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THE LOWER MIDDLE CAMBRIAN KALBY-LER (KALBY CLAY) ON THE ISLAND OF BORNHOLM

BY

VALDEMAR POULSEN

København 1963
Kommissionær: Ejnar Munksgaard

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Synopsis

The Kalby-ler (Kalby clay) formation is a new name for the deposit previously believed to be weathered *Exsulans* limestone, which belongs to the *Triplagnostus gibbus* zone. The emendation is necessitated by evidence, which shows that the clay belongs to the *Tomagnostus fissus* — *Ptychagnostus atavus* zone. The evidence is discussed, and the lower Middle Cambrian stratigraphy is revised. A tentative account of the Lower and lower Middle Cambrian history and paleogeography is presented.

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Introduction

In 1942 C. POULSEN described several new fossils from the Middle Cambrian clay at Læsaa. The fossils were obtained by elutriation of a limited quantity of clay, and therefore the present writer a few years ago collected more material hoping to obtain additions to the fauna. Apart from the species reported by C. POULSEN the present writer thus found several new species of *Stenothecopsis*, *Stenotheca?*, spicules of *Protospongia?*, eocystid plates, and problematica. The non-trilobite fauna elements, practically all of which presumably are of Lower Cambrian age, will be described in a subsequent paper. The fossils in the clay comprise Lower and Middle Cambrian elements. In the following mainly the Middle Cambrian trilobite material will be discussed.

The material is in the collections of the Mineralogical and Geological Museum of the University of Copenhagen.

Summary of previous work

GRÖNWALL (1902a) described the Middle Cambrian sections and the fauna from the streams Øleaa and Læsaa on the island of Bornholm. At Øleaa the Lower Cambrian Rispebjerg sandstone is overlain by 25 centimetres of gray *Exsulans* limestone. The limestone is rich in grains of glauconite and pyrite, especially in the lower part. Equally conspicuous is the content of irregular, somewhat rounded pebbles of phosphoritic sandstone. The lithology of these pebbles corresponds to the upper 40 centimetres of the underlying Rispebjerg sandstone. Fossils, predominantly trilobites, occur abundantly in the *Exsulans* limestone, especially in the upper part. In the section at the stream Læsaa the Rispebjerg sandstone is succeeded by 15 centimetres of a gray clay, which is

not too well exposed. GRÖNWALL reported that most of the clay was unconsolidated and soft, but contained harder lumps, which showed that the clay was a residual deposit formed by weathering of a fossiliferous limestone. The carbonate supposedly was washed away. Determinable fragments of fossils were not found. The clay was found to be rich in glauconite and pyrite, pebbles or lumps of phosphoritic sandstone, and well-rounded quartz grains identical to those of the Lower Cambrian Rispebjerg sandstone.

Considering the absence of determinable fossils, the agreement in lithology, the thickness, and the position in the sequence it is understandable that GRÖNWALL (1902a, pp. 20 and 32) correlated the clay at Læsaa with the *Exsulans* limestone at Øleaa. The deposits were referred to the lowermost *Ctenocephalus exsulans* subzone of the *Paradoxides tessini* stage. When discussing the Scandinavian *Paradoxides* beds GRÖNWALL (1902b) maintained the correlation as mentioned above.

