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KENT LARSSON

THE LOWER VIRUAN IN THE AUTOCHTHONOUS ORDOVICIAN SEQUENCE OF JÄMTLAND

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The stratigraphy and lithology of the lower Viruan Aseri and Lasnamägi Stages of the autochthonous Ordovician of Jämtland, south-western part of northern Sweden, are described in some detail. It is shown that the same topo- and lithostratigraphic units previously distinguished on Öland and in the Siljan district can be applied.

The Kårgärde and Vikarby Members of the Aserian Segerstad Limestone are recognized in all areas investigated, whereas the Lasnamägi Stage shows a more incomplete development, with the Skärlöv Limestone missing in the Brunflo area and the Folkeslunda Limestone missing in the Lockne area.

Stromatolites in the form of mats and domes are an important constituent in all pre-Folkeslunda rocks studied and characterize especially the Vikarby and Seby Limestones, for which a new term, the Lunne facies, is introduced. Certain palaeoenvironmental conclusions are drawn from the varying development of the stromatolites.

Kent Larsson, Department of Palaeobiology, Box 564, S-751 22 Uppsala, Sweden, 14th July, 1972.

CONTENTS

Introduction

This paper deals with the basal Viruan sequence in the autochthonous Ordovician of Jämtland. This area has been the only major Palaeozoic district in Sweden where there was no previous detailed knowledge of the Aseri and Lasnamägi Stages.

The paper is based on field work carried out during parts of the summers 1967, 1968, and 1969. The study has been concentrated in the Brunflo, Lockne, and Åsarna areas of Jämtland, but some exposures further southwards, down to the Glöte area in Härjedalen, have also been briefly examined (Fig. 1). From each of the major areas, the best of the available exposures was selected for a detailed study, in order to establish a reference section for the area. The localities selected for this purpose were the quarry at Lunne in the Brunflo area, Kullstaberg in the Lockne area, and the exposure on the southern slope of Gammalbodberget in the Åsarna area. Additional localities examined in some detail were Öhntjärn, a road cutting at Bergsböle, two road cuttings on the main road No. 81 in the Lockne area, Oppbodarna and Hallen in the Åsarna area. The section at Oppbodarna to a certain extent supplements that at Gammalbodberget and has therefore been examined in detail. The localities are shown on Figs. 2A and 2B.

The stratigraphic classification used in this paper is shown in Table 1. It has been found that the topo- and litho-stratigraphical classification proposed by Jaanusson 1960 and 1963 is also in the main applicable to the basal Viruan of Jämtland (Table 2).

The microlithology of the limestones at Lunne and Gammalbodberget are only briefly described.

Stromatolitic algal mats appear to constitute a characteristic component in the investigated sequence and have been observed at all localities in beds older than the Folkeslunda Limestone. Especially the uppermost part of the Segerstad Limestone (Vikarby Limestone) and parts of the Seby Limestone are characterized by numerous stromatolites. They are associated with a characteristic lithology which can be observed in all areas. A new term, Lunne facies, is introduced for this type of lithology, the name being derived from the Lunne section, where it has its most distinct development. The classification of the stromatolites used in this paper, is that proposed by Logan, Rezak, & Ginsburg (1964).

The present paper was initiated at the Palaeontological Institute of Uppsala University and completed at the Palaeobiological Department of the same University. I am greatly indebted to Dr. V. Jaanusson, who gave the impulse to this investigation, and who has given much generous help and support during all stages of the present work. He also put unpublished material from the Kullstaberg section, collected in 1950 by himself, Dr. J. Martna and Dr. H. Mutvei,

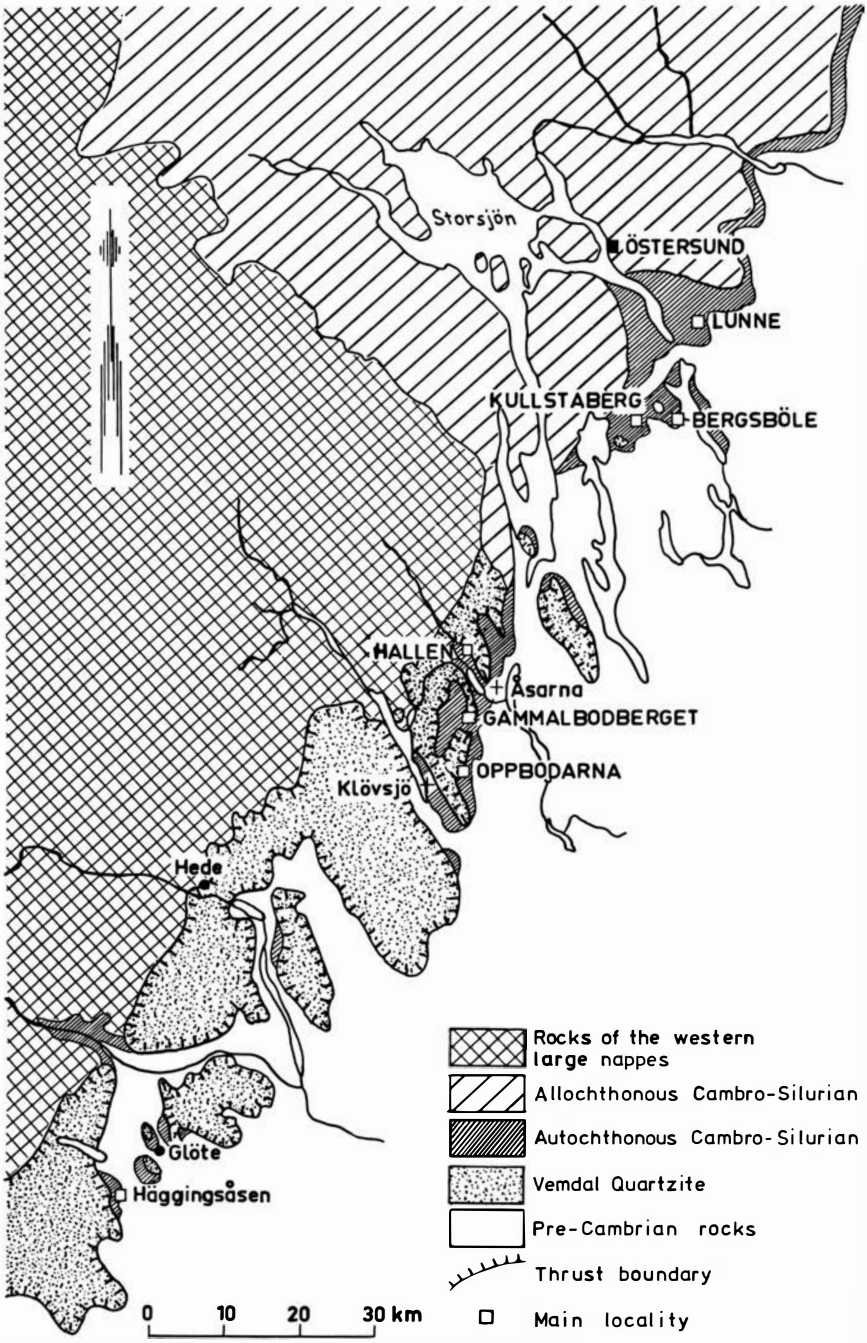

Fig. 1. Geological map of the autochthonous borderland of Southern Jämtland and Härjedalen. Compiled mainly from SGU, Ser. Ba, No. 16, Karta över Sveriges berggrund.

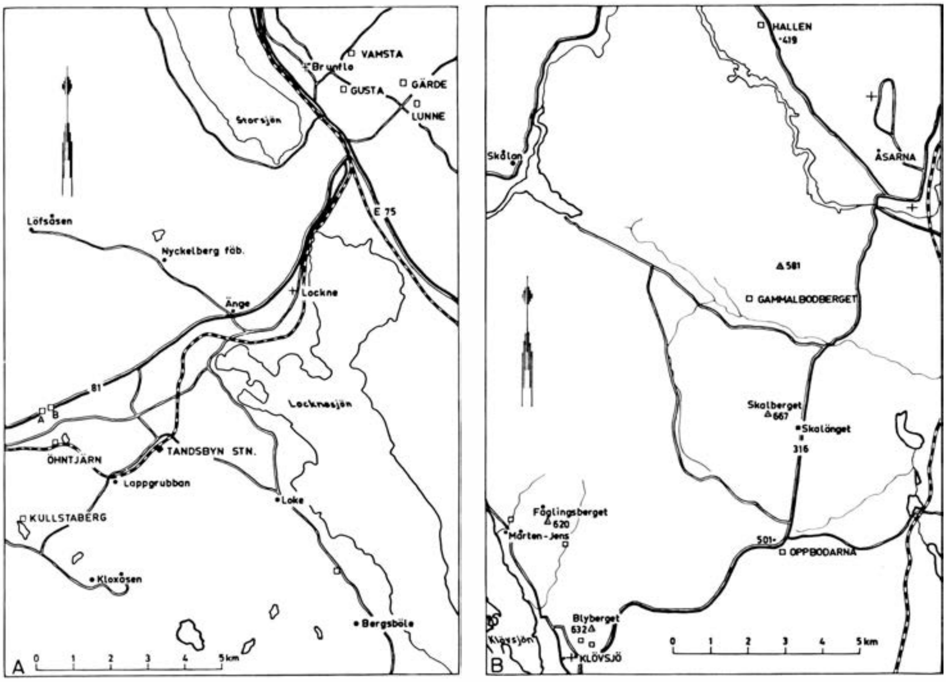

Fig. 2. A. Sketch map of the Brunflo and Lockne Areas, showing localities described in the text (squares). B. Sketch map of the Åsarna and Klövsjö Areas, showing localities described in the text (squares).

Table 1

<table>
<tr><th rowspan="2">WIMAN 1893</th><th rowspan="2">Current use prior to this paper</th><th rowspan="2">Graptolite zones</th><th colspan="3">This paper</th></tr>
<tr><th colspan="2">Topostratigraphic units</th><th>Chronostratigraphic units</th></tr>
<tr><td rowspan="3">Centaurus Limestone</td><td rowspan="3">Schroeteri Limestone</td><td>?</td><td colspan="2">Folkeslunda Limestone</td><td rowspan="3">Lasnamägi Stage</td></tr>
<tr><td rowspan="3">Zone of Didymograptus murchisoni</td><td colspan="2">Seby Limestone</td></tr>
<tr><td colspan="2">Skärlöv Limestone</td></tr>
<tr><td rowspan="2">Platyurus Limestone</td><td rowspan="2">Platyurus Limestone</td><td rowspan="2">Seger-stad L.</td><td>Vikarby L.</td><td rowspan="2">Aseri Stage</td></tr>
<tr><td>Kårgärde L.</td></tr>
</table>

Table 2

Chronostratigraphic units	Topostratigraphic units		
	Åsarna area	Lockne area	Brunflo area
Lasnamägi Stage	Folkeslunda L.	HIATUS ?	Folkeslunda L.
	Seby L.	Seby L.	Seby L.
	Skärlöv L.	Skärlöv L.	HIATUS
Aseri Stage	Segerstad L.	Segerstad L.	Segerstad L.
Kunda stage	*Gigas* L.		*Gigas* L.

at my disposal. I am also indebted to Mr. G. Andersson for making thin sections and some photography work, to Mrs. Ewa Engström for all draughting work, to Miss Kerstin Svensson for final typescript and to Mr. D. Roberts-Jones for examining the manuscript from a linguistic point of view. Finally, I am very grateful for many valuable comments upon the preparation of the paper by Dr. A. Martinsson.

Historical review. – Published information concerning the lower Viruan of Jämtland is very meagre. The first notes were given by Wiman (1893), when he made the first subdivision of the Orthoceratite Limestone in Jämtland in accordance to the classification proposed by Moberg (1890), which was based on the sequence of southern Öland (Table 1). Prior to Wiman's paper only a few notes on the occurrence of Orthoceratite Limestone in different areas of Jämtland were in existance (Linnarsson 1872; Svenonius 1882; Högbom 1889, 1891).

Wiman (1893) distinguished the following divisions of the Orthoceratite Limestone:

Centaurus Limestone?
Platyurus Limestone
Gigas Limestone
Asaphus Limestone
Limbata Limestone

Wiman did not find any fossils in the grey limestone overlying the *Platyurus* Limestone. In this connection he made the remark that the Upper Grey Limestone of Jämtland had a different appearance to that of the other districts in Sweden. The division proposed by Wiman was later used by Högbom (1894).

In the second edition of Högbom's paper (1920), the name of the *Centaurus* Limestone was changed into *Chiron* Limestone in accordance to the changes by Wiman (1908) of the name of the index fossil (*Illaenus chiron* Holm). This term was later changed by Westergård (1939) into *Schroeteri* Limestone in accordance to the changes of the name of its index fossil (*Illaenus schroeteri* Schlotheim). That term has since been used in all papers dealing with the Middle Ordovician of Jämtland. As discussed by Jaanusson (1963), that term should now be abolished because *Illaenus schroeteri* does not occur in Sweden.

From the Lockne and Åsarna areas still less stratigraphic information has been published on the Orthoceratite Limestone than that available from the Brunflo area. As early as 1893 Wiman commented upon the poor fossil record from the areas outside Brunflo and stated that it was not possible to apply the classification of the sequence based on the colour of the rock as introduced by Törnquist (1874) in the Siljan district. Högbom (1894, 1920) arrived at the same conclusion. Thorslund (1935) mentioned the presence of some divisions of the Orthoceratite Limestone (*Gigas, Platyurus,* and *Chiron* Limestones) from the Lockne area, without presenting faunal data. Subsequently (1940) he listed some fossils from the *Schroeteri* Limestone of the Lockne area and recorded the presence of this division in the Åsarna area.

Minor notes on the Lower Viruan of the autochthonous of Jämtland can also be found in various other papers (e.g. Asklund 1938, 1960; Kautsky 1949; Thorslund in Thorslund & Jaanusson 1960) based in the main on previously published reports. The only sedimentological information published prior to this paper has been given by Hadding (1958) who described some thin sections from the Segerstad and Seby Limestones of the Brunflo and Lockne areas.

Methods. – From every section studied in detail, a series of samples were taken, normally at an interval of 10 cm, but in many cases still closer. Especially careful sampling has been carried out close to the levels with discontinuity surfaces and in the portions of the sections rich in stromatolites.

The main part of each sample was crushed and searched for microfossils, mainly ostracodes. From the sections at Lunne and Gammalbodberget, a part of each sample has been used for microlithological examination, the methods applied being those summarized by Jaanusson (1960). In determining the grain-size of the limestones, the method described by Jaanusson (1952) and Martna (1955) has been followed. For point-counting, a new integration stage "Integrationsplatte I" manufactured by Zeiss has been used, thus making the modal analysis convenient and rapid. The grain-solid (Dunham 1962) of the particles has been measured.

Before photography of the stromatolites, the polished surfaces have been etched for 20 to 30 seconds in dilute acetic acid. This treatment makes the laminae and the structures stand out more distinctly.

Faunal notes. – In the following description of the sections, several groups of fossils have deliberately been omitted from the lists. The reason for this being, in many cases, the fact that parts of the Viruan fauna of Sweden are still poorly described or have not been treated at all. The assemblages of fossils that have been distinguished in this paper seem to be satisfactory for subdividing the basal Viruan beds of Jämtland stratigraphically, and this has been the main purpose of the present study. Several undescribed species have been found in the sections examined but their description is beyond the scope of the present paper. The vertical range of most of these species has been taken into account in stratigraphic considerations.

As to some groups of fossils, the following notes may be useful.

(1) Ostracodes with a sigmoidal adductorial sulcus have not been listed in this paper on account of the difficulties encountered identifying such ostracodes even at the genus level without detailed information on the structure of the antrum. Some of the specimens obviously belong to *Sigmobolbina* and *Lomatobolbina* but further material is needed for their proper identification.

(2) Numerous small trilobites have been found, among which representatives of the genus *Remopleurides* are most frequent. A few agnostids have also been found, almost exclusively in the Segerstad Limestone. The Balto-Scandian material of both groups lacks a monographic treatment. In addition there occur scattered fragments of other small trilobites, which have not been identified so far.

(3) As has been pointed out by Jaanusson (1960), the cephalopods of the Lower Viruan beds are acutely in need of revision. A number of new species are involved, and in many cases also the generic attribution is uncertain.

(4) Throughout the investigated sequence there occur numerous small undescribed articulate brachiopods. These are especially abundant in the Segerstad Limestone from which considerable material is available. Their average size is 3 to 4 mm. As no interiors are available, these brachiopods cannot at present be identified at the genus level.

(5) No attention has been paid to microfossils other than ostracodes in this paper. Thus, conodonts, chitinozoans and hystricosphaeridians have not been considered, since they all require special treatment for their study.

The Brunflo area — general remarks

The Lower Viruan of the Brunflo area can best be studied in quarries in which various parts of the Orthoceratite Limestone are exposed. The quarries are situated along an elongated ridge, situated approximately 1.5 km east of the European Highway E 75 (Fig. 2A). The beds are somewhat disturbed by tectonic movements, mostly faulting. When not disturbed, the beds are almost horizontal or with some dip towards NW.

Among the quarries examined (Vamsta, Gusta, Gärde, and Lunne), the Lunne quarry turned out to have the most complete section through the Aseri and Lasnamägi Stages. Moreover, there the beds are but slightly affected by tectonic dislocations.

The Lunne quarry

The quarry at Lunne (Lundegårdh 1965, p. 103, Fig. 79), is situated 2.6 km W of Brunflo, 300 m S of the road between Brunflo and Rissna (Fig. 2A). It has been cut into the southern slope of a small hill, Lunneberg, which rises up to 425 m above the sea level. The quarry has since been abandoned. An excellent section is exposed through the Aseri and Lasnamägi Stages as well as the upper part of the Ontikan Kunda Stage. Above the quarry on the slope of the hill, there occur small exposures of the Dalbyan Conglomerate and Loftarstone.

The beds in the quarry are slightly undulating due to slight folding and have a dip of 5° NW in the easternmost part, changing gradually westwards to a maximum dip of 15° NW (Fig. 3A). In the westernmost part of the quarry, the dip of the beds change back to 5° NW. The major fold axis plunges somewhat towards the NE, having a trend of N 50° E. Perpendicular to this another, weaker fold axis can be recognized (Fig. 3B). The beds strike N 40° W.

The sequence in the quarry is intersected by at least two vertical fissure systems running N 75° W and N 10° E.

Small overthrusts are visible on one wall in the middle of the quarry (Fig. 3A). The height of the overthrust is about 10 cm. The dip of the overthrust planes vary between 25° and 40° NW.

Almost every bedding plane shows slickenside phenomena, which can also be seen within the limestone beds. The phenomenon has also affected many macrofossils, which may be distorted to varying degrees.

Above the quarry, on the slope of the hill, the sequence is largely covered by Quaternary deposits. However, through excavations a continuous section up to the Dalby Conglomerate was obtainable. It is shown graphically in Fig. 4.

Description of the section

Dalby Conglomerate 2.00 m +

2.00 m +. Polymict conglomerate consisting of Ontikan and Lower Viruan limestone pebbles and numerous pebbles of Revsund granite, the latter becoming more abundant in the upper part of the conglomerate. The pebbles occur in a dark grey, calcareous matrix with some subordinate argillaceous matter. The size of the granite pebbles increases towards the top, as does the sphaerocity. Granite pebbles up to 15 cm in diameter were observed.

Folkeslunda Limestone 0.99 m

0.35 m. Grey to dark grey, thick-bedded (thickness of individual beds, 8 to 11 cm), fine-grained limestone.
Remopleurides sp.
Euprimites cf. *effusus* Jaanusson
Laccochilina (Laccochilina) cf. *paucigranosa* Jaanusson

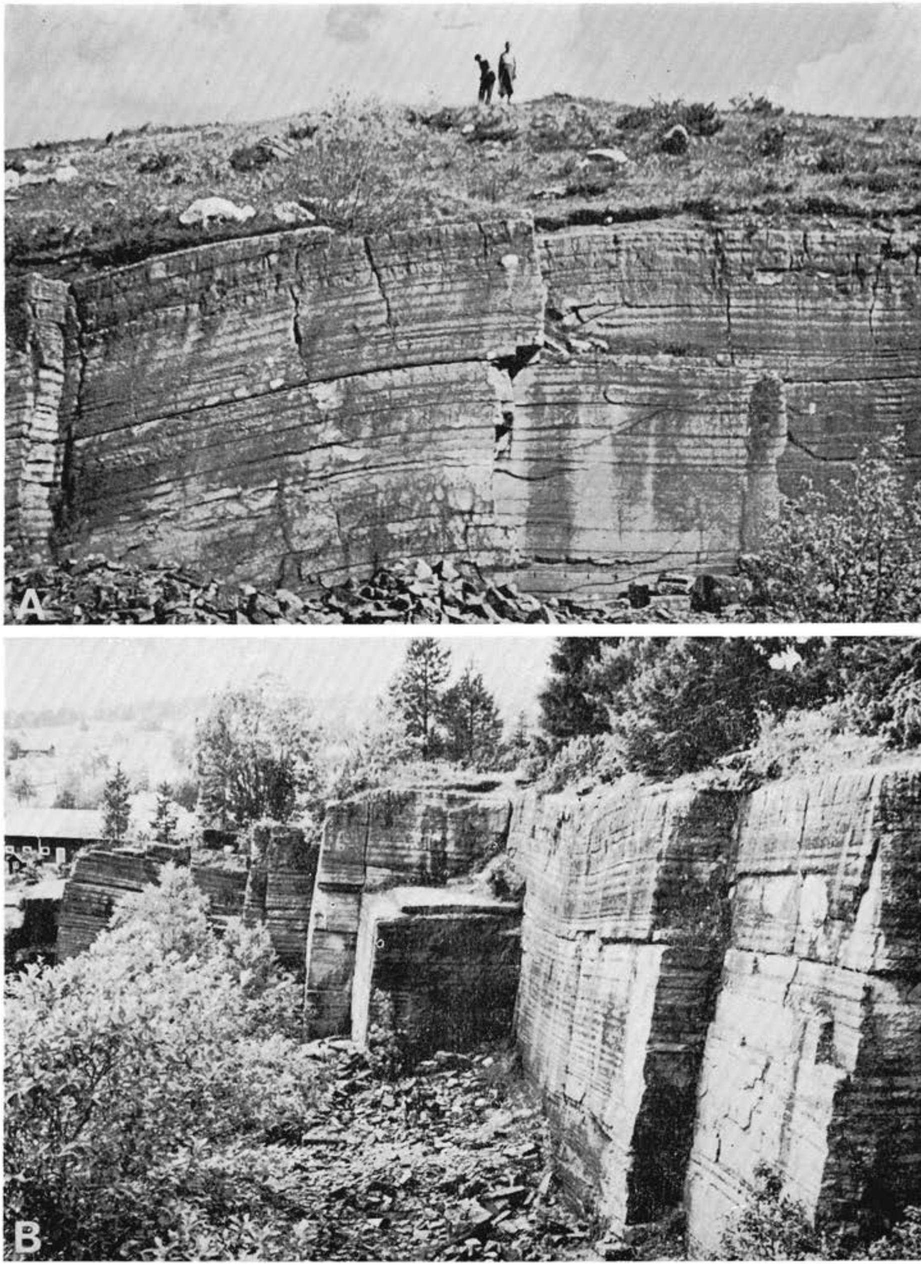

Fig. 3. Lunne Quarry. A. View of the middle part of the quarry, exposing the Segerstad Limestone and divisions (a) and (b) of the Seby Limestone. To the right, small overthrusts in the Segerstad Limestone. Photo by P. Thorslund. B. View from the easternmost part of the quarry, showing the undulating character of the beds and the fissure systems.

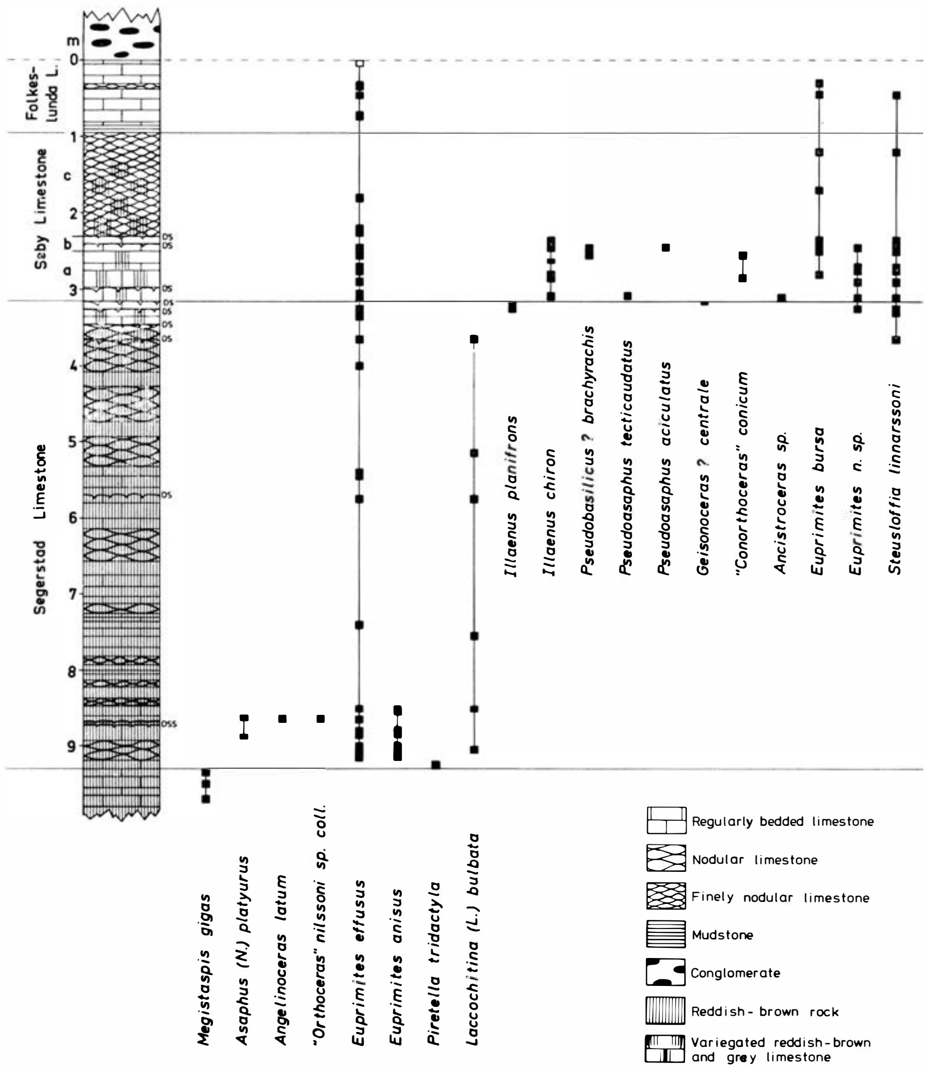

Fig. 4. Range of selected species in the *Gigas*, Segerstad, Seby and Folkeslunda Limestones of the Lunne section. DS: discontinuity surface, DSS: double discontinuity surfaces.

