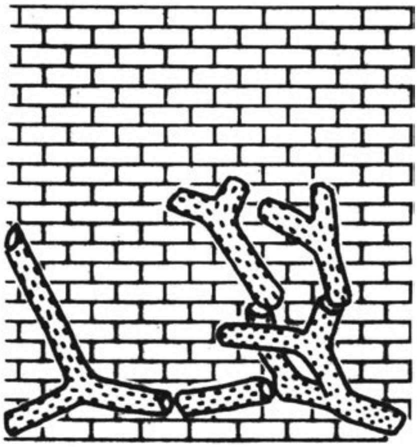

CHALK AND BRYOZOAN LIMESTONE: FACIES, SEDIMENTS AND DEPOSITIONAL ENVIRONMENTS

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The Maastrichtian/Danian boundary in Denmark is invariably marked by an omission surface. The beds above and below this junction are exclusively carbonate rocks, with the exception of a thin clay layer, the Fish clay. More detailed descriptions of the lithofacies of these rocks are given elsewhere in this book (Håkansson & Hansen; Håkansson & Thomsen; Floris; Surlyk) and it remains here to give a general introduction to the major facies types, their constituents, depositional environments and some diagenetic features.

LITHOFACIES TYPES

Apart from the Fish clay mentioned above, the rocks on either side of the boundary in Denmark comprise a closely related suite of facies. They have in common a very low terrigenous content and a matrix of coccolith-rich mud, containing a variable and diverse fraction of other skeletal material. The nature and abundance of the skeletals give rise to a wide range of contrasting and distinctive lithofacies. The central facies, being the common matrix of most of the other facies, is chalk.

Chalk

The word has ancient origins and has carried with it into geological usage a simple definition: "an opaque white earthy limestone" (Oxford English Dictionary); "a calcareous earthy substance, of an opaque white color, soft, and easily pulverized" (Webster's New Twentieth Century Dictionary). Thus, similar white, soft materials have been described as chalky, e.g. 'chalky aragonite' for a stage in calcitization of corals (Pingitore, 1976) and 'chalky deposits' for the rapidly laid down, soft shell layers in oysters (Yonge, 1960).

In the past decade there has been an explosive acceleration in chalk research, and our increasing knowledge of the facies is bringing about a concomitant refinement of the definition. Individual investigators nowadays define chalk in terms that accord with the approach and techniques they use. Thus, for example Scholle (1977a, p. 2), familiar with the downward increase in lithification of the chalk of the North Sea Basin, and with the appearance of the rock with SEM, defined chalk as "fine-grained carbonate sediments composed primarily of calcareous nannofossils (especially coccoliths) and calcareous microfossils (such as foraminifera and calcipheres). No limitation is placed on the degree of induration of a chalk".

This biological definition is of limited use for the field geologist, concerned with lithostratigraphy. He cannot determine the nature of the fine grains, whereas he can detect and use minute differences in hardness. In our facies descriptions here, therefore, we retain the old usage, calling the soft, white, fine-grained facies 'chalk', and reserving the more general term 'limestone' for the other facies. Thus our definition of chalk for our present needs is: poorly or unlithified, white or nearly white, pure calcilutite.

The proportion of sand-sized skeletals in the Danish chalk varies considerably (Håkansson *et al.*, 1974). In cases where skeletons of a particular group dominate the fabric this may be reflected in the subfacies name. Thus the uppermost Maastrichtian at Stevns Klint is represented by bryozoan chalk.

Bryozoan limestone

The lower Danian rocks of much of the area contain a higher proportion of bryozoan skeletons than the bryozoan chalk (Fig. 1; Cheetham, 1971, Fig. 13). Nevertheless, the fabric remains in large part mud-supported, and the rock is generally rather feebly lithified. Bedding is distinct, and in many places reveals large-scale mound structures. These rocks are grouped together as the bryozoan limestone facies, but details of composition, fabric and diagenetic alteration are very varied and produce a wide range of subfacies.

Moltkia limestone

In the middle Danian the distinctive coral limestone facies occurs at many localities, dominated by branched ahermatypic scleractinian corals in a mud matrix (see Floris, this volume). However, this facies is not known to occur close above the base of the Danian and so does not concern us here.

