MEGASPORES FROM THE JURASSIC OF THE ISLAND OF BORNHOLM, DENMARK

By

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Abstract

An account is given of the lithology, areal extent and depositional history of the Jurassic sediments and a preliminary description is given of the megaspore content of the sediments (excluding new species). The deltaic deposits below the marine Lias γ horizon are Lias α in age and the deltaic deposits above this horizon are referred to the Dogger.

INTRODUCTION

The Mesozoic succession in Bornholm comprises beds of Keuper, Jurassic and Cretaceous age.

The Jurassic beds were deposited under deltaic conditions. The sediments are mainly fine-grained (fine sand, silt and clay). Coarser fluviatile sand beds, often cross-bedded, occur alternating with finer-grained beds, while conglomerates are very rare.

Finely bedded silts and clays with bands of clay ironstone are common; these comprise deposits that were laid down by slowly moving currents and show ripple marks, and deposits that were laid down in still water and show finely developed plane-parallel bedding. Thick, compact grey clay beds lacking clear stratification are lacustrine deposits, which usually occur as elements in a more-or-less pronounced cyclic sedimentation reflecting the development in a lake that was filled up, became a swamp and was overgrown. A complete cycle comprises, from base upwards: sand or clayey sand, sandy clay, grey clay, black clay rich in humus and containing plant roots and coal. Horizons representing complete overgrowth can, however, also occur in fine-grained sand beds. Some of the beds underlying the coal seams contain agglutinating foraminifera, which show the paralic nature of the beds.

The fluviatile, lacustrine and lagoonal deposits referred to here nearly always contain plant remains. Larger or smaller fragments of carbonized wood occur in the coarser sand; in the fine-grained sand deposits, which were laid down in water with active currents, there are thin stripes with small carbonized wood fragments and other plant remains, and the bedded silts and clays usually contain large amounts of fine plant detritus, fragments of cuticula, etc.

The fine-grained marine sandstone described in the following paragraph was deposited so far outside the delta proper that plant remains are, as a rule, not found in it.

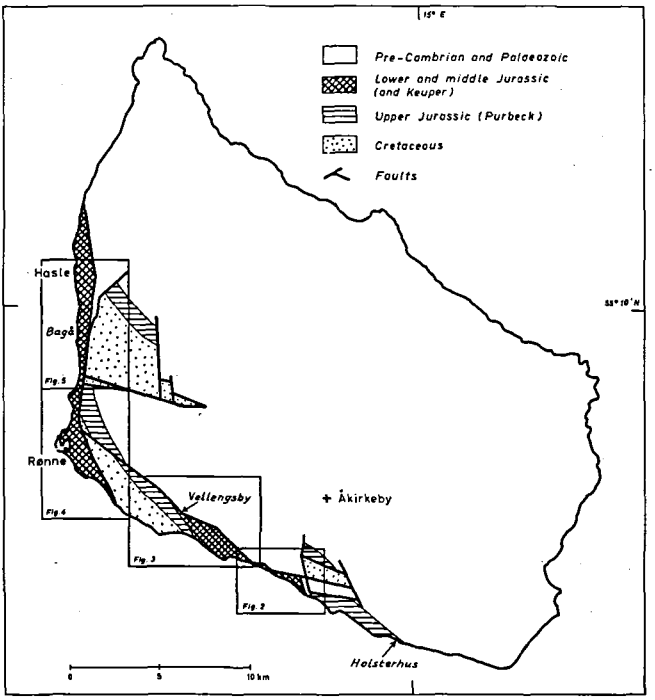


Fig. 1. The distribution of the Jurassic deposits of Bornholm. The location of the maps in figs. 2–5 is shown.

The marine sequence is from Lias γ and occurs in most places as a friable, limonite-bearing fine sandstone with bands of clay ironstone, but it can also be developed as a thinly laminated deposit of fine sand and clay. The marine sequence is 80–100 m thick. It divides the freshwater deltaic beds into a lower and an upper coal-bearing sequence. In the lower section a brackish water horizon with *Cardinia follini* occurs; this is also known from Lias α in Skåne (Scania).

A deltaic sequence from the Purbeck and the Wealden rests unconformably on the coal-bearing Jurassic deposits and on the Precambrian and Palaeozoic rocks (GRY, 1956; BRUUN CHRISTENSEN, 1963). This sequence is overlain slightly unconformably by marine Cretaceous sediments, whose oldest part, which is only found in redeposited form in the Middle Cenomanian basal conglomerate, is of Lower Albian age.

The Mesozoic floras of Bornholm have been described by BARTHOLIN (1892, 1894, 1910), HJORTH (1899) and MÖLLER (1902, 1903). According to these old descriptions species ranging from the Rhaetic to the Dogger and Wealden are found in the deposits. However, according to HARRIS (1937, p. 88) Rhaetic plants do not occur in the formations.

The Mesozoic deposits occur in areas that are separated from each other

by faults, in part of Laramide age (fig. 1). Of special importance are a N–S fault situated inland from the west coast of Bornholm and a WNW–ESE fault running across southern Bornholm. The difficulty in correlating the scattered plant-bearing localities lies in the fact that they occur in various tectonic units, whose succession, with a single exception, has not been well known.

In this account a description will be given of the writer's investigations of the lithology, areal extent and depositional history of the individual beds in the various blocks, and a preliminary report will be given of the content of megaspores in the beds so far as concerns species earlier described in the literature.

The writer wishes to thank Professor TOM M. HARRIS, Reading, Dr N. F. HUGHES, Cambridge, Dr S. J. DIJKSTRA, Heerlen and Dr KARL MÄDLER, Hanover for allowing him to study their collections of Mesozoic megaspores, Professor ALFRED ROSENKRANTZ, Copenhagen, for determining the molluscs and Mr OLE BRUUN CHRISTENSEN for determining the ostracods and foraminifera. Mr G. HENDERSON translated the manuscript into English.

THE INDIVIDUAL JURASSIC AREAS

In this account the various Jurassic areas will be discussed, starting with the easternmost occurrences to the south and continuing with the beds towards the west as far as Rønne and from there northwards along the west coast. The Purbeck beds, whose development has been described earlier (GRY, 1956), (Rabekke Formation and Robbedale Formation, GRY 1960), will only be briefly mentioned at the end of the account.

