with the actual distribution. The results suggest that approximately half of the sediments existing today are younger than 600 million years (m.y.), whereas the remainder is distributed irregularly through a stratigraphic column representing 2,500 to 3,000 m.y. Such a distribution means that the total mass of sediments deposited during geologic time would have to be 4 to 6 times the existing mass and that sedimentary material is rapidly recycled forward in time. Thus, one may think of the half-mass age of all sedimentary rocks as approximately 600 m.y.; however, the half-mass age of carbonate rocks is less, about 300–400 m.y., and that of evaporites even less, about 200–300 m.y.

The relatively high percentage of carbonate rocks, and the almost complete restriction of evaporites to the post-Precambrian result from the fact that the components required to make these rocks are cycled forward at a rate 1.5 to 2 times the rock mass as a whole. Geochemical "uniformitarianism"—the concept that the total mass of sediments existing at any one time in the geologic past had about the same composition as observed today—should be considered when geological conclusions are drawn that are based on the proportions of sedimentary rock types in the geologic column.

THOMAS G. GIBSON, U.S. Geol. Survey, Washington, D.C.

Mobility of Atlantic Coastal Plain and Shelf[1]

Although the Atlantic margin of the United States has been considered to have a similar but less mobile history than the Gulf margin, new data and reevaluation of existing data indicate quite different histories for the two areas. The Atlantic margin is a mobile area with sediment thicknesses approaching those of the Gulf margin, but most of the deposition along the Atlantic margin occurred during the Mesozoic whereas the Gulf received the largest amount of sediments during the Cenozoic. Mobility, however, continued in the Atlantic margin during the Cenozoic, but this mobility did not always parallel that occurring in the Gulf; times of transgression in the Gulf Coast may correspond to regressions in the Atlantic Coast and *vice versa.*

Cenozoic mobility of the Atlantic margin is illustrated by a consideration of Miocene paleoenvironments and stratigraphic data. Several basins existed along the Atlantic margin during the Miocene; some of the basins were open to the ocean, but others were restricted from open circulation. Among those basins, mobility was differential throughout the Miocene. Miocene deposition took place in water as deep as upper bathyal within the present coastal margin, and primary phosphorite is associated with the deeper parts of the basins.

MACKENZIE GORDON, JR., U.S. Geol. Survey, Washington, D.C., and CHARLES G. STONE, Arkansas Geol. Survey, Little Rock, Ark.

New Evidence for Dating Carboniferous Flysch Deposits of Ouachita Geosyncline, Arkansas and Oklahoma[1]

Ammonoids and other invertebrate fossils from the Stanley Shale, Jackfork Sandstone, and Johns Valley Shale provide new information on the ages and correlations of these three stratigraphic units. The Stanley Shale is Late Mississippian (Chesterian) in age through most of the Ouachita Mountains region, except for a basal part, approximately 75 ft thick, of probable Meramecian age. In Saline and Perry Counties, Arkansas, Pitkin Limestone fossils, most of them in reworked boulders, are present about 500 ft below the top of the Stanley. Near Little Rock, Arkansas, ammonoids in the upper part of the Stanley represent the *Reticuloceras tiro* zone of the lower Hale.

The Jackfork Sandstone is of Early Pennsylvanian (Morrowan) age in Arkansas, but near Talihina, Oklahoma, its basal plant-bearing beds are of Late Mississippian (Chesterian) age. *Cymoceras,* an early Morrowan ammonoid genus, has been recognized in the lower part of the Jackfork near Amity, Arkansas. The Game Refuge Formation of Harlton at the top of the Jackfork has yielded Morrowan brachiopods and trilobites in Atoka County, Oklahoma.

The Johns Valley Shale contains indigenous ammonoid assemblages representing the *Branneroceras branneri, Axinolobus modulus,* and *Diaboloceras neumeieri* zones. These three zones are present also in the type section of the Bloyd Shale, indicating a direct equivalence of the two formations. Masses of Caney Shale in the Johns Valley, some of them enormous, as well as boulders of Lower Ordovician to Lower Pennsylvanian rocks, were introduced largely by turbidity flow and gravity gliding.

DONN S. GORSLINE, Dept. Geological Sciences, Univ. Southern California, Los Angeles, Calif.

Geology of Continental Margins: Introduction and Review

Continental margin is assumed here to include the continental shelf, the continental slope, the continental rise, and other equivalent features in less mature margins such as marginal troughs, marginal plateaus, outer ridges, and continental borderlands. Petroleum industry's interest in continental margins is based on the same factors that delineate oil provinces on land: (1) zones of thick fine-grained sediment deposition with high organic content (source rocks); (2) lenses, layers, and wedges of sandstone (reservoir rocks); and (3) active tectonism to produce the necessary structure and to provide driving forces for the migration of petroleum into reservoirs. These factors occur in an area that encompasses more than 20% of the earth's surface area. If the shelves are considered to be regions of erosion and transport, the slopes and rises still occupy 10–15% of the earth's surface; this is an area larger than that of major onshore oil production. Present technology makes it possible to drill about 35% of the continental margin areas. Such projects as JOIDES and similar projects being planned can provide at least preliminary data on the remaining 65%. The advent of deep submersibles makes it possible for geologists to see the surface of the entire area as other techniques are used to probe beneath the surface.

Historically, the investigation of the margins began when the first measurement of water depth was made as an aid to navigation in shallow coastal water. However, the major contribution of modern workers can be restricted to the last 30 years in which the expansion of knowledge has been exponential. It is no exaggeration to say that the time necessary for the publication of these abstracts is sufficient to include new basic discoveries and interpretations. Thus earth scientists are in

[1] Publication authorized by the Director, U.S. Geol. Survey.

the scientifically fortunate position of being reduced to obsolescence as they speak.

