21. DOLOMITIC BASAL SEDIMENTS FROM NORTHERN END OF NINETYEAST RIDGE

Christopher C. von der Borch, Flinders Institute for Atmospheric and Marine Sciences, Flinders University, South Australia
and
Norman A. Trueman, Mines Exploration Pty. Ltd., Pasadena, South Australia

ABSTRACT

A variety of dolomitization textures occurs within the lower 64 meters of Deep Sea Drilling Project Site 217, situated on the crest of the northern end of Ninetyeast Ridge. Immediately above the dolomitized zones near the bottom of the column and below pelagic sediments are strata characterized by layers of undolomitized gravel-sized bioclastic debris interbedded with biomicrite beds. This sediment type has shallow off-reef affinities. Below this level, saccharoidal dolomite layers occur with rhombs typified by one dolomite overgrowth around corroded sparry calcite nuclei. These are interbedded with silicified biomicrites. At the deepest cored levels similar layers of dolomite are composed of rhombs showing one to two calcite zones alternating with one to two dolomite zones around corroded dolomite nuclei. The sequential variation in dolomitization texture with depth, along with independent evidence for occasional shallow water to subaerial conditions, provides good evidence for origin of the dolomite by dolomitization of back-reef sediments. The mechanism which best fits the facts is one of seepage refluxion of high Mg/Ca solutions from a periodically desiccating lagoon.

INTRODUCTION

Dolomitized bioclastic limestones of coral reef, fore reef, and lagoonal environments are relatively widespread in their occurrence. Ancient examples from continental areas are typified by the Permian reef complex of the Guadalupe Mountains in the United States (Newell et al., 1953). Comparable examples in an oceanic environment have been described from Guam (Schlanger, 1964) and from drill holes in mid-Pacific atolls such as Eniwetok, Funafuti, Kita-daitojima, Bikini, and Midway (Schlanger, 1963; Ladd et al., 1970), where dolomites are of lower Tertiary age and appear to replace coarse bioclastic reef debris. Somewhat similar dolomitized limestones, in this case lime sands (calcarenites) of Pleistocene age, have been described from the Island of Bonaire in the Netherlands Antilles (Deffeyes et al., 1964).

The origin of dolomitizing fluids in the above instances is of geological significance. Weight of opinion appears to favor dolomitization of pre-existing calcareous material by some form of seepage refluxion through the sediments of hypersaline brines. The Mg/Ca values of the percolating solutions are postulated to have been enhanced by evaporation and consequent gypsum or aragonite precipitation in a lagoonal environment (Newell et al., 1953; Adams and Rhodes, 1960). This interpretation is strengthened by the observation that oxygen isotopes occurring within Tertiary dolomites from mid-Pacific atolls indicate an origin from evaporated, isotopically heavy seawater (Berner, 1965) rather than from extended contact with pore waters of normal seawater composition.

Drilling on the crest of the northern end of the Ninetyeast Ridge during Leg 22 of the Deep Sea Drilling Project sampled a shallow-water sequence of interbedded cherts, silicified biomicrites, and saccharoidal dolomites. These sediments, of Campanian age, were drilled at Site 217 (Figure 1). They occur near the base of the sediment column and are overlain by approximately 600 meters of mostly oceanic pelagic nannofossil ooze which ranges in age from Campanian to Quaternary. The sedimentary succession and biostratigraphy indicate that the basement of Ninetyeast Ridge stood at or near sea level in the Late Cretaceous and subsequently subsided to its present depth of 3010 meters at Site 217 (The Scientific's Staff, Leg 22, 1972). The replacement dolomites from the basal section of this site, which will be described in detail below, closely resemble the dolomitized sequences from Guam and the Pacific atolls. In addition they contain textural evidence which is in accord with an origin by seepage refluxion dolomitization of bioclastic reef debris.

STRATIGRAPHY AND SEDIMENTOLOGY

The sediment column in Holes 217 and 217A was penetrated to a depth of 664 meters, with the deepest sampled sediments being at least as old as Campanian. Increasing proportions of chert down the hole caused curtailment of drilling before igneous rocks were reached; however, seismic evidence suggests that the deepest recovered sediments lie in close proximity to basalt.