0.06 m. Finely nodular, grey to dark grey limestone with occasionally yellowish brown nodules.

Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Conchoprimitia n. sp.

0.48 m. Dark grey, thick-bedded, fine-grained limestone.

Remopleurides sp.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Steusloffia linnarssoni (Krause)
Laccochilina (Laccochilina) sp.
Conchoprimitia n. sp.

0.10 m. One bed of grey mudstone. The lower boundary is drawn at the level where the first signs of reddish colour appear.

Seby Limestone 2.22 m

(c) 1.36 m. Finely nodular, fine-grained, variegated pale reddish-brown to reddish-grey limestone. The reddish tint is restricted to the nodules and is stronger in the lower part. Greenish-grey argillaceous intercalations occur throughout the division. The nodules are strongly flattened in the lowermost 35 cm of the division. In this part, numerous black horizontal stripes of unknown composition occur.

Remopleurides sp.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Steusloffia linnarssoni (Krause)
Laccochilina (Laccochilina) sp.

The lower boundary is very sharp lithologically.

(b) 0.20 m. Grey to dark grey, thick-bedded (two beds 10 cm each), coarse-grained limestone. Stromatolites without haematite impregnation occur in connection with desiccation surfaces 5 and 20 cm below the top of the division. The uppermost surface is a smooth discontinuity surface, with numerous cephalopods in which the upper part is removed.

Illaenus chiron Holm
Pseudobasilicus ? brachyrachis (Törnquist)
Pseudomegalaspis sp.
Pseudoasaphus aciculatus (Angelin)
Asaphus (Neoasaphus) sp.
Remopleurides sp.
Lituites sp.
Hyolithes sp. indet.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Euprimites n. sp.
Steusloffia linnarssoni (Krause)
Piretella n. sp.
Tallinnella sebyensis Jaanusson
Conchoprimitia sp.

(a) 0.66 m. Grey to brownish-grey, thick-bedded (thickness of individual beds 10 to 25 cm), coarse-grained limestone with numerous stromatolites, strongly stained with haematite (type LLH-C and SH-V). Unstained stromatolites occur 57–62 cm below the top. Numerous red and green fillings occur in ostracodes and small gastropods, being most abundant at the base of the division. The macrofossils are mostly coated by

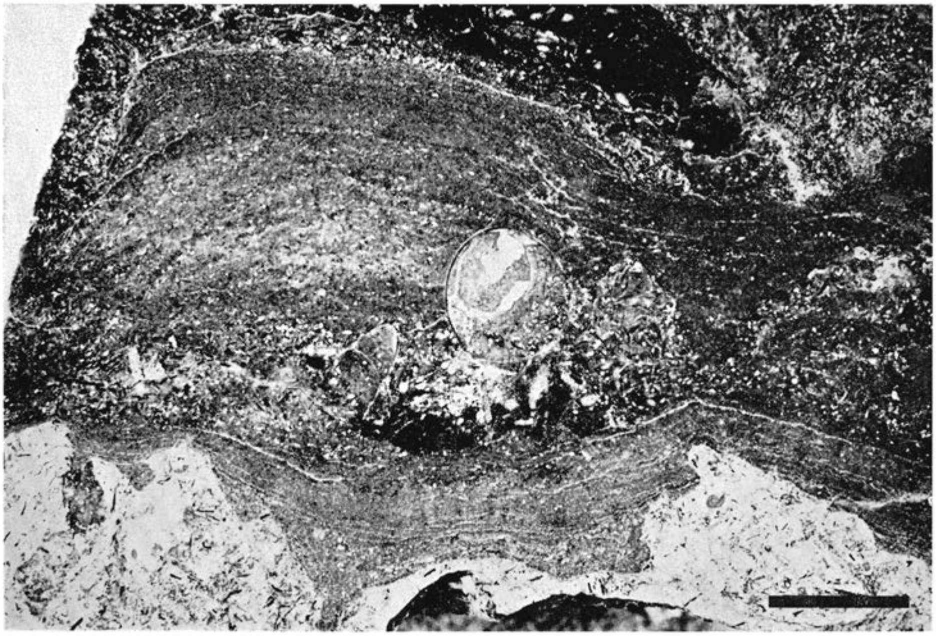

Fig. 5. Discontinuity surface 0.47 m below the top of division (a) of the Seby Limestone at Lunne, covered with stromatolitic laminations. In the upper part stromatolitic domes formed above a cephalopod conch and heaps of coarse skeletal sand. Overturned dome in the upper righthand corner. Polished block. Scale bar = 10 mm.

haematite or chamosite crusts. Numerous desiccation surfaces, one of them being very distinct, *viz.* at 0.47 m below the top of the division. This surface is very rough and shows overhanging portions (Fig. 5). It is coated with stromatolitic mats.

Illaenus chiron Holm
Pseudobasilicus ? *brachyrachis* (Törnquist)
Pseudomegalaspis sp.
Pseudoasaphus tecticaudatus (Steinhardt)
Plectasaphus plicicostis (Törnquist)
Asaphus (Neoasaphus) sp.
Remopleurides sp.
"Conorthoceras" conicum (Hisinger)
Ancistroceras sp.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Euprimites n. sp.
Steusloffia linnarssoni (Krause)
Piretella n. sp.

The lower boundary is formed by an uneven discontinuity surface. The rock on either side of the discontinuity surface cannot be distinguished macroscopically. The surface is covered by latero-linked stromatolitic domes (LLH-C), which can be followed around the whole quarry.

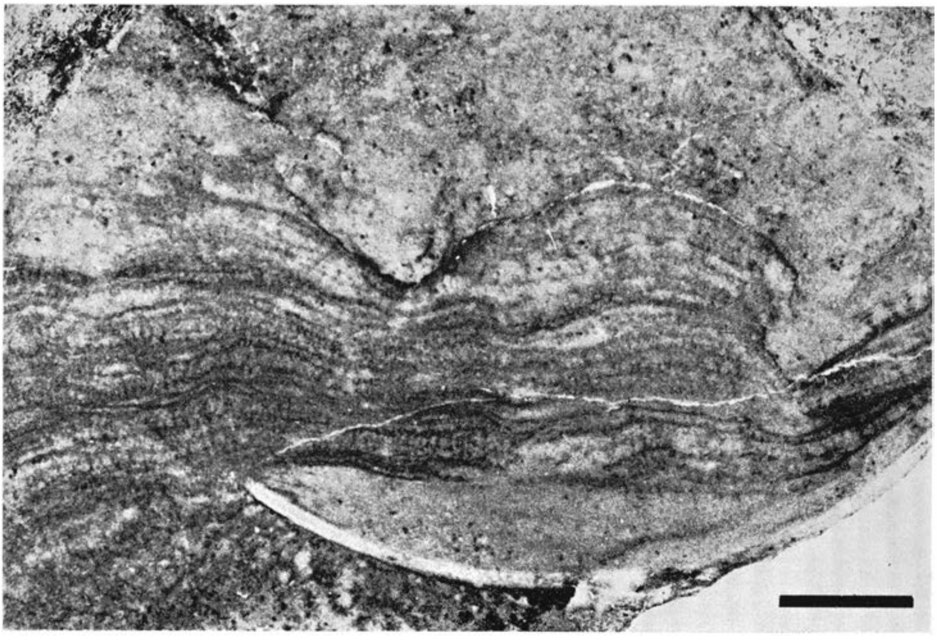

Fig. 6. Stromatolitic domes in the basal part of the Vikarby Limestone at Lunne. Polished block. Scale bar = 10 mm.

Segerstad Limestone 6.12 m

0.30 m. Vikarby Limestone. Grey and red mottled, medium-bedded (thickness of individual beds 5 to 10 cm), coarse-grained limestone, rich in stromatolites stained with haematite (LLH-C, SH-C). Numerous red and green fillings occur in ostracodes and small gastropods together with irregular green grains, about 1 to 2 mm in diameter. The uppermost surface is irregular and rough with overhanging portions. Parts of the surface show desiccation polygons with cephalopods along the cracks. The upper part of these cephalopods is removed. One distinct desiccation surface occur 3 cm from the top.

Illaenus planifrons Jaanusson
Remopleurides sp.
Geisonoceras ? *centrale* (Dalman)
Cameroceras ? sp.
? *Dorsolinevitus dispar* (Holm)
Euprimites effusus Jaanusson
Euprimites n. sp.
Steusloffia linnarssoni (Krause)
Piretella n. sp.
Laccochilina (Laccochilina) sp.

The lower boundary is very rough and irregular, showing overhanging portions. It is covered by a stromatolitic mat, 5 to 6 mm thick, stained by haematite. This mat grades in places into domes of the LLH-C type with a maximum height of 2 cm and a base diameter of 3 to 4 cm (Fig. 6). Several generations of domes may succeed.

1.92 m. Mainly reddish-brown, nodular, fine-grained limestone with green argillaceous intercalations. The uppermost 5 to 10 cm are greenish-grey below the desiccated surface mentioned above. Bedded limestone occurs at 0.65–0.86 m and 1.35–1.48 m from the top, the boundaries between nodular and bedded limestones being transient. At 1.62–1.67 m from the top, there is a distinct marly bed (Figs. 3A and 3B). The whole sequence shows numerous green spots, many with a central core formed by clear calcite, probably representing fillings of organogenic tubes (cf. Jaanusson & Mutvei 1953, p. 28; Taf. II Fig. 1; Jaanusson 1960, p. 7; Pl. I, Fig. 1). A desiccation surface with stromatolitic laminations, ca. 1 cm thick, occurs 19 cm from the top. The limestone immediately above the surface is coarser and more grey than that below it.

Remopleurides sp.
Euprimites effusus Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson
Steusloffia linnarssoni (Krause)

0.38 m. Reddish-brown, thick-bedded (thickness of individual beds 8 to 12 cm) limestone, fine-grained except for one calcarenitic portion 0.33–0.38 m from the top. The lower boundary of this portion is a distinct, strongly furrowed and haematite-stained discontinuity surface located within a bed. The limestone above the surface is intensely reddish-brown.

Euprimites effusus Jaanusson

0.37 m. Reddish-brown, thick-bedded (thickness of individual beds 8 to 11 cm), fine-grained limestone. The upper 5 cm of the limestone below the discontinuity surface is conspicuously paler than the limestone above the surface.

Euprimites effusus Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson

0.48 m. Nodular brownish-red, fine-grained limestone with greenish argillaceous intercalations.

2.15 m. Mainly fine-grained, thick-bedded (thickness of individual beds 8 to 16 cm), reddish-brown limestone, nodular at 0.50–0.63 and 2.22–2.39 m from the top, finely nodular (with flattened nodules) at 1.27–1.34 m, 1.40–1.48 m, 1.55–1.60 m and 1.79–1.87 m from the top. The nodular parts contain greenish argillaceous intercalations, and through the whole section, numerous greenish spots, many with a central core of clear calcite, abound. At 2.13 m and 2.15 m from the top there are two intensely haematite pigmented discontinuity surfaces with deep furrows, covered by thin stromatolitic mats. The lower surface often coincides with a bedding plane, while the upper one is always located within the bed. The limestone above the upper surface contains numerous macrofossils, mainly *Asaphus (Neoasaphus) platyurus* and Cephalopods. This horizon can be traced around the whole quarry.

Asaphus (Neoasaphus) platyurus Angelin
Angelinoceras latum (Angelin)
"Orthoceras" nilssoni (Boll) sp. coll.
Euprimites effusus Jaanusson
Euprimites anisus Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson

0.52 m. Reddish-brown, thick-bedded (thickness of individual beds 8 to 13 cm), fine-grained limestone. This division is lithologically not distinguishable from the division above.

Asaphus (Neoasaphus) platyurus Angelin
Euprimites effusus Jaanusson
Euprimites anisus Jaanusson
Piretella tridactyla Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson

Piretia sp.
Conchoprimitia sp.
There is no lithological boundary between the above and underlying division.

Gigas Limestone 0.80 m +

0.80 m +. Brownish-red, thick-bedded, fine-grained limestone with numerous greenish grey spots.
Megistaspis (Megistaspidella) gigas Angelin
Euprimites aff. *effusus* Jaanusson

Remarks. – The Lunne quarry has earlier been treated briefly by Wiman (1893), when he distinguished the subdivisions of the Orthoceratite Limestone in accordance with those distinguished on Öland by Moberg (1890). Wiman estimated the total thickness of the Orthoceratite Limestone to be about 37 m. No information was given on the thickness of various subdivisions. From beds corresponding to the Segerstad Limestone, *Asaphus (Neoasaphus) platyurus* and *Agnostus* sp. were mentioned together with unspecified Ostracoda and Cephalopoda. No fossils were recorded from the beds above the Segerstad Limestone. In 1896 Wiman described some tectonic features from the same quarry.

In a paper by Högbom (1894), H. Lundbohm gave a brief description of the limestones for industrial purposes. Some measurements of individual beds were presented, but it has not been possible to determine which part of the sequence they belonged to.

Later the Lunne quarry has been described as one of the localities for the excursions of the International Geological Congress 1960. In one of the papers describing the locality (Asklund 1960), there occurs a confusing note concerning the stratigraphy, *viz.* the presence of a conglomerate between the red Segerstad Limestone *(Platyurus L.)* and the grey Seby Limestone *(Schroeteri L.)*. Obviously, this note is based on some misunderstanding, because as described above, the only conglomerate which occurs at Lunne is the Dalby Conglomerate.

Microlithology of the limestones

The Segerstad Limestone consists of bedded and nodular, reddish-brown limestones, except for its uppermost 30 cm. In terms of Folk's (1959, 1962) classification of limestones, the rock of this division is a biomicrite. Using the definitions proposed by Jaanusson (1952), the limestone can be termed a calcarenitic calcilutite. An exception is a bed above the discontinuity surface 2.30 m below the top of the division, where the limestone can be classified as a calcarenite. The matrix is mainly microcrystalline with occasional coarse-grained spots. Umbrella effect (Harbaugh 1960), may be observed in these spots. The skeletal grains are mostly fragmentary, but entire shells of small ostra-

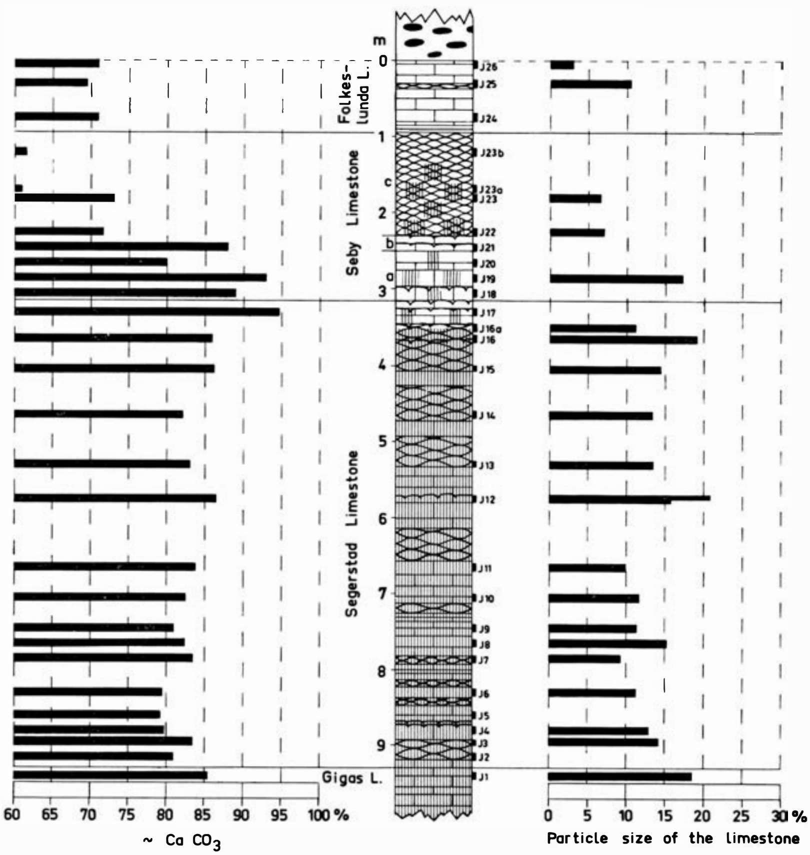

Fig. 7. Gigas, Segerstad, Seby and Folkeslunda Limestones of the Lunne section. To the left material soluble in dilute acetic acid (approximately the content of $CaCO_3$), to the right particle size of the limestone according to the method of Jaanusson (1952). For legend, see Fig. 4.

codes and gastropods also occur. No trace of pelletal structures were observed. The amount of the limestone soluble in dilute acetic acid ranges between 79.5 and 86.5 per cent (Fig. 7).

The uppermost 30 cm of the Segerstad Limestone is a grey calcarenite with numerous spots where the matrix formation is a relatively coarse mosaic of calcite crystals and where the skeletal grains are partly assimilated by the matrix thus rendering a determination of the original particle size impossible. Much of the matrix then is obviously formed by intergranular cement deposited between skeletal sand grains. The rock can be classified as recrystallized calcarenite (Jaanusson 1960) or poorly washed biosparite (Folk 1962). The amount of limestone soluble in acetic acid is fairly high, 94.5 per cent. In the uppermost bed of the division the matrix is more fine-grained and skeletal grains have retained distinct outlines.

The texture and grain size of the two lowermost divisions, (a) and (b), of the Seby Limestone are more or less identical with those of the uppermost Segerstad Limestone. Division (c) of the Seby Limestone consists of variegated pale reddish-brown and reddish-grey finely nodular calcilutites. The matrix is rich in argillaceous matter, concentrated into laminae. The amount of limestone soluble in dilute acetic acid is low, decreasing upwards (Fig. 7).

The Folkeslunda Limestone mainly consists of calcilutites with somewhat increasing particle size in the upper part of the section.

Haematite. The brownish-red colour of the rock is caused by haematite which in the Segerstad Limestone is mostly evenly distributed in the matrix but occasionally also occurs as coatings around skeletal grains or as fillings of cavities within these grains. The latter is particularly common in echinoderm grains. In the Vikarby Limestone as well as in division (a) of the Seby Limestone, the haematite is unevenly distributed and occurs mainly in the stromatolites, as fillings in shells, and as coatings around macrofossils. The staining of the stromatolites is particularly strong. In division (c) of the Seby Limestone, the haematite is restricted to the limestone nodules, while the intercalated argillaceous matrix is greenish-grey. The haematite staining in this division is weak and it decreases upwards in the sequence.

Chamosite has been observed in the Vikarby Limestone and in the Seby Limestone, the latter being particularly rich in the mineral (Fig. 8). Generally, the chamosite occurs as fillings in ostracodes and small gastropods and in the cavities of echinoderman fragments. The mineral also forms rounded grains, which are especially abundant in the Vikarby Limestone and in the lower part of the Seby Limestone.

Goethite occurs in every thin section where chamosite has been identified (Fig. 8). It forms an easily recognized yellow mineral, filling cavities and shells in the same mode as was the case with the chamosite. In many spots, goethite is associated with chamosite, obviously being formed by disintegration of the latter mineral.

Sand fraction of the insoluble residue. – The amount of allochthonous mineral grains of sand size is very low in the insoluble residue. Only a few grains of quartz have been observed, then exclusively in association with some of the discontinuity surfaces.

The amount of the fraction larger than 0.125 mm of the total rock is comparatively high, generally between 2 and 5 per cent (Fig. 8). In a few samples it even reaches values as high as 10 to 23 per cent. As could be expected, the amount >0.125 mm is particularly high in the nodular limestones. In the insoluble residue of these, irregular silty and shaly grains form an important constituent.

Pyrite has only been observed in the insoluble residue of four samples, three of them occurring in the reddish-brown part of the Segerstad Limestone (Fig. 8). The amount of pyrite in these samples is small. The mineral occurs mainly as small crystal aggregates and cubes.

Glauconite has not been identified in the samples studied.

Non-glauconitic internal moulds occur in all samples studied except for the lowermost part of the Segerstad Limestone, below the two discontinuity surfaces. In the reddish-brown part of the Limestone, the moulds consist of haematite and are comparatively few in each sample, except for the sample immediately above the mentioned double discontinuity surfaces (sample J 5, Fig. 8). The internal moulds are formed by small gastropods, ostracodes and rod-shaped fossils, in part hyolithids, all poorly preserved.

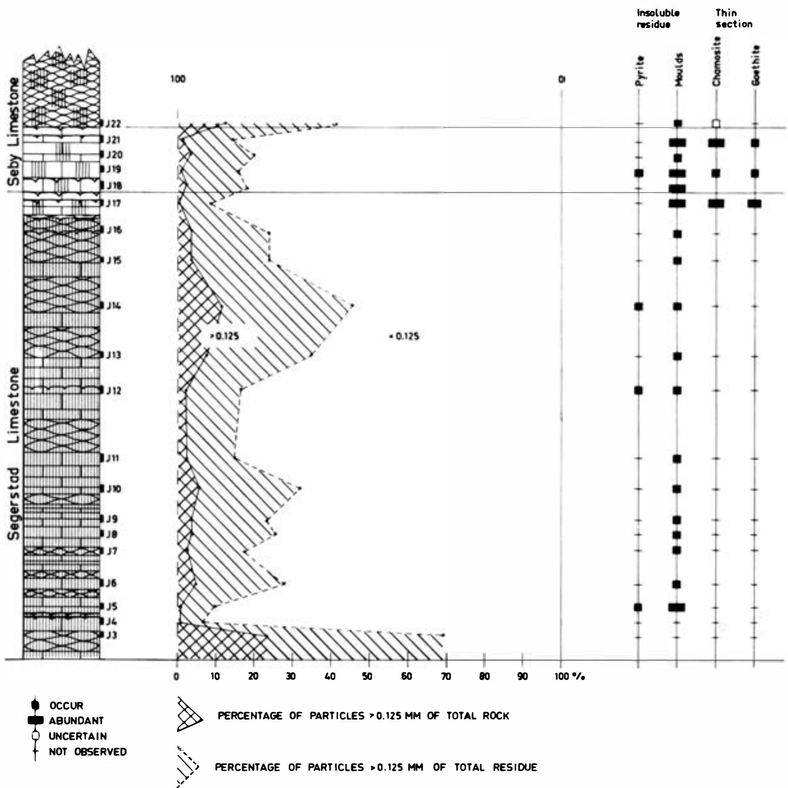

Fig. 8. Segerstad and Seby Limestones of the Lunne section. To the left, percentages of particles >0.125 mm of total rock and of total residue, respectively. To the right, distribution of moulds and some authigenic minerals in the fraction larger than 0.125 mm of the insoluble residue and in thin sections. For legend see Fig. 4.

The Vikarby Limestone as well as the bedded parts of the Seby Limestone, divisions (a) and (b), contain numerous internal moulds. In fact, besides the numerous stromatolites, they give the limestones their special appearance. The internal moulds are comparatively well preserved and consist of haematite and a green to greenish-grey mineral, identified by X-ray analysis as chamosite. They are formed by gastropods, ostracodes and small rod-shaped fossils. The general appearance of the moulds is the same as that pictured and described by Jaanusson 1960 (Fig. 11; Pl. V, fig. 1) and Jaanusson & Mutvei 1953 (Pl. IV, figs. 1 and 2).

Non-glauconitic grains. Throughout the section, irregular, dark, flaky grains are abundant in every sample studied. The size of the grains is mostly 1 to 5 mm, but those larger than 10 mm have also been observed. The colour varies from light grey to almost black. Many of the grains have a greenish tint, suggesting the presence of chamosite. Otherwise, the main constituent of the grains is some unidentified clay mineral. They are most frequent in the insoluble residue of the nodular limestones.

Another important type form the small, rounded to subrounded greenish grains, which occur in great abundance in the Vikarby Limestone and in division (a) of the Seby Limestone. The grains are especially common at the boundary between the two divisions. The average size of the grains is 1 to 2 mm. Many of them are well-rounded. Thorslund (1940) interpreted these grains as ooids, but when examined in thin sections no oolitic structures can be traced. Their mineralogical composition is so far unknown, but the colour suggest chamosite.

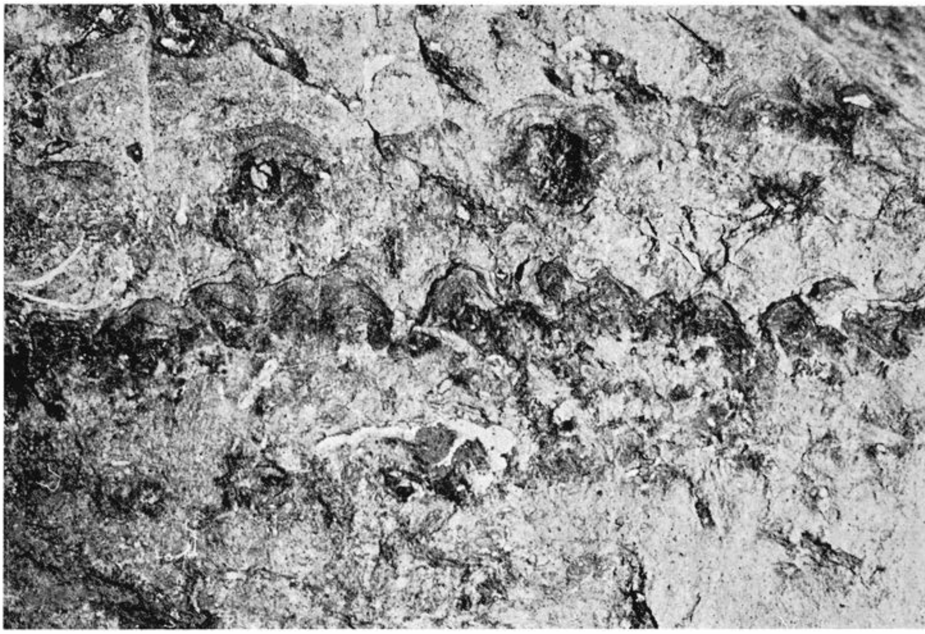

Fig. 9. Stromatolites of the LLH-C mode in the basal Segerstad Limestone at Gärde, Brunflo Area.

