

12. CONE-IN-CONE TEXTURE FROM DEEP SEA DRILLING PROJECT LEG 71, SITE 511, FALKLAND PLATEAU, SOUTH ATLANTIC OCEAN¹

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ABSTRACT

Transformation of aragonite to calcite and of high-magnesian to low-magnesian calcite is accompanied by a substantial increase in volume which produces cone-in-cone texture by tangential compression. Internal stresses stored within in the sediment could not be released until the core was extracted; then material and mounting medium expanded spontaneously.

INTRODUCTION

At Site 511 (51°00.28' S, 46°58.30' W) drilled on the Falkland Plateau during D.S.D.P. Leg 71, sequences of black shale, Late Jurassic–Aptian in age, contained three cone-in-cone textures. Such textures have already been described from Oxfordian–Kimmeridgian black shales at Site 330 (50°55.19' S, 46°53.00' W; Tarney and Schreiber, 1974). This chapter examines the morphology, microscopy, and geochemistry of two levels of cone-in-cone textures from Site 511.

MORPHOLOGICAL, LITHOLOGICAL, AND GEOCHEMICAL CHARACTERISTICS

The materials studied are from carbonate intercalations within the black shales of Cores 511-61 and 511-63. These black shales contain 3.66–5.99% organic carbon, well preserved and marine in origin (G. Deroo and J. P. Herbin, pers. comm., 1981). Microscopic analysis and X-ray diffraction (Holtzapffel, pers. comm., 1981) show that the carbonate intercalations are composed of more or less pure calcite. Specifically, they consist of (1) granular or microgranular calcite, locally compact, passing into true limestone; (2) calcite in large crystals or coarse fibers, locally transverse to clay separations in adjacent black shales (“beefy matrix”); (3) calcite in long, narrow fibers, either rectilinear or undulating, grouped in fans or in “rosettes” (0–360°). Examples of the textures described appear in Figures 1–8.

Locally the narrow fibers form well-defined beds, many centimeters thick. They form conical clusters, showing in longitudinal section the intersecting texture characteristic of cone-in-cone structure (Bonte, 1945; Cayeux, 1935, pl. 20, figs. 75–76; Mackenzie, 1972, figs. 3–5; Woodland, 1964, figs. 32–67 and 82). The clusters commonly end against a more shaly bed, forming parabolic sections or “asparagus head” sections (Figs. 4 and 6). On transverse section, the fibers form more or less open fans or “rosettes” (Figs. 7 and 8), which are equivalent to the clusters seen in longitudinal section.

¹ Ludwig, W. J., Krashenninikov, V. A., et al., *Init. Repts. DSDP, 71*; Washington (U.S. Govt. Printing Office).

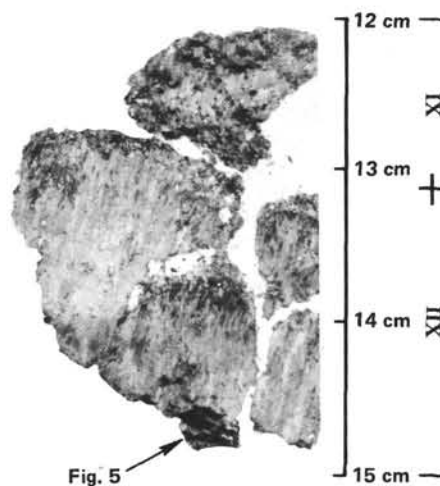


Figure 1. Sample 511-61-5, 12–15 cm, thin section VI bis. Calcite with cone-in-cone structure surrounded by black shale. Upper part, fibrous calcite showing conical texture with black shale fragments; lower part, large elongated calcite crystals. At the base, above the black shale, an exfoliated shale fragment with streaks of “beefy matrix” (see Fig. 5). Chemical analyses were made at points XI and XII.