The stratigraphy and biostratigraphy of the site are described in detail in the site report (Chapter 8, this volume). Briefly, upper sections of the column comprise

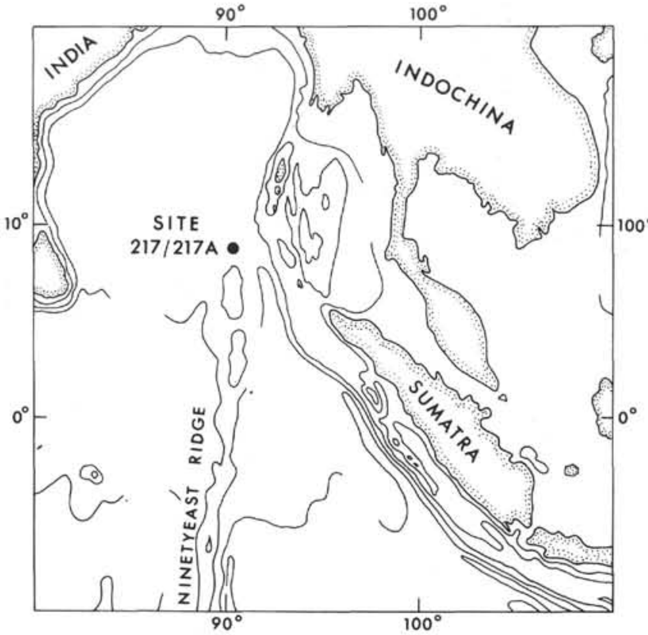

Figure 1. *Location of Deep Sea Drilling Project Site 217 on crest on Ninetyeast Ridge at its northern extremity. Water depth is 3010 meters.*

pelagic nannofossil oozes and chalks ranging in age from Quaternary to mid Eocene. Below this, at a sediment depth of about 370 meters; thin chert stringers of Paleocene age appear, interbedded with micrites and shelly micrites. A molluscan fauna is associated with these lower sediments, including *Inoceramus* sp. and oysters. This, along with associated glauconite, suggests a relatively shallow-water environment. Similar carbonate sediments without interbedded cherts occur below this zone to a depth of about 550 meters, where chert stringers reappear in early Maastrichtian to late Campanian sediments. Below about 600 meters and extending down to the bottom of the hole at 664 meters, an interbedded sequence of saccharoidal dolomites, cherts, and silicified biomicrites appears, associated with a possible mud-cracked layer near the base which suggests subaerial exposure. Core recovery in the lower 110 meters is shown in Figure 2.

A typical 150-cm core section from the dolomite-chert-silicified micrite zone is shown in detail in Figure 3 to illustrate the interbedded nature of these lithotypes. Statistics compiled from the entire dolomitic zone indicate that dolomite beds vary from 2 to 50 cm in thickness and average 12 cm, while cherts vary from whisps to 10 cm, averaging about 5 cm.

As indicated in Figure 3, contacts between dolomite zones and silicified micrites vary from sharp to diffuse and gradational. The dolomites, which appear to have replaced coarse-grained layers of gravel-sized bioclastic debris, occasionally preserve relict sedimentary structures which are clearly predolomite in origin and which include cross-stratification and bioturbation. Evidence of bioturbation is also widespread in the interspersed fine-grained nondolomitic layers.

A plot of percent dolomite versus chert for each 150-cm core section is shown in Figure 4. There are two zones