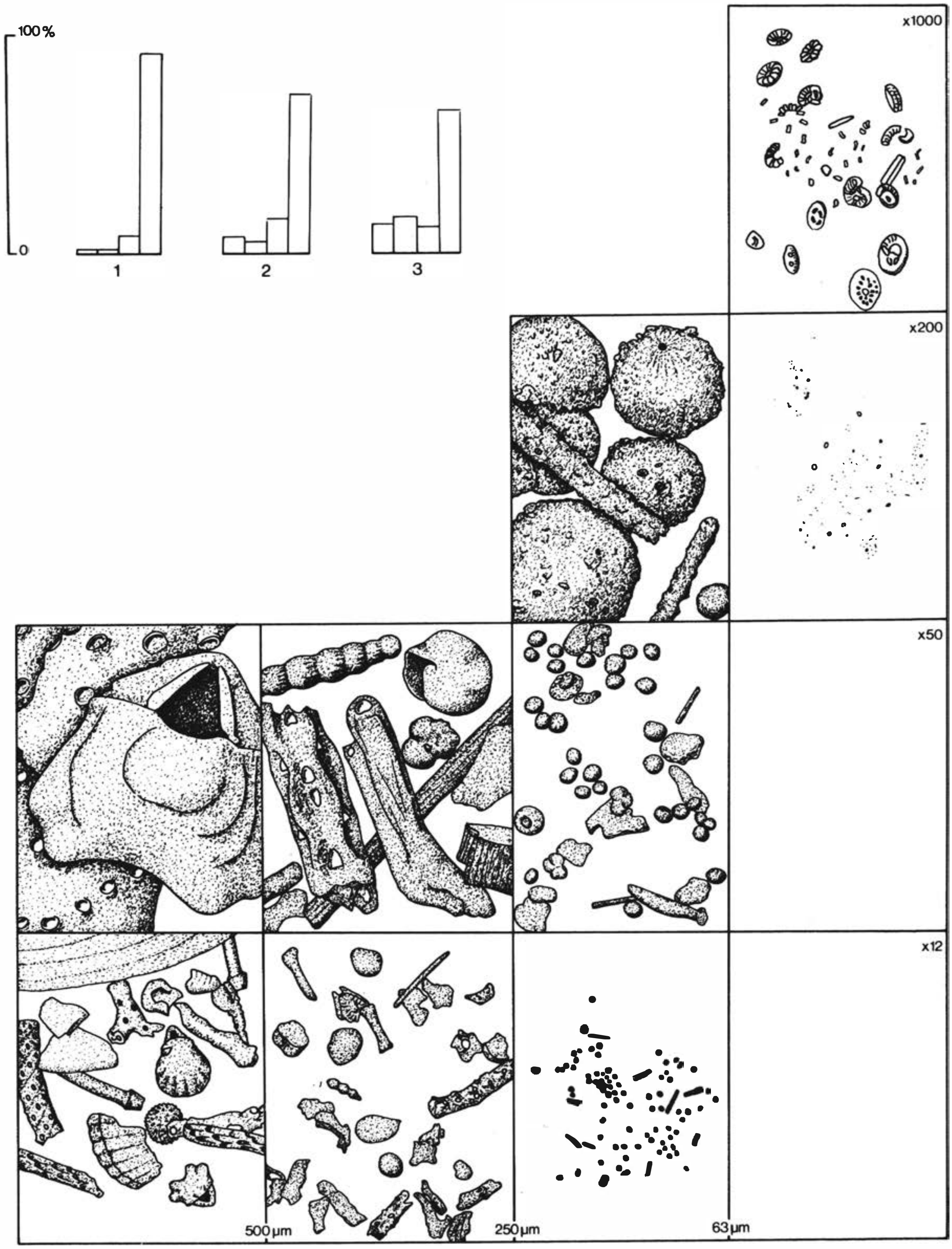
Fig. 1. Graphic representation of the grain-size and constitution of the sediments. Vertical columns represent four size fractions (screen sizes indicated at bottom). The fractions are shown at four magnifications (camera lucida X12 and 50, and sketches of SEM pictures). Note the extreme range of grain-size; at X50, where the >500 µm fraction is almost too large to depict, grains of the <63 µm fraction are not even visible. It should be remembered that the >500 µm fraction ranges up to whole skeletons several centimetres in size.

The histograms show the proportions of the same four fractions in different rocks (dry weight percent); 1: white chalk from 'Dania', 2 m below the boundary; 2: bryozoan chalk from Højerup, Stevns Klint, 2 m below the boundary (both from Håkansson *et al.*, 1974, Fig. 4); 3: bryozoan limestone from Limhamn, upper 1 m of lower Danian (after Cheetham, 1971, Fig. 13B)

Grain-size of the coursest fractions is gradational, the screens representing artificial boundaries. It is clear from the figure (X12), however, that there is a large size difference between these and the finest fraction, i.e. the 63 µm screen falls within a wide, natural hiatus. Thus, if intermediate fractions were considered, the histograms would be strongly bimodal.

Much of the 250-63 µm fraction consists of dismembered chambers of planktic foraminifera which, as whole skeletons, would rightly belong in the 500-250 µm fraction. If breakage occurred on the sea floor, the relative proportions of the two fractions represent the natural sediment. It is possible, however, that some breakage occurred during the maceration of the rock samples (by freeze-thaw with glauber salt) prior to seiving.

Finally, it should be pointed out that each grain of the larger fractions is coated with (Fig. 3) and filled with (Fig. 4) sediment of the finer fractions. A significant amount of the finest fraction is thereby locked up in the coarser fractions. The histograms thus under-represent the extreme dominance of the micrite fraction. Unmacerated lumps of micrite also occur in the coarser fractions, further distorting the results in the same direction.


100%
0
1
2
3
x1000
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x50
x12
500 µm
250 µm
63 µm

A boring in Fakse Bakke, however, revealed over 13 m of a special facies, which Rosenkrantz (1938) called Moltkia limestone, immediately overlying the basal Danian Cerithium limestone. Over 50% of the rock consisted of broken fragments of the octocoral *Moltkia* sp. Octocorals are locally a significant constituent in the bryozoan limestone (see Floris, this volume); they are abundant, for example, in core and transitional facies of middle Danian bryozoan limestone mounds at Limhamn (Cheetham, 1971, p. 30).

