in 10 cores, 3–10 m. thick, from the floor of the Puerto Rico trench form the basis for correlation of graded beds from several millimeters to 7 m. thick over distances of 200 miles. The largest unit is 2–7 m. thick and covers an area of approximately 4,000 square miles. Variations in bottom topography and sediment properties show that the layers were deposited by turbidity currents originating near the Puerto Rico-Virgin Islands shelf. These currents flowed through numerous canyons northwestward down a high-level abyssal plain and into the lower main trench plain where they spread laterally. In at least two places the turbidity currents were powerful enough to deposit 20–50 cm. of fine sand 60 miles away from and 30 feet higher than the place near which they entered the main trench floor. There is a general decrease in the grain-size of the coarsest detritus as well as the thickness of the basal sandy section in each graded bed down the high-level abyssal plain, into and along the trench floor. Thick beds of homogeneous clay, commonly burrowed in the uppermost 10–20 cm. of the beds, make up most of the graded beds in the deepest part of the lower trench floor. The basal sections of most graded units consist of layers of graded or laminated sand whose modal grain-size decreases upward within each graded bed. Cross-stratified fine sand occurs mainly at the base of the graded beds at the distal margins of the lower trench floor.

CRAIG, R. W., Pan American Petroleum Corporation, Anchorage, Alaska

Alaska, New Frontier for Oil

Effective exploration in a frontier such as Alaska is not a result of happenstance or luck. A careful geologic and economic evaluation is a prerequisite in any new frontier. The decision of an aggressive management to explore actively the potential of the area and to commit qualified, experienced, geological and geophysical personnel well versed in the modern integrated techniques of exploration is essential to a successful exploration program.

The explorationist must be versatile and adaptable to operations in an area of excessive costs, where exploration is completely dependent on climatic conditions, and where transportation facilities are poor to non-existent. These conditions are a challenge to the most competent explorationist, even with all the modern exploration techniques at his command. The most modern techniques are needed in Alaska.

CRONEIS, CAREY, Rice University, Houston, Texas, and RESO, ANTHONY, Tenneco Oil Company, Houston, Texas

Physical and Biological Evidence for Major Mid-Cretaceous Stratigraphic Break

A sequence of essentially worldwide, major diastrophic episodes, which had a considerable influence on biological events, occurred during or near mid-Cretaceous time. Mountain ranges were built and a concurrent 95–105-million-year-old episode of granitization is confirmed by accumulated radiogenic data. There is also evidence of widespread withdrawal of seas at or near the end of the Early Cretaceous. Late Early Cretaceous and initial Late Cretaceous times were characterized by diastrophic events, which resulted in the deposition of clastic facies and in the formation of unconformities of different magnitude, the magnitude depending on proximity of the areas involved to mobile belts. Moreover, the Cenomanian or basal Late Cretaceous sediments widely overlap Early Cretaceous beds, or the rocks of older systems, in many geographic locations. A major biological "crisis" also occurred during an interval which may be considered to include Albian-Cenomanian time. The paleontologic record indicates that the resultant biological changes are as significant as those which distinguish most other systemic boundaries. Thus the physical and biological evidence generally suggests that, according to classical concepts, the more than 70-million-year-long Cretaceous time interval should be regarded as comprising two periods.

Significant biological changes (*i.e.*, those involving the higher taxonomic categories) tend to occur at or near system boundaries. Such worldwide organic "crises" probably are caused by major diastrophic episodes which alter environments faster than highly specialized groups in the lower evolutionary categories can adapt to them. The primitive representatives of highly evolved organisms then invade and occupy the vacated ecological niches. The importance of mass extinctions resulting in conspicuous paleontological breaks between periods or eras probably has been overemphasized, compared with the importance of newly introduced and rapidly expanding types of plants and animals.

The mid-Cretaceous paleontological break is expressed in several ways. For example, among the higher taxa which were present but greatly restricted during the Early Cretaceous, and which are marked by population explosion in the Late Cretaceous, are the planktonic Foraminifera, pelagic crinoids, and angiosperms. Groups which were present in some abundance in the Early Cretaceous, but which expanded in the Late Cretaceous, are teleostei fish, bryozoans, and pulmonate gastropods. Significant declines occurred, however, in the abundance of ammonites, stromatoporoids, and sponges. Both extinctions and introductions occurred, for example, among the heterodont pelecypods, scleractinian coelenterates, opisthobranch gastropods, ostracods, and red algae. Examples of introductions during the Late Cretaceous include the ceratopsian dinosaurs, and the octopi and baculitids among the cephalopods.

The accumulating physical and biological evidence for a major mid-Cretaceous stratigraphic break, detailed in this paper, is more noteworthy than has commonly been appreciated in recent years.

DAVIS, RICHARD A., JR., Western Michigan University, Kalamazoo, Michigan

Ordovician Algal Stromatolites in Upper Mississippi Valley

Algal stromatolites locally comprise as much as half of the Willow River Dolomite (Prairie du Chien Group) in the upper Mississippi Valley. They exhibit two basic forms: mounds which may range up to 4 feet in diameter and mats which may be extensive. Laminations in both range from one to several millimeters in thickness and exhibit a variety of textures and compositions in thin section.

The structure of the mounds is distinctive in that the laminations are irregular and non-parallel. Thin sections show them to consist of fine silt-size dolomite debris and recrystallized micrite, and significant quantities of coarse debris including biogenic sand-size material and large pieces of shell material. Small spherical pellets are rare. Most samples contain some quartz, as well as small intraclasts or oölites, trapped between laminations and in small cut-and-fill structures.

