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THE CORAL BANKS OF THE DANIAN OF DENMARK

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Danish Danian (Lower Tertiary) octocorals are not uncommon, but bank construction is unknown. Scleractinians (ahermatypic) mostly rare and represented by solitary species. In a few places coral limestone was formed by species of *Dendrophyllia, Faksephyllia* and *Oculina*. Parts of this coral limestone from the classic locality, Fakse Quarry, show the only certainly recognized banks. Together with bryozoan banks they are known to have formed a large complex more than 90 m in thickness. The coral rocks and structures of the complex are considered and palaeoecological features are summarized. Initiation and features of development of this Lower — Middle Danian bank complex are considered. Comparison with Cretaceous — Quaternary structures demonstrates that the complex at Fakse is unusual.

K e y   w o r d s: corals, Scleractinia, Octocorallia, palaeoenvironment, Danian, Lower Tertiary, Denmark.

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INTRODUCTION

The Lower Tertiary Danian rocks of Denmark are marine and reach a maximum thickness of more than 100 m. They consist of a thin basal clay and of pure, mostly organogene limestones. Sedimentation took place in a warm temperate to subtropical, shallow sea and was most pronounced in the Danish subbasin (Rasmussen 1978) outlined on fig. 1. The subbasin probably continued in a narrow syncline across the Interior of Poland (Pożaryski 1960). A generalized sketch of the Danian sedimentation in Denmark was given by Hansen (1977).

These Danian limestones contain fossil coral faunas and locally coral structures.

OCTOCORALS

Octocorals of the Danian limestones include 12—15 species belonging to 7 genera. In general they preferred the bryozoan facies. They were described mainly in papers by K. Brünnich Nielsen. It has been found later that the amount of skeleton fragments found locally, and mainly in borings in South Zealand, indicates development of octocoral thickets or similar structures (Floris 1979*a*), usually with *Moltkia* as the dominating form. However, octocoral banks have not been recognized in Denmark. According to Cheetham (1971) octocorals may have been essential for the formation of certain Danian bryozoan banks.

SCLERACTINIANS

The largest coral element in the Danish Danian is the scleractinians. Since 1837 they have been studied by a few authors, in particular Nielsen (1922) and Floris (1972, and earlier unpublished reports), and they are still being studied by the latter (Floris 1979*a*). A recent revision resulted in a list of scleractinians known from the Danian of Denmark, table 1. Only ahermatypic scleractinians have been found.

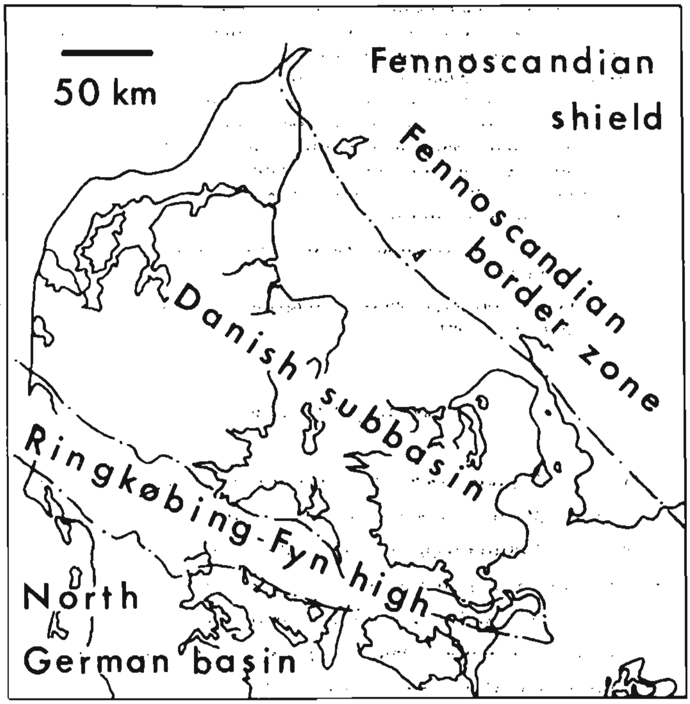

Fig. 1. Schematic structure map of Denmark. (Based on Madsen 1978).

