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

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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.

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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.

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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.