thicken upward and basinward because terrigenous sediment supplied to the fluvial-deltaic system diminished.

The Sweetwater slope system, studied intensively by W. E. Galloway, is composed of numerous broad, coalescing to restricted wedges of mudstone and sandstone averaging 1,000 ft thick. Slope wedges are bounded by carbonate aprons and the wedges thin upward and basinward in response to decreasing terrigenous sediment supply. Sandstone distribution within slope wedges forms fan-shaped patterns that are elongate perpendicular to shelf edges. Principal slope units include shelf-margin, slope-trough, and distal-slope fan facies. Deposition was sporadic, probably by turbidity currents and associated traction carpets. The slope system was fed by major delta distributaries that prograded to the shelf edge, or by tidal or storm currents that transported sediment through local breaches in the bank system. Destructional processes such as slumping, sliding, and minor canyon development alternated with periods of active slope construction.

The eastern flank of the West Texas basin was, therefore, filled by simultaneous upbuilding (fluvial-deltaic and shelf-edge bank deposition) and outbuilding (slope deposition); some slope destructional activity followed episodes of outbuilding. Sites of deltaic and complementary slope deposition shifted widely in response to subtle variations in subsidence and normal avulsion of drainage systems. Fluvial, deltaic, and slope sandstones provide a variety of petroleum reservoirs and stratigraphic traps; early and late compactional and structural traps can be postulated from second-order compactional and structural mapping.

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Environmental Geology and Genetic Mapping

One of the most critical problems facing the world during the last decades of this century will be the effect of expanding population with its myriad needs for water, sanitation, recreation, and proper land use, coupled with complementary industrial expansion in developing magalopolis belts. A paradox exists between a concern about the ultimate supply of natural resources necessary to maintain the present western life style, and a growing concern about diminishing resources and the impact of accelerating exploitation on delicately balanced or endangered environments and ecosystems. Environmental management is the key to proper balance between exploitation and conservation.

Environmental geology is, above all else, the practical or functional application of the science to critical environmental problems; geologists have for years similarly applied the science to mineral exploration and investigations of earth history and processes. More and more traditionally trained geologists will begin filling an increasing number of positions involving environmental studies; these tasks will require the best in research and application that the science of geology has to offer.

A major geologic thrust is needed at this time to define and inventory natural environmental systems, their present status, and the impact of human modification. The principal geologic tool in the battle against pollution, diminishing resources, and indiscriminate land use will be properly conceived and innovative geologic maps. The United States is poorly covered by geologic maps of adequate scale and proper concept for solving impact problems. Maps should be composed principally of genetic units, even if they do not conform to traditional maps nor formally accepted nomenclature. For example, first-order environmental units may include substrate units or facies such as fluvial channel-fill sand or reef limestone; vegetational units such as salt marsh or grass-stabilized dunes; landforms such as tidal deltas or highly dissected badlands; process-defined units such as landslide areas or storm-washover channels; and man-made units. Maps of genetic units allow rapid derivation of special-use environmental maps for a broad spectrum of scientists and nonscientists. Delineation of genetic units allows three-dimensional extrapolation and interpolation of physical properties to predict the behavior of material under varied land use.

Results of environmental geologic investigations should be presented using innovative formats and techniques that encourage interdisciplinary communication, unite diverse specialists, and allow all experts to focus simultaneously on impact problems. Coupled with computer data storage, the environmental geologic map and derivative maps provide a current record of natural environments, processes and materials, as well as a permanent record of rates of erosion, deposition, and human modification and exploitation. Planners, economists, engineers, biologists, chemists, lawyers, legislative councils, and others can plot, plan, refer, and digest specific environmental data that are visually related to detailed inventory maps depicting the distribution and nature of fundamental natural systems.

Approximately 12 man-years of environmental geologic and derivative mapping and study in the 18,000-sq-mi Texas coastal zone by the Texas Bureau of Economic Geology have resulted in text and 64 full-color maps including Environmental Geology, Current Land Use, Physical Properties, Environments and Biologic Assemblages, Active Processes, Mineral and Energy Resources, Man-Made Features and Water Systems, Rainfall, Discharge and Surface Salinity, and Topography-Bathymetry. The "Environmental Geologic Atlas of the Texas Coastal Zone" provides a case history with which the philosophy, approaches, and results of an extensive environmental investigation can be evaluated.