Vamsta

The Vamsta quarry is the northernmost quarry in the Brunflo area where parts of the lower Viruan sequence can be studied. In its northern part, Gråberget, reddish-brown to reddish-grey nodular Segerstad Limestone is exposed, overlain by grey and red mottled Vikarby Limestone. The uppermost part of the nodular beds just below the Vikarby Limestone, shows a distinctly grey to brownish-grey tint. In the Vikarby Limestone, two hyolithid fragments, probably belonging to *Dorsolinevites dispar,* have been found. The beds are strongly dislocated by numerous overthrusts and folds. A drawing of these dislocations was given by Asklund (1960).

Gusta

In the Gusta quarry the Lower Ordovician *Vaginatum* Limestone and parts of the Segerstad Limestone are exposed (Thorslund 1940, Figs. 47–48). The lowermost part of the latter division shows two distinct discontinuity surfaces stained by haematite (cf. Kautsky 1949, Fig. 6). These are probably equal to the two discontinuity surfaces found in the lowermost part of the Segerstad Limestone at Lunne.

Another discontinuity surface, stained by haematite, occurs in the uppermost part of the Gusta quarry. This surface is furrowed and covered by stromatolitic mats and domes. These are poorly developed in places. Generally the surface is covered by numerous trilobites and cephalopods. Probably this discontinuity surface corresponds to the surface situated 2.60 m below the top of the Segerstad Limestone at Lunne. This is suggested by the almost identical position of the two surfaces above the double discontinuity surfaces in the lowermost part of the Segerstad Limestone. The character of the surface at Lunne does not agree with that at Gusta, however. Thus neither stromatolites nor fossil shells have been observed above it. Notable in this connection, however, are some boulders of reddish-brown limestone, which have been found on the floor of the Lunne quarry. These boulders contain a furrowed discontinuity surface with stromatolites and pygidia of *Asaphus (N.) platyurus* and some indeterminable cephalopods with coiled apical ends. The character of this surface is identical to that at Gusta. So far, it cannot be referred to any discontinuity surface found in the sequence of Lunne, however.

As is found in the Vamsta quarry, the beds are affected by NW pressure, causing numerous overthrusts (cf. Thorslund 1940, Figs. 47–48). The dip of the thrust planes vary between 25° and 40° NW.

Gärde

In the Gärde quarry, also called Rödberget, the uppermost *Vaginatum* Limestone and lowermost Segerstad Limestone are quarried. The lower Segerstad beds show several haematite stained, furrowed discontinuity surfaces identical to those described earlier from the Lunne and Gusta quarries. At some places in the quarry three or four surfaces can be distinguished. These are often covered by stromatolitic mats, which grade upwards into small domes (Fig. 9). Above the surfaces, there is also a persistant horizon with *Asaphus (N.) platyurus* and "*Orthoceras*" *nilssoni* sp. coll. The beds are gently undulating and show minor thrusts. The strike of the beds is N 40° E.

The Lockne area — general remarks

Although several papers have been written on the Lockne area, very few treat the lower Viruan strata. The first notes were given by Thorslund (in Thorslund & Asklund 1935), when a conglomerate in the red Orthoceratite Limestone was mentioned from Kullstaberg and from the vicinity of Bergsböle. Later (1940), Thorslund mentioned some additional localities, (Öhntjärn, Lappgrubban), where those beds are exposed.

The exposure at Kullstaberg has been chosen as the reference section for

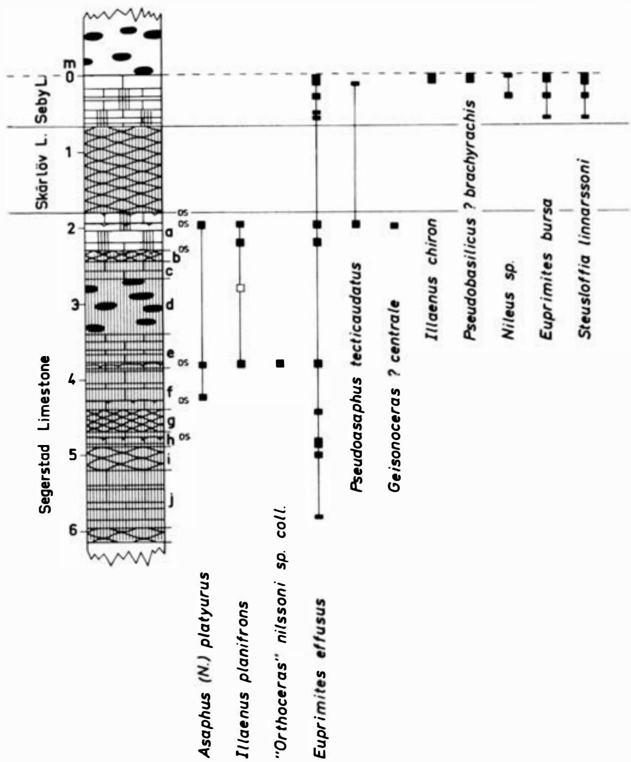

Fig. 10. Range of selected species in the Segerstad, Skärlöv and Seby Limestones of the Kullstaberg section. For legend, see Fig. 4.

the Lockne area. In addition, some other exposures have been visited in order to obtain a regional picture of the area. However, these localities are but briefly treated.

No microlithological studies have been carried out on the lower Viruan deposits within this area.

Kullstaberg

The section at Kullstaberg is situated at the slope of a hill immediately northeast of a tarn, Kullstabergtjärn, 2.4 km NW of Kloxåsen (Fig. 2A). The slope exposes a sequence from the Lower Ordovician up to the Dalby Conglomerate. In a few spots, the conglomerate has been observed to be directly overlain by a yellowish-white quartzitic breccia.

The locality was visited during parts of the summers 1967 and 1969, when excavations were made through the whole Viruan sequence.

The dip of the beds is 5° NE and the strike N 60° W. The sequence is graphically represented in Fig. 10.

Description of the section

Dalby Conglomerate 1.20 m +

1.20 m +. Polymict conglomerate containing pebbles of red and grey Orthoceratite Limestone, Revsund granite and dolerite. The matrix of the conglomerate is a grey, argillaceous calcite. The pebble size is smaller at the base, increasing upwards to a diameter of 10 to 15 cm.

Seby Limestone 0.69 m

0.28 m. Grey, thick-bedded (thickness of individual beds 9 to 13 cm), coarse-grained, fossiliferous limestone with some stromatolitic mats and domes in the uppermost 18 cm.

Illaenus chiron Holm
Pseudobasilicus ? *brachyrachis* (Törnquist)
Pseudoasaphus tecticaudatus (Steinhardt)
Asaphus (Neoasaphus) sp.
Nileus sp.
Remopleurides sp.
Lituites sp.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Steusloffia linnarssoni (Krause)
Laccochilina (Laccochilina) cf. *paucigranosa* Jaanusson

0.13 m. Two beds, 8 and 5 cm thick, of grey, coarse-grained limestone.

Nileus sp.
Remopleurides sp.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Steusloffia linnarssoni (Krause)

0.07 m. One bed of grey, coarse-grained limestone with irregular spots.

0.21 m. Greenish-grey, medium-bedded (three beds 7 cm each), coarse-grained limestone with scattered red portions, stronger in the lowermost bed.

Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Steusloffia linnarssoni (Krause)
Piretia n. sp. A

Skärlöv Limestone 1.10 m

1.10 m. Reddish-brown, nodular, fine-grained limestone with marly, greenish-grey intercalations and some irregular or discontinuous beds of limestone.

Remopleurides sp.

Segerstad Limestone 4.16 m

(a) 0.50 m. Vikarby Limestone. Variegated, grey and pale brownish-red, medium- to thick-bedded (thickness of individual beds 8 to 12 cm) calcarenite. Desiccation surfaces occur at several levels associated with stromatolitic algal mats. Numerous chamositic internal moulds in the insoluble residue. Cephalopods with the upper part removed occur 5 and 35 cm from the top.

Illaenus planifrons Jaanusson
Asaphus (Neoasaphus) platyurus Angelin
Asaphus (Neoasaphus) sp.
Pseudoasaphus cf. *tecticaudatus* (Steinhardt)
Remopleurides sp.
Geisonoceras ? centrale (Dalman)
Euprimites effusus Jaanusson

The lower boundary is a strongly furrowed discontinuity surface covered with stromatolites.

(b) 0.14 m. Variegated pale brownish-red and greenish-grey, finely nodular, fine-grained limestone.

(c) 0.22 m. Two individual beds, 10 and 12 cm thick, of pale, reddish-brown, fine-grained limestone with numerous pale green spots.

(d) 0.75 m. Polymict conglomerate (Kullstaberg Conglomerate) dominated by variegated pale brownish-red and greenish-grey limestone pebbles. Pebbles of granite and amphibolite have also been observed. The matrix is mainly a reddish-brown calcilutite. At some distance from the examined section, the conglomeratic appearance becomes less distinct, and the division resembles a finely nodular limestone.

(e) 0.44 m. Medium- to thick- bedded, in the upper part reddish-brown with pale green spots, in the lower part intensely reddish-brown, fine-grained limestone. The lower boundary is a desiccation surface with polygons. About 2 cm of the overlying limestone bed is greenish-grey with intraclasts of red limestone and scattered haematite stains. Numerous cephalopods are lying along the mud cracks.

Asaphus (Neoasaphus) platyurus Angelin
Illaenus planifrons Jaanusson
"*Orthoceras*" *nilssoni* (Boll) sp. coll.
Euprimites effusus Jaanusson
Piretella tridactyla Jaanusson

(f) 0.58 m. Intensely reddish-brown, medium- to thick-bedded (thickness of individual beds 8 to 12 cm), fine-grained limestone. A desiccation surface with polygons, covered with a stromatolitic mat, 1 cm thick, occurs 42 cm below the top.

Asaphus (Neoasaphus) platyurus Angelin
Illaenus sp. indet.

(g) 0.28 m. Reddish-brown, finely nodular, fine-grained limestone with marly intercalations.

(h) 0.20 m. Dense, reddish-brown, fine-grained limestone with a discontinuity surface 9 cm from the top.

Euprimites effusus Jaanusson
Laccochilina (Laccochilina) sp.
Piretella sp.

(i) 0.30 m. Red, nodular limestone with greenish-grey argillaceous matrix.

(j) 0.75 m. Pale reddish-brown and greenish-grey mottled, thick-bedded limestone.

Euprimites effusus Jaanusson
Piretella tridactyla ? Jaanusson
Steusloffia sp.
Conchoprimitia sp.

The lower boundary has tentatively been drawn below the lowest occurrence of *Euprimites effusus*. From the base of this division downwards, the limestone becomes gradually greenish-grey, the red tint disappearing completely 37 cm below the base.

Remarks. – The Kullstaberg locality was briefly mentioned by Thorslund (in Thorslund & Asklund 1935) in connection with discussions concerning Middle Ordovician sea level changes. He described a partly exposed sequence of red Orthoceratite Limestone, overlain by a polymict conglomerate, 0.70 m thick, containing pebbles and boulders of red Orthoceratite Limestone and Revsund granite. According to Thorslund's interpretation, this conglomerate is overlain by 0.48 m of red *Platyurus* Limestone and the basal fossiliferous part of the *Chiron* Limestone. The latter division has turned out to be the uppermost member, the Vikarby Limestone, of the Segerstad Limestone.

During the summer of 1950, two excavations were made at Kullstaberg by Drs. V. Jaanusson, J. Martna, and H. Mutvei. Parts of their easternmost excavation coincides with the section described in this paper, covering the divisions (a) – (d). The second excavation was made about 70 m west of the first one and, at this locality, the section was similar except for the conglomerate, division (d), which was 0.60 m thick. Some pebbles in the uppermost part of the conglomerate contained macrofossils. Two cranidia of *Illaenus*, probably *Illaenus planifrons* were observed.

In order to study the variations in thickness of the Kullstaberg Conglomerate, the writer made several small excavations along the slope for a distance of 150 m. The thickness could be observed to vary from zero to 0.75 m. The change in thickness is rapid, at one place from 0.25 m to 0.75 m within a distance of 10 m. The variation in the thickness of the conglomerate has earlier been mentioned by Thorslund (1935, 1940). He recorded a thickness of 4.5 m at a place 500 m W of the present section.

Öhntjärn

The Öhntjärn section (Fig. 11) is a railway cut, situated 250 m W of Lake Öhntjärn, about 2.8 km E of the railway station at Tandsbyn. The section shows the lowermost parts of the Viruan and is overthrust by brecciated granite (cf. Frödin 1920). The beds are dislocated by minor faults, as has earlier been shown by Thorslund (1940, Fig. 30). The dip of the beds is 30° W, the strike N 50° E.

Description of the section

Segerstad Limestone 4.72 m +

0.80 m +. Reddish-brown, nodular, fine-grained limestone.

0.90 m. Polymict conglomerate (Kullstaberg Conglomerate) with pebbles and boulders of red and grey Orthoceratite Limestone in a greenish-grey calcareous matrix. Boulders are common, the largest observed has a size of 15×20 cm and is moderately rounded.

0.07 m. One bed of pale reddish-grey, fine-grained limestone.
Euprimites effusus Jaanusson

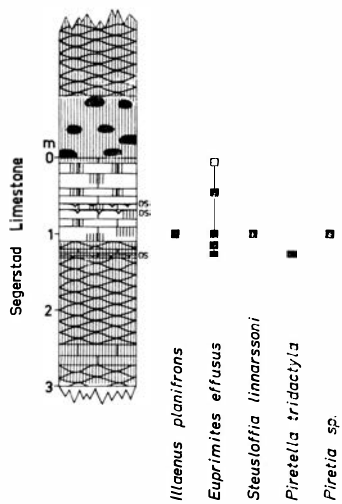

Fig. 11. Range of selected species in the Segerstad Limestone of the Öhntjärn section. For legend, see Fig. 4.

1.02 m. Grey and red mottled, medium- to thick-bedded, mainly fine-grained limestone. The lowermost 15 cm are more coarse-grained. The upper part contains scattered stromatolites associated with desiccated surfaces. The lowermost bed is very rich in grains of pyrite and is also fairly rich in macrofossils.

Illaenus planifrons Jaanusson
Remopleurides sp.
Euprimites effusus Jaanusson
Steusloffia linnarssoni (Krause)
Piretia sp.

0.10 m. Reddish-brown, nodular limestone.

Euprimites effusus Jaanusson

0.13 m. Two beds, 5 and 8 cm thick respectively, of reddish-brown, fine-grained limestone. In the lower bed, there occurs a discontinuity surface with an intense red pigmentation.

Euprimites effusus Jaanusson
Piretella tridactyla Jaanusson

1.12 m. Reddish-brown, nodular, fine-grained limestone.

0.27 m. Reddish-brown, thick-bedded, fine-grained limestone.

0.30 m. + Reddish-grey to grey, nodular, fine-grained limestone.

Remarks. – The Öhntjärn locality has earlier been mentioned and pictured by Frödin (1920), who, however, did not give any stratigraphical data. Thorslund (1940) described the section briefly and mentioned a polymict conglomerate intercalated in a red Orthoceratite Limestone, according to him probably corresponding to the basal part of the *Platyurus Limestone.* The grey and reddish-grey limestone below this division was considered to belong to the *Asaphus*

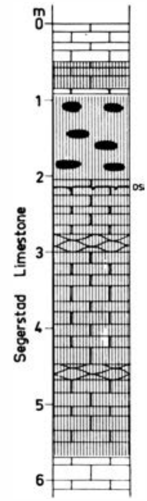

Fig. 12. Diagrammatic representation of the road-section 1.4 km NNW of Bergsböle farm, Lockne Area. For legend, see Fig. 4.

Limestone. When examined by the author, the latter limestone has yielded a few fragments of *Megistaspis*. However, it has not been possible to identify the species due to the poor state of preservation in the mostly dense, brittle limestone.

The gradual change of the colour from intensely reddish-brown into grey, at the base of the Segerstad Limestone, is identical to the conditions found at Kullstaberg. So far, the lower boundary has not been possible to determine.

Bergsböle

The Segerstad Limestone is exposed in a road-section 1.4 km NNW of the Bergsböle farm, along the road between Loke and Berge (Figs. 2A and 12). The exposure has earlier been mentioned by Thorslund (1935, 1940) and was considered to show the basal *Platyurus* Limestone and the basal *Chiron* Limestone.

The beds dip 45° NNW and strike N 50° E. The section is almost identical to that at Kullstaberg.

Description of the section

Segerstad Limestone 6.13 m +

0.57 m. Vikarby Limestone. Grey to dark grey, thick-bedded, coarse-grained, strongly bituminous limestone. The limestone is very fossiliferous, and has a coquinoid appearance. Small, dark green, rounded grains are very abundant. X-ray analysis have revealed that they are mainly composed of chamosite.

Asaphus (Neoasaphus) platyurus Angelin
Asaphus (Neoasaphus) demissus Törnquist
Illaenus planifrons Jaanusson
Pseudoasaphus tecticaudatus (Steinhardt)

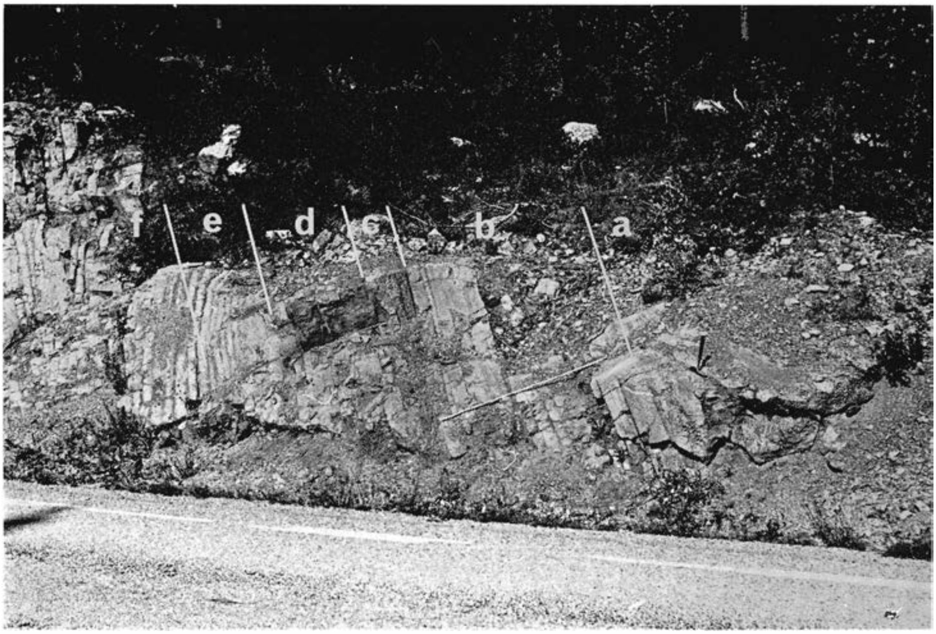

Fig. 13. Locality A at main road No. 81 in the Lockne area, exposing steeply dipping Segerstad Limestone. Kullstaberg Conglomerate to the right (a). For additional divisions, se text.

Remopleurides sp.
Geisonoceras ? centrale (Dalman)
Dorsolinevitus dispar (Holm)
Euprimites effusus Jaanusson
Steusloffia linnarssoni (Krause)

0.10 m. One bed of brownish-red, fine-grained limestone.

0.18 m. One bed of reddish-brown, fine-grained limestone with grey intercalations.

0.08 m. Grey, fine-grained limestone.

1.17 m. Polymict conglomerate (Kullstaberg Conglomerate) with pebbles of grey and red Orthoceratite Limestone, Revsund granite and dolerite in a reddish-brown to grey, calcareous matrix.

0.30 m. Brownish-red, thick-bedded, coarse-grained limestone with irregular haematite spots. About 8 cm from the top, there occurs a furrowed desiccation surface. About 2 to 3 cm of the limestone immediately above the surface is reddish-grey and coarse-grained with numerous haematite grains and some stromatolites pigmented by haematite.

0.37 m. Reddish-brown, thick-bedded, fine-grained limestone.

0.26 m. Reddish-brown, nodular, fine-grained limestone with greenish-grey intercalations.

1.45 m. Reddish-brown, medium- to thick-bedded, fine-grained limestone.

0.18 m. Reddish-brown, nodular, fine-grained limestone with grey intercalations.

0.37 m. Reddish-brown, thick-bedded, fine-grained limestone.

0.67 m. Pale reddish-brown, thick-bedded, fine-grained limestone.

0.43 m. Greenish-grey, medium- to thick-bedded, fine-grained limestone.

The road-cuts at main road No. 81

In two recent road-cuts at the new main road No. 81, sections through the basal Segerstad Limestone and parts of the Skärlöv and Seby Limestones are exposed. The road-cuts are situated 1.0 and 1.2 km, respectively, east of the Skute Nappe, approximately 1 km NNW of Lake Öhntjärn. The beds are strongly dislocated at both localities through numerous faults and overthrusts.

The westernmost road-cut, locality A on Fig. 2A, exposes steeply dipping beds of reddish-brown Orthoceratite Limestone. Its easternmost part belongs to the Segerstad Limestone, which comprises at least 3.85 m of the measured sequence, *i.e.* divisions (a) – (e) on Fig. 13. The lower boundary of the Limestone is, so far, not determined, but it is no doubt situated within division (f). Division (g) is of certain Lower Ordovician age. The dip of the beds is 70° NNW and the strike N 60° W.

Description of the section

(a) 0.75 m +. Polymict conglomerate (Kullstaberg Conglomerate) containing pebbles of red and grey Orthoceratite Limestone and granite in a reddish-brown calcareous matrix. The pebble size is comparatively small, about 2 to 3 cm. The conglomerate is intersected by a thrust plane, over which parts of the conglomerate have moved (Fig. 13).

(b) 0.63 m. Reddish-brown, medium-bedded, fine-grained limestone.
Euprimites effusus Jaanusson
Laccochilina sp. indet.
0.04 m. Reddish-brown, finely nodular, fine-grained limestone with greenish-grey argillaceous intercalations.
0.52 m. Reddish-brown, medium-bedded (thickness of individual beds 7 to 9 cm), fine-grained limestone.
Steusloffia sp. indet.
0.07 m. One bed of reddish-brown, coarse-grained limestone. The lower boundary consists of a furrowed, haematite stained discontinuity surface.
Asaphus (Neoasaphus) platyurus Angelin
0.05 m. One bed of reddish-brown, fine-grained limestone.

(c) 0.31 m. Reddish-brown, finely nodular, fine-grained limestone, in the lower part of conglomeratic appearance with small reddish-brown nodules in a dark greenish, argillaceous matrix.

(d) 0.09 m. One bed of reddish-brown to reddish-grey, fine-grained limestone.
0.23 m. Reddish-brown to reddish-grey, finely nodular, fine-grained limestone.
0.51 m. Reddish-brown to reddish-grey, medium-bedded (thickness of individual beds 6 to 9 cm), fine-grained limestone.
Euprimites anisus Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson

(e) 0.65 m. Reddish-brown to reddish-grey, medium-bedded (thickness of individual beds 5 to 6 cm), fine-grained limestone. One pygidium of *Asaphus (Neoasaphus) platyurus* is found 60 cm below the top of the subdivision.

(f) 1.33 m. Reddish-grey to grey, medium-bedded (thickness of individual beds 5 to 8 cm), fine-grained limestone. The lowermost boundary is a furrowed, haematite stained discontinuity surface.
Remopleurides sp.

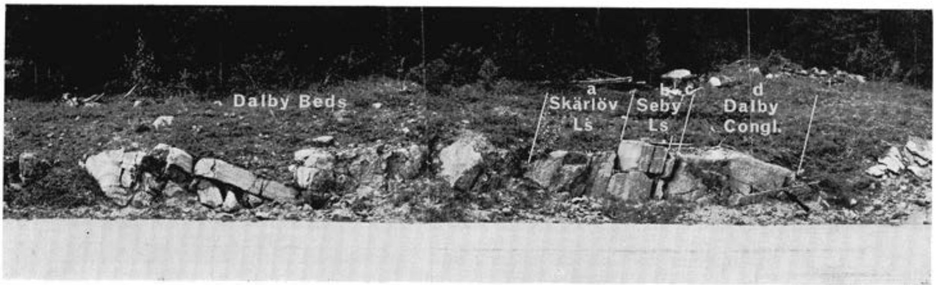

Fig. 14. Locality B at main road No. 81 in the Lockne area, exposing dislocated Lasnamägian and Uhakuan beds overthrust on brecciated granite. Thrust plane at arrow.

(g) 0.05 m +. Grey to reddish-grey, fine-grained limestone.
Megistaspis sp.

The second, easternmost road-cut on main road No. 81, locality B on Fig. 2A, shows a far more complicated pattern of faults and overthrusts than the previous one (Fig. 14). Locality B is situated approximately 200 m E of locality A and exposes beds of Dalby, Seby, and Skärlöv age.

The section consists in its westernmost part of a grey, dense limestone. The dip of this limestone is 30° N and the strike N 20° W. The limestone is overlain by a polymict conglomerate, which at its base is concordant with the substratum, but in its upper part strongly disturbed. The conglomerate contains large pebbles of grey limestone, alum shale with nodules of pyrite, granite and diabase. The size of the pebbles is largest at the base and decreases upwards. The two largest boulders observed consist of diabase and have a size of 25 × 15 cm in cross-section. The matrix of the conglomerate is grey and limy.