Scleractinian coral limestone

In most localities (usually with bryozoan facies) the scleractinian fauna was sparse and almost exclusively represented by solitary forms. Only from a few places (fig. 2) has it been reported that colonial scleractinians proliferated and formed coral limestone: atypically in the Middle Danian at Aggersborggaard (Grönwall 1899; Ravn 1903; Ødum 1926), also in the Fakse limestone quarry (Middle Danian) and in the borings at Fakse (Lower Danian, Rosenkrantz 1938), at Spjellerup (possibly Lower Danian, Milthers 1907) and at Herlufsholm (Middle Danian, Ødum 1937). Bryozoan limestone often and perhaps always accompanies these coral limestones. On fig. 2 are also shown some questionable Danish localities and localities with Swedish Danian scleractinian limestone.

Table 1

Scleractinian genera in the Danian of Denmark
(ca. 35 species are represented)

Brachycyathus?
Caryophyllia (incl. "*Ceratotrochus*", and possibly "*Rhizotrochus*")
Cyathoceras
Coelosmilia?
Dendrophyllia
Discotrochus
Faksephyllia
Flabellum
Oculina
Parasmilia (incl. "*Ceratotrochus*", "*Epitrochus*", and "*Sphenotrochus*")
Stenocyathus *
Trochocyathus?

* new record. Redetermined records in brackets. From Floris 1979*a*.

The fauna of colonial scleractinians in all of these Danian scleractinian limestone occurrences certainly or probably consists of one or more of these three branching species, *Dendrophyllia candelabrum* Hennig, 1899, *Oculina becki* (Nielsen, 1922) and *Faksephyllia faxoensis* (Beck *in* Lyell, 1837).

At present, Danish scleractinian limestone is exposed only in the large Fakse Quarry, where it occurs abundantly and is formed by all of the three branching species mentioned, with *Dendrophyllia* dominating. Associated were *Caryophyllia*, *Cyathoceras*, and *Parasmilia*.

The coral structures of the Fakse Quarry and their palaeoenvironment

It was recognized early that the limestones of the Fakse Quarry demonstrate independently developed and often quite impressing coral structures. These were briefly referred by Floris (1971) to the series of ontogenetic stages of ahermatypic coral structures that Squires (1964) had sketched and called thicket, coppice, and bank. While each member (sometimes atypical) of this series can be certainly or possibly recognized in the Fakse Quarry, it is still unknown which was the kind of scleractinian structures which probably were built elsewhere in the Danish sea. (The scleractinian limestone from the borings in the Fakse area is similar to that of the quarry and should be interpreted correspondingly).

A modern evaluation of the famous locality at Fakse as a coral habitat has only been published incompletely and widely scattered in excursion guides (e.g. Floris

1979b). These modern statements shall be gathered here and completed. Borings in the area reveal limestones similar to those quarried. Lower Danian scleractinian limestone was found in this way, together with *Moltkia* limestone (Rosenkrantz 1938).

