geopressure is related to structure and a high shale/sand ratio. Low isothermal surfaces in the down fault blocks accompanied by anomalous high temperatures in the upthrown blocks indicate vertical leakage of fluids along growth faults from underlying geopressured aquifers. The association of low salinity fluids (less than 60,000 ppm) with leakage zones affirms structural control of fluid movement through the Anahuac and Frio formations (Oligocene) at Kaplan field.

The Frio Formation core samples from 16,700 to 19,600 ft (5,090 to 5,974 m) of depth, representing channel and channel-edge turbidite sandstones, were examined petrographically and by SEM. The arkosic composition of late stage diagenesis sandstones at Kaplan field suggests an original arkose or lithic arkose composition (classification of McBride). Nonferroan calcite cementation, chlorite rims and cement, and quartz overgrowths characterize early diagenesis. At a middle stage of diagenesis secondary porosity is developed by dissolution of unstable grains and calcite cement. Samples flushed by geopressured waters from greater depth show kaolinite pore-fill and quartz overgrowths, chlorite (polytype IIb) and illite cement, and feldspar overgrowths in the late diagenetic stage. Premetamorphic textures are apparent in the deepest section at 338°F (170°C).

The low permeability of sandstones with extensive early chlorite cement (channel-edge sandstones) precludes development of extensive secondary porosity. In contrast, sandstones with little early chlorite cement develop and maintain secondary porosity through the late diagenetic stage. Restriction of fluid movement by early chlorite cement has ramifications for migration of hydrocarbons or geothermal waters, and for gas production at Kaplan field.

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Catalytic Effect of Smectitic Clays in Hydrocarbon Generation

Smectites or three-layer expanding clays promote the thermal decomposition of long-chain aliphatic hydrocarbons to produce hydrocarbons of lower molecular weight. Smectites are believed to act as acid catalysts through the dissociation of water, thus promoting carbonium ion reactions. When sedimentary organic matter, isolated as kerogen from suspected petroleum source rocks, is pyrolyzed in the laboratory, long-chain aliphatic hydrocarbons are in the pyrolyzate, commonly in abundance. When the source rock contains smectite and is pyrolyzed, the pyrolyzate has significantly less high molecular weight aliphatic hydrocarbons and more lower molecular weight hydrocarbons.

Mixtures of kerogens with quartz, silica, alumina, calcium carbonate, kaoline, or illites not containing smectite-illite mixed layer clay, yield pyrolyzates more similar to those of the kerogen alone, i.e., the range of hydrocarbons in the pyrolyzates is broad including those of high molecular weight. This is interpreted to be due to a lack of catalytic activity of these minerals as compared with the catalytically active smectite. The catalytic effect of smectite is observed particularly when the concentration of sedimentary organic matter in the source rock is relatively low, amounting to less than about 2% total organic carbon. Smectites in sediments with a modest or low amount of organic matter are critical regarding the type petroleum generated, exemplified by the gas condensates of the northern Gulf of Mexico basin and Indonesia. Consequently, it is concluded that smectitic argillaceous sediments containing less than approximately 2% organic carbon are poor sources of oil, although they may be productive of gas and gas condensate.

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Sediment Gravity Flow Deposition on a Modern Carbonate Slope Apron: Northern Little Bahama Bank

Carbonate sediment gravity flow sedimentation north of Little Bahama Bank is initiated along a "line source" consisting of numerous small slope gullies on the upper slope and results in deposition of a wedge-shaped lower slope apron of coarse sediment. This broad (over 100 km; 62 mi) smooth apron (30 km, 19 mi, wide) parallels the adjacent carbonate bank margin and lies between 20 and 50 km (13 and 31 mi) seaward of the platform. The apron is marked by a relatively abrupt decrease in slope and ranges from 2° to $^1/_2$° between depths of 850 and 1,400 m (2,789 and 4,593 ft). This apron is composed of a variety of medium to coarse-grained sediment gravity flow deposits of variable thicknesses, interbedded with an equal proportion of fine-grained pelagic ooze. Based on texture alone, ancient slope aprons could easily be misinterpreted as lower slope or inner fan/braided suprafan environments of a submarine fan, which operates as a "point source."