The described sequence comprises the eastern limb of a vague anticlinal fold, which fold axis strikes N – S and plunges somewhat towards north. About 3 m west of the crest of the fold a breccia and a calcareous sandstone, the Loftarstone, are exposed. The position of this exposure suggests that a fault is running just east of it.

The eastern half of the locality comprises of an inverted sequence, which is overthrust on a substratum of brecciated granite (Fig. 14). The thrust plane dips 20° SW and is smoothly ground.

The westernmost part of the sequence begins with 1.35 m of reddish-brown, nodular limestone with grey argillaceous intercalations (div. (a) Fig. 14). The nature of the contact between the base of this limestone and the earlier mentioned conglomerate just to the west is uncertain because of heavy dislocations and unfavourable exposure. Concordantly with this division (a) follows a fossiliferous dark grey, coarse-grained limestone, 0.87 m thick, with stromatolites stained by haematite. This forms div. (b) of Fig. 14. From this limestone, well-preserved fossils have been encountered: *Illaenus chiron, Pseudomegalaspis patagiata, Pseudobasilicus ? brachyrachis, Lituites* sp. indet., and *Euprimites effusus.* According to the fauna and the lithology, this limestone probably belongs to the Seby Limestone.

Above the previous limestone follows one bed, division (c), 16 cm thick, of dense, grey limestone and a 50 cm thick, nodular, reddish-brown, fine-grained limestone with greenish-grey argillaceous intercalations. These beds are overlain by a polymict conglomerate, the lower boundary of which is poorly defined. The first Archaean rock fragments have been observed 34 cm above the base of the nodular, reddish-brown limestone. However, suspected fragments also occur below this level, and probably the whole division from the top of division (c) upwards belongs to the conglomerate. This is in good agreement with the development of corresponding beds at both Lunne and Kullstaberg, where the lowermost part of the Dalby Conglomerate may be very difficult to distinguish from the underlying limestone when examined in the field. In polished handspecimens the conglomeratic nature is obvious, however. The total thickness of the conglomerate may thus be 2.19 m. The pebbles mainly consist of reddish-brown and grey Orthoceratite Limestone and granite. The size of the poorly rounded granite pebbles increases upwards. The matrix is reddish-brown and calcareous.

Divisions (a) – (d) are all inverted as can easily be fudged from the shape of the stromatolitic domes in div. (b) and the sequence dips about 15° W.

The heavily disturbed condition of the beds makes it difficult to reconstruct the details of the stratigraphy of the sequence. As the fossil record is poor, except for division (b) stratigraphical considerations have to be based mainly on the lithology. Based on the different character of the two conglomerates as well as on the known development of the Dalby (Chasmops) Limestone in the area (Thorslund 1940), the following general picture of the stratigraphy can be obtained. The western half of the section with breccia, Loftarstone, grey, dense limestone and polymict conglomerate probably belong to the Dalby Formation. Divisions (a) – (d) are both lithologically and faunistically identical with the section at Kullstaberg, and can thus be referred to the Skärlöv and Seby Limestones and the Dalby Conglomerate, respectively.

Additional localities in the Lockne area

A few localities from the Lockne area, described by Thorslund (1940) but not visited by the present writer, are summarized below.

In the north-western part of the Lockne area between Löfsåsen and Nyckelbergbodarna (Fig. 2A), small outcrops of beds probably corresponding to the Segerstad and Seby Limestones have been recorded. At some places these beds rest on an arcosic breccia. Conglomerates of different ages have also been mentioned *e.g* N of Nyckelbergbodarna where the conglomerate is formed by rounded pebbles of brownish-red limestone resting on a grey and brownish-grey Orthoceratite Limestone. This conglomerate is by Thorslund supposed to be of *Gigas* or *Platyurus* (= Segerstad) age. However, it seems likely that this conglomerate corresponds to the intraformational Kullstaberg Conglomerate as developed at Kullstaberg and Bergsböle. If this is correct, the erosion has been more extensive in this part of the area, reaching down to the grey or reddish-grey parts of the Orthoceratite Limestone.

Another, coarser conglomerate has been observed ca. 0.9 km NW of the north-westernmost Änge farm. It contains pebbles of grey Orthoceratite Limestone and Precambrian rocks and rests on a fossiliferous limestone which can be compared with the Seby Limestone. A similar conglomerate containing pebbles of grey and red Orthoceratite Limestones, dolerite and granite, has been found at the road 0.7 km W of Nyckelbergbodarna. These two conglomerates are probably comparable with the upper conglomerate at Lunne and Kullstaberg which probably is of Dalby age.

In the central Lockne area beds corresponding to the Segerstad and Seby Limestones are exposed at many places as noted by Thorslund (1940). In one of these outcrops, 300 m SSE Lappgrubban farm, beds probably belonging to the Seby Limestone have been reported to contain *Illaenus chiron*, *Pseudomegalaspis patagiata*, *Plectasaphus plicicostis* and *Pseudobasilicus* ? *brachyrachis*. Close to this exposure and at a higher level, there occurs an arcose-like breccia, which probably can be attributed to the Dalby Formation.

The Åsarna area — general remarks

The stratigraphy of the basal Viruan in the Åsarna area has hitherto been unknown. Thorslund (1940) mentioned some exposures of Lasnamägian beds (”*Schroeteri*” Limestone) from Gammalbodberget, Hallen, and Åsarna. From the latter locality, NNW the church, a thickness of 32 m was reported for the ”*Schroeteri*” Limestone. This value is in this paper considered to include the Lasnamägian Folkeslunda Limestone, the Uhakuan Furudal Limestone, and probably also the lower part of the Dalby Formation. A total thickness of 97 m has been estimated for the Orthoceratite Limestone at Skalängen, 9 km S of Åsarna (Wiman 1893), but this value too probably includes beds high into the Viru Series.

The most complete sequence has been found at Gammalbodberget, in this paper described as the reference section for the area. Additionally, a section in a road-cut at Oppbodarna is treated in some detail.

Gammalbodberget

Gammalbodberget is situated 6.5 km SSW of Åsarna, about 2.5 km W of the road between Åsarna and Klövsjö (Fig. 2B). It is a hill 581 m above sea level,

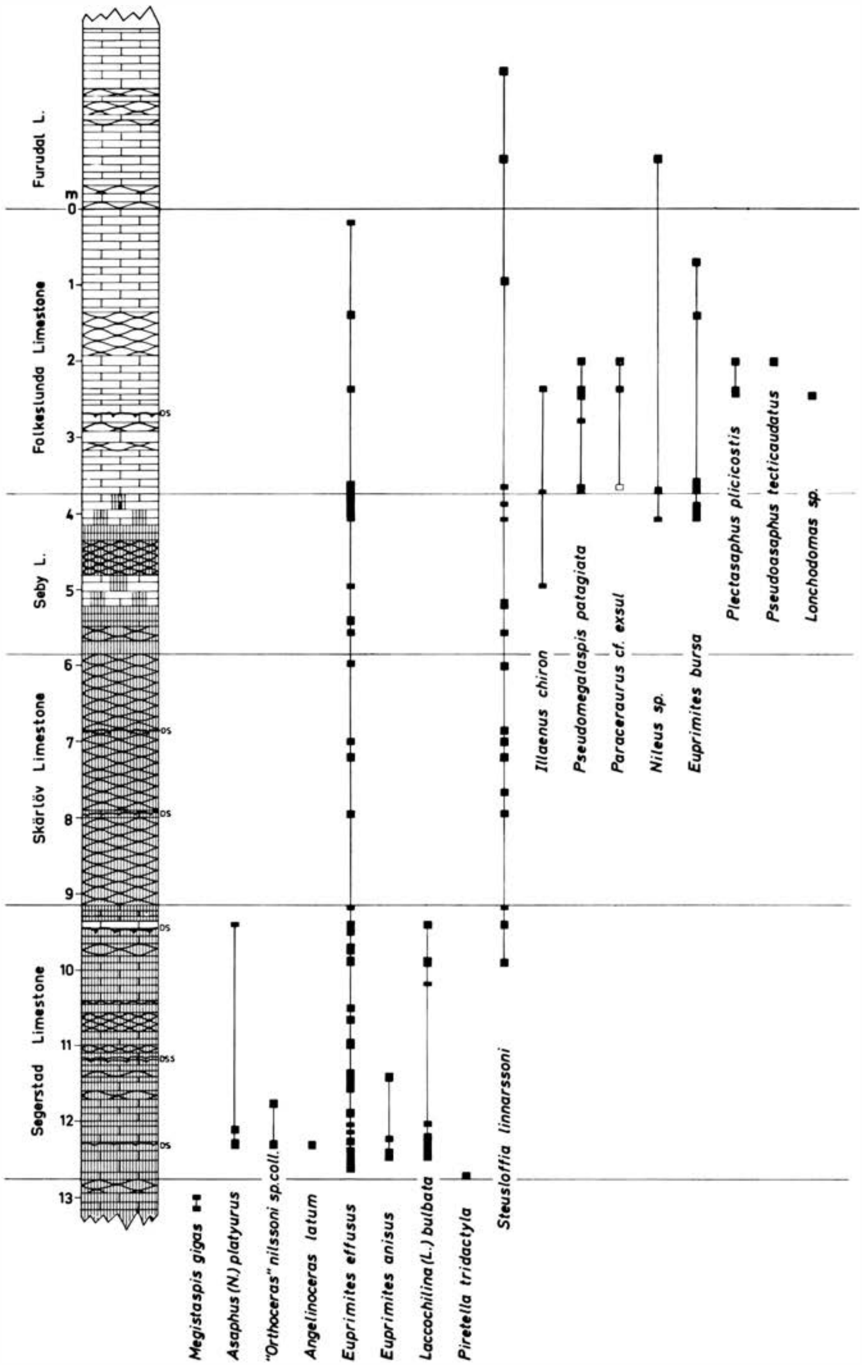

Fig. 15. Range of selected species in the *Gigas*, Segerstad, Skärlöv, Seby, Folkeslunda and Furudal Limestones of the Gammalbodberget section, Åsarna area. For legend, see Fig. 4.

consisting of Lower and Middle Ordovician beds, capped by overthrust Eocambrian quartzite (Vemdal Quartzite). The Middle Ordovician limestones are best exposed in a steep wall for a distance of about 400 m on the southern slope of the hill.

The strike is N 50° W and the average dip 25° NE. At some levels the sequence is repeated on account of very flat dipping overthrusts. Higher up in the Furudal Limestone heavily folded beds occur.

The lower boundary of the Segerstad Limestone is situated about 475 m above sea level.

The section described below and the range of some selected species are shown on Fig. 15.

Description of the section

Furudal Limestone 1.85 m +

0.28 m +. Grey, medium-bedded, fine-grained limestone with uneven bedding surfaces.
Steusloffia linnarssoni (Krause)

0.48 m. Grey, nodular, fine-grained limestone, bedded between 9–17 cm and 34–41 cm, respectively from the top.

0.79 m. Grey, medium- to thick-bedded, fine-grained limestone with uneven bedding surfaces.
Nileus sp.
Steusloffia linnarssoni (Krause)

0.10 m. Grey, nodular, fine-grained limestone.

0.10 m. Bedded, grey, fine-grained limestone.

0.10 m. Grey, nodular, fine-grained limestone.

Folkeslunda Limestone 3.51 m

1.36 m. Grey, thin- to medium-bedded, fine-grained, somewhat nodular in the lower 52 cm.
Remopleurides sp.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Steusloffia linnarssoni (Krause)

0.56 m. Grey to dark grey, nodular, fine-grained limestone.
Remopleurides sp.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)

0.21 m. Two beds of grey, fine-grained limestone, 14 cm and 7 cm thick, respectively.
Asaphus (Neoasaphus) sp.
Pseudomegalaspis patagiata (Törnquist)
Pseudoasaphus tecticaudatus (Steinhardt)
Plectasaphus plicicostis (Törnquist)
Paraceraurus cf. *exsul* (Beyrich)
Remopleurides sp.

0.03 m. Grey mudstone.

0.65 m. Grey to dark grey, thin- to thick-bedded (thickness of individual beds 14, 8, 5 and 4 cm), fine-grained limestone. One yellow surface occurs 52 cm from the top and marks a sharp lithological boundary between a very dark grey and light grey bed.

Illaenus chiron Holm
Pseudomegalaspis patagiata (Törnquist)
Plectasaphus plicicostis (Törnquist)
Paraceraurus cf. *exsul* (Beyrich)
Remopleurides sp.
Lonchodomas sp. indet.
Lituites sp. indet.
Euprimites effusus Jaanusson

0.12 m. Dark grey, nodular, fine-grained limestone.

0.15 m. One bed of dark grey, fine-grained limestone.

0.09 m. Dark grey, nodular, fine-grained limestone with abundant white calcitic spots.

0.34 m. Dark grey, medium- to thick-bedded (thickness of individual beds 15, 11 and 8 cm), fine-grained limestone with irregularly white calcitic spots.

Illaenus chiron Holm
Pseudomegalaspis patagiata (Törnquist)
Pseudomegalaspis sp.
Paraceraurus cf. *exsul* (Beyrich)
Nileus sp.
Remopleurides sp.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Steusloffia linnarssoni (Krause)

Seby Limestone 2.05 m

0.32 m. Grey, thick-bedded, coarse-grained limestone with numerous red haematite grains and spots. The lowermost 6 cm are grey and red mottled. The uppermost 12 cm show numerous dome-shaped stromatolites (type LLH-C), intensely pigmented by haematite.

Nileus sp.
Remopleurides sp.
Hyolithes sp. indet.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Steusloffia linnarssoni (Krause)
Laccochilina (Laccochilina) n. sp.
Laccochilina (Laccochilina) sp. indet.

0.24 m. Reddish-brown, thin-bedded to nodular, fine-grained limestone. The lower 8 cm with red spots of haematite.

0.27 m. Reddish-brown, finely nodular limestone with greenish-grey intercalations.

0.20 m. Reddish-brown, nodular, fine-grained limestone with large greenish-grey argillaceous intercalations.

Remopleurides sp.

0.39 m. Reddish-brown and grey mottled, fine-grained, thick-bedded limestone with increasing grey colour downwards.

Illaenus chiron Holm
Euprimites effusus Jaanusson
Steusloffia linnarssoni (Krause)
Laccochilina sp.

The lower boundary is fairly distinct lithologically.

0.27 m. Reddish-brown, thick-bedded, fine-grained limestone with green spots.
Remopleurides sp.
Euprimites effusus Jaanusson
Steusloffia linnarssoni (Krause)
Laccochilina sp.

0.20 m. Reddish-brown, nodular, fine-grained limestone with greenish intercalations.
Remopleurides sp.
Euprimites effusus Jaanusson
Steusloffia linnarssoni (Krause)

0.16 m. Reddish-brown, medium-bedded, fine-grained limestone.

Skärlöv Limestone 3.30 m

2.06 m. Reddish-brown, nodular, fine-grained limestone. One intensely red furrowed surface occurs 1.02 m from the top.
Remopleurides sp.
Euprimites effusus Jaanusson
Steusloffia linnarssoni (Krause)

0.08 m. One bed of reddish-brown, fine-grained limestone with green argillaceous intercalations. Intensely red-stained stromatolitic algal mats and domes occur, associated with an uneven discontinuity surface.
Euprimites effusus Jaanusson
Steusloffia linnarssoni (Krause)

1.16 m. Reddish-brown, nodular, fine-grained limestone with green intercalations.
Remopleurides sp.

Segerstad Limestone 3.61 m

0.23 m. Reddish-grey, thick-bedded, fine-grained limestone, the upper part being somewhat nodular.
Euprimites effusus Jaanusson
Steusloffia linnarssoni (Krause)
Laccochilina (Laccochilina) bulbata Jaanusson
Laccochilina sp.

0.12 m. One bed of grey, coarse-grained limestone with a faint reddish tinge. The lower surface is furrowed and covered by stromatolitic mats, strongly pigmented by haematite. The limestone above the surface is grey to brownish-grey and carries numerous nodules of haematite and red limestone (Fig. 16A).
Asaphus (Neoasaphus) platyurus Angelin
Asaphus (Neoasaphus) sp.
Euprimites effusus Jaanusson

0.17 m. Reddish-brown, medium-bedded, fine-grained limestone, the uppermost 12 cm with greyish tinge.
Euprimites effusus Jaanusson

0.17 m. Reddish-brown, nodular, fine-grained limestone.
Euprimites effusus Jaanusson

0.58 m. Reddish-brown, medium-to thin-bedded, fine-grained limestone.
Remopleurides sp.
Hyolithes sp. indet.
Euprimites effusus Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson
Steusloffia linnarssoni (Krause)

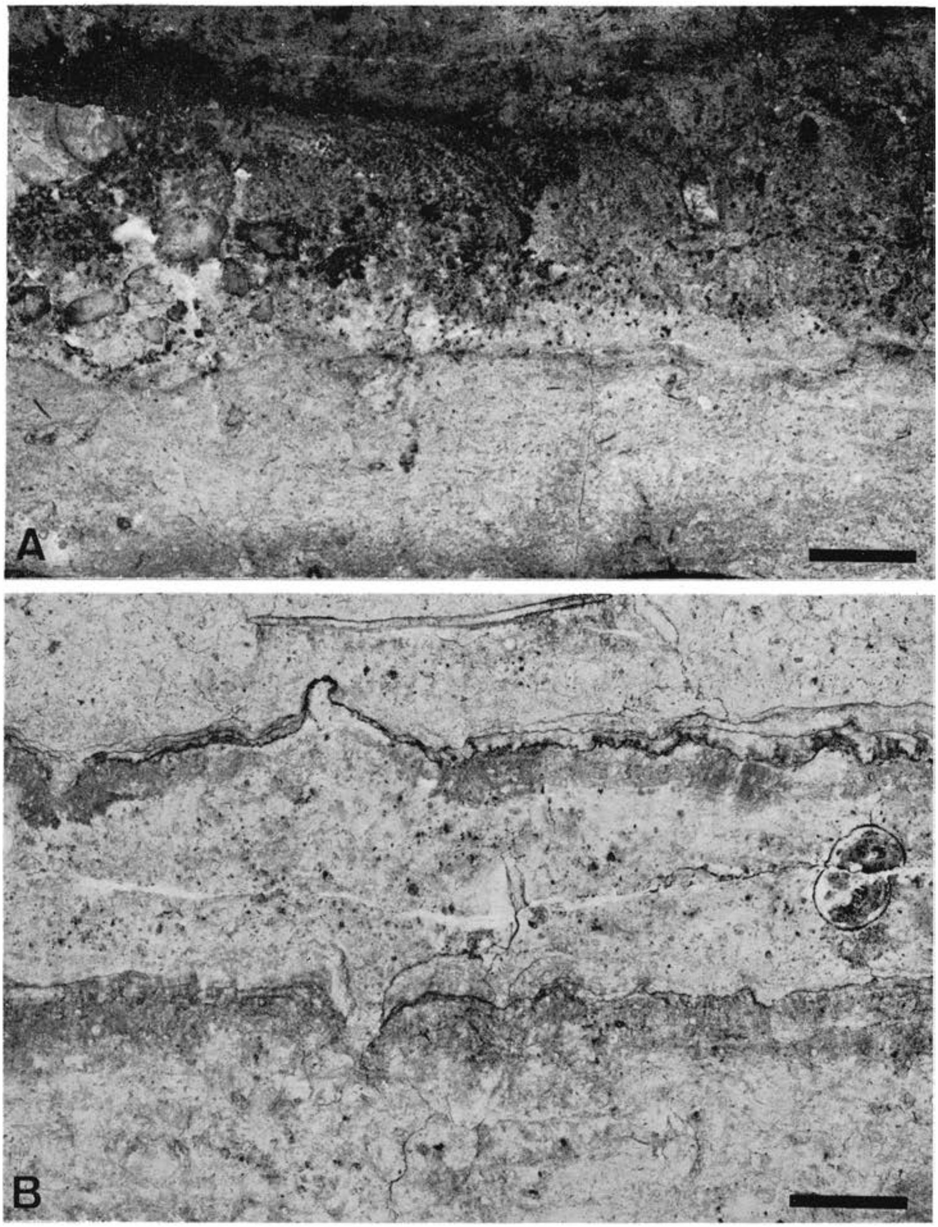

Fig. 16. Gammalbodberget section. A. Discontinuity surface 0.35 m below the top of the Segerstad Limestone. To the left stromatolitic laminations dragging over cephalopod conch and intraclasts. Polished block. Scale bar = 10 mm. B. Discontinuity surfaces 1.93 and 1.95 cm below the top of the Segerstad Limestone covered with stromatolitic algal mats and domes. Polished block. Scale bar = 10 mm.

0.04 m. Reddish-brown, finely nodular, fine-grained limestone. The nodules are strongly flattened.

0.10 m. Two beds, 5 cm each, of reddish-brown, fine-grained limestone.

Euprimites effusus Jaanusson
Chilobolbina lativelata Jaanusson

0.25 m. Reddish-brown, finely nodular, fine-grained limestone with strongly flattened nodules.

Euprimites effusus Jaanusson

0.17 m. Two beds, 10 and 7 cm respectively, of reddish-brown, fine-grained limestone.

0.11 m. Reddish-brown, finely nodular, fine-grained limestone with strongly flattened nodules.

Euprimites effusus Jaanusson

0.12 m. One bed of intensely reddish-brown, fine-grained limestone. At 10 and 12 cm respectively from the top, there occur two very distinctly furrowed surfaces, stained by haematite (Fig. 16B). The surfaces are covered by stromatolitic mats and small domes, the former having a thickness of 3 to 5 mm, the latter 10 to 15 mm. The limestone between the furrowed surfaces is calcarenitic and somewhat paler than the other limestone.

0.13 m. Two beds, 6 and 7 cm thick respectively, of dark reddish-brown, fine-grained limestone.

0.08 m. Reddish-brown, nodular limestone.

Euprimites effusus Jaanusson
Euprimites anisus Jaanusson

0.19 m. Two beds, 12 and 7 cm thick, of reddish-brown, fine-grained limestone. The lower bed is somewhat pale and shows some green portions.

Euprimites effusus Jaanusson
Euprimites anisus Jaanusson

0.10 m. Pale reddish-brown, nodular, fine-grained limestone with grey intercalations.

0.64 m. Reddish-brown, thin-to medium-bedded, fine-grained limestone with scattered green spots. One furrowed, red discontinuity surface occurs 0.50 m from the top.

Asaphus (Neoasaphus) platyurus Angelin
"*Orthoceras*" *nilssoni* (Boll) sp. coll.
Angelinoceras latum (Angelin)
Angelinoceras sp.
Euprimites effusus Jaanusson
Euprimites anisus Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson
Laccochilina sp.
Chilobolbina sp. indet.
Piretia n. sp. B
Conchoprimitia sp.

0.41 m. Three beds, 17, 15 and 9 cm thick respectively, of pale reddish-brown, fine-grained limestone with green spots.

Euprimites effusus Jaanusson
Euprimites anisus Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson
Piretella tridactyla Jaanusson
Tallinnella sp. indet.
Conchoprimitia sp.

There is no lithological difference between this and the underlying limestone.

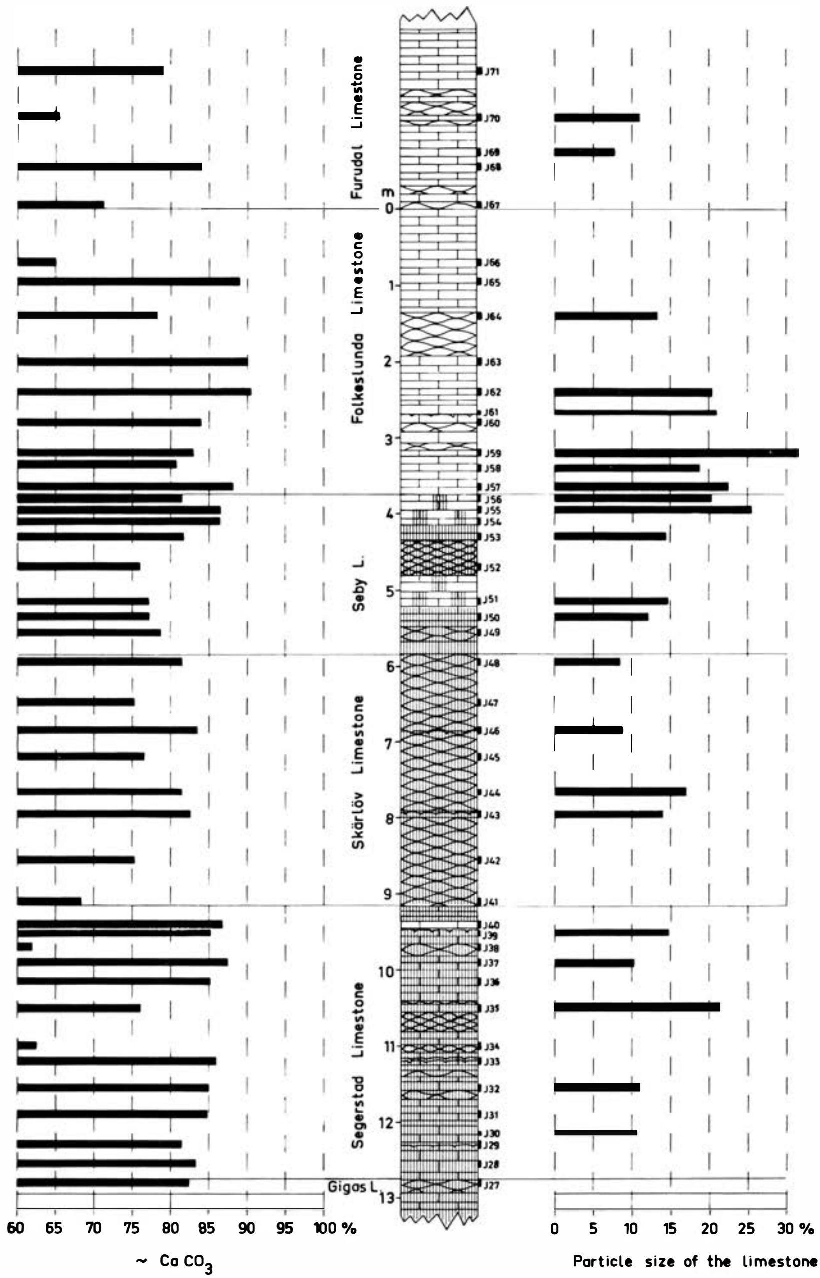

Fig. 17. *Gigas*, Segerstad, Skärlöv, Seby, Folkeslunda and Furudal Limestones of the Gammalbodberget section. To the left material soluble in dilute acetic acid (approximately the content of $CaCO_3$), to the right particle size of the limestone according to the method of Jaanusson (1952). For legend, see Fig. 4.

