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ISBN 91-7158-441-2
ISSN 0082-0024

IUGS UNESCO IGCP

Project
ECOSTRATIGRAPHY

Textkartorna är från sekretessynpunkt godkända för spridning.
Lantmäteriverket 1989-01-16.

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Fotosats: ORD & FORM AB
Tryck: Offsetcenter ab, Uppsala 1989

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ABSTRACT

Frykman, P., 1989: Carbonate ramp facies of the Klinteberg Formation, Wenlock-Ludlow transition on Gotland, Sweden. Sveriges Geologiska Undersökning. Ser. C No 820, pp. 1–79.

The Klinteberg Formation spans the Wenlock-Ludlow boundary and comprises shallow-water limestones and minor argillaceous intervals. The sequence is dominated by crinoidal grainstones, biohermal complexes and oncolitic limestones, all recording very shallow water deposition on a ramp-like setting with shoals and barriers in the high-energy belt.

The lower part of the formation constitutes a shallowing-upward sequence, culminating in a high-energy interval formed by crossbedded crinoidal grainstones. The diagenesis of the sequence suggests intervals of emergence.

Renewed deepening in the early Ludlow terminated the shallow-water deposition and gave way for the overlying formation of argillaceous wackestones.

INTRODUCTION

The exposed Silurian sequence on the island of Gotland in the Baltic (Fig. 1) comprises approximately 500 m of shallow marine carbonate sediments. The succession of Late Llandovery to Late Ludlow age was developed in an intracratonic situation at tropical latitudes. The most recent introduction to the stratigraphy and depositional environments was given by Riding (1981) and Laufeld & Bassett (1981).

The sequence is relatively undisturbed, having a NE-SW strike, and dipping at 2–3 degrees to the SE. Minor variations in this regional pattern are generally results of local gentle folding, insignificant faulting, or original depositional dip around carbonate buildups.

The mapable stratigraphical units on Gotland have traditionally been based on a combination of lithological and palaeontological data and so far no formalised stratigraphy has been defined. Several of the stratigraphical units are considered to be diachronous, most strongly advocated by Bassett *et al.* (1980), whereas others only accept very moderate diachrony. The Klinteberg Formation comprises approximately 70 m and spans the Wenlock-Ludlow boundary. It is dominantly composed of carbonates. In the northeastern part of the island, the formation is represented by oncolite-rich limestones and other bedded shallow-water facies. To the SW this is replaced laterally by facies including small bioherms and associated inter-biohermal sediments. In the extreme southwest argillaceous carbonate lithologies dominate the formation.

This paper suggests a formal lithostratigraphical definition and a description of the carbonate facies in the Klinteberg Formation.

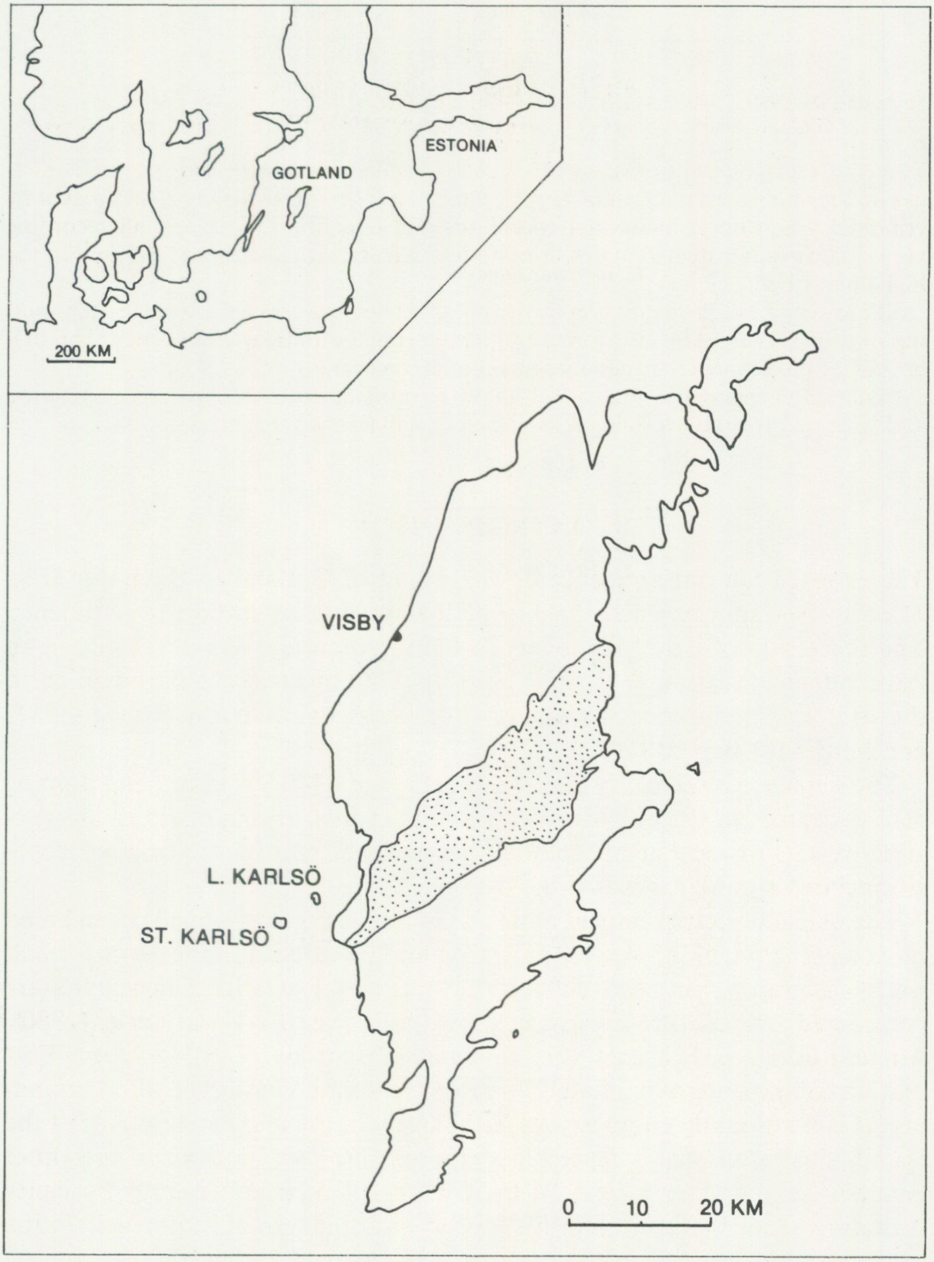


Fig. 1. Map showing location of Gotland, dotted area shows outcrop pattern of the Klinteberg Formation.

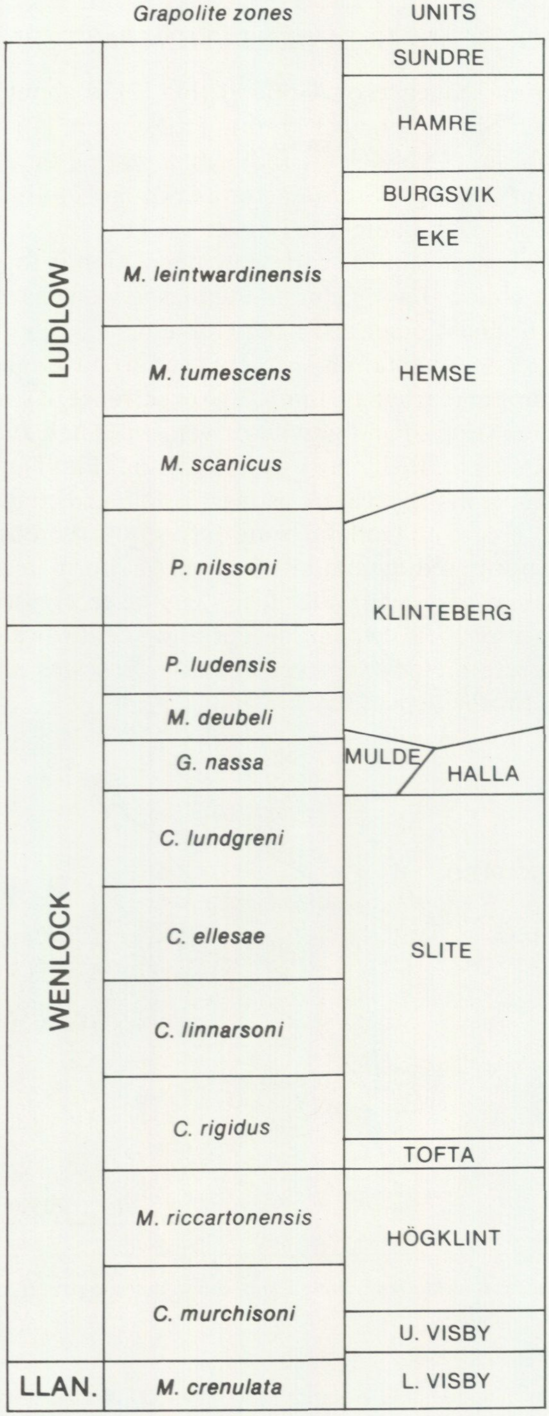


Fig. 2. Stratigraphy of the exposed Silurian sequence on Gotland. (Modified after Laufeld & Jeppsson 1976).

LARGE SCALE SEDIMENTATION PATTERN

The exposed Silurian sequence on Gotland (Fig. 2) is about 500 m thick, underlain by older Silurian (ca. 150 m), Ordovician (75–125 m), and Cambrian-Precambrian (150–225 m) sediments, resting on a Precambrian crystalline basement. Younger Silurian strata crop out south of Gotland on the sea floor (Flodén 1980; Laufeld & Bassett 1981).

The broad facies belt of Silurian carbonate deposition is found also in Estonia in the Soviet Union (Fig. 1), and the sequence includes variable facies, some comparable to facies described from Gotland.

The shallow water sedimentation is interpreted to have taken place on a gently southward dipping carbonate ramp. The occurrence of strongly inclined depositional bedding (Fig. 3) and gravity-driven slides and slumps on Stora Karlsö and Lilla Karlsö immediately west of Gotland (Fig. 1), might indicate relatively steeper slopes in this area suggesting a distal steepening of the ramp.

The sedimentary record on Gotland bears only little resemblance to a classical carbonate platform sedimentation, and no platform margin or strict subdivision in shallow and deep-water facies can be recognised. The apparently gradual transition between the deeper and shallow-water facies, and abundance of beds interpreted as derived by storm processes, support a ramp-like configuration for the depositional system.

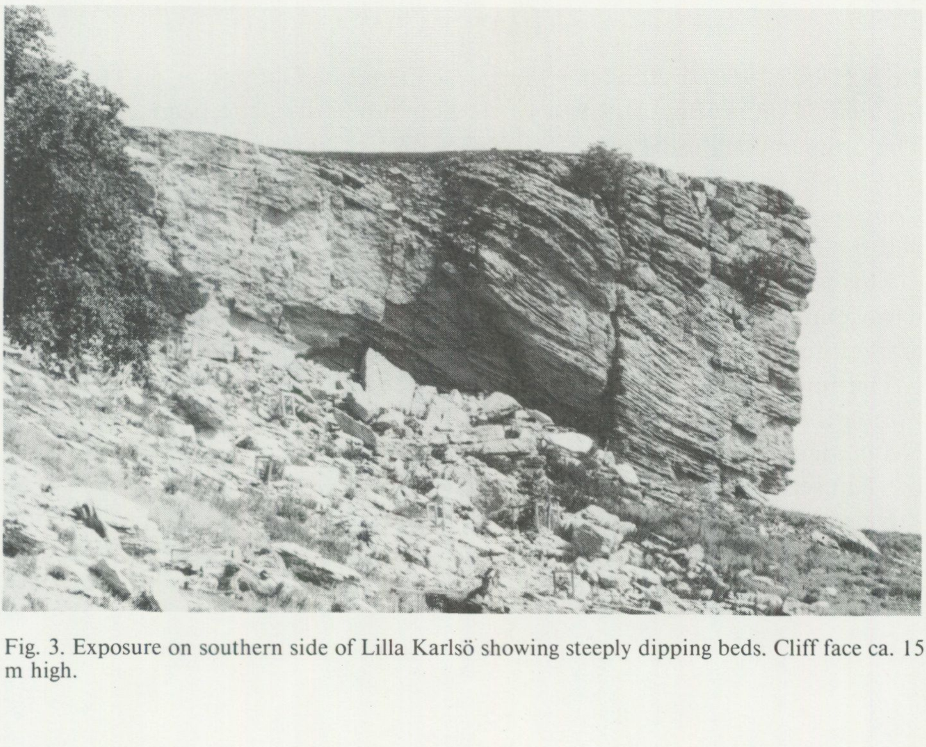


Fig. 3. Exposure on southern side of Lilla Karlsö showing steeply dipping beds. Cliff face ca. 15 m high.

The broad sedimentation pattern through the Silurian was the formation of extensive carbonate sediments and ultimate shallowing owing to influx of siliciclastic detritus from the north (Laufeld 1974a: 7).

This southern progradation was complicated by transgressive/regressive repetitions which produced the pattern of interfingering wedges of shelf carbonates to the north and relatively deeper water marls to the south (Riding 1981).

The depositional pattern was probably influenced by the developing Caledonian orogenic zone to the west, as well as by the tectonic activity in the Central European region to the south of the Baltic.

The limestones of Halla Beds, Klinteberg Formation and lower part of Hemse Beds (Fig. 2), was suggested by Riding (1981) to form a regressive wedge protruding into the southern marly lithologies of Slite Beds, Mulde Beds and Hemse Beds.

By Ludlow time it is suggested that this north-south facies polarity was breaking down to a complex mosaic of very shallow water facies indicating, as everywhere else in northern Europe, the effect of regional regression and approach of Old Red Sandstone continental sedimentation (Riding 1981). The Burgsvik Beds in the Upper Ludlow are regarded as precursors of Old Red Sandstone facies (Laufeld & Bassett 1981).

STRATIGRAPHY

Hede (1958, 1960) divided the Silurian sequence on Gotland into 13 topostratigraphical units (Fig. 2). Most of these major units have been subdivided. The units and subunits represent bodies of rock, although the topostratigraphy combines information of both lithological and palaeontological nature. Consequently, there is not always an identity between the stratigraphical units and the major lithofacies.

This is obvious for the Slite, Klinteberg and Hemse units which are dominantly limestones in the northeastern parts of their outcrops, but pass laterally into marls towards the southwest.

The unit treated here has been designated Klinteberg Beds, Group and Formation by Hede (1958), Laufeld (1974a) and Cherns (1982) respectively. No modern formalised lithostratigraphical description exists, and therefore the Klinteberg Formation will be defined here.

Relevant localities in the Klinteberg Formation for the description and interpretation are given on Fig. 4 and in the Appendix. Localities are listed and described according to directions used by Laufeld (1974b) and Larsson (1979).

KLINTEBERG FORMATION (NEW FORMATION)

HISTORY

Sediments and fossils of the formation have been described by many authors. The most detailed description was given by Hede (1927a, 1927b, 1928, 1929) in descriptions to the map sheets that include outcrops of the Klinteberg Formation (map sheets Hemse, Slite, Katthammarsvik and Klintehamn). In these the name "Klinteberg limestone" was used in the sense of Hede (1921).

The term "Klinteberg stage" was used by Hadding (1941), "Klinteberg Group" was introduced by Hede (1958) and accordingly used by Hede (1960) and Laufeld (1974a). The informal "Klinteberg Beds" has been used extensively by Laufeld (1974b), Larsson (1979), Laufeld & Bassett (1981), and Jeppsson (1983). The term "Klinteberg Formation" has previously been used only sparingly (Cherns 1983).

NAME

From the hill Klinteberget east of Klintehamn on western Gotland (Fig. 1).

TYPE AREA

The Klinteberg Formation outcrops in a 10–15 km wide belt trending SW-NE across the middle part of Gotland (Fig. 1). No exposures are found on the western coast; scattered very low exposures can be found along most of the eastern coast. Inland exposures are relatively sparse, and most are found in old abandoned quarries and in drainage-ditches.

Klinteberg Formation migth also be present in the top of the section on Lilla Karlsö (Fig. 1), since Hede (1927a) assigned these rocks to the Klinteberg Beds. However, at present there are some difficulties concerning the correlation of the sequence to both Lilla Karlsö and Stora Karlsö.

THICKNESS

The maximum thickness of Klinteberg Formation is approximately 70 metres (Hede 1960). The outcrop pattern of the Klinteberg Formation (Fig. 1) shows a marked thinning of the formation in the extreme southwestern region.

LITHOLOGY

The formation comprises a range of lithologies and is developed as argillaceous relatively finegrained limestones in the extreme southwest. This part

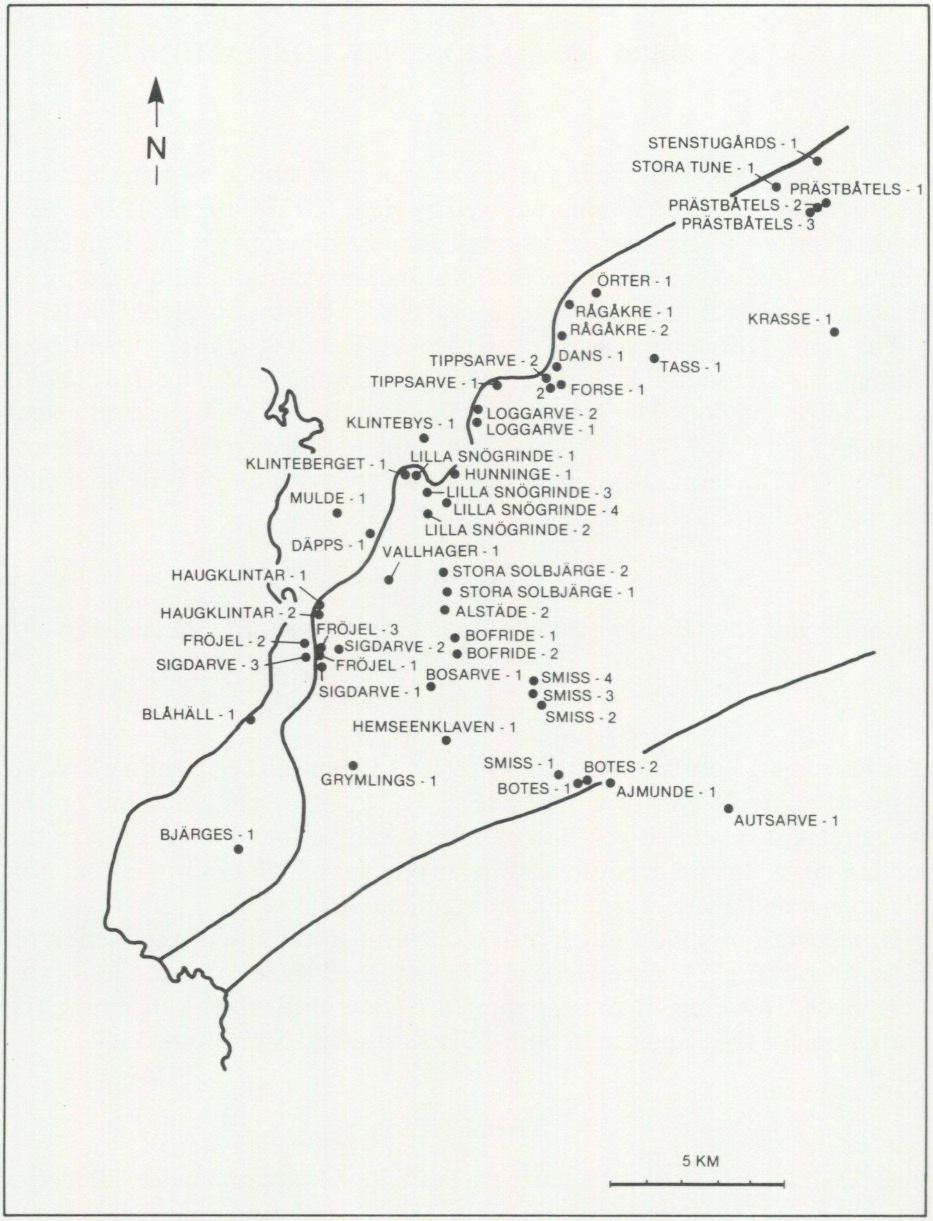


Fig. 4. Locality map covering outcrop area of Klinteberg Formation and a few localities in the adjacent units.