KAJ HANSEN (1937) made a comparison between the Lower Cambrian deposits in Scania and on Bornholm. He called attention to a pyritic layer immediately above the clay at Læsaa. The pyritic layer, previously described by GRÖNWALL, is a 5 centimetres thick conglomerate with pebbles of phosphoritic sandstone, irregular bodies of phosphorite, and fragments of weathered sediments with traces of fossils. The pebbles of phosphoritic sandstone are identical to those found in the underlying clay. Some of the rock fragments could be identified as belonging to the Lower Cambrian siltstone (»Green shales«). The pyrite forms the matrix of the conglomerate. KAJ HANSEN correlated the pyritic conglomerate with a somewhat similar layer occurring at one locality at Øleaa. Here, at HANSEN's locality no. 6, the somewhat calcareous and glauconitic Rispebjerg sandstone is followed by a conglomerate layer 10 centimetres in thickness. The lower part of this layer has a matrix of fine-grained phosphoritic and glauconitic sandstone. The matrix surrounds rounded quartz grains, phosphoritic sandstone, and elongate lumps of pyrite. The upper part predominantly consists of coarse quartz grains embedded in a matrix of phosphorite and pyrite. The pyritic layer at Øleaa is followed by the *Exsulans* limestone, and, consequently, the clay at Læsaa, underlying the supposedly equivalent pyritic conglomerate,

would be older than the *Exsulans* limestone. Thus K. HANSEN referred the clay at Læsaa to the Lower Cambrian as an equivalent to the somewhat calcareous and glauconitic Rispebjerg sandstone at locality no. 6. He concluded that the principal difference between the beds at Øleaa and Læsaa was that the clay at Læsaa was unconsolidated. He further stated that if the clay indeed was the residue of weathered *Exsulans* limestone, one would expect the layer of clay to be much thinner, than it actually is.

By elutriation of samples of the clay K. HANSEN obtained some brachiopod specimens, which were referred by C. POULSEN to *Acrotreta sagittalis* (SALTER) and *Acrotreta cf. eggegrundensis* WIMAN. K. HANSEN then, after comparing these species with the known Scandinavian occurrences of the same species and their associated fossils, referred the clay at Læsaa and the calcareous part of the Rispebjerg sandstone to the Lower Cambrian *Holmia kjerulfi* zone or *Strenuella linnarssoni* zone. GRÖNWALL (1902) was of the opinion that the Bornholm section contained a hiatus comprising these two late Lower Cambrian zones.

C. POULSEN (1942) stated that the vertical range of *Acrotreta eggegrundensis* was unknown, and as *Acrotreta sagittalis* is widely distributed in the Middle Cambrian, the two species were accordingly of no value for the correlation. Attempting to obtain species, which might be of stratigraphical relevance, C. POULSEN had excavated additional material of the clay for elutriation of fossils. He made a distinction between worn (rolled) and well-preserved shell specimens. The well-preserved specimens were supposed to be normal members of the fauna of the clay, and worn specimens supposedly had been washed out of older deposits to be embedded in the clay and in the *Exsulans* limestone. However, the present writer in his considerably larger fossil material has observed worn as well as well-preserved specimens of *Hyolithellus* and other genera, and, consequently, the state of preservation is of little or no value with regard to the determination of the relative age of the fauna elements. A comparison of the non-trilobite fauna of the clay with similar faunas elsewhere has caused the present writer to believe that the majority of the species must be of Lower Cambrian age.

When excavating the clay C. POULSEN succeeded in finding

fragments of a relatively fresh and hard limestone containing *Jincella parva*, *Ctenocephalus exsulans*, and *Holocephalina linnarssoni*. As these species are well-known from the *Exsulans* limestone, he followed GRÖNWALL in correlating this with the clay at Læsaa. The present writer may add that by etching samples of the *Exsulans* limestone he has obtained species listed from the clay. Thus the beds are in good agreement faunistically and lithologically.

C. POULSEN concluded that the Rispebjerg sandstone, deposited at the time of the *Holmia torelli* zone, was followed by presumably thin deposits belonging to the *Holmia kjerulfi* zone or the *Strenuella linnarssoni* zone. Both zones might have been developed, but the beds most likely were thin and consequently readily removed by the erosion in the time interval corresponding to the *Eccaparadoxides oelandicus* stage. The numerous worn shells of *Acrothele* (*Redlichella*) *granulata* supposedly indicated that a deposit corresponding to the *Acrothele granulata* conglomerate, which is the lowermost bed in the *Paradoxides paradoxissimus* stage, once existed in the Bornholm area. C. POULSEN pointed out that the specimens of *Acrothele* were quite free of adhering rock particles. Probably the deposit only existed a very short time and was eroded, before lithification could take place. He finally concluded that in the time interval between the deposition of the Rispebjerg sandstone and the *Exsulans* limestone the Bornholm region was affected by two transgressions, the first of which occurred in the late Lower Cambrian, the second in the Middle Cambrian.

