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SEDIMENTATION AND DIAGENESIS OF PELAGIC SEDIMENTS : OBSERVATIONS FROM THE DEEP SEA FLOOR AND IN MOUNTAIN RANGES

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(1 figure dans le texte)

RÉSUMÉ

Le déchiffrage de carottes océaniques est souvent compliqué par la petitesse de leur taille comparée à la dimension et à la complexité des phénomènes géologiques sous le fond marin. De plus en plus, le géologue marin doit s'en référer, pour leur interprétation, aux modèles tridimensionnels qui ont pu être établis sur terre, là où la dimension temps est bien enregistrée.

Deux exemples se rapportant aux sédiments pélagiques montrent à quel point l'étude des sédiments océaniques et des sections stratigraphiques établies sur le continent peuvent devenir complémentaires.

ABSTRACT

The deciphering of deep-sea cores is hindered by their small size relative to the size and complexity of geological features beneath the sea floor. More and more, the marine geologist needs the help of the three dimensionnal models which have been established on land, where the time dimension is fully recorded.

Two example involving pelagic sediments illustrate how the study of oceanic sediments and of continental stratigraphic sections can become interrelated and complementary.

Extensive knowledge of pelagic sediments first became available through the voyage of the HMS CHALLENGER a century ago. Until recently, sampling of oceanic sediments was limited, as in the case of the CHALLENGER expedition, to deposits at or very near the surface of the sea floor. Because it was not possible to recover samples from very far beneath the sediment-water interface, marine geologists were for the most part unable to sample the important geological dimension of time (as represented by thickness of sediment) until the advent of the Deep Sea Drilling Project (JOIDES) made drilling in the deep ocean possible using the research vessel GLOMAR CHALLENGER.

Geologists have traditionally viewed marine geology and the study of modern sediments as the source of models which could be applied to ancient sedimentary rocks on the continents. Useful though this approach has been, it was always somewhat unrealistic as long as the dimension of time was not considered. Moreover, a reversal of this pattern has occurred in recent years because geological models from the continents are now required to explain some features observed in JOIDES

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cores. The problem with the latter is their small size relative to the size and complexity of geological features beneath the sea floor.

Two examples involving pelagic sediments illustrate how study of oceanic sediments and of continental stratigraphic sections can become interrelated and complementary : (1) Spatial and age relationships between basalts and pelagic sediments, and (2) Lithification of pelagic carbonate sediments on the sea floor.

BASALT-PELAGIC SEDIMENT RELATIONSHIPS

The Problem at JOIDES Sites 53 and 54.

In the eastern part of the Philippine Sea, coring at JOIDES sites 53 and 54 encountered basalt beneath mid-Tertiary coccolith oozes. Near the contact between ooze and basalt, the ooze is lithified and somewhat recrystallized, and lithified ooze occurs *within* the basalt as small pockets and fracture fillings.

At first these relationships were interpreted as evidence that the basalt was a sill intruded into the coccolith ooze, causing incorporation of some of the ooze as inclusions in the magma and resulting also in thermal metamorphism and lithification of the sediment. Observations elsewhere, however, challenge this initial interpretation and suggest a more complex sequence of events.

Models from Olympic Mountains

Among these observations, the most significant are those made in Eocene eugeosynclinal rocks of the Olympic Mountains in the northwestern United States. The Eocene rocks are chiefly pillow basalts and submarine basaltic breccias, but they also include pelagic limestones composed of coccoliths and planktonic Foraminifera. Outcrops of these rocks display varied and complex relationships between the basalts and limestones (Garrison, 1972, 1973). One kind of relationship developed when uncompacted pelagic ooze was intruded and disrupted by pillowed basalts on the sea floor. Another type of interpillow limestone was formed in these Eocene rocks when carbonate sediment infiltrated from the sea floor downward into cavities between, and in some cases within basalt pillows; precipitation of void-filling calcite with radiaxial fibrous mosaic texture frequently preceeded or alternated with sediment infiltration.