Gigas Limestone 0.40 m +

0.18 m. Nodular, pale reddish-brown, fine-grained limestone.
Conchoprimitia erratica (Krause)

0.22 m +. Pale reddish-brown, medium-bedded limestone.
Megistaspis (Megistaspidella) gigas (Angelin)
Tallinnella sp. indet.
Conchoprimitia sp.

Microlithology of the limestones

The Segerstad Limestone is formed by bedded calcarenitic calcilutites and subordinate nodular limestones (Fig. 17). The particle size of the latter have not been determined, but they look fine-grained. One calcarenitic bed occurs 1.31–1.37 m from the top. In this bed particularly, the outlines of the skeletal grains are well-preserved and include entire shells of ostracodes and gastropods. In the top division, above a haematite pigmented, deeply furrowed surface, the limestone is a grey calcarenite with numerous recrystallized spots where skeletal grains are partly fused into the matrix, thus rendering a determination of the particle size impossible.

The Skärlöv Limestone is dominated by nodular calcilutites, although some beds of calcarenitic calcilutites occur as well.

The overlying Seby Limestone can in its lower part be defined as a calcarenitic calcilutite. In its uppermost variegated part, the limestone is calcarenitic with large recrystallized portions (Fig. 17).

The Folkeslunda Limestone mainly consists of bedded, grey calcarenites with relatively low amount of skeletal grains larger than 0.1 mm. The particle size tends to decrease upwards in the section.

Haematite occurs in the whole section up to the Folkeslunda Limestone. In the Segerstad Limestone, the whole matrix is intensely pigmented by haematite. The only exception is the bed immediately above the discontinuity surface 0.35 m below the top of the division, where the matrix is almost devoid of the mineral (Fig. 16A). In this bed, many of the fossils have thin coatings of haematite. This is also the case in the lower parts of the division, where an enrichment of haematite can be observed around and within the fossil fragments. The stromatolites above the mentioned discontinuity surface, all strongly pigmented by haematite, constitute a special case. A strong enrichment of haematite can also be observed on the different discontinuity surfaces of the Segerstad Limestone.

In the Skärlöv Limestone, the distribution of haematite in the matrix is very uneven. The intensity of pigmentation varies from dark brownish-red crusts to almost haematite free spots. However, the macroscopic appearance of the rock is brownish-red. The main body of the haematite is concentrated around and within skeletal grains.

In the uppermost part of the Seby Limestone the haematite only occurs as coatings around skeletal grains and as pigmentation within the stromatolites. The matrix is here completely devoid of haematite staining.

Chamosite has with certainty only been observed in thin sections in the top division of the Seby Limestone and in the Folkeslunda Limestone (Fig. 18). A green mineral has been observed in the grey limestone at the top of the Segerstad Limestone, but the mineral has not yet been identified.

In the Seby and the Folkeslunda Limestones, the chamosite occurs mainly as fillings in

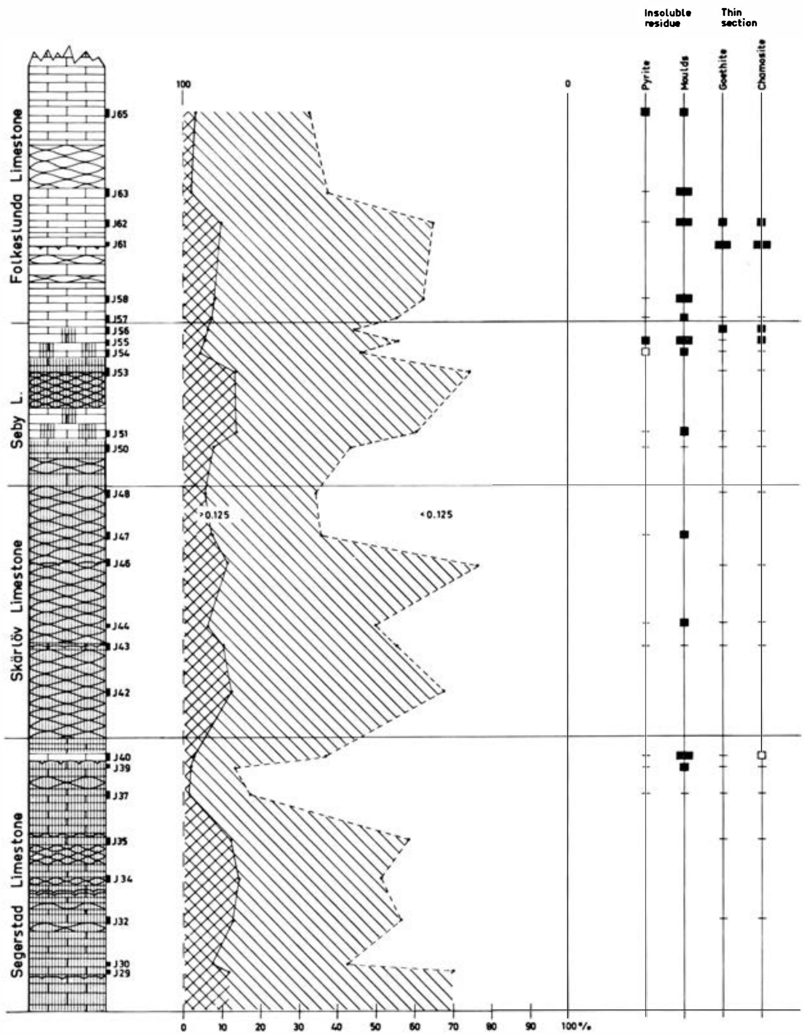

Fig. 18. Segerstad, Skärlöv, Seby and Folkeslunda Limestones of the Gammalbodberget section. To the left, percentages of particles >0.125 mm of total rock and of total residue, respectively. To the right, distribution of moulds and some authigenic minerals in the fraction larger than 0.125 mm of the insoluble residue and in thin sections. For legend, see Figs. 4 and 8.

ostracode and gastropod shells. The mineral is also fairly abundant as fillings within the cavities of pelmatozoan fragments.

Goethite occurs almost in all thin sections, where chamosite has been proved (Fig. 18). The mineral always forms the secondary alteration product of chamosite, visible in chamosite filled shells, where yellow, irregular spots occur fairly frequently. One discontinuity surface in the Folkeslunda Limestone shows a yellow staining together with more greenish portions. This green mineral is probably composed of chamosite while the yellow colour originates from goethite. Yellow grains have also been observed in the stromatolitic domes. Their identity is, however, uncertain.

Sand fraction of the insoluble residue. – In the insoluble residue of the samples studied, very few quartz grains >0.125 mm have been observed.

The amount of the fraction >0.125 mm of the insoluble residue of the total rock has a maximum of 14.6 % and a minimum of 1.7 % (Fig. 18). The highest amounts are found in the nodular limestones.

Pyrite. The pyrite content is very low. Only two samples, one from the stromatolitic part of the Seby Limestone, the other from the top of the Folkeslunda Limestone, have yielded some aggregates and cubes of pyrite (Fig. 18). The number of grains are very low, 5 to 10 grains per 100 g dissolved limestone.

Glauconite has not been observed in the limestones studied.

Non-glauconitic internal moulds occur through the entire section. In the Segerstad Limestone, they are very numerous above the desiccation surface in the uppermost part of the limestone. All moulds are haematitic and have the shape of ostracodes, gastropods and rod-like fossils. The latter are especially abundant, but generally poorly preserved. The Skärlöv Limestone also contains some poorly preserved haematite moulds of ostracodes and gastropods in the sand fraction of the insoluble residue of each sample.

In the Seby Limestone, the lowest samples have yielded a few haematite moulds of ostracodes and rods, while the uppermost samples from the grey and red variegated stromatolitic limestone are very rich in different kinds of internal moulds. The moulds consist both of haematite and of a greenish mineral, very likely chamosite. A few of the latter moulds show irregular, yellowish spots, which most likely represent goethite. All stages of alteration can be seen, from bright yellow goethite to green, unaltered chamosite. The proportion of chamosite moulds increases upwards in the division. In the Folkeslunda Limestone, the haematite moulds are completely lacking and most moulds are either chamositic or goethitic or both. In addition also grey internal moulds have been observed, probably composed of some clay mineral. The state of preservation of all moulds is in general very poor.

Non-glauconitic grains. As was mentioned earlier, irregular flakes and grains play an important rôle in the fraction >0.125 mm. In the red or reddish-grey mottled limestone, these grains mainly consist of haematite aggregates and grains in cubic form. Grey to greenish-grey, flaky material is also important especially within the nodular limestone. The mineral constituent of these flakes is most likely some clay mineral.

In the uppermost variegated part of the Seby Limestone as well as in the Folkeslunda Limestone, many of the flakes and grains show spotted alterations into a yellowish colour. These spots are interpreted as goethite. If this is correct, chamosite may be an important component in the greenish flakes. X-ray analysis of the total residue has also revealed presence of chamosite.

Upwards to the top of the Folkeslunda Limestone, the greenish tint of the flakes and the grains decreases. In this portion, a light grey colour dominates.

No rounded greenish grains similar to those found in the Seby Limestone at Lunne have, so far, been observed.

Oppbodarna

A new section through the lower Viruan is exposed in a road-cut, 6 km SE of Gammalbodberget, along the road between Åsarna and Klövsjö (Fig. 2B). In the present paper this locality is called Oppbodarna, after a small summer-grazing area having the same name.

The exposed beds have been cut for a distance of about 150 m in a NE–SW direction through a strongly folded sequence with overthrusts and small faults.

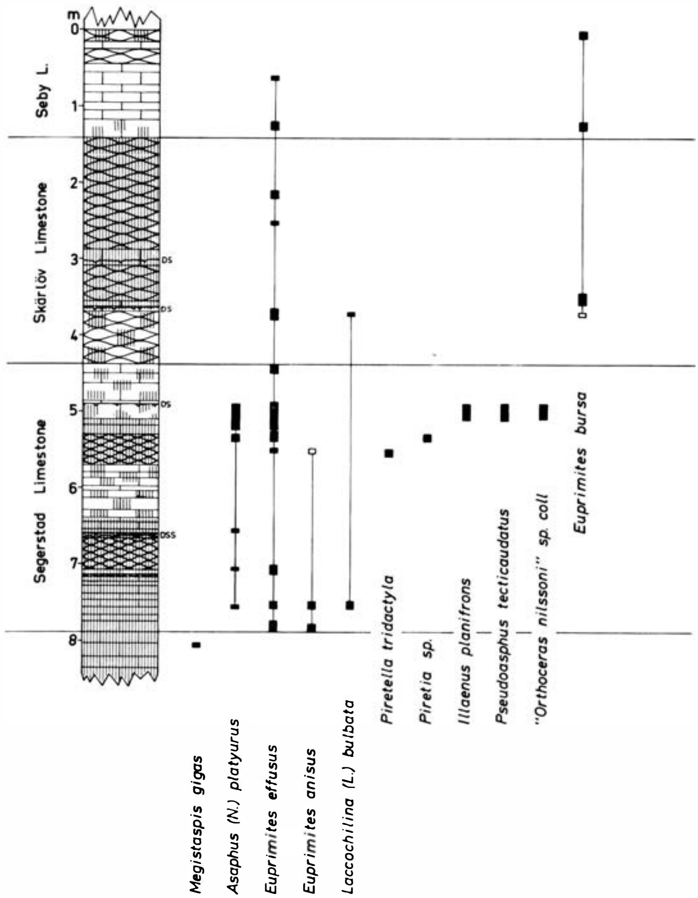

Fig. 19. Range of selected species in the *Gigas*, Segerstad, Skärlöv and Seby Limestones of the Oppbodarna section. For legend, see Fig. 4.

In the northern part the beds are less disturbed, and there a continuous section could be obtained. In this part the beds are dipping 30°–40° NNE, striking N 80° W.

Through the whole sequence, the usual reddish-brown colour of the limestone has been post-depositionally altered, thus giving the rock a grey to greyish-brown tint. Irregular light grey or brown portions also occur, some covering a considerable area. These changes in colour have probably occurred along fissures.

The sequence above the Segerstad Limestone is best studied along the eastern side of the road. The described sequence below is graphically shown on Fig. 19.

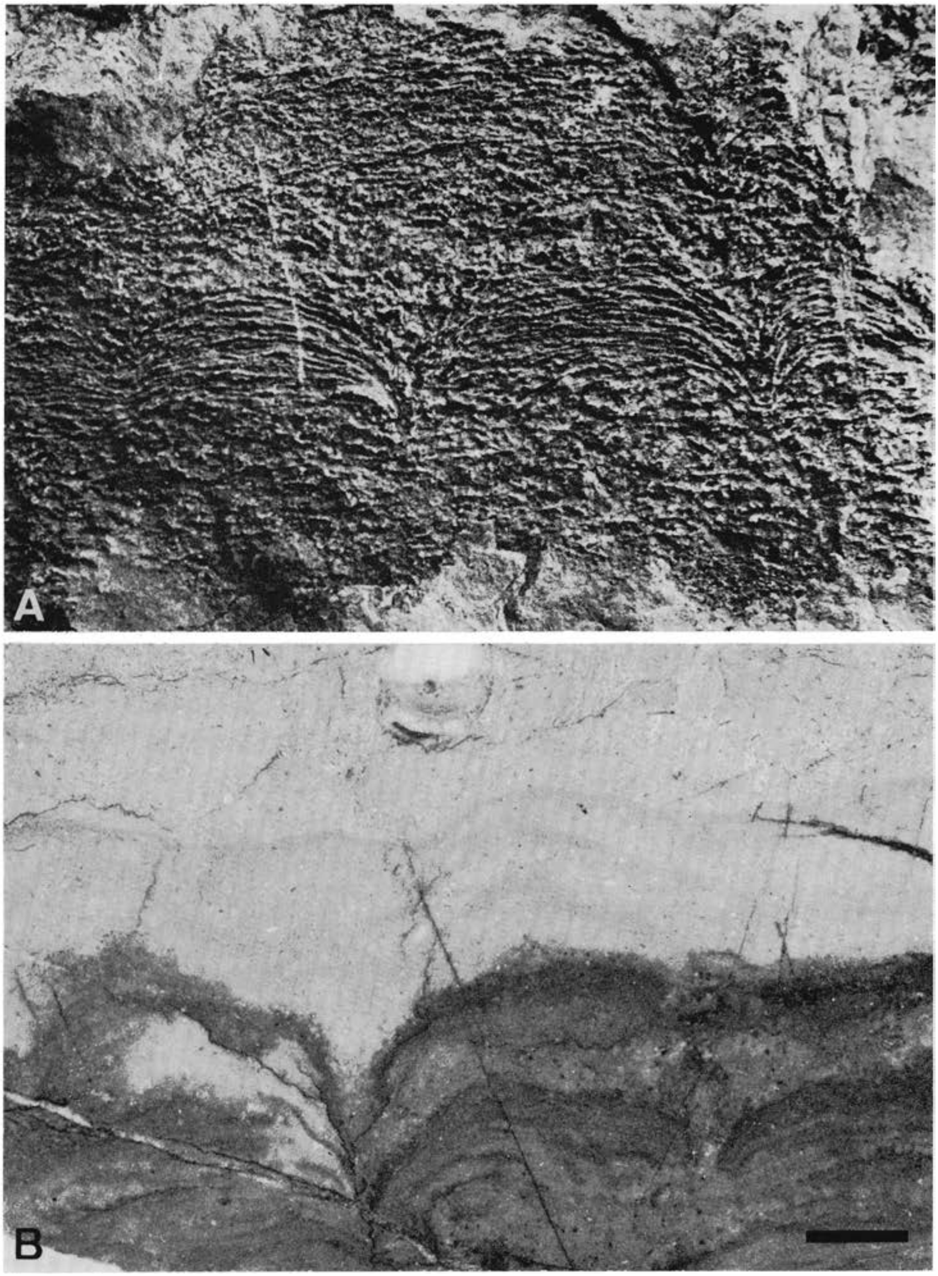

Fig. 20. Stromatolitic algal domes (type LLH-C) in the Skärlöv Limestone at Oppbodarna. A. Weathered surface. B. Polished block. Scale bar = 10 mm.

Description of the section

Seby Limestone 1.49 m +

0.23 m +. Dark grey, somewhat nodular, fine-grained limestone. One deeply furrowed discontinuity surface occurs, covered by a 1 to 3 mm thick haematite crust.
Euprimites bursa (Krause)

0.11 m. One bed of dense, grey limestone with some nodular portions.

0.20 m. Grey, nodular, fine-grained limestone.

0.72 m. Grey, dense, thick- to medium-bedded limestone with uneven bedding planes.
Euprimites effusus Jaanusson

0.23 m. Grey, medium-bedded, fine-grained limestone with some scattered pale red grains The uppermost 10 cm are very bituminous.
Remopleurides sp.
Euprimites effusus Jaanusson
Euprimites bursa (Krause)
Conchoprimitia sp.

Skärlöv Limestone 2.97 m

0.78 m. Reddish-brown, nodular, fine-grained limestone, in the upper part mainly dark grey.
Euprimites effusus Jaanusson

0.69 m. Reddish-brown, nodular, fine-grained limestone with greenish-grey argillaceous intercalations.
Remopleurides sp.
Euprimites effusus Jaanusson

0.20 m. Reddish-brown, thick-bedded, fine-grained limestone with greenish intercalations.

0.48 m. Reddish-brown, nodular, fine-grained limestone with grey intercalations.
Remopleurides sp.
Euprimites bursa (Krause)

0.06 m. One bed of grey, fine-grained limestone with some nodular portions.

0.05 m. One bed of reddish-grey limestone with numerous stromatolites of the LLH-C mode, associated with desiccation furrows (Figs. 20A and 20B). The stromatolites are intensely red stained by haematite, except for their upper part (Fig. 20 B). The height of the domes is 3 cm or less and the basal radius 5 cm.

0.71 m. Reddish-brown and grey mottled, nodular, fine-grained limestone.
Remopleurides sp.
Euprimites effusus Jaanusson
Euprimites bursa ? Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson

Segerstad Limestone 3.52 m

0.48 m. Dark grey to grey, thick-bedded, fairly coarse-grained limestone with numerous red spots. Fossils are haematite coated.
Euprimites effusus Jaanusson

0.04 m. One bed of grey, coarse-grained limestone with red spots.
Lituites ? sp. indet.
Euprimites effusus Jaanusson

0.21 m. Grey and red mottled, coarse-grained limestone with numerous desiccation surfaces and stromatolites of the LLH-C and SH-C types, all strongly pigmented by haematite. This division is rich in fossils, coated with haematite, chamosite and goethite. The top of the division is formed by a deeply furrowed desiccation surface.

Asaphus (Neoasaphus) platyurus Angelin
Illaenus planifrons Jaanusson
Pseudoasaphus tecticaudatus (Törnquist)
Pseudomegalaspis ? sp.
Remopleurides sp.
"*Orthoceras*" *nilssoni* (Boll) sp. coll.
Hyolithes sp. indet.
Euprimites effusus Jaanusson

0.18 m. Two beds, 7 and 11 cm thick respectively, of reddish-brown, fine-grained limestone, occasionally with a faint greyish tint.

Asaphus (Neoasaphus) platyurus Angelin
Euprimites effusus Jaanusson
Piretia sp.
Laccochilina sp.

0.41 m. Reddish-brown, nodular, fine-grained limestone. The uppermost 29 cm, at several places along the section, are light grey with scattered light red portions. The lowermost 12 cm are dark grey with a reddish-brown tint. The average length of the nodules is 2 cm.

Euprimites effusus Jaanusson
Euprimites anisus? Jaanusson
Piretella tridactyla Jaanusson

0.35 m. Grey to dark grey, medium-bedded, fine-grained limestone with a faint reddish-brown tint.

0.34 m. Dark grey and brownish-red mottled, thick- to medium-bedded fine-grained limestone. Greyish colour dominates.

0.19 m. Reddish-brown, medium- to thin-bedded, fine-grained limestone. The lower boundary is a furrowed, haematite stained desiccation surface. The limestone 5 cm above it, is very rich in pygidia of *Asaphus (N.) platyurus*.

0.09 m. Greyish-red, thin-bedded, fine-grained limestone. One bedding plane 2 cm from the top is enriched in haematite and is probably a discontinuity surface. This surface together with the furrowed top surface of the bed, in all probability correspond to the double discontinuity surfaces in the lower part of the Segerstad Limestone at Gammalbodberget.

Asaphus (Neoasaphus) platyurus Angelin

0.40 m. Dark grey to reddish-brown, nodular, fine-grained limestone with greenish-grey argillaceous intercalations. The average length of the partly strongly flattened nodules is 2 cm.

Asaphus (Neoasaphus) platyurus Angelin
Illaenus sp.
Euprimites effusus Jaanusson

0.05 m. One bed of grey to brownish-red, fine-grained limestone.

Euprimites effusus Jaanusson

0.04 m. Dark grey to reddish-brown, nodular, fine-grained limestone. The nodules are strongly flattened.

0.50 m. Dark grey to brownish-red, medium- to thick-bedded, dense limestone. At 48 cm from the top, there occurs a red furrowed surface, probably a discontinuity surface.

Asaphus (Neoasaphus) platyurus Angelin
Euprimites effusus Jaanusson
Euprimites anisus Jaanusson
Laccochilina (Laccochilina) bulbata Jaanusson

0.24 m. Reddish-brown, thick-bedded, dense limestone with scattered haematite spots.
Euprimites effusus Jaanusson
Euprimites anisus Jaanusson
Laccochilina sp.
Conchoprimitia sp.
There is no lithological difference between this and the underlying limestone.

Gigas Limestone 0.76 m +

0.76 m. Grey to reddish-brown, thick-bedded, fine-grained limestone with large portions coloured light grey along fissures. Numerous organogenic tubes filled by clear calcite occur. A furrowed haematite stained surface occurs 68 cm from the top.
Megistaspis (Megistaspidella) gigas (Angelin)

Hallen

At Hallen the same development of the Aserian and Lasnamägian Stages has been found as at Gammalbodberget. However, due to a heavily dislocated sequence no continuous section is available. The thickness probably agrees well with that at Gammalbodberget, but owing to the above mentioned tectonic disturbances this could not be proved.

In the Seby Limestone, stromatolites have been observed. These are mainly of the LLH-C type, but thin mats occur as well.

Southern Jämtland and Härjedalen — general remarks

In the surroundings of Klövsjö, Ordovician beds occur in a stripe along the eastern shore of Lake Klövsjön (Fig. 1). To the northeast it is limited by a quartzite massive, covering the greater part of the Åsarna area.

The Orthoceratite Limestone is outcropping in several places, but generally the outcrops are small. They are to a great extent also strongly disturbed tectonically, thus making it difficult to find continuous sections.

In a rivulet 400 m NNW of the farm Mårten-Jöns (Fig. 2B), strongly block-faulted, grey, dense limestone outcrops, in which a few pygidia of *Pseudoasaphus tecticaudatus* have been found together with some fragments of *Lituites* sp. indet. The lithology of the limestone, as well as the fossils indicate the beds are of Folkeslunda age. The grey limestone continues up the rivulet in a complicated faulted pattern. The distance to the first quartzite outcrop is fairly short. This makes is probable that the quartzite is resting directly on the basal beds of the Furudal Limestone. This seems also to be the case along the rivulet Kvarnbäcken on the eastern side of the hill Fåglingsberget, where the contact between the quartzite and a grey limestone can be followed for a fair distance. This level constitutes the plateau on which Bergvallen summer-grazing is situated. The vertical distance between the quartzite and the first reddish-brown limestone is small. Because of these conditions, it may be supposed that the grey limestone at the top is of Furudal age. However, until faunal evidence has been obtained, these assumptions must be considered unproven.

Beds of probable Middle Ordovician age are also outcropping 400 m NNE of the church of Klövsjö, on the southern slope of the hill Blyberget. Here, small exposures of very bituminous, arenitic, grey limestone have been encountered. No determinable fossils have, so far, been found in these beds. The same kind of limestone is also outcropping farther eastwards, about 200 m from the main road to Åsarna.

In Härjedalen, in the area around Glöte, there are some small Cambro-Ordovician deposits remaining, preserved by the overlying quartzite nappes. The southernmost outcrop occurs at Häggingsåsen, a hill situated about 8 km SSW of the village of Glöte (Fig. 1). In this place, a relatively well-exposed sequence through the Lower and Middle Ordovician beds occurs on the eastern side of the hill. Immediately below the summit of the hill, a section of Aserian and Lasnamägian beds is discontinuously exposed. Brownish-red, fine-grained limestone with *Asaphus (Neoasaphus) platyurus* has been found, and farther up the section, approximately 5 to 6 m above this bed, a dark grey and red mottled, coarse-grained limestone outcrops. The limestone is rich in haematite spots, sometimes arranged into laminae, probably of stromatolitic origin. Fragments of *Lituites* sp., *Remopleurides* sp. and ostracodes, such as *Euprimites effusus,* have been identified. This bed rests, with a sharp boundary, on reddish-brown, somewhat nodular limestone with green argillaceous intercalations, yielding *Conorthoceras ? conicum.* The lithology and the fossils point towards a Skärlöv age for these beds. The overlying red and grey mottled limestone can probably be referred to the Seby Limestone. The similarity in development to the corresponding beds in the other areas investigated is striking. An estimate of the thickness of the Aserian and Lasnamägian sequence gives a value fairly close to that obtained at Gammalbodberget.

