(3) braided interlobe deposits which are nearly mud-free, thick sand sequences made up almost exclusively of small trough crossbeds.

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SANDSTONE AND CHERT COLUMNS IN PERMIAN ROCKS OF SOUTHWEST MONTANA: BIOGENIC OR INORGANIC?

Enigmatic columnar structures of sandstone, cherty sandstone, and chert in the Phosphoria Formation were studied at 18 localities in southwest Montana. The structures have circular to elliptical cross sections, diameters of 0.5 to 8 in. and are up to 13 ft long. Most have irregular external annulations, perhaps due to compaction; others are smooth sided.

The structures are in and can be traced through a variety of host rocks. They are most common and best developed in the nonglauconitic littoral to sublittoral facies of the Shedhorn Sandstone. In the sandstone they are almost always oriented perpendicular to bedding. In the intercalated shale or chert host rock, approximately 50% are inclined at very low angles to the bedding. Up to 95% of a host bed may consist of the columns.

The high-density packing of the columns, their morphology, highly variable composition, and association with several host-rock types indicate the structures are organic, probably burrows, rather than inorganic in origin. Their great length, sparse bulbous bases, and the presence of other poorly preserved patterns suggest that the organisms that formed the structures mainly were escaping sediment influx by moving upward rather than burrowing downward. If so, the structures may have important implications about rates of sedimentation on the Permian platform of western United States, if the life span of the organism that produced them can be determined. However, no organism capable of producing the burrows has been found preserved within one.

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GROUNDWATER FLOW AND URANIUM DEPOSITION, POWDER RIVER BASIN, WYOMING

The relation between regional groundwater flow, hydrochemistry, and uranium distribution in the Powder River basin indicates that uranium was deposited during the Tertiary Period in groundwater recharge areas where the groundwater changed from a sulfate-bicarbonate water to a bicarbonate-rich water.

The regional recharge and discharge areas of present groundwater-flow systems have about the same locations as the recharge and discharge areas of the Tertiary groundwater-flow systems. The present groundwater is recharged in the eastern, western, and especially the southern margins of the basin and is discharged in the valley of the Powder River, especially in the north. Flow nets for the groundwater were constructed on the basis of piezometric data from existing water wells in the Powder River basin.

The groundwater chemistry of this area during the Tertiary was probably similar to that of today because the groundwater flowed through the same sediment as present groundwater. Anions in the present groundwater undergo the following sequence of hydrochemical changes along the regional flow path from the southern recharge area to the northern discharge area:

$$HCO_3^- + SO_4^{--} \rightarrow SO_4^{--} + HCO_3^- \rightarrow HCO_3^-.$$

Major unoxidized uranium deposits in the Powder River basin occur near the transition zone between the $SO_4^{--} + HCO_3^-$ and HCO_3^- facies. The uranium is transported in solution by groundwater in the $HCO_3^- + SO_4^{--}$ and the $SO_4^{--} + HCO_3^-$ facies and precipitated in the transition zone between the $SO_4^{--} + HCO_3^-$ and HCO_3^- facies. Precipitation occurs where strong reducing conditions exist around abundant organic material in which sulfate-reducing bacteria may live and multiply.

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PLATE TECTONICS OF SOUTHEAST ASIA AND INDONESIA

The plate-tectonic evolution of a region can be deduced by following the assumptions that (1) subduction zones are characterized by ophiolite, mélange, wildflysch, and blueschist; (2) intermediate and silicic calc-alkaline igneous rocks form above Benioff zones; and (3) truncations of orogenic belts indicate rifting. Interrelations provide cross checks, as do marine geophysical data.

Southeast Asia and "Sundaland" are an aggregate of small continental fragments. Late Paleozoic subduction westward beneath Malaya and Thailand (recorded by granites in eastern Malaya, and by mélanges in western Laos and Cambodia) ended when Indochina collided with them. Early and Middle Triassic subduction was eastward, beneath the west side of the aggregate. Late Triassic and Jurassic subduction from the north ended in collision of the aggregate with China. Early Cretaceous subduction was also from the west. Late Cretaceous subduction was beneath the east side of the aggregate and followed continental rifting there. Cenozoic subduction, from the west once more, ended in the north when the aggregate collided with India, but subduction still continues in the south. Borneo similarly reflects changing subduction patterns.

The Philippines, Sulawesi, and Halmahera consist wholly of upper Mesozoic(?) and Cenozoic island-arc subduction and magmatic complexes and lack old continental foundations. The scrambled fragments of the Philippines came from several arc systems, including 2 extending to Borneo. Sulawesi and Halmahera record primarily subduction from the east and may be rifted and contorted fragments initially continuous with southeast Borneo and central Java.

In the early Tertiary, Australia and New Guinea, which then had a stable-shelf northern margin, moved northward until they collided with a southward-migrating island arc, behind which had formed the Caroline oceanic plate. Late Cenozoic tectonics in New Guinea have been dominated by southward subduction of the Caroline oceanic plate beneath the Australian-New Guinea continent, and by left-lateral strike-slip faulting. Such faulting tore the Sula Islands from northwest New Guinea and carried them to Sulawesi.

The islands of the outer Banda arc are formed of mélanges of the shallow-water sediments of the New Guinea and Australian continental shelf, which is now disappearing beneath the active arc.

