and calcification of dolomite and anhydrite or gypsum have occurred.

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PALEOECOLOGIC ASPECTS OF TRACE FOSSILS[1]

Many physical aspects of the depositional environment in which some rocks are formed may be reconstructed with the aid of trace fossils such as tracks, trails, borings, or other evidences of organism activity. Trace fossils are extremely abundant in sedimentary rocks of all ages, but commonly have not been used by geologists as an aid in paleoecologic interpretation. Water depth, salinity, current action, relative acidity, kinetic energy of the depositional environment, rate of sedimentation, and mode of life of the organisms may be deduced by using trace fossils as an interpretation tool.

Orientation of trace fossils in beds may indicate approximate directions of current action, whereas the type of trace preserved connotes the habitat preferred by the organism. Vagile, benthonic, filter-feeding organisms commonly build nearly vertical burrows; detritus-feeding organisms tend to burrow horizontally. Filter-feeders live in an environment where the current velocity is sufficient to winnow fine particles; detritus-feeders live where fine-grained sediments and finely divided organic matter slowly settle from the water. Delicate tracks and trails preserved in rocks are indicators of a calm environment and slow sedimentation rate, whereas tubes, burrows, and borings are built and preserved in current-activated waters.

In sedimentary rocks that are lacking skeletal or body fossils, trace fossils are valuable aids for use in reconstructing the physical history of the depositional environment.

[1] Publication authorized by the Director, U.S. Geol. Survey.

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UPPER DEVONIAN AND LOWER MISSISSIPPIAN SEDIMENTARY RECORD, WESTERN CANADA SHELF

Western Canadian Upper Devonian and Lower Mississippian shelf rocks, several thousand feet thick, are characterized by three sedimentary domains: a carbonate-evaporite area on the southeast (Saskatchewan), a central area dominated by carbonates (Alberta), and a terrigenous clastic and argillaceous carbonate area on the north (northeastern British Columbia). The carbonate-evaporite and carbonate domains include sabkha-type microdolomite-evaporite cycles, as well as barriers and blankets of skeletal and nonskeletal limestones. Although many of these rocks compare closely with sediments of certain Holocene carbonate settings, the makeup of these fossil sediments tends to be distinctive at various stratigraphic levels.

To illustrate: within the carbonate domain (Alberta), the Frasnian Stage contains wave-resistant organic reefs in which stromatoporoids and colonial corals are abundant. In contrast, reefs, stromatoporoids, and colonial corals are almost unknown in Fammenian strata, most of which form an extensive blanket of nonskeletal limestone with evaporites and redbeds on the east. A widespread black shale unit caps the Fammenian. Kinderhookian rocks are argillaceous carbonates in which echinoderm detritus increases upward. Although colonial corals reappear in the Kinderhookian, the Mississippian lacks organic reefs. The Osagian is distinguished by an explosive and geologically unique development of echinoderms—the main source of the enormous volumes of skeletal sands of this age which cover much of the area—and also contains well-developed cyclic lagoon-sabkha sediments.

Two dominant factors that influenced Late Devonian–Early Mississippian sedimentary patterns on this continuous shelf are oscillatory variations in water depth (probably tectonically controlled) and change in composition of the dominant fauna and flora from frame-builders to sediment-contributors.

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FORAMINIFERAL TEST AS AN ENVIRONMENTAL BUFFER

Despite many studies of foraminifers, very few suggestions have been made concerning the function of the test. If the adaptive significance of the test were known, this would provide a theoretical basis for understanding the ecological importance of test shape and construction.

Observation of the behavior of many shallow-water species in response to environmental changes indicates that the test may function as a chemical and physical buffer between the organism and the environment. Shallow-water foraminifers construct a test of much larger volume than needed merely to house the living protoplasm. Under conditions of stress, *Sorites, Planorbulina, Bolivina, Discorbis,* and miliolids occupy only the inner chambers of the test; the outer chambers may be filled with a less dense, highly vesiculate cytoplasm, or may be empty. If the individual chambers of the test are connected only through one or a few small openings, adverse osmotic effects produced by changes in salinity can affect the protoplasm only slowly. Complex tests may thus serve as a baffle to reduce the rate of chemical diffusion.

Some chambers are sites of concentration of symbiotic algae. In *Elphidium,* algal-filled chambers are in communication with each other, but the apertures of the final chamber are sealed. The foraminifer communicates with the outside only through the tortuous passageways of the canal system except during relatively brief intervals of chamber addition. The test functions as a protected greenhouse for the foraminifers' symbiotic algae.

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ENVIRONMENTAL INTERPRETATION OF UPPER PART OF MESAVERDE FORMATION, NORTHWESTERN COLORADO, FROM OUTCROP, CORE, AND SUBSURFACE STUDY

Various lines of evidence, such as the vertical succession of gross lithologic character, textures, and sedimentary structures, the fauna, and the geometry of rock stratigraphic units, indicate that the upper part of the Hayden Gulch outcrop section of the Mesaverde Formation in northwestern Colorado is a sequence of former barrier islands and lagoons intertonguing with overlying offbeach marine shale of the Lewis Formation. The collective criteria used to recognize the different depositional environments at the outcrops were readily apparent in a core taken along depositional strike from the outcrop section; the nearly perfect vertical sequence of lithology in a core compensates for the loss of lateral exposure in outcrop. Correlation of the outcrop section with electric logs permitted mapping of the distribution of the rock-stratigraphic units, and the resultant geometric interpretation precluded a delta interpretation for this particular stage of Mesaverde deposition in this area.