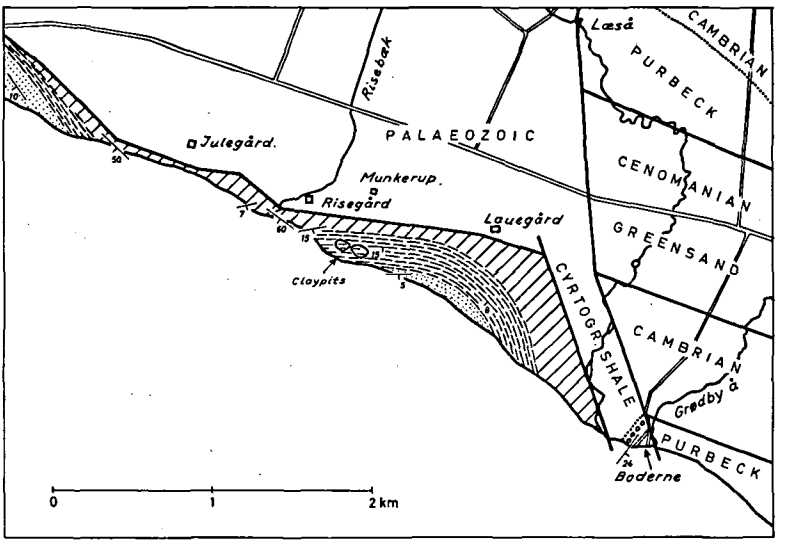
Boderne (fig. 2)

The Cyrtograptus shales at Boderne are overlain unconformably by a conglomerate 4½ m thick. The conglomerate contains rather well rounded blocks of sandstone, highly weathered blocks of Lower Cambrian glauconitic siltstone and dark Palaeozoic shales. All the blocks seem to have come from the Palaeozoic rocks of Bornholm, and it is clear that the land surface the blocks came from was somewhat weathered (kaolinized). The schists the conglomerate rests on are likewise weathered, and are softer and lighter in colour than usual.

The conglomerate passes up into a sequence consisting mainly of sands and sandy clays with carbonized wood and other plant remains.

The beds are essentially unfossiliferous, but one sample yielded some megaspores. The following forms were identified:

Trileites murrayi HARRIS, *Trileites turbanaeformis* HARRIS, *Thomsonia phyllica* MURRAY and a new species of *Hughsisporites* which, elsewhere in Bornholm, is present in beds younger than Lias γ. The three forms whose species were identified have all been found in the Dogger deposits in Yorkshire, and the sequence must belong to the upper coal-bearing sequence.



KEUPER
- Variegated clay and sandstone

JURASSIC
- Compact grey clay with black clay and coal seams
- Finely bedded silt and clay with bands of clay ironstone
- Sand, finesand or unknown
- Marine horizon Lias γ
- Principal coal seams
- Strike and dip
- Faults
- Clay pit

Fig. 2. The Munkerup-Risegård area and Boderne. Distribution of the sediment types in the Jurassic (somewhat simplified). Legend to the maps in figs. 2–5.

The coast section between Boderne and Risegård (fig. 2)

A downfaulted block with Mesozoic deposits occurs here, limited by faults on the northern and eastern sides. Close to the faults there are green, red and variegated clays and green sandstone. On the basis of the lithologies these beds have been referred to the Keuper. OLE BRUUN CHRISTENSEN has determined the ostracod content of the clays and has thereby found the age to be Lower Keuper. The Keuper clay also contains oogonia of characeae, and skolithos-like burrows occur in the sandstone. The beds are very steeply dipping close to the faults, but farther away they have a somewhat gentler southward dip. The Keuper beds are overlain by a sequence of grey and black Jurassic clays with subordinate sand beds. The clay contains horizons with plant roots and thin coal seams. Boreholes have shown the presence of up to 20 m of the clay that, under the name

Munkerupler (Munkerup Clay), has been used for brickmaking. Fossil plants from the clay were referred by BARTHOLIN to the Rhaetic (GRÖNWALL and MILTHERS, 1916, p. 90). On the basis of the occurrence of *Lycostrobus Scotti spores,* now called *Nathorstisporites hopliticus* JUNG (JUNG, 1958), the writer has referred the sequence to the Lower Lias (GRY, 1960, p. 5).

Samples from boreholes and surface outcrops have yielded, in addition to *Nathorstisporites hopliticus,* which occurs abundantly in several horizons, *Verrutriletes franconicus* JUNG, *Horstisporites areolatus* and *Horstisporites harrisi* MURRAY (= *H. Semireticulatus* JUNG).

From Sosevig to Vellengsbygård (fig. 3)

The E–W fault runs very close to the coast from Risegård westwards for more than 1 km and only disturbed Keuper is found along it. Thereafter, the fault continues with a roughly north-western direction towards Vellengsbygård, and on the south side of the fault a block with Jurassic beds rests on Keuper. The beds dip 3–5° to the south-south-west, and are steeper up against the fault. Boreholes have shown the presence of steeply dipping Keuper along a stretch of 4½ km to somewhat over 1 km east–south-east of Vellengsbygård.

The Keuper is overlain by clays corresponding to the Munkerup Clay and these clays are overlain by deltaic deposits consisting of interbedded sands with abundant carbonized wood fragments, light-coloured, more-or-less bedded sandy clay and subordinate beds of dark clay and a few thin coal seams. A typical part of the sequence can be seen in a coast section at Sosevig. Close to Soseodde the predominantly sandy sediments give way to thinly bedded silty clay with abundant plant remains and bands of clay ironstone (lagoonal deposits laid down in calm water).

West of Soseodde these deposits pass into a fine-grained limonitic sandstone with clay ironstone bands and still farther west there are striped silts and clays, in which a mussel belonging to the family *Nuculana* was found. In the same beds in two boreholes close to the coast agglutinating foraminifera – *Haplophragmoides sp.* and *Ammodiscus silicius* – were found, in addition to indeterminable casts of molluscs. Both the limonitic sandstone and the silts and clays to the west of this resemble sediments from the marine Lias γ horizon (the clay contains beds with innumerable tracks of burrowing organisms) but it is likely that this represents a brackish-water intercalation in Lias α. In one of the boreholes mentioned, deltaic deposits 60 m thick were found under the foraminifera-bearing beds; below this level the borehole entered the variegated Keuper clay.

North-west of Lille Myregård drilling penetrated over 60 m of a predominantly deltaic freshwater sequence, which probably overlies the brackish-water intercalation.

The content of megaspores in more than ten boreholes and in the outcrop at Sosevig was examined.

The content of spores is generally low. Characteristic of the sequence are *Nathorstisporites hopliticus,* which is rare, however, and *Verrutriletes*