The calcitic masses may be relatively pure, as in the fibroconical beds (about 50% CaO), or may contain brown material rich in organic matter, similar to the black shales in the immediate vicinity. This material occurs in varying forms: as compact elements, exfoliated pieces with streaks of “beefy matrix,” dilacerated shales mixed with calcite crystals, and micro-inclusions inside the calcite fibers. The organic material which impregnates the fibers is composed of algal filaments and cysts, singly or in groups (R. Coquel, pers. comm., 1981), mixed with considerable light brown unidentifiable chitinous material. The mode of sedimentation, microscopic texture, and chemical composition are similar to those described by Mackenzie (1972).

SAMPLE DESCRIPTIONS

Sample 511-61-5, 11–17 cm has a carbonate fraction extending from 511-61-5, 12–15 cm (chemical analyses,

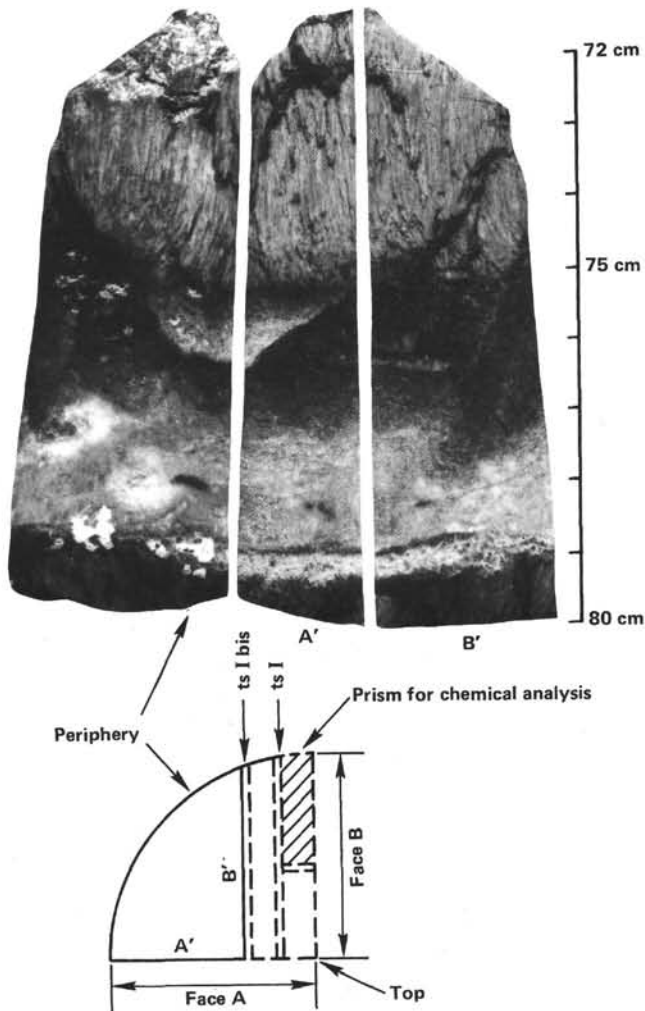


Figure 2. Sample 511-63-3, 72-80 cm. Developed surface of the polished and varnished sample. Granular or microgranular calcite, more or less cemented, between two layers of fibrous calcite with cone-in-cone structure. The upper layer presents a characteristic fibroconical arrangement, "asparagus heads"; the lower layer is disturbed (see Fig. 6). The outline indicates the position of the photographs (periphery, A', B') and of the thin sections (ts)I and I bis, as well as the position of the prism for chemical analysis (IV-X).

Table 1; points XI and XII on Fig. 1). It is framed by two black shale layers (511-61-5, 11-12 cm), and 511-61-5, 15-17 cm), containing 3.66% and 3.84% organic carbon, respectively, (Deroo and Herbin, pers. comm., 1981); the chemical composition of these samples, obtained using techniques described by Robert and Maillot (this volume), are given in Table 1.

The carbonate fraction, which disintegrated on contact with the diamond saw, comprised two zones:

1) An upper zone, formed of fibrous calcite with a conical texture (CaO = 47.7%), stained by numerous impurities (black shale beds; Al₂O₃ = 1.77%, SiO₂ = 5.55%) and more or less exfoliated.