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Recognizing Estuarine and Tidal Creek Sandbars by Biogenic Sedimentary Structures

Estuarine and tidal creek sandbars bear many similarities to fluvial channel sandbars in their physical sedimentary structures, but are considerably different with respect to biogenic sedimentary structure. Consideration of these biogenic structures with current-produced physical sedimentary structures and with facies geometry produces unique, readily recognizable, paleoenvironmental indicators.

The abundant burrowing fauna collectively found in estuarine and tidal-creek bars represents species which are individually characteristic or very common in other intertidal environments, such as beach (burrowing shrimp, *Callianassa major*), tidal flat (burrowing shrimp, *Callianassa atlantica*, and polychaete worms *Onuphis* and *Diapatria*), marsh (fiddler crab, *Uca*), estuarine channels (burrowing shrimp, *Upogebia*), and sand flats (acorn worm, *Balanaglossis*). Other biogenic structures found in tidal creek bars include tracks, trails, and markings produced by more typical subtidal organisms such as the sand-collar snail, *Polinicies;* hermit crab, *Clibanarius;* blue crab, *Callinectus;* mantis shrimp, *Squilla;* and feeding depressions made by rays.

Two subenvironments are found on most of the tidal creek sandbars studied and each contains a characteristic suite of biogenic and physical sedimentary structures. The channel side of the bar consists predominantly of sand and preserves a record of megaripples and small current ripples. Associated with these structures are burrows of *Onuphis, Callianassa major, Callianassa atlantica,* and *Uca*. Energy is less and muddy sand accumulates on the side of the bar away from the channel current. Ripple laminae generally are not developed here and bioturbated sediments comprise the principal structures. A great density of burrows is found in this subenvironment, and *Upogebia, Diapatria*, and the razor clam, *Tagelus*, are typical burrowing forms.

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Geological Reservoir Analysis, Madison Formation, Elk Basin Field, Wyoming-Montana

The Elk Basin field is in the northeast end of the Big Horn basin, on the Wyoming-Montana state line. The structure is a NW-SE-trending asymmetrical anticline, approximately 8 mi long and 4 mi wide, with about 5,000 ft of structural closure. Oil production from the Madison Formation was discovered in 1946, and the Madison has supplied more than 75 MM bbl of oil within 5,100 productive acres from a closure of about 1,400 ft. A recent core study of the Madison reservoir shows that it can be divided into several separate, distinct, geologic and production units.

The Madison carbonate sequence has been altered greatly and distorted by groundwater erosion as a result of the formation of karst topography, by subsequent solution brecciation in Late Mississippian-Early Pennsylvanian time, and by selective remineralization in some areas of the field. The overall effects are the collapse of sections of the upper Madison—up to 300 ft thick—into brecciated rubble zones, thereby removing blocks from effective communication with each other. There are areas of remineralization which, because of redeposition of dissolved carbonates, silica and anhydrite into pore space and fractures by the downward percolating groundwater, have caused local, relatively tighter zones, forming, in effect, local stratigraphic traps. Zones of insoluble reside of clay and rock fragments form an effective barrier between the "A" and "B" producing zones, and account for the different reservoir characteristics of these zones.

An important effect of the groundwater action has been the removal of the more soluble limestone, leaving the less soluble dolomite and thereby forming the good secondary porosity found in the Elk basin Madison. The development of this secondary porosity can be correlated and subdivided into readily recognizable and distinct zones. This shows a certain degree of continuity, which is necessary in evolving an efficient drilling and flooding program. Electric-log and core evaluation of other Big Horn basin fields which penetrate the Madison indicate the existence of a situation similar to that in the Elk Basin reservoir, except that the Madison in other fields generally does not have such pronounced karst-solution development.

The above-mentioned variations can be unified into a practical working hypothesis for reservoir engineering analysis; the hypothesis so developed provides a useful three-dimensional reconstruction of the Elk basin Madison reservoir. Application of the hypothesis has led to a dramatic production response within the reservoir. The practical success of the hypothesis has important exploration implications; specifically, the exploration geologist must understand known producing reservoirs before effective exploration for new reservoirs can be carried out successfully.

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Variations in Late Pennsylvanian Molluscan Faunas

Certain nearshore facies of the upper half of the Pennsylvanian System in the Mid-Continent region are characterized by faunas which are dominantly molluscan. Although individual faunules are reasonably well known, few comparisons have been made between successive faunas. Five molluscan faunules ranging in age from Desmoinesian to Virgilian were examined on the specific and supra-specific levels. The abundance of individual species, genera, and families within each formation, variations in the abundances with time, and the phylogenetic changes aid in the interpretation of the paleoecologies of these unusual populations.

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Comparison of Recent and Ancient Coarse-Grained Point Bars[1]

Sequences of sedimentary structures in modern point-bar deposits of the Amite River in east Baton Rouge Parish, Louisiana, are analogous to features ob-

[1] Publication authorized by the Director, Bureau of Economic Geology, The Univ. of Texas at Austin.