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 upper members, respectively, of the Gros Ventre Formation) contain evidence of shoaling carbonate-clastic associations within a major transgressive sequence.

Death Canyon carbonates accumulated far offshore in relatively shallow water of restricted circulation. The basal portions of the Death Canyon represent subtidal blanket carbonates consisting of burrowed and mottled biomicrites and peloidal biomicrites. Strandline stability resulted in prolonged periods of vertical aggradation of this carbonate platform into progressively shallower water. Evidence for this shoaling includes: (1) increase in abundance of ooids and intraclasts up section; (2) increase in the relative abundance of siliciclastic debris up section; (3) coarsening upward of the siliciclastics; (4) occurrence of cryptalgal structures and large algal stromatolites as well as desiccation features near the top of the Death Canyon. These stromatolites are closely spaced circular mounds from 1 to 3 m (3 to 9 ft) in basal diameter and 0.5 to 2 m (1.6 to 6.6 ft) in height. The mounds consist of a thick inner faintly laminated zone and a thinner outer zone of discrete columns composed of curved laminations. Pits and channels occur on the outer surface and probably represent areas where low-water stage runoff was concentrated.

Carbonate production diminished with the influx of fine-grained siliciclastics near the Death Canyon–Park contact. Although the lower Park is predominantly dark, micaceous shale, it also contains cryptalgal micrites, algal stromatolites, and lenticular beds of feldspathic and arkosic arenites. These deposits all accumulated in shallow water a considerable distance from the Middle Cambrian shoreline. The siliciclastics were derived from nearby source areas that were probably offshore islands of Precambrian crystalline basement. Facies associations indicate deposition of the coarser clastics in subtidal settings.

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Barreirinhas Basin, an Equatorial Atlantic Transform Basin

A regional study of the Barreirinhas Basin, located in the Brazilian equatorial Atlantic margin, revealed that this basin does not fit the classical rifted Atlantic margin model and that it should be interpreted as a transform basin.

Three major stratigraphic sequences, Canarias, Caju, and Humberto de Campos, limited by unconformities, represent the principal evolutionary steps of the basin. The basin evolved from an initial rift phase dominated by tension (early or pre-Aptian?) to a transform phase dominated by lateral motion with tension/compression produced by a wrench system (late Aptian). These events were followed by a more quiet period as final separation (Albian-Cenomanian) and subsequent continental drifting (Upper Cretaceous to Holocene) occurred.

The Aptian sediments (Canarias) were formed by clastics representing fluvial-deltaic and fan delta, slope, and basinal depositional systems. The Albian-Cenomanian sediments (Caju) comprise cyclical deposits of carbonates and shales representing carbonate shelf and slope depositional systems. The Upper Cretaceous to Holocene sediments (Humberto de Campos) are composed of mixed coarse clastics, carbonates, and shales representing fan delta, carbonate platform, and slope-basinal depositional systems.

Structural and isopach maps, based on seismic and well data, allowed the determination of the structural framework and displayed several features not related to a normal rift basin. The structural grain of the basin at the end of the Aptian is formed by a succession of folds arranged in a consistent north-northeast en echelon pattern displaced by normal and strike-slip faults. Also, inversion structures affecting deep sedimentary sections and local shale mobilization associated to fault zones are present in the central and eastern area of the basin. All these features indicate that the area was affected by a right-lateral motion in connection with the separation of African and South American plates. The motion was directly related to the Romanche fracture zone, as shown by the reconstruction of continents at the end of the Aptian.

From east to west, the complexity and magnitude of the wrench tectonics gradually decrease, and in the westernmost area (Plataforma de Ilha de Santana) only horst-and-graben rift tectonics is observed. The stratigraphy, controlled by tectonics, also changes from a thick Aptian section in the east to a thick Upper Cretaceous to Holocene section in the west.

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Depositional Patterns in Point Lookout Sandstone, Northwest San Juan Basin, New Mexico

The Point Lookout Formation, which is well exposed along the northwest margin of the San Juan basin in northwestern New Mexico, includes nearshore sediments deposited during a regression of the Late Cretaceous epicontinental sea in earliest Montanan time. The unit is composed of sandstone and siltstone with sand percentage increasing up-section. Principal outcrop lithofacies include a lower interbedded, highly bioturbated, very fine sandstone and shale that represents the transition from inner-shelf to shoreface environments. The middle part of the unit gradationally overlies the lowermost lithofacies and represents a complex depositional history in the nearshore zone. These progradational units are thickly bedded and coarsen upward. This simple sequence is interrupted by the occurrence of hummocky stratified storm deposits and by broad surfaces of nondepositional scouring in the lower shoreface. A medium-grained upward-fining sandstone lithofacies that caps the entire formation has an erosional base and large-scale lateral accretionary bedsets.

Measured sections from the outcrop of the Point Lookout closely correspond with electric-log patterns from subsurface data east of the outcrop belt. The mapped distribution of SP-pattern facies (representing sandstone textural characteristics) depicts the primary depositional elements of the progradations. Correlation of genetically related sand packages permits the evaluation of changing sedimentation patterns through time. Seven regressive events (time-stratigraphic units) are recognized based on subsurface identification of the transgressive boundaries that rise stratigraphically away from the basin and obliquely traverse lithofacies boundaries. Each unit is composed of three depositional phases (progradation, transgression, and aggradation) that occur in regular succession.

Discrete distributary and interdistributary areas were maintained in the initial depositional phases throughout the history of the Point Lookout. In the broad areas between depositional axes the shoreline prograded by the seaward accretion of beach ridges until sediment sources became insufficient to maintain the shoreface advance. Transgressive reworking of the seaward part of the unit followed and dominated the arrangement of net-sandstone thicks by redistributing the sands into a strike-alignment. Each time-stratigraphic sedimentary unit is therefore the product of a progradational-transgressive depositional couplet. Whereas periodic transgressions were mainly erosive, they did cause the formation of coalesced shallow-shelf bars analogous to estuarine-shoal retreat massifs found on the modern continental margin of the Mid-Atlantic Bight.

During periods of shoreline stability following transgression a