1. The Viruan (Middle Ordovician) of Kinnekulle and Northern Billingen, Västergötland

By

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ABSTRACT.—The stratigraphy of the Viruan (Middle Ordovician) sequence of Kinnekulle and northern Billingen in Västergötland, south-central Sweden, is described from the information obtained from cores of three borings and from examinations of some selected outcrops. The Aserian beds on the south-eastern slope of northern Billingen are very thin. They are separated from the under- and overlying beds by a considerable break and belong exclusively to the upper part of the stage (Vikarby Limestone). On Kinnekulle the Aserian deposits are entirely missing. On the south-eastern slope of northern Billingen the Vikarby Limestone is overlain by a few variegated, preponderantly calcarenitic beds of Lasnamägian age for which the new term Skövde Limestone is proposed. Their correlation with Lasnamägian divisions in the other districts is uncertain. Overlying the Skövde Limestone is a thick sequence consisting mostly of mudstones with limestone nodules here referred to the new division Gullhögen Formation. On eastern Billingen the lowermost part of the Gullhögen Formation is probably of late Lasnamägian age, whereas the age of the main part of the formation is early Uhakuan. At present it is impossible by either faunal or lithological criteria to determine within the Gullhögen Formation the level of the boundary between the Lasnamägi and Uhaku Stages. On Kinnekulle the Skövde Limestone is missing, and the Gullhögen Formation rests directly upon the Ontikan Kunda Stage. Because the lowermost part of the Gullhögen Formation, as developed on Billingen, is obviously also missing on Kinnekulle, the possibility is not excluded that there the basal Viruan beds are of early Uhakuan age. The late Uhakuan beds of Västergötland are developed as a tongue of the Furudal Limestone and are designated here with the new name Ryd Limestone.

The *Ludibundus* beds are subdivided into two formations, viz. the Dalby Formation and the Skagen Formation (new name, corresponding to the suprabentonitic *Ludibundus* beds in Västergötland). On Kinnekulle and Mösseberg the Dalby Limestone can be subdivided into two members. The Lower Member is relatively thin and consists of calcilutites in the lower part and calcarenitic calcilutites to calcarenites in the upper part. The Upper Member has a thin, oölitic calcareous mudstone with chamosite oöids at the base and consists preponderantly of mudstones with occasional beds of calcilutite. On Billingen and Varvsberget the whole formation is composed of limestones which are calcilutitic in the basal part and preponderantly calcarenitic in the main upper part. On eastern Billingen the formation has its minimum known thickness in Sweden.

The Skagen Limestone consists of calcilutites and calcareous mudstones and contains a distinctive fauna. It is suggested that the Skagen Limestone of Västergötland comprises the lower part of the suprabentonitic *Ludibundus* beds only, and that beds corresponding to the upper part of the suprabentonitic *Ludibundus* beds of Östergötland and the Siljan district are missing in Västergötland. If this is correct, the Skagen and Mossen Formations on Kinnekulle are separated by a considerable break which probably also involves beds comparable to the lower part of the zone of *Dicranograptus clingani*. On the south-eastern slope of northern Billingen beds comparable to this graptolite zone are completely missing, and the Skagen Limestone is directly overlain by Harjuan (Upper Ordovician) strata.

Discontinuity surfaces at the base of the Viru Series are described in some detail.

Contents

Introduction

The present paper deals with the description of the Viruan (Middle Ordovician) sequence on Kinnekulle and northern Billingen in Västergötland, south-central Sweden. It is the fourth contribution in the series of papers by the present writer devoted to the general description of the Viruan shelly strata of Sweden. In the previously published reports (Öland, JAANUSSON 1960*a*; Östergötland, JAANUSSON 1962; the Siljan district in Dalarna, JAANUSSON 1963) only the infrabentonitic (Lower and Middle) Viruan sequence has been treated, and a description of the suprabentonitic part of the series has not yet been published. In this paper also the suprabentonitic Viruan strata are included up to the top of the *Ludibundus* beds. The topmost Viruan unit of Kinnekulle, the Mossen Formation (*Dicranograptus clingani* beds), has recently been exhaustively described by SKOGLUND (1963), and here only some remarks are given.