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SPACE PHOTOGRAPHY'S ROLE IN EXPLORATION

Space, or hyperaltitude, photographs are defined as

photographs taken from orbital altitudes. Sufficient relatively high-quality space photography is available to permit evaluation of selected areas offering a broad spectrum of structural complexities, rock types, and geographic locations. An important aspect of hyperaltitude photography is the synoptic overview of large areas without regard to natural and artificial boundaries. This type of view will prove quite valuable in regional geologic studies and the planning of exploratory programs. Many difficult geologic problems in one area may easily be solved by comparison with another area where the critical relations are exposed. Certain electronic image enhancement techniques may prove to be a valuable aid in the interpretation process, especially for the ERTS imagery. The ERTS program scheduled for 1972 will furnish imagery with a ground resolution of 400–600 ft. The Skylab program in 1973 will provide the geologist with excellent color photography with 30–60-ft resolution of large areas between the 50th parallels. Space photography should yield important data which will result in a much better understanding of such things as major tectonism, continental drift, nearshore deposition, and comparative geology on a global scale.

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TRANSPORT OF OCEAN SEDIMENTS BY DEBRIS FLOW

Debris flow, a gravity-transport mechanism commonly observed on land, may be a significant agent of high-density mass transport of sediment in the oceans. Debris flow is distinguished from other mass-transport agents by the mechanism of support of granular solids in the flow. Support is provided mainly by the strength of the debris, but also by buoyant forces. Strength is derived from the fluid phase of the debris (clay minerals plus water), which acts as a plastico-viscous material. Suspension of granular solids by this mechanism does not depend on flow conditions and occurs if the debris is moving very slowly or even not at all. Movement of a debris flow depends on a critical thickness of the debris as well as the internal-friction angle. The slope angle required for debris flow typically is less than the 18–37° required for normal grain flows or avalanching. Thus, debris flow may carry large amounts of sediment in suspension while moving sluggishly down a gentle slope. The amount of clay, relative to granular solids, necessary completely to support sand-size material is on the order of 10% or less. Thus, sandy debris-flow deposits may be texturally similar to current-deposited sands.

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SIGNIFICANCE OF THIN CARBONATES IN INTERPRETING DEPOSITIONAL ENVIRONMENTS OF THICK CLASTIC SEQUENCES

When interpreting depositional environments of dominantly clastic sequences, thin carbonates, if present, often are overlooked or given short shrift. Detailed study of the carbonates, however, can be instrumental in environmental interpretations of enclosing clastics. This is particularly true if the clastic units lack fossils or environmentally significant sedimentary structures. This hypothesis is supported by 2 examples from Pennsylvanian and Permian strata of southeastern Wyoming.

The Permian Goose Egg Formation consists of thick, red siltstone and mudstone with interbedded thin, widespread carbonates. The clastic units have been interpreted by various workers as deep-water marine, shallow marine, deltaic, specialized marine, or continental deposits. Petrographic examination of the carbonates suggests that they were deposited in shallow subtidal, intertidal, and supratidal environments. The facies mosaic exhibited by the carbonates suggests that enclosing siltstone and mudstone were deposited in nonmarine environments.

Festoon cross-stratified sandstone which characterizes the Casper Formation (Pennsylvanian-Permian) in the extreme southern Laramie basin has been interpreted as marine, subaerial, or fluvial in origin. Carbonate beds in the Casper Formation are thin, lenticular lithosomes of limited geographic extent. Petrologic studies of these limestones suggest that they were deposited in small lakes or ponds which periodically were emergent. The inferred environment of carbonate deposition supports a subaerial dune environment for the festoon cross-stratified clastics.

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EXPLORATION AND DEVELOPMENT OF NATURAL GAS, 1970–1975

The energy crisis in the United States has been making headlines for more than 2 years. Most energy materials are expected to be in short supply, but the shortage of natural gas is recognized as being most critical. Liquefied natural gas and coal gas will supply a part of the demand but most of the new gas required must result from domestic drilling. An all out effort must be made to discover and develop the 1,178 trillion cu ft of gas estimated by the Potential Gas Committee to remain undiscovered in the United States. Cost of finding and developing this new gas might well be in the same range as the estimated cost of LNG and coal gas.

Compensation for today's higher risks and higher costs must be provided by incentives in the form of tax credits and higher wellhead prices. A graduated wildcat-well tax credit, similar to the now repealed investment tax credit, may be the way to encourage the drilling of the higher risk new-field wildcats required to discover the gas that the country will require during the next 2 decades.

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COPRECIPITATION OF STRONTIUM AND MAGNESIUM WITH HOLOCENE CAVE CALCITES, BARBADOS, WEST INDIES

Within stalactites from Barbados caves, progressively younger calcite conical growth layers and central canal void-filling calcites contain smaller amounts of Sr and Mg. The observed distribution of Sr and Mg in the stalactites is in agreement with a solution-reprecipitation model in which calcite-to-calcite transitions within a low-Mg calcite vadose zone yield amounts of Sr and Mg decreasing with time to vadose water seeping into ventilated cavern macropores. Within the overall trend of decreasing Sr and Mg content, vadose seepage and speleothem calcites may become locally enriched in Sr and Mg when (1) the groundwater temperature decreases, thus affecting the temperature dependence of the calcite-water distribution coefficients for Sr (0.14 ± 0.02 at 25°C) and Mg (0.062 ± 0.015 at 27°C), or (2) meteoric waters bypass the upper vadose zone to dissolve low-Mg calcites of higher Sr and Mg content in the