N
GOTHEMSHAMMAR - 1
6
2
3
4
5
FJÄRDINGE - 1
BARA - 1
VÄSTERBJÄRS - 1
VÄSTERBJÄRS - 2
BOTVALDE - 1
BOTVALDVIK - 1
BOTVALDVIK - 2
MAGNUSE - 1
RÅBY TRÄSK - 1
SUDERBYS - 2
SUDERBYS - 1
MEDEBYS - 2
MEDEBYS - 1
DIBJÄRS - 3
DIBJÄRS - 2
DIBJÄRS - 1
VALLMYR - 1
TIMANS - 3
TIMANS - 2
TIMANS -1
LINE - 1
HANGRE - 1
LILLSUND - 1
NÄSAR - 1
GODRINGS - 1
GODRINGS - 2
GANTHEM - 2
GANTHEM - 1
DJUPÅVIKEN - 1
SKÄRSUDDEN - 1
KRAKFOT - 1
BÅTELS - 1
BÅTELS - 2
FJÄLE - 5
FJÄLE - 3
FJÄLE - 2
FJÄLE - 4
FJÄLE - 1
SANDVIKEN - 1
HÄLLINGE - 1
HÄLLINGE - 2
TULE - 1
MÖLLBOS - 1
GRUNNSUDDEN - 1
BENDES - 1
BENDES - 2
KRAKSKJÄR - 1
SKARNVIK - 1
GARNUDDEN - 1
GARNUDDEN - 2
GURPE - 1
STENSTU - 1
GURPE - 2
SUTARVE - 1
SUTARVE - 3
SUTARVE - 2
TINGS - 1
TINGS - 2
GYLE - 1
BUTTLEGÅRDE - 3
VIVUNGS - 1
BUTTLEGÅRDE - 2
BUTTLEGÅRDE - 1
ALTAJME - 2
ALTAJME - 1
BJÄRBYHOLM - 2
BJÄRBYHOLM - 1
5 KM

Fig. 4. (Cont.).

of the formation is referred to as the "Klinteberg Marl" by Laufeld (1974a, 1974b) and shows similarities to the underlying Mulde Beds and the overlying Hemse beds, both being marls and claystones in the southwest region. Towards the northeast the argillaceous lithologies grade into purer limestones, crinoidal grainstones, biohermal complexes and stromatoporoid floatstones forming most of the western part of the formation. These lithologies interfinger with oncolitic limestones, stromatoporoid floatstones and peloidal and crinoid-rich limestones occurring in the northeastern region.

BOUNDARIES

LOWER BOUNDARY OF THE KLINTEBERG FORMATION

The Klinteberg Formation overlies two separate units, the Mulde Beds which only occur in the southwest and the Halla Beds occurring only in the northeast. The boundary is seemingly diachronous (Fig. 5) in that the upper part of Mulde Beds can be extrapolated laterally into the lower part of the Klinteberg Formation on topographic relations.

Tentaculitid faunas indicate a correlation of the upper Mulde Beds with the lower and middle parts of the Halla Beds, and furthermore of the lower Klinteberg Formation with the uppermost Halla Beds (Larsson 1979).

Lower boundary against Mulde Beds

The contact to the Mulde Beds is currently well-exposed at the road-cutting at Loggarve 2 (Jeppsson 1982, 1983) where more than 3 m of Mulde Beds is exposed underlying approximately 0.90 m Klinteberg Formation (Figs. 6, 7). The sequence referred to the Mulde Beds by Jeppsson (1982) includes crossbedded crinoidal grainstones and graded bioclastic packstones separated by argillaceous limestones and marly beds up to 20 cm thick. Compared to other localities in the upper Mulde Beds (e.g. Klinteberget 1 as described by Hede (1927a) and Tippsarve 1) this is an atypical development. Only at Loggarve 2 crossbedded and graded grainstones and packstones have been seen. Sigdarve 3 and other localities in the upper Mulde Beds expose nodular or wavy bedded argillaceous wackestones with argillaceous partings.

The localities Loggarve 2 and Tippsarve 1 represent the northeasternmost extension of the Mulde Beds (Hede 1927a: 37), and in this area Mulde Beds interfinger with the underlying Halla Beds according to Bergman (1980: 14).

At Loggarve 2 the lowest 0.90 m of Klinteberg Formation consists of well-bedded crinoidal grainstone and rudstone, with many rounded fragments of stromatoporoids (1–5 cm), and abundant *Conchidium* sp. (Fig. 8).

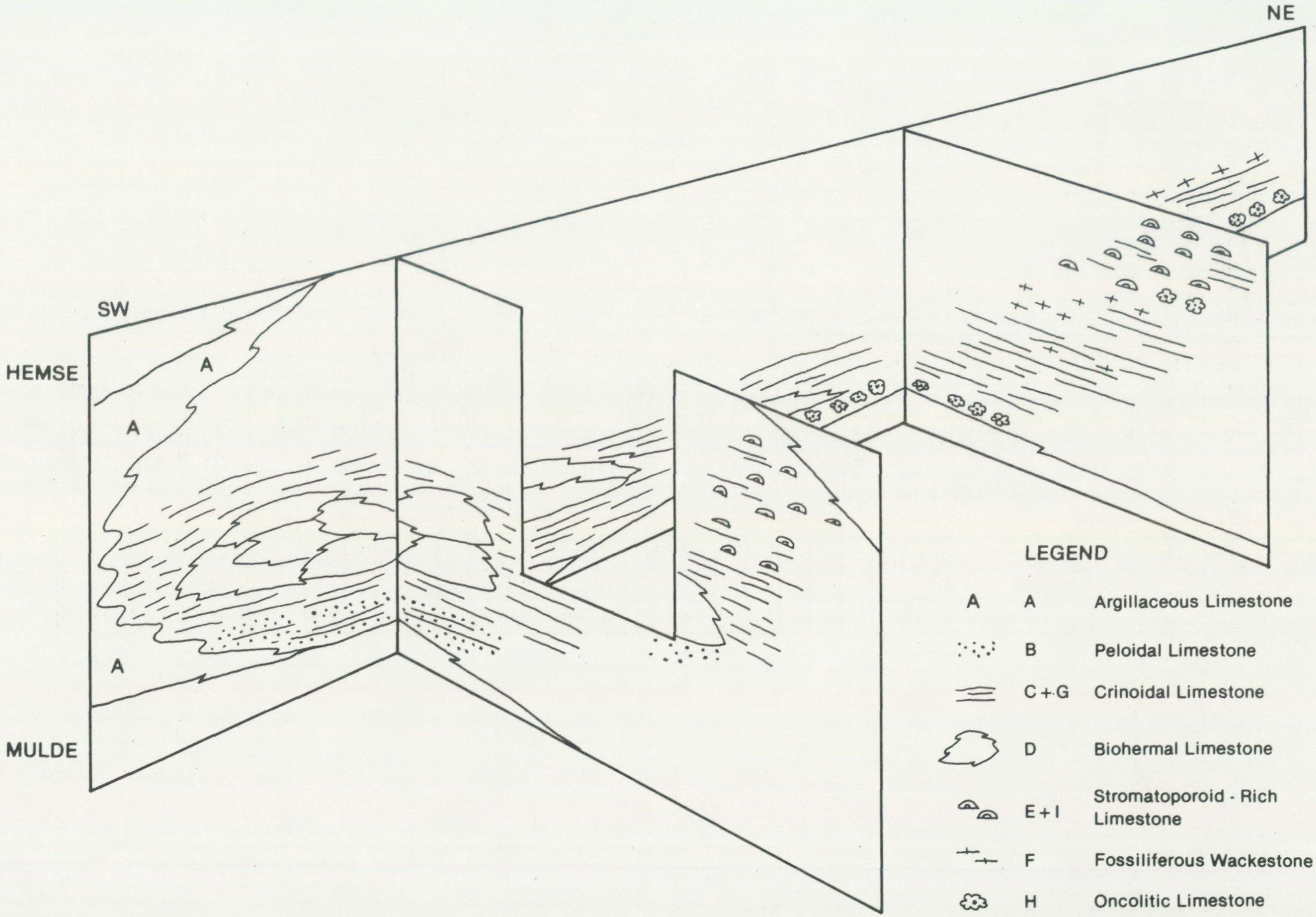


Fig. 5. Schematic fence diagram of Klinteberg Formation and adjacent units. Main profile is a transect SW-NE. Lithofacies distribution is projected into the diagram from the closest localities. The diachronous lower boundary against Mulde Beds and Halla Beds is illustrated, as well as the upper boundary to Hemse Beds being slightly diachronous in the southwestern region.

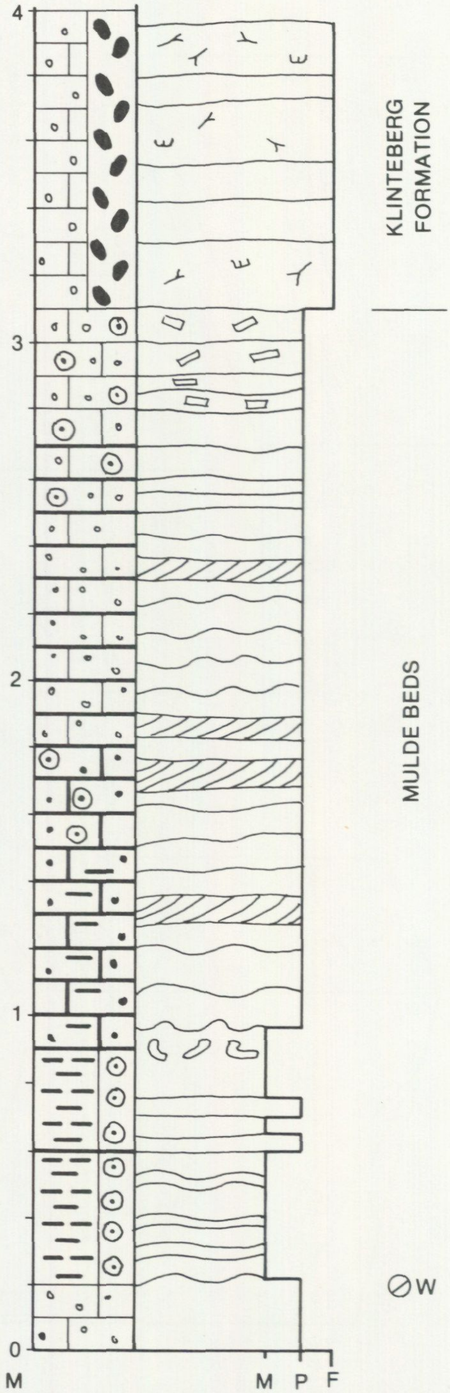
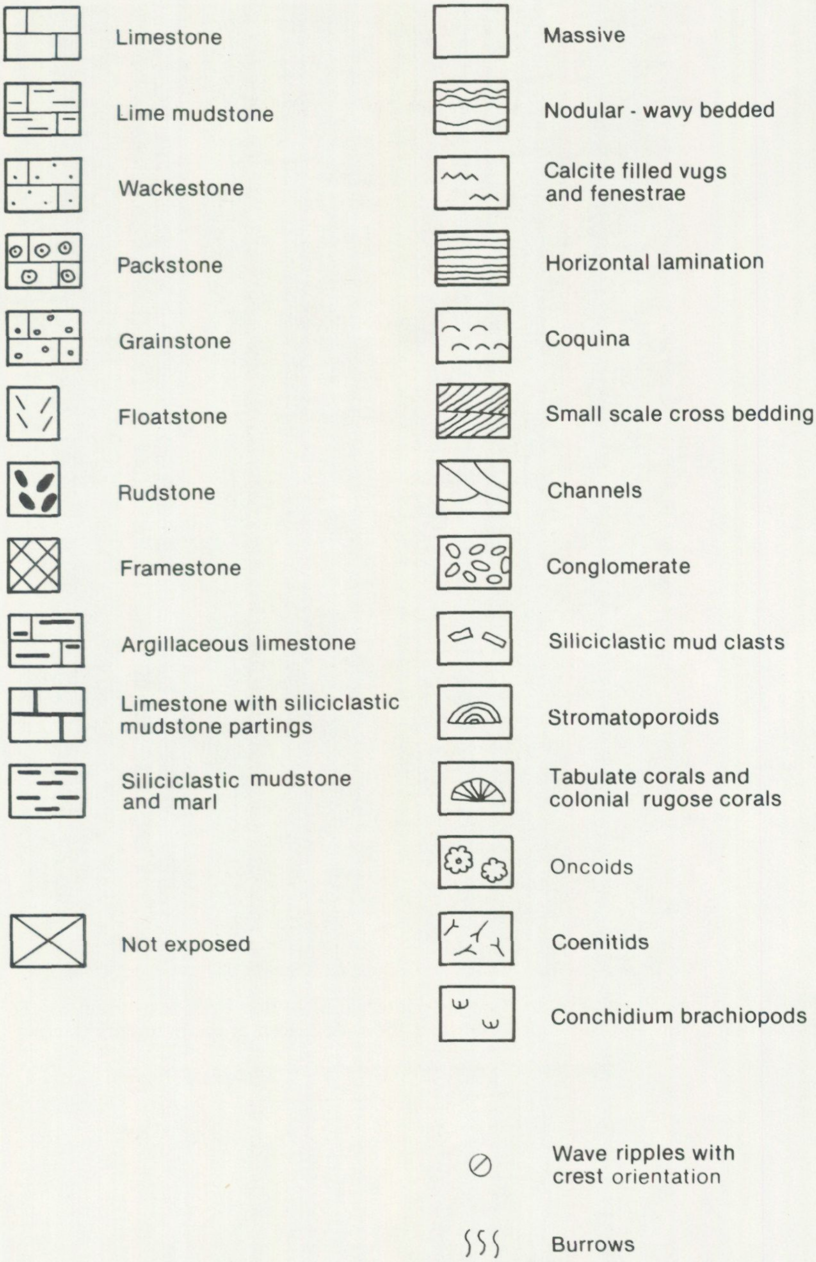


Fig. 6 a,b. Sediment log. – a. Sediment log of section at Loggarve 2. The lower part is assigned to Mulde Beds and the upper part to Klinteberg Formation. – b. Legend covering all figured



sections. The stepped nature of the right hand line of the sedimentary column seen in the sections is a gross characterisation of grain size divided into three main categories: 1) Lime mudstone and wackestones (M), 2) Pack- and grainstones (P), and 3) Float-, rud- and framestones (F). If category 3 is present, a split is made in the lithological column; the left hand side of which depicts the interstitial microfacies of the float-, rud- or framestone unit. Intervals of heterolith including interbedded marl and carbonates are shown with a split in the column. Description of sediments follows the classification of Dunham (1962) as modified by Embry & Klovan (1971). The sections are figured in a style adopted from Hurst (1984).

Fig. 7. Section at Loggarve 2. The marly interval of Mulde Beds is overlain by the Klinteberg Formation grain- and rudstones. Hammer for scale placed at the boundary (arrow).

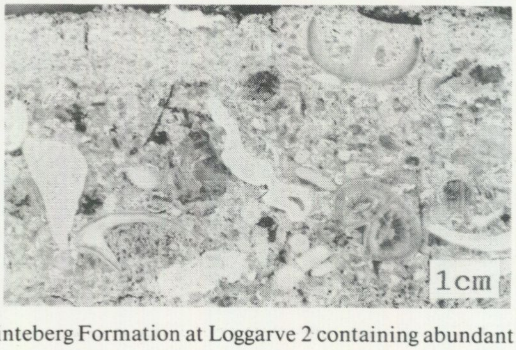


Fig. 8. Lowermost Klinteberg Formation at Loggarve 2 containing abundant *Conchidium* brachiopods.

Lower boundary against Halla Beds

In the northeastern region the base is only exposed at the extreme northeast at Gothemshammar 2, 3, 4, and 5, where the boundary is defined by an omission surface on the top of the underlying Halla Beds (Hede 1928: 54–55) (Figs. 9, 10).

The omission surface is developed as a hardground consisting of a layer of large oncoids (4–10 cm) which are crosscut and planed off to a smooth and almost polished surface. Lithified interoncoidal sediment also forms parts of the hardground (Fig. 11). The planed surfaces of the oncoids are bored by

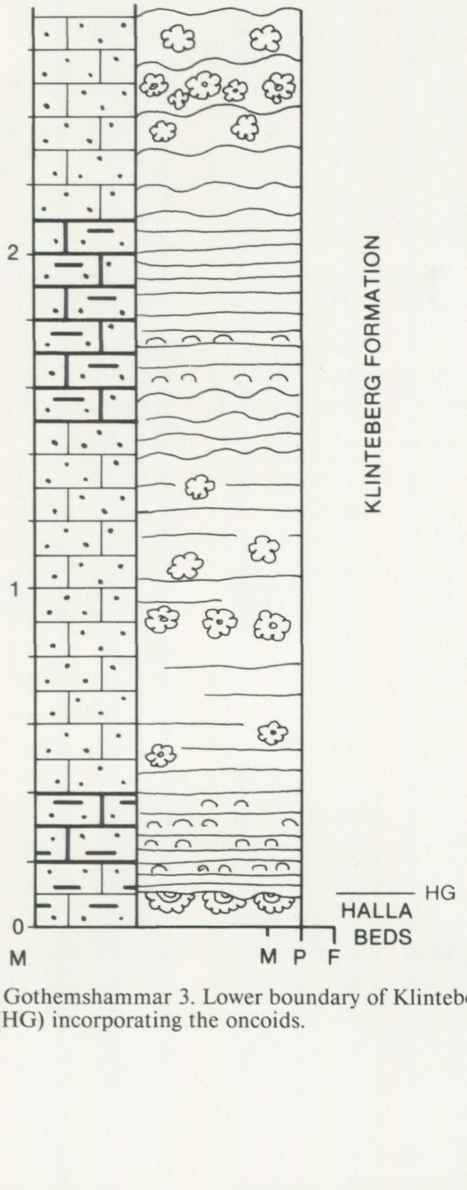


Fig. 9. Sediment log section at Gothemshammar 3. Lower boundary of Klinteberg Formation is placed above the hardground (HG) incorporating the oncoids.

Fig. 10. Type section of the lower boundary of Klinteberg Formation at Gothemshammar 2. The boundary is at the top of the vertical cliff just at the level of the roots of the rowan tree (arrow).

small *Trypanites*-type and by branching ctenostome bryozoans *Ropalonaria venosa* (P. Taylor, London, personal communication 1985). The surface has a brownish coloured impregnation of the upper millimetres.

The omission surface is overlain by a 0.25 m thick unit of marl containing thin beds of limestones (Fig. 12). The pockets of the omission surface are filled by marl yielding well preserved fossils e.g. brachiopods and ostracods. In the marl and limestone beds brachiopods are common, including: *Salopina conservatrix, Homoeospira baylei, Microsphaeridorhynchus nucula, Sphaerirhynchia* ssp, and molluscs: *Pteronitella retroflexa,* (from Hurst, 1975).

The overlying few metres of Klinteberg Formation exposed in this area are brownish grey, thickbedded oncolitic limestones containing e.g. brachiopods, tabulate corals, cephalopods and gastropods. The limestones have a marly intercalation in the lower part (Fig. 9).

Despite the pronounced sedimentological break and obvious time-gap at this omission surface, no significant biostratigraphical hiatus is recognizable (Larsson 1979; L. Jeppsson, Uppsala, personal communication 1984).

The contact between the two units cannot be followed inland owing to Quarternary cover, and the areal extent of the hardground is not known. However, the zone including the boundary between Halla Beds and the Klinteberg Formation is expressed in the topography over two large areas, one

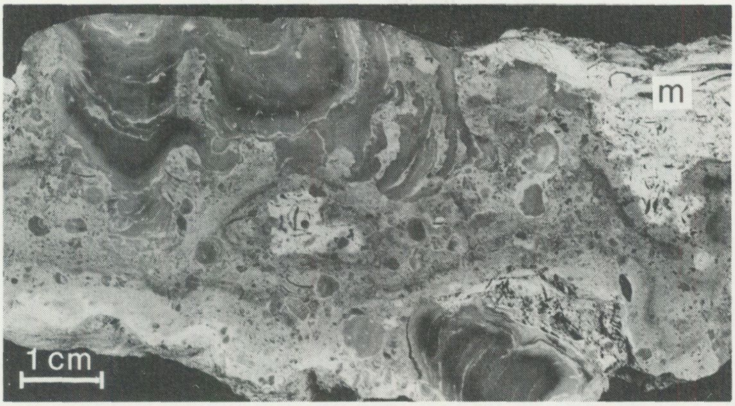


Fig. 11. Vertical slice of the hardground at the upper boundary of Halla Beds at Gothemshammar 2. The oncoids at the top are planed at the erosional surface and bored by *Trypanites* type borings. Lithified sediment also constitutes part of the hardground and is here overlain by marly sediment (m).

stretching from west of Hejde to Väte, the other from Hällinge southeast of Halla to Västerbjärs northwest of Gothem. The boundary forms a topographical step from the high lying Klinteberg Formation down onto the Halla Beds. This expression is probably due to more argillaceous or marly lithologies at the boundary being susceptible to erosion.

Fig. 12. Lower part of Klinteberg Formation at Gothemshammar 3. Hammer is placed on hardground surface. Marly interval with thin limestone beds overlies the hardground, going upwards into more resistant oncolitic limestone.

Excluding the hardground and overlying marly beds, similarity exists between the uppermost Halla Beds and the overlying Klinteberg Formation, both comprising oncolitic limestones.

However, the boundary is considered adequately recognizable and, considering the long background of previous usage by e.g. Hede (1928) the present position of the boundary is retained in this study.

