Synthesis of seismic data, geologic mapping, and satellite imagery suggests a general 3-stage model of thrust and fold development in the Southern Appalachian belt. Essential to the model is the contrast in gross physical properties of the 2 basic rock packages present: (1) lower Paleozoic carbonates and chert, which behave competently, and (2) upper Paleozoic sandstones and shales, which behave incompetently. The individual structural development of each of the 2 rock packages differs but both are directly related to the development of a thrust structure.

Stage 1.—Initial displacement (0-3 mi) creates a large hanging-wall anticline (drag fold) in the lower Paleozoic.

Stage 2.—With greater displacement (2-5 mi), a J. L. Rich model anticline develops in the lower Paleozoic hanging wall. In the process, the upper Paleozoic was bulldozed by the lower Paleozoic, creating more internal folding and faulting.

Stage 3.—With further displacement (>5 mi), the thrust will probably become a major overthrust. It develops by ramping of the lower Paleozoic through the highly deformed upper Paleozoic with intense penetrative deformation developing in areas of significant overthrusting.

From this 3-stage model, it may be possible to infer source rock and reservoir juxtapositions, relative timing of hydrocarbon generation, and fracture development. The regional distribution of structural types suggests that initiation of thrusting progressed westward with time. The model may have application in other orogenic belts (e.g., the Idaho and Wyoming Overthrust belt.

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Morphologic Variations of Calcite Crystals in Waterfall Travertine Deposits, Arbuckle Mountains, Oklahoma

A motley assortment of low-magnesian calcite morphologies occurs in travertine deposits in Oklahoma. These morphologic variations result from (1) precipitation, (2) dissolution, and/or (3) neomorphism in this nonmarine environment; analogous morphologic variations in both marine and nonmarine strata may likewise indicate nonmarine processes.

Commonly precipitated crystals include hexagonal prisms and rhombohedrons (2-150 μm long), and bladed to fibrous forms (0.02-2 mm long, many revealing triangular cross sections). Many of these crystals contain inclusion-defined growth layers that dissolve preferentially, leaving abundant intracrystalline porosity. This porosity parallels crystal outlines, imparting a nested appearance to the crystals. Partial dissolution also creates parallel "spikes" (4-30 μm long, 1-10 μm wide), and parallel "ribbon" crystals (30-150 μm long, 3-12 μm wide) that repeatedly narrow and widen, and occasionally twist. In addition to precipitational and dissolutional forms, aggradational neomorphism produces columnar crystals, commonly exceeding 8 mm in length. These crystals originated as elongate spar around filamentous cyanophyte tufts and were transformed subsequently into ragged-edged columnar crystals at the expense of overlying micritic crystals.

Morphologic variations in calcite crystals often have been attributed to ionic concentrations (particularly Mg and SO_4) of ambient waters. In this study, however, the low concentrations of both Mg (averaging 12 ppm) and SO_4 (approximately 16 ppm) may be interpreted as supporting theories relating precipitational morphologies to growth rates rather than to "poisoning" ions. In any case, recognition of similar morphologic suites resulting from precipitation, dissolution, and/or neomorphism may aid in the identification of nonmarine processes in marine and nonmarine strata.

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Sedimentation Dynamics About Salt Features

Detailed side-scan sonar and gridded bathymetric surveys on continental margins reveal the existence of numerous submarine canyons. Recently published compilations of current velocities in submarine canyons indicate that alternating and undirectional flows often exceed 20-30 cm/sec with peak velocities ranging from 70 to 100 cm/sec. Current meters attached to the ocean floor have been lost at current velocities of 190 cm/sec. Such velocities are ample to transport sand-size sediments. The results of DSDP Leg 96 show the existence of massive sands and gravels on the Louisiana slope, deposited during the last glacial advance. Thus, present physical oceanographic data may be an analog to conditions during glacially induced lowered sea levels. Salt ridges and domes underlie much of the Louisiana slope, determining morphology. Submarine canyons lace the slope. Given a prograding shelf, the net sediment transport routes will be down the submarine canyons. Sediment deposition patterns around the salt ridges and domes include parallel-bedded foredrifts on the upslope side, lee drifts on the downslope side, and moats along the lateral flanks of the salt features. Major differences exist between the sedimentation patterns around a ridge and a dome. The size and shape of the flow pattern will determine whether there can be a flow over the salt feature with a resulting turbulent wave that may influence sedimentation. Sedimentation patterns about salt features on the present slope should be applicable to similar paleoenvironments.

