mining. Reserves of oil in stripper wells amount to about 5,200 million bbl. Research on only 2 basins, Gulf Coast and Permian, indicates that, should a high rate of drilling activity persist into the future, at least 10,000 million bbl more in small fields could be anticipated in the United States. This suggests that a total of at least 19,000 million bbl of oil in small fields remains to be recovered in the future in the United States.

Gas from presently-known small oil fields should account for more than 17 tcf, nearly all nonassociated. In addition, at least 67 tcf of gas and nearly 2,000 million bbl of condensate will come from small, nonassociated gas fields. It is not known how much gas, as compared with oil, will be found in small fields as a result of future exploration. The amount will be substantial.

An enormous exploration effort will be required to yield this petroleum. The aggregate return is substantial, but because it is from a collection of small fields, it will not be possible to optimize exploitation in the same way as for a similar amount of petroleum from a few large fields.

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.

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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 Eureka 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.

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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.

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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 corres-

ponding 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.

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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.

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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