UPPER BOUNDARY AGAINST HEMSE BEDS

According to Hede (1929: 23–24) the contact is exposed around Altajme and Tings on central Gotland, where Klinteberg Formation grainstones and wackestones are overlain by finegrained to dense limestone containing the bivalve *Megalomus gotlandicus,* referred to the Hemse Beds. These exposures have not been refound, and no locality suitable for type locality for the upper boundary can be indicated at present.

In the easternmost region it seems that the bay of Skarnvik and the associated rivulet is the topographical expression of the contact. The upper part of Klinteberg Formation in this area is exposed at Skarnvik 1 comprising crinoidal grainstones and stromatoporoid float- and rudstones.

Small exposures in this easternmost area (Skarnvik 2) of argillaceous wackestones with silty partings might represent the transition into the lower Hemse Beds of which the overlying beds are well exposed at Garnudden 2, forming the southern shore of the bay of Skarnvik. Here the Hemse Beds consist of stromatoporoid-rich, well bedded bioclastic limestones interbedded with thin marly beds. In these limestones two hardgrounds occur.

The exact boundary between Klinteberg Formation and Hemse Beds is not exposed in the northeastern region, but is defined as the change from stromatoporoid float- and rudstones, into the overlying bedded argillaceous wacke- or packstones with argillaceous partings.

In the southwestern region the boundary seems to be a transition from the argillaceous limestones of the Klinteberg Formation, referred to as the Klinteberg Marl by Laufeld (1974a, b) into the marly Hemse Beds (in this western region designated the "Hemse Marl NW").

In this work it has not been possible to outline any clear lithological distinction between the Klinteberg Marl and the Hemse Marl NW, and therefore no distinct upper boundary to the Klinteberg Formation is defined in this area. It is proposed that the boundary is placed between Ajmunde 1 and Botes 2, generally following the outcrop pattern as shown on the geological map of Gotland (Fogdestam 1981), which is compiled from Hede's (1927a, b, 1928, 1929) original map sheets. However, the Klinteberg Marl seems to have a recognizable lower contact to the underlying part of the Klinteberg Formation. A significant change in lithology occurs between Smiss 2 and Smiss

3, where Smiss 3 comprises stromatoporoid floatstones and a conglomerate, whereas the overlying beds at Smiss 2 consist of argillaceous packstone with marly partings. The contact itself is not exposed, but runs somewhere between the two localities Smiss 2 and 3.

GEOLOGICAL AGE

Biostratigraphical analyses of a variety of different organism groups have been carried out in the very fossiliferous Silurian succession of Gotland. Some difficulties still exist concerning the exact correlation with the international graptolite succession. This is partly due to the sparse finds of graptolites, and partly to the heterogeneous distribution of fossils among the varied facies.

Martinsson (1967) investigated the ostracod faunas and suggested an interval for the deposition of Klinteberg Formation between two and three graptolite zones (*ludensis, nilssoni* and *scanicus*?), and younging of the formation towards the northeast. On the basis of Chitinozoa, Laufeld (1974a) narrowed the interval to slightly more than one graptolite zone (*ludensis*, part of *nilssoni*).

Larsson (1979) analysed tentaculitid faunas and correlated Klinteberg Formation with three graptolite zones (*ludensis, nilssoni* and *scanicus*).

Jaeger (1981) reported finds of graptolites in the Mulde Beds, suggesting correlation of much of this unit with the Interzone of *M. dubius/G. nassa*, but the occurrence of an early form of *Monograptus deubeli* in the uppermost Mulde Beds indicates that this unit extends into the succeeding zone of *M. deubeli* (Jaeger 1981).

The underlying Slite Beds are indicated not to range higher than the top of the Upper Wenlock zone of *C. lundgreni* (Jaeger 1981).

The upper part of the Klinteberg Formation is probably not extending into the *M. scanicus* zone. This is indicated by Jaeger (1981), who reports this zone to be found at the locality Lilla Hallvards 1 high up in the Hemse Marl NW.

From all these investigations it seems that stratigraphical difficulties exist in correlating different groups of organisms with the standard graptolite zonation. However, groups indicate diachrony of both lower and upper boundary of the Klinteberg Formation (Martinsson 1967; Larsson 1979), and the stratigraphical scheme on Fig. 5 illustrates the relations between the Klinteberg Formation and adjacent units.

SUBDIVISION

In the northeast region six subunits a–f of the formation were established by Hede (1958, 1960) from the descriptions to map sheets Katthammarsvik

(Hede 1929) and Slite (Hede 1928) covering this region (Fig. 4). In the Slite map sheet (Hede 1928) it seems that unit a is lacking (Laufeld 1974a: 11). However, this is contradicted by the assignment of the localities Gothemshammar 2, 3, 4 and 5 on the Slite map sheet to unit a (Laufeld 1974a: 21, 1974b: 46–49).

In the Slite map sheet (Hede 1928) it seems that unit e is lacking and that unit f is represented by a very thin sequence of strata in a very small area only (Laufeld 1974a: 11). Some of the units are composed of more than one gross lithology, and the areal extent of such units sometimes appears to be noncontinuous and even patchy when their distribution is based on the descriptions by Hede (1928, 1929). Furthermore, the subdivision cannot be applied for the southwestern region covered by the map sheets Klintehamn (Hede 1927a) and Hemse (Hede 1927b). Because of these difficulties, Hede's subdivision will not be applied further in this paper, although the unit designations are listed in the locality descriptions in the appendix. Instead the main carbonate facies will be described.

The southwesternmost part of the Klinteberg Formation (of the main island) in the Hemse map sheet (Fig. 4) is referred to as "Klinteberg Marl" by Laufeld (1974a) designating a marly facies in this southwestern region. The unit will be considered as an informal member of Klinteberg Formation.

FACIES DESCRIPTION

This paper includes an attempt to differentiate and describe carbonate facies and their associations in the Klinteberg Formation.

Owing to lack of detailed correlation of the scattered exposures, the complex pattern of shallow water facies is not suitable for defining formal members of the Klinteberg Formation. Instead, the most important lithofacies and their associations will be described.

Lithological descriptions of sediments follow the classification of Dunham (1962) as modified by Embry and Klovan (1971).

Owing to the very limited exposure in the central part of the outcrop area of the formation, the descriptions have been separated for the southwestern and northeastern regions of the outcrop area.

SOUTHWESTERN REGION FACIES

Exposures in this region are in some places fair since quarrying has been carried on for many years. However, although old as well as a few new quarries exist these rarely offer sections extending for more than 2 metres in thickness.

In this region 5 facies will be described:

Facies A: Argillaceous wacke-/packstone.
Facies B: Peloidal wackestone.
Facies C: Crinoid grainstone.
Facies D: Biohermal facies associated with several types of lithologies.
Facies E: Stromatoporoid-rich rud- and floatstone.

FACIES A: – ARGILLACEOUS WACKE-/PACKSTONE

Type locality for facies: Grymlings 1.
Other localities. Bosarve 1, Botes 1, 2, Hemseenklaven 1, Smiss 1, 2.

Description:

Argillaceous wacke- and packstones occur as nodular to wavy bedded units with marly partings. The rock is poor in larger skeletal fragments, and mainly contains mm-size debris of crinoids, brachiopods, and trilobites (Fig. 13). This facies occurs in the westernmost part of Klinteberg Formation, constituting the very sparsely exposed informal member, the Klinteberg Marl. Grymlings 1 is the southwesternmost locality in the Klinteberg Formation, and consists of argillaceous wackestones. The argillaceous wackestones and packstones at Bosarve 1 are difficult to correlate but it is suggested that they correspond to the lithologies found to the southeast at the localities Hemseenklaven 1, Smiss 1 and 2, and Botes 1 and 2.

Interpretation:

The depositional environment is interpreted as the deeper part of the shelf. The association with graded and crossbedded bioclastic beds in the upper

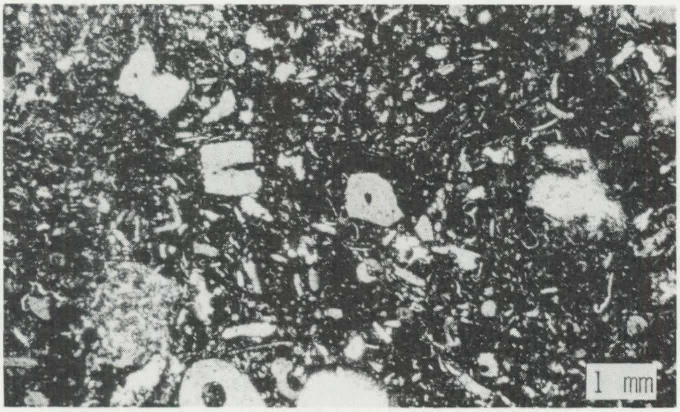


Fig. 13. Microphotograph of argillaceous wackestone from facies A at Grymlings 1.

part of the Mulde Beds at Loggarve 2 suggests a position for this locality on a deep carbonate ramp where storm-derived deposits occasionally were deposited. The more consistently marly intervals like the Klinteberg Marl might have been deposited slightly seawards of this belt with storm deposits. Thin beds of shell-debris from minor storm episodes were possibly mixed into the marls by bioturbation, and are not recognised. The nodular and wavy bedding is interpreted as largely derived by diagenetic enhancement of incipient layering in the sediment.

FACIES B: – PELOID-RICH WACKESTONE

Type-locality: Fröjel 3.
Other-localities: Altajme 1, Bofride 1, Buttlegårde 1, Hunninge 1, Klinteberget 1, Sigdarve 1, Smiss 3.

Description:

The peloidal limestone either has a micritic or sparry matrix, and generally shows sorting with a low but variable content of recognisable biogenic material. The peloids range in size from 20 to 200 µm, and are rounded or slightly elongate (Fig. 14a).

Some beds are finely laminated. Some of the peloid-rich beds contain skeletal material of crinoids, brachiopods and Solenoporoid algae. Skeletal fragments with micritised rims occur (Fig. 14a).

Beds of peloid-rich limestones occur in connection with various other facies types throughout the Klinteberg Formation.

In the southwestern region this facies is common in the lowermost parts of the Klinteberg Formation (Fig. 5). At Hunninge 1, Klinteberget 1, Fröjel

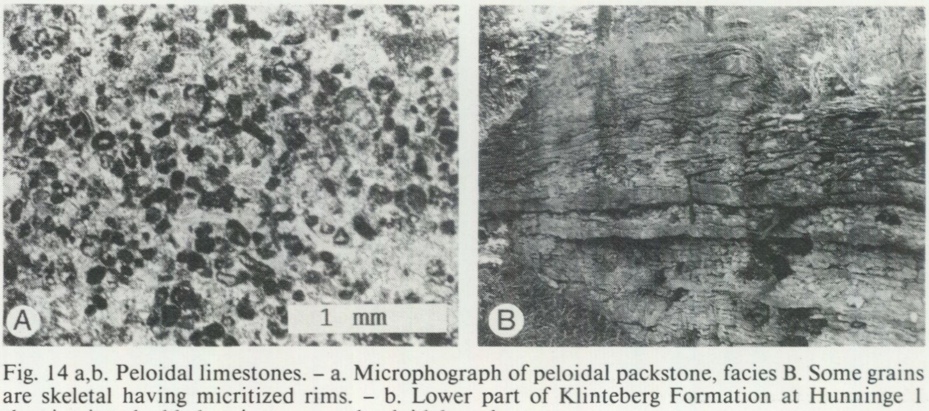


Fig. 14 a,b. Peloidal limestones. – a. Microphograph of peloidal packstone, facies B. Some grains are skeletal having micritized rims. – b. Lower part of Klinteberg Formation at Hunninge 1 showing interbedded grainstones and peloidal wackestones.

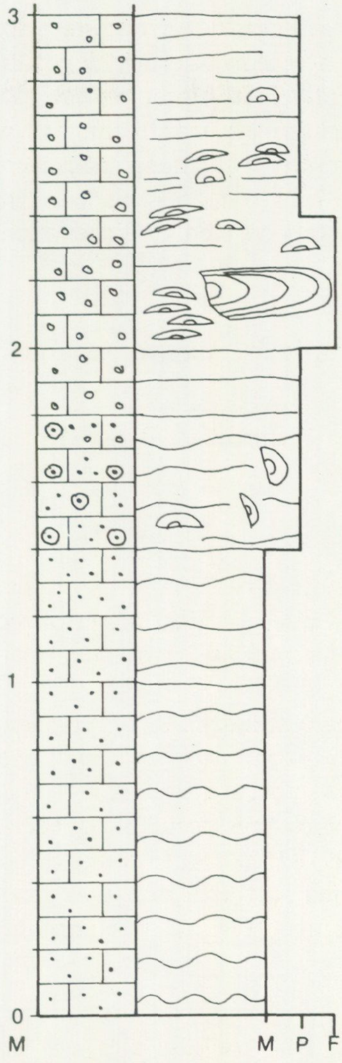


Fig. 15. Sediment log of section in lower part of Klinteberg Formation at Fröjel 3.

3 and Sigdarve 1, peloidal limestone is the dominant lithology in the lowest part of the sections; at Hunninge 1 and Klinteberget 1 interbedded with crinoidal grainstone (Fig. 14b). At Fröjel 3 and the neighbouring Sigdarve 1, the facies occurs as a unit of nodular to wavy bedded peloidal limestone (Fig. 15) grading relatively abruptly into the overlying bedded crinoidal grainstone. At Bofride 1, nodular and wavy bedded peloidal limestone forms a basal unit (Figs. 16, 17).

An intraclast 5 cm in diameter of peloid-rich lithology was found in a bio-

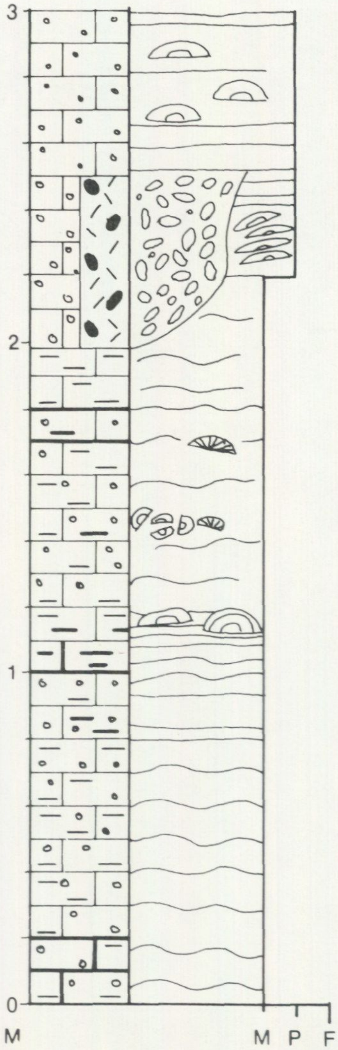


Fig. 16. Sediment log for section at Bofride 1. Lenticular bodies of conglomerates with stromatoporoid clasts occur in the section. Bentonite layer is located at 1.15 m just below the stromatoporoids.

hermal deposit at Klinteberget 1. The clast is well cemented by bladed calcite, some of it interpreted as marine cement.

Near the top of the section at Klinteberget 1, peloidal limestone locally caps the biohermal deposits.

In a subfacies at Altajme 1 and Buttlegårde 1, peloidal limestone beds contain abundant spar filled fenestrae of two types:

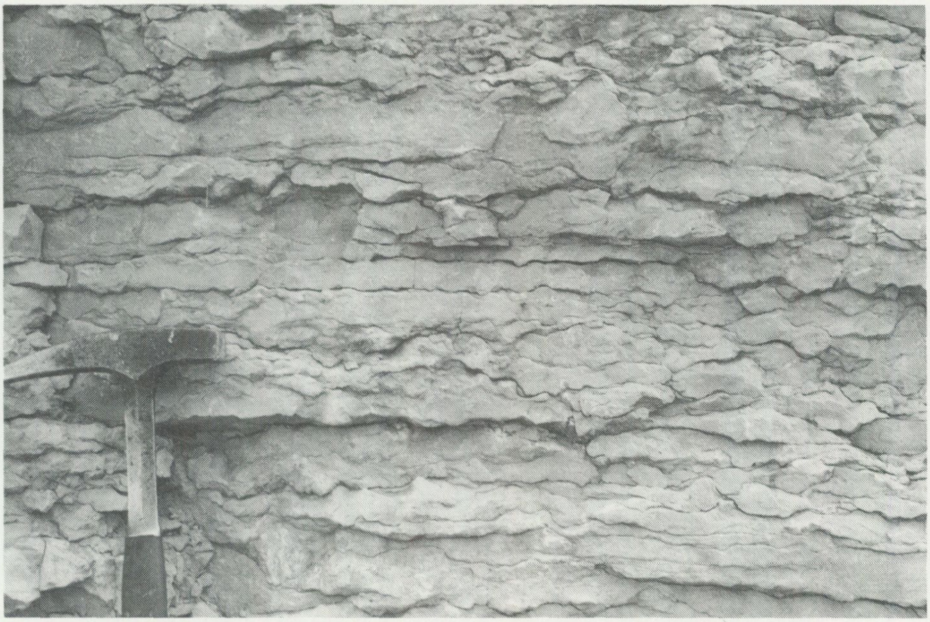


Fig. 17. Wavy to nodular bedded peloidal wacke- to packstones at Bofride 1.

1. Rounded or irregulary shaped fenestrae, having a marginal rim of cloudy fibrous cement, the interior filled by clear equant calcite spar (Fig. 18). The margins of these fenestrae seem to be defined exclusively by peloids, and no shelter-effect by larger grains is visible.
2. Subvertical elongate fenestrae filled with clear equant calcite spar.

In the peloidal wackestone, pockets of shell-fragments, and scattered stromatoporoids (5–10 cm) occur.

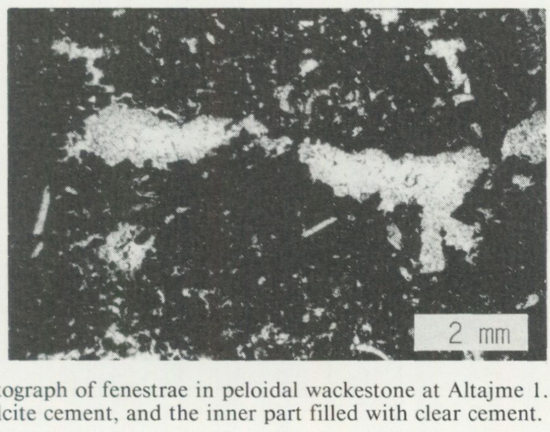


Fig. 18. Microphotograph of fenestrae in peloidal wackestone at Altajme 1. The fenestrae have a rim of cloudy calcite cement, and the inner part filled with clear cement.

Interpretation:

The peloid material is interpreted as dominantly of faecal peletal origin. Some peloids apparently have an origin as micritised debris.

The peloidal material formed in relatively protected environments under shallow-water conditions. Early cementation by finely crystalline marine cement is suggested to have added to the preservation of the peloids during redeposition. Some beds show redeposition by currents, having lamination and low-angle cross-bedding. The described fenestrae of type 1 have great similarity to "birdseyes" which have been used extensively to indicate supratidal or intertidal deposition (Shinn 1968; Grover & Read 1978). Recently, Shinn (1983) warned against this rigorous interpretation because of occurrence of similar fenestrae in fully subtidal deposits. Additional indicators of episodic emergence are therefore required to argue for supratidal or intertidal origin. The early cementation of the type 1 fenestrae forms an isopachous rim, and indicates marine phreatic conditions.

The interbedding of peloidal limestone and crinoid grainstone at Hunninge 1 and Klinteberget 1 is interpreted as deposition on the medium-deep part of a ramp where supply of grainstones by storm processes were relatively common. This environment was situated immediately seawards of the belt with higher energy and skeletal sand deposits.

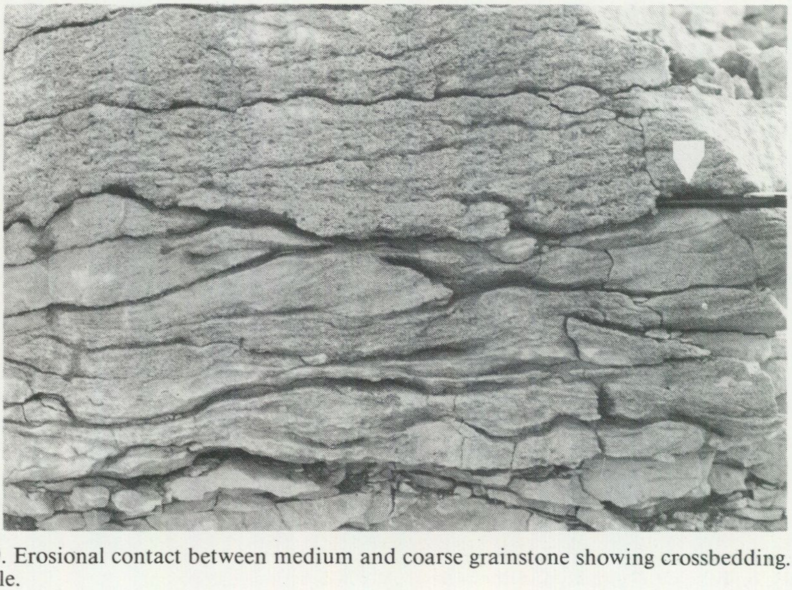


Fig. 19. Erosional contact between medium and coarse grainstone showing crossbedding. Pencil for scale.