Close to the summit, 15 m up from the described exposure, a grey fine-grained limestone of probable Furudal age outcrops.

Stratigraphical and faunal remarks

Segerstad Limestone. – In Jämtland the Segerstad Limestone can be well distinguished in all areas without much variation. It consists of intensely reddish-brown calcarenitic calcilutites and red and grey mottled calcarenites with recrystallized portions, the latter lithology prevailing in the upper part of the formation. Nodular and finely nodular beds are common, the latter rock being mostly confined to the lower portions of the formation. The nodular beds comprise about 43, 17, 21 and 24 % of the thickness of the formation at Lunne, Kullstaberg, Gammalbodberget and Oppbodarna, respectively.

The lower boundary of the Segerstad Limestone is a bedding plane which cannot be distinguished from other similar bedding planes. At this boundary the change in the macrofauna is reasonably distinct in all sections studied in the Brunflo and Åsarna areas, *Megistaspis gigas* occurring close below and *Asaphus (Neoasaphus) platyurus* close above the boundary. In the ostracode faunas the boundary is less sharply defined than in many other districts of Sweden. The absence in the uppermost two to three metres of the Kunda Stage of genera such as *Glossomorphites, Aulacopsis,* and *Pinnatulites,* is particularly noteworthy. *Conchoprimitia erratica* is the only ostracode species characteristic for the Upper Kunda in other localities, which has been found in the *Gigas* beds of the sections studied, and it has been found only at Gammalbodberget.

In the Lockne area the lower boundary of the Segerstad Limestone has been difficult to determine because no macrofossils have been found in the boundary region. The boundary has been tentatively drawn according to the evidence from the ostracode faunas, which more precisely is below the bed in which the lowermost *Euprimites effusus* has been found. This level may not correspond to the exact boundary because *E. effusus* or a closely related species occurs also in the *Gigas* beds in Jämtland, as well as in the other Cambro-Silurian districts of Sweden. It is interesting to note that at Kullstaberg, Bergsböle and Öhntjärn the colour of the rock grades from Segerstad Limestone downwards from reddish-brown to grey or greyish-green. This would give the impression that beds corresponding to the reddish-brown *Gigas* Limestone in the Brunflo and Åsarna areas are not developed here or, if developed, have a different colour. However, without further biostratigraphic data it is difficult to prove either of these alternatives.

The two zones of the Aseri Stage, zone of *Illaenus planifrons* and zone of *Angelinoceras latum,* distinguished by Jaanusson & Mutvei (1953), can be recognized in many sections. *Angelinoceras latum* has been found close to the base of the Segerstad Limestone at Gammalbodberget and Lunne. *Illaenus planifrons* is not uncommon in the upper part of the formation, particularly in beds which contain surfaces with mud cracks and stromatolitic algal mats. Also some other species which characterize the zone of *I. planifrons* have been encountered in these beds. Such species are *Geisonoceras ? centrale* and *Dorsolinevites dispar.* The latter species has in Jämtland hitherto been reported only from an erratic boulder found in a gravel-pit at Pilgrimstad, 33 km SE of Östersund (Holm 1893).

The middle part of the Segerstad Limestone is generally poor in macrofossils and it has not been possible to define the boundary between the two zones in any section, in Jämtland or elsewhere.

In the Lockne area *Illaenus planifrons* has been found above as well as below (Kullstaberg, Öhntjärn) the polymict conglomerate indicating that the conglomerate is situated within the zone of *I. planifrons*.

Based on lithological characteristics, the Segerstad Limestone of some areas can be subdivided into two members, lithologically comparable to the Kårgärde and Vikarby Members (Jaanusson 1963). This subdivision is best defined in the Vikarby section of the Siljan district (Jaanusson & Mutvei 1953). In several sections of the autochthonous of Jämtland a similar lithological subdivision is possible.

Beds with the lithological characteristics of the Kårgärde Member consist of bedded, nodular and finely nodular, reddish-brown calcarenitic calcilutites (average content of skeletal sand of sand grain size 13.7 and 13.6 % in the Lunne and Gammalbodberget sections, respectively). The division is generally poor in macrofossils with the exception of some isolated horizons. At Lunne, as well as in some other exposures of the Brunflo area, there occurs a fossiliferous horizon just above the double discontinuity surfaces 5.50 and 5.60 m below the top of the Segerstad Limestone, yielding *Asaphus (N.) platyurus*, *Angelinoceras latum* and "*Orthoceras*" *nilssoni* sp. coll. There are two fossiliferous horizons above the discontinuity surfaces of the divisions (e) and (f) in the Kullstaberg section. At Gammalbodberget, the bed below the discontinuity surface 0.55 m above the bottom of the Segerstad Limestone has yielded numerous trilobites and cephalopods. In all these beds trilobites and orthoconic cephalopods are dominant amongst the macrofossils.

The polymict conglomerate in the Segerstad Formation of the Lockne area is situated within the upper part of the beds having the lithology of the Kårgärde Member. The thickness of the conglomerate varies considerably within short distances and it seems in places to grade laterally into a rock which cannot be distinguished from a normal finely nodular limestone of the Segerstad Formation.

The division having the lithological character of the Kårgärde Member also contains discontinuity surfaces. These have, in general, good lateral continuity and they are comparatively easy to distinguish within the different areas. The double discontinuity surfaces in the basal Segerstad Limestone at Lunne occur as three or four surfaces at Gusta and Gärde. Double discontinuity surfaces similar to these also occur in the basal Kårgärde Member of the Åsarna area, but so far it cannot be proved whether these surfaces are contemporaneous or not.

Several discontinuity surfaces of the Kårgärde Member, including the surfaces above, are developed as mud cracks. At Lunne the surface 2.60 m below the top of the Segerstad Limestone is desiccated. This surface can also be traced at Gusta, where it is overlain by well-developed stromatolitic algal mats and domes. At Kullstaberg, polygonal mud cracks occur in divisions (e) and (f). These are also developed at Bergsböle, Öhntjärn and at locality A on main road No. 81.

In several cases the mud cracks are associated with stromatolitic algal mats. In the Brunflo area such mats are developed above the two lowest discontinuity surfaces in the Kårgärde Member. Upwards these algal mats grade into small domes at Lunne and Gärde. At Gusta stromatolites have only been observed above the uppermost desiccated surface of the quarry. In the Lockne area well-developed stromatolitic mats occur at Kullstaberg above the discontinuity surface in division (f). In the Åsarna area, stromatolites have been observed only above the double discontinuity surfaces situated 1.55 and 1.57 m above the bottom of the Kårgärde Member.

The finds of *Illaenus planifrons* in the upper part of the sequence with the lithology of the Kårgärde Member suggest that in the autochthonous of Jämtland the member belongs in part to the zone of *I. planifrons*.

The Vikarby Member consists of variegated, predominantly coarse-grained limestones, mostly recrystallized calcarenites, and in Jämtland it contains numerous surfaces with mud cracks and stromatolitic algal mats. Irregular grains of chamosite are also characteristic. The thickness of the member is 0.30 m in the Lunne section and 0.50 m in the Kullstaberg section. Downwards the member is limited by a discontinuity surface which is generally very irregular and rough and shows overhanging portions. This indicates that the bed has been lithified before the deposition of the overlying bed. At Lunne and Kullstaberg 5 to 10 cm of the limestone below the surface is grey to greyish-green and gives the impression of being bleached, possibly during the subaerial exposure. The surface is covered by a stromatolitic algal mat, 5 to 10 mm thick, which grades upwards into stromatolitic domes (Fig. 6). The Vikarby Limestone at Bergsböle has a somewhat different lithology to the other localities. The limestone is dark grey and strongly bituminous with numerous greenish black chamosite grains. No stromatolites have been observed.

In the probably corresponding portion of the Gammalbodberget section, only the lowermost 12 cm of the limestone are developed as a coarse-grained, grey to greyish-red limestone whereas the beds above are reddish-grey. At Oppbodarna, only 6 km SE of Gammalbodberget, on the other hand, the member is characterized by the same lithology as in the Brunflo and Lockne areas, consisting of variegated, coarse-grained calcarenites with numerous stromatolitic algal mats and domes. Beds with the lithology of the Vikarby Member are 0.73 m at Oppbodarna.

Beds with the lithology of the Vikarby Member are mostly rich in macrofossils which occasionally show coquina-like accumulations. This is particularly the case at Bergsböle. Cephalopods and trilobites are the dominant macrofossils. Among the cephalopods orthoconic shells dominate greatly. When situated on mud crack surfaces they are often arranged after the polygonal pattern of the cracks. This can be studied particularly well at Lunne, where quarrying has exposed several surfaces with desiccation cracks.

At Bergsböle the Vikarby Limestone contains a remarkable amount of *Dorsolinevites dispar*. This is notable because in all other localities examined but few fragments of hyolithids have been found.

Sedimentological features indicate that the beds with the Vikarby type of lithology may have been deposited in higher water energy conditions than most of the Kårgärde Limestone. Moreover, mud cracks covered with stromatolitic algal mats indicate that subaerial exposure has repeatedly taken place during the deposition of these beds.

The thickness of the Aseri Stage is given in Table 3.

Table 3. Table showing the thickness of the various units of the Aseri and Lasnamägi Stages at some localities in the autochthonous of Jämtland.

Locality	Segerstad L.	Skärlöv L.	Seby L.	Folkeslunda L.	Lasnamägi Stage
Lunne	6.12 m	0 m	2.22 m	0.99 m	3.21 m
Kullstaberg	4.16 m	1.10 m	0.69 m	0 m	1.79 m
Gammalbod-berget	3.61 m	3.30 m	2.05 m	3.51 m	8.86 m
Oppbodarna	3.52 m	2.97 m	1.49 m +	–	4.46 m +

Skärlöv Limestone. – In the Lockne and Åsarna areas the predominantly bedded limestones of the Segerstad Formation are overlain by a division consisting in the main of nodular and finely nodular, reddish-brown limestone, the Skärlöv Formation. In this respect the sequence of these areas agrees with that of Öland, Östergötland and the Siljan district, excepting the Vikarby section. The thickness of the Skärlöv Formation is greater in the Åsarna area (3.30 m at Gammalbodberget and 2.97 m at Oppbodarna) than in the Lockne area (1.10 m at Kullstaberg), Fig. 21. The rock of the formation is mainly calcilutitic with some thin portions of calcarenitic calcilutite (average content of sand fraction of skeletal sand 12.0 % at Gammalbodberget). Green and greyish-green, argillaceous intercalations are fairly common. At Kullstaberg the lower boundary of the formation coincides with a discontinuity surface whereas in the Åsarna area the boundary is transitional lithologically.

In the Åsarna area, distinct discontinuity surfaces have been observed in the middle of the Skärlöv Limestone of each section studied. At Gammalbodberget they are situated 1.02 and 2.10 m below the top of the formation and are developed as furrowed surfaces stained by haematite. The lowermost surface

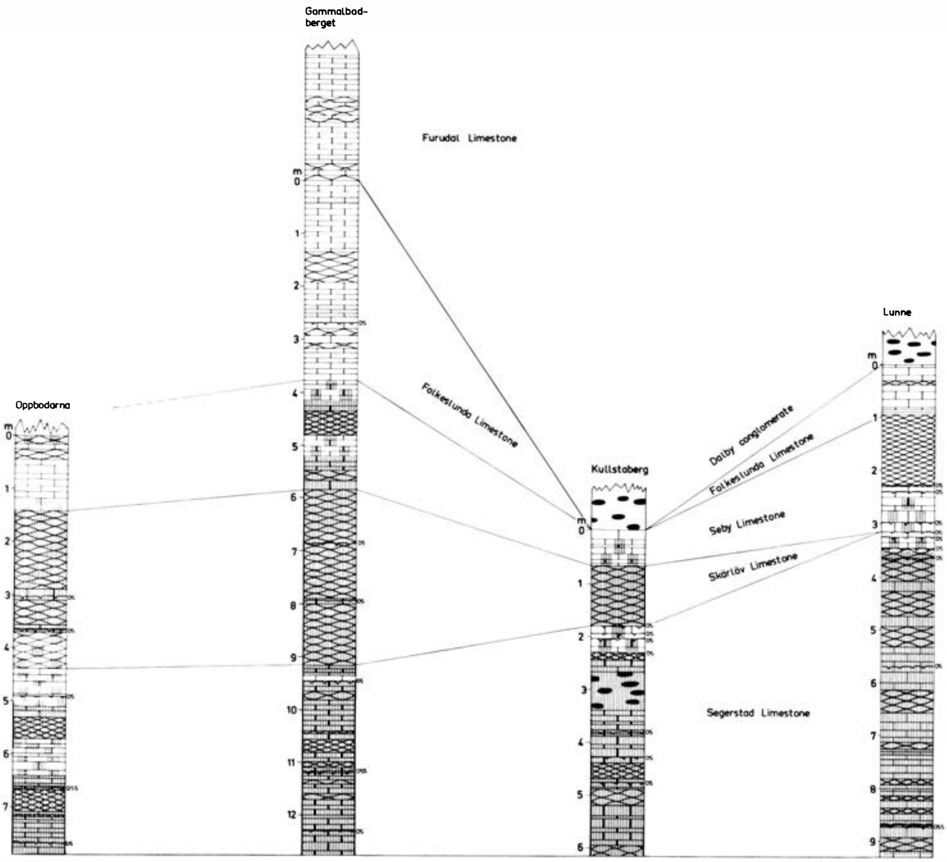

Fig. 21. A comparison of the Aserian, Lasnamägian and Uhakuan sections in the Åsarna, Lockne and Brunflo areas. For legend, see Fig. 4.

is associated with stromatolites. At Oppbodarna a similar discontinuity surface, covered with stromatolites, is situated 2.26 m below the top of the Skärlöv Limestone. The stromatolites are developed as mats or as domes of the LLH-C type (Figs. 20A and 20B). The similarity of this surface and the lower surface at Gammalbodberget suggests that they are contemporaneous.

In the Brunflo area the Skärlöv Formation is not developed and the Seby Limestone directly overlies the Vikarby Limestone.

The position of the boundary between the Aseri and Lasnamägi Stages in the limestone sequence of Sweden is still not clear. The Segerstad Limestone is certainly of Aserian age but also part of the Skärlöv Limestone may belong to this stage (Jaanusson 1960). The Skärlöv Limestone is very poor in macrofossils and the specimens are usually poorly preserved and not identifiable at the species level. No macrofossils indicative of either Aserian or Lasnamägian age have so far been encountered in the Skärlöv Formation of the autochthonous of Jämtland. Also the ostracodes found do not include species known to be restricted to either of these stages. Thus the fossils from the Skärlöv Formation found in the course of the present study do not contribute to defining the position of the boundary between the Aseri and Lasnamägi Stages. It is hoped that future studies on conodonts or inarticulate brachiopods may solve the chrono-stratigraphical classification of these beds. It must also be taken into account that the boundaries of the Formation might be metachronous.

Seby Limestone. – In the Brunflo area the lower division of the Lasnamägian Seby Limestone, division (a), is lithologically indistinguishable from the underlying Aserian Vikarby Limestone. As the Skärlöv Limestone is not developed here and the Seby and Vikarby Limestones are in contact, the boundary between them can be defined by means of faunal criteria only. Faunally the boundary is sharp with *Illaenus planifrons* and *Geisonoceras* ? *centrale* immediately below and *Illaenus chiron* immediately above a discontinuity surface. This surface is partly developed as a surface with mud cracks and overhanging portions and it is similar to other discontinuity surfaces in the Vikarby and Seby Limestones.

The stratigraphical conditions in the Lunne section very much resemble those in the Vikarby section of the Siljan district. There too the Skärlöv Limestone is not developed and the Seby and Vikarby Limestones, indistinguishable lithologically, are in contact (Jaanusson 1963).

The type of lithology characteristic for the Seby and Vikarby Limestones of the Brunflo area deserves a special name, and here the term Lunne facies is proposed. The Lunne facies is characterized by the occurrence of numerous discontinuity surfaces, partly wholly developed as surfaces with mud cracks, associated with numerous stromatolitic algal mats in a mottled, partly sparitic calcarenite (Figs. 22 and 23). In the Lockne area too, *e.g.* at Kullstaberg, the Seby and uppermost Segerstad Limestones are developed as the Lunne facies, but there these divisions are separated by the Skärlöv Formation.

The division (b) of the Seby Limestone at Lunne is developed as a grey limestone, without haematite staining, but still contains abundant stromatolites. Contrary to the other occurrences of stromatolites in the Lower Viruan of the autochthonous of Jämtland, except those occurring in the Skärlöv Limestone of Oppbodarna, these are not stained by haematite and therefore are difficult to recognize when the rock is fresh or without preparation of peels. The upper boundary of this division is formed by a smooth discontinuity surface along which the upper part of numerous cephalopod conchs are removed. The thickness of the division (b) varies from 10 to 20 cm, and the surface can be

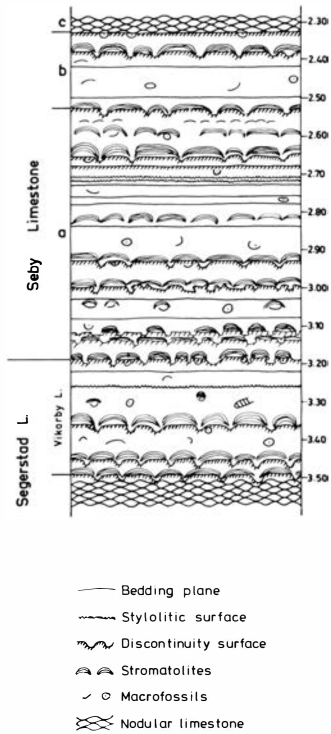

Fig. 22. Diagrammatic representation of discontinuity surfaces and occurrence of stromatolitic structures in the Vikarby Limestone and divisions (a) and (b) of the Seby Limestone in the Lunne section.

observed to have cut the sequence of the division discordantly. Thus a distinct erosional event had preceded the final formation of the surface.

In the Lunne section the typical Seby Limestone is overlain by a division (c), 1.36 m thick, consisting of finely nodular, fine-grained limestone. In the lower part the nodules of the limestone have a slight reddish tint which disappears upwards. The stratigraphic attribution of this division is not yet clear as no identifiable macrofossils have been found and the ostracodes encountered do not include species which are with certainty restricted to either the Seby or Folkeslunda Limestone. In this paper the division is tentatively referred to the Seby Formation due to the presence of reddish tints in the limestone.

The development of the Seby Limestone of the Åsarna area is somewhat different from that of the other areas. In the lower part the formation consists of reddish-brown and mottled, fine-grained limestone. In the upper part reddish-brown, nodular, fine-grained beds and thick-bedded calcarenites containing stromatolitic algal mats dominate. The latter limestones are developed as the Lunne facies. The upper boundary is at Gammalbodberget drawn

Fig. 23. Lowermost Seby Limestone and uppermost Vikarby Limestone at Lunne, showing discontinuity surfaces covered with stromatolites, mainly of the LLH-C mode. Unstained stromatolites occur 4–9 cm above the discontinuity surface between the Seby and Vikarby Limestones (S/V).

according to lithological criteria, *viz.* at the level where the reddish colour of the rock disappears completely.

The Seby Limestone has yielded a rich fauna which is similar to that on Öland and in the Siljan district. The divisions (a) and (b) at Lunne include locally coquina-like concentrations of cephalopods and trilobites. On account of the great difficulties to extract cephalopods undamaged from the rock, it is difficult to obtain identifiable specimens. Moreover, the cephalopod fauna is in part undescribed as yet; it is certainly much more varied than it appears from the faunal lists. Regrettably, no specimen of *Lituites* could be obtained which could be identified at the species level, and hence the lituitid zones established by Holm (cf. Jaanusson 1960) could not be recognized. Hyolithids are rare in the Lasnamägian sequence studied, only some poorly preserved fragments being found.

Among trilobites *Illaenus chiron*, *Pseudobasilicus ? brachyrachis*, and *Pseudoasaphus tecticaudatus* dominate in the Seby Limestone. Also small trilobites are common at some levels, particularly *Remopleurides*.

Ostracodes are common throughout the Seby Formation. They are especially abundant in the limestone developed as Lunne facies. In these *Euprimites effusus* and *Steusloffia linnarssoni* dominate. At Lunne two new species of the genera *Euprimites* and *Piretella* seem to be confined to the Lunne facies.

Folkeslunda Limestone. – The Folkeslunda Formation has its most complete development in the Åsarna area, where it attains a thickness of 3.51 m. In the Brunflo area the thickness of the formation is far less, 0.99 m, and in the examined sections of the Lockne area, the Folkeslunda Limestone is missing (cf. Fig. 21).

Compared to northern Öland and the Siljan district the Folkeslunda Limestone is considerably more fine-grained in the autochthonous of Jämtland. In this respect the development of these beds resembles those of southern Öland and Östergötland. At Gammalbodberget in the Åsarna area the lower part of the formation contains calcarenitic beds but the rest of the limestone is calcilutitic. At Lunne the whole sequence is calcilutitic. In the Gammalbodberget section the upper boundary of the formation has been drawn at the level where *Euprimites effusus* disappears. The same palaeontological criterium for this boundary has been used in almost all other Cambro-Silurian districts of Sweden.

In the Brunflo area no identifiable macrofossils have so far been found in the Folkeslunda Limestone. In the Åsarna area some beds of the formation are fairly rich in macrofossils among which *Illaenus chiron*, *Pseudomegalaspis patagiata*, *Plectasaphus plicicostis* and *Paraceraurus* cf. *exsul* dominate. The fauna is quite similar to that of the formation in the other Cambro-Silurian districts of Sweden. A few fragments of a *Lituites* have been found but none of them could be identified at the species level. Among ostracodes *Euprimites bursa* and *E. effusus* are the dominating species.

Furudal Limestone. – This formation is missing in the Brunflo and Lockne areas where the youngest known strata below the Dalby Conglomerate are the Folkeslunda and Seby Limestones, respectively. In the Åsarna area a full sequence of the formation is probably developed but only the lowermost beds have been examined in connection with the present study. Throughout its vertical range the Furudal Limestone seems to consist of grey, bedded, nodular and finely nodular calcilutites, generally very poor in macrofossils. Beds possibly belonging to the lower part of the formation have been observed also at Häggingsåsen, southern Härjedalen, where they rest on grey limestone of probable Folkeslunda age. They are probably the youngest autochthonous beds of that area.

Dalby Conglomerate. – In the Brunflo area the Dalby Conglomerate rests upon the Folkeslunda Limestone. In the Lockne area the conglomerate is known to overlie various horizons, down to Precambrian rocks (Thorslund 1940). Jaanusson (1947) suggested that, since in that area the youngest known rocks below the conglomerate belong to the "*Schroeteri*" beds (Lasnamägi Stage), the Uhaku Stage is missing. In the sections examined by the present writer the youngest beds below the conglomerate turned out to belong to the Lasnamägian Seby Limestone and thus also the Lasnamägian Folkeslunda Limestone may not be represented in this area. In the Åsarna area the sequence is much more complete than in the other areas. The sequence of the Uhaku Stage is presumably complete and the Dalby Conglomerate probably lies within the Dalby Formation (Stig Bergström and Valdar Jaanusson, personal communication).

Algal stromatolites

Structures resembling recent algal stromatolites have turned out to be a characteristic constituent of the investigated sequence. These structures consist of laminations which occur either as continuous mats occasionally doming over irregularities, or as discrete, stacked domes. So far, stromatolites have been unknown from Jämtland.

During the last decade our knowledge about the occurrence and mode of formation of recent algal stromatolites has increased considerably. The pioneer work on this subject is the monograph by Black (1933). Recent important papers include those of Ginsburg (1960), Logan (1961), Logan, Rezak & Ginsburg (1964), Monty (1965, 1967), Multer & Hoffmeister (1968), Kendall & Skipwith (1968), and Gebelein (1969). As a result of these papers the interpretation of the mode of formation and the palaeoecological and palaeoenvironmental significance of the fossil stromatolites are more realistic than previously.

Algal stromatolites are defined as "laminated structures composed of particle sand, silt, and clay-size sediment which have been formed by the trapping and binding of detrital sediment particles by an algal film" (Logan *et al* 1964). Recent investigations (Monty 1967) have shown that this defination could be modified to some extent for certain fresh- and brackish-water types of stromatolites, in which lime precipitation is of importance.

In defining the structures, the important descrimination between algal stromatolites and fossil algae should be noted, the latter having preserved, recognizable skeletal structures, whilst algal stromatolites only show fine lamination and fragmental texture.

Algal stromatolites occur generally in three major shapes: (1) mats, (2) domes, and (3) unattached biscuits (oncolites). In earlier papers many of these structures have been named under different form genera e.g. *Cryptozoon*, *Col-*

lenia, Spongiostroma for attached forms and e.g. *Osagia, Pycnostroma, Ottonosia* for the unattached oncolites. Several laminated structures described with a binomial nomenclature have since been proved to be of inorganic origin. The more common *Collenia* and *Cryptozoon* structures have generally been accepted as fossils. Modern discoveries of similar structures formed by the sediment binding effect of blue-green algae are impressive support for the organic origin of similar forms in the geological record.

Classification. – The classification used in this paper for the stromatolitic structures is that proposed by Logan, Rezak & Ginsburg (1964). This classification is descriptive and is based on the geometrical shape of the stromatolites. The basic geometrical units used are the hemispheroid and the spheroid. These units are formed into varying arrangements depending on the interaction between sediment-trapping algae and environmental factors. Thus the nomenclature used has the advantage of not only describing the morphology of the stromatolites, but also giving an appreciation of the environmental processes and setting during the formation of the structures. The geometrical classification also simplifies the description of compound structures (Logan *et al.* 1964; Howe 1969), which earlier caused confusions due to the varying character of the structures.

