Carbonate Sediments: Oriented Lithified Samples from the North Atlantic

Abstract. *Indurated carbonate samples, obtained from the North Atlantic sea floor with a deep-sea drill coring apparatus, suggest that the phenomenon of deep-sea carbonate lithification is more complex than had been thought previously. Lithified-nonlithified couplets can now be related in age and orientation. Age determinations based on the method of carbon-14 dating show that adjacent nonlithified-lithified layers may differ in age by more than 30,000 years.*

Many hypotheses have been proposed to explain the mechanism and time of formation of deep-sea lithified carbonates (*1, 2*). All theories are hampered by the fact that they are based, for the most part, on the study of dredged samples. This creates obvious difficulties because the samples are unoriented. Interbedding of lithified-nonlithified layers and variations in the degree of lithification add to the difficulties. Many of these problems can be overcome or at least mitigated if oriented drill core samples are available. Samples of lithified carbonate sediment have been obtained from drill cores in the eastern North Atlantic (45°00′ to 45°30′N, 27°30′ to 29°30′W) and seamounts in the western North Atlantic (30°00′ to 40°00′N, 50°00′ to 70°00′W). The carbonate sediment in these samples is arranged in alternately lithified and nonlithified interbedded layers. The degree of lithification apparently depends on whether the samples are obtained from crests, slopes, or flanks. In addition, the oriented samples show important discontinuities or breaks between the lithified and nonlithified carbonate layers. The sedimentological significance of the latter feature would not be appreciated in unoriented, dredged samples.

Two main types of carbonate lithology appear in the samples derived from a rock core drill (*3*). The first of these consists of nonlithified carbonate layers typically composed of corals, gastropods, pelecypods, pteropods, and some foraminifera. The smaller faunal remains in this lithology are preserved fairly intact; the larger ones are broken fragments. The matrix of the nonlithified carbonate is a very fine lime mud, predominantly calcite. The second major lithology observed in the drill core samples is a lithified carbonate. These are hard layers, predominantly globigerina-pteropod oozes with occasional molluscan fragments, but some samples may be almost entirely lacking in organic constituents.

The presence of dolomite rhombs in the lithified carbonate samples from the western Atlantic Ocean poses a problem, as they are absent from comparable lithified carbonates in the eastern North Atlantic. The presence of the rhombs may be a function of age; the lithified carbonates in the western Atlantic Ocean are generally older than those recovered from the eastern North Atlantic.

The two main types of carbonate lithologies described above alternate in what have been called lithified-nonlithified carbonate couplets (*2*). These couplets are not very thick, varying from 3 to 6 cm. The most interesting aspect of the carbonate couplets is the contact between the lithified layer and the overlying nonlithified layer. This contact is often very undulating and stylolitic, and the lower or lithified layer shows what appears to be an impregnation of ferromanganese oxide near the contact with the overlying nonlithified layer. The amount of ferromanganese oxide appears to decrease downward in the lithified layer. These undulating surfaces between the lithified and nonlithified layers may be erosional or solutional surfaces; certainly they are discontinuities of major geological significance. The other contact relation, that between the lithified layer and the underlying nonlithified layer, is generally a smooth, gradational contact and shows no abrupt discontinuity (Fig. 1).

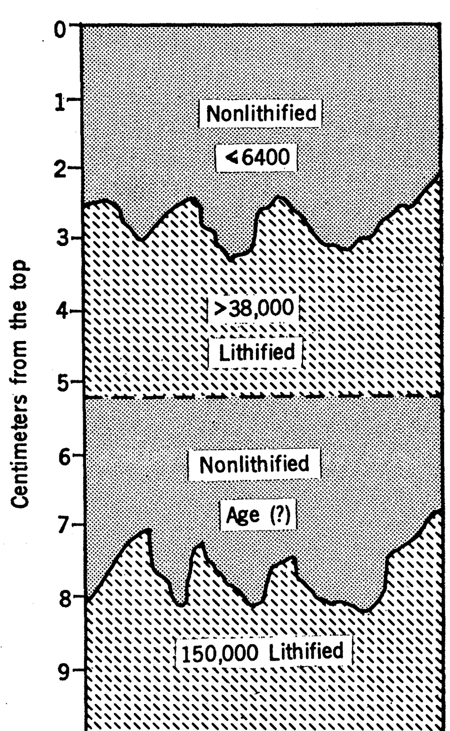

Fig. 1. Schematic diagram of typical carbonate sediment collected by rock core drills from ridges and seamounts in the North Atlantic. Position of undulating contacts and age difference between lithified and nonlithified layers are shown.

Inorganic components of the sediments have been dated radiometrically by the C^{14} method; the presence of cold- and warm-water planktonic foraminifera has also been used as an indication of the age of the sediment layers. In those samples dated radiometrically, two interesting relations appear. The lower, lithified layer is often 30,000 years or more older than the nonlithified layer immediately above it; the nonlithified layer generally has included in it foraminifera of a cold-water type, whereas the lithified layer carries a warm-water fauna. The difference in age between the nonlithified and lithified layers reported here should not be taken as an average figure; other couplets not yet dated may show much greater or lesser age differences. The significant feature is that there is a great age difference across the contact in the samples studied.

Examination of drill cores and thin sections shows that the thin sections are divided into approximately equal portions of quite different carbonate lithologies. Invariably, the upper lighter-colored lithologies are the nonlithified layers and contain cold-water faunas; the lower, darker carbonate lithologies, impregnated with ferromanganese oxides, contain the warm-water foraminiferal faunas. The undulating contact between the two lithologies is quite sharply developed. The two portions of these carbonate couplets, nonlithified above and lithified below, have been dated by the C^{14} method (Fig. 1). The upper layers have been dated at less than 6400 years; the lower layers have been dated at greater than 35,700 years.