The paper is based on three borings, viz. Kullatorp and Norra Skagen on Kinnekulle, and Stora Åsbotorp on northern Billingen. In addition several exposures have been examined, particularly the Mossen section on Kinnekulle and the Gullhögen quarry on Billingen. Until the borings became available the strata in question were among the least-known parts of the Cambro-Silurian sequence of Kinnekulle and Billingen. This is due to a pelitic development of much of the Viruan deposits, particularly on Kinnekulle. There the soft shales, mudstones, and finely nodular limestones are rarely accessible in natural exposures and seldom quarried for practical purposes. The existence of some Viruan divisions (the complex of bentonitic beds in the Dalby Limestone and the *Dicranograptus clingani* Shale) on Kinnekulle became known first in connection with the borings (THORSLUND 1945, 1948), and some of the basal Viruan strata of Billingen described in the present paper were previously virtually unknown. The presence of a considerable break at the base of the Viru Series on Kinnekulle and Billingen was not expected.

On southern Billingen and in Falbygden considerable parts of the Viruan sequence still remain to be described. These areas lie outside the scope of the writer's stratigraphical studies as originally planned. Preliminary and brief descriptions of the Viruan portion of the available borings in these areas have been published by SKOGLUND (1963). Only one of these borings (the Häggum boring on southern Billingen) pierces the entire Viru Series, but the infrabentonitic part of this core has not yet been studied and is not included in SKOG-

LUND's descriptions. All the other borings do not reach the base of the Dalby Limestone.

The main field work for the present study was carried out during part of the summer of 1957, but the exposures were visited repeatedly on several other occasions. As in the case with the study of the Viruan strata of the other districts only some selected exposures of the area were studied in detail, and no effort was made to find or examine all small outcrops of the strata in question.

The methods used are those summarized by JAANUSSON (1960*a*). In this paper the lithologic studies are less complete than in the treatment of the other districts and, in some respects, than is necessary for obtaining a satisfactory conception about the composition of the described strata. This is due, in part, to the fragmentary condition of parts of the cores when submitted to the present writer for study.

The paper has been elaborated at the Palaeontological Institute of the University of Uppsala, and the writer is deeply indebted to the Director of the Institute, Professor PER THORSLUND, for much generous help, constructive criticism, and for placing much of his unpublished material on the strata in question at the writer's disposal. In 1957 Dr. HINREK NEUHAUS accompanied the writer in the field and has collected some of the best material. Dr. JÜRI MARTNA generously placed his unpublished detailed section of the Skagen Limestone at Mossen as well as an extensive series of samples from that exposure at the writer's disposal. At an early stage of this study Mr. RAGNAR NILSSON, Lund, kindly identified many of the flattened graptoloids found in the mudstones of the cores. The extensive help from the technical staff of the Palaeontological Institute, Uppsala, is gratefully acknowledged. The cores of the Norra Skagen and Stora Åsbotorp borings were lent for study by the authorities of the Geological Survey of Sweden.

Historical Review

KINNEKULLE.—The first who referred to a specific part of the Viru Series on Kinnekulle seems to be LINNAEUS (1747). He describes a division, termed by the local population as *gorsten*, which overlies a sequence of limestones termed *rödsten* (= Ontikan beds) or *röd täljsten* (the uppermost part of *rödsten*). The prevailing type of the *gorsten* is described as coarse, nodular, brownish limestone which disintegrates in the air or at quarrying in rounded, apple-shaped pieces (LINNAEUS 1747, pp. 23 and 40). The slope of the mountain immediately above the outcrop area of the *gorsten* is steep (*Höga backar*) and covered with boulders (*gråstenar*). It is obvious that LINNAEUS' division *Gorsten* corresponds to LINNARSSON's (1869) division *Leversten*, and to the Gullhögen and Ryd Formations of the present paper. The figure, 77 *alnar* (= *c*. 46.2 m), given by LINNAEUS as the approximate thickness of the *Gorsten* is evidently meant as the total thickness of *Gorsten* as well as of *Rödsten* (cf. also his diagrammatic section of Kinnekulle).

ANGELIN (1854, p. VI) distinguished within his *Regio Trinucleorum* a lower division, lettered *Da* and characterized by *Asaphus glabratus* and *Ampyx costatus*.

Kinnekulle is the only locality given by him for the occurrence of these species in Sweden, and hence this mountain evidently is his type area for this division. These species indicate that the stratum *Da* corresponds to what in this paper is termed the Dalby and Skagen Formations. ANGELIN did not give any information about the characters of the rock in this division.

