CAMBRIAN PALAEONTOLOGY OF FENNOSCANDIAN BASEMENT FISSURES

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Fossils from two ecologically and palaeogeographically interesting Cambrian outliers in the Precambrian basement of Fennoscandia are described or discussed. One of the localities is a fissure system, filled with sandstone, at Långbergsöda-Öjen in Saltvik, Province of Åland, Finland. The occurrence of the brachiopod *Ceratreta tanneri* (Metzger 1922) indicates a Late Cambrian age rather than Early Cambrian as assumed hitherto. The other locality, about 1.5 km W of the Fortress of Bohus, at Kungälv, Province of Bohuslän, Sweden, consists of a fissure and a trench-like crevice bounded by joints, containing a sequence of calcareous sedimentary breccia, grey limestone with coarse sand, and a late Medial Cambrian fauna. The sequence continues with black shale and bituminous dark limestone, containing large fragments of older igneous and sedimentary rocks as well as a Late Cambrian fauna.

The jointed Precambrian of Fennoscandia contains a large number of fissure fillings, usually consisting of sandstone. The present author has on several occasions treated the occurrences fringing the Baltic area, forming the roots of its Palaeozoic sequence and potentially dating otherwise unknown events in its sedimentary history (cf. Martinsson 1955, 1956a, 1956b, and 1958).

In the latter respect, however, the evidence has been extremely unsatisfactory. Transgressive marine sandstones of totally different Phanerozoic ages would look exactly the same when subjected to a standard petrographical examination. A critical review of the general statements as to the Early Cambrian age of the deposits shows that they are based on a very weak analogy with fissure fillings in Dalsland, containing the Lower Cambrian fossils *Mickwitzia monilifera* and *Torellella laevigata* and found in such a topographical position that they form a natural continuation of the corresponding beds in the Palaeozoic hills of Västergötland (cf. Gavelin 1909). When the find of a brachiopod in a similar sandstone from a fissure on northern Åland was published by Tanner in 1911, an equally weak but very persistent petrographical analogy with the small erratic piece of rock with *Mobergella* from Mariehamn (Wiman 1903; Wærn 1952; cf. Åhman & Martinsson 1965, Fig. 5) seemed to provide another indication as to the Early Cambrian age of the fissure fillings in general. The brachiopod in question was later described by Metzger (1922) as *Acrotreta tanneri*, but it has not been of any objective use in datings hitherto. The third literature

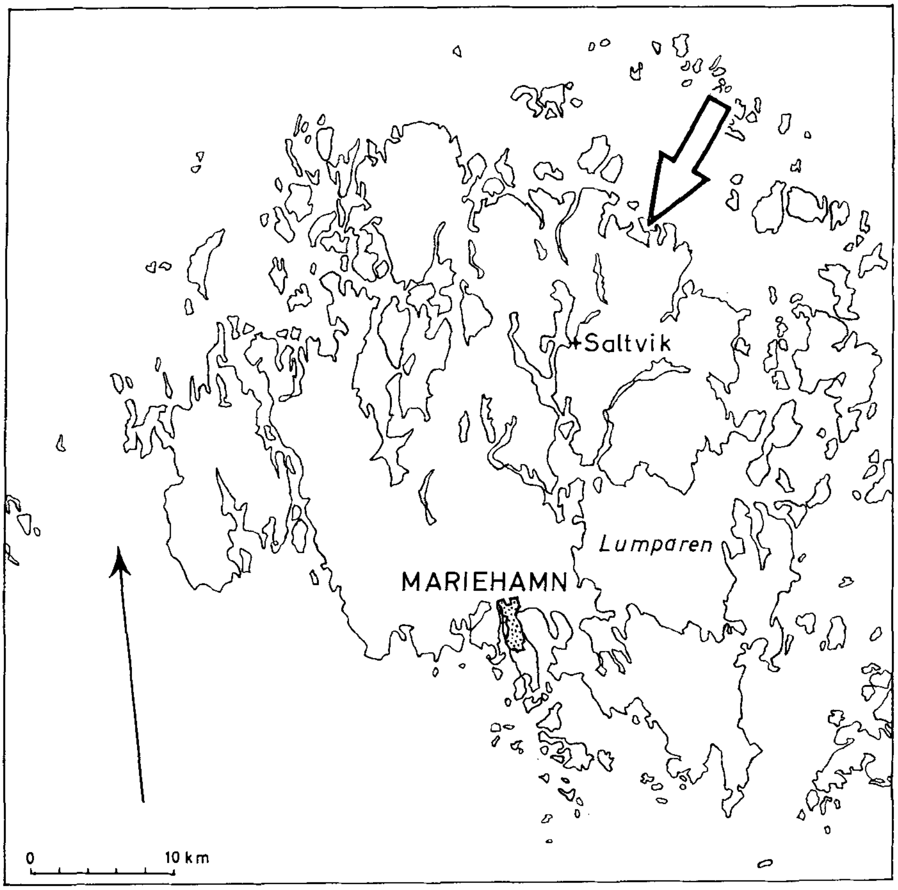

Fig. 1. Map of Main Åland *(Fasta Åland)* showing the location of Långbergsöda-Öjen in the parish of Saltvik. The floor of Lumparen largely consists of Palaeozoic rocks (its Ordovician sequence has been extensively drilled from the ice), and fissures filled with sandstone are scattered in the dissected topography (mapped by Martinsson 1955, Fig. 3; new finds around Långbergsöda are shown by Mattsson 1960, Fig. 1A).

record of a fossil in a fissure filling is an indeterminate phosphatic shell fragment in a thin section from the island of Jungfrun (Mattsson 1962, Pl. XIIa).

Critical views have appeared as to the age of the deposits, but the detailed evidence (relationships between sedimentation and minerogenic and tectonic events, absence or presence of authigenic minerals, such as glauconite) provide no more convincing datings than the analogy criticized in the preceding paragraph. Mattsson (1962), who has made the most detailed investigations in this respect, holds critical views as to the contemporaneous origin of the fissure fillings and other minor outliers, tentatively referring them to early or late phases of the Early Cambrian but avoiding definite conclusions based on the diagnostics used. Hausen (1934) suggested a Mesozoic age of the karst cavity fillings in Pargas and Västanfjärd in Finland. The evidence presented was the low degree of consolidation of the sandstone and the general impression of associated weathering phenomena. Simonen & Kouvo (1955) find no petrological reasons for distinguishing these occurrences from other allegedly Cambrian sandstones in the region.

As to the fossiliferous fissure localities, the one with *Torellella* and *Mickwitzia* in the sub-Cambrian peneplain of Dalsland presents no immediate problems. The occurrence on Åland and a new one in Bohuslän have some features in common and will be described here. In addition, Dr. Åke Mattsson, Lund, has provided the author with material of fossiliferous sandstone from Jungfrun in the Kalmarsund which, however, needs additional field studies in order to yield determinable fossils.