The differences between the two nonlithified and lithified carbonate layers—degree of lithification, temperature as indicated by the contained foraminiferal assemblage, and difference in age—are such that seasonal variations in oceanic circulation or short-lived tectonic emanations do not appear sufficient to account for the entire process. Therefore, major changes such as the advance or retreat of continental ice sheets, extended tectonic activity associated with sea-floor spreading, or the alternate occurrence of reducing or oxidizing bacteria as a result of the other features are suggested as possible mechanisms. Whatever the mechanism, it seems that it must involve fluctuating temperature and salinity conditions. This suggestion has been made by Gevirtz and Friedman (*2*) to explain the soft- and hard-layer lutite couplets in the Red Sea.

The development of a lithified carbonate rock from the soft, nonlithified ooze formed on the sea bottom must involve not one, but many, periods of lithification interrupted by periods of solution. The processes involved, lithification, solution, and related chemical changes, must be random and fluctuating in intensity, duration, and location. The process of alternating lithification and solution is responsible for the removal of significant quantities of carbonate sediment at the sediment-water interface. The result is a column of carbonate strata that represents not only the net product of ocean floor deposition and erosion but also the later effects of lithification, recrystallization, and solution of the carbonate rock that follow uplift of the sea floor or regression of the sea. Thus carbonate strata presently cropping out on the continents must represent several episodes involving lithification and solution on the sea floor, lithification due to physical and chemical changes, and lithification that follows uplift into subaerial environments.

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References and Notes

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4. We are grateful to Dr. B. D. Loncarevic and J. Brooke, Atlantic Oceanographic Laboratory, for material from the eastern North Atlantic and to Dr. F. Aumento, Geological Survey of Canada, for samples from the western North Atlantic. For laboratory analyses and technical assistance we are indebted to M. Gorveatt and K. Robertson, Atlantic Oceanographic Laboratory, and J. Robertson, Queen's University.
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6 May 1969

Zircon Ages of Felsic Volcanic Rocks in the Upper Precambrian of the Blue Ridge, Appalachian Mountains

Abstract. *Five zircon samples from Pennsylvania, Virginia, and North Carolina yield discordant uranium-lead ages which suggest an original age of 820 million years and an episodic lead loss at 240 million years. The indicated age of lead loss is interpreted as the age of movement of the Blue Ridge thrust sheet.*

Nonfossiliferous sedimentary and volcanic rocks, generally assigned a late Precambrian age, crop out extensively in the Blue Ridge of the Central and Southern Appalachians. These rocks are directly involved in the recurring controversy over the base of the Cambrian (*1*). They rest nonconformably upon billion-year-old plutonic rocks, and where the stratigraphic succession is preserved, they are overlain with apparent conformity by Lower Cambrian(?) clastic rocks of the Chilhowee Group. Many workers have suggested that these upper Precambrian rocks are, at least in part, correlative and not greatly different in age from those of the Chilhowee Group (*2*). Some workers, in fact, suggest that many stratified rocks here assigned a late Precambrian age should be included with the Chilhowee in the Cambrian (*3*).

We present zircon ages determined from five felsic volcanic rocks spanning a horizontal distance of about 580 km in three upper Precambrian stratigraphic units of the Blue Ridge (Fig. 1). Uranium-lead ages are discordant, but they indicate an original age of 820 million years and are interpreted to indicate episodic lead loss at 240 million years. Although the three widely separated units yield the same original age, that age is somewhat older than we had expected. The Pb/U systems in the zircons were apparently not disturbed during regional metamorphism about 350 million years ago. The suggested age of lead loss is compatible with a late Paleozoic (Appalachian) age for the major movement of the Blue Ridge thrust sheet, the probable age of thrusting in the western Valley and Ridge belt.

Because of the overprint of Paleozoic metamorphism, the radiometric technique most likely to yield meaningful original ages of the upper Precambrian rocks is the uranium-lead isotope method applied to zircons from interlayered felsic volcanic rocks. These are restricted to three areas (Fig. 1) in the Blue Ridge belt. They occur sparsely in the Grandfather Mountain Formation, form a major part of the Mount Rogers Formation, and reappear in the Catoctin Formation in Maryland and Pennsylvania where they are a significant component. At least one dated felsite sample comes from each of the above formations.

The Blue Ridge belt is essentially anticlinal with a more or less continuous core of billion-year-old granitic gneiss. Upper Precambrian stratified rocks flank the granitic gneiss for much of the length of the anticlinorium, but locally on the northwest limb Chilhowee rocks overlap onto the basement. A mid-Paleozoic metamorphism, which mineral ages date as about 350 million years old (*4, 5*), produced a gradient across the Blue Ridge from unmetamorphosed Paleozoic rocks of the Valley and Ridge on the northwest to rocks of kyanite-staurolite grade on the southeast. The ambient metamorphic grade at our sample sites is low, probably in the chlorite or biotite zone. South of Roanoke, Virginia, the Valley and Ridge belt has an imbricate structure, and, at least in northwestern North Carolina, the Blue Ridge is also allochthonous, as shown by the presence of the Grandfather Mountain window, which contains lower-grade rocks eroded through the crystalline rocks.

The Grandfather Mountain Formation (*6, 7*), present only within the Grandfather Mountain window and at least 3000 m thick, rests nonconformably upon granitic basement that has yielded two zircon samples suggesting an original age of about 1050 million years if one uses a continuous diffusion model (*8*). The top of the formation is not exposed.

The Mount Rogers Formation, present in several thrust sheets, is about 3000-m thick and contains a thick pile of rhyolite in the middle. Both the base and top of the Mount Rogers are preserved, although commonly not in the same tectonic unit. Our dated samples come from two petrographically different rhyolites in a thrust sheet that does