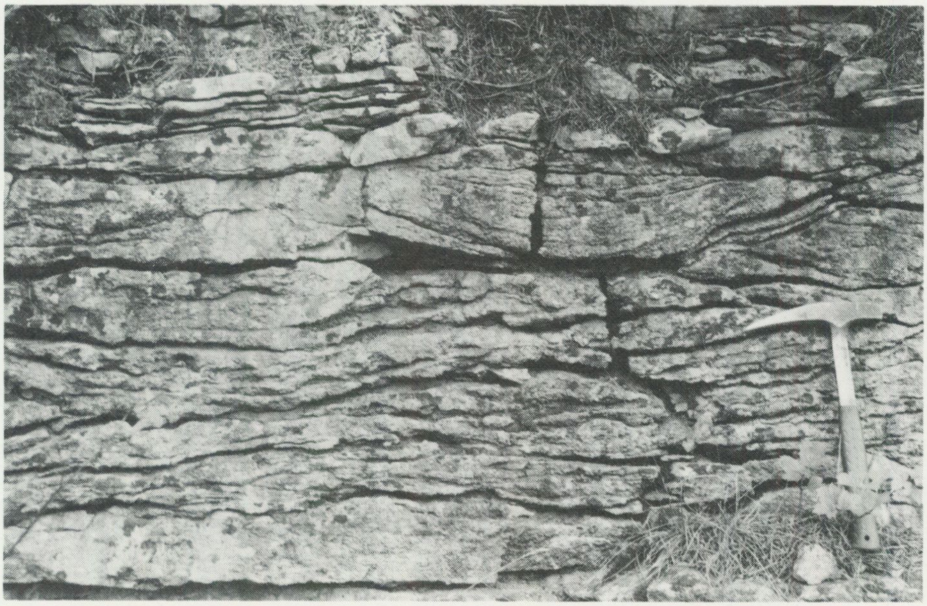


Fig. 20. Trough cross bedding in section at Sigdarve 2.

FACIES C: – CRINOID GRAINSTONE

Type locality: Sigdarve 2.
Other localities: Alstäde 1, Dans 1, Fröjel 3, 4, Klinteberget 1, Krasse 1, Hunninge 1, Lilla Snögrinde 1, 2, 3, 4, Loggarve 1, 2, Örter 1, Rågåkre 1, Tippsarve 1.

Description:

Crinoid grainstone is the dominant lithology in the southwestern region, but occurs throughout the formation (Fig. 5). In the southwestern region crinoid grainstone is closely associated with the biohermal facies and occurs as beds within the biohermal complexes as well as adjacent to these.

The sedimentary structures reflect a setting with relatively high current and/or wave energy. Medium- and smallscale planar cross-bedding and trough cross-bedding, and erosional contacts are common in the sections (Figs. 19, 20).

Wave-ripples are seen at several localities e.g. Rågåkre 1, Sigdarve 2, Klinteberget 1 and Lilla Snögrinde 4. All four localities have examples showing crest-orientation approximately NE-SW, and in Sigdarve 2 one example shows NW-SE orientation. The ripples at Rågåkre 1 have been measured and described by Bergman (1979). The ripples, which have wavelengths of ca. 50–80 cm, are symmetrical (Fig. 21a), and where they can be investigated on surface exposures they display rare crest bifurcations.

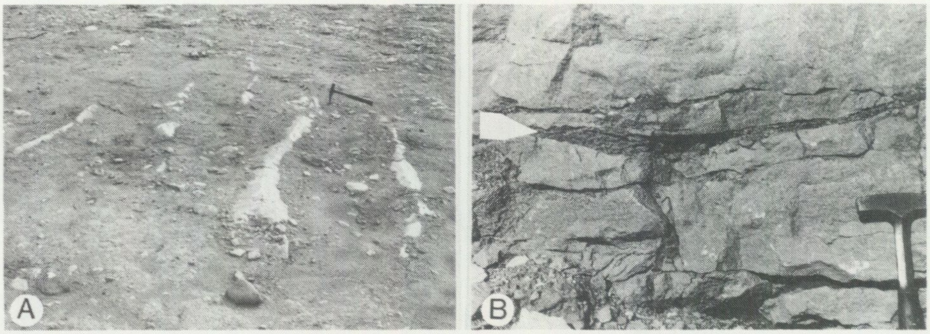


Fig. 21 a,b. Wave ripples. – a. Wave-ripples in coarse grainstones at Lilla Snögrinde 4. – b. Wave-ripple seen in vertical section draped by mud-layer (arrow). Lilla Snögrinde 4.

Most of the rippled surfaces are covered by a 2–10 mm thick clay or marl (Fig. 21b) which at Rågåkre 1 is seen to be penetrated by *Planolites*-like burrows entering the underlying rippled sediment (Fig. 22). At Lilla Snögrinde 4 a cm-size clay-clast was found ca. 10 cm above the clay-covered rippled surface in the overlying grainstone bed.

The crinoid grainstones are always fully cemented by epitaxial calcite overgrowths on the crinoid fragments (Fig. 23). Some of the overgrowths are cloudy

Fig. 22. Crest of wave-ripple at Rågåkre 1 with burrows having penetrated an overlying muddy layer. Pencil for scale at left.

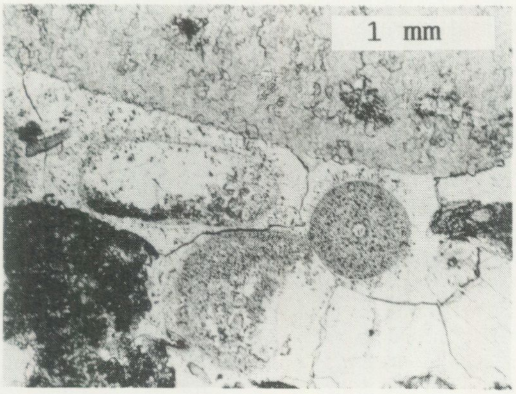


Fig. 23. Crinoid grains with epitaxial calcite cement. Note partial dissolution of crinoidal grains. The grain in the upper part is a stromatoporoid fragment.

calcite and have been interpreted as marine cement by Frykman (1985). Most of the epitaxial cement is clear calcite. The cementation of the grainstones seems to have occurred relatively early, and indications of compaction or crushing of shell material are rare.

Most beds consist of fully disarticulated crinoid remains, but in some coarsegrained beds (gravel-size), stem parts comprising 2–5 ossicles are preserved.

A variety of facies C containing very large stromatoporoid heads is found at Fröjel 3. The large stromatoporoids are all of columnar to domal shape, and some are overturned. The large stromatoporoids occur scattered in the 6 m high section and no distinct distribution of the colonies in horizons is recognizable. Most of the domal forms are preserved in growth position.

The height of the largest stromatoporoids are slightly more than 80 cm, but most are around 40 cm. The domal forms are up to 50 cm in diameter. Thin laminar stromatoporoids 5–10 cm in diameter and small domical forms also occur.

In the crinoid grainstone matrix, other fossils than stromatoporoids are rare; only brachiopods and small tabulate corals (*Favosites*) were recorded.

In the top part of the section at Fröjel 3, pebbles of rounded and abraded stromatoporoid fragments occur in crinoidal grainstone filling an erosional channel ca. 2 m wide.

Interpretation:

The sedimentary structures including different types of small- to medium-scale cross-bedding, wave-ripples and erosional contacts are interpreted to reflect a high-energy environment and/or shallow water (less than 10 metres). The structures available for directional measurements are too few to indicate a possible bipolar tidal current influence. The rather well sorted sediment and the sedimentary structures suggest a shallow water environment dominated by current activity. The beds with mediumscale planar and trough cross-bedding might have formed by migrating ripples on shoals. The large wave-ripples indicate episodic storm-processes. The preservation of the wave-ripples and their clay-drape is suggested to be caused by settling of the layer of clay and finegrained sediment. The cohesiveness of this layer is illustrated by the clay-clast observed at Sigdarve 2. The settling could be a product of lifting of the wave-base after the storm, or a shelter effect caused by temporary barriers constructed during the storm episodes. This protective skin preserved the ripples even if the high energy conditions and current dominated regime returned, and was only occasionally ripped up to form clasts.

Higher energy than average for this facies is suggested by erosion forming the channeled deposits in the upper part of the section at Fröjel 3. It is unclear if this erosion has a tidal component, or if it is caused by currents induced by storms.

In the facies containing large stromatoporoids, the dominating lithology of crinoid grainstone suggests an environment comparable to the general facies. The environment for some reason allowed the growth of very large stromatoporoid heads. The large colonies could be overturned by erosion undercutting their basal support in the sediment and/or by storm surges.

A somewhat similar facies type has been described by Ruppel & Walker (1982) and Aigner (1985), and was interpreted as shallow skeletal sand banks and shoals.

A possible modern analogue may be the carbonate sand belt on the ramp on the western edge of Florida Bay (Ball 1967; Aigner 1985); where skeletal sand is concentrated in a belt along a small break in slope. This sand belt is influenced by storms, and has migrated and grown episodically.

The occurrence of parts of crinoid stems consisting of several ossicles argues for a relatively limited transport and early burial since the crinoid skeleton is very sensitive to postmortem disintegration.

The more clean-washed and well-sorted crinoidal grainstones require prolonged reworking according to Cain (1968), and might have been deposited in the most shallow settings where repeated reworking occurred. Hagdorn (1978) showed some crinoid debris accumulations in the German Triassic Muschelkalk to be largely autochthonous, while others were deposited as subtidal bars on palaeohighs.

The crinoid grainstone facies in the Klinteberg Formation is inferred to have been produced largely in situ and redistributed into a complex system of shallow-water banks and shoals by the physical processes.

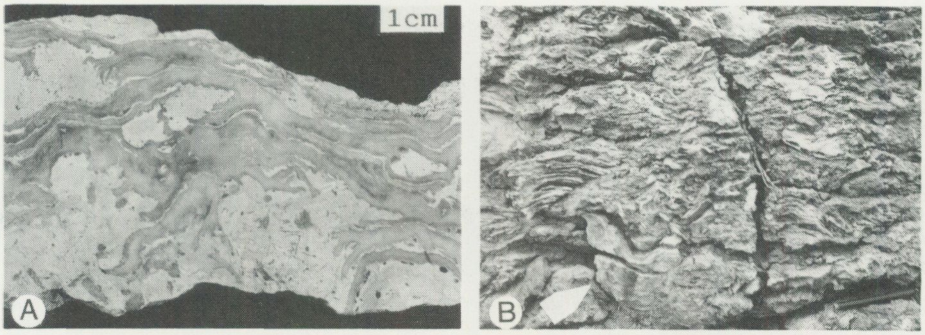


Fig. 24 a,b. Stromatoporoids. – a. Vertical section in laminar stromatoporoid including sediment between the laminae. – b. Rudstone from biohermal accumulation at Lilla Snögrinde 4 showing overturned stromatoporoid (arrow). Pencil for scale at lower right.

FACIES D: – BIOHERMAL FACIES

Type locality: Klinteberget 1.
Other localities: Bofride 1, 2, Hunninge 1, Lilla Snögrinde 1, Prästbåtels 1, 2, 3.

Description:

For readers having heard about the famous Silurian reefs on Gotland, the localities in the Klinteberg Formation are not too impressive. At the main locality, Klinteberget 1 (Fig. 4) only small patches of autochthonous framework are found in association with rudstone and grain- to wackestone. The same general appearance is seen at the other localities. The overall appearance of the Klinteberg bioherms is comparable to the occurrences of bioherms at Wenlock Edge, England, of approximately the same (Wenlock) age (Scoffin 1971; Riding 1981).

The largest biohermal accumulation in the Klinteberg Formation is approximately 9 m thick, but generally the bioherms only attain thicknesses of a few metres. All are of lenticular shape (Manten 1971).

The fauna is dominated by stromatoporoids (e.g. *Stromatopora, Labechia*), tabulate corals (*Favosites, Halysites, Heliolites*), but colonial rugose corals (*Acervularia*) occur commonly.

The stromatoporoid assemblage is dominated by flat to laminar forms (Fig. 24a), but domical specimens also occur.The larger skeletons rarely construct a framework but occur as accumulations. Much of the larger skeleton material is not in growth position; however, although overturned (Fig. 24b), it shows no serious abrasion.

Encrustration on some grains occurs by the alga (Problematicum?) *Rothpletzella* and the foraminifer? *Wetheredella* (Fig. 25a).

The biohermal accumulations are associated with adjacent deposits of cri-

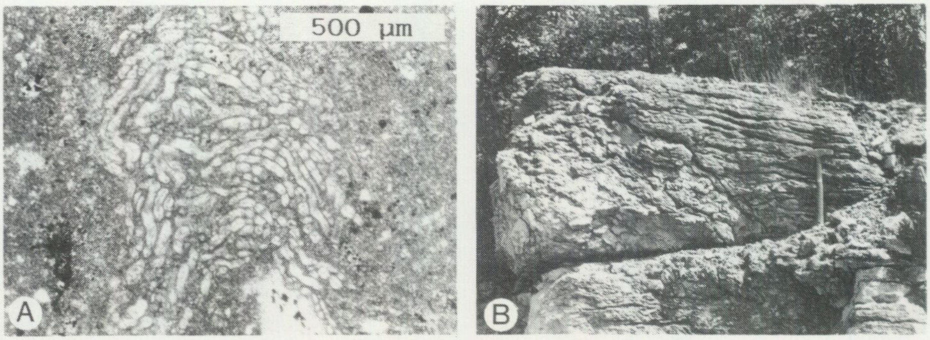


Fig. 25 a,b. Biohermal rocks. – a. Algal encrustation of *Rothpletzella* ?. – b. Biohermal association of stromatoporoid framestone (left) and bedded grainstone (right).

noid grainstone in a complex facies mosaic, but the boundaries are generally clearly defined at individual localities (Fig. 25b). The bioclastic sand and gravel commonly are evenly bedded and some parts show cross-bedding and erosional contacts. At Bofride 1 the biohermal facies complex includes metre-wide channels filled with conglomerates where the pebbles are dominantly fragmented and rounded stromatoporoid clasts (Fig. 26).

The matrix of the biohermal accumulations consists chiefly of crinoid debris, but in some areas appears to be slightly more argillaceous than the adjacent, bedded bioclastic sediment. Fine grained internal sediment occurs in the biohermal rocks (Fig. 27a). At Lilla Snögrinde 1 finely laminated sediment can be found to fill voids up to 8 cm in diameter. The lamination shows internal disconformities, and calcite filled fractures cut the internal sediment (Fig. 27b).

A few crinoid holdfasts encrust larger skeletons, but not at all in numbers that would account for the overwhelming amount of crinoidal debris present.

Bioerosion is sparse, and only few macroborings of *Trypanites* type occur in the stromatoporoid skeletons. Microborings and micrite envelopes are seen on some grains. At Klinteberget 1 peloidal limestone locally occurs in the upper part of the biohermal complexes. Diagenetic investigations of the cement stratigraphy has shown that some bioherms were subjected to meteoric diagenesis at a very early stage, and that some parts might have been periodically emergent (Frykman 1985, 1986).

Interpretation:

This facies formed in a relatively high-energy environment where currents and surges disintegrated and transported the crinoid grainstone matrix and overturned larger skeletons. The living crinoids were closely associated with the bioherms and some occurred attached to larger skeletons in this facies.

Fig. 26. Lenticular body of conglomerate at Bofride 1. The stromatoporoid clasts are dark in a lighter matrix.

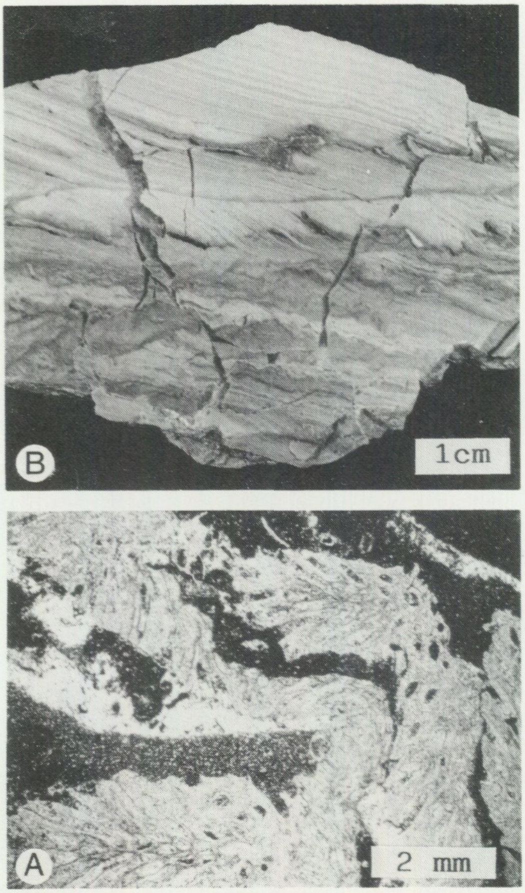


Fig. 27 a,b. Internal sediments. – a. Microphotograph of internal sediment partly filling void in irregular tabulate coral. – b. Vertical section in internal sediment found in large void in biohermal accumulation at Lilla Snögrinde 1. Internal unconformities and microscale cross-bedding? are seen.

Pores and cavities in the bioherms gave shelter for deposition of argillaceous material or calcareous finegrained internal sediment.

Very little bioerosion occurred and did not contribute to the weakening of the skeletons, as is common in modern reefs (Bromley 1978). In the upper part of the biohermal complexes at Klinteberget 1, local more tranquil environment allowed peloid-rich sediments to accumulate.

Early marine cementation of the deposits and encrusting algae presumably had a binding effect on the sediment and contributed to the stability of the biogenic accumulations. However, only very few intraclasts have been observed incorporated in the biohermal sediments.

FACIES E: – STROMATOPOROID RUD- AND FLOATSTONE

Type locality: Altajme 1.
Other localities: Altajme 2, Bjärbyholm 1, 2, Buttlegårde 1, 2, 3, Forse 1, 2, Ganthem 2, Smiss 3, 4, Stora Solbjärge 1, 2, Tass 1, Vallhagar 1, Vivungs 1.

Description:

This facies includes float-/rudstone with pack-/grainstone matrix containing stromatoporoids up to 15–30 cm in diameter apparently in situ. Stromatoporoid debris of rounded pebbles (1–5 cm) occurs together with crinoidal and bryozoan debris (Smiss 3 and 4).

Stromatoporoids 20–30 cm in diameter and domical to flat domical occur in growth position adjacent to crinoid-rich grainstone (Vallhagar 1).

At Buttlegårde 2 stromatoporoid rudstone overlies a unit of stromatoporoid floatstone containing patches of stromatoporoid rudstone and framestone (Fig. 28). Rudstone and framestone with laminar to domical stromatoporoids in grainstone matrix, occur at Stora Solbjärge 1 and 2. Coenitid colonies up to 20 cm and stromatoporoids occur in situ at Tass 1.

Fig. 28. Section at Buttlegårde 2 showing stromatoporoid rudstone overlying stromatoporoid floatstone.

Interpretation:

This facies is interpreted to be biostromes formed under diverse conditions on the shallow part of the ramp. Some occurrences probably are closely associated with nearby biohermal facies, e.g. at Lilla Snögrinde 2, Vallhagar 1 and Stora Solbjärge 1 and 2 very close to Klinteberget 1. Facies E might be considered as a lateral stromatoporoid-rich equivalent to the biohermal complexes. In other areas the facies clearly occurs in isolation and might be interpreted as thin biostromes.

Beds containing abraded and overturned stromatoporoids indicate intermittently higher energy conditions.

NORTHEASTERN REGION FACIES

This region includes a range of very diverse carbonate facies. The individual lithologies are difficult to correlate, but six subunits in the formation were established by Hede (1958, 1960) from the descriptions accompanying the map sheets Katthammarsvik (Hede 1929) and Slite (Hede 1928), covering the northeastern region (Fig. 4).

For this investigation, my own recent observations supplemented by information extracted from Hede (1928, 1929, 1958, 1960) Laufeld (1974a), Larsson (1979) and Jeppsson (1983) form the basis for the facies descriptions and interpretations.

Most outcrops in this region are small and only a few decimetres of section are generally available at the localities. It is therefore difficult to establish reliable facies-associations. However, along the east coast of Gotland the Klinteberg Formation is exposed intermittently from Gothemshammar in the north to Skarnvik in the south. This composite sequence is incorporated in the descriptions of the units and the facies, and in some places facies associations have been established in this sequence.

Definition and delineation of distinct facies in this region is difficult owing to poor exposures and variable lithologies. Only four facies are distinguished in this part of the formation, each encompassing more than one gross lithology, and as a result a rather coarse picture of the facies distribution appears.

