ing and meet the crest and trough at sharp angles; stoss slopes are wholly erosional. At higher velocities, ripples become progressively lower and more rounded, and the resulting laminae are complex and sigmoidal; stoss-slope laminae become more common, resulting in temporary development of ripple-drift configurations, even in the absence of net bed aggradation. Low ripples are succeeded by a flat bed with relatively crude lamination and textural lineation parallel with flow.

At the lowest velocities capable of maintaining ripple migration, sediment is transported entirely as bed load. Suspended-sediment concentration is high at velocities near and above the transition from ripples to flat bed, but the sediment-water mix behaves as a turbulent fluid rather than as a slurry.

The 2 silts, derived from Illinois Pleistocene loess, have median diameters of 30 and 40 μ, are well sorted, and consist mainly of angular quartz chips. The flume used is a recirculating open channel 36 ft long and 3 ft wide.

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Sand Surface Textures: Exploration Applications

Interpreting depositional environments by scanning electron microscope analysis of sand surface textures is a useful new technique for petroleum exploration. The method enhances the geologic interpretation of well cuttings, and is particularly attractive where no other direct geologic information may be available.

Diagnostic surface textures appear on quartz sand grains from dune, high- and low-energy littoral, glacial, glaciofluvial, and diagenetic environments. With the scanning electron microscope, dune and littoral grain textures were observed on sand in cuttings from 4 offshore Gulf Coast wells. These primary depositional textures may be preserved to depths of 14,000 ft, and consistent preservation of depositional textures is common to 10,000 ft. Grains of Pleistocene and late Pliocene sediments commonly display primary depositional textures, fairly independently of depth. Diagenetic textures normally obliterate the primary depositional textures at depths below 10,000 ft and in sediments older than late Pliocene, but a few breaks in the general pattern of increasing diagenesis with depth allow reasonably accurate environmental interpretations of scattered deep sandstones. The depositional environments as determined from grain textures closely parallel the environmental interpretations derived from paleontologic and lithologic analyses.

The recognition of distinctive types of diagenetic surfaces holds additional promise for enhancing the geologic interpretation of well cuttings. Some diagenetic textures appear independent of one another in their occurrence and stratigraphic distribution, though the causes of these variations are not presently known. The relations of diagenetic sand surface textures to cementation, chemistry of formation waters, and fluid migration currently are being studied.

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Recognition and Delineation of Fluvial Sedimentary Bodies in Subsurface

A new method of recognition and delineation of ancient stream channels is based on the interpretation of subsurface sedimentary structures. A study of the Columbia Formation (Pleistocene) was conducted in a small area in northern Delaware. Forty holes were drilled through the formation and 486 samples were collected. In the absence of definite correlation between sedimentary units in various holes, and in the absence of any dependable horizon markers, the Columbia sediments have been thought of as divided into horizontal layers spaced 5 ft apart, and referred to their height above sea level.

Primary sedimentary structures (crossbedding in sands and gravels, horizontal bedding in coarse sands, and horizontal lamination in clayey silts) determined from the drilling samples were mapped for each layer separately. This mapping made possible the recognition and delineation of Pleistocene stream channels. The behavior of these ancient streams, interpreted from the maps, is suggestive of low, flat topography, easily eroded banks, shallow and wide channels, frequent change in water and sediment discharges, and flooding. All these are the characteristics of a braided stream system. In spite of frequent lateral shifts of stream courses, the channel bodies of the Columbia Formation are vertically continuous.

The method of subsurface investigation of fluvial sedimentary bodies described here could be applied to the exploration for oil and gas in areas where sufficient well control and sampling are available.

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Distribution of Forms of *Millepora* (Hydrozoa) on Recent Coral Reef, Barbados

The genus *Millepora* Linné 1758 is a common, although generally subordinate, component of Caribbean and western Atlantic hermatypic coral communities. It is one of the few extant heavily calcified hydrozoans and has been compared with the extinct stromatoporoids. It shows a wide range of morphologic forms which have been interpreted as either ecophenes or biospecies.

The distribution of morphologic variants of *Millepora* was studied on a fringing reef and submerged barrier reef off the western coast of Barbados, West Indies. At depths between 0 and 15 m 4 morphologic forms of *Millepora* can be distinguished: (1) encrusting (taking the form of the substrate), (2) boxwork (erect, short-curved coalescing plates with irregular nodose surfaces), (3) bladed (smooth discrete plates), (4) branching (erect, smooth, digitate, irregularly dendroid to fan shaped). These forms are moderately distinct. Some specimens are hard to categorize but they do not represent a continuum of variation. Forms 2, 3, and 4 appear to correspond with the species *M. squarrosa*, *M. complanata*, and *M. alcicornis*, respectively. At depths exceeding 10 m all the forms are present in the small area studied. With decreasing depth as the shore is approached the branching, bladed, boxwork, and encrusting forms disappear in that order.

This distribution appears to reflect the relative strengths of skeletons of the different forms: those which are more compact and stronger extend farther into shallow water. This suggests that local water turbulence is the main factor governing the distribution of forms. Distinct forms in the same environment support the view that major variation in the form of *Millepora* is controlled genetically rather than environmentally.