Three major forms of algal stromatolites were established by Logan *et al.* (1964); 1) Laterally-linked hemispheroids (LLH), subdivided into close-linked hemispheroids less than a diameter apart (LLH-C), and spaced hemispheroids (LLH-S); 2) Discrete, vertically-stacked hemispheroids (SH), subdivided into those which overlap upwards (SH-C) and those which do not expand vertically (SH-V); 3) Discrete spheroids (SS), subdivided into inverted-stacked (SS-I), randomly-stacked spheroids (SS-R) and concentric spheroids (SS-C). Additions to these forms have been given by Kendall-Skipwith (1968), who established the form SH-I for inverted-stacked hemispheroids. Krüger (1969) has established three new forms from the Otavi Series of SW Africa: SC, vertically stacked cones with constant basal radius (SC-C), or variable basal radius (SC-V). The structural formula VCC-C has been designated for discrete, vertically arranged concentric cylindroids with constant diameters.

In the present investigation, only LLH and SH types and compounds of these, have been met with.

Horizontal and vertical distribution. – The stromatolitic structures have been found at all localities described earlier in this paper. The stromatolites are especially well-developed at Lunne and at Kullstaberg in the Brunflo and Lockne areas respectively, and at Oppbodarna in the Åsarna area.

Stratigraphically, stromatolites have been observed in all pre-Folkeslunda rocks. Their best development occur in the Seby and the Vikarby Limestones

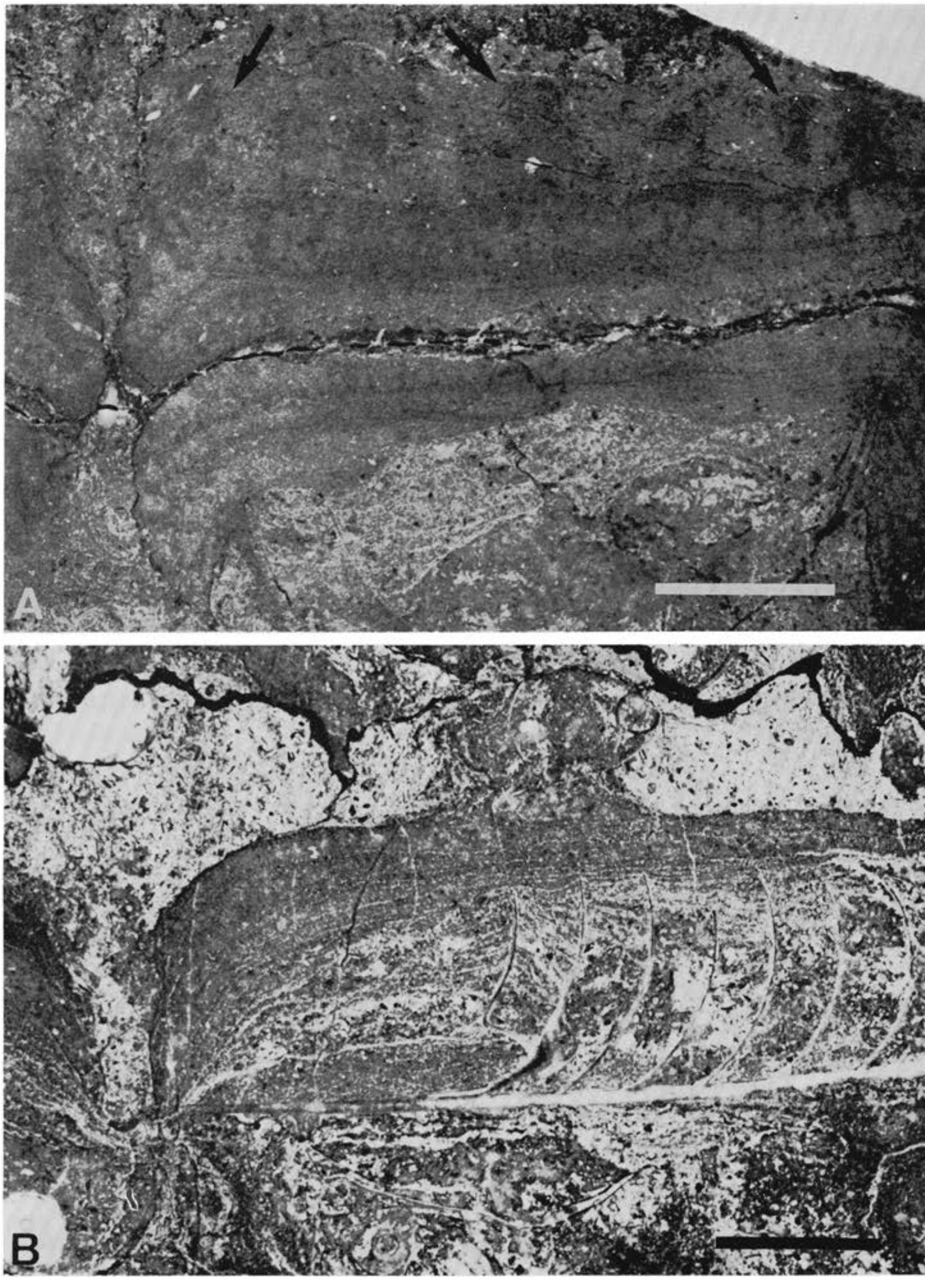

Fig. 24. A. Stromatolitic laminations dragging over an uneven discontinuity surface in the Seby Limestone at Lunne. These grade upwards into small discrete stacked domes (arrows). Polished block. Scale bar = 10 mm. B. Stromatolitic laminations draggning over a cephalopod conch. Note separating groove to the left. Seby Limestone, Lunne section. Polished block. Scale bar = 10 mm.

Fig. 25. Stromatolitic laminations with separating groove undercutting the laminations. Seby Limestone, Lunne section. Polished block. Scale bar = 10 mm.

at Lunne, Kullstaberg and Oppbodarna. At the latter locality well-developed stromatolites occur in one bed of the Skärlöv Limestone as well. In the Kårgärde Limestone, stromatolitic mats have been observed over the discontinuity surfaces in the lower part of the Limestone. At Gusta, Lunne and Gammalbodberget, it has been observed how these mats grade upwards into weakly developed domes of miniature size.

Description. – The algal stromatolites occur either as continuous mats, often wrinkled into hemispheroids, or as separate laminations over irregularities, such as fossils, desiccation polygons, uneven discontinuity surfaces, rock fragments etc. The structures are clearly visable due to an intense staining of haematite (Figs. 9, 20B and 23). On exposed weathered surfaces, selective weathering of the calcite between the haematite-rich laminae makes the structures generally stand out distinctly (Figs. 20A, 23). At a few levels in the Seby

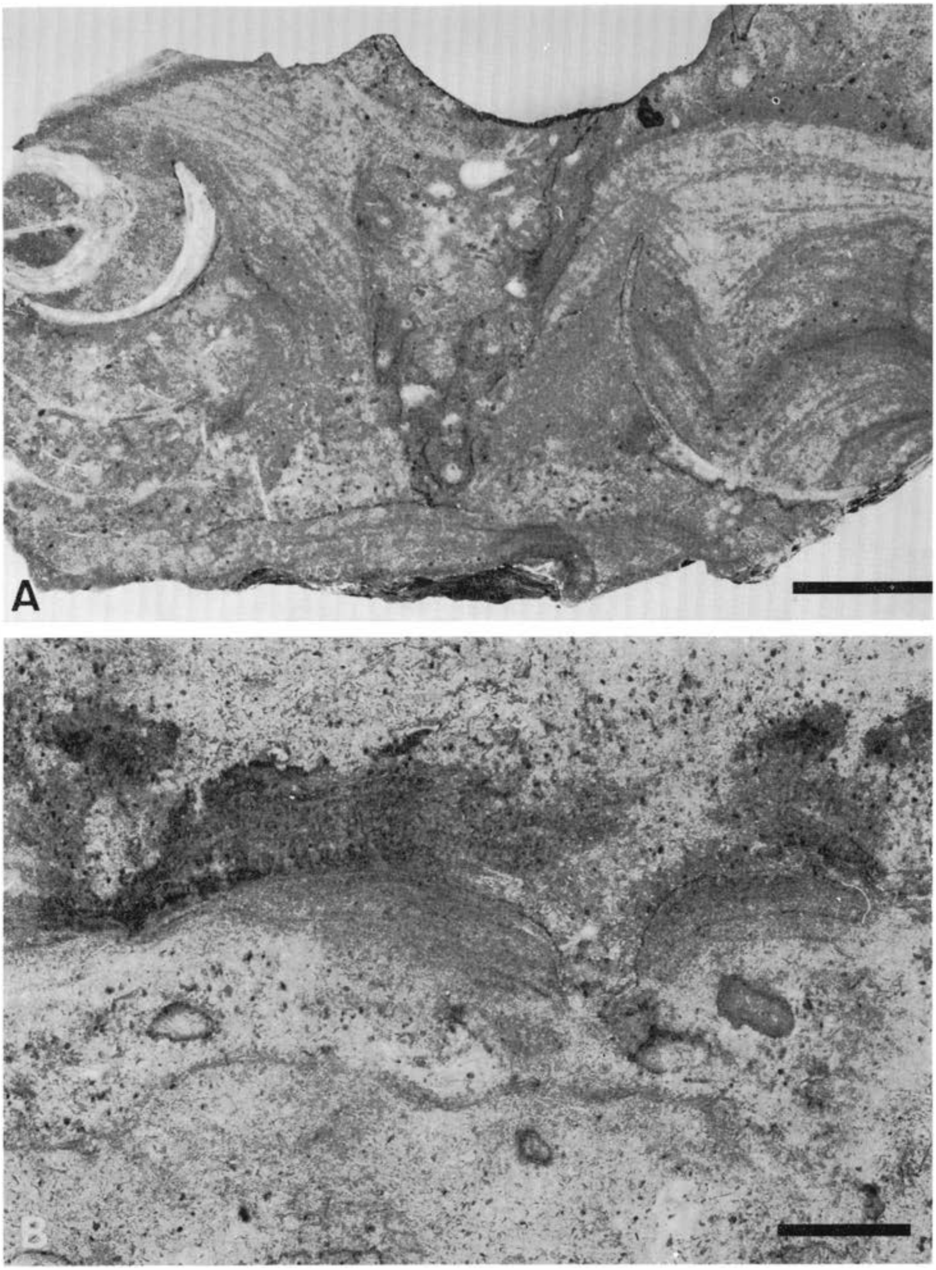

Fig. 26. A. Stromatolitic domes formed above cephalopod conchs in the Seby Limestone. Separating groove truncating the sides. Lunne section. Polished block. Scale bar = 10 mm. B. Stromatolitic domes formed above intraclasts. Vikarby Limestone. Lunne section. Polished block. Scale bar = 10 mm.

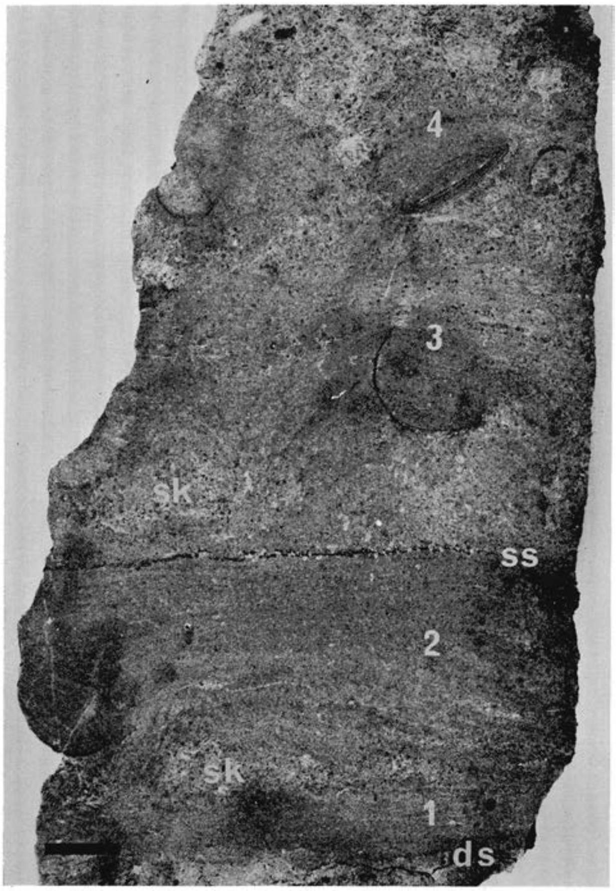

Fig. 27. Succession of stromatolitic domes formed above heaps of coarse-grained skeletal sand and fossil. Numbers denote successive generations of stromatolites. ds = discontinuity surface; ss = stylolitic surface; sk = heaps of skeletal sand. Seby Limestone. Lunne Section. Polished block. Scale bar = 10 mm.

Limestone at Lunne (Fig. 23) and in one bed of the Skärlöv Limestone at Oppbodarna (Fig. 20B), non-stained stromatolites occur, visable as fine-grained laminations in the usually calcarenitic limestone.

The algal mats occur as laminations varying between 2 to 20 mm in thickness. The laminations are conformable with the substratum, generally dragging over rough discontinuity surfaces (Figs. 5 and 24A), desiccation surfaces (Fig. 23) or fossils (Figs. 24B and 25). The mats are generally continuous, but interruptions may occur, e.g. at places where the mat covers very rough discontinuity surfaces or objects with pointed relief, e.g. abraded cephalopod conchs (Fig. 23). The laminations have a tendency of smoothing out the relief. This is illustrated at Lunne above uneven discontinuity surfaces and uneven objects, e.g. cephalopod conchs (Figs. 24B and 25).

Dome structures are the most common feature of the stromatolites. The domes are formed by convex upward laminations over pre-existing irregulari-

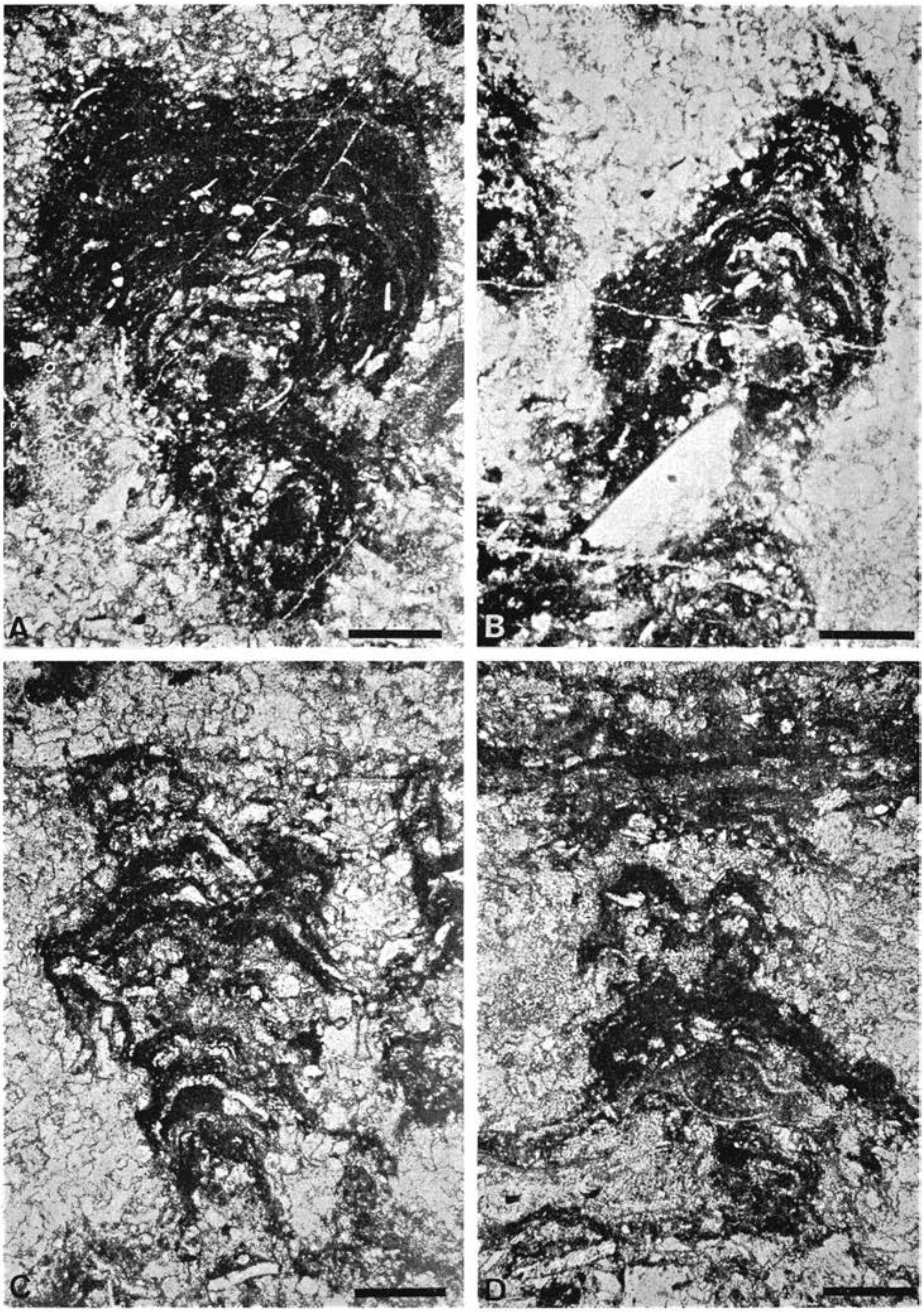

Fig. 28. Micrographs of stacked stromatolitic domes of miniature size in the Seby Limestone, Lunne. A, B. Domes of SH-V type. C. Dome of SH-V type composed of close-linked hemisphaeroids. D. Compound stromatolites of LLH-C → SH-V type. Scale bar in all figures = 500μ. Thin sections.

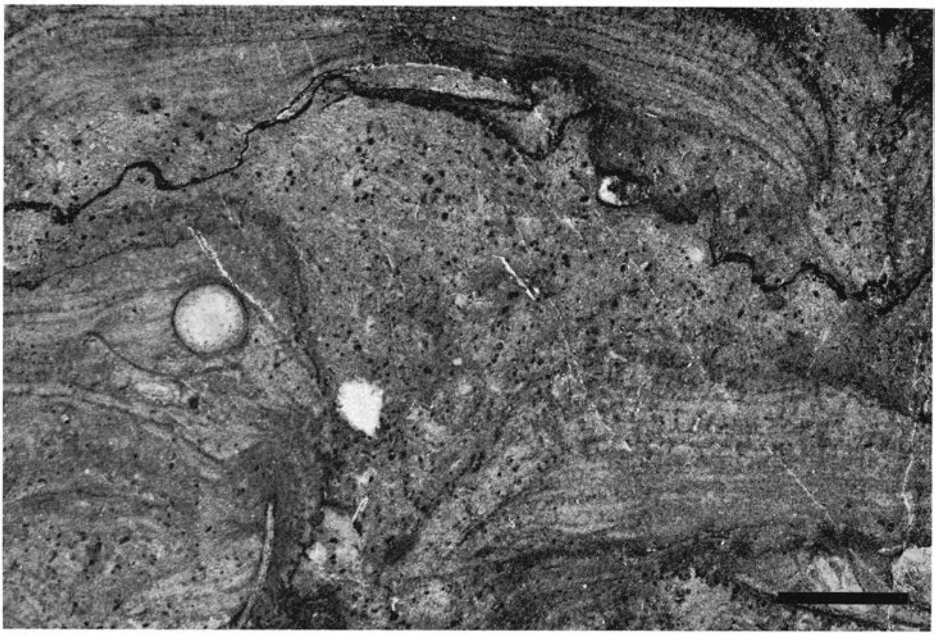

Fig. 29. Stromatolitic domes with separating grooves undercutting the laminations. Seby Limestone. Lunne section. Polished block. Scale bar = 10 mm.

ties. These consist of varying objects: fossils (Figs. 23 and 26A), intraclasts (Figs. 23 and 26B), uneven discontinuity surfaces (Fig. 9), mud cracks (Fig. 20B), pre-existing stromatolitic domes (Fig. 20B) and heaps of coarse-grained skeletal sand (Figs. 5 and 27). The most important of these are the fossils, mud cracks, intraclasts and pre-existing domes.

The size of the domes varies from 1 to 60 mm in diameter and 1 to 30 mm in height. The average size is 30 to 40 mm in diameter and 20 to 30 mm in height. Those sizes are representative for the domes found in the Vikarby and the Seby Limestones. A few exceptions have been observed, *viz.* at Lunne, where discrete, stacked and compound hemispheroids with a maximum diameter of 2 mm and a height of 3 mm, occur 44–45 cm below the top of div. (a) of the Seby Limestone (Fig. 24A). At road cut B on main road No. 81 in the Lockne area, the stromatolitic domes do not exceed a diameter of 1 cm and a height of 2 cm. The domes found in the Kårgärde Limestone are all small, not exceeding 1.5 cm in diameter and 1 cm in height. These small domes are rather well-developed at Gammalbodberget (Fig. 16B) and at Gärde (Fig. 9) in the basal part of the Limestone.

The domes consist of hemispheroids, which may be either lateral-linked (type LLH) or stacked, discrete (type SH). The lateral-linked hemispheroids

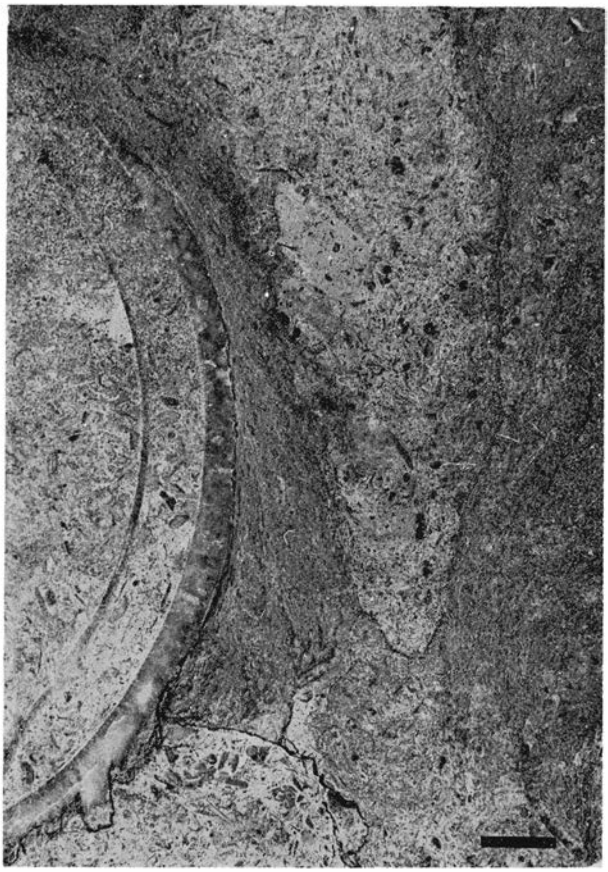

Fig. 30. Detail of separating groove showing scour-and-fill structures and the parallell arrangement of elongate particles to the lamination surface in the algal stromatolites. Seby Limestone. Lunne section. Polished block. Scale bar = 2 mm.

are fairly consistant and may be traced for a considerable distance, as seen along the walls of the Lunne Quarry. Two such horizons are particularly predominant, *viz.* at 64–66 cm below the top of div. (a) in the Seby Limestone and at 15–17 cm below the top of the Vikarby Limestone. The general appearance of the lateral-linked hemispheroids are in small groups of 5 to 10 domes. These are normally close-linked (LLH-C).

Stacked, discrete hemispheroids (SH) are less common than the preceding types. The stacking height is moderate, never exceeding 2–3 cm. The basal radius is generally constant (SH-C). Small discrete domes occur 44–45 cm below the top of div. (a) in the Seby Limestone (Fig. 24A). These are 1 mm high and 1 to 1.5 mm in diameter. The basal radius is variable, increasing or decreasing upwards, type SH-V (Figs. 28A and 28B). Often, the hemispheroids are composed of close-linked hemispheroidal laminae (Figs. 28B and 28C).

Compound stromatolites occur rarely in the investigated sequence. The only occurrence of more well-developed forms has been observed in the abovementioned horizon in the Seby Limestone with small discrete domes. Structurally, the compound forms consist of close-linked hemispheroids passing into discrete, stacked hemispheroids with variable basal radius, LLH-C→SH-V (Fig. 28D).

In several cases, the depressions between the domes have been deepened into grooves of varying depth. These grooves generally truncate the sides of the domes (Fig. 26A). They are filled by coarse skeletal sand and intraclasts, the latter sometimes deriving from torn-off pieces of the stromatolites. The scouring may sometimes also have reached deep into the substratum of the stromatolites, causing undercutting of the laminations (Figs. 6, 25 and 29). Several scour-and-fill events may be traced in these grooves (Fig. 30). The depth of the grooves generally do not exceed 2 cm. When stromatolites dome over desiccation polygons, the grooves constitute an upward continuation of the mud cracks (Fig. 20B). These may be laterally offset when several generations of stromatolites occur.

No structures which could be referred to as oncolites (type SS) have been observed. Intraclasts with laminated haematite crusts occur, but nothing supports an oncolitic origin of these.

The lamination of the stromatolites is caused by laminae alternatively rich and poor in haematite. On polished surfaces etched in dilute acetic acid, the haematite-rich laminae stand out as irregular lines (Figs. 24B, 25 and 31A). Small diffuse haematite stained lines occur perpendicular to the laminae rich in haematite in most of the structures studied (Figs. 6, 26B, 29 and 31B).

The laminations are quite smooth, although there also occurs crinkling and crenulation in some of the mats. Generally the laminations conform to the relief provided by the core. It is often difficult to trace individual lamina, excepting over very short distances.

No noticeable differences in grain-size occur between the calcareous debris trapped into the haematite stained laminae and that trapped into the interjacent haematite-poor laminae. The grain-size of the particles is <0.03 mm. Larger, scattered particles occur, however, rarely exceeding 0.2 mm in diameter. Elongate particles are deposited parallel to the surface of the laminations, even on vertical surfaces (Figs. 28A, 28B and 30), where mechanical deposition is impossible.

The thickness of the non-stained, or poorly stained laminae seldom exceed 1 mm. At Oppbodarna 2 to 3 mm thick laminae occur in the stromatolites of the Skärlöv Limestone (Fig. 20B). In the smallest structures observed, the thickness is less than 0.01 mm. The haematite stained laminae generally have a thickness of 0.05 to 0.5 mm.