Marl and clay seams

Thin beds of marl, a few centimetres thick, occur within the chalk and bryozoan limestone facies. The sediment differs from the surrounding rock chiefly in having a higher non-carbonate content.

A particularly thick marl seam, about 35 cm thick, occurs in Jylland several metres below the top of the Maastrichtian chalk. This was designated as the Kjølby Gaard Marl Member by Troelsen (1955), who noted several distinctive features of the foraminiferal fauna of this bed in contrast to that of the surrounding chalk.

The Maastrichtian chalk in Jylland, e.g. at 'Dania', contains a number of argillaceous horizons some tens of centimetres thick where the colour of the chalk is tinted faintly brownish or greyish (see Jørgensen, 1975, Figs 2-3). The preservation of microfossils, nannofossils and small skeletal grains tends to be better in these horizons, and the diversity and abundance of coccoliths and foraminifera higher than in normal chalk (Jørgensen, 1975, p. 305; Stenestad, this volume).

The base of the Danian at Stevns Klint is marked by a clay bed unusual in both spatial extent and composition. It consists of a dark brown, calcareous clay and lies directly on the upper surface of the Maastrichtian bryozoan chalk in the troughs between the bioherms (Surlyk, this volume). At the centres of these troughs it is thickest, reaching over 15 cm, and is strongly laminated. Christensen *et al.* (1973) examined the clay minerals of the Fish clay and divided it into several sub-beds. A similar, but laterally more continuous, brown clay seam occurs at the base of the Danian at many localities, both in Sjælland and in Jylland (Hansen, 1977; Håkansson & Hansen, this volume).

Constituents

On both sides of the Maastrichtian/Danian boundary, the constituent particles of the rocks have similar origins; it is the great variation in proportion of these constituents that creates the variety of facies and subfacies. Indeed, equivalent seived and washed fractions of

Maastrichtian chalk and Danian limestone are almost indistinguishable under the microscope, until taxonomy of the skeletons is taken into consideration. (However, the Maastrichtian bryozoan colonies are larger and stouter, producing a large size-fraction that is hardly represented in the Danian). The constituents are almost exclusively of biogenic origin: skeletons of organisms that have been fragmented to different degrees, or preserved more or less whole. Not surprisingly, the different size fractions of grains have contrasting compositions (Fig. 1) owing to both the original size of the skeletons and to inherent differences of breakdown.

Some of the more important skeletons and their breakdown products are represented in Fig. 2. Clearly, the breakdown of skeletons introduces different degrees of difficulty of fragment recognition in different organism groups. Species distinctions are generally lost at an early stage of fragmentation. Echinoderms, however, yield numerous grains of highly diagnostic shape, yet of small size, such as minute spines, pedicellaria jaws, etc., that often can be recognized in finer sediment fractions (e.g. Nielsen, 1925). As usual in carbonate sediments, however, echinoderm fragments are particularly prone to precocious overgrowth by syntaxial cement, which obliterates details of morphology. Bryozoans are thus probably determinable in even smaller fragments than echinoderms.

At the other end of the scale, bioerosion processes give rise to a host of recognizable flakes and chips of hard substrates as a result, e.g. of gnawing by regular echinoids or scraping by crabs. The original scratches are clearly recognizable on preserved substrates (Bromley, 1970 , 1975a), showing that the process has, in fact, operated, but the resultant debris is unrecognizable. On the other hand the methodical production of silt-grade chips of substrates by boring sponges results in readily recognizable grains having arcuate surfaces (Fütterer, 1974). Sponge borings are abundant in the bryozoan limestone, though in the chalk they are rather sparse, owing to rarity of suitable substrates. Sponge chips have been included, therefore, in Fig. 2, although their presence has not yet been recognized in the rocks under consideration.

Finally, a problem that should be mentioned in grain identification is illustrated in Figs 3 and 4, namely that each grain is coated by a 'single layer' of the finest fraction of the sediment. Finer details of morphology and ultrastructure are thereby masked. Grains from argillaceous chalk are cleaner than those from normal chalk, indicating that the coating represents an early stage of intergranular cement, corresponding to the familiar, minute syntaxial overgrowth seen in coccoliths (Figs 5 and 6; Jørgensen, 1975; Perch-Nielsen, this volume).