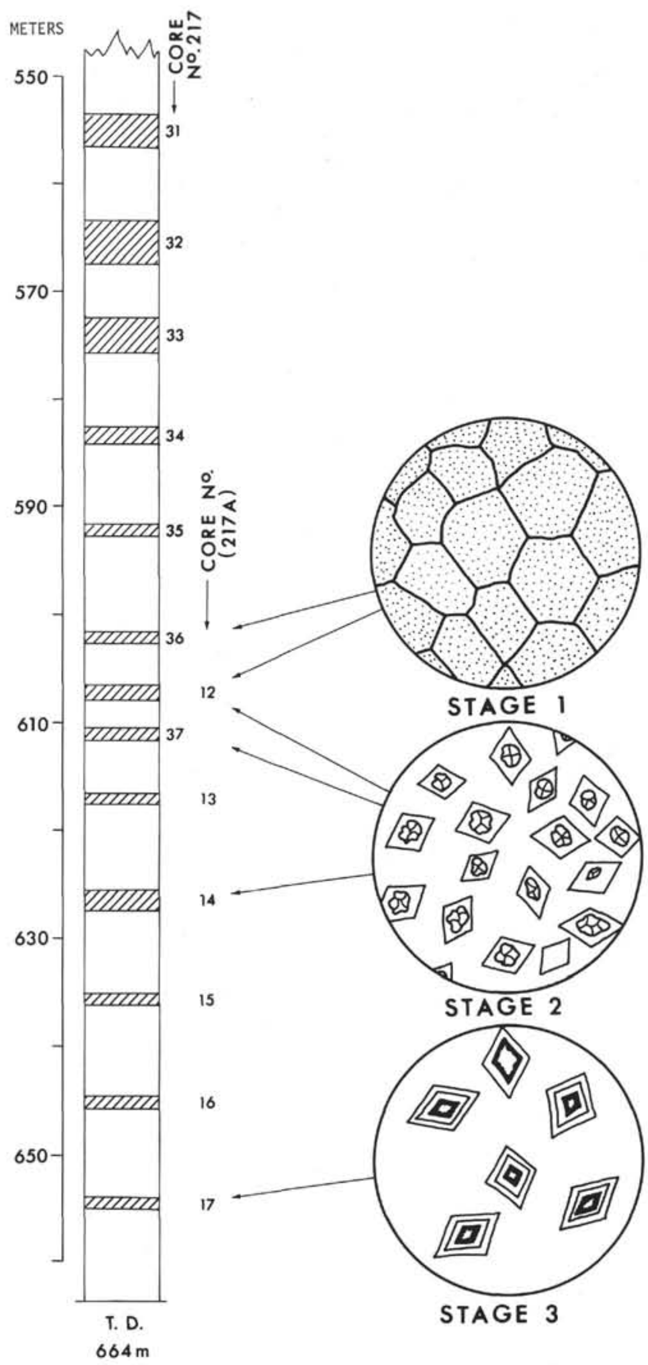

Figure 2. *Summary stratigraphic column of the basal sediments of Holes 217 and 217A. Shaded zones on the column represent recovered material, the remainder being voids. Line drawings (not to scale) of representative textures are shown, based on thin-section petrography. These are grouped as: Stage 1, bioclastic sparry calcite debris with micritic matrix from above dolomitized zone. Stage 2, dolomite rhombs of uppermost dolomitized zone showing an outer dolomite overgrowth over a rounded calcite core of preexisting bioclastic material. Dolomite rhombs with no calcite nuclei are also present at this level. Stage 3, dolomite rhombs of deepest sampled interval showing one to two calcite zones and one to two dolomite zones overgrowing corroded dolomite nuclei.*

