controlled in part by underlying, commonly inconspicuous, erosional surfaces. Reconstruction of the paleotopography of the unconformity thus may commonly delineate prospective trends. The distribution of trap barriers may be controlled by environment. For example, discrete shoreline sandstone bodies replaced updip by lagoonal shales are better prospects than those replaced updip by sandy ("leaky") deltaic deposits. Such sandstones are more likely to be related to interdeltaic rather than deltaic areas.

Most progress will come from further development and refinement of depositional models. A greater understanding of shallow-marine sandstone bodies is especially needed. Moreover, as exploration emphasis shifts offshore, there will be a growing premium on one's ability to recognize depositional models in the absence of cores and outcrops.

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CHEMICAL HISTORY OF OCEANS

The reaction "igneous rocks plus acid volatiles to give sedimentary rocks plus seawater" has long been the basis for geochemical balance calculations, and also the basis for chemical arguments for the constancy of seawater composition. In most balance calculations based on continental igneous rocks as the sediment source, there is an unaccounted excess of iron and calcium in the sediments. This excess may well have come from submarine alteration of mafic volcanic rocks, a process shown to be important today by recent dredging and coring, and probably of greater relative importance in early earth history. Both subaerial and submarine weathering contribute to the mass of cycling sedimentary rocks and hence to oceanic composition.

The submarine alteration branch of the sedimentary geochemical balance may be written: mafic volcanics + volatiles = greenstones + cherty iron formations + carbonate rocks. No major differences in oceanic composition have been deduced as stemming from early greater relative submarine alteration, but the sedimentary mass is predicted to have been richer than now in carbonate rocks, chert, and iron minerals. Most of the early carbonate rocks, because of selective cycling, now exist as Phanerozoic deposits.

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DEPOSITIONAL ENVIRONMENT OF MISSION CANYON (MISSISSIPPIAN) OIL FIELDS IN NORTH-CENTRAL NORTH DAKOTA

Three fourths of the oil fields in the Mission Canyon carbonates of north-central North Dakota are stratigraphic traps. The hydrocarbons in the Mission Canyon carbonates occur in 6 marker-defined beds, each representing a generally regressive off-lap carbonate cycle which is capped with the supratidal evaporite facies. Two types of depositional cycles are recognized: those formed when the shelf was stable and those which developed when the shelf was structurally deformed. The vertical patterns of the facies changes have been analyzed in the context of these 2 types.

The deepest part of the Williston basin during Mission Canyon deposition was in the northwestern corner of North Dakota. A broad open shelf extended eastward, where marine water circulation was sufficient to support bottom-dwelling and skeletal-producing organic communities. A trend of oolitic bars separated the open shelf from a restricted lagoon farther east. The lagoon was an area of nonskeletal carbonate sedimentation which changed facies eastward to tidal flats and supratidal "sabkhas" where evaporite deposition occurred.

The stratigraphic traps are related to the tidal flat facies. The reservoir rocks are covered by evaporites and are best developed where lobes of shelf carbonates extend eastward into the predominantly evaporite areas. Locally, traps also were formed within the structurally controlled mud islands. The preferential dolomitization of tidal-flat and mud-island facies resulted in good reservoirs.

Prolific growth of blue-green algae on the tidal flats probably provided the organic source material for petroleum within the stratigraphic traps.

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PETROGRAPHY OF COMPOSITE VERTICAL SECTION OF CINCINNATIAN SERIES LIMESTONES, SOUTHWESTERN OHIO AND ADJACENT AREAS

An offshore, shallow-water environment was in existence during the accumulation of the major part of the Cincinnatian Series, Eden to Saluda. The upper part of the section, Saluda and Whitewater, was formed under nearshore, subtidal, and lagoonal conditions.

The average limestone, Eden to Saluda, is a biocalcirudite, an autochthonous coquinoid rock. It is coarse-grained, poorly sorted and contains approximately 38% fossil allochems which were originally deposited with ooze. The carbonate mud of the limestones has been recrystallized almost completely and many fossil allochems have undergone recrystallization as well. Coarse pseudospar forming 40% of the rock is about equal in abundance to allochems with microspar (5–30 μ) forming the remaining 20%. Chemically precipitated sparry calcite is uncommon and apparently exists only in fossil cavities and under umbrellas.

Bryozoa are slightly more abundant than brachiopods through all of the units and each of these phyla exceeds echinoderms by 3 to 2 and trilobites by 3 to 1. Pelecypods, gastropods, and ostracods are minor constituents. The relative order of abundance of phyla holds through all of the formations.

Allochems average about 28% of the upper part of the series; microspar forms about 55% of the average rock and pseudospar forms about 15%. Micrite is minor but more abundant than in the lower, thicker part of the series. The major fossil phyla have the same relative order of abundance, but bryozoans exceed brachiopods by 10%. Ostracods, algal products, and coral become very conspicuous and are the only allochems in some beds. Dolomite is abundant in many beds of the upper Cincinnatian.

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"MUDDY" MISSISSIPPI

The application of geologic science to oil exploration requires achievement of sufficient understanding to make predictions. One of the most important predictions geologists are called upon to make is the distribution of rock stratigraphic units. Prediction may be enhanced by interpreting the vertical profile of associated environments within an overall framework of deposition.