Since interpillow limestones thus may be either younger or older than the enclosing basalts, it becomes crucial to distinguish between the two categories in outcrops or in cores from the sea floor. Among the criteria useful for recognizing younger sediments infiltrated into cavities between and within older basalts are : (1) the presence of void-filling fibrous calcite, mentioned above, (2) laminated interpillow sediments, with laminae parallel bedding indicated by pillow tops, (3) interpillow sediments occur as small bodies with flat floors and arched tops between tightly packed pillows. In the opposite case, sediments which have been intruded by younger basalts : (1) will tend to be massive, any primary structures such as bedding having been destroyed, (2) interpillow limestone may occur as angular clasts, or the pillows may be loosely packed in a limestone matrix, (3) evidence of thermal metamorphism may or may not be present (see below), (4) any sparry calcite which is present tends to be blocky spar resulting from thermal recrystallization of limestone rather than the fibrous, void-filling drusy calcite noted above.

Depositional vs. Intrusive Contacts

When attempting to distinguish between intrusive and depositional contacts separating igneous and sedimentary rocks, geologists have traditionally considered the presence or absence of contact metamorphism as unequivocal evidence for one or the other. But several lines of enquiry indicate this may be an unreliable criterion. In the Olympic Mountains, some inclusions of pelagic limestones within basalts and diabases are nearly unaltered despite clear evidence that they were engulfed in basic magmas at temperatures exceeding 1000° C. In basalt pillows dredged from the Mid Atlantic Ridge, pockets of lithified coccolith ooze in the basalt have been attributed to thermal metamorphism. But petrographic and isotope analyses indicate the lithification probably occurred through precipitation of calcite and phillipsite at low temperatures on the sea floor (Garrison, Hein and Anderson, in press).

The association of lithified carbonate sediment and secondary zeolites with altered basaltic glass is widespread in samples collected from the ocean floor, and suggests some sort of connection between low temperature submarine weathering of basaltic glass and carbonate cementation (Thompson, 1972). This connection may involve palagonitization of the glass on the sea floor, with consequent release of alkali elements into pore waters of adjacent sediments, elevation of pH in these pore waters, and precipitation of authigenic calcite and zeolite cements. Of practical importance is the fact that low temperature alteration of this kind can produce zones of lithified and altered carbonate sediments which may mimic contact zones of thermal metamorphism.

A Reinterpretation of JOIDES Sites 53 and 54

Interpretation of these complex phenomena in small diameter cores from the ocean floor is therefore not a simple matter. And Figure 1 suggests, in highly schematic fashion, some of the interpretive difficulties a geologist on the GLOMAR CHALLENGER might encounter when attempting to differentiate, in cores, between oceanic basement rocks and intrusive rocks.

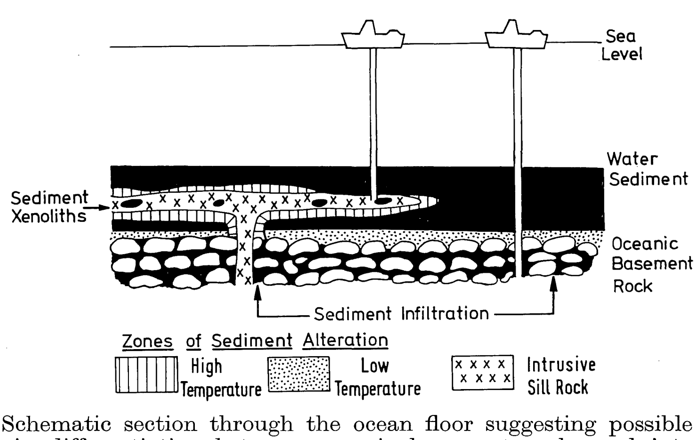

Fig. 1. — Schematic section through the ocean floor suggesting possible interpretive problems in differentiating between oceanic basement rocks and intrusive sills.

In the case of the first example cited above — at JOIDES Sites 53 and 54 in the Philippine Sea — re-examination of the cores indicated that lithification of the coccolith ooze within and near the basalt was probably a low temperature process of the kind described above; and that the pockets of sediment within the basalt resulted, not from incorporation during intrusion, but from infiltration of younger sediment into older basalt. The mid-Tertiary coccolith ooze thus lies depositionally above basalt which forms oceanic crust in the Philippine Sea.