H. R. GOULD, Esso Production Research Co., Houston, Tex.

ENVIRONMENTAL INDICATORS—A KEY TO STRATIGRAPHIC RECORD

Since Leonardo da Vinci made his first environmental analysis in the 15th century, geologists have become increasingly concerned with sedimentary environments. Accordingly, their methods for recognizing environments of deposition have become more sophisticated, and their determinations have become more precise.

The major types of criteria conventionally used in recognizing sedimentary environments are the physical, chemical, and biologic characteristics preserved in the rock. These features can be determined from a single small outcrop or subsurface core. Where larger or multiple outcrops are accessible, or where numerous subsurface cores are available, criteria of a much larger order of magnitude, such as lateral and vertical facies relations and the three-dimensional geometric framework of the strata, can be employed to strengthen and broaden the environmental interpretation.

In the symposium papers presented at this meeting, the speakers review the major sedimentary environments and identify for each the unique set of criteria which permit its recognition. Such information is important, not only to interpret the stratigraphic record, but also to explore for and produce most natural resources, including oil and gas, mineral deposits, and underground water supplies. Knowledge of sedimentary environments also is essential in engineering-geology studies of numerous and diverse types.

A. HALLAM, Oxford Univ., Oxford, England

ASPECTS OF MESOZOIC SHELF IN WESTERN EUROPE

During the Mesozoic, the major paleogeographic units of western Europe were the Tethyan Ocean on the south, where predominantly calcareous marine sediments were deposited, and a shelf zone on the north, where dominantly arenaceous and argillaceous marine sediments and nonmarine intercalations were deposited. Clear-cut distinctions cannot be made between the two units because of gradational changes and fluctuations in space and time. An additional complicating factor is the fact that in some parts of the section, particularly in lower Mesozoic strata, extensive Tethyan deposits on the margins of the present-day Mediterranean apparently were laid down in shallow water.

Within the areas of sedimentation there can be distinguished a series of basins, such as the Lower Saxony, Paris, and Wessex basins, characterized by relatively thick, continuous sequences, and swells which are areas of relatively thin, discontinuous sequences which in many places correspond to the margins of Precambrian or Paleozoic massifs, *e.g.*, Scandinavia, Scottish Highlands, Brittany, Massif Central, and Harz Mountains. These massifs were transgressed by the sea only to a limited extent before Late Cretaceous time.

The Triassic of the northern shelf zone is composed largely of continental redbeds with subordinate evaporites. However, there is a marine intercalation, the Muschelkalk, between the Bunter and Keuper of Germany and the southern North Sea region. The Muschelkalk consists of limestone and dolomite with a restricted fauna suggesting abnormal salinity. The Triassic deposits of the southern (Tethyan) zone are thick and largely marine; particularly striking are several thousand meters of Carnian, Norian, and Rhaetian shallow-water limestone and dolomite.

Just before the Jurassic, the sea began to transgress progressively northward across the shelf zone. Except for some minor regressions, the transgression persisted until late Oxfordian-early Kimeridgian time and was accompanied by the gradual northward spread of shallow-water, calcareous, relatively open-sea deposits at the expense of terrigenous clastic and ferruginous deposits laid down close to river deltas. Salinity probably controlled the regional faunal distribution. The latest Jurassic and Early Cretaceous was a time of widespread regression when nonmarine deposits (Purbeckian-Wealden) were laid down from southern England across northern France to Germany. Renewed transgression in Aptian-Albian time preceded the major Mesozoic transgression in the Late Cretaceous, when great thicknesses of chalk were deposited. During the deposition of the ancient coccolith ooze, most of western Europe was, for the first time, a deep shelf. Mesozoic history ended with a Cretaceous regression.

BRUCE B. HANSHAW, U.S. Geol. Survey, Washington, D.C.

INORGANIC GEOCHEMISTRY OF CARBONATE SHELF ROCKS[1]

Carbonate rocks constitute approximately 20% of the sedimentary record; their economic value is even more important than this percentage would indicate. For example, carbonate rocks contain about 50% of the world's known petroleum reserves; they serve as important host material for base-metal deposits; and they are important industrial minerals.

At the time of formation, by organic or inorganic processes, carbonate rocks consist primarily of the two calcium carbonate minerals, aragonite and calcite. Aragonite is metastable with respect to normal, low-magnesium calcite. In addition to calcium, these minerals commonly contain varying amounts of other divalent cations, especially magnesium, strontium, manganese, iron, and barium. The ecosystem of the depositional environment is reflected by the trace-element composition of the carbonates. For example, strontium and magnesium content of carbonates increases near a reef complex and reflects the aragonitic and high-magnesian calcitic carbonates of organic origin. The inorganic precipitation of aragonite rather than calcite is favored by the presence of strontium ion, warm water, high pH, high ionic strength, and pronounced supersaturation of the water with respect to calcite. The precipitation of calcite is inhibited by a high magnesium content of the solution. Calcite may contain several mole percent magnesium which substitutes for calcium in the lattice; some organisms contain as much as 30 mole percent magnesium. High-magnesian calcite is even more metastable than aragonite and generally inverts to low-magnesian or relatively pure calcite. Aragonite, with time, generally inverts to calcite although it is known to occur in shells from rocks at least as old as early Paleozoic. Indeed, one of the enigmas of carbonate geochemistry is that normal modern marine deposits are composed predominantly of the metastable phases, aragonite and high-magnesian calcite, whereas ancient rocks are chiefly low-magnesian calcite and dolomite.

[1] Publication authorized by the Director, U.S. Geol. Survey.