The object of the present and following papers is to extract some of the essential information as to datings, palaeogeography, and biotic history of a number of Cambrian localities which have attracted the author's interest parallel to his main branches of research. In both cases treated here, there are attractive topics which cannot be scheduled for the nearest future, such as the sedimentology of black shale and bituminous limestone in an environment hardly expected to be associated with such rocks, but this should be no reason for postponing the publication of aspects which have already been worked out.

The author is much obliged to Drs. Jan Bergström, Åke Mattsson, and Lennart Samuelsson for information and for material treated in this paper. Professor Nils Edelman, Dr. Eero Karppinen, Dr. Björn Kurtén, Dr. Marjatta Okko, and Professor Ernst Palmén kindly contributed to the efforts to locate V. Korvenkontio's collection of *Ceratreta*.

Review of *Ceratreta tanneri* (Metzger 1922)

Original Description. – Tanner (1911 Pl. 2, figs. 1–5) published figures of the brachiopod from Långbergsöda-Öjen based on examination by C. Wiman (cf. Tanner 1911, p. 10). Its nomenclature was left open, but a detailed description was announced. Metzger (1922) described the species as *Acrotreta Tanneri* n. sp. and provided new figures (op.cit. Fig. 1A–I),

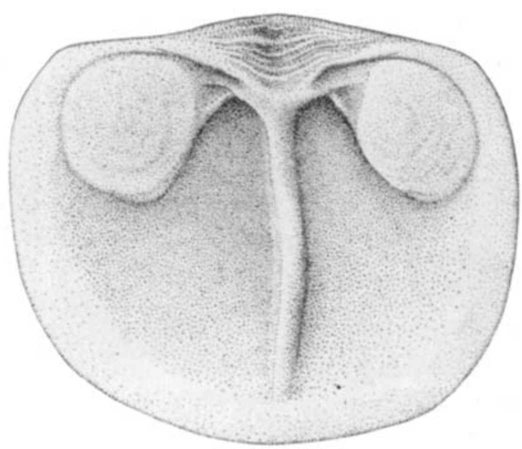

Fig. 2. Inside of brachial valve of *Ceratreta tanneri* (Metzger 1922), reconstruction, $\times 30$. The asymmetry demonstrated in this figure is very frequent in the species. As reconstructed here, the septum is medium-high; there are specimens in which there is a strong tendency towards broadening of the septum in the same place as where a process is formed in *Ceratreta hebes*.

based on new material collected by V. Korvenkontio. There are no further references of taxionomic importance to add to the synonymy.

Though consisting of much simpler drawings than the very inaccurate ones published by Tanner, Metzger's figures give a fairly detailed view of all essential parts of the fossil. As will be shown below, misinterpretations are only associated with the shape of the pedicle foramen and the anterior outline of the valves.

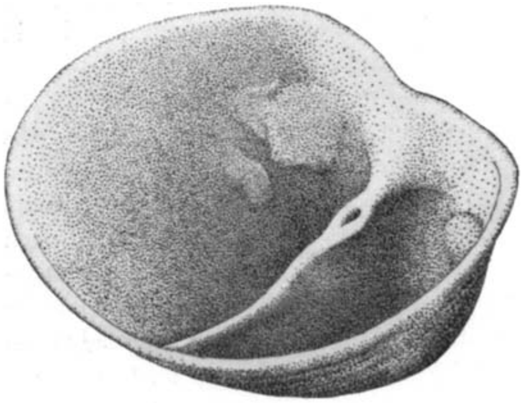

Fig. 3. Inside of a ventral valve of *Ceratreta tanneri* (Metzger 1922), slightly schematic reconstruction, × 30, showing the septal arrangement of the apical process. Reference is made to a reconstruction of the soft parts in *Ceratreta* by Rowell 1965, Fig. 96.

THE GENUS CERATRETA. – The monotypic genus *Ceratreta* was described by Bell (1941, p. 233). Its generotype was described in the same paper as *C. hebes* n.sp. The shape of the septum of the dorsal valve, with a horn-like projection anteriorly, was referred to as the distinctive generic character. Comparisons as to the septal morphology were made with *Acrotreta microscopica* (Shumard 1861) and '*A.*' *tetonensis* Walcott 1902. The material came from the Upper Cambrian Dry Creek Shale of Montana.

Bell & Ellingwood (1962, p. 409; Pl. 61, figs. 10–15) described additional material of the generotype from Montana and the Upper Cambrian Wilberns Formation (basal *Conaspis* Zone) of central Texas. They corrected the original description in one essential respect, pointing out that the pedicle foramen is large and slit-like, not minute and round. The striking similarity between *C. hebes* and *Clistotrema buchi* (de Verneuil 1845) was stressed (the new name *Clistotrema* was introduced by Rowell 1963, p. 34).

Rowell (1965, p. H278) erected the subfamily Ceratretinae (family Acrotretidae, superfamily Acrotretacea) comprising the genera *Ceratreta* and *Clistotrema*. Rowell's new diagnosis of *Ceratreta* (l.c.), in which the detailed morphology of the dorsal septum is not included (referred to as a specific character herein), need not be revised in any detail in order to cover *Ceratreta tanneri* (Metzger 1922).

DIAGNOSIS OF CERATRETA TANNERI. – *Ceratreta* species with a moderately high median septum, without a high process, in the dorsal valve. Ventral valve deep, apical process forming a very high sagittal septum, dividing the apical half of the valve space into two lateral portions.

Description. – The detailed morphology of *Ceratreta tanneri* is shown in Figs. 2–7. The following remarks may be added.

The horizontal outline of the valves is more or less perfectly circular in its anterior and lateral portions; its almost straight posterior portion cuts