2) A lower zone, formed of large calcite crystals (CaO = 49.67%), nearly pure in spite of microscopic inclusions, with a few isolated particles of black shale (Al₂O₃ = 1.24%, SiO₂ = 3.35%); at the base is an exfoliated shale fragment with streaks of "beefy matrix" (Fig. 5).

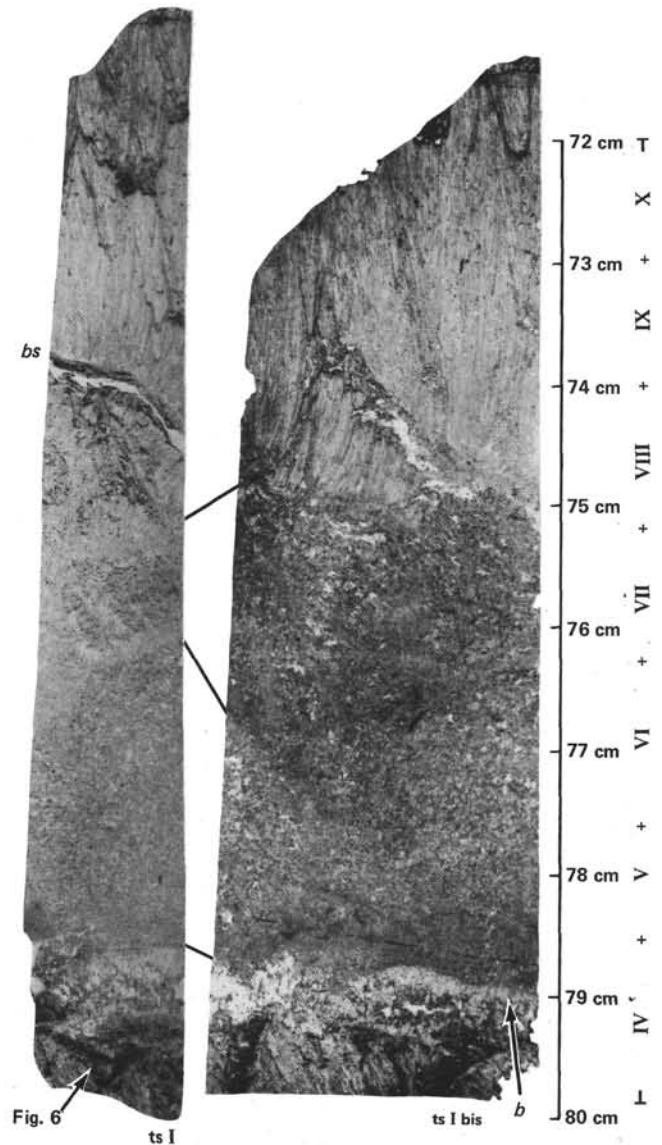


Figure 3. Sample 511-63-3, 72-80 cm, thin sections (ts) I and I bis. Thin vertical sections of the preceding sample, faces B (ts I) and B' (ts I bis) with sampling locations for chemical analysis (IV-X): 72-75 cm, long vertical fibers with crossed fibroconic texture; bs, intercalation of dislocated black shale. 75-79 cm, granular or microgranular calcite with incomplete calcite "rosettes." 79-80 cm, fibroconic calcite with dislocated black shale fragments intercalated (see Fig. 6); at the top, layer of coarse vertical fibrous calcite fibers, b.

The carbonate Sample 511-63-3, 72-97 cm is surrounded by black shales (511-63-3, 70-72 cm and 511-103-3, 97-99 cm) containing 5.59% and 3.96% organic carbon, respectively (Deroo and Herbin, pers. comm., 1981); their mineral and chemical compositions are summarized in Table 1. The carbonate specimen (Figs. 2 and 3) has been divided into three zones on the basis of morphological aspect and lithological composition:

1) *Zone 1*, 511-63-3, 72-80 cm. Chemical analyses show a high carbonate fraction, poor in strontium and relatively rich in manganese (rhodochrosite?, manganiferous calcite?). The upper part (511-63-3, 72-75 cm) consists of long intersecting fibers in which a few cones

