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Fox Hills Sandstone, Rock Springs Uplift, Wyoming: Shoreline-Tidal River Sandstone Model for Upper Cretaceous

The Upper Cretaceous Fox Hills Sandstone exposed in outcrop on the east flank of the Rock Springs uplift is a regressive sequence of sandstone and siltstone which was deposited along barrier island coastlines in littoral, shallow-neritic, and tidal-river environments. The littoral and shallow-neritic sandstones are very fine- to fine-grained, and form coarsening upward sequences which are heavily burrowed by deposit-feeding organisms in the lower part and contain walled burrows of suspension-feeding organisms (principally *Ophiomorpha*) in the upper part.

The littoral and shallow-neritic sandstones are commonly overlain by fine- to medium-grained, channel sandstones interpreted to have been deposited in tidal-river environments. These sandstones exhibit a characteristic vertical sequence of stratification and sedimentary structures. The channel base is defined by a sharp scour surface at which there is a marked grain-size increase from that of the underlying sandstone. Lag deposits of oyster shells, wood imprints, and clay clasts are present above this surface. Individual sandstone units become finer upward and are commonly trough cross-stratified in the middle and lower parts and subparallel bedded in the upper part. The trace fossil *Ophiomorpha* is abundant, and a root zone is present at most places in the upper 1–3 ft. The tidal river sandstones intertongue in a seaward direction with finer grained, littoral and shallow-neritic sandstones. In a landward direction they pass into lagoonal, marsh, and swamp deposits.

The origin of the widespread tidal-river sandstones is interpreted to be associated with the migration of tidal river and estuary channels on the landward and lateral sides of seaward prograding barrier islands.

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Contemporaneous Dolomitization of Middle Pleistocene Reefs by Meteoric Water, North Jamaica

Middle Pleistocene reefs of northern Jamaica, and elsewhere in the Caribbean, are distinctly different from the late Pleistocene 120,000 year-old "Sangamon" reefs. They are more extensively developed, better lithified, and commonly dolomitized.

In Jamaica, the contact between the two units, the "Sangamon" Falmouth Formation and the middle Pleistocene "Yarmouth"(?) Hope Gate Formation, is erosional. This contact demonstrates that the diagenesis and dolomitization of the Hope Gate took place before Falmouth deposition. The Hope Gate dolomite replaces micrite and fills pores created by the dissolution of aragonite, demonstrating the near contemporaneity of aragonite solution and dolomite precipitation. The dolomites have low Sr (220 ppm) and Na (350 ppm) contents, precluding their precipitation from marine fluids.

Dolomitization took place as meteoric waters first infiltered the seaward growing, submarine-cemented reefs. The composition of the fluid from which the dolomite precipitated was controlled by the composition of the influxing meteoric water, but more significantly by the composition of the primary reef carbonate. Continued meteoric flushing, after the available Mg was consumed by dolomitization, resulted in low Na, low Sr, and C^{12}- and O^{16}-enriched calcites.

The vadose textures superimposed on the intense phreatic-meteoric diagenesis consists only of insignificant amounts of speleothems, despite more than 300,000 years of subareal exposure.

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Petroleum Generation in Gulf Coast Tertiary Sediments

Organic detritus deposited in sediments is composed principally of carbon, hydrogen, oxygen, and nitrogen. At the time of deposition, only small amounts of hydrocarbons are present. However, this organic matter has the potential to generate hydrocarbons in quantities that depend largely on its hydrogen content.

Studies show that organic matter disseminated in sediments, when heated, undergoes carbonization by mechanisms very similar to the thermochemical processes responsible for coalification. Carbonization is a thermal process marked by the generation of volatiles relatively rich in oxygen and hydrogen and by the formation of a kerogen residue increasingly enriched in carbon. The most significant oxygen-rich volatile is carbon dioxide and the most significant hydrogen-rich volatiles are hydrocarbons. By measuring changes in the elemental composition of the organic matter as a function of depth, the principal volatile products of the carbonization reactions can be determined. Data from the Gulf Coast Tertiary indicate carbon dioxide is the *principal volatile product of early carbonization and* that hydrocarbons are not significant products until the later stages. The amounts of hydrocarbons generated during carbonization are vast compared with amounts from any other naturally occurring source or process.

The data indicate that the rate of carbonization or, more specifically, hydrocarbon generation is a chemical process that follows the general rules of chemical kinetics. That is, as sediment age decreases, the temperature required to reach the level of carbonization associated with hydrocarbon generation increases. For example, significant hydrocarbon generation occurs in the Oligocene at a log temperature of 175°F and above; in lower Miocene at log temperature 186°F; and in upper Miocene at log temperature 205°F. Appreciably higher temperatures are required for significant hydrocarbon generation in post-Miocene sediment.

It is suggested that kerogen with relatively low hydrogen levels (similar to levels found in coals) would generate gas rather than oil. Thus, the relatively low hydrogen level in organic matter from the rocks discussed suggests that the sections penetrated would be better sources for gas than oil.

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Comparison of Types of Imagery for Photogeomorphic Studies

This discussion is limited strictly to photogeomorphic, not bedrock mapping, applications of airborne imagery. Two factors control the value of a particular image in a particular study—scale and type of imagery.