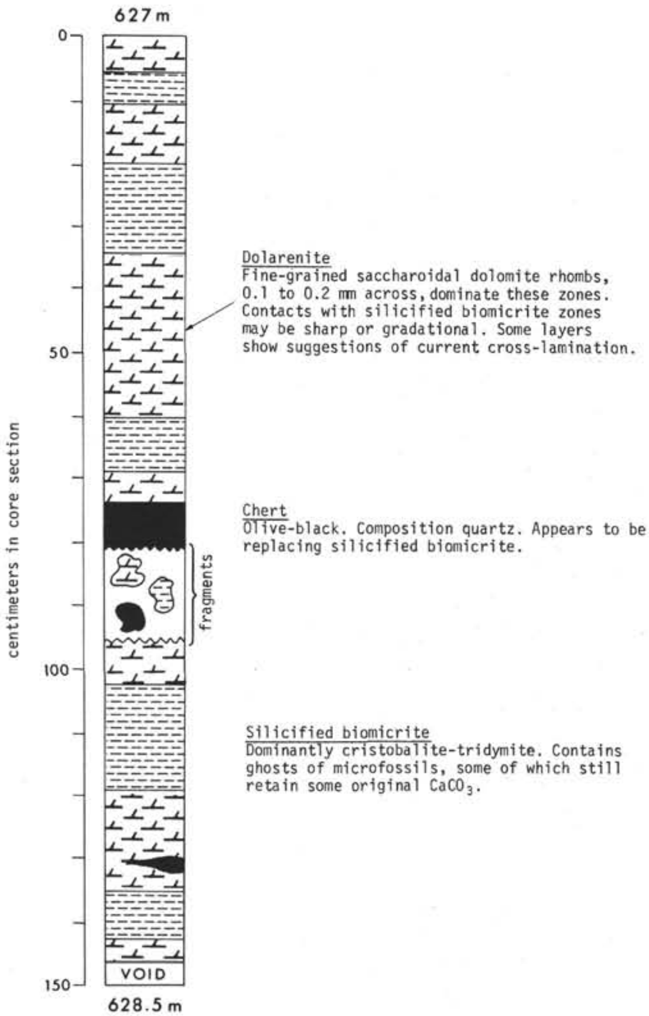

Figure 3. *Lithology of a typical core section from the Campanian dolomitized basal zone of Hole 217A (14-2). The alternation of beds rich in sugary dolomite rhombs with fine-grained silicified biomicrites and olive black chert layers is apparent.*

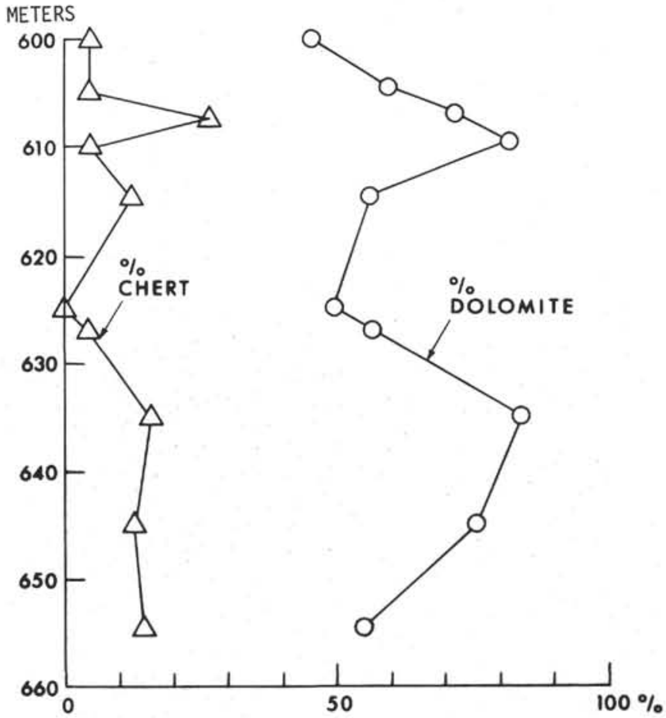

Figure 4. *Graph of percent dolomite and chert versus depth in hole. The percentages were calculated by summing up for each 150-cm core section the lengths representing dolomite and chert and recalculating this to percentage of length of a particular core section. The graph shows a covariance between dolomitization and chertification, suggesting a genetic relationship. The two peaks in dolomite content may represent an abundance of suitable host beds for dolomitization at these two levels.*

which are particularly rich in dolomite layers, with the amount of chert appearing to covary with the dolomite.

MICROSCOPIC TEXTURES

A total of 20 microscopic thin sections of the dolomitized basal sediments was prepared. Before cementing cover slips onto slides, the sections were stained with alizarin red solution in order to distinguish between calcite and dolomite. Selected photomicrographs are illustrated in Figures 5 and 6.

Studies of mineralogy and texture of thin sections of sediments immediately overlying the dolomites and the dolomite-rich layers themselves reveal a vertical sequence in degree and texture of dolomitization, summarized as Stages 1, 2, and 3 in Figure 2.

Stage 1, exemplified by Figures 5a and b, is typified by undolomitized coarse bioclastic debris. Recrystallization makes it difficult to identify the original material, although fragments of coral (Figure 5a and 5b) and calcareous algae can be recognized with confidence. In all cases the bioclastic fragments are composed of sparry calcite and are set in a calcite-micrite matrix. This lime mud also infills interseptal spaces in the corals.

Stage 2, illustrated in Figures 5c and 5d, occurs at a greater depth in the sediment than Stage 1. Textures consist either of an interlocking mosaic of euhedral to subhedral dolomite rhombs with rounded sparry calcite cores (Figure 5c) or in some layers of euhedral rhombs composed entirely of dolomite (Figure 5d). The polycrystalline calcite cores in Figure 5c may be relict bioclastic material and may originally have been aragonitic. In both of these cases the matrix between the rhombs is isotropic silica.