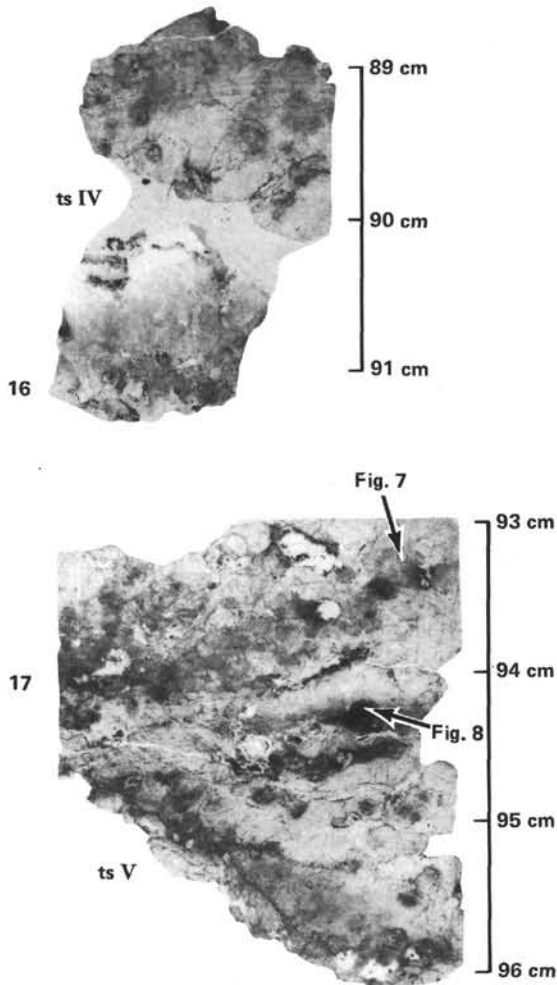


Figure 4. Samples 511-63-3, 89-91 and 511-63-3, 93-97 cm, thin sections (ts) IV and V. Vertical sections showing the distribution of "rosettes" representing oblique sections of fibroconic clusters, in the shape of "asparagus heads" (see Figs. 7 and 8).

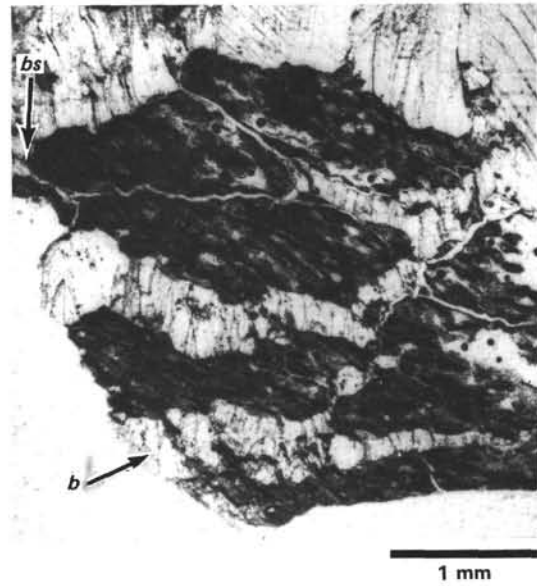


Figure 5. Sample 511-61-5, 15 cm, Thin section (ts) VI bis. Microphotographs of an exfoliated shale fragment, *bs*, with layers of "beefy matrix," *b* (see Fig. 1).

tend to be individually distinct; black shale material emphasizes their shape. This zone is crossed obliquely by a discontinuous shaly layer (Fig. 3, *bs*). The lower part (511-63-3, 79-80 cm) is also fibroconical, with intercalations of dislocated black shale fragments (Fig. 6); at the top, it is bounded by a layer of fibrous carbonate of the "beefy matrix" type (Fig. 3, *b*).

