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SOME ASPECTS OF LITHIFICATION IN CHALK

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Chalk is affected by different diagenetic processes in comparison with other carbonate rocks. Commonly observed lithification processes are pressure-solution and reprecipitation and neomorphism. The first process is divisible into: (a) spot-welding or welding; (b) overgrowth; (c) stylolitization and cementation. Further, pressure-solution and reprecipitation is dependent on (a) geostatic pressure and (b) the ratio of Mg/Ca in the pore fluid. Overgrowth of calcite cement is controlled by the size and shape of the biogenic crystals. Neomorphism is also important in diagenesis. Neomorphic process dominates when pressure-solution process is ineffective. Organic and insoluble residue content dictate neomorphism. In conclusion, pressure-solution or neomorphism or a combination of both accounts for various modes of lithification observed in chalk.

† † †

The initial reports of the deep sea drilling project (JOIDES) have yielded new data and new impetus to studies of pelagic and deep water carbonate sediments. A further aid to the understanding of depositional and diagenetic environments of the pelagic sediments has been given by the recent discoveries of oil fields under the North Sea where the Cretaceous chalk is a major petroleum reservoir. Further, detailed observations with the scanning electron microscope have disclosed different processes of lithification, such as dissolution and precipitation. Application of these new ideas to the study of chalk has been an interesting revelation to many petrographers.

Chalk is a pelagic sediment of biogenic origin. The *Glossary of Geology* (1973:117) defines chalk as "soft, pure, earthy, fine-textured, usually white to light gray or buff limestone of marine origin, consisting almost wholly (90-99%) of calcite, formed mainly by shallow-water accumulation of calcareous tests of floating micro-organisms (chiefly foraminifers) and of comminuted remains of calcareous algae (such as coccoliths and rhabdoliths) set in a structureless matrix of very finely crystalline calcite (some of which may have been chemically precipitated) and marked by a porous, somewhat friable, and unindurated or slightly coherent character."

At the present time, pelagic sedimentation is virtually confined to ocean basins. In the Mesozoic era, on the other hand, pelagic deposits, including chalk, were laid down on the continental basement. In Late Cretaceous time there were widespread continental seaways, and practically every continent was affected by this world-wide marine transgression.

The best known and most widely distributed deposits of these seaways are chalks of the Cenomanian-Maastrichtian age. The chalks of western Europe are of particular interest here because of their economic importance and their contribution to progress in chalk petrography.

Lithification includes all diagenetic processes which serve to convert unconsolidated sediment to coherent rock. The diagenetic alteration of chalk has long been a subject of controversy in petrography. For example, the lithification of the Irish Chalk has been variously attributed to the presence of aragonite in the original sediment and to metamorphism by overlying basalts (Bathurst, 1975:401-408). Similarly, major hypotheses offered to explain radical differences in hardness of Cretaceous chalk in Great Britain all appear inadequate (Scholle, 1974:178). In this paper, an attempt is made to summarize the new data and examine the mechanisms proposed by various authors to explain patterns of chalk diagenesis.

Unlike most regions of shallow water carbonate deposition where the major carbonate component is aragonite (e.g., the Arabian Gulf), the bulk of chalk mud is totally biogenic in origin, consisting mostly of stable, low-Mg calcite. Consequently, the mechanisms of chalk diagenesis have to be explained by processes other than simple compaction, leaching, solution (fresh-water influx), and cementation. Common and widely observed processes are pressure-solution and reprecipitation and neomorphism. The mechanism of pressure-solution and reprecipitation is divisible into: (a) spot-welding or welding; (b) selective overgrowth on some calcite grains; and (c) stylolitization and cementation. The process of reprecipitation is usually local and occurs as calcite cement. Solution-precipitation is dependent on two factors: the depth of burial and pore-water chemistry.