The Muddy Formation (Lower Cretaceous) in northeastern Wyoming is a clastic unit approximately 150 ft thick composed of sandstone, siltstone, shale, and carbonaceous deposits. Detailed core studies and selected isopach maps suggest that the unit was deposited in a manner very similar to the modern Mississippi deltaic complex. Oil productive distributary channels, crevasse splays, and marginal barrier bars are recognized by the vertical distribution of sedimentary structures observed in cores and by comparing the distribution in space of the interpreted elements to a Mississippi model.

In considering the Mississippi model, one must realize that different processes are taking place side by side at different elevations relative to sea level, hence the unidirectional current-flow processes of a distributary may occur 100 ft or more below sea level at the same time that the wave processes of a beach occur at and near sea level. The Muddy Formation must be understood as a total depositional system; detailed vertical subdivision will only obscure genetic relations.

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UTILIZATION OF WELL LOGS IN EXPLORING FOR STRATIGRAPHIC TRAPS

Well logs are used qualitatively to make stratigraphic correlations and environmental interpretations. Formational fluid properties, porosity, and compositional attributes are computed quantitatively from many well logs for use in preparation of exploration maps. Dipmeter data are treated statistically and incorporated with other log data for use in making stratigraphic interpretations and predictions in the subsurface. Computers may be used effectively to process digitized well logs and associated data; plotters are used to display exploration maps automatically.

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DELTAIC ORIGIN OF DIFUNTA GROUP (LATE CRETACEOUS TO PALEOCENE), PARRAS BASIN, COAHUILA AND NUEVO LEÓN, MEXICO

The Difunta Group is predominantly gray calcareous mudstone, siltstone, and sandstone with 3 wedge-shaped redbed units. The redbeds provide a basis for subdividing the group into 7 formations with a composite thickness of 12,000 ft. Simple structure, continuous exposures, and lithologic variability provide an excellent opportunity for paleoenvironmental interpretations.

The Difunta Group is largely the product of deltaic sedimentation in the Parras basin, a shallow embayment off the ancestral Gulf of Mexico. Major delta progradation was from southwest to northeast as shown by facies changes, thickness trends, and paleocurrent data. The redbed units are interpreted as delta-plain deposits that accumulated as lake and bay muds and silts and fluvial and distributary-channel sands.

Redbeds are bounded by resistant gray blanket sandstones 20–60 ft thick that have sharp bases, scour-and-fill bedding, *Ophiomorpha,* and local mudstone, wood, and oyster clasts. These sandstones are interpreted as delta-front and delta-destructional deposits formed during progradation and retrogradation of the deltaic complex.

Prodelta facies are gray sequences of either (1) burrowed mudstone or muddy sandstone, many beds of which have ball-and-pillow structure and a sparse molluscan fauna, or (2) interbedded graded sandstone and burrowed mudstone. The graded sandstone beds of the later facies were deposited by turbidity currents that were generated at the delta front probably by hyperpycnal flow.

Patchlike carbonate banks up to 1,000 ft thick developed in the north during episodes of low terrigenous influx in this area. Bank deposits are chiefly micritic bioclastic rocks; boundstone is rare.

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RESERVOIR ANALYSIS, PENNSYLVANIAN TENSLEEP FORMATION, LITTLE BUFFALO BASIN, WYOMING

The Little Buffalo Basin field, in northwestern Wyoming on the southwest side of the Big Horn basin, is a north-south asymmetric anticline 3½ mi long, 1½ mi wide, with about 1,000 ft of structural closure. Oil was discovered in 1943 in the Pennsylvanian Tensleep. Cumulative production has been over 30 million bbl of oil from the 1,500 acres. Reservoir energy is from an active water drive from the north-northwest. A core study of the Tensleep revealed that extensive crossbedding, permeability variation, and fracture orientation influence oil recovery from this reservoir.

The Tensleep sandstone and dolomite gradationally overlie the Amsden Formation carbonates and shales, and average 275 ft in thickness. There is a general increase in average grain size of the Tensleep sandstone progressing upward in the section and also an increasing amount of crossbedding and poor sorting. Deposition occurred in relatively high-energy transporting currents in a shallow water, nearshore, and/or deltaic marine environment. Nonmarine channeling and sand-dunes also occur in the upper part of the section. Pore-filling cements of carbonate, silica, anhydrite, and clay particles are generally due to 2 factors: (1) primary deposition of carbonate and clay with dissolution of these and other minerals during fluvial channeling and erosion in Late Pennsylvanian-Early Permian, and (2) redeposition of these minerals in open pore spaces and fractures by downward-percolating groundwater.

As a direct result of this reservoir study, well spacing has been reduced from 40 to 20 acres by drilling 30 new wells in certain areas of the field that would not otherwise have been efficiently depleted. These additional wells have accelerated production from 3,000 b/d to a new peak rate of 9,400 b/d and have increased ultimate oil recovery.

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OIL OCCURRENCES RELATED TO BREAKUP OF GONDWANALAND

The fragmentation of the Gondwana supercontinent during the Mesozoic Era produced tectonic features and depositional environments favorable for the genesis and entrapment of petroleum. Large-scale rifting is directly responsible for the pericratonic basins which may occur as taphrogenes or sphenochasms depending on rift phase and geometry. Deltaic environments de-