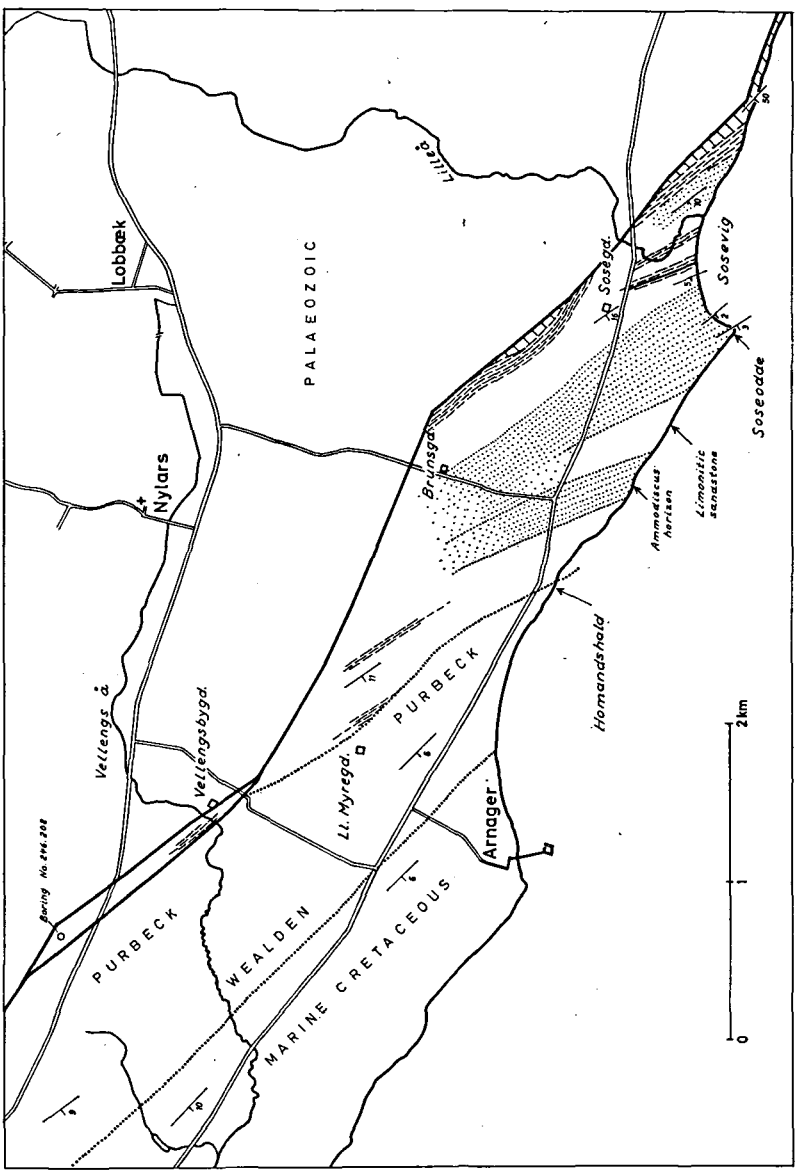


Fig. 3. The Sose and Vellengsbygård areas. Distribution of the sediment types in the Jurassic (somewhat simplified). Legend see fig. 2.

franconicus. In addition *Trileites turbanaeformis, Horstisporites areaolatus* HARRIS and *Horstisporites harrisi* occur. The first two forms show that the beds belong to Lias *α*.

South-west of the Lias α beds there are sands and clays of Middle Purbeck age, which are overlain by Wealden clay and marine Cretaceous. The whole of this sequence has the same strike and dip direction as the Lias α beds. The relation between the two sequences is not entirely clear, but there is evidence suggesting that the Purbeck beds rest on younger Jurassic beds and that they have transgressed across a fault that extends beneath the Purbeck beds from the coast at Homandshald to Vellengsbygård. At Homandshald the beds are considerably disturbed.

The Vellengsby Clay (fig. 3)

The locality from which HJORTH determined a Rhaetic flora (1899) is situated 200 m west-north-west of Vellengsbygård. The sequence examined consists of 3½ m of clay, slightly reddish at the top, light grey in the middle and whitish at the base. The clay rests on sand. According to HARRIS (1937, p. 88) the flora comprises forms that may belong to the *Thaumatopteris* flora.

The pits have long been overgrown, and an attempt to drill through the clay was unsuccessful since the borehole went down into the underlying Jurassic sand, which proved to be resting on the Cambrian Balka Sandstone. The sand was unfossiliferous. Examination of a number of samples from collections at the Geological Survey of Denmark, the Mineralogical Museum of the University of Copenhagen and the Bornholm Museum showed that, apart from indeterminable spore remains and fern sporangia the clay only contained *Verrutriletes franconicus*. In Bornholm *Verrutriletes franconicus* is only found in the Thaumatopteris zone and HARRIS's conclusion that the Vellengsby Clay belongs to this zone is supported by the spore content.

1½ km north-west of Vellengsbygård, just south of the fault, a borehole was put down (D.G.U. file no. 246.208) and showed the presence of Jurassic beds resting on the Eocambrian Nexø Sandstone. Above the sandstone there is 4.2 m of grey clay with subordinate fine sandy beds, and above this 3.6 m of coarse sand. The coarse sand is unfossiliferous, while the lowest part of the clay contains megaspores and fern sporangia. It was possible to identify *Nathorstisporites hopliticus* and *Verrutriletes franconicus*. The spore content shows clearly that the beds belong to the Lower Lias (α).

The beds at Vellengsbygård and those in the borehole undoubtedly belong to the same tectonic unit, which forms a narrow "step" between the most up-faulted block to the north and the down-faulted block to the south. The fact that Lias α rests on both Palaeozoic and Keuper beds shows that considerable tectonic movements took place in the period between the Keuper and the Lias.

The Rønne area (fig. 4)

The beds at Rønne form a fold as already shown by JESPERSEN (1869). With the aid of measurements along the coast and sections obtained during

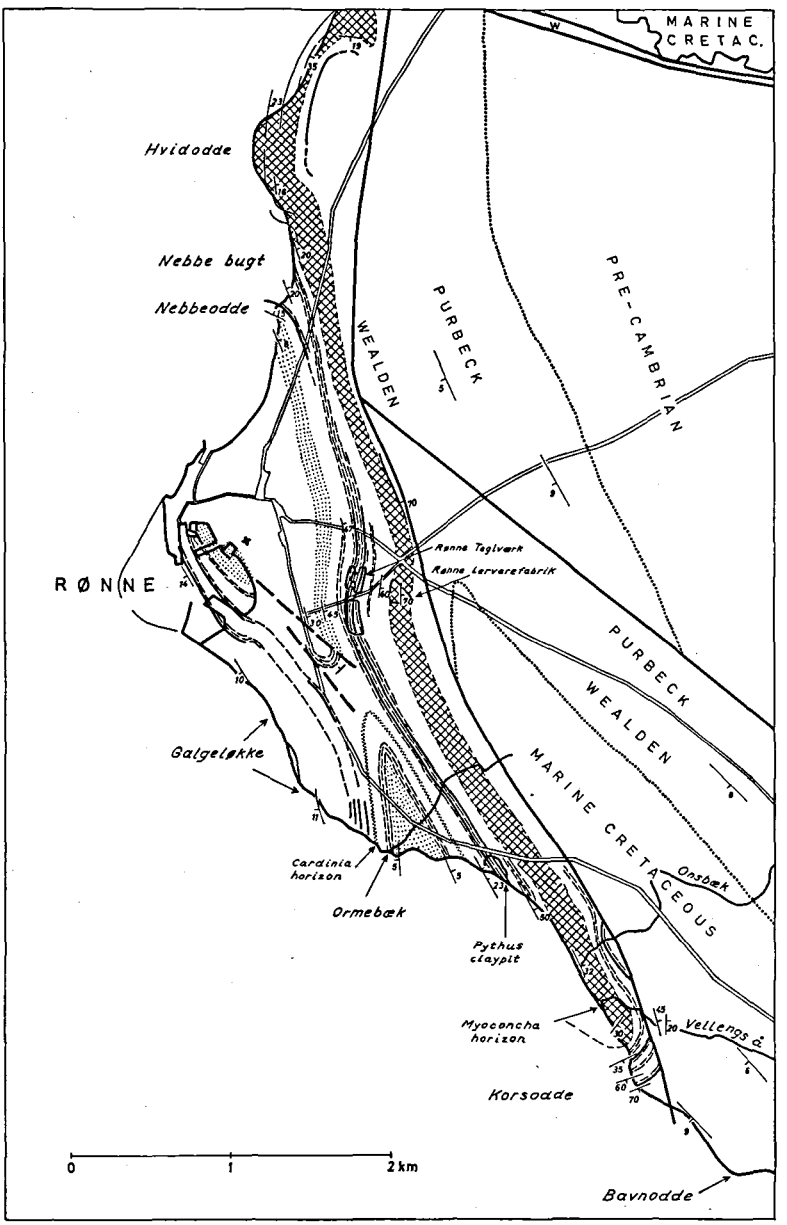


Fig. 4. The Rønne area. Distribution of the sediment types in the Jurassic (somewhat simplified). Legend see fig. 2.