The age of the Kalby-ler (Kalby clay)

When restudying C. POULSEN's trilobite material from the clay, the present writer noticed that all the specimens were molds consisting of a fine-grained, phosphoritic and argillaceous sandstone. This type of preservation does not occur in the *Exsulans* limestone, where only carbonate exoskeletons are present. Also the present writer's elutriated material contains molds of fragmentary cranidia. Especially interesting is a considerably worn agnostid cephalon (text-fig. 1).

Fig. 1. Fragmentary cephalon of *Ptychagnostus atavus* (MMH no. 9296), X 15. From the Kalby clay at Læsaa.

Even if the border and part of the posterior lobe of glabella are missing in the specimen (MMH no. 9296), it may safely be referred to *Ptychagnostus atavus* (TULLBERG). A comparison with Swedish species listed by WESTERGÅRD (1946) from the *Triplagnostus gibbus* zone (B 1), to which the *Exsulans* limestone belongs, shows that the above mentioned specimen differs from the species of *Peronopsis* in the shape of glabella and in the genal region being corrugated. The specimen differs from *Triplagnostus praecurrens* and *T. gibbus* in possessing a corrugated genal region. It shows some resemblance to *Tomagnostus fissus* and *T. cf. corrugatus*, but the anterior glabellar lobe in these species is subquadrate, cleft in front by a short sagittal furrow, which for a short distance continues into the preglabellar field. The Bornholm specimen has an anterior glabellar lobe tapering forward, and a distinct sagittal furrow crossing the preglabellar field, presumably reaching anterior border.

None af the Swedish species from the *Eccaparadoxides oelandicus* stage show any resemblance to the specimen from the clay. The lower alum shale overlying the clay and the *Exsulans* limestone contains *Ptychagnostus atavus* and *Hypagnostus parvifrons* and thus belongs to the *Tomagnostus fissus — Ptychagnostus atavus* zone (B 2). Accordingly, the worn specimen of necessity must

belong to the lower part of this zone, among the species of which only the index fossil *Ptychagnostus atavus* bears any resemblance. A comparison shows that the fragmentary cephalon in all preserved details, including the pattern of genal furrows, is identical to this species.

The *Exsulans* limestone then must be older than the clay, which the present writer prefers to regard as a separate formation, the Kalby-ler formation. See also text-fig. 2.

The pyritic conglomerate overlying the clay must belong to the same zone as the clay. The pyrite in the matrix most likely is of later, epigenetic origin, the precipitation being dependant upon the presence of a considerable amount of detrital pyrite grains. Determinable fossils have not been found in this conglomerate.

The Kalby-ler formation

Type locality: Section at the western bank of the stream Læsaa, Bornholm. The section is situated 240 metres southeast of the farm Kalbygård. This so far is the only known occurrence of the Kalby clay. The thickness of the formation amounts to 15 centimetres. It is delimited vertically by the Lower Cambrian Rispebjerg sandstone and the Middle Cambrian pyritic conglomerate immediately below the lower alum shale. Due to the dip of the strata the outcrop is very small, situated close to the water-level of the stream.

Stratigraphical position: The *Tomagnostus fissus — Ptychagnostus atavus* zone (B2).