LITHIFICATION OF PELAGIC CARBONATE OOZE ON THE SEA FLOOR

The European Hardgrounds

Early diagenetic lithification of carbonate sediments on the sea floor has only recently been recognized and studied by marine geologists in the oceanic realm. European stratigraphers, however, had long suspected this phenomenon based on their knowledge of limestone hardgrounds and other characteristics in the stratigraphic record which indicated lithification on the sea floor (e.g. Cayeux, 1935; Voigt, 1959, 1968).

Some of the best evidence for early diagenetic lithification occurs in pelagic carbonate rocks of the Jurassic ammonitico rosso facies (Hollman, 1964; Jenkyns, in press), which is widespread in the circum-Mediterranean region. These condensed red limestones contain abundant evidence for cementation at or near the sediment-water interface, such as : (1) well developed nodular structure, (2) occasional reworking and abrasion of nodules by currents on the sea floor, (3) boring and encrusting organisms, (4) evidence for both dissolution and precipitation of calcium carbonate, and (5) secondary mineralization in the form of manganese-iron oxide crusts and nodules.

Information from the Ocean Basins

Formation of limestone nodules appears to be one of the earliest stages of lithification in fine-grained carbonate sediments on the sea floor, and nodules of this kind are present in a variety of carbonate rocks in western Europe. Although long unrecognized, similar nodular structures occur also in lithified pelagic carbonate sediments of Tertiary and Quaternary age from various oceanic areas including the Caribbean and Mediterranean Seas (Fischer and Garrison, 1967; Milliman and Müller, 1973). They are present also in Mesozoic limestones cored from the Atlantic Ocean floor during Leg 11 of JOIDES (Bernoulli, 1972). In these oceanic examples, the most common cement is high magnesium calcite (5 to 15 mol % of $MgCO_3$), suggesting that the cementation is initiated by inorganic precipitation of this metastable mineral.

Models from the Cretaceous Chalk Seas of Western Europe

While the oceanic samples provide some insights into the mineralogy and geochemistry of early lithification and hardground genesis, study of such specimens does not allow a complete reconstruction of events. The problem once again is that the oceanic samples typically are too small and sparse to illustrate complex processes.

Upper Cretaceous chalks in southern England contain a spectrum of characteristics which are interpreted as representing progressive stages in the lithification of chalk ooze on the sea floor and in the development of hardgrounds (Bromley, in press; Kennedy and Juignet, in press). The earliest stage is the growth of small, dispersed nodules of cemented chalk near the sediment-water interface; this occurs during periods of sharply reduced sedimentation, and presumably involves precipitation of magnesium calcite cement (Jenkyns, in press). Continuation of this kind of cementation leads to coalescence of adjacent nodules and development of incipient and simple hardgrounds. If the cementation is interrupted by renewed sedimentation, nodular development is arrested and subsequent compaction modifies the embryonic nodules into lensoid or Flaser shapes.

If the cementation is allowed to proceed without interruption, however, hardened surfaces form directly at the sediment-water interface on the sea floor. Most of these surfaces undergo considerable modification by erosion, by boring and burrowing organisms, and by mineralization of glauconite and phosphorite (Bromely, 1965). The result is an irregular and highly complex mature hardground surface.

The Common Denominators

Nearly all of the examples of early lithification of pelagic carbonate oozes cited above contain evidence for two processes : (1) very slow sedimentation, or non-sedimentation, and (2) growth of carbonate nodules at or slightly below the surface of the sea floor. In addition, the oveanic samples suggest the initial cement is, in most cases, high magnesium calcite (Jenkyns, in press), and the sum of evidence indicates that early lithification is related to chemical gradients at the sediment-water interface, across which large volumes of fluid move.

CONCLUSIONS

Geologists who work on the land have long benefited from the information collected by their seafaring colleagues. But they are now in a position to reciprocate, based on the models they can provide through study of well exposed, three dimensional outcrops. Marine geologists, faced with the problem of attempting to recognize and interpret complicated features in small core and dredge samples, find themselves more and more in need of guiding principles from their terrestrial compatriots.

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