A detailed piston core study utilizing X-radiography, grain-size analyses, and standard petrographic techniques revealed 36 sediment gravity flow deposits displaying a spectrum of depositional characteristics. Single-layer deposits are either: (1) muddy, poorly sorted (debris flows); (2) clean, massive to inversely graded (grain flows); or (3) normally graded (turbidites). Double-layer deposits are composites of single-layer types resulting from flows that occur in two phases. They consist of either: (1) normally graded overlying muddy, poorly sorted, or (2) normally graded overlying clean, massive to inversely graded deposits. A ratio of 3:2:1 exists among debris flow, turbidity current, and grain flow deposits respectively.

Debris flow deposits, up to 5.6 m (18 ft) thick, display a downslope transition from mud to grain-supported fabrics. This transition is interpreted as a progressive downslope loss of muddy matrix due to turbulence. Grain flow deposits, up to 5.2 m (17 ft) thick, occur close to the slope break and represent deposition from flows of high concentration. Turbidites, up to 1.4 m (5 ft) thick, are ubiquitous on the apron. Typically they are simple graded "basal turbidites", lacking upper Bouma-sequence laminated intervals. Some exhibit multiple-graded sequences suggesting pulsating flows.

The sediment gravity flow deposits lack shallow-water sediment, but contain resedimented intraclasts derived from submarine cemented upper slope deposits (nodules) along with lithified layers and deep-water corals from the lower slope. Although textures and structures appear similar in both terrigenous submarine fan and carbonate slope apron environments, sedimentation models differ radically. Knowledge of those differences should aid in the recognition of ancient carbonate slope apron deposits.

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Hardground Petrography and Carbonate Microfacies: Paola Limestone (Upper Pennsylvanian), Southeastern Kansas

The Paola Limestone (Missourian) of the Mid-Continent region is the basal carbonate member of the Iola Formation (Kansas City Group). The Paola is a thin (1 to 3 ft; .3 to .9 m) massive layer of bioturbated, fossiliferous (algae, crinoids, and foraminifers) calcilutite containing abundant phosphatic nodules. This distinctive limestone is, according to previous investigators, correlative from Nebraska, southward, into northeastern Oklahoma. The Paola Limestone is overlain (in ascending order) by the Muncie Creek Shale and Raytown Limestone.

In a NE-SW outcrop trend across Allen County, Kansas, the Paola Limestone forms the initial substrate on which a phylloid algal buildup developed within the Raytown Limestone. The Paola consists of three distinctive carbonate microfacies (described below). Microfacies 2 overlies microfacies 1; this microfacies association occurs only beneath the phylloid algal buildup. Both exhibit petrographic features indicative of submarine lithification. Northeastward, away from the phylloid algal buildup, microfacies 1 and 2 change abruptly into microfacies 3.

Microfacies 1 is a moderately bioturbated pyritized calcilutite with *Archaeolithophyllum* crusts, *Hikorocodium, Tetrataxis, Tuberitina*, and low-spired gastropods. This microfacies has a highly irregular (scoured) upper surface that is encrusted by *Nubecularia, Archaeolithophyllum lamellosum*, and bryozoans and locally penetrated by borings.

Microfacies 2 consists of profusely bioturbated, matrix-supported, crinoidal-fusulinid biocalcarenite. Large, bean-shaped, algaloid concretions of *Nubecularia* and *Archaeolithophyllum lamellosum* are common accessory components. The large, ramose burrow networks are infilled with microcrystalline dolomite and scattered phosphate nodules; small rugose corals also occur in the burrow fills.

Microfacies 3 is a crinoidal-pelletoidal biocalcarenite containing *Archaeolithophyllum* crusts. *Composita*, oncolites, productid brachiopods, small gastropods, fenestrate bryozoans, brachiopod and echinoid spines, *Nubecularia*-encrusted bioclasts, ostracods, and neomorphosed pelecypods shells are accessory components. Baroque dolomite occurs as a filling within phylloid algal blades. Bioturbation textures are present, but sparse, relative to microfacies 1 and 2.