Lithology: The gray Kalby clay is extremely heterogeneous with regard to composition of components and grain sizes. The material may be identified as debris from Lower and Middle Cambrian deposits and comprises fragments of siltstone ("Green shales"), rounded quartz grains and phosphoritic pebbles from the Rispebjerg sandstone, glauconite, pyrite, muscovite, Middle Cambrian fine-grained sandstone or siltstone, brachiopod fragments and tubular fossils. According to K. Hansen (1937) 60 % of the particles are below 0,2 mm. in diameter, and this fraction contains 7,5 % calciumcarbonate, possibly originating from the *Ex-*

sulans limestone. Most of the pyrite undoubtedly is of later origin.

There is no evidence that the Kalby clay should be regarded as the residue of a decomposed limestone. The deposit probably never was subjected to lithification. As mentioned earlier, the solid, fossiliferous samples collected by C. POULSEN consist of silt, practically devoid of calciumcarbonate. The present writer unsuccessfully attempted to obtain fresh or only partly decomposed samples of a possible original limestone. Furthermore, the presence of well-preserved eocystid plates consisting of calciumcarbonate indicates that the sediment can only have been influenced by solution to a very small extent.

The source rocks must predominantly have been non-calcareous sediments. The Lower Cambrian fossils, usually well-preserved and free of adhering rock particles most likely came from the same unconsolidated sands, which contributed to the *Exsulans* limestone.

Probably due to an insufficient amount of calciumcarbonate cementation did not take place. It has been suggested that carbonate cementation in sandstones may be based on carbonate introduced from without, but in most cases the carbonate will be the product of the solution of shells and other calcareous material buried in the sand. By slight migration and reprecipitation the local cement is formed. In the Bornholm region at the time of the deposition of the Kalby clay the only carbonate source available was the *Exsulans* limestone, the upper part of which must have been developed as a siltstone corresponding to the samples from the clay containing *Jincella parva* and *Ctenocephalus exsulans*. The time interval between deposition of the *Exsulans* limestone and the Kalby clay was supposedly of short duration, only allowing the erosion to remove the upper, non-calcareous part of the *Exsulans* sequence. The conclusion must be that the supply of calciumcarbonate was very limited, and this possibly accounts for the missing lithification at the time of or shortly after the sedimentation. The reason why lithification has not taken place up to the present day is not known.

Discussion: The type locality of the *Exsulans* limestone is Kiviks Esperöd in Scania. The limestone, even if not properly named according to modern principles of stratigraphical classi-

fication, ranks as a formation. The name is well-established in the literature, and for this reason possibly should not be rejected.

With regard to Bornholm the present writer considered dividing the *Exsulans* limestone as a formation into two members: The Borregård limestone member (the limestone proper) and the Kalby clay member. The two members then in many respects would form a unit, and they are only separated by a minor break in sedimentation. On the other hand the *Exsulans* limestone is widely recognized as a unit belonging to the *Triplagnostus gibbus* zone. Then, by establishing the Kalby clay as a formation the *Exsulans* limestone is maintained in the customary sense.

On the island of Öland the *Exsulans* limestone is overlain by gray, more or less calcareous, thin-bedded limestone with interstratified laminae and thin strata of shale. This sequence, although none of the index fossils from zone B 2 have been found, is correlated with that zone (Westergård, 1946, p. 14). The basal part of the sequence may be equivalent to the Kalby clay. In Scania the *Tomagnostus fissus* — *Ptychagnostus atavus* zone sequence consists solely of alum shale, as does the part of this zone overlying the Kalby clay.

Early Middle Cambrian history and paleogeography

After deposition of the Rispebjerg sandstone at the time of the Lower Cambrian *Holmia torelli* — *Kjerulfia lundgreni* zone (see text-fig. 2) a regression set in, and phosphorite impregnated the upper part of the sandstone. The following hiatus, apart from a minor transgression, corresponds to the rest of the Lower Cambrian and the basal part of the Middle Cambrian. The presence of beds from the *Eccaparadoxides oelandicus* stage in the South Baltic has not been ascertained. A thin sequence of shales and limestones without any distinctive fossils found at some Scanian localities may arbitrarily be referred to this stage or to the *Paradoxides paradoxissimus* stage.