drainage work in the town it is possible to recognize the individual parts of the sequence from place to place, even if there are major variations in detail. The sequence comprises, from the base up: freshwater deltaic beds, including white clay at Ormebæk, succeeded by a brackish-water intercalation (*Cardina follini* bed, Lias α); this is overlain by more freshwater deltaic beds, to which belong the clay occurrences at Pythus, Rønne Teglværk and Nebbeodde. Next in the sequence are the marine Lias γ beds, consisting of fine-grained limonitic sandstone and thinly bedded fine sands and clays with clay ironstone (the Myoconcha horizon at Vellingså, Rønne Lervarefabrik, the coast at Nebbebugt and Hvidodde); these beds are overlain by further freshwater beds (Korsodde, clay pit at Onsbæk).

Below the white clay at Ormebæk there are striped clays and fine sands with clay ironstone, which contain *Cyrena*. These beds are probably the equivalent of sediments of the same type in the northern part of Rønne harbour and south of Nebbeodde where it contains *Cyrena menkei*.

The equivalent beds on the west flank of the fold to the coal-bearing clay beds at Pythus and Rønne Teglværk on the east flank are coal-bearing beds in the eastern part of Galgeløkken and in the central part of Rønne harbour. The fine sands at Galgeløkken are equivalent to beds between Rønne Teglværk and the marine beds in the clay pit at Rønne Lervarefabrik.

The Lias γ beds in the clay pit at Rønne Lervarefabrik were found to be 80 m thick; the sequence on the coast is about the same thickness. The overlying deltaic beds at Korsodde are over 210 m thick.

The underlying sequence varies very much in thickness. For example, the *Cardinia* horizon on the south coast is about 150 m below Lias γ and the comparable horizon in the town of Rønne is about 210 m below Lias γ. The maximum thickness of the lower sequence was measured in Rønne, where it is over 350 m thick. At Nebbeodde the beds are considerably thinner.

In the western part of the fold it is seldom that the dips of the beds exeed 10–15° south-west, whereas the east flank is considerably steeper; over considerable areas the dips are 30–45°. Up against the fault that separates the Jurassic beds from the Cretaceous beds to the east the dips become steeper and steeper until eventually they reach vertical or are perhaps slightly overturned.

The beds generally have a low spore content or are unfossiliferous. A number of examples of *Nathorstisporites hopliticus* were found in the white clay at the mouth of the Ormebæk stream in beds lying under the zone with *Cardinia follini*. This form also occurs as a few individuals in other samples and was still found in the youngest of the samples examined by the writer, viz. the clay from the pit at Rønne Teglværk. In the Rønne area the sequence below the marine beds also yielded a number of examples of *Horstisporites areolatus* and occasional *Trileites turbanaeformis*.

The occurences of *Nathorstisporites* show that by far the largest part of the lower coal-bearing sequence in the Rønne area must belong to Lias α. The other two forms are non-diagnostic.

Jurassic coal-bearing beds younger than Lias γ occur at Korsodde and Onsbæk. At the latter locality clay has been worked opencast and in shafts about 200 m from the coast; at Korsodde there has been coal mining as well as clay working.

The sequence differs from deposits of the same age in Bornholm in containing a few conglomerates, the lowest of which contains hard, well rounded sandstone blocks with a diameter of up to 20 cm. This conglomerate was at one time exposed at both Korsodde and Onsbæk. Coarse-grained cross-bedded sandstone is also abundant. The sequence also contains finer sand and sandstone, clay with horizons containing plantroots, and thin coal seams.

Megaspores only occur in a few of the samples examined. The commonest form is *Erlansonisporites sparassis* MURRAY. *Trileites turbanaeformis*, *Trileites murrayi*, *Echitriletes russus* HARRIS, *Thomsonia phyllica* and the Wealden form *Maexisporites soldanellus* DIJKSTRA also occur. These forms show the beds to be Middle Jurassic.

The area between Rønne and Sorthat (fig. 5)

The marine beds extend from Nebbebugt northwards along the coast to Sorthat. The curved form of the outcrop was described by JESPERSEN (1865, p. 33), and the fossil content was determined by MALLING (1914). The beds consist of bedded clays and sands with abundant clay ironstone bands and horizons with oolitic chamosite.

The beds dip 20–40° inland, where they are overlain by coal-bearing beds that are not well known in the southern part as far as the stream Blykobbeå. The equivalent beds to the north are the Sorthat beds.

The curved form of the outcrop may be related to drag effects in connection with a northwards-directed movement of the Jurassic block and a southwards-directed movement of the eastern block. This could give rise to folds and faults with a NW–SE trend.

The Sorthat beds are rather well known from JESPERSEN's description (1866). Above the marine limonitic sandstone, which dips about 55° east-north-east at the coast, there is an even more steeply dipping coal-bearing sequence with 15 coal seams, several of which have been worked. The course of the coal seams can still be seen by means of holes resulting from collapse above old mine workings.

On the basis of JESPERSEN's measurements and observations made by the writer, the various components of the sequence can be estimated to have the following thickness:

uppermost: sand and clay	approx. 60 m
coal-bearing sequence	approx. 140 m
limonitic marine sandstone	approx. 110 m

In the uppermost part of the coal-bearing sequence and in the overlying beds there are three or four horizons with agglutinating foraminifera. For example, *Spirillina sp.* was found in the clay pit, and in boreholes in the