Facies F: Fossiliferous wackestone and packstone.
Facies G: Crinoidal and coenitid grainstone.
Facies H: Oncolitic wackestones, packstone and grainstone.
Facies I: Stromatoporoid floatstone and rudstone.

FACIES F: – FOSSILIFEREOUS WACKESTONE AND PACKSTONE

Type locality: The shore exposures from Grunnsudden 1 towards southwest to Bendes 2.
Other localities: Shore exposures at Djupåviken 1, Lillsund 1, Medebys Bodar 2, Sandviken 1, Skärsudden 1; and inland localities at Bendes 1, Hangre 1, Krakfot 1, Medebys Bodar 1, Stenstu 1, Vallmyr 1.

Description:

This facies includes several other lithologies in addition to the dominating fossiliferous wacke- and packstone, but no attempt has been made to differentiate on a finer scale.

This facies constitutes nearly all of unit d of Hede (1958, 1960) as seen in the exposures at the east coast; however, it also occurs in unit a, e and f. At Medebys Bodar 2 abundant *Ilionia prisca* (bivalve) occur in wacke-/packstone together with gastropods, tabulate corals, rugose corals, brachiopods, crinoidal and coenitid debris, and scattered small stromatoporoids. Nearly all the *Ilionia* bivalves occur in vertical life position in the sediment.

Ilionia prisca was considered one of the characteristic faunal elements by Hede (1927b) in his subunit d. At Medebys bodar 2 a thin conglomeratic horizon occurs, and an overlying wackestone has burrows with conglomeratic infill. Argillaceous wackestone with *Chondrites*-type trace-fossils are found at Lillsund 1 and Hangre 1.

At Grunnsudden 1 thinbedded argillaceous wackestone contains diverse faunas of brachiopods, trilobites and ostracods, supplemented by gastropods, bivalves, cephalopods and colonial rugose corals. Associated packstone contains small stromatoporoids and some tabulate corals. One bed shows stromatoporoids whose upper surfaces are cross-cut and planed and overlain by crinoidal grainstone.

Interpretation:

This mixed class of varied lithologies is difficult to give a simple interpretation, but generally a relatively quiet depositional environment is indicated by the carbonate mud fraction.

Intermittent higher energies are recorded in the interbedded grainstone beds and the few thin conglomerates.

The deposition might have taken place either in a partly protected lagoon on the backside of skeletal sand shoals or in the deeper parts of the shallow ramp area.

FACIES G: – CRINOIDAL/COENITID GRAINSTONE

Type locality: Coastal exposures between Lillsund 1 and Näsar 1.
Other localities: Båtels 1,2, Botvalde 1, Botvaldvik 1,2, Dibjärs 2, Fjäle 1,2,3, 4,5, Grunnsudden 1, Hällinge 1,2, Medebys Bodar 1, Sutarve 1,2, Timans 2,3, Västerbjärs 2.

The present facies is comparable to facies C described in the southwestern region. However, most of the beds assigned to facies G lack the characteristic cross-bedding found in facies C.

Description:

The dominantly crinoidal grainstone range into packstone at some localities, and commonly contain large proportions of coenitid material in certain beds (Figs. 29a, 29b). In most places the crinoid material is well sorted. The coenitid material shows no serious abrasion or fragmentation.

Lamination or cross-bedding has not been noted from this facies, except for one example of medium-scale planar cross-bedding at Hällinge 1.

A coenitid-rich subfacies occurs in the lower part of Klinteberg Formation at localities east of Hörsne (Timans 2 and 3). This subfacies constitutes a rock-body outcropping over ca. 1 x 4 km. Some beds contain oncoids and coated grains. This subfacies was also noted by Hede (1928: 59).

The facies is found intercalated with oncolitic grainstone and rudstone containing small stromatoporoids and rounded fragments of stromatoporoids. These relations are seen at Hällinge 1 and 2 and Båtels 1 and 2.

Intervals of this facies occur associated with widely different lithologies dominated by fossiliferous wackestone and packstone included in facies F. Facies G is exposed at the east coast at Botvaldvik 1 and 2, Grunnsudden 1, between Lillsund 1 and Näsar 1, and inland at Botvalde 1 and Fjäle 1,2,3,4 and 5.

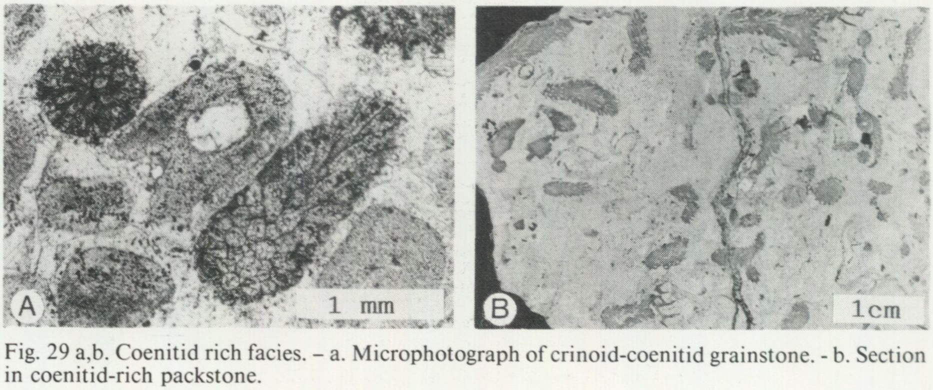


Fig. 29 a,b. Coenitid rich facies. – a. Microphotograph of crinoid-coenitid grainstone. - b. Section in coenitid-rich packstone.

Interpretation:

This facies is interpreted to reflect shallow water deposition under relatively protected conditions, only affected by storm-induced wave-reworking episodically. Current activity can rarely be traced in the sediments, which either indicates absence of this process or destruction of structures by bioturbation.

The well sorted beds are interpreted as reworked sediments, where only the larger skeletal particles remained. However, this reworking was apparently not dominated by currents, but probably wave-induced, since cross-bedding is not seen to be developed. The coenitid-rich beds are interpreted as derived from essentially in-place accumulations of coenitids, only gently winnowed free of finer sediment.

The depositional environment is interpreted as shallow skeletal sand shoal, probably on the lagoonal side as indicated by the interbedding with oncolitic beds and lithologies of facies F.

FACIES H: – ONCOLITIC LIMESTONE

Type locality Västerbjärs 1.
Other localities: Båtels 1,2, Bendes 2, Dibjärs 1, Fjäle 5, Fjärdinge 1, Ganthem 2, Gothemshammar 2,3,4,5, Hällinge 1,2, Prästbåtels 1,2,3, Råby Träsk 1, Stenstugårds 1, Suderbys 2.

Description:

The oncoids are dominantly skeletal, composed of a mixture of the alga (problematicum?) *Rothpletzella* and the foraminifer? *Wetheredella* (Fig. 30a). The oncoids can attain large sizes, up to 4–5 cm, and often have an irregular outline and a recognizable core of different macrofossils, including stromatoporoids, gastropods, rugose corals, and cephalopods (Fig. 30b).

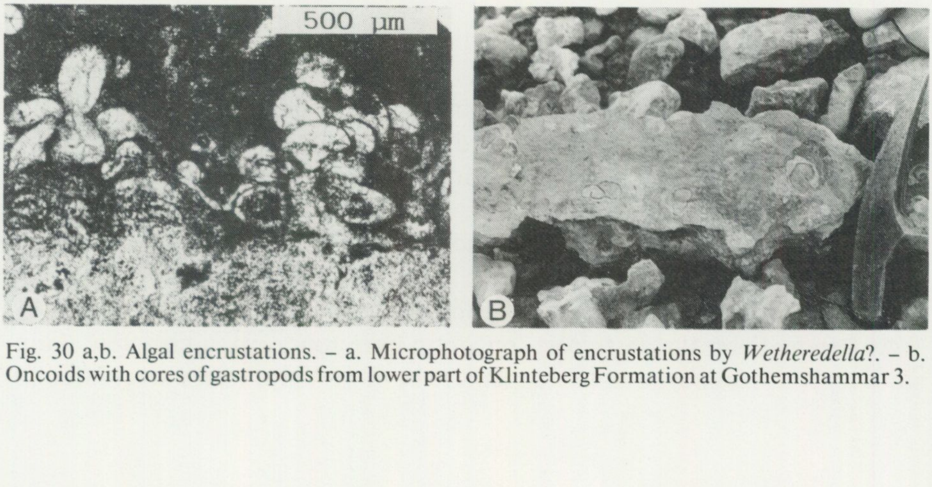


Fig. 30 a,b. Algal encrustations. – a. Microphotograph of encrustations by *Wetheredella*?. – b. Oncoids with cores of gastropods from lower part of Klinteberg Formation at Gothemshammar 3.

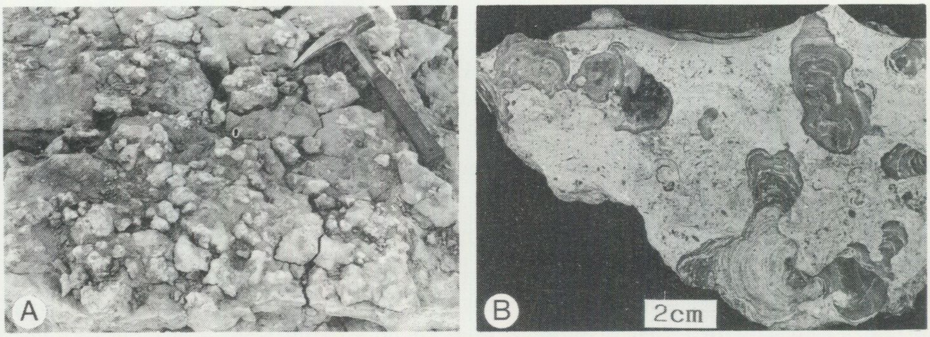


Fig. 31 a,b. Oncoids. – a. Weathered bedding surface showing the density and distribution of oncoids in the upper part of Halla Beds at Gothemshammar 2. – b. Vertical section of oncoid packstone showing irregular oncolites. Halla Beds, Gothemshammar 2.

The oncoids occur in lithologies ranging from wackestone to rudstone consisting of closely packed oncoids and stromatoporoids.

This facies occurs both in the southwestern and northeastern region of the Klinteberg Formation (Fig. 5). Some variation in the lithology is seen, and the oncoids occur in more coarse grained and mud-free matrix in the western part of Klinteberg Formation. This development can be seen at Tippsarve 2, Stenstugårds 1, Prästbåtels 1 in the lower part of Klinteberg Formation, and at Hällinge 1 and 2 and Båtels 1 and 2.

At these localities crinoidal grainstone is a common matrix for the oncoids, and small stromatoporoids also occur in these beds.

In the extreme northeast this facies is well developed at Gothemshammar 2, 3 and 4 where it rests directly on the Halla Beds (Hede 1928). At the Gothemshammar localities the oncolitic limestone, here being a slightly argillaceous wackestone, is associated with two marly intercalations (0.25 and 0.75 m thick) with thin beds of packstone (0.5–2 cm). The marly beds and the thin limestone beds contain abundant brachiopods and other fossils. In the thinbedded limestone beds most brachiopods are disarticulated and in concave-up position.

The Halla Beds are very similar to the overlying Klinteberg Formation in their upper 3–4 metres. The oncoids in the Halla Beds are relatively large (1–4 cm), having a very irregular outline (Figs. 31a, 31b).

At Hällinge 1 and 2 and Båtels 1 and 2 the oncolitic limestones are associated with different lithologies: crinoidal grainstone, in part cross-bedded; peloidal wackestone with lamination and sparfilled fenestrae, overlain in some places by crinoidal stromatoporoid rudstone above an erosive contact (Hällinge 1).

At Fjäle 5 algal-coated grains, but no true oncoids, occur.

At Bendes 2 on the east coast, oncolitic limestone with a crinoidal grainstone matrix is found, but this bed seems to be of strongly limited areal extent.

Interpretation:

Oncolites are typical for shallow, relatively quiet, back-(reef) bank environments where they form on edges of channels and ponds (Wilson 1975; Aigner 1985). The typical oncolite facies of the Klinteberg Formation occurs at the supposed landwards side of the belt with crinoid grainstone facies, and might represent a back-bank environment. The unsorted and muddy wacke- to packstone reflects a relatively lower energy where oncoids occur as autochthonous.

This facies is interpreted as a shallow-water back-shoal environment in which moderate agitation secured the nodular growth of the oncoids. Intermittent high energy episodes introduced crinoidal sands and winnowing of the sediment occurred. Beds of closely packed nodules and large stromatoporoids indicate reworking of the sediment carrying away the fine-grained fraction. The shell-rich packstones in the marly units at Gothemshammar indicate pulses of higher energy reaching into quiet conditions.

The large size of some oncoids might be interpreted as reflecting periods of slow sedimentation rates and/or very favourable conditions for growth of the algae.

The multiphase growth of the oncoids indicates phases of reworking which could be caused by storm episodes. Storms are responsible for reworking of oncoids in modern facies of the Bahamas (Hine 1977).

FACIES I: – STROMATOPOROID FLOAT- AND RUDSTONE.

Type locality: Krakskjär 1.
Other localities: Gurpe 1, 2, Skarnvik 1, Sutarve 3, Tings 1, 2, Tule 1.

Description:

This facies is comparable to facies E in the southwestern region; and together the two facies characterise the uppermost part of Klinteberg Formation over a large area. The stromatoporoid float- and rudstones have a crinoid grainstone matrix. Most stromatoporoids are dome-shaped and 10–20 cm in diameter, and many occur in growth-position. A few tabulate corals and rugose corals occur. Some beds contain fragmented and worn stromatoporoids.

Interpretation:

The facies comprises biostrome-type deposits dominated by stromatoporoids. The grainstone matrix as well as the fragmented skeletons indicate a relatively high energy in a shallow-water setting. The facies probably represents the high-energy belt on a shallow ramp.

FACIES ASSOCIATIONS

FACIES ASSOCIATION 1

Description: (Facies A, B, C and D)

Within limited areas in the southwestern region the different facies types can be correlated and composite sections show facies that occur in a consistent sequence of order.

In the area around Fröjel 3 and Sigdarve 1, 3 the sequence from facies A (here constituted by the uppermost part of the Mulde Beds) followed by B and C in the lowest part of the Klinteberg Formation, can be recognised (Figs. 15, 32 , 33).

In the upper part of the section at Fröjel 3, facies C includes crinoidal bedded sediments. In facies C at Sigdarve 2 an intercalation of a thin interval (ca. 10 cm) of argillaceous wackestone (facies A) is found (Fig. 34). The wackestone overlies a wave-rippled surface in the crinoidal grainstone, a clay layer marking the contact. The argillaceous interval is abruptly overlain by crinoidal grainstone of facies C displaying medium-scale planar cross-bedding.

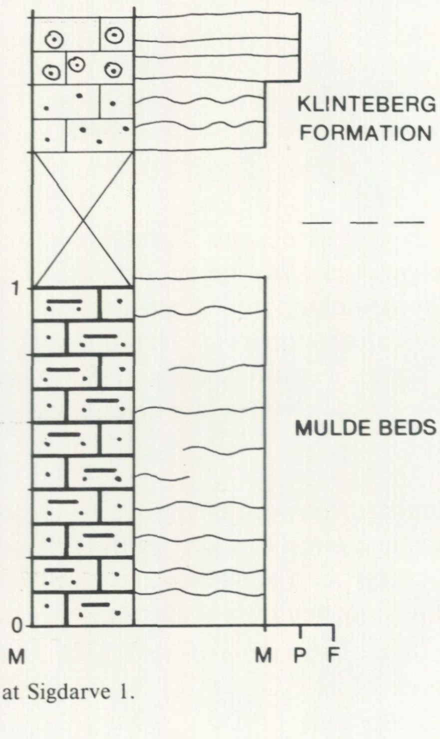


Fig. 32. Sediment log of section at Sigdarve 1.

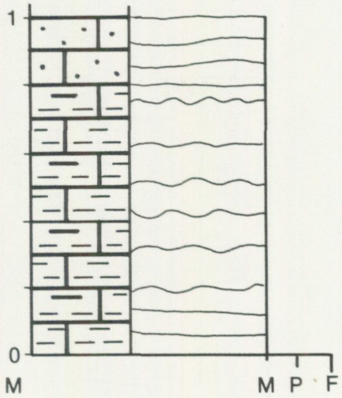


Fig. 33. Sediment log of section at Sigdarve 3.

In the area at Klinteberget 1 and Hunninge 1 a sequence from B to C and D can be followed in the lower to middle part of Klinteberg Formation (Figs. 35, 36). The transition from B to C as seen at Hunninge consists of an 1.5 m interval where B and C are interbedded in beds 2–10 cm thick.

Where the biohermal facies (D) occurs, crinoidal grainstone forms some of the matrix in the bioherms, as well as being a separate facies (facies C) interfingering with the biohermal facies.

In the upper part of the sections at Klinteberget 1 the biohermal facies is overlain by peloidal bedded limestone assigned to facies B.

At Tippsarve 1 a transition is seen from facies A (constituted by the uppermost part of the Mulde Beds) directly into facies C (Fig. 37).

The sequence from facies A to facies C also occurs at Bosarve 1, but here it is developed in the upper part of Klinteberg Formation.

Interpretation:

The succession of facies from A through B, C and D is interpreted as a shallowing-upward sequence formed in a subtidal environment, maybe ranging into the intertidal zone.

The sequence shows the transition from the dominantly marly Mulde Beds and reflects an increasing dominance of carbonate deposition and an increase in energy.

The peloidal limestones of facies B are interpreted as subtidal normal marine deposits reflecting moderate energy conditions. The peloids were subjected to some redeposition by currents but withstood this because of their slight early cementation. Redeposition of recent peloids during storm periods was described from the Bahama Banks (Purdy 1963).

Facies A and B are interpreted as deposited on the deeper part of a ramp, where argillaceous material as well as carbonate mud accumulated. Interbed-

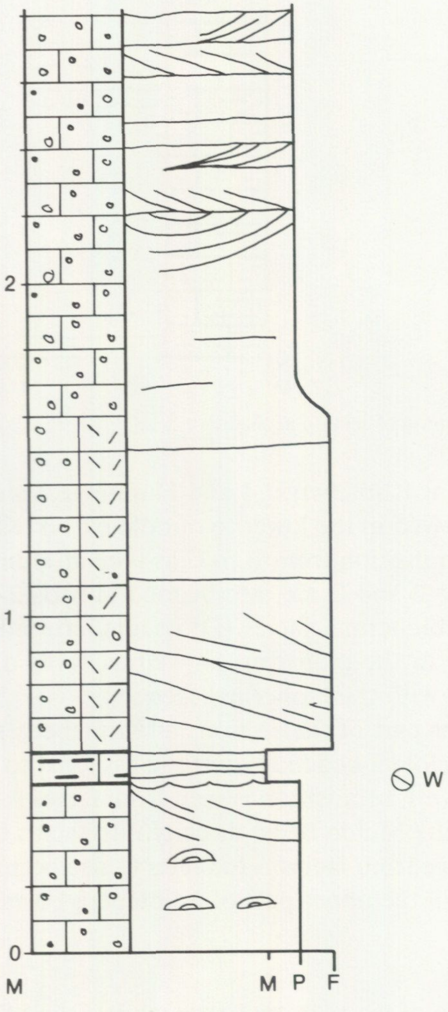


Fig. 34. Sediment log of section at Sigdarve 2.

ding of facies B and C marks the approach of a skeletal sand shoal, where storm-derived grainstones were shed into the deeper parts of the ramp.

Facies C of crinoidal grainstone and floatstone is interpreted as deposited on shallow subtidal shoals subjected to currents and waves. The wave-ripples probably reflect storm episodes, where the associated currents might have caused the medium-scale cross-bedding, erosive channels, and overturning of large stromatoporoids and other skeletons. Wave-ripples with somewhat comparable parameters have been described from the Hemse Beds and interpreted to reflect water depths of 10 m or less by Sundquist (1982).

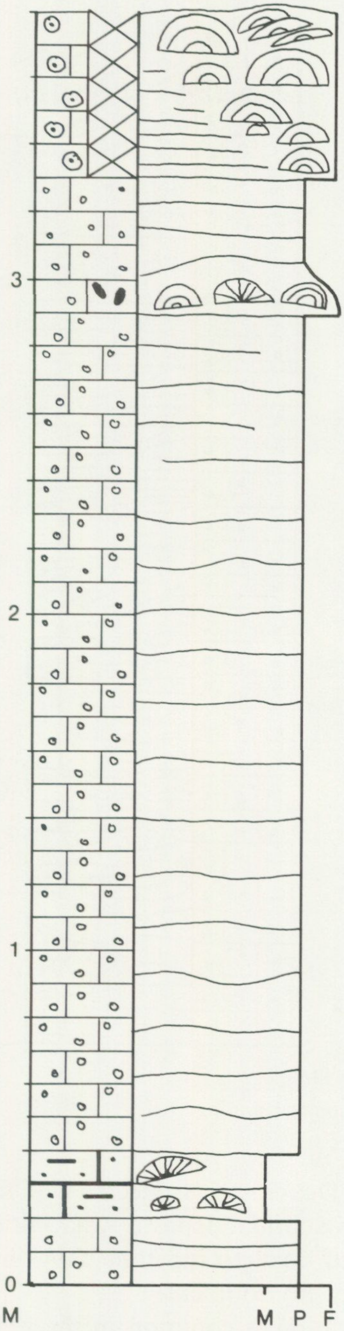


Fig. 35. Sediment log of section at Klinteberget 1.