Stage 3, which occurs below Stages 1 and 2 in the sediment column, is shown in Figures 6a, b, and c. At this level dolomite rhombs are notably zoned, with somewhat corroded dolomite cores surrounded by one (Figure 6a) or two (Figures 6b and 6c) zones of calcite alternating with one or two zones of dolomite. Matrix between the rhombs is generally isotropic silica as in Stage 2. At this lowest level in the column any evidence of former bioclastic debris has been obliterated by the growth of the dolomite rhombs.

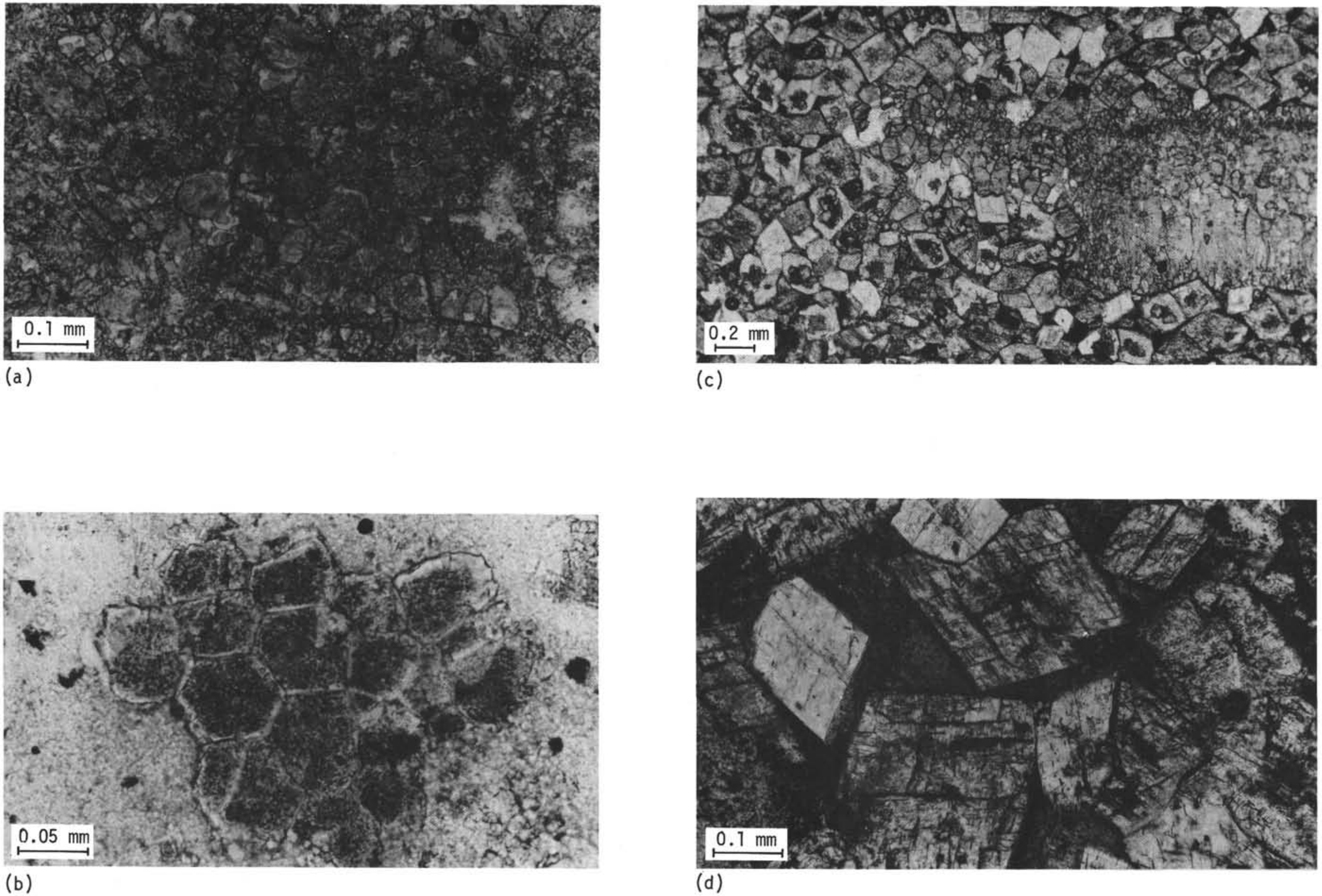

Figure 5. *(a) Sample 217A-12-1, 78 cm, coarse biocalstic debris (sparry calcite) of Stage 1 (Figure 2) associated with micritic calcite matrix. Material similar to this is presumably host to dolomitization at depth. (b) Sample 217A-12-1, 78 cm. Fragment of possible coral, composed of calcite. Equivalent to Stage 1 (Figure 2). (c) Sample 217-13-1, ? cm. Close-packed mosaic of dolomite rhombs of Stage 2 (Figure 2). Sparry calcite cores, representing relict bioclastic calcite, show as rounded dark centers of rhombs in this stained slide. Rare matrix probably cristobalite. Fragment of* Inoceramus *to right center. (d) Sample 217A-12-1, 140 cm. Close-packed mosaic of interpenetrating dolomite rhombs of Stage 2 (Figure 2) without nuclei. Brown isotropic matrix probably cristobalite.*