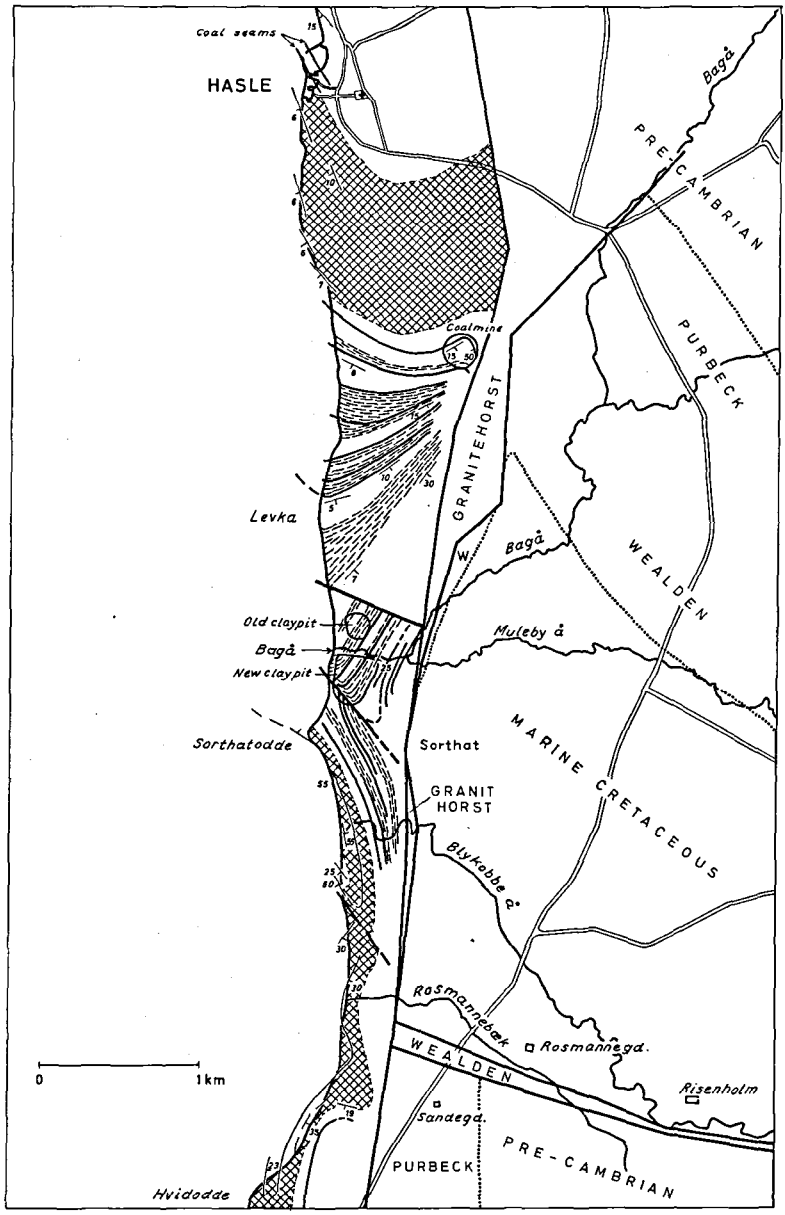


Fig. 5. The Sorthat, Bagå and Levka-Hasle areas. Distribution of the sediment types in the Jurassic (somewhat simplified). Legend see fig. 2.

uppermost part of the sequence two or three horizons with *Haplophragmoides* were found.

The Sorthat beds are delimited against the Bagå beds to the north by a fault striking N40°W with a dip of about 45° to the south-west. Part of the fault can be seen in the southern side of the large pit belonging to the Hasle Klinker- og Chamottestensfabrik south of Bagå (GRY, 1960, fig. 6).

Megaspore content. Material was obtained from the uppermost part of the coal-bearing sequence (collected from the pit at the Klinkerfabrik) and from boreholes that went down into the highest beds in the sequence. Samples from the pit at the Klinkerfabrik contained *Trileites turbanaeformis, Horstisporites areolatus* and a few new species, which were also encountered in the coal-bearing part of the Levka beds.

The boreholes yielded *Horstisporites areolatus, Erlansonisporites sparassis, Thomsonia phyllica* and *Minerisporites volucris* MARC. (MARCINKIEWICZ found one example in the Upper Lias). These forms also occur in the Levka beds (see p. 84). The megaspores show that the age of the Sorthat beds must be Upper Lias to Dogger. As these beds are of the same age as the Levka beds they are referred to the Dogger.

The Bagå beds (fig. 5)

The Bagå beds comprise freshwater sediments, mainly clays with coal seams. The sequence occurs on both sides of the lower reaches of the Bagå river. Knowledge of the beds stems originally from coal mining (started around 1800). Best known are the occurrences in the clay pit opened around 1890 north of the river, and in the present clay pit, opened south of the river in 1905. As the beds dip east-south-east the oldest part of the sequence is found in the old pit north of the river and the upward continuation in the new pit south of the river. In the last-named pit (GRY, 1960, p. 13) a sequence 106 m thick is exposed, consisting of clays with horizons containing plant roots and thin coal seams, and subordinate sandy beds. The highest (easternmost) part of the sequence consists mainly of mudflow sediments.

A borehole in the bottom of the western part of the pit showed the presence of an additional 30 m of predominantly clayey beds, which correspond in part to the beds in the old pit, and below this 10 m sand. The sequence continues east of the new pit. Coal mining was carried out here in the past, and as in the Sorthat beds traces of mining activity in the form of surface collapse can be seen. The eastern continuation of the sequence as far as the easternmost coal seam must be at least 45 m thick. There is thus a bed thickness of 190 m. The thickness of the beds farther to the east up to the narrow granite horst that forms the eastern boundary of the Jurassic beds is not known.

The strike of the beds in the new clay pit varies from N35°E to N25°E in most of the pit; the dip is 17° south-east in the western part and 25° south-east in the eastern part.

The strike and dip in the old clay pit north of the river are about the same.

As mentioned, the Bagå beds are separated from the Sorthat beds by a fault running NW–SE and dipping south-west. According to FORCHHAMMER (1837), a fault is also found between the Bagå beds and the Levka beds. The beds, however, have the same strike and about the same dip on each side of the presumed fault, and therefore it is impossible on this basis to decide whether the fault exists or not. The Bagå beds may thus be younger than the Levka beds, but can also be of the same age as these and the Sorthat beds (which are definitely the same age as the Levka beds).

Since the relations at the fault between the Bagå and Sorthat beds can presumably only be interpreted as showing that the Bagå beds have undergone relative uplift, the second alternative is the more likely. The Bagå area thus represents a horst, whose northern boundary can only be placed as shown on the map, fig. 5.

The age of the beds at Bagå has been the source of considerable argument. Both C. T. BARTHOLIN (1892) and HJALMAR MÖLLER (1902–03) found species from the Rhaetic-Lias as well as from Oolite and Wealden. GRÖNWALL (GRÖNWALL and MILTHERS, 1916, p. 129) referred the beds to the Upper Lias, and in his classification of the Jurassic and Wealden of Bornholm, MALLING (1920) assigned the beds mainly to the Dogger. HARRIS (1937, p. 90) states, "The other floras – those of Bagaa etc. are intermediate in general character between the European basal Liassic flora on the one hand and the upper Liassic flora of Poland or the similar Lower Oolitic flora of England and Italy, etc. On the grounds of this intermediate character it may be regarded as belonging to a period in the middle of the Liassic".

ROSENKRANTZ (1939, p. 526) identified marine fossils of Lias γ age from a thin pebbly bed rather high in the sequence in the clay pit south of Bagå, and established the following sequence:

top:	freshwater beds	Lias δ and possibly Upper Lias
	2 m bed representing marine transgression	Lias γ
bottom:	freshwater beds with *Thaumatopteris*	Lias α and possibly β

He assumed that the Bagå flora of BARTHOLIN and MÖLLER derived from the upper freshwater beds.