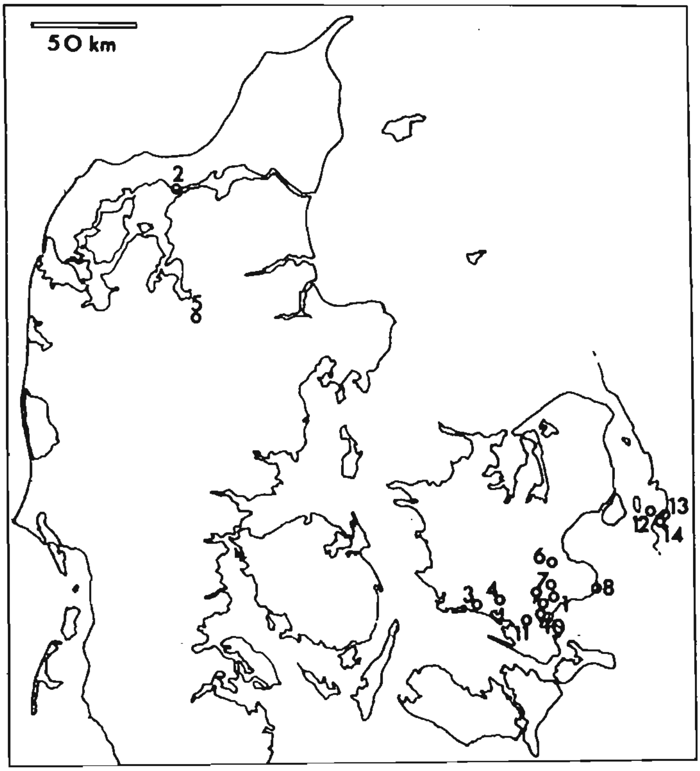

Fig. 2. Danian scleractinian limestone localities of Denmark and Sweden. Certain occurrences in Denmark: *1* Fakse; *2* Aggersborggaard; *3* Spjellerup; *4* Herlufsholm. Questionable Danish occurrences (registration numbers of the Geological Survey of Denmark): *5* Viborg (66.315); *6* Saedder (217.233); *7* Viverup (217.178); *8* Stevns Klint (Rosenkrantz 1938); *9* Kongsted (222.328); *10* Baekkeskov (222.394); *11* Snesere (222.219). Occurrences in Sweden: *12* The Sound (Larsen 1966; questionable); *13* Malmö (Lundgren 1880); *14* Limhamn = Annetorp (Johnstrup 1867; Brotzen 1959).

Table 2

Scleractinians of Fakse

Occurring exclusively in coral facies (12 species):
Brachycyathus?
Cyathoceras
Coelosmilia?
Occurring exclusively in bryozoan facies (4—5 species):
Solitary dendrophylliid
Occurring in both facies (4 species):
Caryophyllia
Dendrophyllia
Faksephyllia
Oculina
Parasmilia

The coral limestone of the quarry is found together with beds of almost exclusively autochtonous bryozoan limestone. These may contain conform layers of chert and are mostly subhorizontal or slightly oblique, but sometimes they distinctly demonstrate scleractinian-free bank-formation. According to my unpublished revision of the scleractinian fauna of Fakse Quarry, these corals are represented in the two main facies as shown in table 2. The three colonial species are rare in the bryozoan facies.

The coral limestone is chertless and occurs in a wide range of subfacies owing largely to variations in diagenesis but also to depositional differences. Generally the coral limestone is unbedded and obviously has arisen through local growth of the branching corals. The skeletons have not been found in rooted growth position (Floris 1967) and show all degrees of fragmentation and tilting. The supposedly very small bases should be found there, but it appears, that they have been overlooked. Fatal riddling of skeletons by boring sponges has been observed (Asgaard 1968), but colony portions as much as 30 cm in diameter have been recognized. Micrite filled the interstices within the coral frame to a varying degree. A kind of bedding is shown by small subhorizontal mudflats. The trapped micrite is partly coccolithic and partly must be the result of bioerosional and other type of disintegration of shells and skeletons.

A different kind of coral limestone is found in what may be rare fossil thickets, namely about 20 cm thick bodies in the subhorizontally bedded bryozoan limestone. Evidence for typical fossil coppices has not been recognized in the bryozoan limestone, whereas remains of coppice-like structures are suggested by common low bodies with a pure and unstratified micrite filling, which must have been introduced during the "lifetime" of the structures. These obviously had reached a certain critical size (or were seated optimally on other structures) and had become at least reminiscent of true bank through the sediment trapping and the fauna. But they apparently were too small for housing large thalassinoid-borrowing animals. Also larger bodies rose to stand free of the surrounding bryozoan sea-floor. They must have been eminent trappers of suspended micrite and fall within the definition of banks. The fossil cores consist of the normal type of coral limestone. The banks housed a more or less dependant follow-fauna of hard-substrate epibenthos and of mud-dwelling endobenthos including thalassinoid-burrowing crustaceans.

As a contrast, an evenly zonated coral limestone (first mentioned by Johnstrup 1864; Floris 1971: fig. 40) has often been found. It consists of coral debris reinforced with micrite but with oblique thick zones of almost massive limestone alternating regularly with thin zones of very open limestone. Both have small subhorizontal mudflats and are reflecting slopes on the sea-floor. The slopes have had a topographic expression of sometimes more than ten meters and dip as much as 40°—60°. The sediments on them were allochtonous and consisted of material which must have come down from unconsolidated densely populated surfaces of coral structures. On the lastformed sheet new compact coral structures could develop. The zonated coral limestone indicates varying conditions of sedimentation. Agitated waters are suggested. Submarine erosion of bryozoan beds is also indicated. But it cannot be decided, if waves, currents, or both have been the agent.