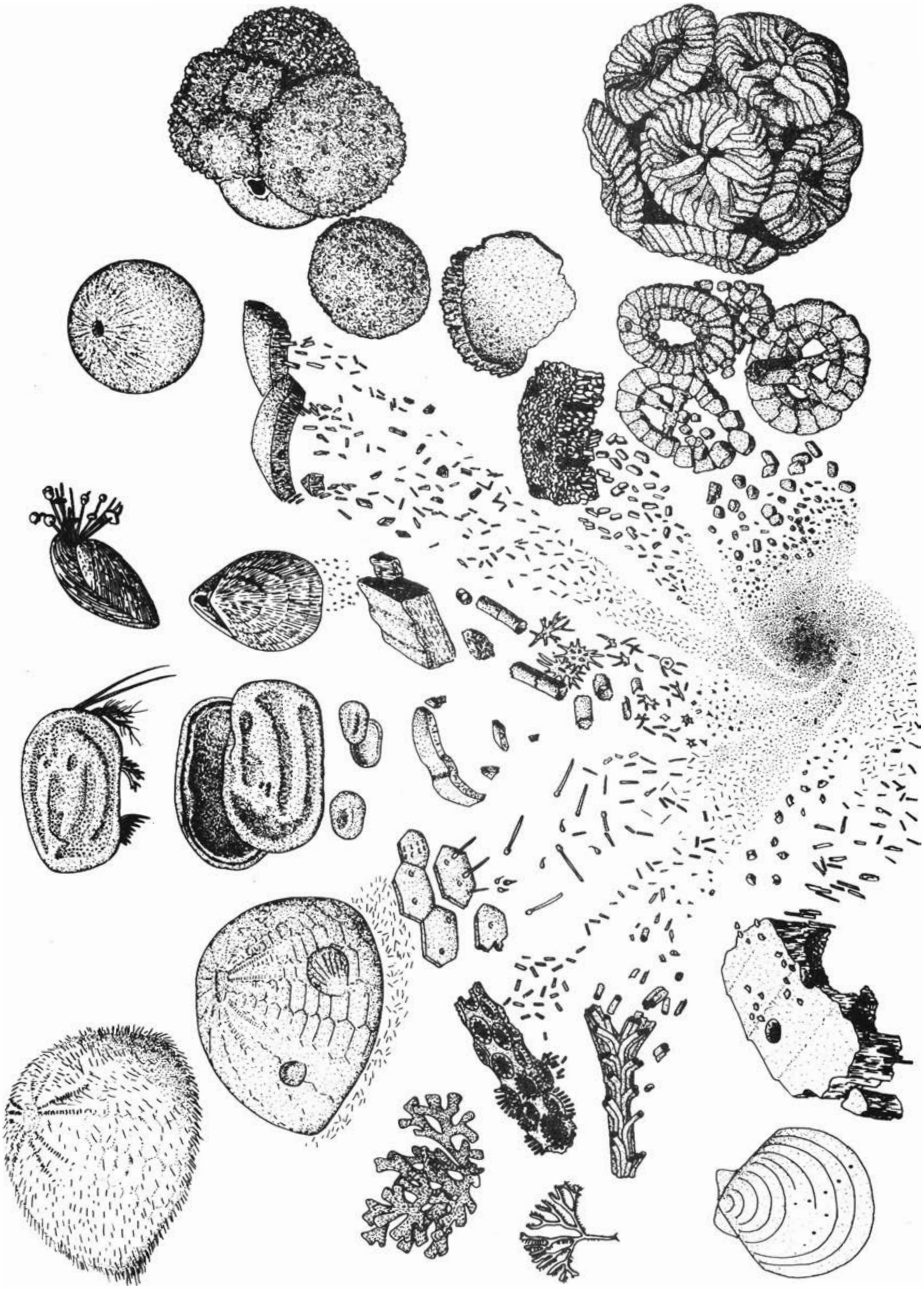


Fig. 2. Graphic representation of the constituents of chalk and bryozoan limestone. All stages of breakdown of skeletons occur in the final rock, but proportions of various breakdown stages and proportions of various organism groups vary considerably from facies to facies and from bed to bed. No indication of proportions is given here. Represented are (clockwise from lower left): bivalves and sponge borings; cyclostome and cheilostome bryozoans; echinoids, represented by a holasteroid irregular; crustaceans, represented by an ostracode (juvenile instars); brachiopod (valves and mesodermal spicules); calcispheres; planktic foraminifera and coccolithophores. Among the locally rock-forming groups omitted, for lack of space, are coelenterates (especially octocorals), serpulid worms, asteroids and the organisms having siliceous, purely aragonite or organic skeletons, which are represented in significant quantities in certain beds. Scale is variable, increasing and then decreasing again centripetally. Sources of information are numerous and divers, but much personal advice from colleagues is acknowledged. Original inspiration was Multer, Frost & Gerhard (1977, Fig. 8).

DEPOSITION

Chalk facies

The major fraction of the chalk is of pelagic origin and was produced in the water column above the sea floor. This material consisted largely of coccoliths (Figs 5 and 6), together with smaller amounts of planktic foraminifera, dinoflagellate cysts and radiolarians (though the latter were dissolved during early diagenesis). To this were added subordinate quantities of skeletal material produced by the benthos (Fig. 2).

According to Black (1965) the chief level of coccolith production in tropical seas today is about 50 m from the surface, and rather shallower in temperate seas. It is most probable that the majority of the coccolithophore algae, alive and dead, together with their shed coccoliths, were consumed by planktic predators and scavengers, and their skeletons bound together as faecal material. These excreta may have been consumed in turn by further scavengers and the cycle repeated several times before the coccolithic material arrived at the sea floor. The coccoliths may have accumulated as silt-sized bodies in this way, rather than settling individually as mud fraction.

