different contractors searched so intensely for oil anywhere in southeast Asia. More miles of geophysical work have been done in the past 5 years than in all previous periods of Indonesian exploration. Even though oil drilling activity in Indonesia began in 1872, more widely scattered exploratory tests have been drilled in the current exploration cycle than during any comparable exploration period. The results have been variable. Although most exploration data remain confidential, it is known that some geologic interpretation and dogma have been disproved. Even though the majority of the exploratory ventures have resulted in economic failure, a measure of success has been recorded in 3 areas. The Ardjuna and Cinta fields are producing at the rate of 25,000 and 40,000 bbl/day of oil, respectively, and the Ardjuna complex is expected to reach 75,000 bbl/day of oil in late 1972. Also, the Attaka field was scheduled at 30,000 bbl/day of oil by October 1971 and to exceed 100,000 bbl/day of oil during 1973. These do not appear to be giant oil fields, but they are economic ventures. The Attaka field, containing an estimated 300 million bbl of recoverable oil, appears to be Indonesia's best offshore discovery to date.

Will another giant oil field like Minas be found? The applicable geologic criteria do not rule out the possibility, but the probability of several small giant fields being present appears better. The current search, with a fair measure of success, should discover them.

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### Near-Surface Coal Resources and Reserves of Western United States

Near-surface resources of coal and lignite in 11 of the 14 western states of the conterminous United States are estimated by the Bureau of Mines to be 48 billion tons; of this amount 26.7 billion tons could be economically recovered under present economic conditions by strip mining.

About 24.8 billion tons of this strippable reserve is low-sulfur coal (below 1% sulfur), 1.5 billion tons is medium-sulfur coal (1–2% sulfur), and 0.5 billion tons is high-sulfur coal (over 2% sulfur).

The Bureau has estimated the near-surface resources of coal and lignite in the United States to be 119 billion tons. About 45 billion tons of this resource is economically recoverable by strip mining. About 32 billion tons of this is low-sulfur coal, 4 billion tons is medium-sulfur coal, and 9 billion tons is high-sulfur coal.

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### Depositional Cycles of Lodgepole Formation (Mississippian) in Central Montana

Detailed stratigraphic and petrographic investigations of lower Madison Group outcrops reveal that the Lodgepole Formation is composed of 5 two-part depositional cycles. The stratigraphically lowest cycle includes the entire Paine Member; the remaining cycles comprise all but the lower part of the Woodhurst Member.

Each cycle is characterized by a fine-grained lower unit and a coarser upper unit. The lower unit is dominated by horizontally laminated carbonate mudstones, pellet carbonate grainstones, and finely crystalline dolomites. These lithologies are interpreted to be the deposits of calm, nonturbulent lithotopes. The upper unit of each cycle is characterized by cross-laminated, medium- to coarse-grained, bioclastic and oolitic carbonate grainstones, interpreted to have been deposited in shallow, turbulent environments. From the lithology, sedimentary structures, lateral petrographic and stratigraphic continuity, and modern analogues, these oolitic and bioclastic beds are interpreted to be generally synchronous within individual outcrop belts in central Montana. Regionally, however, cycle-capping intervals are probably diachronous stratigraphic units.

Facies interpretations of Lodgepole depositional cycles suggest that rocks of the fine-grained lower unit are deposits of deeper water transgressive phases of the Lodgepole sea; lithologies of the upper coarse-grained unit are accumulations of the shallower water regressive phases.

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### Reef Calcification

Of the life processes on a coral reef, calcification produces the most conspicuous end product—the reef framework and sediments. Most of the information relevant to coral-reef calcification comes from studies of the rates of $CaCO_3$ retention by the reef or studies of individual organism calcification rates. Neither of these types of studies really assesses the rate at which the reef community produces $CaCO_3$.

Alkalinity depletion as water flows across a reef, together with volume transport of that water, can be used to compute the rate of reef calcification. This procedure has been employed across a predominantly coral community and across a predominantly coralline algal community on windward inter-island reef flats of Eniwetok Atoll, Marshall Islands.

The mean alkalinity of water approaching the reef is about 2.30 meq/l, and the alkalinity as the water crosses the reef is typically depleted by less than 0.01 meq/l. The product of $\Delta$ alkalinity times volume transport, divided by the reef length, averages approximately 0.0025 (meq/sq m)/sec, with no significant difference in depletion rate between the 2 calcifying communities examined. This alkalinity depletion rate is equivalent to a $CaCO_3$ production rate of $4 \times 10^3$ (g $CaCO_3/m^2$)/year.

If the porosity of the sediment produced by calcification is 50%, then the $CaCO_3$ production rate is sufficient for an upward reef growth rate of about 3 mm/year. Because the present rate of eustatic sea level rise is considerably less than 3 mm/year, the reef is either catching up with sea level, or most of the $CaCO_3$ produced is being removed. Sediment accumulations downstream from actively calcifying reef areas favor the latter hypothesis.

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### Sequence of Bedform and Stratification in Silts, Based on Flume Experiments

Flume experiments with 2 silt sediments indicate development of a sequence of bed forms and stratification which is systematically related to flow intensity. At a fixed flow depth, each silt is transported as ripples over a wide range of mean velocities above the threshold for movement. With still higher velocities, ripples disappear abruptly and a flat-bed mode of transport occurs. Dunes are not present at velocities intermediate between rippled and flat beds, as they are for sand.

At lower velocities, ripples develop forms very similar to sand ripples: planar lee slopes accrete by slump-

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 $\mu$, 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