A few steep beds contain well-rounded debris of local rocks (Rosenkrantz 1938; Asgaard 1968). Wave action can also be here suggested, but evidence is not conclusive. This and similar debris, and also local overhangs, demonstrate early lithification of coral as well as bryozoan limestone.

The famous fauna from the two main facies in Fakse Quarry are not very varied within the occurrences of each of the facies. Calcialgae seem to be absent, boring algae have been recorded with doubt (Asgaard 1968; Floris 1979*b*). Zooxanthellae are documented through finds of *Heliopora* and *Millepora* (see Floris 1962, 1971, and Rasmussen 1973).

Information about the ecological factors was considered by, e.g., Asgaard (1968) and Floris (1975, 1977, 1979*a*, *b*). It can be summarized thus: The bank complex was built in an agitated sea at a depth probably averaging about 50 meters and in a temperature of probably about 18°C. A constant temperature can easily be assumed in analogy with modern coral requirements (Squires 1964). The kind of water-agitation has been under discussion for a long time, but it seems that conclusive evidence so far is missing for either currents or waves (and winds). Probably both types existed. Eventual killing of the Danian coral structures has been ascribed to mud-covering (Floris 1971). Submarine erosion and periods with fatal temperature conditions also may have been responsible.

That the Fakse ahermatypic structures were successful in their high-energy environment seems to result from a combination of the high temperature and the early lithification of the large supply of micrite, and probably also from a rich supply with nutrients and oxygen.

Continuous observation of the quarry walls and of the local borings should reveal the real position of bodies of coral limestone and bryozoan limestone. Unfortunately, it has not been made. A few registrations of rocks in the enlarging quarry exist, however, and the published ones (i.e. Johnstrup 1864; Fischer-Benzon 1866; Rosenkrantz 1938; Asgaard 1968; Rasmussen 1977; Floris 1977) have now been compiled with two sets of relevant measurements placed at my disposal by the late Professor Alfred Rosenkrantz who, thanks to grants from the Carlsberg Foundation, had made them in 1933 and in 1959. They also are now combined with evidence from published (Rosenkrantz 1938) and unpublished boring logs. In the unpublished, the scleractinian limestone is treated here as being of undifferentiated Lower-Middle Danian age.

Descriptions and collections warrant that most of the early results can be utilized safely. Each rock-type considered can also generally be placed in only one of the following main types: common coral limestone, zonated coral limestone (allochtonous oblique beds, often prolonged into horizontal beds), bryozoan limestone and the rare *Moltkia* limestone. The recorded occurrence of such rocks reveals temporary sections through banks and bank-like structures, because the rocks are autochtonous or nearly so. Chert and conglomerates also give useful information. Leaving some