As indicated by the non-trilobite material in the Kalby clay the Bornholm area was submerged for a short while in the late Lower Cambrian. The present writer has not yet finished his studies of the non-trilobite fossils, but he believes that all of the

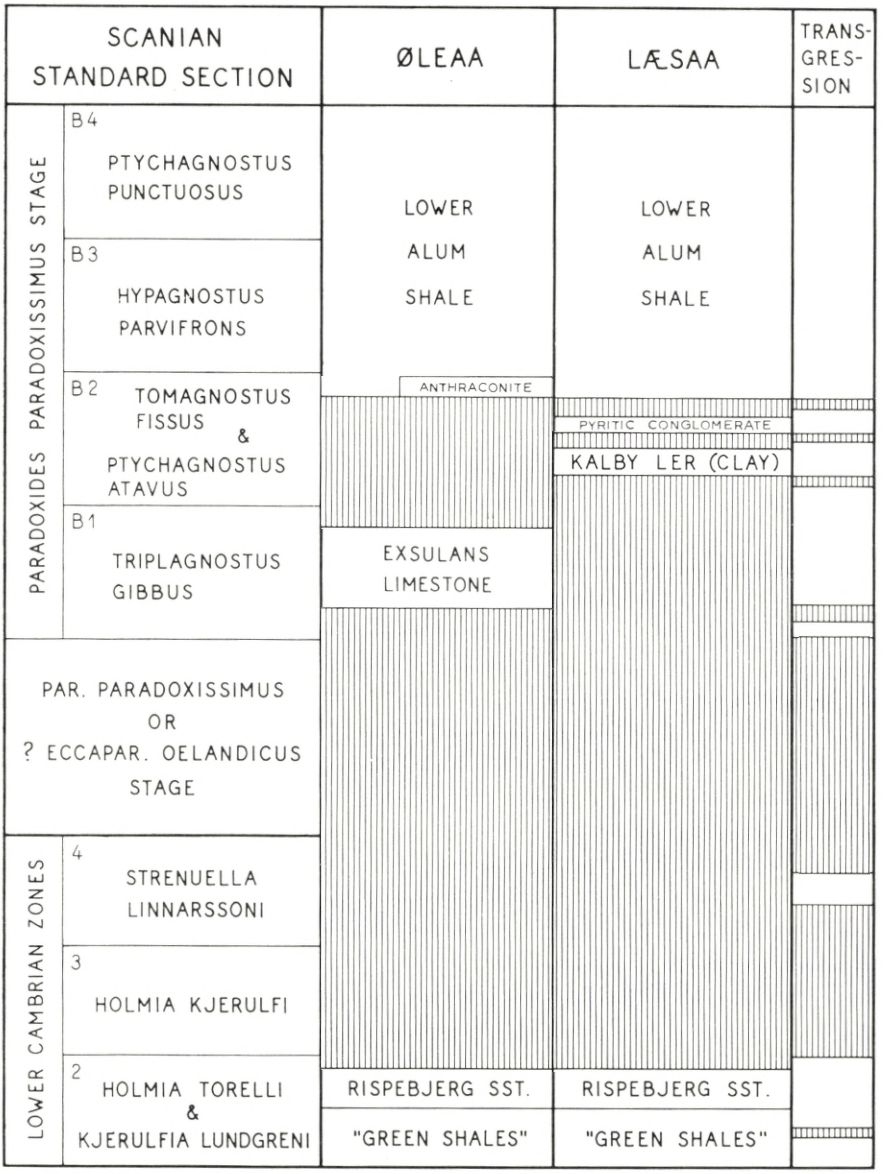

Fig. 2. The Lower and early Middle Cambrian sections at Øleaa and Læsaa, Bornholm.