Firm evidence for this is lacking in the sediments under consideration, any primary pellets having been obliterated by later biogenic reworking. In the less pure carbonate rocks of the Cretaceous of Kansas and

Saskatchewan, however, Hattin (1975) has demonstrated faecal pellets composed largely of coccoliths set in a matrix that is largely coccolith-free. Hattin argued that the pellets represented excreta of planktic coccolithophore predators, such as copepods.

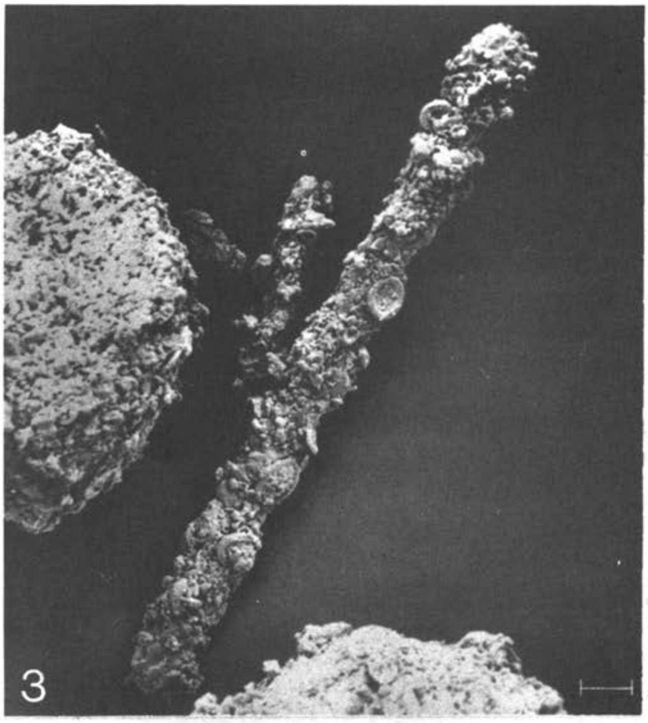
On the European chalk sea floor the detritus was rapidly recycled by deposit-feeding benthos. Evidence for this is provided by the preserved skeletons of superficial deposit-feeders such as echinoids, asteroids and ostracods. The sediment continued to be injested after burial to up to at least 1 m by the burrowing infauna of deposit-feeders, as demonstrated by the presence of the trace fossils *Thalassinoides*, *Chondrites* and *Zoophycos*.

The result of this activity must have been the production of an at least partially pelleted sediment at the sea floor. Individual pellets, however, have been preserved only rarely at a few horizons in abnormal microenvironments (Kennedy, 1970) associated with hardgrounds, phosphatic chalks and within macrofossils; the rocks do not exhibit a general pelletal texture.

Bryozoan chalk facies

In this facies, for example the grey chalk of Stevns Klint, the marked increase in contribution of benthic skeletons altered the depositional pattern of the sediment. Bedding changed from more or less horizontal to biohermal, with the production of low mounds (see Rosenkrantz & Rasmussen, 1960; Surlyk, this volume). These mounds have been considered by some to be comparable to megaripples, having a physical, grain-transport origin (e.g. Rasmussen, 1971). However, it is clear

Figs 3 - 6. SEM pictures of chalk. 3: Unidentifiable rods from 250-63 µm fraction, Maastrichtian, 'Danmark' chalk pit. Note coating of grains of next size fraction, obscuring all details. Scale bar 10 µm. 4: Spherical grain from same sample. It is filled with sediment of the next size fraction. The skeleton appears to have suffered some aggrading neomorphism, and a little overgrowth of epitaxial cement, rendering identification of the original ultrastructure and taxonomic position of the grain uncertain. Scale bar 10 µm. 5: Fracture surface of middle Danian chalk from Hanstholm Havn showing unusually low degree of fragmentation of coccoliths. Note overgrowths on individual crystals of the coccoliths. Scale bar 2 µm. 6: Fracture surface of Upper Maastrichtian chalk from Bjerre showing high degree of disintegration of coccoliths. Most of the small, rounded grains are probably dismembered coccoliths. Scale bar 2 µm. Figs 5 and 6, courtesy of N. O. Jørgensen.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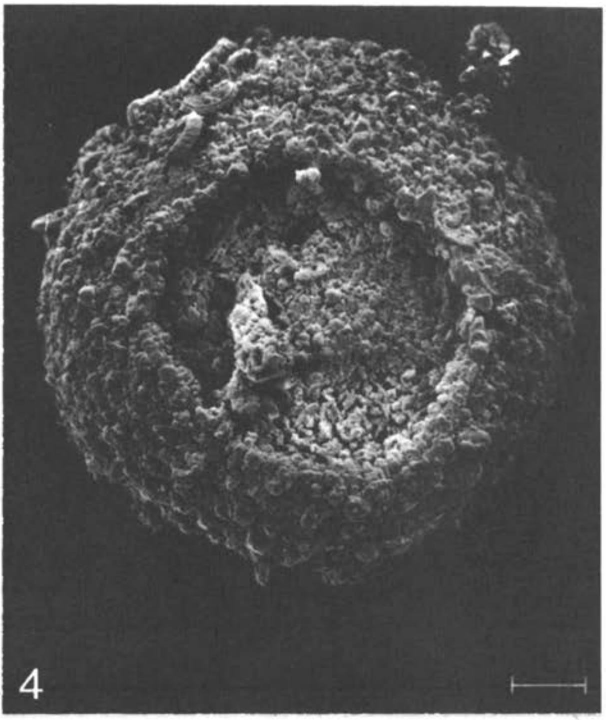
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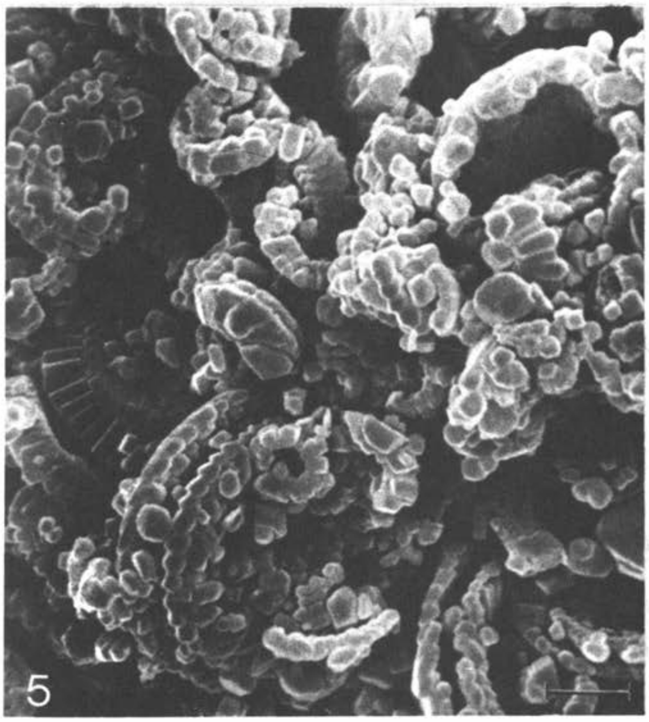
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from the form of the mounds and the distribution and nature of the grains that these are more or less autochthonous (Håkansson, 1971; Surlyk, 1972, p. 12).