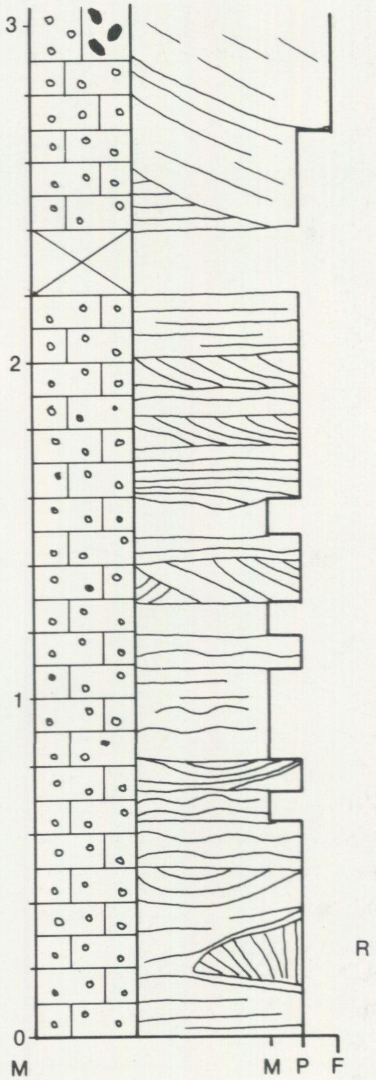


Fig. 36. Sediment log of section at Hunninge 1.

The biohermal facies D is closely connected with facies C and likewise interpreted as a very shallow subtidal deposit. Adjacent to biohermal deposits the crinoidal grainstone and float- to rudstone show crossbedding and channels suggesting a high-energy environment.

Early marine cementation is common in these deposits, probably due to efficient pumping of sea water through the porous sediment.

Meteoric diagenesis in parts of the biohermal complexes suggests Silurian emergence of some horizons.

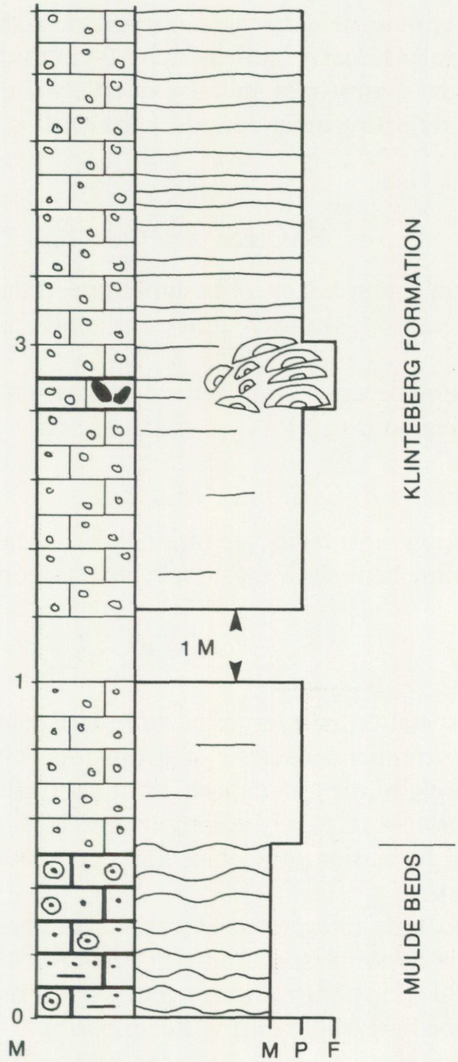


Fig. 37. Sediment log of section at Tippsarve 1.

In the upper part of the sections at Klinteberget 1, some of the biohermal deposits are capped by peloidal limestone assigned to facies B. Some peloid-rich deposits show many early developed fenestrae which might indicate an intertidal environment, but as other criteria for intertidal deposition are lacking, this indication is inconclusive.

The peloidal beds overlying the biohermal facies might be interpreted as back-shoal lagoonal material, and is probably derived from the shallow part of the ramp during progradation. These beds should therefore be distinguished from the main peloidal facies interpreted as deep ramp environment.

In facies C and D, marly laminae up to 3 cm thick frequently separate the bedded crinoidal grainstones and also overlie wave-rippled surfaces. This is interpreted as reflecting quiet periods when settling of the fine-grained material took place.

FACIES ASSOCIATION 2

This association comprises oncolitic limestone, crinoidal grainstone, peloidal limestone, stromatoporoid-rich limestone, and fossiliferous wacke-/packestone.

The association occurs mainly in the northeastern region stretching into the southwestern region (Fig. 5).

Description: (Facies B, C, E, F, G, H, and I)

In this association most facies are interbedded, facies B occurring as a minor component. Some beds show erosional contacts, conglomerates, and abraded fossils.

Interpretation:

This facies association is interpreted to reflect deposition in a shallow subtidal ramp environment. Facies I of stromatoporoid float- and rudstone records high-energy biostrome deposit. In most facies reworking and redeposition seems to be a relatively common process, but periods with moderate energy allowed formation of oncoids and deposition of fine-grained and peloidal sediments.

Facies F and H is interpreted as back-shoal channels and lagoonal areas where oncolitic deposits and mud-rich carbonates accumulated. The interbedded facies G grainstone is interpreted as reworked material from the shoal washed onto the back-shoal during storm periods.

A slight deepening occurring over the area introduced a high-energy belt where the biostromes (facies I) developed, forming the upper part of the Klinteberg Formation.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENT

The general setting for the Klinteberg palaeogeography was deposition on a ramp with shallow water shoals. The shore line generally trended NE-SW. This direction is indicated by wave-ripple orientation in several horizons in the whole Silurian sequence on Gotland (Bergman 1979; Laufeld & Bassett 1981), including the described examples from the Klinteberg Formation.

The middle and lower part of Klinteberg Formation in the SW region, i.e. around Klinteberget, Hunninge and down to Fröjel (including Tass 1, Tippsarve 1 and Rågåkre 1) is interpreted to be a shallowing-upward sequence. This sequence was constituted by the facies shifting through A, B, C, and D, and developed from the argillaceous lithologies of the Mulde Beds. The overlying subtidal peloid-rich sediments were subsequently overstepped substituted by crinoidal sands. The crinoid material formed shallow shoals and barriers, which were redeposited and modified in a high-energy environment by currents and wave action. Biohermal complexes were associated with these shoals and early meteoric diagenesis indicates periods of emergence. These bioherms were also strongly influenced by currents and waves, and they could have constituted parts of a barrier system including the crinoidal sand shoals.

Slightly deeper water is interpreted to have been present southwest of this barrier system, which is indicated by the laterally equivalent marly upper Mulde Beds and the argillaceous wackestone of the Klinteberg Marl.

No exposures were found in the interval directly overlying the shallowing-upward sequence, but stromatoporoid-rich packstone (Vallhagar 1, Stora Solbjärge 1, 2) is followed by nodular slightly argillaceous wackestone which can be seen at Bosarve 1.

In the upper part of the Klinteberg Formation stromatoporoid floatstone at Smiss 3 is followed by argillaceous wacke- and packstone at Smiss 2 and Botes 1, 2 forming the transition from the Klinteberg Marl into the Hemse Marl NW. This is probably reflecting a deepening in the upper Eltonian to Bringewoodian (*scanicus* to *tumescens* graptolite zones).

The trend of shallowing succeeded by deepening during deposition of the Klinteberg Formation as suggested by Riding (1981) can clearly be traced in the southwestern region.

The equivalent to the shallowing-upward sequence described in the lower half of the formation in the southwest is in the northeastern region constituted by facies H, G, B, and F comprising oncolitic limestone intercalated with crinoidal grainstone and peloid-rich limestone, and fossiliferous wacke- to packstone. Oncolitic limestone (Facies H) is dominantly found in the lowest part of the formation (Fig. 5).

The lower part of the Klinteberg Formation in the northeastern region is interpreted as a relatively low-energy shallow water environment. One possible model is that this area was partly protected by a shoal complex comparable to that described from the southwestern region. Only occasional storm episodes reworked and winnowed the sediment in this sheltered area. The shallow water environment gave rise to a complex facies mosaic in which the varied lithologies described from this area developed. The shoal complex might have been located partly outside the present outcrop area. On the east coast the uppermost Klinteberg Formation was indicated by Flodén (1980) to be a continuation of one of the SW-NE trending structural barrier systems found in the submarine Silurian east of Gotland in seismic investigations. This rock body was interpreted to consist of stromatoporoid-rich, usually hard limestones , and is here suggested to correspond to facies I. The extension of the structural barriers system was tentatively suggested to run SW across the Klinteberg Formation towards the biohermal complexes on the west coast (Flodén 1980: 182). Structures seen on the offshore seismic sections, occurring on the seaward slope of the structural barriers were interpreted as bioherms. Onlap configuration is seen in one section on the seaward margin of one of the barrier structures (Flodén 1980, Fig. 80).

The structural relationships interpreted from seismic investigations are compatible with the general facies interpretation presented in this study.

The production of carbonate was dominated by crinoidal material, mostly deposited in the high-energy environments. Calcareous algae contributed significantly to the production in some facies. Finer grained material was produced by disintegration and abrasion of larger skeletal particles, and bioerosion played a minor role by microboring activity in shell-material.

In the uppermost part of the Klinteberg Formation in the middle part of the outcrop area, the stromatoporoid biostrome facies (E and I) and associated cross-bedded crinoidal grainstone of facies C indicate a high energy environment. The overriding by the Hemse Marl is interpreted to reflect an overall decrease in energy-conditions caused by a deepening during *scanicus* and *tumescens* time.

SEA-LEVEL CHANGES

Laufeld et al. (1975) proposed a shallowing around the *nassa/dubius - ludensis* transition in latest Wenlock, probably as a result of a world-wide regression.

A widespread regression at the Wenlock/Ludlow boundary was suggested by Bassett (1976) to have affected sequences in the Anglo-Baltic area (Pembrokeshire, Norway, Estonia). In the Gotland sequence the shallowing was suggested to reflect local differential tectonism (Bassett 1979). The deepening seen in southern Wales and the Welsh Borderland in the same period was considered an effect of fairly local tectonic warping (Bassett 1979).

Contrary to this, McKerrow (1979) suggested deepening over a fairly wide area, including Gotland, around the Wenlock/Ludlow boundary. The transgression in early Ludlow was suggested to have affected only the European continent, and interpreted as a feature induced by tectonism (McKerrow 1979). The Silurian in Estonia contains 3 major regressive sedimentary cycles, which are interrupted by relatively short transgressions. One of these cycles ends at the Wenlock/Ludlow boundary (Kaljo & Jürgenson 1977: 148) and the earliest Ludlow was the time of a short transgression (McKerrow 1979).

Kaljo & Klaamann (1982) states that the *nilssoni/colonus* graptolite zones coincide with changes in sedimentation cycles from regression to transgression in Estonia.

The cause for these relative sea-level changes was discussed by Laufeld et al. (1975) who were inclined to suggest world-wide changes in sea-level, which in turn may be explained as the result of glaciation events. They further suggested that tectonic events may have played a role locally.

Concerning the tectonic impact on the sedimentation pattern, Laufeld & Jeppsson (1976) stressed the possible connection with volcanic activity in areas south of the Baltic, e.g. Barrandium of Czechoslovakia. The southern source for volcanic products during late Wenlock was also invoked by Bjerreskov & Jørgensen (1983) for material found on Bornholm. A marked period of unrest in the Polish region was demonstrated by Tomczyk & Tomczykowa (1978) in the Late Wenlock and especially at the end of *Testograptus testis* zone (= *lundgreni* zone), at which Tomczyk & Tomczykowa (1978: 110–111) untraditionally places the Wenlock/Ludlow boundary. According to Tomczyk & Tomczykowa (1978) this level is associated with accelerated subsidence, and at this time, i.e. at the end of the *lundgreni* zone, the Slite Siltstone was deposited on Gotland, forming a relatively coarse terrigenous clastic wedge in otherwise marly deposits and carbonates of the Slite Marl, Mulde Beds and Halla Beds.

In general the Klinteberg Formation comprises shallow water facies in response to a major episode of shallowing during the time interval corresponding to the *nassa-ludensis* graptolite zones. This was followed by renewed deepening in the Early Ludlow in *scanicus* and *tumescens* time.

DISCUSSION OF DEPOSITIONAL ENVIRONMENT

The development of bioherms in the late Wenlock in both the sequence at Wenlock Edge and in the Klinteberg Formation on Gotland seems to record the same environmental trend. At Wenlock Edge a reduction in siliciclastic sediment input and a shallowing gave way to carbonate sedimentation and bioherm growth (Riding 1981). The shallowing ultimately terminated reef growth (Scoffin 1971).

The same basic pattern is recognized in the Klinteberg Formation, which also bears indications of emergence and meteoric diagenesis of parts of the bioherms (Frykman 1985).

The association of bioherms and crinoid-rich sediments is common and reported from several other settings during the Silurian (Scoffin 1971; Abbot 1976; Bourque 1982), but also from the Middle Ordovician (Ruppel & Walker 1982) and the Lower Devonian (Laporte 1967; Burchette 1981).

In all these examples the crinoid-rich sediments were interpreted as shallow-water deposits formed in shallow subtidal environments. The occurrence of the crinoidal sediments as skeletal sand bars and banks is invoked in all these interpretations.

When looking for a recent analogue to the Silurian example, difficulties arise due to ecological and evolutionary changes since the Palaeozoic. The overwhelming importance of bio-erosion in modern carbonate environments, and the substitution of crinoids by other organisms are differences that hamper the comparison.

However, modern carbonate ramps with skeletal sand shoals are described from the Sandy Key area at the western edge of Florida Bay (Ball 1967) and from the Persian Gulf (Wilson & Jordan 1983). These sand shoals are not associated with bioherms or reefs comparable to the Silurian facies pattern, but the same examples have been used for comparison with crinoid sand shoals from the German Upper Muschelkalk (Triassic) by Aigner (1985). Therefore, these examples are probably the closest analogues for the Silurian depositional system as it functioned on Gotland when the carbonates of the Klinteberg Formation were deposited.

CONCLUSIONS

Carbonate deposition during the Wenlock-Ludlow transition took place on a carbonate ramp with very little influx of terrigenous clastic material. The bioherms and grainstone deposits indicate deposition in a shallow-water high-energy belt of shoals and banks, suggested to trend NE-SW.

The Klinteberg Formation is constituted by a mosaic of dominantly shallow-water facies types, most of them differentiated according to energy level.

The Klinteberg Formation was deposited during a period of shallowing in the Late Wenlock – Early Ludlow. Slight deepening influenced deposition of the upper part of the formation, and it was ultimately substituted by facies assigned to the overlying Hemse Beds.

ACKNOWLEDGEMENTS

I thank Richard G. Bromley, Copenhagen and Sven Laufeld, Uppsala for inspiration and critical review of the manuscript. For support on Gotland I thank Richard Carthew, Cambridge, Candace Brooke, Cardiff, Sarah Nyman, Visby, and Karin Olsen. Staff at the Geological Survey of Denmark helped preparing this publication. I gratefully acknowledge the constructive critisism from the two reviewers L. Jeppsson and M. Lindström. This paper forms a contribution to the IGCP Project Ecostratigraphy on Gotland, and the Swedish group is thanked for permission to use the Allekvia Field Station on Gotland. The publication of this paper was kindly defrayed by a grant from the Swedish Natural Science Research Council (NFR).

REFERENCES

ABBOTT, B.M., 1976: Origin and evolution of bioherms in Wenlock Limestone (Silurian) of Shropshire, England. – Bull. Amer. Ass. Petro. Geol. 60, 2117–2127.

AIGNER, T., 1985: Storm depositional systems. Dynamic stratigraphy in modern and ancient shallow-marine sequences. – Lecture notes in earth sciences, Vol. 3. Springer-Verlag, Berlin Heidelberg New York, Tokyo. 174 pp.

BALL, M.M., 1967: Carbonate sand bodies of Florida and the Bahamas. – J. Sed. Petrol. 37, 556–591.

BASSETT, M.G., 1976: A critique of diachronism, community distribution and correlation at the Wenlock-Ludlow boundary. – Lethaia 9, 207–218.

BASSETT, M.G., 1979: Discussion of "Ordovician and Silurian changes in sea level" by W.S. McKerrow. – Jour. Geol. Soc. 136, 144.

BASSETT, M.G., CHERNS, L. & LARSSON, K., 1981: Silurian lithofacies and palaeogeography of Balto-Scandia. – Field Guide for Working Groups, Gotland, August 25–28, 1981, 22 pp. 41 figs. (Copy deposited in the library at Allekvia Geological Field Station on Gotland).

BERGMAN, C.F., 1979: Ripple marks in the Silurian of Gotland, Sweden. – Geol. Fören. Stockholm Förh. 101, 217–222.

BERGMAN, C.F., 1980: Macrofossils of the Wenlockian Slite Siltstone of Gotland. – Geol. Fören. Stockholm Förh. 102, 13–25.

BERGMAN, C.F., 1987: Silurian paulinitid jawed polychaetes from Gotland. - University of Lund, Sweden. Unpublished Ph.D. thesis, 145 pp.

BJERRESKOV, M. & JØRGENSEN, K.A., 1983: Late Wenlock graptolite-bearing tuffaceous sandstone from Bornholm, Denmark. – Bull. Geol. Soc. Denmark 31, 129–149.

BOURQUE, P.A., 1982: An Upper Silurian reefal limestone platform: from supratidal to marginal slope. – In: R. Hesse, G.U. Middleton, & B.R. Rust(eds.) Guidebook, Excursion 7B: Paleozoic continental margin sedimentation in the Quebec Appalachians. IAS 11th International Congress on Sedimentology, Hamilton, Ontario, Canada.

BROMLEY, R.G., 1978: Bioerosion of Bermuda reefs. – Paleogeogr., Paleoclimatol., Paleoecol., 23, 169–197.

BURCHETTE, T.P., 1981: European Devonian reefs: a review of current concepts and models. – Soc. Econ. Pal. Min. Spec. Publ. 30, 85–142.

CAIN, J.D.B., 1968: Aspects of the depositional environment and paleoecology of crinoidal limestones. – Scott. Jour. Geol. 4, 191–208.

CHERNS, L., 1982: Palaeokarst, tidal erosion surfaces and stromatolites in the Silurian Eke Formation of Gotland, Sweden. – Sedimentology 29, 819–833.

CHERNS, L., 1983: The Hemse-Eke boundary. Facies relationships in the Ludlow series of Gotland, Sweden. – Sver. Geol. Unders., serie C nr. 800, 45 pp.

CLAESSON, C., 1979: Early Palaeozoic geomagnetism of Gotland. – Geol. Fören. Stockholm Förh. 101, 149–155.

DUNHAM, R.J., 1962: Classification of carbonate rocks according to depositional texture. – Classification of carbonate rocks – a symposium. Mem. Amer. Assoc. Petrol. Geol. 1, 108–121.

EMBRY, A.F. & KLOVAN, J.E., 1971: A Late Devonian reef tract on northeastern Banks Island, Northwest Territories. – Bull. Canadian Petrol. Geol. 19, 730–781.

FLODÉN, T., 1980: Seismic stratigraphy and bedrock geology of the central Baltic. – Stockholm Contr. Geol. 35, 240 pp.

FOGDESTAM, B., 1981: Map of the bedrock of Gotland. – Sver. Geol. Unders. Serie Ah nr. 3, specialkarta 1.

FREDHOLM, D., 1988: Vertebrate biostratigraphy of the Ludlovian Hemse Beds of Gotland, Sweden. – Geol. Fören. Stockholm Förh. 110, 237–253.

FRYKMAN, P., 1985: Subaerial exposure and cement stratigraphy of a Silurian bioherm in the Klinteberg Beds, Gotland, Sweden. – Geol. Fören. Stockholm Förh. 107, 77–88.

FRYKMAN, P., 1986: Diagenesis of Silurian bioherms in the Klinteberg Formation, Gotland, Sweden. – In: J.H. Schroeder and B.H. Purser (eds.) Reef Diagenesis. Springer-Verlag., 399–423.

GROVER, G.JR. & READ, J.F., 1978: Fenestral and associated vadose diagenetic fabrics of tidal flat carbonates, Middle Ordovician New Market Limestone, southwestern Virginia. – J. Sed. Petrol. 48, 453–474.

HADDING, A., 1941: The Pre-Quarternary sedimentary rocks of Sweden. VI. Reef limestones. – Lunds Universitets Årsskrift, N.F., 2, 37, 137 pp.