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Spanish Mediterranean Amposta Marino Oil Field

The Spanish Mediterranean new-field discovery

(Amposta Marino), found by a consortium led by Shell, is scheduled to produce 40,000 BOPD by October 1972. Oil reserves are estimated at ½ billion bbl. Oil is 19° API with 5% sulfur and a pour point of 75°F. The field appears commercial and will help to reduce Spain's daily import of 410,000 bbl. Amposta Marino produces from porous, fractured dolomites of late Mesozoic age (Neocomian-Aptian) which are capped by the probable source beds of Miocene clays. The Miocene itself tested subcommercial(?) gas from several shallow sandstones and 37° API oil and gas from a basal carbonate which becomes biogenic on the flanks of tilted fault blocks. The field is on a relatively stable marine platform (not in a delta model) which accumulated thick (10,000 ft) Mesozoic carbonates. The early Tertiary was a period of emergence during which the easternmost fault blocks were stripped down to the Paleozoic rocks. In Miocene time, the area sank and marine clays, as well as evaporites of the Mio-Pliocene, were deposited in a basin between the mainland and the Balearic Islands. As exploration continues, the Tertiary and not the Mesozoic is postulated to become the main target. A drifting away of the Balearic Islands from the Spanish mainland is proposed by some to accommodate the geologic history.

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Grand Canyon Bight—Significant Tectonic Feature of the Southwest

A bight, by definition, is a curve in a coastline, or a bend, angle, or corner in any configuration. This seems to be descriptive of the dominant tectonic feature of southwestern Utah, northwestern Arizona, and a small adjacent tract of Nevada. The Grand Canyon is the best-known local geographic feature of the region, hence the name Grand Canyon bight.

The Grand Canyon bight is the somewhat drawn out and distorted southwest corner of the Colorado Plateau; more importantly, it is a region of relatively simple structure between the converging Wasatch line on the north and the Central Arizona uplift (Mogollon rim?) on the south. These great structural trends approach each other but, due chiefly to the change of direction of the Wasatch line from southerly to westerly and the dying out of the Central Arizona uplift, they do not merge and there is a space of relatively simple structure between them.

The bounding tectonic features came into topographic prominence when the Mesocordilleran highland was elevated in Middle Triassic time. Subsequent sedimentary deposits, especially the marine and fluvial formations, are strongly influenced by the bight. Cretaceous shorelines and isopachs show this influence particularly well. The river system which deposited the Salt Wash Sandstone Member of the Morrison Formation entered the region of the Colorado Plateau through the Grand Canyon bight; the present Colorado River leaves the bight in a reverse direction. Other geologic references also are simplified by recognition of the Grand Canyon bight as a tectonic entity.

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Stratigraphy and Exploration of Lower Cretaceous Muddy Formation, Northern Powder River Basin, Wyoming and Montana

The Lower Cretaceous Muddy Formation in the northern Powder River basin of Wyoming and Montana was deposited during a marine transgression across a stream-dissected surface of the underlying Skull Creek Shale. The transgression occurred over most of the area, but was limited on the northeast by a prograding delta, which supplied most of the sand.

The Muddy Formation is divided into lower and upper units. The lower Muddy was restricted to a system of dendritic channels incised into the Skull Creek Shale during a period of emergence. The sands from the delta source were transported south by longshore currents. They were deposited principally in a transitional marine and estuarine environment, and are composed of fine-grained, moderately well-sorted, partially clay-filled quartzose grains.

By the time of deposition of the upper Muddy, the incised depressions in the Skull Creek topography had largely been filled. The upper Muddy sands were deposited in a complex marine shoreline environment, which resulted in offshore bars, barrier islands, beaches, and tidal deposits. Several shoreline trends are recognizable in the upper Muddy. They are progressively younger eastward and reflect the overall west to east transgression. These trends were controlled by the remnant Skull Creek topography and changing conditions of sediment supply.

Production from the Muddy Formation is principally from stratigraphic traps; however, structure has been important in localizing some of the oil and gas accumulations.

Lower Muddy pools are restricted to updip channel boundaries and are localized by structural noses and updip channel reentrants. Upper Muddy production is controlled chiefly by porosity development and lateral facies changes.

Exploration for Muddy sandstone reservoirs is aided by the use of an isopach map of the total Muddy Formation. This map shows the configuration of the Skull Creek channels and, therefore, the distribution of the lower Muddy sandstone. It also is helpful in predicting the orientation of the upper Muddy shoreline trends where they were related to remnant Skull Creek highs, and in showing an increased Muddy thickness due to sand buildups in nonchannel areas. Electric log maps, combined with zonal sandstone isopachs, provide a means of visualizing the rapid changes in sandstone geometry and also aid in the interpretation of depositional environments.

Exploration must be focused on the location of primary stratigraphic traps which have not been strongly altered by later structural movements. The widespread clay-filled porosity has resulted in large areas being nonproductive. It is believed that the clay fill is largely diagenetic and occurred subsequent to accumulation of primary oil. The lower percentage of clay fill in the oil-filled primary traps suggests that the presence of the oil inhibited clay diagenesis.

In the last 3 years, nearly 3,000 wells have been drilled in the study area in the search for Muddy oil. Every year new fields of significant size are discovered. Detailed stratigraphic work is called for as well as courage to use the drill as an exploration tool.

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Lithologic Associations and Sandstone Provinces

A limited number of clastic lithologic associations