LOWRIE, ALLEN, Geologist, Picayune, MS

Seismic Stratigraphy, Pleistocene Climate, and Tertiary Sea Level Changes

The Quaternary is characterized by 2 climatic signatures: that of the last 800,000 yr, the upper Pleistocene climatic signature (UPCS), and that of the period from 900,000 to 1,800,000 yr ago, the middle Pleistocene climatic signature (MPCS). Glacial cycles within the UPSC are about 100,000 yr long with interglacials of 10,000-12,000 yr duration and a "full" glacial period of 20,000-30,000 yr. The cycles of the MPSC range from 20,000 to 40,000 yr duration. Interaction between the 3 planetary orbital parameters of eccentricity, tilt, and precession are believed to cause the observed climatic signatures.

From DSDP cores, 8 major Miocene hiatuses have been described. There is a roughly equal duration of hiatuses and deposition, with periods ranging from 0.5 to 2 m.y. $\pm$0.5 m.y. The deep-ocean hiatuses correlate well with the seismically determined lowered sea levels of P. Vail. The hiatuses are interpreted to be caused by increased activity of ocean-bottom currents, in turn initiated by increased glacial activity. Thus, it is geologically reasonable that within each period of increased glacial activity there are 100,000-yr long UPSC-type cycles. The UPCS cycles have been tentatively identified in seismic data on the Louisiana, east Greenland, and Caribbean shelves and on the Indus Cone. Miocene glacial cycles should be sought in seismic data using innovative data processing techniques.

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Effect of Biological Markers and Kerogens in Geochemical Exploration for Oil and Gas

The aliphatic hydrocarbons of 29 Tertiary argillaceous rock samples from eastern China have been examined by computerized gas chromatography-mass spectrometry. The steroid and triterpenoid components provide new information for the characterization of depositional environments, organic matter, and maturation of the source rocks. These samples contain gamaceranes, 8,14-open-hopanes, diterpenoid hydrocarbons, and diasteranes. The abundant gamaceranes correspond to the preference of even carbon atoms. The highest gamacerane occurs in the strongly reducing environment. The abundant diterpenoid hydrocarbons relate with the type III kerogen. These diterpenoid hydrocarbons are derived from higher plant forms. The threshold of oil formation can be correlated with the ratio of 20S (22S) and 20R (22R).

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Distribution of Dolomite in Deep Marine Sediments as Function of Time

The distribution of dolomite in deep marine sediments as a function of time was determined for the Cretaceous and Cenozoic, 150 Ma to present, using data from 1,142 DSDP samples. The general distribution patterns for the Atlantic and Indo-Pacific are similar. Their curves show a maximum in the Miocene, minimum in Paleogene, and 2 maxima in the Cretaceous separated by a Cenomanian low. The less time-extensive data of the Gulf-Caribbean and Mediterranean have a Miocene maximum. Red Sea data peak in late Miocene to early Pliocene. The general similar-

ity of the patterns from such diverse areas and sediment types suggests that the distribution of dolomite in these sediments is not due to random groupings and may be a consequence of a common global cause.

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Fibrous Calcium Sulfate in Veins

In an extensional vein, fibrous anhydrite is reported for the first time. It resembles satinspar and is termed "satinspar-A." Satinspar-A contains most features typical for satinspar (subhorizontal attitude of the veins, vertical fibers, a parting separating a lower from an upper seam, incorporated wall-rock fragments), but several observations are new, such as the stacked nature of the fibers, tapering of wall-rock fragments, pressure shadows next to the wall-rock fragments, and parabolic alignment of the fragments.

Previous interpretations of satinspar veins are unsatisfactory and partly contradictory. The combination of the foregoing features leads to a generally applicable interpretation of the mode of infilling of veins of this type. In this process, the veins are opened owing to vertically tensile stress. The vein-filling crystals grow centrifugally outward from the initial plane of rupture (which now forms the parting) keeping pace with the dilation. The mode of incorporation of wall-rock fragments in the fibers requires repeated differential opening of the fissure. Thereby, the wall-rock and fiber interfaces rupture in a statistically alternating fashion.

The source of the calcium sulfate may be adjacent evaporite beds but, at least, in the case of satinspar-A, an external source is indicated by trace-element data and the absence of evaporite deposits in the area. In contrast to previous interpretations, the hydration of anhydrite to gypsum in the host rock is not a prerequisite for the formation of satinspar veins.

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Geology of Fulmar Oil Field, United Kingdom Sector, Central North Sea

The Fulmar field is situated within the United Kingdom sector of the central North Sea, 170 mi (270 km) southeast of Aberdeen, in water depths averaging 265 ft (81 m). The field was discovered in 1975 when Shell/Esso well 30/16-6 established the presence of an important oil play within shallow-marine sands of Late Jurassic age in the southwest Central graben of the North Sea basin. The well encountered an oil column of 668 ft (204 m) within apparently homogeneous sandstones displaying excellent reservoir properties. Commercial production was confirmed by an appraisal well, and 4 development wells were pre-drilled from a subsea template prior to platform production, which commenced in February 1982. The reservoir geology was consequently found to be more complicated than originally thought and has led to a diversity of depositional and structural models. To date, 23 development wells have been drilled. Current recoverable oil reserves are estimated at 427 million bbl with an oil gravity of 40° API.