Schlanger (1974) concludes that lithification generally increases with age and the depth of burial. The history of compaction starts with dewatering and is followed by increased packing, spot-welding, subsequently by dissolution-precipitation (selective overgrowth cement) and stylolitization and extensive cementation. Interesting advances in theoretical understanding of pressure-solution have come about with Neugebauer's (1974) analysis of the solution in the chalk. His main thesis is that chalk remains soft and uncemented because Mg-rich pore fluids, which are supersaturated

with respect to low-Mg calcite, inhibit pressure-solution and reprecipitation until considerable overloads are reached. When this inhibiting factor (supersaturation) is removed, pressure-solution and cementation can proceed at an accelerated pace. During diagenesis, the Mg/Ca ratio of the pore-fluid generally decreases considerably (Neugebauer, 1974:156), which, along with the inevitable rise in geostatic pressure, leads to extensive pressure-solution and culminates in stylolitization and cementation. Neugebauer constructed a model, illustrating the relationship among such factors as overburden, dissolution of nanofossils and cement fabric, and the ratio of Mg/Ca in the pore solution. His results compared well with deep-sea drilling data, and he concluded that an overburden of at least 2000-4000 m is required for the complete lithification of the chalk by pressure-solution.

It is very interesting to note where the precipitation of cement in chalks takes place. Cement in a typical chalk occurs as pore-filling, sparry calcite and also as overgrowths on nanofossils. Neugebauer (1974:168) observed that different group of fossils (coccoliths, foraminifera, *Inoceramus*, etc.) are coated with different amounts of overgrowth cement. He noted that size and geometrical shape of the host grain control the form of calcite overgrowths. Foraminifera acquire smaller overgrowths than macrofossils but larger overgrowths than coccoliths. Neugebauer (1974:172) points out further that coccolithic elements, unlike other biogenic crystals of the same size, are somewhat protected from dissolution because of their stable form. Adelseck (1975:969-970) demonstrates that dissolution is further dependent on the thickness of the coccolith plates and that within the foraminifera, the individual species resistance is dependent on the pore size and pore density of the test.

Wise and Kelt (1972) demonstrated the cementation of an Oligocene, South Atlantic chalk by calcite overgrowths on coccoliths and discoasters. Scholle (1974) attributed cementation of English chalk to overgrowth on coccoliths, while Mapstone (1975) believed that the cement in the Danian and Maastrichtian chalk from the Tor Field (North Sea) was derived from pressure-solution of calcite grains (mostly individual coccolithophorids). Similarly, Jørgensen (1975) favored the consolidation of the soft sediment to white chalk in the Danish region over pressure-solution.

Scholle (1976:719) states that small variations in initial grain size, faunal composition, or clay content can lead to significant stratum-to-stratum variations in lithification. Jørgensen (1975:312) noted in Danish chalk that, though argillaceous chalk and pure chalk were subjected to the same lithostatic pressure, the lack of lithification in argillaceous chalk was due to the fact that very little cement was produced at the clay/carbonate grain contact. The *hard grounds* that are seen in the Cretaceous chalk of Europe and in the chalk and shaly chalk strata of the Greenhorn Formation (Upper Cretaceous) in the western interior U.S. are examples of this type of cementation. *Hard grounds* are layers of hard,

well cemented chalk in a sequence of porous, poorly cemented, soft-chalk strata; they are believed to be the remnants of hardened sea floors.

Neomorphism plays a key role in hardening a loose, noncoherent, carbonate mud to chalk wherein pressure-solution processes are subordinate. Neomorphism as used by Folk (1965:20-21) includes all transformations between one mineral and its polymorph. The newly formed crystals can be of differing sizes. The growth of carbonate mud to sparry calcite is controlled by insoluble residue and organic content. The Upper Cretaceous Greenhorn chalk is a good example of lithification by the growth of calcite grains (Kirumakki, 1976:47; Hattin, 1976:83-86).

The conclusion is inescapable: Variations in the character of chalks are related to different diagenetic histories. The occurrence of spot-welding at point contacts of calcite grains, the presence of extensive overgrowth cement, and the abundance of stylolites all testify to the idea that pressure-solution is a possible mechanism of cementation. The various modes of lithification found in chalks can, to a large extent, be attributed to: (1) cementation by pressure-solution, and (2) independent neomorphism, or (3) some combination of the above processes.

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