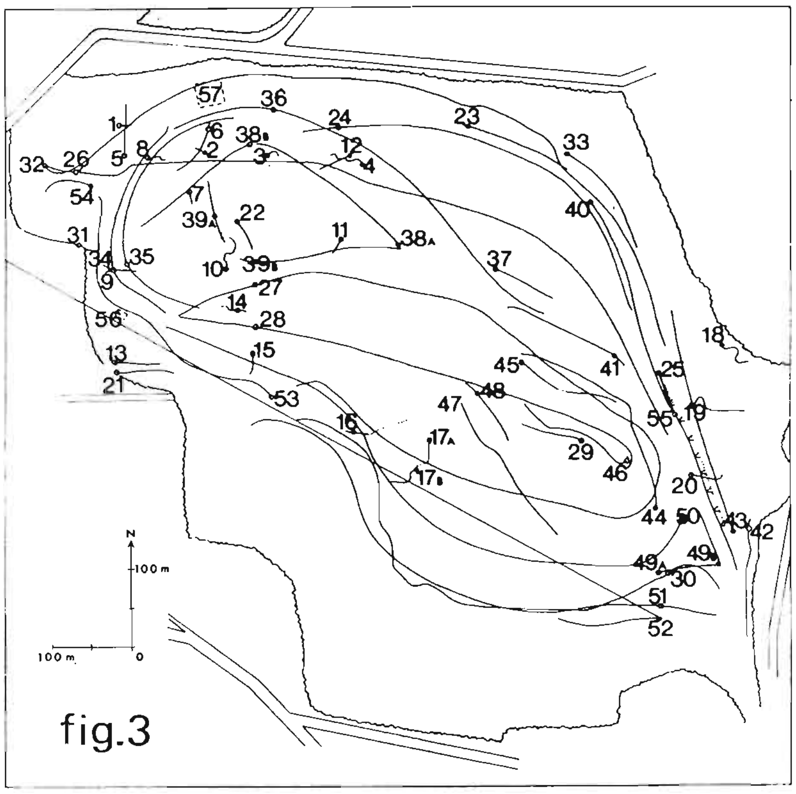

fig.3

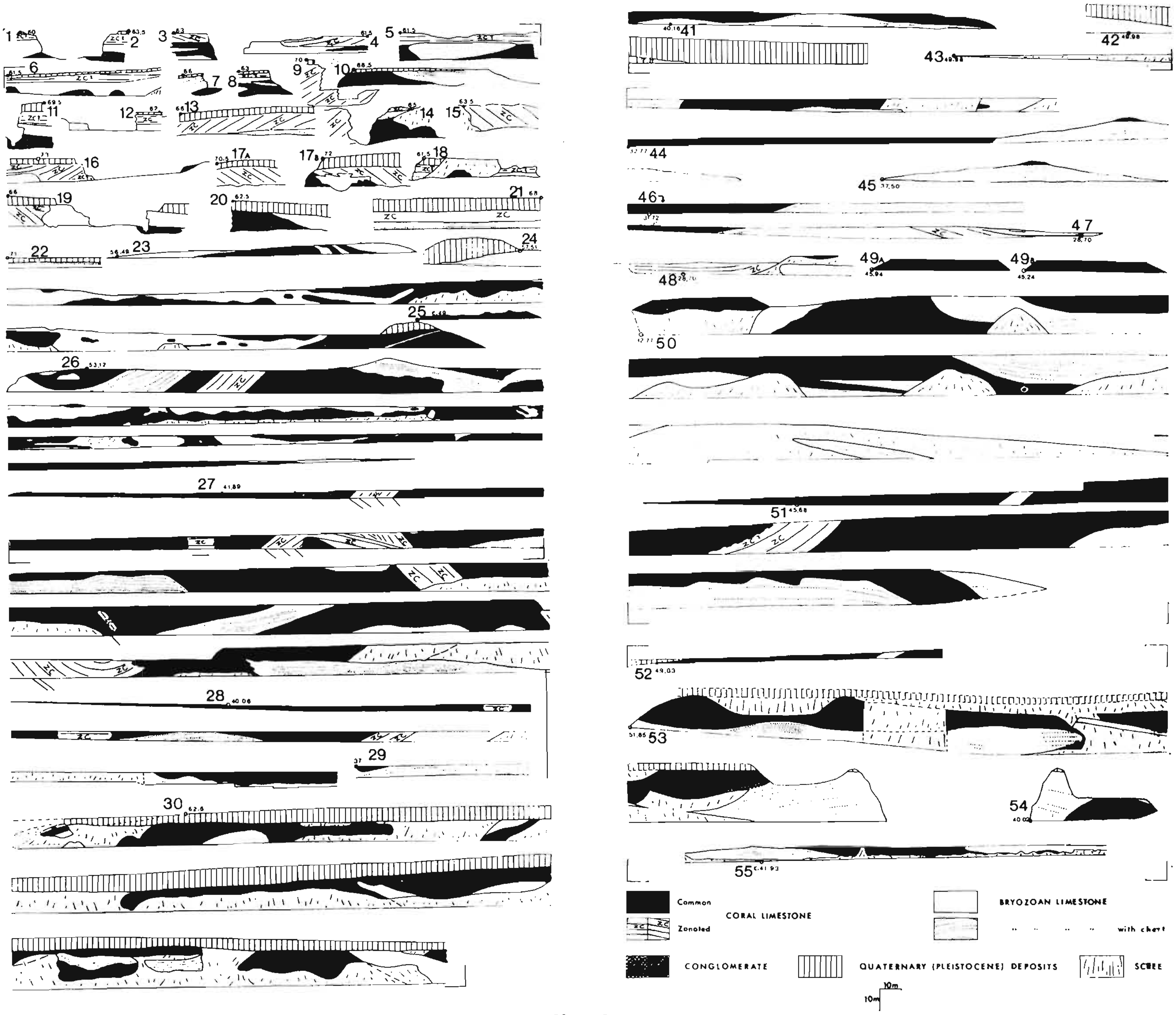

fig.4

Fig. 3. Fakse Limestone Quarry. Boundary as in 1977. Location of top of sections 1—20 measured 1860 by Johnstrup (Johnstrup 1864); of top of sections 21—22 measured 1863 by Fischer-Benzon (Fischer-Benzon 1866); of top of sections 23—31 measured 1933 by Rosenkrantz (no. 31: Rosenkrantz in Asgaard 1968); of base of sections 32—54 measured 1959 by Rosenkrantz; of base and top of section 55 measured 1976 by Rasmussen (Rasmussen 1977); of features (56, 57) observed 1977 by Floris (Floris 1977). A NW — SE