HAGDORN, H., 1978: Muschel/Krinoiden-bioherme im Oberen Muschelkalk (mol, Anis) von Crailsheim und Schwabisch Hall (Sudwestdeutschland). – V. Jb. Geol. Palaont., Abh., 156, 31–86.

HEDE, J.E., 1921: Gotlands silurstratigrafi. – Sver. Geol. Unders. C, 305, 100 pp.

HEDE, J.E., 1927a: Berggrunden (Silursystemet). – In H. Munthe, J.E. Hede & G. Lundquist: Beskrivning till kartbladet Klintehamn. Sver. Geol. Unders. Aa 160, 12–54.

HEDE, J.E., 1927b: Berggrunden (Silursystemet). – In H. Munthe, J.E. Hede, & G. Lundquist: Beskrivning till kartbladet Hemse. Sver. Geol. Unders. Aa 164, 15–56.

HEDE, J.E., 1928: Berggrunden (Silursystemet). – In H. Munthe, J.E. Hede & G. Lundquist: Beskrivning till kartbladet Slite. Sver. Geol. Unders. Aa 169, 13–65.

HEDE, J.E., 1929: Berggrunden (Silursystemet). – In H. Munthe, J.E. Hede, & G. Lundquist: Beskrivning til kartbladet Katthammarsvik. Sver. Geol. Unders. Aa 170, 14–57.

HEDE, J.E., 1958: (Silurian entries in) Lexique stratigraphique international 1, Europe 2c Suede-Sweden-Sverige. 498 pp.

HEDE, J.E., 1960: The Silurian of Gotland. – In G. Regnell & J.E. Hede: The Lower Paleozoic of Scania. The Silurian of Gotland. International Geological Congress XXI Session Norden 1960, Guide to excursions Nos. A 22 and C 17. 87 pp. Stockholm.

HINE, A.C., 1977: Lily Bank, Bahamas: history of an active oolite sand shoal. – J. Sed. Petrol. 42, 1554–1581.

HURST, J.M., 1975: Some observations on brachiopods and the level bottom community ecology of Gotland. – Geol. Fören. Stockholm Förh. 97, 250–264.

HURST, J.M., 1984: Upper Ordovician and Silurian carbonate shelf stratigraphy, facies and evolution, eastern North Greenland. – Bull. Grønlands geol. Unders. 148, 73 pp.

JAEGER, H., 1981: Comments on the graptolite chronology of Gotland. – In: S. Laufeld (ed.). Proceeding of Project Ecostratigraphy Plenary meeting, Gotland, 1981. Sver. Geol. Unders., rapporter och meddelanden nr. 25, p.12.

JEPPSSON, L., 1982: Third European Conodont Symposium (ECOS III). – Guide to excursion. Publications from the Institute of Mineralogy, Palaeontology and Quarternary Geology, University of Lund, Sweden, 239, 32 pp.

JEPPSSON, L., 1983: Silurian conodont faunas from Gotland. – Fossils and Strata 15, 121–144.

KALJO, D.L. & JÜRGENSON, E., 1977: Sedimentary facies of the East Baltic Silurian. – Academy of Science, Estonian S.S.R., Tallinn, 122–148.

KALJO, D.L. & KLAAMANN, E., 1982: Communities and biozones in the Baltic Silurian. – Academy of Science, Estonian S.S.R., Institute of Geology, Tallinn, 140 pp.

KERSHAW, S., 1981: Stromatoporoid growth form and taxonomy in a Silurian biostrome, Gotland. – Jour. Paleontology 55, 1284–1295.

LAPORTE, L., 1967: Carbonate deposition near mean sea-level and resultant facies mosaic: Manlius Formation (Lower Devonian) of New York State. - Amer. Ass. Petro. Geol. Bull. 51, 73–101.

LARSSON, K., 1979: Silurian tentaculitids from Gotland and Scania. – Fossils and Strata 5, 130 pp.

LAUFELD, S., 1974a: Silurian Chitinozoa from Gotland. – Fossils and Strata 5, 130 pp.

LAUFELD, S., 1974b: Reference localities for palaeontology and geology in the Silurian of Gotland. – Sver. Geol. Unders. C 705, 172 pp.

LAUFELD, S., BERGSTRÖM, J. & WARREN, P.T., 1975: The boundary between the Silurian Cyrtograptus and Colonus Shales in Skåne, southern Sweden. – Geol. Fören. Stockholm Förh. 97, 207–222.

LAUFELD, S. JEPPSON, L., 1976: Silicification and bentonites in the Silurian of Gotland. – Geol. Fören. Stockholm Förh. 98, 31–44.

LAUFELD, S. & BASSETT, M.G., 1981: Gotland: the anatomy of a Silurian carbonate platform. – Episodes 1981, 2, 23–27.

MANTEN, A.A., 1971: Silurian reefs of Gotland. – Developments in Sedimentology 13, 539 pp., Elsevier, Amsterdam.

MARTINSSON, A., 1967: The succession and correlation of ostracode faunas in the Silurian of Gotland. – Geol. Fören. Stockholm Förh. 89, 350–386.

MCKERROW, W.S., 1979: Ordovician and Silurian changes in sea level. – Jour. Geol. Soc. London 136, 137–145.

POULSEN, K.D., SAXOV, S., BALLING, N. & KRISTIANSEN, J.I., 1982: Thermal conductivity measurements of Silurian limestones from the Island of Gotland, Sweden. – Geol. Fören. Stockholm Förh. 103, 349–356.

PURDY, E.G., 1963: Recent calcium carbonate facies of the Great Bahama Bank. 2. Sedimentology. – Journal of Geology 71, 472–497.

RAMSKÖLD, L., 1984: Silurian odontopleurid trilobites from Gotland. - Palaeontology 27, 239–264.

RAMSKÖLD, L., 1985: Silurian phacopid and dalmanitid trilobites from Gotland. – Stockholm Contr. Geol. 40, 1–62.

RIDING, R., 1981: Composition, structure and environmental setting of Silurian bioherms and biostromes in northern Europe. – Soc. Econ. Pal. Min., Spec. Publ. 30, 41–83.

RUPPEL, S.C. & WALKER, K.R., 1982: Sedimentology and distinction of carbonate buildups: Middle Ordovician, east Tennessee. – J. Sed. Petrol. 52, 1055–1071.

SCOFFIN, T.P., 1971: The conditions of growth of the Wenlock reefs of Shropshire (England). – Sedimentology 17, 173–219.

SHINN, E., 1968: Practical significance of birdseye structures in carbonate rocks. – J. Sed. Petrol. 38, 215–223.

SHINN, E., 1983: Birdseyes, fenestrae, shrinkage pores, and loferites: a re-evaluation. – J. Sed. Petrol. 53, 619–628.

STRIDSBERG, S., 1985: Silurian oncocerid cephalopods from Gotland. – Fossils and Strata 18, 1–65.

SUNDQUIST, B., 1982: Palaeobathymetric interpretation of wave ripple-marks in a Ludlovian grainstone of Gotland. – Geol. Fören. Stockholm Förh. 104, 157–166.

TOMCZYK, H. & TOMCZYKOWA, E., 1978: The development of the Prototethys Ocean and its influence on the differentiation of Palaeozoic deposits in Poland. – Bulletin de l'Academie Polonaise des Sciences, Series des Sciences de la Terre 26, 103–118.

WILSON, J.L., 1975: Carbonate facies in geologic history. – Springer-Verlag, Berlin Heidelberg New York, 471 pp.

WILSON, J.L. & JORDAN, C., 1983: Middle shelf. – In: P.A. Scholle, D.G. Bebout & C.H. Moore (eds.). Carbonate depositional environments. Am. Assoc. Petrol. Geol. Mem. 33, 297–343.

APPENDIX: LOCALITIES

The locality list includes all localities mentioned in the text and in the description of facies. The positions of the localities within the Klinteberg Formation and adjacent units are synthetised on Fig. 38. In the list of references to each locality, an asterisk marks the publication in which a full description of the locality is found. For localities described by Laufeld (1974b), Laufeld & Jeppsson (1976), Larsson (1979) and Jeppsson (1983), earlier litterature will not be cited.

The locality descriptions are given according to the directions by Laufeld (1974b, pp. 7–9) and Larsson (1979, pp. 15–18). The unit designation from Laufeld (1974 a, b) and the facies assigned to the locality in this publication are given.

Grid references refer to the Swedish National Grid system and (within parentheses) the Universal Transverse Mercator (UTM) system.

AJMUNDE 1.

Hemse Beds, Hemse Marl NW.
References: Laufeld 1974a, b*; Laufeld & Jeppsson 1976; Larsson 1979; Jeppsson 1983; Ramsköld 1985; Bergman 1987.
Earlier referred to as Klinteberg Beds, Klinteberg Marl top by Laufeld (1974a,b). According to Jeppsson (1983) in his work on conodonts, it represents the same unit as other localities referred to the Hemse Marl NW, in which it is now included.
Argillaceous wackestone facies (A).

ALSTÄDE 1.

636015 164735 (CJ 3475 5910), ca. 4100 m SSE of Klinte church. Top. map sheet 6I Visby SO. Geol. map sheet Aa 164 Hemse.
Old quarry, nearly filled. In the forest northwest of the road-fork formed by the two minor roads just west of the main road (141) north of Ansarve. Accessible by field road from the western branch of the road-fork.
Klinteberg Formation. Crinoid grainstone facies (C).

ALTAJME 1.

Klinteberg Formation, upper part.
References: Laufeld 1974a,b*.
Interbedded peloidal wackestone and stromatoporoid float- and rudstone facies (B,E).

ALTAJME 2.

636585 166420 (CJ 5200 6350), ca. 1600 m SSE of Buttle church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 170 Katthammarsvik.
Old quarry, nearly filled. Low section along field-road ca. 100 m south of farm buildings. Accessible from farm or from field-road leading from road 143 ca. 3 km south of Buttle.
Klinteberg Formation, upper part. Stromatoporoid float- and rudstone facies (E).

AUTSARVE 1.

Hemse Beds, Hemse Marl NW.
References: Laufeld 1974a,b*; Jeppsson 1983; Fredholm 1988.

BAJU 1.

Klinteberg Formation?
Reference: Bergman 1987*.

BARA 1.

Halla Beds, Bara Oolite.
References: Laufeld 1974a,b*; Larsson 1979; Ramsköld 1985; Jeppsson 1982, 1983; Bergman 1987.

BÅTELS 1.

Klinteberg Formation, Unit c.
References: Hede 1929, p. 18, lines 5–17 f.b.; Laufeld 1974a,b*; Bassett et al. 1981; Jeppsson 1983; Bergman 1987.
Interbedded crinoid grainstone and oncolite wackestone facies (G, H).

BÅTELS 2.

Klinteberg Formation, Unit b.
References: Hede 1929, p. 18, l. 22–25 f.b.; Laufeld 1974a,b*; Bergman 1987.
Interbedded crinoid grainstone and oncolite wackestone facies (G, H).

BENDES 1.

637785 167645 (CJ 6515 7460), ca. 2900 m NE of Anga church. Top, map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Excavation for telegraph pole at road-side where road branches.
Klinteberg Formation. Fossiliferous packstone facies (F).

BENDES 2.

637705 167770 (CJ 6630 7360), ca. 3800 m ENE of Anga church. top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Low section in drainage ditch running from the swamp area Gylar into Skarnvik.
Klinteberg Formation. Fossiliferous packstone and oncolite packstone facies (F, H).

BJÄRBYHOLM 1.

636415 166140 (CJ 4895 6130), ca. 3300 m NNW of Etelhem church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 164 Hemse.
Surface exposures east of road-crossing on the way to Bjärbyholm from road 143.
Klinteberg Formation. Stromatoporoid floatstone facies (E).

BJÄRBYHOLM 2.

636330 166140 (CJ 4905 6205), ca. 1400 m NNW of Etelhem church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 164 Hemse.
Low section at the old rail-road track which is now a fieldroad running to Buttlegårde.
Klinteberg Formation. Stromatoporoid floatstone facies (E).

BJÄRGES 1.

Mulde Beds, upper part.
References: Laufeld 1974a,b*; Larsson 1979; Bergman 1987.

BLÅHÄLL 1.

Mulde Beds, lower part.
References: Laufeld 1974a,b*; Larsson 1979, Claesson 1979, Poulsen et al. 1982; Bassett et al. 1981; Jeppsson 1983; Ramsköld 1984, 1985; Bergman 1987.

BOFRIDE 1.

Klinteberg Formation, upper part.
References: Laufeld 1974a,b*; Larsson 1979; Bergman 1987.
Biohermal facies with crinoid grainstone (D).

BOFRIDE 2.

Klinteberg Formation, upper part.
References: Laufeld 1974a,b*; Bergman 1987.
Biohermal facies with crinoid grainstones (D).

BOSARVE 1.

635785 164730 (CJ 3450 5770), ca. 3900 m ESE of Fröjel church. Top. map sheet 6I Visby SO. Geol. map sheet Aa 160 Klintehamn.
Nice ditch section at the old rail-road track which is now a field road. Accessible from south just north of Magnuse at road 141.
Klinteberg Formation. Argillaceous packstone facies (A).

BOTES 1.

Klinteberg Formation, Klinteberg Marl.
References: Larsson 1979*.
Argillaceous wackestone facies (A).

BOTES 2.

Klinteberg Formation, Klinteberg Marl.
References: Larsson 1979*.
Argillaceous wackestone facies (A).

BOTVALDE 1.

Klinteberg Formation, unit e.
References: Jeppsson 1983*; Bergman 1987.
Crinoid grainstone facies (G).

BOTVALDVIK 1. Klinteberg Formation, unit b. Spelt Botvaldevik and misprinted as being unit c by Jeppsson (1983).
References: Larsson 1979*; Jeppsson 1983.
Crinoid grainstone facies (G).

BOTVALDVIK 2.

638835 167920 (CJ 6835 8490), ca. 4100 m ENE of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Low shore exposure just south of the harbour.
Klinteberg Formation. Crinoid grainstone facies (G).

BUTTLEGÅRDE 1.

636675 166130 (CJ 4915 6440), ca. 2500 m WSW of Buttle church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 164 Hemse.
Section in anomalously dipping strata (15–20°) at small artificial pond used for the steam-engines on the former railroad. This is now a field road running just east of the pond. Accessible from north at Buttlegårde.
Klinteberg Formation. Stromatoporoid float- and rudstone facies (E).

BUTTLEGÅRDE 2.

636685 166120 (CJ 4910 6450), ca. 2600 m WSW of Buttle church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 164 Hemse.
Sections at western end in still open quarry. Nice walls 2–3 m high easily accessible. Field road from Buttlegårde passes the quarry.
Klinteberg Formation. Stromatoporoid float and rudstone facies (E).

BUTTLEGÅRDE 3.

636825 166135 (CJ 4940 6610), ca. 2500 m WNW of Buttle church. Top. map sheet 6J Roma SV. Geol. map sheet Aa Hemse.
Low section and surface exposure at the old rail-road track, now a field road.
Klinteberg Formation. Stromatoporoid float- and rudstone facies (E).

DANS 1.

Klinteberg Formation, lower part.
References: Laufeld 1974a,b*.
Crinoid grainstone facies (C).

DÄPPS 1.

Mulde Beds, upper part.
References: Laufeld 1974a,b*; Larsson 1979; Bergman 1987.

DIBJÄRS 1.

Klinteberg Formation, unit a.
Reference: Larsson 1979*.
Oncolite wackestone facies (H).

DIBJÄRS 2.

638430 166785 (CJ 5710 8190), ca. 800 m WSW of Hörsne church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Low field road section 500 m NE of main road from Hörsne.
Klinteberg Formation (unit b?).
References: Hede 1928, p. 57, 1.20–29.
Crinoid grainstone facies (G).

DIBJÄRS 3.

638500 166790 (CJ 5710 8230), ca. 800 m E of Hörsne church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Section along Hörsne drainage ditch just below the Fornborg with a rillstone-assemblage.
Halla Beds, upper part.

DJAUPVIKSUDDEN 1.

Hemse Beds, units b and c.
References: Laufeld 1974a,b*; Larsson 1979.

DJUPÅVIKEN 1.

638190 167785 (CJ 6680 7840), ca. 5900 m SSE of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik. Low shore exposure at small spit pointing southeast.
Klinteberg Formation, unit d.
References: Hede 1929, p. 20, 1.6.
Fossiliferous wackestone facies (F).

FJÄLE 1.

Klinteberg Formation, unit e.
References: Laufeld 1974a,b*.
Crinoid grainstone facies (G).

FJÄLE 2.

Klinteberg Formation, unit d.
References: Laufeld 1974a,b*; Bergman 1987.
Crinoid grainstone facies (G).

FJÄLE 3.

Klinteberg Formation, unit e.
References: Laufeld 1974a,b*; Bergman 1987.
Crinoid grainstone facies (G).

FJÄLE 4.

Klinteberg Formation, unit e.
References: Laufeld 1974a,b*.
Crinoid grainstone facies (G).

FJÄLE 5.

637930 167330 (CJ 6210 7640), ca. 2300 m ENE of Norrlanda church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik. Low ditch section at road-side north of the road. Just west of open patch in the forest.
Klinteberg Formation. Oncolite and crinoidal grainstone facies (G, H).

FJÄRDINGE 1.

Klinteberg Formation, unit b.
References: Laufeld 1974a,b*; Larsson 1979; Bergman 1987.
Oncolitic wackestone facies (H).

FORSE 1.

Klinteberg Formation, lower part.
References: Laufeld 1974a,b*; Larsson 1979.
Stromatoporoid float- and rudstone facies (E).

FORSE 2.

636680 165020 (CJ 3820 6565), ca. 2600 m SW of Hejde church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 160 Klintehamn.
Low road section on both sides of road just at diversion to Tippsarve.
Klinteberg Formation. Stromatoporoid float- and rudstone facies (E).

FRÖJEL 1.

Mulde Beds and Klinteberg Formation.
References: Laufeld 1974a,b*.

FRÖJEL 2.

Mulde Beds, upper part.
References: Laufeld 1974a,b*; Bergman 1987.

FRÖJEL 3.

Mulde Beds, upper part and Klinteberg Formation, lower part.
References: Laufeld 1974a,b*.
Peloid wackestone and cinoid grainstone facies (B, C).

FRÖJEL 4.

Klinteberg Formation, lower part.
References: Larsson 1979*.
Crinoid grainstone facies (C).

GANTHEM 1.

Klinteberg Formation, unit c. The locality seems to be completely covered at the present.
References: Laufeld 1974a,b*; Larsson 1979.

GANTHEM 2.

638100 166700 (CJ 5590 7845), ca. 1200 m NE of Ganthem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Shallow ditch section immediately west of the road. Just north of road diversion to the east from road running north-south.
Klinteberg Formation, unit c? Stromatoporoid floatstone (E) interbedded with wackestone and coenitid grainstone.

GARNUDDEN 1.

Hemse Beds, unit a.
References: Laufeld 1974a,b*; Bergman 1987; Fredholm 1988.

GARNUDDEN 2.

637600 167900 (CJ 6750 7250), ca. 5000 m E of Anga church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Low shore exposure on north side of Garnudden. Section with several hardgrounds.
Hemse Beds, unit a.

GODRINGS 1.

Halla Beds and Klinteberg Formation. The boundary previously described has not been refound during this investigation.
References: Laufeld 1974a,b*; Bergman 1987.

GODRINGS 2.

Halla Beds, uppermost part.
References: Laufeld 1974a,b*; Larsson 1979; Bergman 1987.

GOTHEMSHAMMAR 1.

Halla Beds and Klinteberg Formation. According to Laufeld (1974b), the boundary should be easy to uncover in the scree. However, this is not agreed upon after this investigation, since the massive bed marking the upper part of the exposure can be correlated to the north along the beach to be relatively low in the Halla Beds (ca. 1.5 m).
References: Laufeld 1974a,b*; Larsson 1979; Jeppsson 1983; Bergman 1987.

GOTHEMSHAMMAR 2.

Halla Beds and Klinteberg Formation. Type locality for the boundary between the two units.

References: Laufeld 1974a,b*; Hurst 1975; Larsson 1979; Claesson 1979; Bassett et al. 1981; Jeppsson 1983; Bergman 1987.
Oncolitic wacke- and packstone facies (H).

GOTHEMSHAMMAR 3.

Klinteberg Formation, unit a according to Laufeld 1974b.
References: Laufeld 1974a,b*; Larsson 1979; Hurst 1975; Poulsen et al. 1982; Jeppsson 1983.
Oncolitic wacke- and packstone facies (H).

GOTHEMSHAMMAR 4.

Klinteberg Formation, unit a.
References: Laufeld 1974a,b*.
Oncolitic wacke- and packstone facies (H).

GOTHEMSHAMMAR 5.

Klinteberg Formation, unit a.
References Laufeld 1974a,b*.
Oncolitic wacke- and packstone facies (H).

GOTHEMSHAMMAR 6.