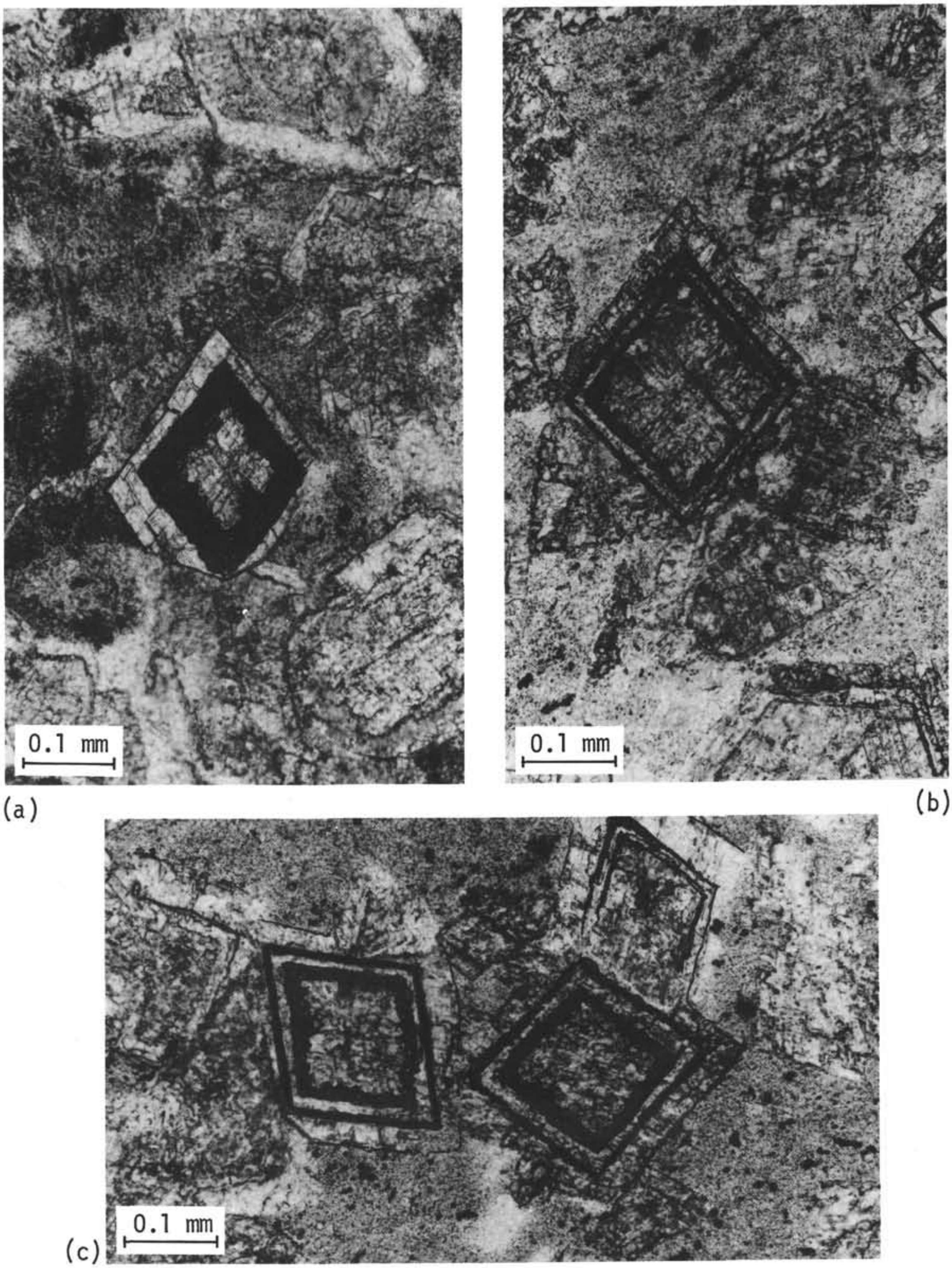

Figure 6. *(a) Sample 217A-17-1, 83 cm. Euhedral dolomite rhombs of Stage 3 (Figure 2) showing dolomite cores followed by a calcite (stained) and dolomite zone. Matrix possibly cristobalite. Innermost calcite zone appears to be corroding dolomite core. Calcite zone retouched in black. (b) Sample 217A-17-1, 65 cm. Euhedral dolomite rhombs of Stage 3 (Figure 2) showing corroded dolomite nuclei, followed by calcite-dolomite-calcite-dolomite zones. Slide stained, calcite zones retouched in black. (c) Sample 217A-17-1, 65 cm. Similar to (b).*

X-RAY MINERALOGY

Table 1 illustrates the mineralogical composition of samples from the dolomite-chert-silicified micrite sequence.

It is apparent that the dolomites are either dominantly composed of the mineral dolomite or of subequal portions of stoichiometric dolomite and calcite. Accessory minerals, possibly representing the groundmass between the rhombs, are generally cristobalite and tridymite. The interbedded fine-grained sediments, the silicified biomicrites, are dominantly cristobalite and tridymite and may represent an early stage in the process of chertification. The olive black cherts are dominantly quartz in composition, associated with traces of calcite which may represent relict calcareous microfossils.

INTERPRETATION

The presence of coarse, occasionally current-bedded, bioclastic debris and interbedded biomicrites of Stage 1 (Figure 2) suggests that the basal portion of the sediment column was originally a reef talus, possibly formed in a shallow off-reef environment. The occurrence of a possible mud crack near the base of the sediment column indicates periodic subaerial exposure as would be expected during periodic desiccation in a lagoon.

Stage 2 textures (Figure 2), which underlie Stage 1, are typified by almost complete obliteration of original forms by dolomitization. Textures at this level consist in some layers of rhombs made up entirely of dolomite, and in others, of single euhedral overgrowths of dolomite over relict corroded calcite nuclei. A single episode of dolomitization is suggested at this depth by these textures, with sparry calcite nuclei representing the remnants of bioclastic debris similar to Stage 1. The dolomite rhombs without calcite cores may represent complete dolomitization with consequent obliteration of preexisting nuclei, or they could represent rhombs which nucleated originally as dolomite.