Further information about the upper part of the series on Kinnekulle was given by ROEMER (1856, p. 807). He recorded, from a verbal communication by ANGELIN, the presence of dense marly limestones with siliceous beds (= evidently the Skagen Limestone and the immediately underlying beds of the Dalby Formation) which, in ANGELIN's opinion, rest upon the Orthoceratite Limestone. Between these limestones and the *Ampyx* Marl (= Jonstorp Formation) are beds characterized by a species of *Cytherina.* No information was given about the rock of the beds with *Cytherina*, and it is difficult to understand exactly which part of the sequence is meant. LINNARSSON (1869, p. 33) suggested that the beds with *Cytherina* might correspond to the upper part of his *Beyrichia* Limestone, but it does not seem excluded that ANGELIN referred to the shales of the Mossen or Fjäcka Formations, or both. In these shales small, smooth ostracodes (*Parapyxion obesum*, *Conchoprimitia* ? *nigra*) are locally abundant. ROEMER himself did not succeed in finding any exposure of these beds on Kinnekulle.

LINNARSSON (1866, p. 10) recorded the occurrence of a hard, greenish-black shale with *Echinosphaerites* above the Orthoceratite Limestone in Västergötland but did not supply information about the site of the exposure. These beds between the Orthoceratite Limestone and the Trinucleid Shale he (1868, p. 58) distinguished as a separate division, *Beyrichia* Limestone.

The first more or less complete description of the Viruan sequence of Kinnekulle was given by LINNARSSON (1869, pp. 32–33) in his monographic treatment of the Palaeozoic rocks of Västergötland. The lower part of the series was included in the Orthoceratite Limestone as its uppermost member, the *Leversten* (= liverstone, a name for these beds used by local inhabitants; LINNAEUS (1747, p. 22) has used this term in a quite different sense). In the classification proposed in the present paper the *Leversten* corresponds to the Gullhögen Formation and the Ryd Limestone. Upon the *Leversten* rests the *Beyrichia* Limestone (= Dalby Formation and Skagen Limestone of the present paper). LINNARSSON recorded also that the overlying beds consist of a black shale (= Mossen Formation and Fjäcka Shale). According to him the black shale has a fairly considerable thickness, and the lithological boundary against the underlying *Beyrichia* Limestone is sharp.

The same classification of the Viruan beds was used by HOLM (1901) in his monographic treatment of the bedrock of Kinnekulle, except that he replaced the term *Beyrichia* Limestone by *Chasmops* Limestone. The latter term was introduced in Sweden by LINNARSSON (1871). On Kinnekulle the *Leversten* rests upon a division of the Orthoceratite Limestone which HOLM called Upper

Redstone (*Övre rödsten*; = *Röd täljsten* of Linnaeus 1747). He (1901, p. 54) suggested that the uppermost part of the Upper Redstone corresponds to the lowermost part of his *Lituites* Limestone, i.e. to the *Platyurus* Limestone according to Moberg (1890) and the Segerstad Limestone according to the writer's classification. This correlation, based on the colour of the rock, was previously proposed by Moberg (1890, pp. 18–19). If it were correct, the uppermost Upper Redstone would be of early Viruan age. Holm's correlation was based on a find of *Orthoceras tortum* Ang. (= "*Orthoceros*" *nilssoni* (Boll)) in these beds. However, the distinctive group of species currently included in "*O.*" *nilssoni* appears already in the *Gigas* Limestone of the latest Ontikan age (Jaanusson & Mutvei 1951; cf. also Westergård 1931, p. 57) and is not indicative exclusively of Aserian age. Angelin (1854, p. 54) listed *Asaphus platyurus* from Kinnekulle, but no specimen of this species from that area could be found in the collections of the Riksmuseum. It is possible that, in this case, Angelin confused *A. platyurus* with a new species of *Asaphus* (*Neoasaphus*) which is common in the *Gigas* Limestone of Västergötland and attains a fairly large size. Ostracodes clearly indicate that the topmost Upper Redstone of Kinnekulle is of Kundan age.

The correlation suggested by Moberg and Holm was followed by subsequent writers (Wiman 1910, Westergård 1943).

Westergård's (1943) treatment of the Viruan sequence of Kinnekulle was based largely on Linnarsson (1869) and Holm (1901). He pointed out that the predominating rock in the *Chasmops* beds of Kinnekulle seems to be a greenish shale (= mudstone). This suggestion was based on observations in the Norra Skagen core (cf. Westergård 1943, Fig. 27).