Halla Beds, unit c.
References: Laufeld 1974a,b*; Jeppsson 1983; Bergman 1987.

GRÖNDALEN 1

Klinteberg Formation, lower part. Lilla Karlsö.
References: Laufeld 1974a,b*; Bergman 1987.

GRUNNSUDDEN 1.

637760 167870 (CJ 6725 7425), ca. 4800 m WNW of Anga church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Low shore exposure starting at the point of the spit and going south.
Klinteberg Formation. Fossiliferous wacke- and packstone and crinoid grainstone facies (F, G).

GRYMLINGS 1.

Klinteberg Formation, lower-middle part.
References: Jeppsson 1983*; Bergman 1987. According to the outline by Laufeld (1974a), this locality would be located in the informal member Klinteberg Marl, but this has not been indicated by Jeppsson (1983).
Argillaceous wackestone facies (A).

GURPE 1.

637480 167095 (CJ 5930 7190), ca. 4200 m NW of Kräklingebo church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 170 Katthammarsvik. Low section in small quarry in the forest, at the end of ca. 1 km long field road. Klinteberg Formation. Stromatoporoid floatstone facies (I).

GURPE 2.

637380 167350 (CJ 6185 7085), ca. 1600 m NW of Kräklingebo church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 170 Katthammarsvik. Low section along drainage ditch. Klinteberg Formation. Stromatoporoid floatstone facies (I).

GYLE 1.

Hemse Beds, unit b. References: Laufeld 1974a,b*; Larsson 1979; Bergman 1987; Fredholm 1988.

HÄLLINGE 1.

Klinteberg Formation, unit b. References: Laufeld 1974a,b*; Bergman 1987. Crinoid grainstone and oncolite wacke- and packstone facies (G, H).

HÄLLINGE 2.

Klinteberg Formation, unit a. References: Laufeld 1974a,b*; Jeppsson 1983; Bergman 1987. Crinoid grainstone and oncolite wacke- and packstone facies (G, H).

HANGRE 1.

688400 167720 (CJ 6630 8040), ca. 3700 m SSE of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite. Excavation for telegraph poles at road-side. Klinteberg Formation. Fossiliferous wackestone facies (F).

HAUGKLINTAR 1.

Mulde Beds, upper part. References: Laufeld 1974a,b*.

HAUGKLINTAR 2.

Klinteberg Formation, lower part. References: Laufeld 1974a,b*; Jeppsson 1983; Bergman 1987.

HEMSEENKLAVEN 1.

Klinteberg Formation, lower-middle part.
Reference: Larsson 1979*.
Argillaceous wacke- and packstone facies (A).

HUNNINGE 1.

Klinteberg Formation, lower-middle part.
References: Laufeld 1974a,b*; Larsson 1979; Jeppsson 1983; Bergman 1987.
Interbedded peloidal packstone and crinoid grainstone facies overlain by biohermal facies (B, C, D).

KAKHUSE 1

Klinteberg Formation, lower part.
Reference: Bergman 1987*.

KLINTEBERGET 1.

Klinteberg Formation, lower-middle part.
References: Hede 1927, p. 40, l. 2–22; Hede 1960, pp. 75–76; Martinsson 1962, p. 53; Manten 1971; Laufeld 1974a,b*; Larsson 1979; Claesson 1979; Bassett et al. 1981; Laufeld & Martinsson 1981; Jeppson 1982; Ramsköld 1985; Jeppsson 1983; Bergman 1987.
Interbedded peloidal packstone and crinoid grainstone facies overlain by biohermal facies (B, C, D).

KLINTEBYS 1.

Slite Beds and Halla Beds.
References: Laufeld 1974a,b*; Larsson 1979; Bassett et al. 1981; Jeppsson 1983.

KRAKFOT 1.

638020 167295 (CJ 6180 7820), ca. 2400 m NE of Norrlanda church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Ditch section east of the road in the upper waters of Djupåen.
Klinteberg Formation, unit d?
References: Hede 1929, p. 19, 1.3–6; Bergman 1987.
Fossiliferous wacke- and packstone facies (F).

KRAKSKJÄR 1.

637650 167760 (CJ 6615 7310), ca. 3600 m E of Anga church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Low shore exposure just north of the spit where field road ends.
Klinteberg Formation. Stromatoporoid float- and rudstone facies (I).

KRASSE 1.

Klinteberg Formation, middle part.
References: Laufeld 1974a,b*; Bergman 1987.
Crinoid grainstone facies (C).

LILLA SNÖGRINDE 1.

Klinteberg Formation, lower-middle part.
References: Laufeld 1974a,b*; Larsson 1979.
Crinoid grainstone and biohermal facies (C, D).

LILLA SNÖGRINDE 2.

Klinteberg Formation, middle part.
References: Laufeld 1974a,b*.
Crinoid grainstone facies (C).

LILLA SNÖGRINDE 3.

Klinteberg Formation, lower-middle part.
References: Laufeld 1974a,b*.
Crinoid grainstone facies (C).

LILLA SNÖGRINDE 4.

Klinteberg Formation.
Reference: Frykman 1985*.
Crinoid grainstone and biohermal facies (C,D).

LILLSUND 1.

638520 167920 (CJ 6830 8180), ca 4400 m WSW of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Excavated material from water-filled pond placed at wire-fence ca 200 m northeast of fishing-huts at Fjärden.
Klinteberg Formation. Fossiliferous packstone and crinoid grainstone facies (F,G).

LINE 1.

Klinteberg Formation, lower-middle part.
Reference: Larsson 1979*.

LOGGARVE 1.

Mulde Beds and Klinteberg Formation. The upper 0.75 m in the section belongs to the Klinteberg Formation.
Reference: Jeppsson 1983*; Bergman 1987.
Crinoid grainstone facies (C).

LOGGARVE 2.

Mulde Beds and Klinteberg Formation. Here described as type locality for the boundary between the two units.
Reference: Jeppsson 1982*; Ramsköld 1985; Bergman 1987.
Crinoid grainstone facies (C).

MAGNUSE 1.
Klinteberg Formation, unit b.
Reference: Larsson 1979*.

MEDEBYS BODAR 1.

638690 167770 (CJ 6690 8350), ca 2400 m E of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Low ditch-section at road-side on the field road to Medebys Bodar.
Klinteberg Formation. Fossilifereous wacke- and packstone facies (F).

MEDEBYS BODAR 2.

638740 167915 (CJ 6830 8390), ca 3800 m E of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Low shore exposures. The locality includes the stretch from the fishing hut at Medebys Bodar and ca. 0.5 km south.
Klinteberg Formation. Fossiliferous wacke- and packstone facies (F).

MÖLLBOS 1.

Halla Beds, unit b.
References: Laufeld 1974a,b*; Larsson 1979, Jeppsson 1983; Stridsberg 1985; Ramsköld 1985; Bergman 1987.

MULDE 1.

Slite Beds, Slite Siltstone.
References: Laufeld 1974a,b*.

NÄSAR 1.

638430 167890 (CJ 6805 8090), ca 4700 m SE of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Low shore exposures eastnortheast of Nors. The exposures stretch over more than 200 m and can be reached either from Agbod in the north or from Hangrebod in the south by walking.
Klinteberg formation. Crinoid grainstone facies (G).

ÖRTER 1.

Klinteberg Formation, lower part.
References: Laufeld 1974a,b*.
Crinoid grainstone facies (G).

PRÄSTBÅTELS 1.

Klinteberg Formation, lower part.
References: Laufeld 1974a,b*.
Biohermal facies (D) and oncolitic packstone facies (H).

PRÄSTBÅTELS 2.

Klinteberg Formation, lower part.
References: Laufeld 1974a,b*; Bergman 1987.
Biohermal facies (D) and oncolitic packstone faices (H).

PRÄSTBÅTELS 3.

Klinteberg Formation, lower part.
References: Laufeld 1974a,b*.
Biohermal facies (D) and oncolitic packstone facies (H).

RÅBY TRÄSK 1.

638735 167170 (CJ 6110 8440), ca 3500 m W of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Low section at northern end of Råby Träsk at field road NW of main road ca 200 m southwest of point 19,92 on the map.
Klinteberg Formation, unit b? Oncolitic wacke- and packstone facies (H).

RÅGÅKRE 1.

Klinteberg Formation, lower part. Locality has been assigned to the Halla Beds by Bergman (1979), but it seems more likely that the locality is in the Klinteberg Formation as originally described by Laufeld (1974a,b).
References: Laufeld 1974a,b*; Bergman 1979, 1987.
Crinoid grainstone facies (C).

RÅGÅKRE 2.

636830 165070 (CJ 3890 6700), ca 2000 m W of Hejde church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 160 Klintehamn.
Low section in road-side ca 300 m south of Rågåkre.
Mulde Beds, uppermost part.

SANDVIKEN 1.

637960 167665 (CJ 6540 7630), ca 4100 m NE of Anga church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Low shore exposure in the bay just south of main spit. Can be reached from the north by the field road running from Hammars.
Klinteberg Formation, unit d.
References: Hede 1929, p. 20, 1. 1–7.
Fossiliferous wacke- and packstone facies (F).

SIGDARVE 1.

635845 164380 (CJ 3115 5740), ca 700 m SSE of Fröjel church. Top. map sheet 6I Visby SO. Geol. map sheet Aa 164 Hemse.
Road-cuts including section at road 140 south of the road to Eksta and section in ditch on north side of Eksta road at the entrance to Styrmansberget.
Mulde Beds, uppermost part, and Klinteberg Formation, lowest part. Argillaceous wackestone and crinoid grainstone facies (A,C).

SIGDARVE 2.

635900 164420 (CJ 3150 5800), ca 600 m E of Fröjel church. Top. map sheet 6I Visby SO. Geol. map sheet Aa 164 Hemse.
Sections up to 2 m high in abandoned quarry.
Klinteberg Formation, lower part. Crinoid grainstone facies (C).

SIGDARVE 3.

635865 164360 (CJ 3085 5760), ca 600 m S of Fröjel church. Top. map sheet 6I Visby SO. Geol. map sheet Aa 164 Hemse.
Section in road-cut.
Mulde Beds, upper part.

SKARNVIK 1.

635760 167740 (GJ 6585 7220), ca 3500 m ESE of Anga church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Low shore exposures. Accessible from the south by field road.
Klinteberg Formation. Stromatoporoid rudstone facies (I).

SKARNVIK 2.

637545 167715 (CJ 6560 7200), ca 3300 m ESE of Anga church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Low section in ditch. Accessible by the field road.
Hemse Beds, lower part.

SKÄRSUDDEN 1.

638140 167730 (CJ 6620 7810), ca 6100 m SSE of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 170 Katthammarsvik.
Low shore exposure north of the spit. Accessible from fishing huts to the south, east of Hammars.
Klinteberg Formation. Fossiliferous wacke- and packstone facies (F).

SMISS 1.

Klinteberg Formation, Klinteberg Marl, top.
References: Laufeld 1974a,b*; Larsson 1979 (Klinteberg Marl); Bergman 1987.
Argillaceous packstone facies (A).

SMISS 2.

635700 165040 (GJ 3743 5575), ca 5 km W of Lojsta church. Top. map sheet 6J Roma SV. Geol. Map sheet Aa 164 Hemse.
Low ditch exposure along field road approximately at roadfork 1.5 km north of the main road through Stenbjärs.
Klinteberg Formation. Argillaceous packstone facies (A).

SMISS 3.

635750 165020 (CJ 3732 5627), ca 5200 m W of Lojsta church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 164 Hemse.
Surface exposure in bottom of gravel pit just beside the field road through forest.
Klinteberg Formation. Peloidal packstone and stromatoporoid floatstone facies (B,E).

SMISS 4.

635820 165030 (CJ 3746 5712), ca 5300 m W of Lojsta church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 164 Hemse.
Surface exposure at field road, ca 200 m south of main road from Klinte.
Klinteberg Formation. Stromatoporoid floatstone facies (E).

STENSTU 1.

Klinteberg Formation, upper part.
Reference: Larsson 1979*.
Fossiliferous wacke- and packstone facies (F).

STENSTU 2.

Klinteberg Formation, unit f.
Reference: Bergman 1987*.

STENSTUGÅRDS 1.

Klinteberg Formation, lower part.
References: Laufeld 1974a,b*; Bergman 1987.
Oncolitic wacke- and packstone facies (H).

STORA SOLBJÄRGE 1.

Klinteberg Formation, upper part.
References: Laufeld 1974a,b*.
Stromatoporoid rudstone facies (E).

STORA SOLBJÄRGE 2.

Klinteberg Formation, upper part.
References: Laufeld 1974a,b*.
Stromatoporoid rudstone facies (E).

STORA TUNE 1.

Klinteberg Formation, lower part.
References: Laufeld 1974a,b*; Bergman 1987.

SUDERBYS 1.

Klinteberg Formation, unit b.
Reference: Larsson 1979*.

SUDERBYS 2.

Klinteberg Formation, unit b.
Reference: Larsson 1979*.
Oncolitic wackestone facies (H).

SUDERBYS 3.
Klinteberg Formation, unit b or c.
Reference: Hede 1928: 58, lines 28 to 31; Bergman 1987*.

SUTARVE 1.

Klinteberg Formation and Hemse Beds. The boundary has not been refound.
References: Laufeld 1974a,b*.
Crinoid grainstone facies (G).

SUTARVE 2.

Klinteberg Formation, unit f, top. In Laufeld 1974b misprinted as "Hemse Beds, lower part"; corrected in Laufeld & Jeppsson 1976.
References: Laufeld 1974a,b*; Laufeld & Jeppsson 1976; Jeppsson 1983; Bergman 1987.
Crinoid grainstone facies (G).

SUTARVE 3.

Klinteberg Formation, upper part.
References: Laufeld 1974a,b*; Bergman 1987.
Stromatoporoid floatstone facies (E).

TASS 1.

Klinteberg Formation, lower part.
Reference: Larsson 1979*.
Stromatoporoid float- and rudstone facies (E).

TIMANS 1.

639340 166900 (CJ 5820 8090), ca 2300 m WSW of Hörsne church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Surface exposure at field road at the northwestern edge of the forest.
Klinteberg Formation, unit b?.
References: Hede 1928, p. 59, lines 12–14.
Crinoid and coenitid grainstone facies (G).

TIMANS 2.

638400 166950 (GJ 5845 8113), ca 2500 m WSW of Hörsne church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Surface exposures at field road at the northwestern edge of the forest.
Klinteberg Formation, unit b?
References: Hede 1928, p. 59, lines 12–14.
Crinoid and coenitid grainstone facies (G).

TIMANS 3.

638410 166960 (CJ 5875 8275), ca 2600 m ESE of Hörsne church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Low field road section ca 300 m NW of main road.
Klinteberg Formation.
Reference: Hede 1928.
Crinoid and coenitid grainstone facies (G).

TINGS 1.

Klinteberg Formation, unit f.
References: Laufeld 1974a,b*; Larsson 1979; Bergman 1987.
Stromatoporoid floatstone facies (I).

TINGS 2.

637145 167310 (CJ 5930 6840), ca 1800 m WSW of Kräklingebo church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 170 Katthammarsvik.
Ditch section north of road ca 600 east of the farm house at Tings.
Klinteberg Formation. Stromatoporoid floatstone facies (I).

TIPPSARVE 1.

Mulde Beds, uppermost part and Klinteberg Formation, lower part.
References: Laufeld 1974a,b*.
Crinoid grainstone facies (C).

TIPPSARVE 2.

636685 165005 (CJ 3800 6630), ca 2900 m WSW of Hejde church. Top. map sheet 6J Roma SV. Geol. map sheet Aa 160 Klintehamn.
Excavation for telegraph pole north of the road bend just before it joins the main road.
Klinteberg Formation, lower part. Crinoid grainstone facies (C).

TULE 1.

Klinteberg Formation, unit e?.
References: Laufeld 1974a,b*; Laufeld & Jeppsson 1976; Bergman 1987.
Stromatoporoid floatstone facies (I).

VALLHAGAR 1.

636080 164580 (CJ 3320 5985), ca 3200 m S of Klinte church. Top. map sheet 6I Roma SO. Geol. map sheet Aa 164 Hemse.
Low section at old rail-road which is now a field road. The exposure is at southern end of open patch in the forest.
Klinteberg Formation. Stromatoporoid float- and rudstone facies (E).

VALLMYR 1.

Klinteberg Formation, unit d.
References: Larsson 1979*; Jeppsson 1983; Bergman 1987.
Fossiliferous wacke- and packstone facies (F).

VÄSTERBJÄRS 1.

638830 167360 (CJ 6290 8506), ca 2100 m NW of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Low ditch section along road on north side of road crossing.
Klinteberg Formation.
Reference: Bergman 1987.
Oncolitic packstone facies (H).

VÄSTERBJÄRS 2.

638810 167270 (CJ 6220 8510), ca 2700 m WNW of Gothem church. Top. map sheet 6J Roma NV & NO. Geol. map sheet Aa 169 Slite.
Abandoned shallow quarry at end of field road.
Klinteberg Formation, unit b? Crinoid grainstone facies (G).

VÄTE 2.

Klinteberg Formation, lower part.
Reference: Bergman 1987*.

VIVUNGS 1.

Klinteberg Formation, middle-upper part.
References: Laufeld 1974a,b* Larsson 1979.
Stromatoporoid floatstone facies(E).

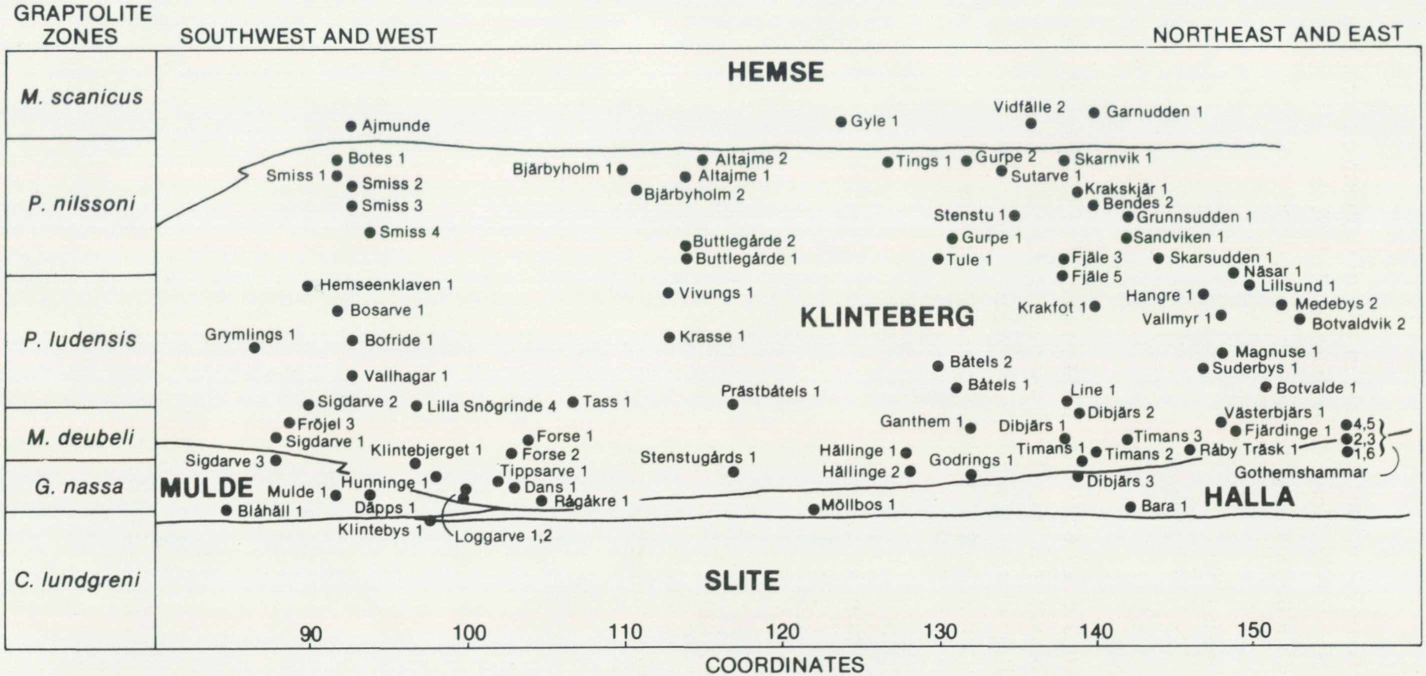


Fig. 38. Synthetic diagram showing position of localities in the Klinteberg Formation and adjacent units. The diagram shows two of the dimensions of the beds, time and place, when projected onto a N45 E plane, i.e. a plane approximately parallel to strike. The SW-NE co-ordinates used for a locality are derived by adding its S-N and its W-E UTM co-ordinates. The localities are also assigned an approximate stratigraphical level. The construction is similar to the method applied by Jeppsson (1983).

PRISKLASS B

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Fotosats: ORD & FORM AB
Tryck: Offsetcenter ab, Uppsala 1989

ISBN 91-7158-441-2
ISSN 0082-0024