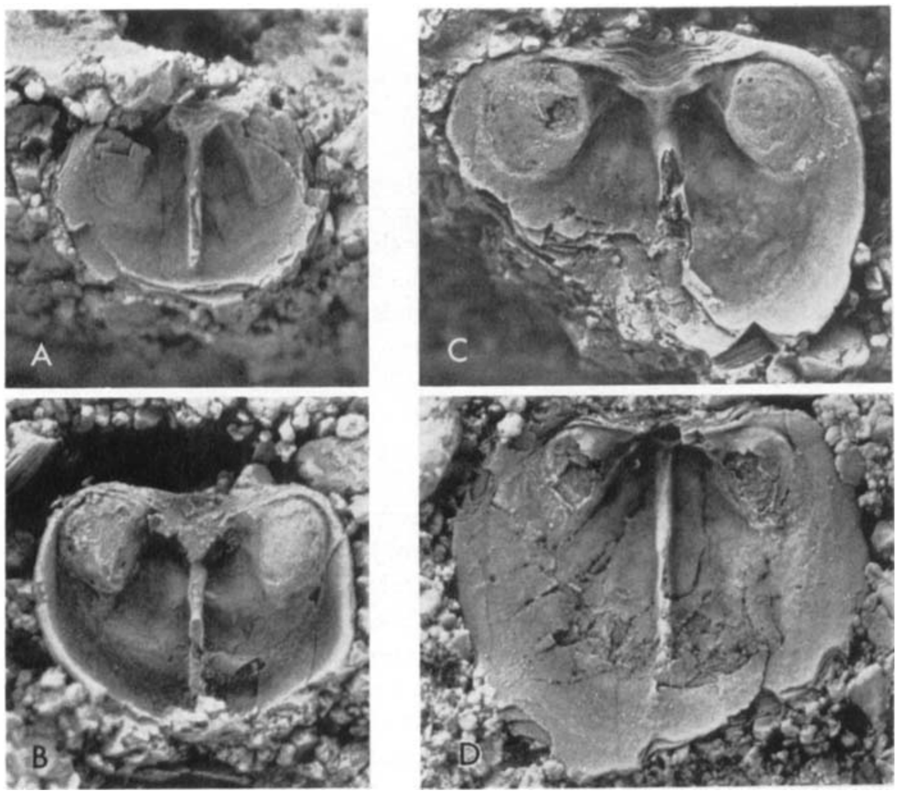

Fig. 4. Four brachial valves of *Ceratreta tanneri* (Metzger 1922), internal view, ×25. Tanner's collection, Mus. Pal. Inst. Univ. Uppsala. A: No. F 23. B: No. F 24. C: No. F 25. D: No. F 26.

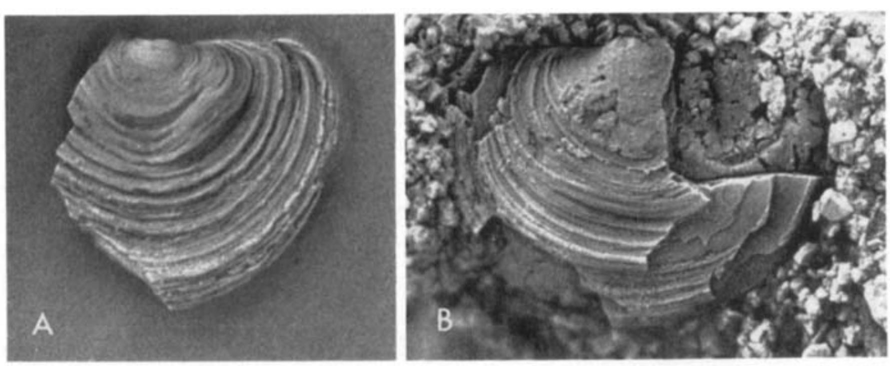

Fig. 5. Two brachial valves of *Ceratreta tanneri* (Metzger 1922), external view, ×25. Tanner's collection, Mus. Pal. Inst. Univ. Uppsala. A: No. F 27. B: No. F 28.

off a segment at about half the radius of the circle. The umbonal processes protrude but little beyond the posterior outline. Exceptions are old specimens which have changed growth direction like the one in Fig. 7A–B.

In lateral outline the dorsal valve is usually flattened, but occasionally the margins may be folded down as shown in Fig. 4B. The ventral valve is bluntly conical, flattened posteriorly in proportions indicated by the horizontal outline. The pseudointerarea is in normal specimens slightly procline (much less than in *C. hebes)* or even catacline; in some old specimens the umbonal portion swings backwards as just stated.

The pseudointerarea is broadly and roundedly triangular, with an apical angle of slightly less than 90°. There is a narrow, not very deep trough tapering towards the extrenal pedicle opening which is comparatively short as compared with *C. hebes* but still distinctly elongate (length about three times its width). Not infrequently it becomes closed in old specimens (the lamellation in the apical region of such valves tends to become very thick).

The ornamentation of the valves consists of a growth ring system which, particularly on the dorsal valve and in old specimens in general, tends to become very rough and irregular. In the ventral valves it is easy to distinguish a system of major growth rings superimposed in regular periodicity on the pattern of minor rings.

There are no very small specimens present in the material, but the ontogeny is inferred by the growth pattern. There is an ostreous, irregular growth, which probably was one reason why Wiman compared the species with the problematic genus *Kutorgina*. There is an apparent lateral asymmetry in the growth of the valves, increasing or decreasing during growth, apparently owing to environmental influence. Damages to the mantle during the deposition of shell substance resulted in irregular growth of the valves.

The internal morphology of the dorsal valve agrees very well with the main features in the generotype. The proparea is short and practically orthocline, with a wrinkled pattern of growth lines. The cardinal muscle scars are elevated and pad-like. Irregularities in the valve may indicate the insertion of the anterocentral muscles. The median septum is distinct. The possibility cannot be excluded that it was occasionally higher anteriorly (this part is damaged in most specimens), but in other instances it tapers in this direction.

The ventral valve displays distinct and somewhat elevated cardinal muscle scars (Fig. 6A–B). The septal structure formed by the apical process has a concave, irregularly thickened and somewhat undulating margin (Figs. 6A–C). The internal pedicle opening is longish, rounded posteriorly, and tapering in anterior direction. Particularly in older specimens with a marked thickening of the septal margin, there is a tendency to form a small platform around the opening.

DIMENSIONS. – Length—width—depth (of ventral valves), missing dimension indicated with x, in millimetres: 2.1—1.8—1.25; 1.95—x—2.2 (old, thick-shelled specimen); 1.35—1.9—1.4 (width influenced by damage); x—2.4—

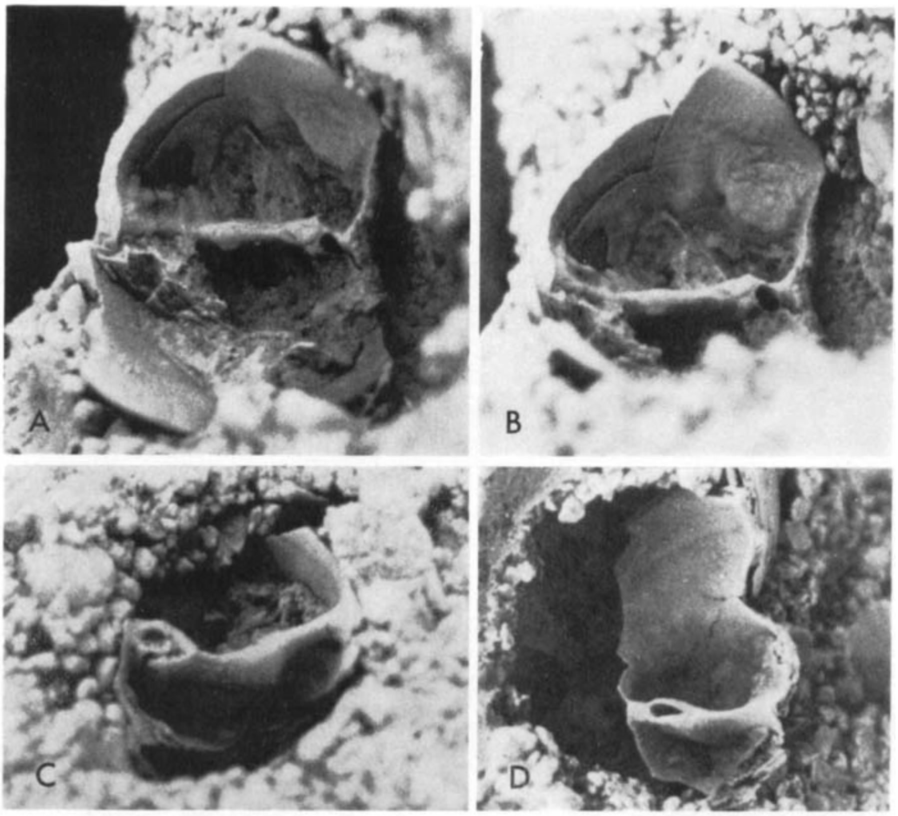

Fig. 6. Pedicle valves of *Ceratreta tanneri* (Metzger 1922), internal view, ×25. Tanner's collection, Mus. Pal. Inst. Univ. Uppsala. A and B: Same specimen in different orientation, No. F 29. C: Fragmentary specimen, anterior end to the right, No. F 30. D: Fragment, anterior end to the right, No. F 31.