Finally, FLORIN (1958, p. 334), who has studied the taxads and conifers in Bornholm, states, "All the five organ genera represented at Bagå (two also at Hasle) occur in the middle Jurassic flora of Yorkshire (Lower to Upper Deltaic) but are unknown from the Lower Liassic floras of Scania and Bornholm".

He concludes that at any rate part of the upper freshwater sequence in Bornholm probably belongs to the Middle Jurassic (Bajocian?)

ROSENKRANTZ's interpretation of the succession could explain the fact that BARTHOLIN and MÖLLER found both old and young plant species.

However, the pit in which the marine fossils were found was first opened in 1905, i. e. after the fossils described by BARTHOLIN and MÖLLER were collected. Until about 1880 there was a clay pit south of the Bagå

river near its outlet, and it was there that BARTHOLIN collected his material. In 1892 he reported that he had collected material in a new pit north of the river. At both localities the plant-bearing beds occur below the lowest of those coal seams that are called Knobberænderne, and these are situated at a considerable depth below the marine horizon.

BARTHOLIN and MÖLLER's collections can only have been made in the lowest part of the sequence*, and the flora is considered by GRÖNWALL, MALLING, HARRIS and FLORIN to be young. Thus there is a discrepancy between the age indicated by the flora and that indicated by the marine fossils. However, the marine fossils which were collected by Dr CHR. POULSEN in 1933 came from a loose concretion, and it is doubtful whether they originated in the Bagå beds. In spite of diligent search in subsequent years in a layer in the pit which has the same petrographic character as the fossiliferous block, it has not been possible to find marine fossils in situ in the pit. Consequently, it is most likely that the concretion was an erratic block.

Megaspores. The samples from the Bagå beds yielded the following megaspores:

1. Forms described from the Yorkshire Deltaic Series (Bajocian and Bathonian): *Horstisporites harrisi, Trileites turbanaeformis, Trileites murrayi, Aneuletes patera* HARRIS, *Bacutriletes corynactic* HARRIS, *Erlansonisporites sparassis* and *Thomsonia phyllica.*

2. Forms described by MARCINKIEWICZ from Poland: *Bacutriletes clavatus* (stated to occur in beds ranging from Lias γ to Aalenian).

3. Wealden forms: *Maexisporites soldanellus* DIJKSTRA.

The close relation to the Middle Jurassic of England is clear. The only modern account of plants from Bagå (FLORIN, 1958) indicates a Middle Jurassic age and if this evidence is compared with that of the spores, the Bagå beds can be referred to the Middle Jurassic without hesitation.

The Levka beds (fig. 5)

The marine Hasle Sandstone (Lias γ), like the marine sandstone in other parts of Bornholm, consists of a limonite–bearing fine sandstone with clay

*) Statements that the Bagå flora came from collections made at various localities (FLORIN, 1958, p. 334; TRALAU, 1966, p. 32) seem to be based on HANSEN's account of GRÖNWALL's remarks. HANSEN (1939, p. 464) writes, "GRÖNWALL maintains that the term Bagå flora .... conceals a mixture of material from the old Bagå clay pit .... and from Hasle Kulværk" (translation). GRÖNWALL does not say this. GRÖNWALL (GRÖNWALL and MILTHERS, 1916, p. 111, footnote) writes that some of the samples stated to have come from Hasle Kulværk may not have come from there, but from Bagå.

GRÖNWALL believed that the beds from Hasle Kulværk belonged to the Lower Lias and the Bagå beds to the Upper Lias. In order to be able to refer the flora from Hasle Kulværk to the Lower Lias he used the above-mentioned assumption to eliminate the youngest element in the beds at Hasle Kulværk (Wealden forms) from the list of flora.

GRÖNWALL never stated that the Bagå flora as described by BARTHOLIN and MÖLLER had forms mixed with it that did not come from Bagå. It is hoped that the myth concerning mixing of museum samples as an explanation of the character of the Bagå flora has now been finally disposed of.

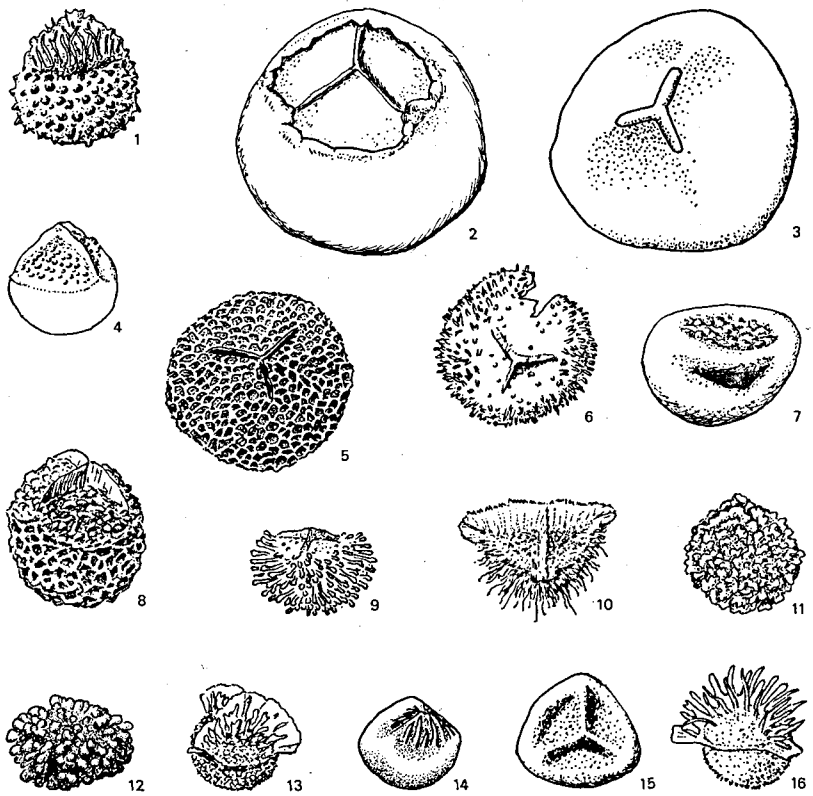


Fig. 6. Megaspores from the Lower and Middle Jurassic of Bornholm (× 40). 1. *Nathorstisporites hopliticus*, 2. *Trileites turbanaeformis*. 3. *Trileites murrayi*. 4. *Verrutriletes franconicus*. 5. *Horstisporites areolatus*. 6. *Echitriletes russus*. 7. *Aneuletes patera*. 8. *Horstisporites harrisi*. 9. *Bacutriletes corynactis*. 10. *Minerisporites volucris*. 11. *Erlansonisporites sparassis*. 12. *Bacutriletes clavatus*. 13. *Thomsonia phyllica*. 14. *Hughesisporites galericulatus*. 15. *Maexisporites soldanellus*. 16. *Thomsonia* cf. *pseudotenella*.

ironstone bands. It outcrops along the coast for a distance of 1½ km from Hasle harbour and has been encountered inland in wells in the town of Hasle and in the area south of the town. In Hasle harbour there are a few coal seams with gentle dips (6–8°) together with sandstone and thin clay horizons; farther north along the coast there is sandstone of clear fluviatile origin.