line marks the vertical projection plane of the combined sections (measured 1933) in Rosenkrantz 1938: fig. 1.

Fig. 4. *1—55* Sections (measuring data, see fig. 3) being projections of rock distribution on vertical planes. Elevation above the sea in metres. (Some details in sections 21 and 22 are based on Johnstrup 1864).

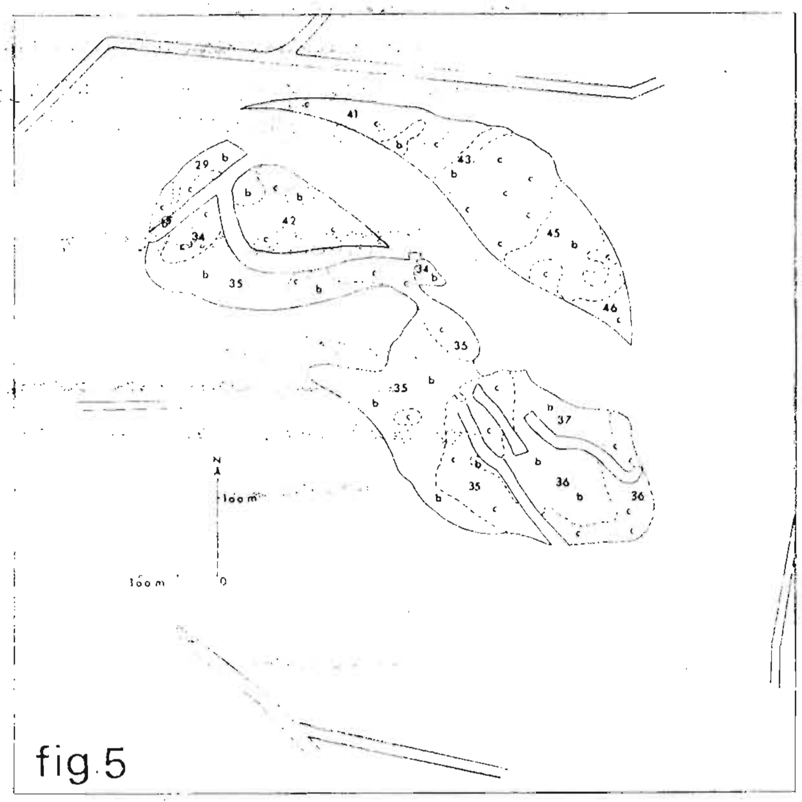

Fig. 5. Sketch of distribution in Fakse Limestone Quarry of bryozoan limestone (*b*) and scleractinian coral limestone (*c*) on part of the floors, 1959, after field sketches by Rosenkrantz. Approximate elevation above the sea in metres.