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Original and Secondary Pores in Sedimentary Reservoir Rocks: Relation to $CaCO_3$ Cements

Retention of original pore space, development of secondary pores, and precipitation of $CaCO_3$ cement in pores of sedimentary reservoir rocks are the result of a delicate balance among organic processes, composition of water and migration of fluids, and the depositional and diagenetic history of calcium carbonate sediment particles and carbonate rocks.

In a high-energy marine environment, where waves and currents impinge on the sediment particles, original pore space may persist and thus may be available in subsurface reservoirs. However, in reefs, cements are precipitated early. Original pore space will be preserved only if hydrocarbons are introduced early, if shale seals off the reef from migrating fluids, or if the reef is invaded by meteoric waters undersaturated with respect to $CaCO_3$. Where reefs or ooid and skeletal accumulations are subject to leaching by meteoric water subaerially, in the subsurface, or on the sea bottom near leaks of meteoric water, leaching creates secondary (moldic) pore space while solutions are undersaturated with respect to $CaCO_3$. These new secondary pore spaces are added to the preserved original pores; they increase the total porosity. In corals leaching begins in sclerodermites. The newly created pores merge and form channels. In such leached corals porosity values may exceed the porosity values found in corals of unleached modern reefs. Hence conditions for developing maximum pore space include exposure of reefs or high-energy carbonate sands to meteoric waters. However, once meteoric waters become saturated with respect to calcite, calcite cement is precipitated in the pores. This cement progressively eliminates primary and secondary pores.

Under both surface and subsurface conditions, sulfate-reducing bacteria use sulfate from seawater, or from meteoric or formation waters as an oxidant for that part of organic matter which they oxidize for energy production. Calcite as a cement is formed when CO_2 produced in the bacterial oxidation of organic matter combines with calcium. CaS, an intermediate product in sulfate reduction, hydrolizes, because it is not stable in aqueous solution, and in this reaction the pH rises. At high values of pH not only does calcite cement tend to be precipitated, but also quartz particles tend to be peripherally corroded and ultimately replaced. Such cementation and replacement of quartz by calcite have been observed in subaerially exposed sandstones <10,000 years old, in subsurface reservoir rocks, and in modern beachrocks. Other bacteria form CO_2 from methane, such as that found in lagoonal sediments or tidal marshes, and this CO_2 can trigger precipitation of carbonate cement in sediments lying on the sea floor or occurring in the subsurface.

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PRACTICAL CLASSIFICATION OF REEFS AND BANKS, BIOHERMS, AND BIOSTROMES

Reefs and banks form stratigraphic traps which account for more than 40 percent of the total petroleum production of the world. Yet there is much confusion concerning the classification and terminology of these skeletal deposits. Following Lowenstam and Nelson *et al.*, I apply the terms "reef" and "bank" to denote the origin of the structures, whereas I use the terms "bioherm" and "biostrome" to designate the shape of the structures and their relations with the associated layered facies.

A reef is a structure built by the *in-situ* growth of organisms which have the ecologic potential to act as frame-builders. It is a wave-resistant, prominent structure on the sea floor and will, therefore, influence and modify the sedimentation in its vicinity.

A bank, however, is made up of organisms which did not have the ability to act as frame-builders. Banks may be formed in place or by mechanical accumulation following transport of the skeletal remains. Banks are also wave-resistant. They may or may not be prominent structures on the sea floor. Correspondingly, they may or may not influence the sedimentation in their surroundings.

According to the mode of their formation, banks may be further subdivided into mechanical aggregational banks and biogenic banks. The biogenic banks result from (a) biogenic baffling of sediment; (b) biogenic sediment binding; (c) biogenic accretions of cementing organisms; and (d) local gregarious growth of organisms which did not cement themselves to one another or to the substratum.

Thus, reefs and banks represent distinctly different biogenic structures. A reef is a structure in which the *in-situ* growth of organisms is more important than sediment trapping and binding. In banks the sediment-baffling and binding functions of the organisms are the predominant source of sediment accumulation. In a reef, the organic productivity of the frame-building organisms is by itself sufficient to elevate the structure above the surrounding sea floor. Frame-builders in general are organisms which cement themselves to the substratum and form a rigid reef mass.