Prior to lithification, the hardground (microfacies 1) was bioturbated; following lithification it was scoured, encrusted, and bored. The lithification of microfacies 1 is inferred to have occurred in a submarine environment because: (1) it contains a fauna of encrusting marine organisms and (2) petrographic features indicative of subaerial exposure are lacking. Microfacies 2 is interpreted as a firm ground. Microfacies 3 represents a normal, shallow marine subtidal environment.

The recognition of ancient hardgrounds allows a more thorough understanding of the sedimentologic, paleoecologic, and diagenetic histories of carbonate sequences. Submarine diastems also have potential as chronostratigraphic markers.

Because petroleum accumulations are commonly associated with diastems, an awareness of these features could provide insights for the location of some obscure hydrocarbon traps. Additionally, hardgrounds can create intraformational permeability barriers; the recognition of such reservoir heterogeneities is essential for optimum hydrocarbon recovery. Detailed petrographic analysis is a prerequisite to the location and understanding of ancient hardground sequences.

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Regional Fracture Analysis in Western Valley and Ridge and Adjoining Plateau, West Virginia and Maryland

Approximately 2,500 stations were occupied for joint analysis in the western Valley and Ridge and eastern Allegheny Plateau of West Virginia and Maryland. Structural positions range from the Georges Creek-Stony River syncline atop the Allegheny Plateau to the Nittany anticlinorium and western Broad Top synclinorium in the Valley and Ridge. Rocks exposed range in age from Middle Ordovician carbonate within the core of the Wills Mountain anticline to Pennsylvanian coal measures on the Allegheny Plateau. The highest percentage of joint readings was obtained from Middle to Upper Devonian sandstone, siltstones, and shales because of the widespread areal distribution of these rocks within the Bedford and Clearville synclines. Here, fracture trends are similar to those observed in Devonian shale cores taken farther west.

As many as eight different joint sets are present within the study area although only four to five major systematic sets are pervasive throughout the entire region. Most commonly only two, or at the most three, joint sets are present at the scale of the individual outcrop. Consideration of joint crosscutting and offset relationships, tendential and transient features, fibrous mineralization, stylolites, and slickenlines has permitted the establishment of a consistent chronology of joint development throughout the region. Joint set I (N30° to 50°W) formed first as extension fractures early in the lithification history of all formations, followed by a less commonly developed orthogonal set trending N40° to 60°E. Both sets predated Alleghenian folding. Fracture plume data indicate upward propagation for joint development, perhaps associated with regional northeastward extension into the deepest part of the Paleozoic depositional basin. Joint set II (N55° to 70°W) formed second in response to early Alleghenian compressive stress, coupled with continuous subsidence, before folding. Locally, minor and nonregionally pervasive fractures showing shear joint geometry also developed at this time. Joint set III (N20° to 30°E) formed as extension fractures parallel to fold axes, with fracture inception early in fold development. Joint set IV (N75°E to N75°W) shows slickenlines more commonly than other sets and formed late in the folding history, possibly as shear joints where structures were effectively "locked." More likely this set formed as extension joints in response to post-folding stresses, perhaps consistent with the present-day regional stress field. A moderately to poorly developed joint set V (N10°E to N10°W) formed last in the region as an orthogonal set to IV.

The dominant joint set or sets at any location within the study area depend on the bedding thicknesses, lithology, structural position, and early fracture history. Prediction for joint trends, and possible hydrocarbon migration timing at depth in potential fractured reservoirs, must consider this aspect as well as chronological development, especially in view of the different stress fields within lower and upper thin-skinned plates.

The study did not reveal large-scale zones of high joint frequency except for the confirmation of increased fracturing in linear belts such as the Petersburg lineament and Parsons lineament previously reported by Sites, Dixon, Wheeler and Dixon, and Wilson.

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Sedimentology of a Shallowing-Upward Sequence in Middle Cambrian Carbonate-Siliciclastic Associations, Western Wyoming

The Middle-Upper Cambrian succession in western Wyoming comprises a series of interbedded siliciclastics and carbonates, some of which were deposited in a variety of shallowing-upward sequences. Although the overall succession of basal Flathead Sandstone-Gros Ventre Formation-Gallatin Limestone suggests a classic transgressive package, minor and major oscillations of the strandline resulted in several regressive phases. Carbonates of the upper Death Canyon Limestone member and siliciclastics and carbonates in the lower Park Shale member (middle and