rowing invertebrates, trilobites, nautiloids, pelmatozoans, brachiopods, gastropods, rostroconchs, and archaeoscyphiid sponges.

Thrombolite mounds are circular in plan, up to 2 m in diameter and thickness, with an estimated depositional relief of 0.3 m at most. Individual mounds commonly coalesced form circular and linear patch reefs, or banks with grooved margins. Large archaeoscyphiid sponges and *Pulchrilamina* (encrusting sponge?) contribute in a minor way to the framework in scattered horizons. Rare small mounds are composed of an intergrowth of thrombolites and *Lichenaria* corals.

Large thrombolite *Lichenaria-Renalcis* reef complexes, up to 12 m thick, with an estimated depositional relief of up to 1.5 m, occur in the lower part of the St. George. One particularly well developed complex is composed of vertically superimposed reef stages composed of *Lichenaria,* thrombolites, and the "calcareous alga" *Renalcis.* The framework is surprisingly complex, with abundant cavities and a demonstrably uneven growth surface. Cavity walls are commonly coated by algalaminites and internal sediments are burrowed. Some cavities are sediment conduits. *Renalcis* occurs as free-standing heads of varying shapes, as encrusting walls on small thrombolite mounds, and as manes in cavities under corals.

These bioherms span a critical time gap in the development of reefs, the transition period from algal-dominated bioherms of the Precambrian and Cambrian to the metazoan-dominated bioherms of the Middle Ordovician and remaining Phanerozoic.

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Early Guadalupian (Permian) Bank Margin Erosion Surfaces, Guadalupe Mountains, Texas

Two basin-sloping erosion surfaces occur in the early Guadalupian carbonate rocks on the western Guadalupe Mountains escarpment. Their longitudinal profile resembles a slump scar. Each truncates (with 20 to 40° dips) 70 to 100 m of flat-lying bank-top strata, and then flattens basinward. The younger surface, previously unreported and virtually inaccessible because of sheer cliffs, sharply truncates about 70 m of upper Grayburg shelf strata at its headwall. It flattens basinward and appears to more gradually truncate the uppermost part of the Getaway (also Grayburg) bank. Initiation of the characteristic high-angle foreslope deposits of the Goat Seep and Capitan "reef" began at this 70-m-high headwall. Early Goat Seep foresets, contrasting with later Goat Seep and Capitan, have little rock equivalent in a gentler-dipping toe-of-slope section. The older erosion surface is the regional unconformity at the base of the Brushy Canyon Sandstone. At its headwall (the Brushy Canyon pinch-out) about 100 m of Cutoff and Victorio Peak Formations are truncated abruptly.

The two Guadalupian erosion surfaces somewhat resemble the closely associated late Leonardian basin-sloping (5 to 10°) surface that truncated 200+ m of Victorio Peak bank in pre-Cutoff time. We believe all formed in a submarine environment. Conceivably they are "half-channels" with their south or southwestern side eroded or kilometers away. We believe they were formed by shelfward retreat of the depositional bank margin. The erosion agent and mechanism are enigmatic. We believe the Victorio Peak and probably the Grayburg were rock when eroded, but we are uncertain regarding pre-erosion lithification of the Cutoff Formation.

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Hydrocarbon-Trapping Structures in Southern Canadian Rockies Segment of Cordilleran Foreland Thrust Belt

The hydrocarbon reservoirs consist of upper Paleozoic platformal carbonate rocks in northeasterly verging, imbricate, listric thrust-fault wedges, and in related flexural-slip folds. They formed in Maestrichtian to early Paleogene time, after these rocks had been buried under more than 5 km of Late Jurassic to Paleogene molasse. Both the generation and entrapment of the hydrocarbons result from subduction of the floor of the Cordilleran miogeocline.

Palinspastic reconstructions of the foreland thrust and foldbelt, based on balanced structure sections that take into consideration the deep crustal structure as outlined by seismic refraction, magnetic, gravity, and geomagnetic depth sounding data, show that: (1) there has been about 200 km of net horizontal convergence between the Mesozoic magmatic arc of the eastern Cordillera and the autochthonous cover on the North American craton; (2) the convergence is expressed at a shallow level, in the eastern, more external zone, by horizontal compression and vertical thickening within supracrustal rocks that overlie an unbroken basement of cratonic continental crust; but at deeper levels, in the western, more internal zone, it involved the subduction of the former basement of the miogeocline; (3) the Cordillean miogeocline is a northeasterly tapering wedge of craton-derived sedimentary rocks that accumulated outboard from the edge of the continental craton, on oceanic or tectonically attenuated continental crust; (4) the foreland thrust and foldbelt is a shallow subduction complex that was tectonically prograded northeastward as the miogeoclinal, platformal, and exogeoclinal supracrustal rocks were scraped off the underriding slab and accreted to the overriding slab; (5) subsidence in the migrating foredeep was due to flexure of the lithosphere under the weight of the encroaching subduction complex, and of the molasse itself.