Lower Cambrian species contained in the clay and in the *Exsulans* limestone most likely originated from the *Strenuella linnarssoni* zone. The sea covering Bornholm at that time was supposedly shallow, leaving a thin deposit of sand poor in carbonates. The deposit was not affected by lithification. This appears from the beautifully preserved fossils, free of adhering sediment, found in the Kalby clay.

The next transgression occurred at the time of the initiation of the *Triplagnostus gibbus* zone. The occurrence of numerous specimens of *Acrothele* (*Redlichella*) *granulata* in the Kalby clay indicates the former presence of a bed similar to the *Acrothele granulata* conglomerate, as clearly demonstrated by C. POULSEN (1942). The species is known from the *Eccaparadoxides oelandicus* stage, but as all the Læsaa specimens are strongly worn and rolled, they most likely originated from a conglomerate like the basal layer of the *Triplagnostus gibbus* zone (B1). During this transgression part of the Lower Cambrian unconsolidated deposits was reworked, and the resulting bed, of a lithology similar to that of the Kalby clay, contained a mixture of Middle Cambrian brachiopods and Lower Cambrian brachiopods and tubular fossils.

After deposition of the basal conglomerate the sea withdrew for a short while. The sea returned, and the *Exsulans* limestone was deposited. Material from the unconsolidated *Acrothele granulata* conglomerate including rounded quartz grains and phosphoritic pebbles from the Rispebjerg sandstone were incorporated. Also previously undisturbed deposits from the *Strenuella linnarssoni* zone were reworked, and Lower Cambrian fossils were embedded in the limestone.

Towards the end of the time of the *Triplagnostus gibbus* zone the basin shallowed up, and fine sand was deposited. A regression followed, and phosphorite impregnated the sandy upper part of the *Exsulans* limestone. Possibly the sedimentation continued practically uninterrupted slightly across the boundary between the *Triplagnostus gibbus* zone and the *Tomagnostus fissus* — *Ptychagnostus atavus* zone. This possibility is indicated by the specimen of *Ptychagnostus atavus* showing the same phosphoritic state of preservation as the *Exsulans* siltstone trilobites found in the clay.

At early *Tomagnostus fissus — Ptychagnostus atavus* zone time the sea withdrew completely for a short while, and the erosion removed the sandy upper part of the *Exsulans* limestone. Still at the time of this zone the sea returned, and the Kalby clay was deposited probably over an area of the same extent as that of the *Exsulans* limestone. In the clay the elements of the four previous transgressions may be identified, as demonstrated above. The Lower Cambrian fossils may be divided into a group of well-preserved specimens and a group of badly preserved (worn) specimens. Some of the species are found in both groups. Probably all of the species originated from the *Strenuella linnarssoni* zone. The badly preserved group is supposed to have been redeposited two or three times, in the first place in the *Acrothele granulata* conglomerate, secondly in the *Exsulans* limestone, and finally in the Kalby clay. The well-preserved specimens are supposed to have been washed out from original *Strenuella linnarssoni* zone beds, undisturbed by the previous transgressions.

The transgression responsible for the deposition of the Kalby clay was of short duration. Following a short break in the sedimentation the pyritic conglomerate was deposited on top of the Kalby clay. Another hiatus followed, and during this interruption the erosion removed the remaining undisturbed parts of the *Strenuella linnarssoni* zone beds, the rests, if any, of the *Acrothele granulata* conglomerate, and in most places the Kalby clay and the overlying conglomerate.

When the subsequent transgression set in at the time of the upper part of the *Tomagnostus fissus — Ptychagnostus atavus* zone the environment had changed, and abruptly, without any transition beds, alum shales were deposited. This phase was initiated at the close of zone B 2, as the basal part of the shale sequence at Øleaa contains the index fossil *Ptychagnostus atavus*. The stable conditions persisted throughout the *Hypagnostus parvifrons* zone and the *Ptychagnostus punctuosus* zone of the *Paradoxides paradoxissimus* stage.

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