Stage 3 textures (Figure 2), which occur at the deepest levels, consist of corroded dolomite nuclei, overgrown by one or two zones of calcite alternating with one or two zones of dolomite. This suggests two to three episodes of dolomite growth separated by periods conducive to calcite formation.

If the sampling is representative of the lithologies, then the zoned textures of the dolomite rhombs indicate that deepest sediments have been subjected to more episodes of dolomitization than overlying sediments. This is in accord with an origin of the dolomite by periodic seepage refluxion of high Mg/Ca solutions during or soon after sedimentation. Climatic variations or oscillations in relative sea level could cause periodic hypersalinity of the lagoon at which times dolomitizing fluids would be produced. The fact that deepest sediments record two or even three periods of dolomitization while shallower sediments only record one argues for dolomitization during building up of the sediment column. The earliest phase of dolomitization, perhaps due to an initial phase of lagoonal hypersalinity, produced the dolomite nuclei of Stage 3 textures before much of the overlying sediments were deposited. This was followed by further sedimentation of reef debris and interbedded biomicrites during which time a calcite overgrowth formed over the early-formed dolomite rhombs under the influence of normal seawater pore solutions. A subsequent episode of lagoonal hypersalinity produced another influx of dolomitizing pore solutions, causing calcite fragments from younger sediments to be overgrown by dolomite and adding a second dolomite overgrowth to the deeper, older dolomite rhombs. This process may have been repeated three times before the crest of Ninetyeast Ridge finally sank below sea level with consequent deposition of oceanic nannofossil ooze which has persisted to the present. The possibility should also be stated that the calcite zones of the rhombs could have formed during periods of emergence of the island, with subaerial solution