Bryzoan limestone facies

A further increase in benthic skeletal production relative to pelagic input resulted in a facial change to bryozoan limestone. Bedding of this facies is locally biohermal, the scale of the structures being rather larger than that of the bryozoan chalk. Lower Danian mounds at Karlby Klint, Jylland, have been studied in detail by Thomsen (1976) who considered that his findings more or less were applicable to the facies in general.

None of the branched bryozoans have retained their erect life position or have remained unbroken. However, the distribution of encrusting bryozoans on the broken branched forms, together with the close proximity of fragments of the same colony, led Thomsen (1976, p.501-503; 1977a, Fig. 4) to consider the colonies to be virtually autochthonous and fragmentation to have occurred *in situ*.

On the basis of the assumption that erect colonies are thickened in response to increased current exposure, the relative distribution of colonies of different thicknesses indicated a clear current orientation of the Karlby Klint mounds (Thomsen, 1976, p. 503; 1977b, p. 363-364). The flanks containing the thicker colonies, interpreted therefore as having faced up-current, are steeper than the lee sides. Bed thickness is also greater on the steeper flanks than on the less steep, showing that the crest of the asymmetrical bank migrated gradually up-current.

Finally, it was also found that the fabric of the two flanks was different. The up-current fabric was mud-supported, the branched skeletons lying largely at random within the matrix, whereas the lee-side fabric was grain-supported, the bryozoans largely lying parallel to bedding. This was interpreted as due to a baffle effect, the stouter, more rapidly growing colonies on the up-current flank acting as a more efficient trap and producing a more open fabric than the leeside bryozoans (Thomsen, 1976, p. 503).

It remains to be seen to what extent this detailed interpretation can be applied to bryozoan limestone elsewhere. It should be pointed out that Cheetham (1971) looked very differently at the middle Danian bryozoan mounds of Limhamn. He saw lithic buildups grading through three different facies: core, transitional and flank, each having a distinctive biological constitution. Cheetham's core facies does not occur in the lower Danian mounds studied by Thomsen at Karlby Klint, or in those at Stevns Klint. It would seem likely, then, that study of bryozoan limestone in other areas will bring further differences to light.

Bioturbation levels of bryozoan limestone are normally low, bedding planes and, locally, fine lamination remaining distinct and largely undisturbed. Trace fossils are not easily detected in sediments of this type, dominated by coarse sand fraction. However, flint layers at many levels clearly demonstrate the existence of horizontal networks of *Thalassinoides*.

Depositional environments

The high mud content, parallel bedding and lack of signs of transport of grains indicate that the chalk was deposited in relatively still water. The asymmetrical mounds of the bryozoan chalk and, to a greater degree, the bryozoan limestone suggest deposition under the influence of a dominantly unidirectional water flow. All the sediments, therefore, appear to have accumulated below normal wave base.

Taking into account the palaeogeographical setting, the history of transgression and regression, and biological evidence, the depth of deposition of the sediments can be estimated.

Hancock (1975, p. 519) recently concluded from a variety of evidence that the white chalk of NW Europe was deposited under 100-600 m of water. 600 m is abnormally deep for a shelf sea, and a figure nearer Hancock's minimum would probably better fit the geological setting of the Maastrichtian chalk of Denmark.