Between the fibrous calcite layers (511-63-3, 75-79 cm) occurs a heterogeneous mass of granular calcite or of incomplete "rosettes" with considerable scattered organic material. The granular or microgranular calcite forms more compact masses, appearing white on polished surfaces (Fig. 2). The boundaries between these

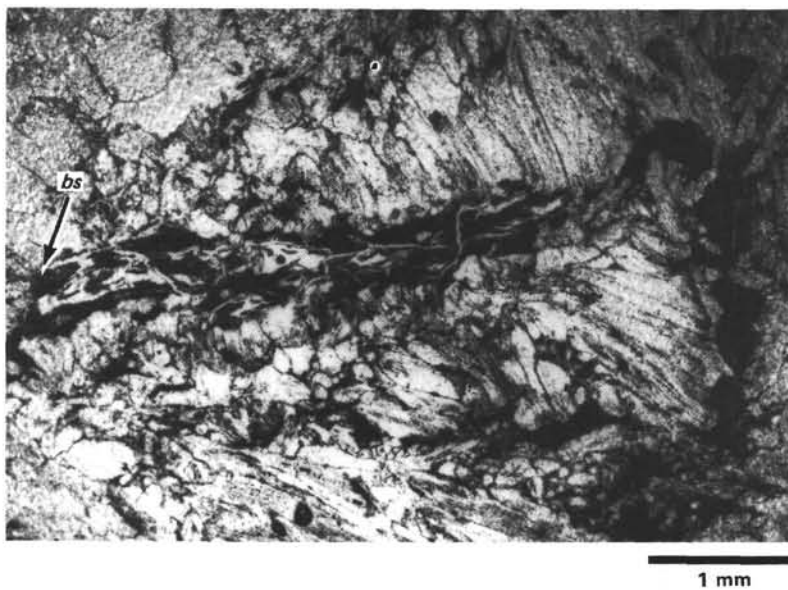


Figure 6. Sample 511-63-3, 79-80 cm, Thin section (ts) I. Microphotograph of fibroconical calcite with exfoliated shale fragment, *bs* (see Fig. 3).

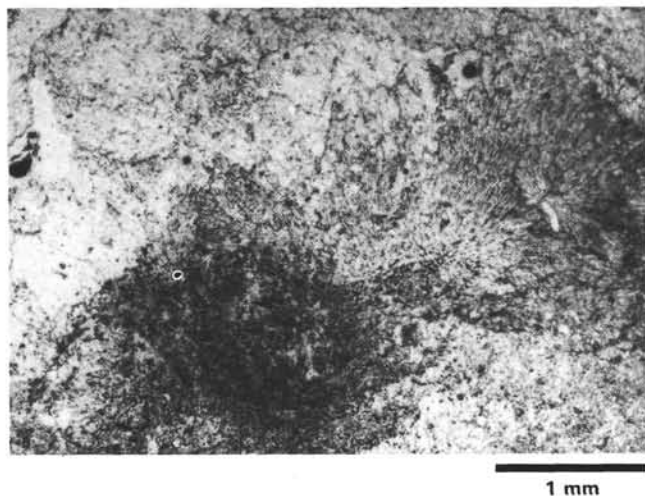


Figure 7. Sample 511-63-3, 93 cm. Thin section (ts) V. Large "rosette" in the NE quadrant (see Fig. 4).

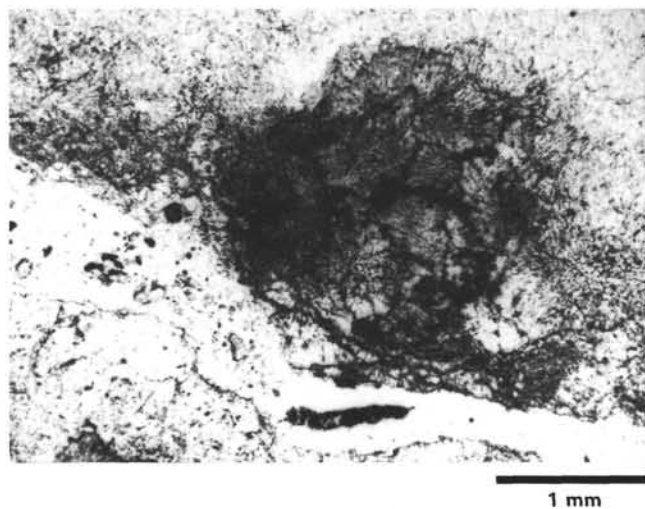


Figure 8. Sample 511-63-3, 94 cm. Thin section (ts) V. Incomplete "rosettes" in a fibroconical mass of which the axes are randomly oriented (see Fig. 4).