All specimens show the internal opening of the pedicle foramen. In Figs. A and B the apical process has been broken in the region of the opening, showing a subcircular cross-section of the foramen where it passes through the 'process'. In C, the platform-like extension of the process around the foraminal opening is somewhat fractured. D shows a specimen where the septum and platform development is less pronounced than in most specimens examined.

1.4; 1.8—2.2—x; 1.95—2.2—x; 1.55—1.95—x; 1.45—1.95—x; 1.3—1.65—x; 1.1—1.45—x. The last six specimens are dorsal valves. Young specimens are apparently disproportionately rare in the material, and very young specimens are entirely absent.

TYPE REFERENCE. – The dorsal valve figured by Metzger 1922 Abb. 1C is designated herein as lectotype of *Acrotreta Tanneri* Metzger 1922. The type locality is the fissure filling numbered III by Tanner (1911, Pl. 1), at Långbergsöda-Öjen, parish of Saltvik, Åland. The type level is according to present evidence Upper Cambrian.

The reason why the lectotype is not refigured needs some explanation. After several colleagues had searched in vain for the originals, it was believed that they formed part of V. Korvenkontio's large collections at Högholmen which were destroyed in a bomb raid. However, when this paper was already in the page proofs, the author had an opportunity to visit Helsingfors and succeeded in identifying the material in the Geological Museum of the University. The label data (ICZN 72B) are given here: 'Helsingin Yliopiston Mineralogis-geologinen Laitos. Geologia Fennoscandiae. *Acrotreta Tanneri* Metzger Silur Kambrium Olenellidium *Långbergsöda-Øjen* Saltvik Åland Originale zu A. A. Th. Metzger Bull. de la Com. Géol. Finlande No. 56 Abb. 1. V. Korvenkontio leg.' (Metzger's handwriting). The specimens A, C, D-E (damaged), F, H, and I are indicated by paper arrows on five rock pieces with numerous specimens. The material is clearly associated with a sample numbered 924.

Some observations on the syntype material may be added here. On the same piece as specimen C there is a dorsal valve with the highest septal process observed. Furthermore, it is evident that Korvenkontio collected brachiopods from two lithologically different sandstones. An unlabelled sample contains an unweathered greyish sandstone with abundant, dark-coloured *Ceratreta*. Many of the specimens were filled with fine mud before being embedded in the sandstone, and there are pieces of unweathered shale and fine-grained sandstone in the coarser matrix. Galena occurs frequently in this rock. Another galena sample and an isolated label in the collection suggest that it may have come from another fissure (VI ?).

There are hundreds of syntype specimens.

MATERIAL. – The material studied here comes from the type locality and has been obtained from the waste of the material sent to Wiman by Tanner. Except for two specimens, Wiman worked with wax squeezes of internal and external moulds in the sandstone, but it was evident that the remaining rock pieces contained shell fragments in some abundance. These pieces were broken down into very small units, and fragments of hundreds of specimens were obtained. 54 of them are large or well enough preserved to serve as a basis for illustrations of the kind presented here.

The material is concentrated at a fairly distinct level of more porous sandstone in which the fossils are often situated in voids, mostly sharply cracked and firmly cemented against the irregular wall of the voids at one or more points. Owing to the hard siliceous cement and the cracked and brittle condition of the brachiopods, very few specimens have been obtained in good condition. All parts of the dorsal and ventral valves, however, have been observed as to both external and internal morphology. Most difficult to observe is the internal apical part of the ventral valve which is filled with a finely grained, pyritic substance.

The age of the sandstones in Saltvik

The statement in the type reference about the Upper Cambrian age of the sandstone is based on the following evidence.

The subfamily Ceratretinae is known exclusively from Upper Cambrian and Tremadocian beds. Its known occurrence, however, is restricted to fairly limited areas in North America (Montana and Texas) and Europe (Estonia and Åland).