In the mats, laminae are essentially smooth and parallel. Mats are composed almost entirely of fine silt-size dolomite and commonly bear desiccation features which suggest a calm shallow environment. This is in contrast to the presence of intraclasts and algal clasts in the mounds which indicate a relatively high-energy environment. Together, both forms of stromatolites suggest a shallow, intertidal, locally hypersaline environment very much like that of the areas where algal stromatolites occur today.

DENNISON, JOHN M., University of Tennessee, Knoxville, Tennessee, and MORRISON, ANNE K., Hamburg, Germany

FACIES RELATIONS OF HYSTRICHOSPHERES IN ONESQUETHAW STAGE (DEVONIAN) OF CENTRAL APPALACHIANS

Eighteen stratigraphic sections in the Valley and Ridge area of Virginia (10), West Virginia (6), Maryland (1), and southern Pennsylvania (1) were sampled in detail to establish the distribution of hystrichospheres in the Onesquethaw Stage of that region. The localities were chosen carefully relative to the stratigraphic and paleogeographic interpretation of Dennison (1961). Rock-stratigraphic units sampled include the Tioga Metabentonite, Huntersville Chert (including Bobs Ridge Sandstone Member), Onondaga Limestone, and Needmore Shale (with three subfacies: calcitic shale and limestone, calcitic shale, and Beaver Dam black shale).

No hystrichospheres were observed in the Bobs Ridge or other glauconitic sandstone beds in the Huntersville Chert. Only one fragmentary form was seen in the Tioga Metabentonite. The Onondaga Limestone, the three subfacies of Needmore Shale, and the chert of the Huntersville all contain hystrichospheres. Hystrichospheres are rare in Huntersville Chert adjacent to the Monroe Island of middle Onesquethaw age but are abundant in chert elsewhere. Similarly, they appear to be absent in all three subfacies of Needmore Shale adjacent to Monroe Island (at Covington, Virginia). Farther from land, in a basin toward the east between the island and a source of clastic mud near Baltimore, hystrichospheres are abundant in the calcitic shale and common in black-shale, calcitic-shale, and limestone subfacies.

Nineteen species have been identified, assignable to *Hystrichosphaeridium, Veryhachium, Polyedryxium, Michrystridium,* and *Cymatiosphaera. Michrystridium* seems more abundant and *Veryhachium* less common in the calcitic-shale and limestone subfacies of the Needmore Shale than in the other hystrichospherid-bearing rocks. *Cymatiosphaera* is less abundant in Beaver Dam black shale than in other rock types. No other statistically valid distribution trends could be observed.

There is no evidence that hystrichospheres can be used to subdivide the Onesquethaw Stage in this region.

DONATH, FRED A., Columbia University, New York, New York

EFFECTS OF DUCTILITY AND PLANAR ANISOTROPY IN FOLDING OF ROCK LAYERS

The mechanisms of folding that can operate within a sequence of layered rocks are dependent on the relative ductilities and on the nature of inherent anisotropy in the rocks. Flexural mechanisms require the presence of mechanical anisotropy, and folding is effected by slip between layers, by flow within layers, or by a combination of the two. Flexural folding represents a true bending of layers. Passive mechanisms operate only in rock sequences that are mechanically isotropic. This condition may exist either because of the absence of effective planar anisotropy or because of the ineffectiveness of anisotropy resulting from high ductility. The geometry of flow in passive folding reflects only the stress field and velocity gradients existing during deformation. Flow occurs across the layering, and the layering serves only to record the relative displacements. A gradational mechanism, by which certain layers are flexed in response to passive behavior in the associated rocks, causes quasi-flexural folding. This mechanism operates primarily in layered sequences characterized by high-ductility contrast, and produces strongly disharmonic folding.

Because changing environmental conditions can alter both the ductilities of the rocks involved and the effectiveness of planar anisotropy, the mechanism that initiates folding may be superceded by one or more other mechanisms during the course of deformation. The effect of layering in the folding process decreases with increasing ductility, and every gradation exists between ideally flexural and ideally passive folding.

DOTT, ROBERT H., JR., University of Wisconsin, Madison, Wisconsin

COHESION AND FLOW PHENOMENA IN CLASTIC INTRUSIONS

Physical differences between water-saturated cohesionless sand and cohesive fine mud account for many sedimentary structures. Relative bulk cohesion is controlled by relations of intergranular adhesion caused by electromagnetic or Van der Waal's forces versus the disturbing effect of forcible migration of pore fluid or gas. Where expulsion of fluid is slow, mud retains greater cohesion than sand. If sand is loosely packed, movement of fluid, especially if sudden, may cause spontaneous liquefaction and conversion to a viscous slurry with negligible strength.

Empirical evidence of major differences of cohesion comes from abundance of shale pebbles, load structures, current sole marks, contorted stratification, and clastic intrusions. These are most characteristic of alternating sand-mud sequences which possessed many inherent-strength discontinuities. All degrees of liquefaction, flow, intrusion, and stopping are "frozen" in rocks—from local in-place liquefaction of sand strata to immense dike complexes and sand volcanoes. Clastic dikes are of special interest. Typically they contain fine sand, but in a few places may have coarse gravel. Wall rock is generally mud, and stoped cohesive mud xenoliths are common; some dikes split and even rejoin along strike. Internal lamination and some grain alignment may occur, and these suggest chiefly laminar flow of viscous suspensions. A few dikes display excellent groove and flute marks on their sides, evidencing scouring of cohesive wall rock during intrusion and indicating direction of intrusion. Some large dikes completely evacuated their source stratum with concomitant subsidence of all overburden.

Important relative age criteria are provided. Most dikes are straight, suggesting that compaction was completed largely before intrusion. In fact, compac-