Håkansson *et al.* (1974) discussed this problem and arrived at the conclusion that deposition occurred in a rather shallow epicontinental sea on the broad northwest European Maastrichtian shelf, but within the euphotic zone at only a few levels in restricted areas corresponding to the bryozoan chalk subfacies. Recent investigations based on lithology and microfauna led Ernst (1978) to suggest similar sea depths for the deposition of older chalk at Lägerdorf, north Germany.

The close of the Maastrichtian was marked by a considerable regression. Increase in benthic skeleton production may be correlated with shallowing, reaching a climax in the bryozoan chalk at the top of the Maastrichtian at Stevns Klint. Håkansson *et al.* (1974) considered this bryozoan chalk to have been deposited around the lower limit of light penetration, in about 150 m.

The characteristics that distinguish bryozoan chalk from white chalk are even more pronounced in bryozoan limestone, and we may therefore estimate that the bryozoan limestone accumulated in still shallower water. Calcareous red algal grains are entirely absent in the bryozoan limestone, however (E. B. Nielsen, pers. comm. 1979), and deposition appears to have occurred below wave base. Moreover, most of the exposed occurrences of bryozoan limestone in Denmark and Scania lie rather marginally around the Danish Basin (Håkansson & Thomsen, this volume), for which setting the depth range of 80-150 m suggested by Thomsen (1976, p. 486) does not seem unreasonable, though perhaps verging on the deep side.

Rates of deposition

Even in the more or less stable environment of the chalk, the rate of deposition must have varied considerably from place to place and from bed to bed. An average rate for a whole series of strata, arrived at by dividing thickness by duration, will therefore be of limited value for palaeobiological or sedimentological assessment of individual beds within that series. This is partly because the average figure includes hidden hiati (bedding planes, omission surfaces) of unknown duration - periods of time unrepresented by sediments - and the figure will therefore be lower than the true rate of deposition of individual beds. Furthermore, the post-depositional processes of compaction and stylolitization cause shortening of the rock column which influences the figure in the same way, causing underestimates of depositional rate.

Yet another potential source of error lies in the interpretation of marl seams. If these represent sudden influx of fine terrigenous material into the basin (e.g. Troelsen, 1955; Jefferies, 1963, p. 27), then marl seams may be considered to represent more rapid accumulation than normal. In contrast, however, marl seams may represent a failure of carbonate sedimentation owing to dissolution of calcite on the sea floor (Worsley, 1971; Hansen, 1977; Ernst, 1978). In this case, the seams will represent a drastic reduction of depositional rate, and an average figure for a chalk sequence containing several marl seams, such as the Maastrichtian chalk, will not be an accurate representation of the situation for either marl-depositing or chalk-depositing conditions.

Hancock (1975, p. 522) divided 700 m Maastrichtian chalk in the central part of the Danish Basin by 6 million years, and arrived at 117 m/m.y. or 11.7 cm/1000 years. This is the raw figure for rate of rock production.

Håkansson *et al.* (1974, p. 215), working with a duration of 6 m.y., took account of an assumed compaction of 10% and arrived at a figure of 15 cm/1000 years. If corrected to 6 m.y. this becomes 13 cm/1000 years. However, no account has been taken here of hiati or pressure solution effects, for both of which there is abundant evidence in the Maastrichtian chalk. Stylolites are particularly well developed in the more deeply buried chalk. The amount of column shortening for which this pressure solution has been responsible would be difficult to estimate, but at least it may be considered significant in the present context.

We may safely assume, therefore, that the figure 13 cm/1000 years is a considerable underestimate of the actual rate of accumulation of sediment in the white chalk during periods of deposition. Furthermore, the bryozoan chalk facies, included within this estimate, probably had a somewhat higher rate of accumulation, considering the increase in benthic skeletal input that characterizes it. A figure around 20-25 cm/1000 Years would probably be nearer the truth.

We may approach the bryozoan limestone with the same degree of caution. Although compaction and pressure solution have played minor roles in this facies there is evidence of numerous, long-lasting hiati within the sequence. Thomsen (1976, p. 506) reckoned with 50 cm of lower Danian bryozoan limestone covering a span of about 1 m.y. and so arrived at an average rate of 5 cm/1000 years. He suggested, on this basis, that accumulation on summits of bioherms proceeded at about 5 cm/1000 years, on the up-current flanks at 10 cm and on the lee surfaces at 3 cm.

These figures assume continuous deposition throughout the 1 m.y. period, and take no account of compaction. The figure 5 cm/1000 years is, in fact, no more than a rock production rate.

It is probable, in fact, that long periods of time elapsed while 'dead' bioherms were gradually buried by the accretion of neighbouring mounds; the surfaces of the 'dead' bioherms have locally been lithified as hardgrounds during that period of exposure. Bedding planes within the mounds also may indicate interruptions in accretion. In short, we can probably safely double the average figures in order to arrive at an approximate rate of accumulation of individual beds of bryozoan limestone: i.e. 10-20 cm /1000 years.