Table 1. Chemical analyses, Hole 511 samples.

Core/Section (level in cm)	SiO ₂ (%)	Al ₂ O ₃ (%)	CaO (%)	MgO (%)	Na ₂ O (%)	K ₂ O (%)	TiO ₂ (%)	Fe ₂ O ₃ (%)	Mn (ppm)	Sr (ppm)
61-5, 11	43.80	9.57	13.36	1.72	1.48	1.79	0.31	2.83	442	189
61-5, 12	5.55	1.77	47.71	0.58	0.24	0.16	0.03	0.55	1510	237
61-5, 14	3.35	1.24	49.67	0.50	0.15	0.07	0.01	0.48	1605	242
61-5, 15	48.40	9.39	10.88	1.33	1.31	2.23	0.38	3.18	3.95	163
63-3, 70	49.45	13.28	4.37	1.60	1.52	2.99	0.46	4.90	237	116
63-3, 72	1.90	0.80	50.79	0.65	0.07	0.09	0.03	0.54	1789	184
63-3, 73	4.75	1.51	48.97	0.62	0.13	0.21	0.05	0.53	1432	105
63-3, 74	8.75	2.90	44.14	0.77	0.27	0.42	0.01	0.83	947	100
63-3, 75	5.60	2.13	47.47	0.76	0.20	0.24	0.05	0.54	963	111
63-3, 76	2.65	0.99	51.07	0.67	0.11	0.04	0.02	0.27	1074	84
63-3, 77	1.90	0.70	51.42	0.69	0.07	0.01	0.01	0.46	1126	84
63-3, 79	2.30	1.10	50.55	0.81	0.10	0.12	0.03	0.46	1105	142
63-3, 82	0.05	0.33	53.69	0.36	0.03	0.01	0.03	0.22	1658	405
63-3, 85	1.55	0.77	51.98	0.51	0.09	0.01	0.06	0.24	1974	432
63-3, 87	0.85	0.71	52.61	0.58	0.08	0.01	0.05	0.29	2295	447
63-3, 89	5.80	2.78	46.94	0.73	0.34	0.06	0.02	0.42	2447	337
63-3, 92	4.65	1.89	48.97	0.63	0.22	0.05	0.02	0.40	2474	363
63-3, 97	54.70	14.76	2.31	1.51	1.42	3.82	0.05	4.65	221	142

different facies are indistinct, perhaps as a result of postsedimentary movements.

2) *Zone 2*, 511-63-3, 82-88 cm. The upper part of this zone is cut by an oblique fault which, in thin section, is marked by calcite particles (chemical analyses, Table 1; X-ray diffraction, Holtzapffel, pers. comm., 1981). Along this fault the calcite has disintegrated as the result of a kind of spontaneous expansion, which has affected the mounting medium.

Aside from the oblique fault, the sample is composed of white calcite fibers at 45° to the axis of the core. The obliquity of the fibers, which are largely recrystallized, somewhat masks the conical texture, which nevertheless manifests itself in the upper part, where calcite "rosettes" occur within black shaly material. The carbonate fraction is noticeably richer in strontium than in Zone 1. The manganese concentration is also markedly higher (Table 1).

3) *Zone 3*, 511-63-3, 89-91 cm and 511-63-3, 92-97 cm; Fig. 4. These two samples are slightly less rich in carbonate than those of the preceding zone (Table 1). They show a correlative enrichment in silica and aluminum. They are characterized by abundant "rosettes," rarely complete, with all orientations, stained by black shale material (see chemical analysis). The "rosette" centers, which resemble, in thin section, circular spots (Fig. 4), correspond to the centers of the fibrous clusters ("asparagus heads"), the axes of which have a variable orientation and have been obliquely sectioned by the vertical cut (Figs. 7 and 8).