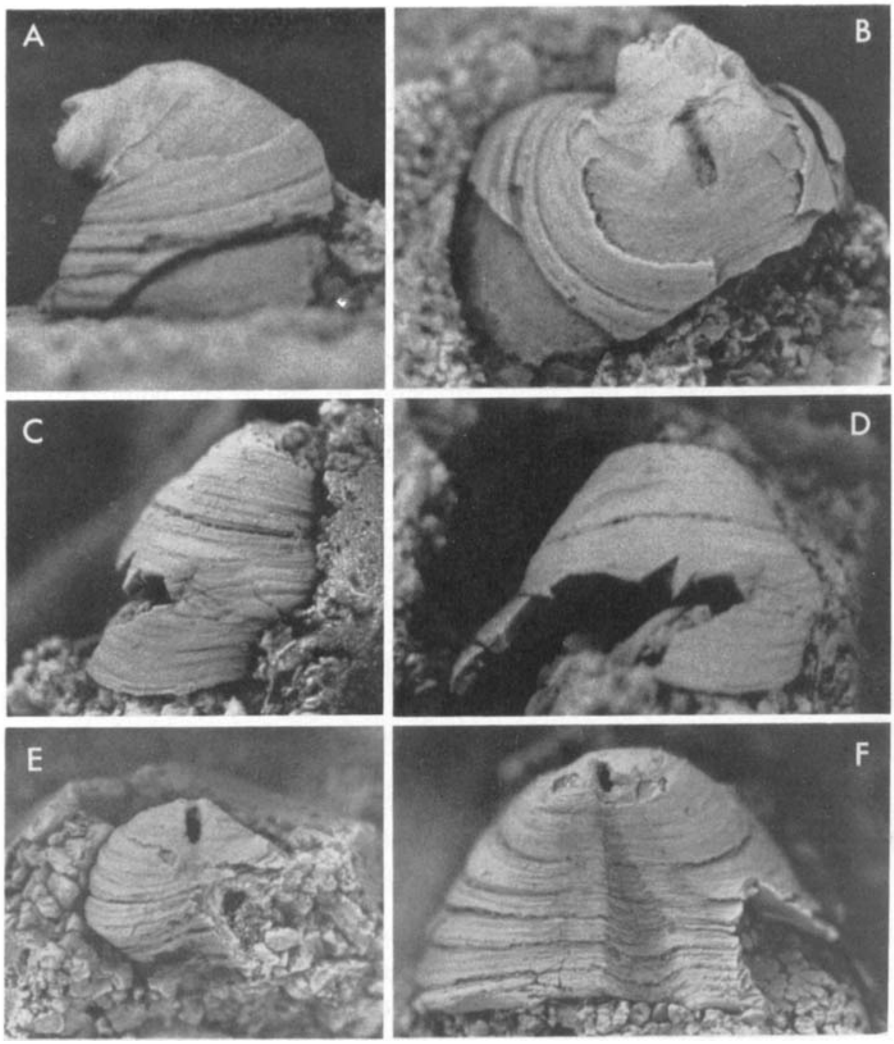

Fig. 7. External morphology of pedicle valves in *Ceratreta tanneri* (Metzger 1922). Tanner's collection, Mus. Pal. Inst. Univ. Uppsala. × 25. A and B: Left lateral and ventral views of the same specimen, No. F 32, drawn out in the region of the closed pedicle foramen. Shell lamellae exfoliated, exposing the lower part of the foramen. C: Right lateral and anterior view of the same specimen, No. F 33. The growth of the right half of the valve has been affected by a damage to the mantle epithelium. E: Fragmentary specimen in posterior view, No. F 34, showing the external opening of the pedicle foramen. F: Specimen in posterior view, No. F 35, showing the pseudointerarea and the external opening of the pedicle foramen.

The genus *Ceratreta* is exclusively Upper Cambrian. *Ceratreta tanneri* from Europe must be said to be very closely related to the generotype, *C. hebes*, from America. In accordance with general knowledge of related brachiopods, it is extremely unlikely that the former species is Lower Cambrian and the latter species Upper Cambrian.

There is no reason to believe that *Ceratreta* was a strongly specialized 'sandstone brachiopod' and that this could be the primary reason why *C.*

tanneri is known only from this very specialized fossil locality on Åland. The occurrence of the morphologically closely similar *C. hebes* does not support this hypothesis.

Of course a Medial Cambrian or Early Ordovician age cannot be entirely excluded. The Middle Cambrian has been much studied in Baltoscandia but there are no records of ceratretines. The transgressive Tremadocian is of more interest in this connection, and a comprehensive material from *Obolus* Beds in Estonia, the South Bothnian area, and Dalecarlia has been surveyed for *Ceratreta*, but no specimens have been found.

Öpik has repeatedly (1952, pp. 120 and 121; 1956, pp. 99–100; cf. Öpik 1929, pp. 12—13, and Öpik 1930, Pl. V) questioned the Ordovician age of the lowermost part of the *Obolus* Sandstone in Estonia and pointed to the possiblity that it is Upper Cambrian. There is no detailed palaeontological treatment of this 'Lower *Acrotreta–Lingulella* Zone'. No trilobites have been found in these beds.

However, there is a definite record of Upper Cambrian trilobites in the sandstones of the Russian Platform. Balašova (1963) recorded *Parabolina lobata rossica* and *P.* cf. *longicornis* in the Pestovo core in beds referred to the 'Fucoid Sandstone' (Izora Beds), i.e. equivalents of the Tiskri Beds of Estonia, if the correlation is correct (so far the fossil record only tells us that the level of this Upper Cambrian sandstone is well below the local occurrence of *Clonograptus tenellus*). Balašova correlated the sandstone with the *Peltura scarabaeoides* zone of western Baltoscandia. Pestovo is far from Estonia, and even if the find indicates a transgression over the Russian Platform, it gives no hints as to the details of the palaeogeography.

In conclusion it may be stated that the palaeontological indication of the Saltvik sandstones being Upper Cambrian is very strong. It has been confirmed that the Upper Cambrian is widely transgressive on the Russian Platform, and the general evidence stresses earlier statements as to the possibility of Late Cambrian sandstone deposition even in Estonia.

The palaeontology of a Cambrian deposit in Bohuslän

The first definite indication as to the presence of Palaeozoic bedrock in Bohuslän was published by Ljungner (1927, pp. 127–129, cf. Ljungner 1941, etc.). He found on the shores of Tosterödsvatten, a lake occupying a valley of tectonical origin, fissure fillings consisting of 'carbonaceous mudstones', shales, and black limestones. In one case these rocks were shown to be younger than a 'Cambrian' sandstone filling. The observations have been reviewed by Mattsson (1962, pp. 257–265), who added new figures and observations. It now seems natural to associate these finds with the locality to be discussed just below.

The finding conditions and petrology of this locality have been described quite recently by Samuelsson (1967) as a breccia occupying two fissures in the pre-Cambrian basement on the island of Hisingen, 1.5 W of the Fortress

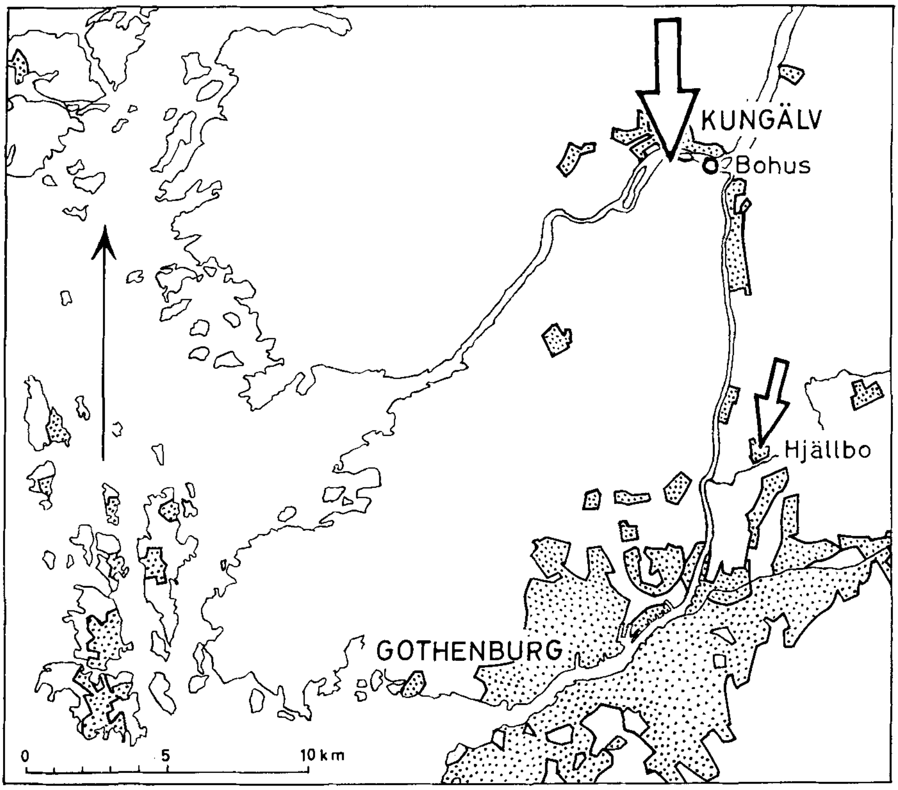

Fig. 8. Map showing the location of the brecciated Cambrian rocks 1.5 km W of the Fortress of Bohus. The small arrow points to the place from which Samuelsson (1967, p. 458) has reported a considerable number of fissure fillings.

of Bohus. One of the fissures is trench-like, about 3 m broad, the other about 0.5 m. Samuelsson concludes that the material in the breccia, considering the diagenesis of the rock, has probably come into place by brecciation of quite local deposits in the Permian and that the breccia has later been tectonized once more.