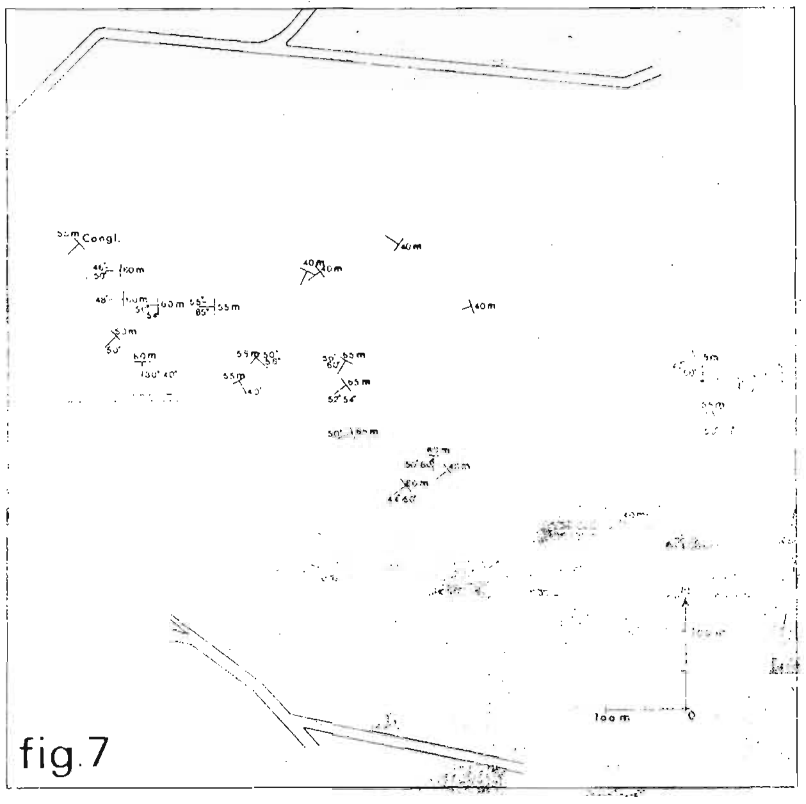

Fig. 7. Strike and dip of zonated coral limestone and of one conglomerate (Congl.) in Fakse Limestone Quarry. Based on Johnstrup (1864) and on measurements in 1933 and 1959 by Rosenkrantz. Approximate elevation above the sea in metres.

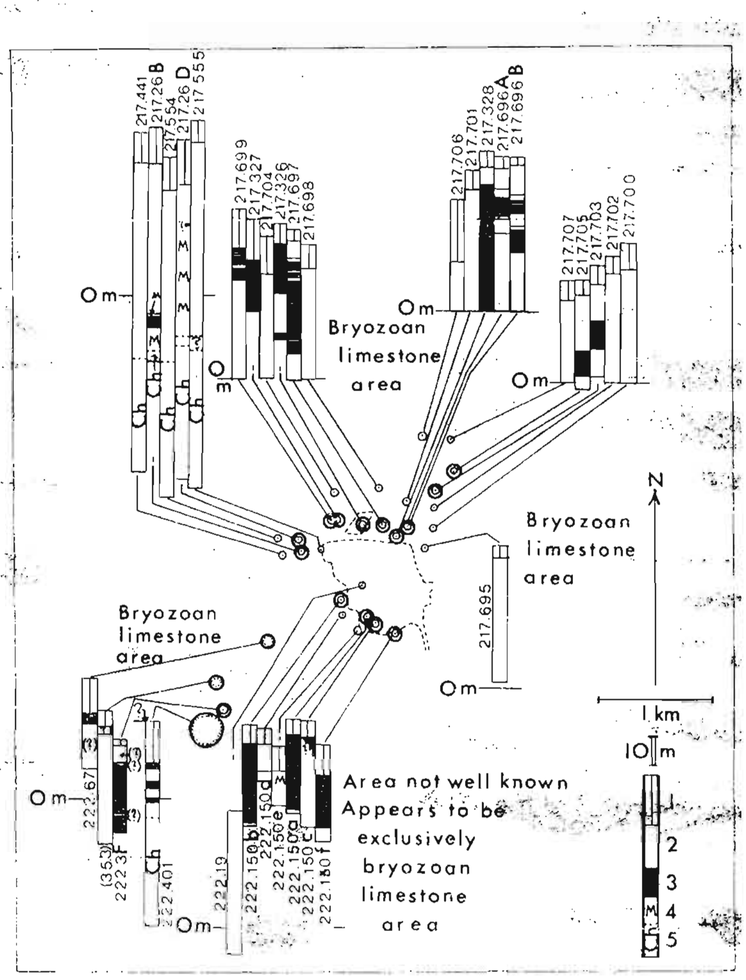

Fig. 6. Location and rocks (often drawn simplified) of boring in the Fakse area, with Fakse Quarry in the centre, outlined as it was in 1977. Including all borings with *Moltkia* limestone and all (double ringed) with scleractinian limestone. With registration numbers of the Geological Survey of Denmark (217.26 B: see Rosenkrantz 1938). *1* Pleistocene, *2* bryozoan limestone, *3* scleractinian limestone, *4 Moltkia* limestone; *5* Chalk. On the Chalk is resting in no. 217.554 Fish Clay (max. 0.5 m), in no. 217.26 B 15 cm Fish Clay and *Cerithium* Limestone, in no. 217.26 D 3.30 m grey micrite. "?" in no. 217.555 means Chalk or bryozoan limestone.

details aside, the documented distribution of these rock-types has now been plotted into a common map (fig. 3) and redrawn in vertical sections (fig. 4). Rock distribution in quarry floors in 1959 is shown in fig. 5.