In summary, all the analyzed samples present cone-in-cone structures, different in aspect. They appear as (1) regular bands of fibroconical structure (511-61-5, 12-13 cm and 511-63-3, 72-75 cm), or dislocated (511-63-3, 79-80 cm) and exfoliated bands (511-61-5, 15 cm), the axes of the fibrous clusters being vertical; and (2) isolated fibrous clusters, irregularly orientated and distributed (511-63-3, 89-97 cm).

Organic matter, in the form of black shale remains, occurs everywhere, in more or less exfoliated masses or as minute particles, along or at the tips of the conical clusters, or even dispersed inside the crystals as microscopic fragments. However, the steplike arrangement characteristic of this texture was never observed. It occurs locally as isolated steps, along calcite cleavages, but never in sawtooth sections comparable to those described by Tarney and Schreiber (1977).

ARAGONITE — CALCITE OR MAGNESIUM CALCITE — CALCITE TRANSFORMATION AND THE OCCURRENCE OF CONE-IN-CONE TEXTURE

Average Composition of Sedimentary Calcite

From the chemical compositions of the sample (Table 1) the chemical form of the carbonate enriched fraction can be determined.

The sedimentary calcite corresponds to the formula



When $0 < x < 0.25$ the calcite is stable (Debrabant and Chamley, in press). It is very stable when $x \cong 0$. The many chemical analyses of North Atlantic sediments (Debrabant et al., 1979) or in the Southern Atlantic (Maillot, 1980; Maillot and Robert, 1980) show that the average amount of magnesium contained in the shales is given by the relation

$$\frac{\text{MgO}}{\text{Al}_2\text{O}_3} = 0.16.$$

It is possible to calculate the amount of MgO present in the shales and thus deduce the quantity of Mg present in the carbonates. Applied to the two series of carbonate-enriched samples described above (511-61-5, 12-15 cm and 511-63-3, 72-97 cm), the calculation shows that the calcite is always in the form



It is therefore a calcite with very little Mg, that is to say very stable (Berner, 1971).

Diagenetic Evolution of Carbonates

The evolution of the ratio 10^3 Sr/CaO indicates the stage of carbonate diagenesis (Debrabant et al., 1979; Chamley et al., 1979). For the two sections studied, 511-61-5 and 511-63-3, the ratios are very low, which indicates a high diagenetic evolution. The Mg calcite is therefore very stable. In three samples, 511-61-5, 12-14, 511-63-3, 72-80, and 511-63-3, 82-92, 10^3 Sr/CaO was, respectively, 0.50, 0.23, and 0.78.

Hypothesis for Cone-in-Cone Texture Formation

Early diagenesis in a reducing environment determines the removal of Mn^{2+} and the partial dissolution of CaCO_3 . Mn^{2+} and Ca^{2+} are able to precipitate again when the Eh and pH increase or when interstitial solutions are concentrated above an impermeable layer. These processes are probably responsible for the crystallization of inorganic aragonite and of manganocalcite.

Many studies have shown that the transformation of aragonite to calcite and of high-magnesian to low-magnesian calcite are both accompanied by a volume increase, equal to 8.14% of the initial volume in the first instance and between 2.80 and 6.53% in the second instance. The transformation of an original aragonitic or highly magnesian calcitic material to a weakly magnesian calcitic material is accelerated by strong reducing conditions, as is the case here. The resulting volume increase could represent the mechanism that generates cone-in-cone texture (Bonte and Maillot, 1979), by different processes:

1) The sedimentary factors or conditions necessary to form cone-in-cone texture may come into being shortly after carbonate enrichment occurs. Surface alteration and the absence of diagenesis with burial may lead to

early and significant growth of the cones (Bonte and Maillot, 1979).

2) The sedimentary factors or conditions necessary to form cone-in-cone texture may not be met until the sediments are subjected to strong diagenetic effects after the carbonate transformation, during burial. Under these conditions, the strains caused by the increase in volume might remain partially stored in the sediment and the internal stresses would not be released until the core was extracted. The samples analyzed here may fall into this second category but in this instance stress liberation may have been incomplete; thus the explosion of Sample 511-61-5, 12-15 cm during cutting and the spontaneous expansion of Sample 511-63-5, 82-88 cm might mark the end of carbonate expansion.

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