The marine beds are overlain by coal-bearing beds, which FORCHHAMMER (1837) called the Levka System. From olden times 19 coal seams here have been known and mined. Boreholes put down in 1941 led to the discovery of a new coal field with 12 seams below the lowest of the seams known previously. These coal seams were worked by opencast mining in the years 1944–46.

The extent of the Levka beds and the strike and dip of the beds are well known as a result of the numerous boreholes that have been put down in the search for coal and clay. As shown on the map in fig. 5, the sequence forms a gentle anticline, whose axis plunges south-west. The west flank has a dip of about 6–10°, while the east flank dips 20° or more farthest east. Close to the narrow granite horst that forms an eastern boundary to the Jurassic sediments the beds turn up again, however, at any rate in the northernmost part.

The sequence consists of sandy sediments (often fine-grained) and clays, which occur mainly in association with the coal seams. During coal mining at Hasle Kulværk, clay with plant remains was found; this yielded the flora called the Hasle Kulværk Flora. Most of the plants were collected in the tips outside the shafts. The clay is whitish or light grey and comes from a clay horizon above coal seam no. 16.

The total thickness from the brown marine sandstone to the top of the uppermost coal seam (no. 19) is about 185 m. Above this comes about 18 m sand, which is overlain by a sequence 30–40 m thick, consisting of grey, partly sandy clay with subordinate sand beds. Above this is a thick sand sequence.

Three brackish-water intercalations have been found. *Haplophragmoides sp.* was found below two of the coal seams in the opencast coal mine at Hasle and *Spirullina sp.* was found in clay under the uppermost coal seam in the Levka beds (coal seam no. 19).

Megaspores. A number of borehole samples, which give complete coverage of the succession, and a few samples from the opencast coal mine south of Hasle were investigated.

Spores occur only rarely in the coal-bearing sequence, but are abundant in the overlying clays, which show a spore assemblage rich in individuals, but poor in species. The state of preservation is generally good, but in the coal sequence some of the thin-walled forms are very much deformed, owing to pressure from the sand grains in the surrounding sediment.

The following forms were identified in the coal-bearing sequence:

1. Forms described from the Yorkshire Deltaic Series: *Horstisporites areolatus, Horstiporites harrisi, Trileites turbanaeformis, Bacutriletes corynactis, Erlansonisporites sparassis* and *Thomsonia phyllica.*

2. Forms described by MARCINKIEWICZ from Poland: *Bacutriletes clavatus* and *Minerisporites volucris.*

3. Wealden forms: *Hughesisporites galericulatus* DIJKSTRA and *Thomsonia cf. pseudotenella* DIJKSTRA.

The similarity to the spore assemblage in the Bagå beds is great. The two Wealden forms, which in Bornholm occur in the Purbeck as well as in the Wealden beds, occur rather low down in the sequence and suggest that the spore assemblage is young. For the time being, the writer will refer the whole sequence to the Middle Jurassic.

The overlying beds contain numerous examples of *Erlansonisporites sparassis,* especially forms with large appendages (= *tegimentus* MARC.). In a large number of these specimens, some or all of the appendages have fallen off, as described by HARRIS and MARCINKIEWICZ. Other Yorkshire

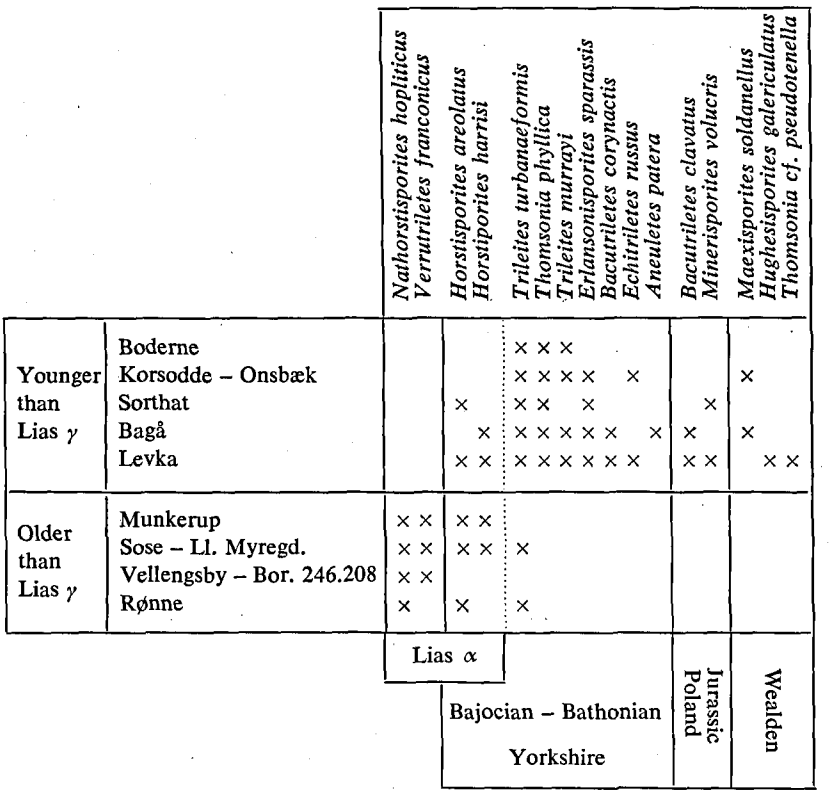


Fig. 7. Megaspores from the Lower and Middle Jurassic of Bornholm and their stratigraphical distribution in Europe.

Note regarding the Yorkshire forms. According to MARCINKIEWICZ (1962), in Poland *Thomsonia phyllica* occurs already in Lias δ, *Trileites murrayi* already in Lias ε, and *Erlandsonisporites tegimentus* (which the present writer considers identical with *E. sparassis)* already in Lias δ.

Note regarding the Polish forms. *Bacutriletes clavatus* is an infrequent species, which occurs in Poland in beds ranging in age from Lias γ to the lowermost Dogger (Aalenian) (MARC. 1962). *Minerisporites volucris* has been found (represented by one example only) in the Upper Lias (MARC. 1960).

forms that occur are *Horstiporites harrisi, Trileites turbanaeformis, Trileites murrayi, Echisporites russus* and *Thomsonia phyllica.* The Polish form *Minerisporites volucris* also occurs. Like the underlying coal sequence these beds must be referred to the Middle Jurassic.

The Purbeck beds (fig. 1)

After deposition of the beds from the Lower and Middle Jurassic considerable tectonic disturbances took place in the Bornholm area and a Purbeck sequence (Rabekke and Robbedale Formations) was deposited, partly on

the Jurassic beds and partly on older rocks (Precambrian rocks and various Palaeozoic beds). These Purbeck beds are overlain by Wealden clay (Jydegård Formation).