The first of two main pulses of subduction occurred outboard from the craton, during Late Jurassic and Early Cretaceous time. It involved outward verging thrusting and folding on either side of the uplifted core of the miogeocline, and it produced a thick wedge of molasse that covered the western craton. The hydrocarbon reservoirs formed during the second pulse, in Late Cretaceous and early Paleogene time, as the cratonic cover rocks were deformed and accreted to the growing subduction complex, while the continental craton moved under the detached miogeocline.

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Petroleum Exploration and Wrenching Model, Michigan Basin

The writer has previously proposed a wrenching model for the Michigan basin based on the close relation of lineaments gleaned from Landsat imagery to the geometry of shear faults and related shear folds anticipated in such a model.

Recent studies by colleagues have been focused on old linear oil producing structures where (1) the density of wells permits structure maps drawn on a small contour interval, and (2) sufficient well samples allow the construction of dolomite-limestone ratio maps. Geometry of dolomite distribution patterns in Middle Devonian carbonate rocks shows close comparisons to pay zone distribution coincident with shear faults and related shear folds, cross faults, and cross folds—all related to the wrenching model. Producing well patterns follow dolomite distribution patterns. Lateral displacement can often be detected along shear faults on structure maps. Some faults not detectable on the structure map are shown on the dolomite-limestone ratio map. The application of the wrenching model to future exploration for linear producing fields in the basin appears self evident; strike-slip faults in nearly horizontal rocks are elusive seismic targets. The shear faults generally show little vertical movement. Not all shear faults developed shear folds, as in the giant Albion-Scipio field (Ordovician).

Evidence suggests that movement along shear faults was episodic, with the axes of related shear folds showing some migration downward. Further testing of the shearing mechanics in this regard may assist in exploration for deeper targets.

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Shale—an Overview

Shale and mud form at least 60% of the world's sediments, have been deposited throughout geologic history, and occur in every major depositional basin. They are major source beds for hydrocarbons, hosts for metallic minerals, sources of ceramic materials, cause of unstable foundation conditions, and precursors of soils that produce our food. Yet the study of shales has lagged far behind that of other sedimentary rocks. Factors that have retarded the study of shales are: (1) we are presently unable to isolate, study, and deduce the histories of the single particles that form shales. Consequently we have had to rely on bulk properties which are based on the average of many particles of diverse origin; these combine the effects of source area, depositional environment, and post-depositional change; (2) we fail to recognize and interpret in shale the equivalents of the "vertical profiles" that have been so successful in the study of sandstones and carbonate rocks. Such sequences for shales should be based on the vertical variation of bedding, on bioturbation and fossils, and on the amount and type of organic matter. These properties most closely reflect primary depositional processes; (3) we rarely have an idea of the paleocurrent or paleocirculation system of most shaly basins; (4) finally, we have not integrated our present knowledge of shales with the geometry of shale bodies nor has it been common to study the associated lithologies, bounding contacts, and positions of shale bodies within basins.

These factors, and others that will emerge, appear to be the directions in the future sedimentologic studies and interpretations of shaly basins.

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Drilling in San Andreas Fault

Research on earthquake prediction prior to 1978 depended largely on the gathering of geophysical observations prior to earthquakes. These include measurements of changes in seismicity, strain, magnetic field etc. Recently, however, in an attempt to relate these observations to a physical model of the pre-earthquake failure process, the U.S. Geological Survey has begun a program of direct measurement of the properties of faults through drilling holes in and near the active fault trace.

Laboratory data on failure of rocks show that nonlinear strains develop just prior to rupture, but the character of the failure process is strongly dependent on material properties, pore-fluid pressure, and applied stresses. These parameters are virtually unknown in faults at depths where earthquakes occur. The drilling and insitu measurements program was designed to determine these quantities and provide samples of the actual fault-zone materials.

Preliminary results from holes near the San Andreas fault can be tentatively interpreted to show that the level of shear stress on the fault is surprisingly low, about 100 bars. The fault-zone rocks at a depth of 600 m are a low-permeability clay-rich gouge in the first hole drilled along the creeping part of the fault. The hole is presently being deepened to allow measurements of stress and pore pressure at depths of 1 km.

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Paleogeography of Northern Arizona During Deposition of Permian Toroweap Formation

Stratigraphic and facies analyses of the Toroweap Formation have yielded reliable indicators of the paleogeographic conditions that existed in northern Arizona during the Permian. Four depositional environments have been recognized that are based on definitive facies. The four environments and their respective facies laterally from west to east are: (I) open marine; skeletal packstone and wackestone, pelletal wackestone; (II) restricted marine; aphanitic lime mudstone, dolomite mudstone, sandy dolomite; (III) sabkha; gypsum, horizontal and gnarly bedded sandstone; and (IV) eolian dune; cross-bedded sandstone.

A marine transgression encroached upon coastal and continental sabkhas eventually drowning a large eolian dune field in its eastward advance across northern Arizona depositing the Toroweap Formation. Eventually the sea slowly withdrew westward and thick prograding