Lennart Samuelsson kindly sent a description of the find and rock samples to the author in March 1967. A light grey limestone piece with fragments of inarticulate brachiopods was etched with acetic acid, and Jan Bergström, Lund, who examined the residue, recognized pieces of *Dictyonina ornatella* in it. This led to the reexamination of Samuelsson's entire material, and fossils could be secured from the dark limestone, too, during the author's visit to the locality together with Samuelsson in May, 1967.

THE DEPOSITIONAL ENVIRONMENT. – In one very important respect the interpretation of the origin must be complemented. The brecciated character of the deposit is not only tectonical in origin but is largely the result of the embedding of small and large angular pieces of the basement rocks and of older sediments. This is true for both the grey and the 'black' carbonate rocks, as will be further discussed below. Both clearly reflect the influence of the very specialized environment in which they were deposited. Where fossils occur, they are mixed with rock fragments in a matrix which displays no traces at all of disturbances after sedimentation except for transient, calcite-filled cracks. This seems to be the first record of alum shale and associated stinkstones in such a depositional environment. Leaving a detailed examination of its sedimentary petrology to a later special study, we may summarize under interpretative aspects the evidence as to datings and palaeography.

MIDDLE CAMBRIAN. – The oldest rocks encountered are represented by the light grey limestones. These were formed after a marine transgression over a landscape with open crevices along the same SE—NW lineaments as in the present landscape. During the initial phase of this transgression much of the weathered material must have been cleaned out of the fissures and removed from the land surfaces around them; unfortunately the temporary

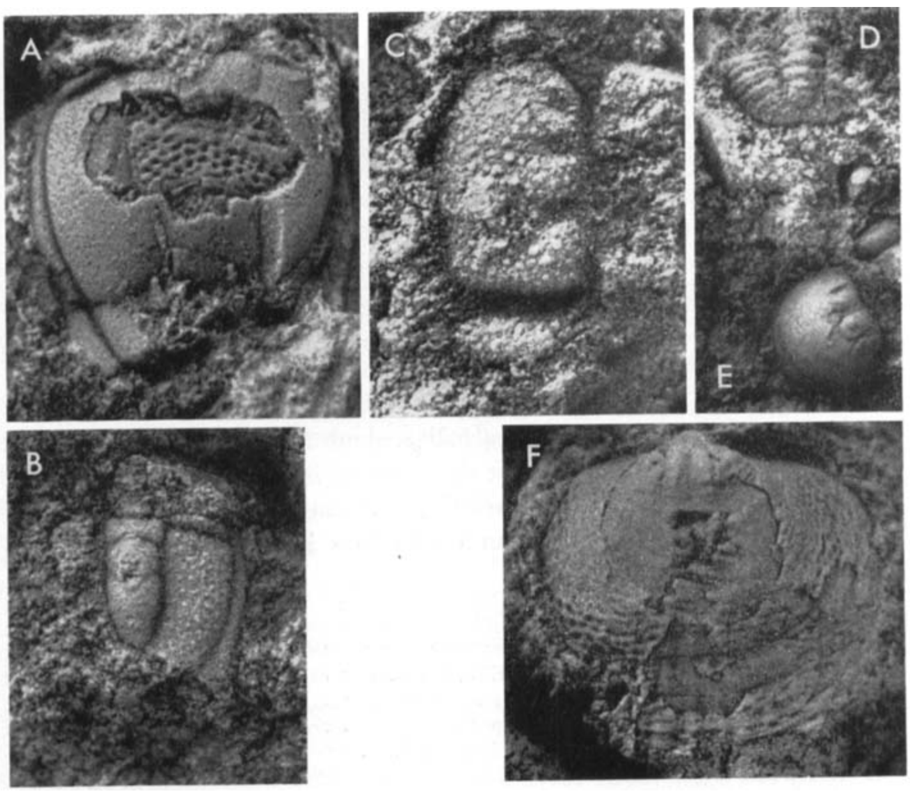

Fig. 9. Synthesis of the Middle Cambrian fauna of Bohus, showing its state of preservation. ×25. Div. Palaeozool., Sw. Mus. Nat. Hist., Stockholm. A: *Lejopyge laevigata* (Dalman), fragmentary pygidium. A shell fragment of *Dictyonina ornatella* is to be seen in the hole in the pygidium. No. Ar. 47416. B: Fragmentary pygidium of the type found in the Andrarum Limestone and tentatively referred to by Westergård as *Tomagnostella exsculpta* (Angelin). No. Ar. 47417. C: Glabellar mould of *Solenopleura canaliculata* (Angelin). No. Ar. 47419. E on the same piece of rock is a specimen of '*Acrotreta socialis*', an unrevised taxion with a wide range in the Middle Cambrian as defined at present. No. Br. 102326. F: *Dictyonina ornatella* (Linnarsson), pedicle valve. No. Br. 102327. Leg. L. Samuelsson and A. Martinsson.

exposure did not penetrate deep enough into the fissures to show with certainty whether there is any basal sandstone present. The only indication of this are the excavated fragments of sandstone with calcitic cement mentioned by Samuelsson (1967, p. 453).

When the carbonate mud was deposited, there were frequent influxes of quartz sand and silt, and pieces of the adjoining basement gneiss were embedded along the sides of the crevices and were also scattered in more central parts of the limestone. These fragments are generally fresher in appearance than those in the dark, bituminous limestones, and somewhat worn.

An abundant fauna of brachiopods and trilobites lived in this sea under such conditions that they could be deposited in the fissures. The fossil material is generally very fragmentary, except for the small inarticulate brachiopods, and the trilobites show compactional flattening and cracks.

The fauna is Late Medial Cambrian, and all species identified indicate a correlation with the Andrarum Limestone in the beds with *Paradoxides forchhammeri*. The brachiopods are '*Acrotreta socialis*' as recorded by Linnarsson 1876 (p. 16), *Dictyonina ornatella* (Linnarsson) and at least two more species. The material is excellently preserved but cannot be described in more detail without a critical revision of the corresponding faunas in Scania and Västergötland. The trilobites are represented by three fragmentary pygidia of *Lejopyge laevigata* (Dalman), a fragmentary pygidium of the type which Westergård (1946, pp. 98, 120, and 140; Pl. 6, fig. 5; Pl. 16, fig. 12) tentatively associated with *Tomagnostella exsculpta* (Angelin), two glabellar casts and a small pygidium of *Solenopleura canaliculata* (Angelin). There is one pleural fragment which may be a *Paradoxides* and a number of indeterminable, fragmentary free cheeks.