Varying thicknesses of separate lamina generally occur across the structures. The laminae are thickest on the crest of the domes, tapering towards the

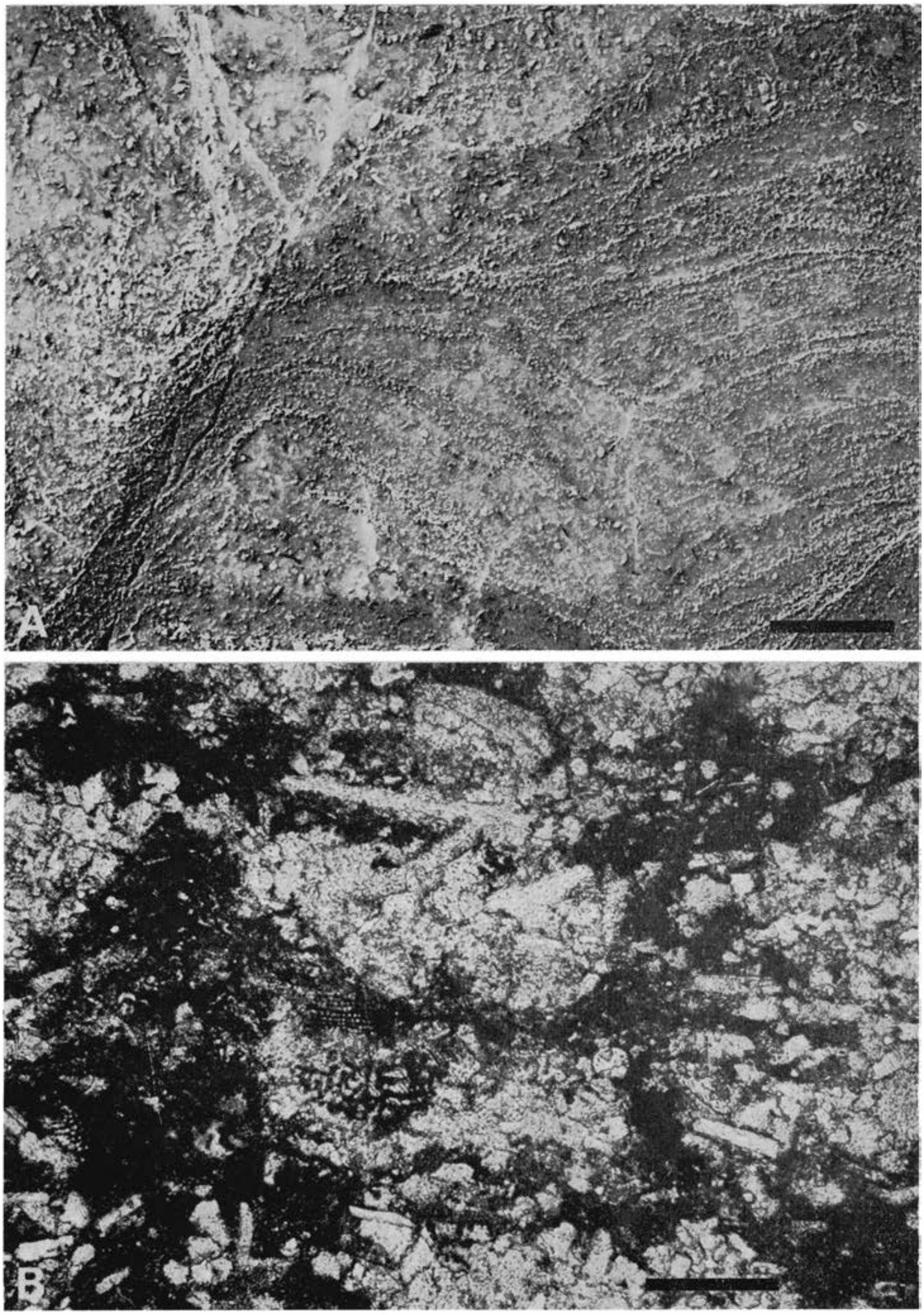

Fig. 31. A. Strongly etched stromatolitic domes with distinct laminations. Note the discordance between the two domes. Seby Limestone. Lunne section. Scale bar = 10 mm. B. Micrograph of thin section showing diffuse haematite stained lines perpendicular to the haematite laminations. Vikarby Limestone. Lunne section. Scale bar = 500μ.

sides of the domes (Figs. 26B and 29). These variations are mostly symmetrical.

Erosional features within the laminations, such as truncations, scour marks etc. rarely occur. They have only been observed in a few structures. Truncations of the laminations on the sides of the domes are on the other hand common (Figs. 25, 26A and 29). These truncations could probably be ascribed to the scouring effect by the traction load. Discordances in the laminations have only been observed in a few domes (Fig. 31A).

No birdseye structures have yet been observed in the stromatolites.

Mode of formation. – The described stromatolitic structures are obviously of algal origin. Studies on recent mats in the Carribean Sea (Monty 1967; Gebelein 1969), Persian Gulf (Kendall & Skipwith 1968) and Western Australia (Logan 1961) have shown how mucilagenious algae are binding sediment particles into mats and domes of varying shapes, the morphology depending on the environmental conditions.

In the structures studied in this paper, the true stromatolitic character is shown by the arrangement of elongate particles parallel to the lamination surface, even on the downwarping sides of the domes. These particles have probably been deposited in the laminations due to the agglutination onto the mucilagenious sheaths of the algae and not formed by mechanical accumulation of the sediment.

In recent stromatolites, blue-green algae play the major rôle as sediment binders. The colonies of algae are either monospecific or polyspecific. Their mucilagenious covering forms a sticky, rubbery mat, which traps debris washed over it or precipitated from a suspension. At low tides this covering permits prolonged exposure of the algae without expiration. During longer exposure, the algal mat is dried up and broken into leathery fragments and cracks (Logan *et al.* 1964).

Recently (1967) Monty has pointed out the ability of certain blue-green algae to precipitate lime in some types of mats.

The trapping of particles is selective and only fine-grained material is agglutinated. Thus, there is generally a pronounced difference in grain-size between the stromatolitic body and the surrounding sediment. Gebelein (1969) noted a ten-fold decrease of the grain-size in the stromatolites compared to the non-stromatolitic portions. This decrease is also evident from the stromatolites studied, although no measurements have been made to determine the magnitude of the ratio of decrease. The conditions described shows that the grain-size of the stromatolite itself does not give a true picture of the character of the sediments being transported over the area.

Two phases of algal growth are recognized (Monty 1967; Gebelein 1969), *viz.* one with erect growth during daylight with sediment trapping, and one with prostrate growth during darkness with binding of the sediment. In the structures described in this paper, the erect haematite lines in the non-stained laminae are believed to reflect the erect growth, whilst the horizontal haematite-rich laminae reflect the prostrate growth. This is further supported by the greater thickness attained by the non-haematitic laminae, being formed during the trapping phase.

The assumption above is based on the thought that the haematite is confined to algal activity. Admittedly, the occurrance of haematite in the stromatolites described in this paper is still obscure. It is possible that the presence of the mineral depends in some way or other on the organic component of the stromatolitic mat, either through selective trapping or precipitation of ferriferous compounds by the algae. This is to some extent suggested by the occurrance of haematite in the grey Vikarby and Seby Limestones, where the mineral is mainly confined to the stromatolites. The formation of ferriferous compounds when plants are present might be the same as that described by Hessland (1949).

The relief of the bottom is of great importance for the formation of domes (cf. Gebelein 1969). When an algal mat forms over irregularities on the bottom, the slopes of the highs may be abraded by the traction load. The upward growth is then favoured by the more active sediment binding at the top, where fine-grained particles in suspension are trapped. The upward growth is further favoured by the greater response to light of the algae on the top of the domes, than on the more shaded sides. When the relief between close-spaced highs and depressions is great, the depressions become areas of preferential water flow and sediment transport during tides, and the growth is diminished towards the sides of the highs, where there is longer wetting and better drainage. If the traction load is heavy, this results in the destruction of the mat in the interarea and the inhibition of the mat growth due to the abrasional and scouring effects (Logan *et al.* 1964; Gebelein 1969). Kendall & Skipwith (1968) have also suggested that the mat growth in the depressions of intertidal stromatolites is inhibited by raised salinity of the accumulated water during low tides. No evidence of this, e.g. gypsum pseudomorphs (Hudson 1970) has been observed in the studied stromatolites.

The present dome structures are supposed to have been initiated and formed by at least two factors working separately or in combination. These are (1) doming over pre-existing irregularities and (2) differentiation of relief features by more active sediment binding in the highs and inhibition of the mat growth in depressions.

The first factor seems to have been the most important at the initial stage. Among irregularities, fossils, desiccation surfaces and uneven discontinuity surfaces are by far the most common, although intraclasts also play an important rôle. These circumstances are also in good agreement with the formation of recent stromatolitic domes. Black (1933) observed, for example, how desiccation polygons were covered with algal mats, the polygonal outline getting lost with further growth and a hemispheroid was finally formed. The later stages of the upward growth were mainly favoured by an increased sediment binding effect at the top of the dome.

Once a stromatolite forming process has started, several generations may succeed each other, only being separated by shorter erosional events. The initiating irregularities may be varying in such a succession. The first dome may form above a desiccation polygon, the outline then being repeated by several succeeding generations of domes (Fig. 20B).

Among the fossils, cephalopods are common initiators of the domes, especially in the Vikarby and Seby Limestones (Figs. 25, 26A, 27 and 29). Trilobites and ostracodes are also important, the latter in the micro domes described from the Seby Limestone (Fig. 28B).

The second factor favouring the formation of domes is shown in the thicker laminations at the crests of the domes (Figs. 26 and 29). The coarse particles filling the depressions and grooves between the domes (Fig. 26A) are thought to reflect the scouring agents abrading the sides of the highs and inhibiting the lateral growth.

Environmental significance. – The usefulness of stromatolites as an indicator of the environment in which they have been formed has been apparent since Black's (1933) description of recent stromatolites from periodically exposed calcareous mudflats on Andros Island, Bahamas. The physical factors controlling their distribution and morphology were shown, as was the similarity with fossil stromatolitic structures. Since Black's paper, numerous accounts on recent stromatolite-bearing carbonate environments have been published, which have provided further reliable criteria for the identification of stromatolites in ancient rocks and given material for palaeoenvironmental implications. In all these papers the prevailing concept has been, that stromatolites are significant for intertidal and supertidal environments. Especially their usefulness on fossil material as indicators on subaerial exposure has been emphasized (Logan *et al.* 1964). Associated desiccation features such as mud cracks, birdseye structures, crinkling, brecciation, and the presence of intraclasts have been presented as evidences on an intertidal or supratidal mode of formation.

Owing to recent papers by Monty (1965, 1967) and Gebelein (1969), who proved the formation of stromatolites in a subtidal environment, stromatolites alone in a sequence cannot any longer be used for environmental interpretations or as evidence for intermittent subaerial exposure. The need for a careful examination of the lamination morphology of the structures as well as the sedimentary features in the non-stromatolitic portions is obvious. Then only, a clear picture of sedimentological conditions, fluctuations in environment and the overall palaeogeographical setting may be obtained. Any single criteria alone is not sufficient to indicate environment (Walker & Laporte 1970).

The different factors influencing the formation of stromatolites in supra- and intertidal environments, have been summarized by Logan *et al.* (1964). That paper as well as other papers show that the varying shapes attained by the stromatolites is a response to difference in location, exposure and tidal amplitude.

The presence of algal mats in supratidal environment depends on abnormal high tides or wetting by storm waters. The supratidal mats are generally broken up into cracks and leathery fragments, which form intraclasts when flooded. Other important desiccation phenomena are crinkling, crenulation and birdseye structures. The latter consist of small voids or vugs, which normally are filled by calcite or anhydrite. Their diameter is generally only a few millimetres. Shinn (1968) has shown that these voids have been formed either by gas bubbles or shrinkage resulting from desiccation. Birdseye structures are common and typical for supratidal carbonate sediments. Sometimes they may also be present in intertidal sediments, but never in subtidal sediments.

Recently Multer & Hoffmeister (1968) have demonstrated subaerially formed crusts from the Florida Keys, formed by subaerial weathering and showing great similarities to laminations of marine algal origin. Very often, the latter laminations are superimposed upon the subaerial crusts, thus leading to confusion and misinterpretation of the ancient environment if caution is not observed. Differentiating features still exist, e.g. crusts will never form domes, do not show desiccation features and remain the same size-grade within the laminations.

The lamination of the stromatolitic mat in a supratidal environment is usually irregular. The sediments are characteristically dolomitized on a lamina-by-lamina scale (Walker & Laporte 1970).

The distribution of algal mats in intertidal settings are determined by tidal amplitude and slope of the littoral substrate. The intertidal mats are thicker than those of the previous described setting and generally more regular. They may grade into dome structures, either formed as laterally-linked hemispheroids (LLH) or as discrete, stacked hemispheroids (SH). The latter type occurs predominantly in more exposed settings. In exposed intertidal areas, where wave action is predominant, spheroidal structures (SS) may form. The prime factor controling the growth of these srtuctures is continuous movement of laminated bodies. These may derive from tornoff pieces from SH stromatolites during abnormous wave action, e.g. during storms (Ginsburg 1960).

The morphology of the domes is controlled by sediment movement, current velocity and wave action. During high tide, when the algal mat terrain is inundated, fine sediment particles in suspension stick to the mucilagenious coatings around the algal filaments and bind into the laminae. The most active trapping and binding occur on the top of the highs. The dome formation is further affected by the inhibition of mat growth at the sides of the domes, due to the coarse traction load, which has a scouring effect. Accumulating tidal and storm waters and coarse sediment particles in depressions between the highs are also inhibiting factors of the mat growth. In higher intertidal positions it is possible that an increased salinity of this water inhibits the mat growth as suggested by Kendall & Skipwith (1968).

Discrete, stacked hemispheroids (SH) are characteristic of a more exposed setting than the laterally-linked hemispheroids (LLH). Mechanical factors are important for the inhibition of the growth of the algal mat in the depressions, thus favouring upward growth. Runoff tidal waters and wave action concentrated in the depressions inhibit mat growth by a simple scouring effect. A tendency to develop elongated domes, parallel to the direction of wave action is noted (Logan 1961; Howe 1966).

Sedimentary features characteristics of the intertidal environment, include mud cracks, intraclasts, erosional channels. Biogenic activity such as vertical burrows are also recognized in this setting.

Subtidal stromatolites are controlled in still higher degree by hydrological and sedimentologic factors than previous stromatolites. As was shown by Gebelein (1969), distribution and morphology are influenced by supply of sediment, grain-size, rate of sediment movement, current velocity and wave action. In areas with accumulation of coarse skeletal material no stromatolites can form, as the algae lack the ability to bind coarse particles. When sediment movement is too rapid the mechanical abrasion becomes too high for a permanent binding. This regime may instead be characterized by ripples. Local conditions such as turbulance and turbidity may have influence in the micro structures such as truncation and discontinuities between the laminae (Monty 1967). Gebelein (1969) has shown that symmetrical laminations in domes, without any preferential thickening on one side, is caused by an equal supply of sediment on both sides of the axis of movement.

Mat thickness also reflects the physical conditions prevailing during their formation. On the island of Bermuda, areas of increased thickness of the algal mat correspond to areas of decreased rates of sediment movement, i.e. in deeper water, where current velocities are lower. The size and shape of the domes are also controlled by the water depth (Monty 1967). Flatter domes are formed in shallower or more turbulent settings, while higher, more dome-shaped stromatolites form in deeper or quiter areas where growth is rapid and regular.

The sediments of the subtidal environment in general show greater lithologic homogeneity than those of other environments. All those features found in the sediments of the other tidal settings are absent in this environment. Biotic activity such as burrowing is common.

Environmental synthesis. – For reasons discussed previously, additional environmental criteria besides stromatolites must be considered to give reliable environmental interpretation of an ancient rock record. Recently (1970), such criteria, mainly physical in nature, have been reviewed by Walker & Laporte, simplifying the identification of ancient tidal carbonate flats. As previously described several of these criteria such as mud cracks, intraclasts and erosional channels are met with in the Lower Viruan deposits of Jämtland. The following account summarizes some conclusions that can be drawn from the stromatolite-bearing sequence.

The morphology and occurrence of the described stromatolites as well as the sedimentological features of the Lower Viruan sequence of Jämtland, suggest a deposition in a tidal flat region on the landward side of a shallow epeiric sea.

During the deposition of the Kårgärde Limestone, subtidal conditions prevailed, with a few exceptions. In the lower and middle parts of the Member, stromatolites occur only associated with discontinuity surfaces. Very likely, the development of the stromatolites as continuous mats and their position directly upon the discontinuity surfaces, represent an initial phase of inundation of a previously subaerially exposed carbonate mud flat. The appearance of several discontinuity surfaces as desiccated surfaces, may imply that the lowermost part of these mats are supratidal, although no positive evidence, such as birdseye structures or early dolomitization, can be presented. The gradual upward transition to laterally-linked domes shows that more intertidal conditions followed subsequently. This is further shown by the calcarenitic character of the limestone above the discontinuity surfaces. Another characteristic feature is the accumulation of trilobites and cephalopods in this portion. These are often covered by discrete algal domes of moderate size (Fig. 9). It cannot be excluded that these stromatolites are subtidal. This assumption is supported by the biomicritic character attained by the limestone immediately above the discrete algal domes.

During the deposition of the Vikarby Limestone and the lower and middle parts of the Seby Limestone, the fluctuations between supratidal and intertidal/subtidal environments were frequent. Compared to the previously discussed period, the energy conditions were considerably higher. The continuous algal mats superimposed upon the desiccation surfaces are obviously formed in supratidal or high intertidal environment. The lack of supratidal indicators such as birdseye structures and early dolomitization in these mats favours the second hypothesis. However, there is also positive evidence that periods of supratidal conditions existed. Some of the discontinuity surfaces in the Vikarby and Seby Limestones have features suggesting longer events of subaerial exposure of the carbonate flat. These surfaces show overhanging portions, indicating that the sediment was indurated and weathered before the deposition of the overlying rock. This could probably only occur when the sediment flat was subaerially exposed for a longer period. Furthermore, the bleached character of the limestone below these surfaces suggests a longer subaerial exposure. Discontinuity surfaces having these features are those separating the Kårgärde and Vikarby Limestones and the Vikarby and Seby Limestones at Lunne. The main number of the desiccation surfaces of these limestones lack the described features, thus giving no suggestions whether they were formed in a supratidal environment or during low tides in an intertidal environment. As pointed out by Walker & Laporte (1970), fluctuations in sea level may be caused by phenomena other than diurnal tides, e.g. by seasonal storms, shifting wind directions or periodic barometric changes. Tidal mud flats with low relief must have been especially sensitive to such phenomena. In the Vikarby and Seby Limestones such abnormal variations in sea level may explain the accumulations of cephalopod conchs lying directly upon desiccation surfaces. In a few cases these cephalopods occur inserted into algal mats and domes (Fig. 25). Sometimes the domes may be overturned (Fig. 5).

The continuous mats are generally succeeded by well-developed laterally-linked domes, which probably reflects intertidal conditions during the formation of these stromatolites. This is also supported by the erosional grooves separating these domes. They have probably been formed by abrading tidal currents. The grooves also show typical intertidal features such as scour-and-fill structures and carbonate intraclasts. In several cases, well-developed laterally-linked domes are formed directly upon a desiccation surface. This could imply that this surface was formed in an intertidal environment during low tides and then directly covered by an algal mat during high tide conditions.

Above the continuous algal mats and laterally-linked domes, the poorly washed biosparitic limestone and the abundant carbonate intraclasts suggest low intertidal or subtidal conditions. The carbonate intraclasts probably derive from torn-off pieces of the indurated and desiccated mud flat during low tides. Subsequent flooding by high tides have re-distributed these intraclasts across the sediment surface within the intertidal zone. The stromatolites found in these portions generally occur discontinuously over the abundant fossils. The low intertidal character of this portion is further indicated by the occurrence of comparatively few taxa but many individuals. The environment has been wetted often enough to provide good and relatively permanent conditions for the inhabitants. In the higher positions of the intertidal environment, some of the organisms were not continuous inhabitants but moved up and down the flats with the diurnal tides. The abundant occurrences of especially ostracodes, trilobites and small gastropods in these portions of the limestone are probably a response to the abundant food resources provided in the tidal environment, not least by the algal mats. The rugged top surfaces of many algal domes (Figs. 20B and 26B), may depend on the activity of algal-browsing organisms.

The previous account is based on observations made in the Brunflo area.

In the other areas, the same major environmental interpretations are valid, with a few exceptions described below.

During the deposition of the Kårgärde Limestone, the depositional environment was fairly uniform in all three investigated areas with mainly subtidal conditions prevailing, interrupted by some events of intertidal and supratidal conditions. In the Lockne area these littoral conditions involved the formation of a polymict conglomerate in the uppermost part of the Member.

The Vikarby Limestone in the major part of the Lockne area was deposited under the same conditions as those described from the Brunflo area. Still, one exception exists, *viz.* at Bergsböle, where the lack of desiccation surfaces and stromatolites as well as the coquinoid accumulation of trilobites, cephalopods and hyolithids and the poorly washed biosparitic character of the limestone, suggest permanent subtidal conditions. In the Åsarna area, certain variations in depositional environment occurred during the formation of the Vikarby Limestone. At Oppbodarna, the numerous desiccation surfaces and abundant stromatolites indicate intertidal conditions, while Gammalbodberget seems to have had a more subtidal position during the major part of the deposition.

During the Skärlöv age, the occurrence of desiccation surfaces associated with stromatolites indicate tidal conditions during at least two periods in the Åsarna area. In the Lockne area, no evidence on near-shore conditions occurs during the corresponding time. In the Brunflo area, non-depositional conditions were probably prevalent, but it cannot be proved whether these were marine or subaerial.

Finally, during the deposition of the Seby Limestone, both the Lockne and Åsarna areas occupied a more off-shore and stable position compared to the Brunflo area. In these two areas desiccation surfaces and stromatolites are met with at a few levels only.

In conclusion the stromatolites described in this paper, when used in conjunction with lithological characteristics, are useful as an index to rather specific environments that in summary were (1) marine, (2) intertidal to supratidal, (3) characterized by relatively moderate energy conditions, and (4) probably associated with oscillatory transgressional and regressional phases of sedimentation. The alternation of laterally-linked domes and mats, as well as their close association to desiccation surfaces, are common characteristics of their occurrence.

Table 4. List of the species found in the Aserian and Lasnamägian beds of the autochthonous of Jämtland.

	Aseri Stage		Lasnamägi Stage		
	Segerstad L.				
	Kårgärde L.	Vikarby L.	Skärlöv Limestone	Seby Limestone	Folkeslunda Limestone
Trilobita					
Asaphus (Neoasaphus) platyurus Angelin	+	+	—	—	—
Asaphus (Neoasaphus) demissus Törnquist	—	+	—	—	—
Asaphus (Neoasaphus) sp. sp.	—	+	—	+	+
Pseudoasaphus aciculatus (Angelin)	—	—	—	+	—
Pseudoasaphus tecticaudatus (Steinhardt)	—	+	—	+	+
Pseudobasilicus ? brachyrachis (Törnquist)	—	—	—	+	—
Plectasaphus plicicostis (Törnquist)	—	—	—	+	+
Pseudomegalaspis patagiata (Törnquist)	—	—	—	+	+
Pseudomegalaspis sp.	—	?	—	+	+
Nileus sp. sp.	—	—	—	+	+
Remopleurides sp. sp.	+	+	+	+	+
Illaenus planifrons Jaanusson	—	+	—	—	—
Illaenus chiron Holm	—	—	—	+	+
Illaenus sp.	+	—	—	—	—
Lonchodomas sp.	—	—	—	—	+
Paraceraurus cf. *exsul* (Beyrich)	—	—	—	—	+
Ostracoda Palaeocopa					
Chilobolbina lativelata Jaanusson	+	—	—	—	—
Chilobolbina sp.	+	—	—	—	—
Laccochilina (Laccochilina) cf. *paucigranosa* Jaanusson	—	—	—	+	+
Laccochilina (Laccochilina) bulbata Jaanusson	+	+	+	—	—
Laccochilina (Laccochilina) n. sp.	—	—	—	+	—
Laccochilina sp. sp.	+	+	—	+	+
Piretella tridactyla Jaanusson	+	+	—	—	—
Piretella n. sp.	—	+	—	+	—
Piretella sp.	+	—	—	—	—
Piretia n. sp. A	—	—	—	+	—
Piretia n. sp. B	+	—	—	—	—
Piretia sp.	+	+	—	—	—
Euprimites effusus Jaanusson	+	+	+	+	+
Euprimites cf. *effusus* Jaanusson	—	—	—	—	+
Euprimites anisus Jaanusson	+	—	—	—	—
Euprimites bursa (Krause)	—	—	+	+	+
Euprimites n. sp.	—	+	—	+	—
Tallinnella sebyensis Jaanusson	—	—	—	+	—
Tallinnella sp.	+	—	—	—	—

Table 4 (continued)

	Aseri Stage		Lasnamägi Stage		
	Segerstad L.				
	Kårgärde L.	Vikarby L.	Skärlöv Limestone	Seby Limestone	Folkeslunda Limestone
Steusloffia linnarssoni (Krause)	+	+	+	+	+
Steusloffia sp.	+	—	—	—	—
Conchoprimitia n. sp.	—	—	—	—	+
Conchoprimitia sp. sp.	+	—	—	+	—
Cephalopoda					
Angelinoceras latum (Angelin)	+	—	—	—	—
Angelinoceras sp.	+	—	—	—	—
Lituites sp. sp.	—	?	—	+	+
Ancistroceras sp.	—	—	—	+	—
"*Orthoceras*" *nilssoni* (Boll) sp. coll.	+	+	—	—	—
Geisonoceras ? *centrale* Dalman	—	+	—	—	—
"*Conorthoceras*" *conicum* (Hisinger)	—	—	—	+	—
Cameroceras sp.	—	+	—	—	—
Hyolithida					
Dorsolinevites dispar Holm	—	+	—	—	—
Hyolithes sp. sp.	—	+	—	+	—

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