Early diagenesis

Post-burial diagenesis is beyond the scope of this paper, these processes having had little to do with Maastrichtian/Danish boundary events. Chalk diagenesis has been discussed by many authors (e.g. Neugebauer, 1973, 1975; Håkansson *et al.*,1974; Bromley *et al.*, 1975; Jørgensen, 1975; Scholle, 1977a & b), whereas this aspect of the bryozoan limestone has been relatively neglected (but see Jørgensen, 1975).

One aspect of sea floor diagenesis that should be mentioned here, however, is hardground development, as this is of widespread occurrence and great significance for the sedimentology and palaeontology of the boundary sequence.

The term hardground is applied to omission surfaces that have been synsedimentarily lithified to produce hard sea floors (Voigt, 1959a; Bromley, 1978). Two aspects of hardgrounds deserve special emphasis in the present context: stratigraphic condensation, and preservation of aragonitic faunas.

The presence of a hardground indicates a break in the depositional record with the omission of a certain amount of sediment. This omission may be primary, owing to non-deposition, or it may be secondary, in which case sediment that was once deposited was removed again by scour. It is not always easy to distinguish which of these two processes has been most significant at any given hardground. It is usually obvious, however, when secondary omission has occurred subsequent to lithification of the sea floor, by processes of erosion.

For several reasons, hardgrounds tend to be conspicuous in the field in pure and weakly lithified limestone sequences such as those with which we are dealing with here. The hardgrounds are highly lithified and jointed or shattered, and thus weather differently from the surrounding rock; they are topped by a distinct, sharp omission surface, which may be tinted with glauconite or ferruginous oxides; and a burrow system of *Thalassinoides* is normally well preserved in the hard rock, containing uncompacted, loose sediment from above the hardground.

It should be emphasized, however, that the conspicuous nature of hardgrounds does not necessarily mean that they represent correspondingly significant breaks in the succession. Omission surfaces today can be cemented rapidly, at least in shallow water, in a matter of decades (Shinn, 1969). Reasons for omission surfaces in some settings becoming cemented while others do not, involve such factors as the movement of major water masses, sea floor supersaturation with $CaCO_3$, etc., and not the period of exposure alone. An unhardened and inconspicuous omission surface may easily represent a longer depositional hiatus than a massive, jointed hardground nearby in the sequence.

Again, the degree of mineralization, e.g. glauconitization, of the surface may depend more upon the rate of the glauconitization process than on the length of exposure of the hardground. Some hardgrounds have been extensively bioeroded by boring organisms (e.g. that locally terminating the middle Danian at Limhamn) whereas others, equally well developed in other respects, contain few or no borings (e.g. the Cerithium limestone of Stevns Klint). Perhaps this is an indicator of the duration of the hiatus. By reference to Recent environments, however, we may equally well explain bioerosional differences by the degree of intermittant coverage of the surface by wandering waves of sediment, periodically burying and then uncovering the hardground and preventing the establishment of an endolithic community, or by the growth of an impenetrable layer of unpreserved organisms (sponges, algae) that prevented access of boring organisms.

In conclusion, then, it may be said that a hardground represents a distinct break in sedimentation, but the lithology of the hardground gives little evidence of the duration of the hiatus.

The other significant feature of hardgrounds is that, by rapid lithification of the sediment, the aragonitic element of the fauna may be preserved, in contrast to the normal situation in calcitic oozes, where it is lost. Preservation occurs as empty moulds owing to cementation of the surrounding sediment before dissolution of the aragonite skeleton. Likewise, siliceous sponges, normally poorly preserved in chalk, retain their shape uncompacted and display faithful moulds of the spicular skeleton in hardground preservation.

Moulds after aragonite do not occur in all hardgrounds, many of which are completely devoid of them (e.g. those on the flanks of the lower Danian bioherms at Stevns Klint). And in the best of cases, what may approach a representative of the entire aragonitic fauna is only preserved patchily and locally (e.g. patchily within the lower Danian Cerithium limestone of Stevns Klint). Again, the degree of aragonite mould preservation has no connection with the degree of lithification of the hardground beyond the fact that some initial lithification is necessary.

Aragonitic species are represented in the thin hardgrounds in the Lower Maastrichtian of Møns Klint, but are absent in the exceptionally well developed hardground that terminates the middle Danian at Limhamn.

At Stevns Klint the details of the era boundary are highly complicated (Bromley, 1975b, fig. 10; Surlyk, this volume). The conspicuousness of the major hardground long obscured the real nature of the boundary at this locality (Gravesen, this volume). However, now that the boundary has been revealed as the undulating crest of the biohermal bryozoan chalk, overlain by Fish clay in the intermound troughs, a potentially ideal situation presents itself for the study of the faunal turnover at the boundary. For the lithification at the cross-cutting hardground has alternately subjected topmost Maastrichtian chalk and basal Danian chalk to virtually identical diagenetic treatment. Both host sediments contain outstandingly well preserved, abundant moulds after aragonite and silica in addition to the calcitic element. Detailed studies of the faunas of the two rocks, Mesozoic and Tertiary, incorporated in the hardground, are yielding much information on the faunal change at the boundary. Two papers in this volume deal with molluscs from the Maastrichtian half of the double hardground (Heinberg; Birkelund), but there are several well represented groups (e.g. gastropods and sponges) about which we still know relatively little.