According to their shape and geologic settings, biogenic buildups may be subdivided into bioherms and biostromes.

A bioherm is a massive, mound-shaped structure which is in discordant relationship to the surrounding layered facies of different lithology. A biostrome is coarsely layered and grades concordantly into the associated layered sediments.

According to the foregoing definitions, a reef represents a bioherm in shape and geologic setting. A bank, however, may appear in the form of a bioherm or a biostrome. Mechanically accumulated banks and biogenic banks resulting from the sediment-baffling activity of organisms usually are found in the form of bioherms. Banks resulting from biogenic binding of sediment may represent bioherms or biostromes. Local gregarious growth of organisms usually leads to accumulations of biostrome type.

Examples of various types of recent and ancient reefs and banks emphasize the fact that structures which superficially appear to be similar may be quite different in their genetic and environmental interpretation.

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BASEMENT TECTONICS AND FOLD PATTERNS—KINEMATIC-MODEL APPROACH

In the study of fold patterns in relation to basement tectonics, the experimental-model approach followed by Mead, Cloos, and others has been elaborated in the development of relevant kinematic models. These models are displayed in motion and have the advantage of arbitrary mechanical reversibility, as well as the capability of showing the effects of deformational influences in both the "before" and "after" stages.

In the application of model results to field examples, the influence of transcurrent basement shearing is invoked to explain the development of extensively repetitive folding over large areas of layered rocks. Thus, pervasive shearing, rather than the application of external lateral stress at a distant point, produced the widely distributed deformation. In this context the kinematic models demonstrate "skin tectonics" and "wrinkle folds."

Various effects in fold patterns can be explained in terms of the varying ratio of horizontal to vertical movement in the shear systems. If the resistance of flexible layers to ductile compression is considered, it may be demonstrated that dilatational areas tend to develop at points of maximum flexure, particularly at crests and troughs of folds. Gravitational stress then augments crestal dilatations and depletes or prevents corresponding dilatations in troughs.

If differential movements occur unevenly within a wide zone of shearing, the effect will be *relative* reversals of movement (or of shear sense) that would not necessarily involve any *actual* reversals in the direction of material movement relative to geographic coordinates. This circumstance would be analogous to the manner in which a body may undergo both positive and negative accelerations while maintaining positive velocity.

The effect of relative reversals of movement is equivalent to that of oscillatory shearing, for which the terms "forward" cycle and "reverse" cycle may be used to describe the *relative* differential movements. A succession of oscillations results in the superimposition of two approximately orthogonal deformation ellipsoids. The ellipsoid generated by the forward cycle maintains a degree of unrecovered strain on which the cross-deformation ellipsoid of the reverse cycle is then superimposed. This process is advanced as an explanation of cross-fold phenomena in which dilatational maxima are located at the tops of domes which mark the intersection of structural cross-trends, or which are aligned *en échelon* along one particular trend. Where layers are steeply dipping as in an isoclinal sequence, the cross-deformation effect is expressed in the form of steeply plunging buckles and "drag folds" with intervening tensional ruptures.

Block tectonics may be simulated by introducing discontinuities of shape and viscosity into kinematic models. In this way, oscillatory shearing may be seen to generate "intracratonic mobile belts" in which successive shear cycles produce repeated increments of unrecovered strain which are compounded within the belt. This compounding gives the effect of a deformation that is disproportionately large for the evident amount of net movement between blocks.

The worldwide prevalence of conjugate systems of crossing shear zones or cross-dislocations that lie in the quadrantal northeasterly and northwesterly directions is seen as a result of accelerations and decelerations in the rotational movement of the earth. The effects may be simulated in the appropriate kinematic model.

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GEOLOGY OF WESTERN CANADIAN CONTINENTAL SHELF

This paper deals primarily with the stratigraphy of the Tertiary sediments in the Tofino and Queen Charlotte basins of Canada's Pacific shelf. Information is included from Mesozoic and Tertiary outcrops along the shoreline margins of the ba-