These data provide a comprehensive picture of the placing of banks and of bank-like structures that is not very adequate, however — safe interpolations can unfortunately in general not be made between the sections, which were too widely spaced. The modern way of quarrying in general prevents every effort to complete the picture effectively. Combined sections (mainly Rosenkrantz 1938) demonstrate that the bank complex exposed in the quarry largely developed as a low cupole or shield consisting of numerous flat structures (fig. 5). The borings (fig. 6) show, that the entire complex covered about 4$^1/_2$ square kilometers. The quarried part is in the center, with a minimum thickness of 90 meters.

Borings at the Northwestern corner of the quarry and (in the same area) one additional boring (217, 26 C) with "limestone" above Fish Clay, above Chalk (at ÷21.7 m) give some information on the substrate of the bank-complex.

Comparison of this information with conditions in Stevns Klint (e.g. Rosenkrantz and Rasmussen 1960) indicates that there was local (submarine) erosion before deposition of the oldest preserved potential bank-rocks. Bank construction at Fakse probably started on a water-swept and uneven sea-floor. The appearance of that sea-floor is not known certainly from the borings, because folding (late Middle Danian or later, as in Stevns Klint?) or faulting (apparently postdepositional) may have taken place. The oldest scleractinian limestone rests on bryozoan limestone or on *Moltkia* limestone. Scleractinian bank formation possibly started in the Western part of the Fakse area, but the indication for this is very weak. It remains unknown, why the scleractinians started their building structures exactly at Fakse. Probably, fast movement of the bottom-waters may be one cause. It is also unknown, if the whole complex, as suggested by some sections, had a central bryozoan cupole.

Patterns in the distribution of growing banks have not been safely recognized. Zonated coral limestone, however, may suggest the direction of the movement of the agitated water. It is suggested that the temporary destruction of parts of the bank complex was caused by water movements, the direction of which was mainly to (or from?) the Southwest (fig. 7). By the way, the dips of zonated coral limestone confirm Johnstrup's assumption (1864) of individual growth-centers in different parts of the complex.

Upwelling could hardly occur precisely at Fakse. But it may have entered the Danish subbasin broadly from about the West. The position of Fakse is in fair agreement with the hypothesis of currents bringing nutritious water to the major coral localities along the coasts. Local uplifts (Sorgenfrei 1951) may have favored the coral communities (Floris 1971).

Coral, and probably also bryozoan life may have stopped at Fakse by the end of the Middle Danian, in consequence of a shallowing of the sea, that can be supposed for the East Danish area. Apparently any possible folding of the bank-complex has been postdepositional. It probably was very faint, in analogy with the Stevns Klint conditions (Rosenkrantz 1938) one may expect changes in dip of at most 7°.

Comparison of the Fakse coral structures with similar occurrences

The Fakse *Dendrophyllia* banks have for a long time been parallelled with several other coral communities (see Floris 1972, 1979*a*). Comparison has now been made to Cretaceous, Lower Tertiary and Upper Tertiary ahermatypic occurrences, and to a number of similar Quaternary occurrences in the South Pacific and Atlantic Oceans and in the Mediterranean Sea (Allen and Wells 1962; Brotzen 1959; Coates and Kauffman 1973; Floris 1972; Gruvel 1923; Johnstrup 1867; Le Danois 1948; Squires 1964, 1965; Stetson *et al.* 1962; Teichert 1958).

Modern parallels may after this preferably be found in some of the Recent Morocco thickets (80 m, 15°—16°C, not well known in other respects) and in the Holocene Guinea Gulf structures (40 m, probably about 15°—20°C, having sedimentology and general geological setting different from the Danish banks).

Among the fossil occurrences it is only the Lower Tertiary ones in West Greenland (with a different sedimentology) and in South Scandinavia that may have been close parallels.

After all, its growth at a depth of about 50 meters in a warm carbonate shelf-environment makes the Fakse complex unusual, if possibly not unique.

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