Fulmar field is operated by Shell U.K. Ltd. on behalf of the Shell/Esso North Sea Venture and the Fulmar Unit.

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Fracture Permeability and High Initial Water Cut in a Carbonate Gas Reservoir

Waveland field in Hancock County, Mississippi, produces gas and condensate from the Lower Cretaceous Mooringsport Formation at approximately 13,400 ft. Total gas reserves have been estimated at 256 bcf. The reservoir is a fractured lime packstone, containing milliolid and orbitolinid foraminifers, mollusk fragments, and echinoderms. Core plug permeability is low, commonly below 1 md, yet productive wells flow at rates of as much as 8,000 MCFGD. Thus, fracture permeability is an important reservoir property. Short-term flow tests can be misleading, as productive wells may initially produce an uneconomically high water cut for several days.

The trap is a south-southwest-plunging anticline with no apparent structural closure to the north. A map of averaged, thickness-weighted porosity values for productive stratigraphic intervals indicates that porosity does not decrease across the northern limit of production. In order to compare the productivity potential of zones with varying porosity and water saturation, Buckles Numbers (product of porosity and water saturation) were mapped for zones within the productive stratigraphic interval. Averaged, thickness-weighted Buckles Numbers indicate that productivity potential does not decline across the northern limit of the field. Thus, it is concluded that the northern (updip) extent of effective fracture permeability controls the northern limit of production at Waveland field.

High initial water cut indicates that water is in the fractures and gas and water are in the matrix. The presence of water in fractures adjacent to rock with much narrower effective pore-throat radii is a normally unstable situation, as capillary pressure would be expected to result in the matrix imbibing water and releasing gas to the fractures. It is proposed that fracturing occurred after hydrocarbon migration and that there is little or no fluid exchange between fractures and matrix prior to wellbore drawdown.

Waveland is an example of a field where limits of productivity are controlled by permeability rather than by porosity, hydrocarbon saturation, or trap geometry. Buckles Numbers maps are a useful tool for describing productivity potential of similar fields.

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Valencia Fan (Northwestern Mediterranean): Channelized Distal Deposition Fan Variant

The Valencia Fan, a large deep-sea depositional system in the western Mediterranean Sea, developed in the structural depression between the Valencia Trough and the Balearic Basin Plain. Six main lithoseismic units are identified from 6,000 km of sparker profiles. Channelized and irregularly stratified units predominate. It is inferred that the sedimentary processes controlling the development of these units include channelized sediment flows that evolve downfan into sheet flows. Three fan depositional provinces are differentiated on the basis of the relative proportions of lithoseismic units and the inferred sedimentary processes.

Regularly stratified seismic units predominate in the non-fan environments. These units are dominated by fine-grained deposits resulting from hemipelagic settling and overbank flows from turbidity currents. Distal flows from the continental slopes of the Iberian Peninsula and Balearic Islands also contribute sediment for the development of these environments. The wavy units flanking the upper fan probably resulted from migrating sediment waves, whereas transparent units are attributed to extensive mass flow. The Valencia Valley is largely an erosional feature across which sediments from several source areas bypassed to the distal, deep-sea depositional system of the Valencia Fan. Deposition begins at the mouth of the valley where it is constricted by a volcano and beyond which there is a break in slope.

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Upper Jurassic Norphlet Eolian Dune, Wadi, and Marine Petroleum Reservoirs, Central and Eastern Gulf of Mexico Regions

The Norphlet Formation (Upper Jurassic) of the central and eastern Gulf of Mexico regions accumulated under arid climatic conditions. Norphlet paleogeography in southwestern and offshore Alabama and the Florida Panhandle was dominated by a broad desert plain rimmed to the north and east by the Appalachian Mountains and to the south by a developing shallow sea. The desert plain extended westward into eastern and central Mississippi. Quartzose sandstones were deposited as dune and interdune sediments. The source of the sand was adjacent and updip alluvial-fan, plain, and wadi deposits. Wadi and playa-lake sediments also accumulated in the interdune areas. A marine transgression was initiated during upper Norphlet deposition resulting in the reworking of previously deposited sediments.

Petroleum reservoir rocks consist primarily of quartzose sandstones that are eolian dune, wadi, and marine in origin. The high-angle (up to 30°) cross-bedded eolian sandstones are moderately well-sorted to well-