TABLE 1
Semi-quantitative X-ray Diffraction Analyses of Selected Samples of Dolomites, Fine-grained Biomicrites, and Silicified Biomicrites

Description		Quartz	Calcite	Dolomite	Montomorillonite	Clinoptilolite	Cristobalite	Tridymite
217A-12, CC	Dolomitized Zone	FTr	CD	CD	–	–	–	–
217A-12-1, 88 cm	Biomicrite	Tr	D	–	–	–	Ac	Ac
217A-14-2, 12 cm	Silicified Biomicrite	Tr	Tr	–	–	–	CD	CD
217A-14-2, 33 cm	Dolomitized zone	Tr	–	D	Ac	Tr	Ac	–
217A-14-2, 90 cm	Silicified Biomicrite	Tr	Tr	–	–	–	CD	CD
217A-17-1, 83 cm	Dolomitized zone	Ac	CD	CD	–	–	Ac	Tr
217A-17-1, 83 cm	Silicified Biomicrite	Tr	Tr	–	–	–	D	SD
217A-17-1, 101 cm	Silicified biomicrite	Tr	SD	Tr	D	–	Tr	Tr
217A-17-1, 128 cm	Silicified biomicrite	Tr	–	–	–	–	D	SD

Legend: D = Dominant (>50%)
CD = Codominant (subequal abundance of major components)
SD = Subdominant (20%-50%)
Ac = Accessory (5%-20%)
Tr = Trace (<5%)
FTr = Faint trace (<1%)

of limestones providing downward-percolating $CaCO_3$-rich solutions.

Zoned, rhombic carbonates were reported by Schlanger (1964) in lagoonal sediments from the Island of Guam. Episodic crystallization of dolomite and calcite zones indicated stages of postdepositional uplift and submergence before final emergence and cementation. On Christmas Island, one of the few oceanic islands in the eastern Indian Ocean (10°30'S, 105°40'E), zoned dolomitic carbonate rocks occur in the depressed central area of the upper plateau (Trueman, 1965). The fauna and textures of the Christmas Island carbonate rocks allow reasonable facies reconstruction in terms of reef limestone complexes and the dolomitic sparry carbonates represent original lagoonal environments in which dolomitization occurred during periodic emergency and submergence.

There are, therefore, close similarities between the form of the dolomitic carbonates from Site 217 and those of back-reef carbonates reported from islands in the Indian and Pacific oceans.

ACKNOWLEDGMENTS

This study benefitted greatly from the meticulous attention to detail in the shipboard core logs by Drs. R. W. Thompson and A. C. Pimm. Ian Dyson, of Flinders University, prepared the excellent set of microscope thin sections. Use of the X-ray diffraction equipment of Australian Mineral Development Laboratories is gratefully acknowledged.

REFERENCES

Adams, J. E. and Rhodes, M. L., 1960. Dolomitization by seepage refluxion: Am. Assoc. Petrol. Geol. Bull., v. 44, p. 1912-1920.

Berner, R. A., 1965. Dolomitization of the Mid-Pacific Atolls: Science, v. 147, p. 1297-1299.

Deffeyes, K. S., Lucia, F. J., and Weyl, P. K., 1964. Dolomitization: Observations on the Island of Bonaire, Netherlands Antilles: Science, v. 143, p. 678-679.

Ladd, H. S., Tracy, J. I., Jr., and Grant Gross, M., 1970. Deep drilling on Midway Atoll: U. S. Geol. Surv. Prof. Paper 680-A.

Newell, N. D., Rigby, J. K., Fischer, A. G., Whitemen, A. J., Hickox, J. E., and Bradley, J. S., 1953. The Permian reef complex of the Guadalupe Mountains region, Texas and New Mexico–A study in paleoecology: San Francisco (Freeman).

Schlanger, S. O., 1963. Subsurface geology of Eniwetok Atoll. U. S. Geol. Surv. Prof. Paper 260-BB, p. 991-1066.

———, 1964. Petrology of the limestones of Guam: U. S. Geol. Surv. Prof. Paper 403-D.

The Scientific Staff, 1972. Deep Sea Drilling Project, Leg 22: Geotimes, v. 17, p. 15-17.

Trueman, N. A., 1965. The phosphate, volcanic and carbonate rocks of Christmas Island, Indian Ocean: J. Geol. Soc. Aust., v. 12, p. 261-283.