The brachiopods have been found in the limestone with arenaceous beds,

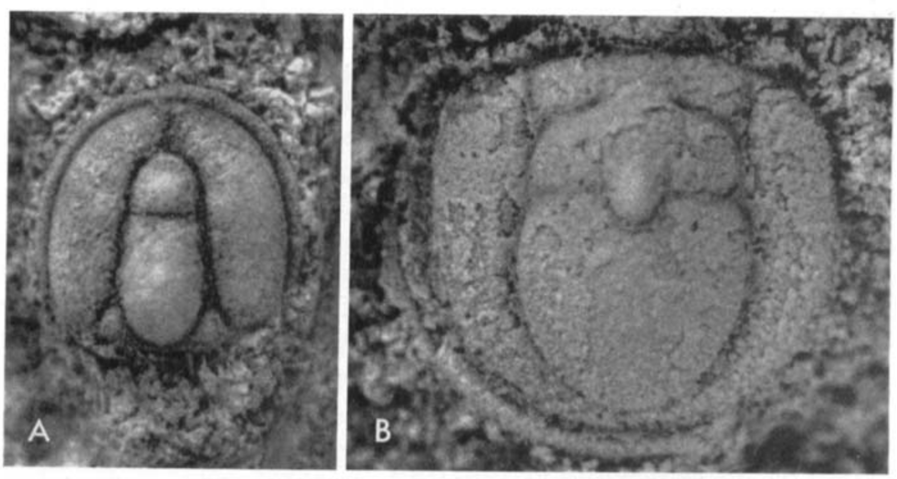

Fig. 10. Homagnostus obesus (Belt) the only species in the Upper Cambrian fauna of Bohus preserved in a fully determinable state. × 25. Div. Palaeozool., Sw. Mus. Nat. Hist., Stockholm. A: Cranidium, No. Ac. 47420. B: Pygidium, No. Ar. 47421.

but their greatest frequency is together with the trilobites in a lighter grey, often considerably weathered variety of the same limestone, with only occasional, rounded quartz grains and larger aggregates of gneiss. It seems logical to assume that this weathered rock is somewhat younger than the darker grey limestone with sandy layers.

The Middle Cambrian limestone was subsequently exposed to weathering (resulting in the lithology just referred to) and erosion. The weathering surface was probably fairly rough, and the cavities mentioned by Samuelsson (1967, p. 456) may be karstic phenomena from this phase.

UPPER CAMBRIAN. – The crevice was again invaded by the sea in Late Cambrian time, and the deposition of alum shale and black limestone took place immediately on the Middle Cambrian limestone surface, without any pure clastic sediment at the base. There are no clear indications as to the depth of the water, but anyway the conditions were such that there was a steady deposition in the limestones of material from the crevice walls and of large angular pieces of considerably weathered, strongly arenaceous limestone of the same type as the Middle Cambrian just treated. The bedrock fragments are considerably decomposed. They occur in all kinds of bituminous limestones, both those having the distinct outline of stinkstone lenses and those which might have formed more coherent stinkstone beds. Large portions of the stinkstones are recrystallized in the same way as is familiar from other alum shale areas in Sweden. The alum shale plays a subordinate role and, as will be discussed just below, is difficult to find in any larger portions displaying original shale structure.

The unrecrystallized parts of the stinkstones contain in some abundance *Homagnostus obesus* (Belt), a characteristic fossil of the zone with abundant *Olenus*, the oldest zone but one in the Upper Cambrian. One badly preserved, small inarticulate brachiopod has also been observed.

TECTONICS. – The sequence has later been disturbed by tectonic brecciation, as described by Samuelsson (1967). As far as the central parts of the crevice filling are concerned, stinkstone lenses and beds as well as protruding and detached rock pieces seem to have acted as persistent units, affected only by cracking, while the shale has been largely decomposed. Exactly how the sequence rested in the crevices after having been tectonized is not known, since the geologists' attention was not drawn to the locality until most of the material had been excavated. The sequence of more or less brecciated material penetrated until 'solid rock' (to build the fundament of a motorway bridge on) was found, was about 4 m (Samuelsson 1967, p. 450).

Notes on the sandstones of Jungfrun

A third of the four fossiliferous fissure localities has attracted particular attention both as being the one which has not hitherto yielded determinable fossils and the one where the palaeotopographical conditions for deposition of sandstones later than Early Cambrian were most favourable. The island of Jungfrun, between the Isle of Öland and peninsular Sweden, is a dome-shaped basement inlier in the Baltic Palaeozoic area, protruding by about 125 m over an even sea-floor of Lower Cambrian rocks of unknown thickness and completeness. The thickness of the Quaternary cover in adjoining areas is usually inconsiderable.

Theoretically, the fossiliferous sandstone fissure on Jungfrun may have been deposited as high as about 50 m above the top of the Lower Cambrian sequence in the area. This, of course, does not imply that this level cannot have been reached by the late Early Cambrian sea, but it is even more possible that it was in the littoral zone at the end of the Cambrian or in the Tremadocian (local pachymetric information is easily obtained from, e.g., Wærn 1952, Fig. 3).

Dr. Åke Mattsson has kindly placed material of the sandstone from Jungfrun at the author's disposal, but thorough investigation of it has not resulted in further finds of fossils. New finds of fossils on the island are not excluded, however, and further investigations of material from Jungfrun will be included in a forthcoming series of papers on the stratigraphy and palaeoecology of the Cambrian-Tremadocian conglomerates in the Kalmarsund area.

Basement fissures as thanatotopes

The sediments in basement fissures constitute a very specialized category of deposits which, however, can provide most important information as to palaeogeography if properly dated. From palaeoecological points of view they are even more specialized and hitherto neglected, and some remarks may be added about the nature and environment of the fossil communities encountered. Some of these aspects have already been presented above in the section on the deposit near Bohus.

Mattsson (1962, p. 327) has discussed the depth of the fissure filling and concludes that even narrow fissures may be filled down to a depth of 5—10 m or more. According to the same author it is necessary to take into account depths of 'at least 20 m, probably 50 m, and possible more'. Cavity fillings in limestones may reflect quite as long distances from the surface of the rocks in which they were deposited.

Mattsson (1962, p. 326) also concludes, after an investigation of a very large number of filled fissures, that they were open not owing to weathering but owing to tectonic tension.

The deeper parts of the fissures were certainly not very favourable as marine invertebrate biotopes, even if they happened to remain unfilled on transgression. They would probably be extremely poorly oxygenated, due both to their isolation from the normal water circulation and their lack of assimilating vegetation.

Even if the space of the fissures is not apparently due to weathering, rock waste resulting from weathering seems to occupy a considerable part of the infill. It is apparent that palaeoecological considerations provide very good guidance in practical work with fissure fillings, not only for finding fossils but also for providing hints as to the depth of the fissures and as to events in sedimentation.