A completely new megaspore assemblage appears in the Purbeck beds, consisting essentially of forms described from the Wealden of Holland and England (DIJKSTRA 1951, HUGHES 1955, 1958). So far, the following of DIJKSTRA's species have been determined: *Verrutriletes carbunculus Echitriletes lanatus, Striatriletes sulcatus, Minerisporites marginatus, Hughesisporites galericulatus* and *Thomsonia cf. pseudotenella.* In addition, *Thomsonia reticulata* MÄDLER (MÄDLER 1954), which was previously only known from the Wealden of northern Germany occurs. In addition to these forms there are other *Thomsonia* species and similar forms.

Only three species were found that also occur in the Dogger. These are: *Thomsonia phyllica* which continues into the lowest part of the Purbeck beds, and *Thomsonia cf. pseudotenella* and *Hughesisporites galericulatus*, which was not previously know in beds older than Wealden.

CONCLUSIONS

1. None of the megaspores that characterize the Rhaetic in Greenland and northern and central Europe have been found in Bornholm.
2. The Jurassic sequence below the marine Lias γ horizon belongs to the *Thaumatopteris* zone, which, according to TROEDSSON, is confined to Lias α. The following floras belong to this: Munkerup, Vellengsby, Ormebæk (older than the *Cardinia follini* zone), Pythus, Onsbæk Teglværk, Rønne Teglværk and Nebbeodde (Galgeodde).
3. The sequence that rests on the marine Lias γ horizon in the western area is regarded as belonging to the Middle Jurassic on the basis of the strong affinities of the megaspore assemblage with the Yorkshire Deltaic Series and the occurrence of Wealden spores. The Sorthat beds, the Bagå beds, the Levka beds, the beds at Hasle Kulværk and the beds at Korsodde and in the clay pit at Onsbæk belong to this group. Of less certain determination on the basis of the spore content, but very probably of the same age, are the Jurassic beds that rest on the Cyrtograptus shales at Boderne.
4. The Purbeck beds contain essentially megaspores found in the Wealden beds in Holland and England. The plant-bearing beds at Holsterhus belong to this group.
5. The geological development in Bornholm accords very well with the development in south-eastern Skåne where, according to TROEDSSON (1951, p. 122), the Rhaetic is absent, while the *Thaumatopteris* flora (Lias α) is present, and where (TRALAU 1966, 1968) the plant-bearing beds above the marine Lias beds belong to the Middle Jurassic (Bajocian and Bathonian). The overlying Fyledal Clay is Kimmeridgian BRUUN CHRISTENSEN, (1968, p. 15), while the sedimentation in the Upper Jurassic in Bornholm first commenced in the Lower Purbeck (Rabekke Formation).

6. There is evidence of tectonic movements with faulting and erosion in the following periods:
   1. Between Lower Keuper and Lias α (Lias α resting on Keuper and Palaeozoic).
   2. Between Lias γ and Middle Jurassic (the conglomerate at Korsodde is probably of the same age as the conglomerate on the Cyrtograptus shales; the Middle Jurassic rests on both Lias and Palaeozoic).
   3. Between Middle Jurassic and Purbeck (Purbeck on Lower and Middle Jurassic, Palaeozoic and Precambrian).
   4. Post-Senonian with formation of the block-faulted pattern seen today.

DANSK RESUMÉ

MEGASPORER FRA BORNHOLMS JURAAFLEJRINGER

Der gives en redegørelse for de jurassiske sedimenters lagserie, deres udbredelse og lejringsforhold og tillige en preliminær rapport over sedimenternes indhold af megasporer (med udeladelse af nye arter).

Fig. 1. viser udbredelsen af juraaflejringerne på Bornholm. Aflejringerne fra Øvre Jura (Purbeck, Rabekke- og Robbedaleformationerne) er angivet med vandret streget signatur. Afhandlingens hovedemne er lejringsforholdene og alderen af de juraaflejringer, der findes i de områder, der er angivet med kryds signatur i fig. 1. Det drejer sig om deltaaflejringer, der består af 3 afdelinger: en nedre kulførende serie, en marin serie fra Lias γ og en øvre kulførende serie. Udbredelsen af disse aflejringers bjergartstyper og lagenes lejringsforhold fremgår af kortene fig. 2–5. Af vigtigere ikke tidligere publicerede iagttagelser kan nævnes forekomsten af et jurassisk konglomerat med overliggende sandede deltasedimenter på Cyrtograptusskiferen ved Boderne, konstateringen af at Vellengsbyleret hviler på Balkasandsten ved Vellengsbygård og i en boring (246.208) nordvest herfor på Neksøsandsten, forekomsten af et brakisk-marint indslag i den nedre kulførende serie vest for Soseodde samt en nøjere udredning af forholdene i Rønnes undergrund.

Megasporeundersøgelser har vist forekomster af 3 forskellige sporeselskaber, der henføres til hhv. Lias α, Dogger og Purbeck. Sporeundersøgelserne har ført til følgende resultater:

1. Der er på Bornholm ikke fundet nogle af de megasporer, der karakteriserer Rhät i Grønland, Nord- og Mellemeuropa.
2. Den jurassiske lagserie under den marine Lias γ-horisont tilhører Thaumatopteriszonen, der ifølge TROEDSSON udelukkende er begrænset til Lias α. Karakteristiske sporer er *Nathorstisporites hopliticus* og *Verrutriletes franconicus*. Hertil hører følgende floraer: Munkerup, Vellengsby, Ormebæk (ældre end Cardinia follini-zonen), Pythus, Onsbæk Teglværk, Rønne Teglværk og Nebbeodde (= Galgeodde).
3. Lagserierne, der hviler på den marine Lias γ-horisont i det vestlige område betragtes som tilhørende Mellemjura på grund af megasporeselskabets stærke affinitet til The Yorkshire Deltaic Series og forekomsten af Wealdensporer. Hertil hører Sorthatserien, Bagåserien, Levkaserien med lokaliteten Hasle Kulværk og lagene ved Korsodde og i lergrave ved Onsbæk. Mindre sikkert bestemt ved sporeindholdet men højst sandsynligt jævnaldrende er de jurassiske lag, der hviler på Cyrtograptusskiferen ved Boderne.
4. Purbeck-lagene indeholder væsentlig megasporer, der er fundet i Wealdenaflejringerne i Holland og England. Hertil hører bl. a. de planteførende lag ved Holsterhus.

5. Den geologiske udvikling på Bornholm stemmer meget nær overens med udviklingen i det sydøstlige Skåne hvor if. TROEDSSON (1951 p. 122) Rhät mangler medens Thaumatopteris floraen (Lias α) er tilstede, og hvor (TRALAU 1966, 1968) de planteførende lag over de marine Lias γ tilhører Mellemjura (Bajocian og Bathonian). Det overliggende Fyledaller er (OLE BRUUN CHRISTENSEN 1968) Portland, medens sedimentationen i Øvre Jura på Bornholm først begynder i Nedre Purbeck (Rabekkeformationen).

Det nævnes desuden i afhandlingen, at der er tegn på tektonisk virksomhed resulterende i bruddannelse og erosion i flere perioder i tidsrummet Keuper – Øvre Kridt.

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