Small scale imagery, less than 1:40,000, is particularly useful in broad, regional studies of structural trends, regional drainage pattern analysis, and lineament mapping. The larger scale imagery is more useful in fracture trace studies, local drainage pattern and single channel feature studies, and local tonal anomaly studies. Large-scale imagery may, of course, be compiled into a mosaic.

A wide variety of image types are available today. The most commonly available are black and white photography with many possible filter combinations, black and white infrared photography, color and color infrared (false color) photography, and thermal infrared and radar imagery. These images have a large range in cost and applicability. As a tool of the photogeomorphologist, color aerial photography appears to be the most generally useful for a basic study. Black and white, and black and white infrared, photography are the least expensive and quite useful. The other types of imagery have special, and sometimes very useful, applications.

Of value in some cases is sequential imagery showing, for example, variations of vegetation throughout the year. Such time-dependent changes in terrestrial features may have significance in photogeomorphic exploration.

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RESPONSE OF STREAMS TO STRUCTURAL UPLIFT

Drainage anomalies over structural uplifts in regions of low relief (less than about 150 ft local relief) and unconsolidated rocks are of 2 types—drainage pattern *anomalies and single-channel anomalies*. Field studies and model investigations have revealed certain basic stream responses to local uplift. In areas of generally uniform regional slope, local reversals or marked divergences of drainage pattern from the regional slope are structurally significant. Radial drainage patterns (full 360° radial patterns) are always anomalous. Concentric drainage is due to the exposure of beds of different resistance and may, or may not, be present. If the unconsolidated material is uniform or very poorly bedded, the local shifting or deflection of drainage is significant, but in well-bedded rocks it may be merely homoclinal shifting downdip. Marked local, opposed drainage deflections are apparently due to almost continuous uplift favoring continuous lateral shifting rather than accelerated incision.

In unconsolidated rocks, the most important single-channel response to slight structural uplift is the local channel width-depth ratio. Changes in this ratio may be seen on aerial photographs. Such changes, however, may also be due to changes in lithology or in tributary streams. Decreases in gradient (such as upstream from a structure) result in increased channel width-depth ratio and increases in gradient decrease width-depth ratio. Meander compression or local changes in sinuosity may be due to structure or lithologic difference. Color aerial photography may aid in distinguishing structural and lithologic causes of single-channel features.

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SOUTHERN LABRADOR SEA—KEY TO MESOZOIC AND EARLY TERTIARY EVOLUTION OF NORTH ATLANTIC

Geophysical studies made in the southern Labrador Sea and related to the drilling of deep holes there, have given evidence of the change from a two-plate to a three-plate spreading geometry in the evolution of the North Atlantic and Labrador Sea. The change is dated at about 60–65 m.y. ago and can be recognized by the magnetic anomaly pattern and the basement topography.

By use of magnetic anomalies and fracture zones, the stages in the evolution of the North Atlantic can be described as follows.

1. 180 m.y. African plate started to separate from North American plate accompanied by shearing between Africa and Europe.
2. Between 180 m.y. and 80 m.y. Separation of European and North American plates along Greenland-Spain fracture zone gave rise to primitive Iceland basin and Rockall trough and separated Spain from the Grand Banks. Orphan Knoll, Porcupine Bank, Flemish Cap, and Galicia Bank were detached and displaced.
3. 150 m.y. to 80 m.y. Spain rotated counterclockwise about rotation pole in Paris to open Bay of Biscay.
4. 80 m.y. to 60 m.y. Spreading occurred between North American plate and plate comprising Greenland, Rockall plateau, and northwest Europe, to create Labrador Sea and North Atlantic.
5. 60 m.y. Rockall plateau separated from Greenland along new spreading axis on east side of primitive Iceland basin. Triple junction developed, and spreading axes and fracture zones shifted to accommodate new geometry.
6. 60 m.y. to 47 m.y. Simultaneous opening of Labrador Sea, Reykjanes Ridge, and North Atlantic.
7. 47 m.y. Greenland virtually stopped moving relative to North America, and Labrador Sea growth finished.
8. 47 m.y. to present. Reykjanes Ridge and North Atlantic grew as European plate separated from North America–Greenland plate.

Paleogeographic reconstructions have been made and their validity tested against the data obtained from drill sites on Leg 12 of the Deep Sea Drilling Project.

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TERTIARY LIMESTONE DIKES, OAMARU, NEW ZEALAND

Indurated calcarenite and calcilutite dikes cut vertically through lower Oligocene volcanic sediments in the Oamaru region, east coast, North Otago, South Island, New Zealand. Individual dikes extend more than 10 m vertically and can be followed for much greater distances along regular or irregular strike. Field relations and paleontologic data suggest the limestone dikes were filled from above; at least 2 younger Oligocene formations contributed debris. Most dikes comprise several sharply defined layers of differing texture, composition, or structure parallel with dike walls. Subhorizontal layering, with either grading or cross-stratification, is also present but less common. Most composite dikes are less than 10 cm thick, but they range up to 30 cm; many of the dikes pinch and swell along both strike and dip. Flow structures are well developed between 2 vertical layers exposed in strike section along one dike. Limestone filling the interstices of a pillow lava was apparently supplied through channels now preserved as dikes.

Some dike layers are well-sorted bioclastic sand, but most layers consist of calcareous mud, with varying