Omitting the theoretically interesting aspects of fissures opening up under a cover of sediment or rock waste, the normal events during a transgression would be the rapid filling up of the larger part of the exposed fissures with badly sorted debris and kaolinic material. By far the larger part of the fissure fillings known reflect such conditions. The most exposed fissures, such as those in the highs of the ancient topography, are most likely to contain well-washed material and reflect a lower rate of sedimentation, mainly due to the poor availability of loose material in this position. They are also most likely to contain biogenic substances in sufficient quantities as to be found and identified in the fossil state.

Such an environment existed when the upper part of the Saltvik fissures were filled. *Ceratreta tanneri* inhabited the zone fairly abundantly around the margins of the fissures attached to the rocks or to minor particles by its pedicle. It belongs to the type of systematically very diversified fossil brachiopods in which it was normal that the pedicle was eliminated at least in old specimens and where its foramen became closed. The brachiopods, attached or resting in the sediment, were washed down into the fissure together with biotic debris of other kinds concentrated at certain levels with better sorting, larger grain and porosity, and with fragments of pre-existing consolidated sandstones and shales from the neighbourhood.

The Bohus environment is somewhat more puzzling. It partly reflects normal, marine low-energy conditions with mud deposition but also indicates a position close to steep features in the topography. Well-worked quartz sand was available when the Middle Cambrian limestone was deposited and was carried into the carbonate sediment periodically, but when the Upper Cambrian sequence was deposited, the occasional influx events were entirely dominated by weathered bedrock debris. In both cases the faunas are the same as those we know from deposits which reflect normal open-sea environments, without considerable littoral influence. Considering the bituminous portion of the sequence we may cautiously assume that the water depth and local relief were such that considerable amounts of not much washed, weathered rock could be carried from even above the surf zone into the environment of deposition.

On evidence provided by the fossils' mode of occurrence, trilobite moulting in the environment, and the casting of fossil traces when coarser silt rarely entered the area of deposition, Martinsson (1965, pp. 199–201) has claimed that the Cambrian black shales in Baltoscandia hardly reflect toxic conditions at the interface between mud and water according to common concepts, and that the Middle Cambrian grey shales are not much different in this respect. Unless preserved in limestone or siltstone beds, the shelly fossils deposited

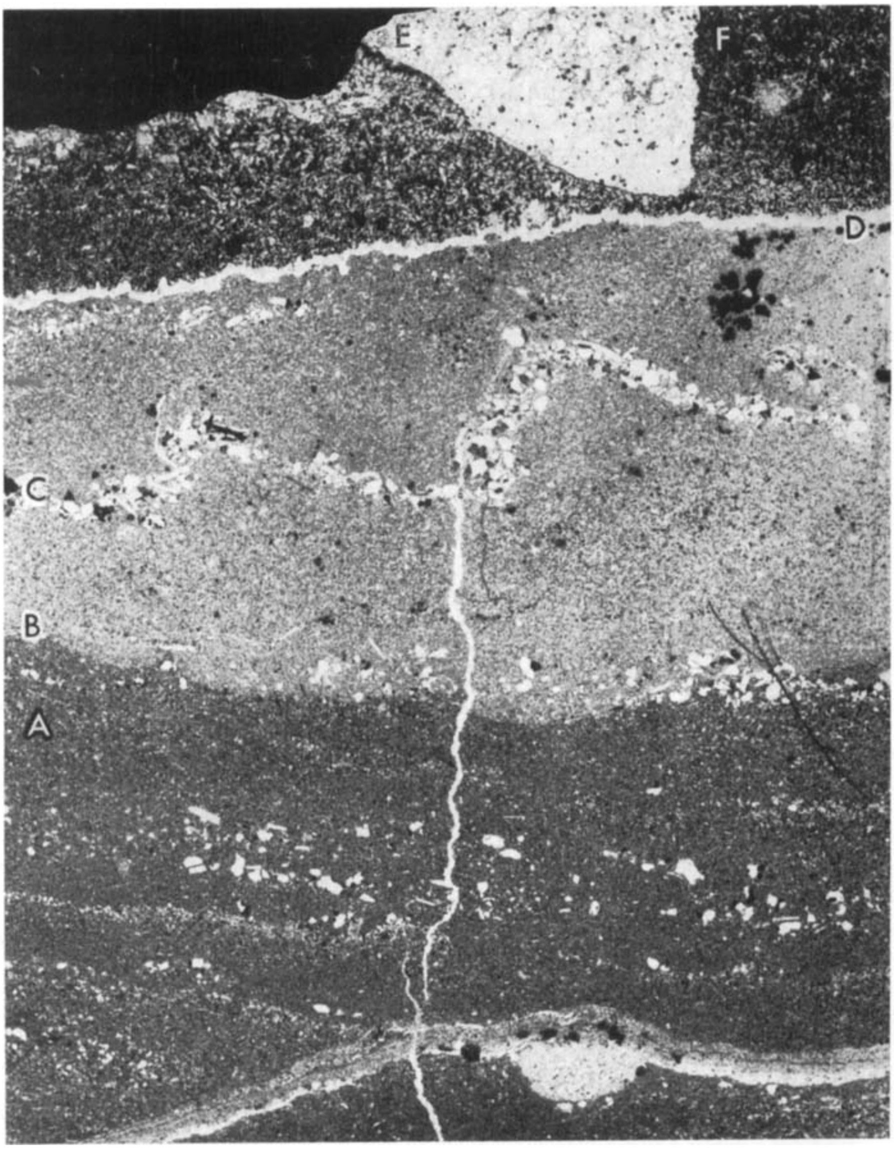

Fig. 11. Thin section through the contact between Middle and Upper Cambrian at Bohus. × 6, ordinary light.

The letter A is in the unaltered grey Middle Cambrian limestone, discoloured by weathering down to B. One of the streaks of sand and fossil debris, C, has been disturbed before consolidation. The Middle-Upper Cambrian contact is at D, and E is a piece of the Middle Cambrian rock with a concentration of the material seen in the streaks. F is the bituminous Upper Cambrian limestone, also containing weathered bedrock debris (no large fragments to be seen in this section).

along mud surfaces later covered by more sediment have become decalcified and squeezed out of the fossil record by compaction. The taphonomic aspects of the successive integration of the very thin, oxygenated surface layer of the mud with the deeper, reduced sediment mass have not attracted much attention in the discussion of shale thanatotopes and of similar conditions in recent embedding of shells. Extended studies of the kind reported on by Bartlett (1966, pp. 19–20), applied to taphonomy, will certainly explain many of the problems of non-preservation or selective preservation of carbonatic and 'chitinous' faunas in different kinds of shales.

This first evidence of alum shale deposition in an environment more or less close to the shore provides another indication that the mud-water interface in areas of black shale deposition and the water above it were a normal biotope for the agnostids, olenids (cf. Henningsmoen 1957, pp. 70 sqq.), and the host of other fossils, particularly in the Middle Cambrian, which are found in limestone intercalations and concretions in these shales.

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