A comparison of the classification of the series used by earlier authors (Linnarsson 1869, Holm 1901, Westergård 1943) with that proposed in the present paper is as follows:

Early authors		*The present paper*
Lowermost part of the black shale		Mossen Formation
Beyrichia or *Chasmops* beds		Skagen Limestone Dalby Formation
Orthoceratite Limestone	*Leversten*	Ryd Limestone Gullhögen Formation
	Upper Redstone	Kunda Stage, upper part (with the *Gigas* Limestone on top)

The first complete section of the upper part of the Viru Series on Kinnekulle was published by Thorslund (1948) from the Kullatorp boring. He distinguished the Viruan part of the black shale above the *Chasmops* Limestone as a separate division and showed it to contain graptolites distinctive for the zone of *Dicranograptus clingani*. The boring revealed the presence in the *Chasmops* beds of numerous and in part astonishingly thick beds of bentonite, some of which were previously known from an excavation at Norra Skagen (THORSLUND 1945). THORSLUND also gave the first description of the Mossen section, measured by Mr. H. RUDBERG, and a diagrammatic columnar section of the uppermost part of the Norra Skagen core down to about the middle of the Ryd Limestone. He suggested that on Kinnekulle there exists a break at the top of the series, since the beds now known as the Bestorp Limestone (SKOGLUND 1963) are completely missing at the base of the *Tretaspis* beds. For further historical data about the Kullatorp and Norra Skagen borings, see the respective chapters.

SPJELDNÆS (in HAGEMANN & SPJELDNÆS 1955) suggested that on Kinnekulle the *Dicranograptus clingani* Shale (incorrectly termed by him *Macrourus* Limestone) is separated from the underlying beds by a considerable break.

BYSTRÖM (1954*a*, 1954*b*, 1954*c*, 1956) described in detail the mineralogy of bentonite beds on Kinnekulle. BYSTRÖM–ASKLUND, BAADSGAARD & FOLINSBEE (1961) dated biotite and sanidine from some bentonite beds at Mossen using the potassium-argon method. The average date was found to be 444 million years.

SKOGLUND (1963) redescribed the uppermost Viruan part of the Mossen section. He recorded that the *Dicranograptus clingani* Shale is overlain by a calcareous mudstone which here forms the topmost Viruan member of the section. Both the mudstone and the shale were included by him in a separate formation for which the term Mossen Formation was proposed.

NORTHERN BILLINGEN.—Published information about the series on northern Billingen is much scantier than about that on Kinnekulle. LINNARSSON (1869, p. 44) reported the occurrence of beds, included here in the Gullhögen Formation and Ryd Limestone, in the valley of a brook at Wåmb on the south-eastern slope of northern Billingen. He could not find any exposure of his *Beyrichia* limestone on this mountain. MUNTHE (1905, p. 39) compared the above-mentioned beds at Wåmb with the *Leversten* on Kinnekulle and listed additional localities where these beds are exposed on the area of the map-sheet Skövde. The *Chasmops* Limestone was known to him on northern Billingen from two small outcrops only, one of the exposures lying *c.* 1 km NW of the Ryd mansion. The redescription by WESTERGÅRD (1928) of the geological map-sheet Skövde did not add any significant knowledge to the stratigraphy of the strata in question.

From a well-digging on northernmost Billingen at Solberga WESTERGÅRD (1931, pp. 57–58) reported the presence of a dark-grey shale (= mudstone) which, according to him, evidently rests directly upon the Orthoceratite Limestone. The most common species in this mudstone was identified as *Trinucleus* cf. *foveolatus*, and the mudstone was termed the Shale with *Trinucleus* cf. *foveolatus*. WESTERGÅRD suggested that this division lies between the *Asaphus* and *Gigas* Limestones or replaces the *Gigas* Limestone of the other districts. Now it is known that WESTERGÅRD's Shale with *Trinucleus* cf. *foveolatus* is the basal part of beds termed here the Gullhögen Formation. The somewhat peculiar stratigraphic position assigned to these beds by him was due to his misidentification of *Gigas* beds as *Asaphus* beds.

BYSTRÖM (1957) gave a highly diagrammatic section of the uppermost Viruan and lowermost Harjuan beds in a boring at Rosenlund, 8 km W of Skövde. The mineralogy of the bentonite was described in some detail. THORSLUND (1958, Fig. 3, Bill.) gave a similar diagrammatic drawing of the uppermost Viruan portion of the Stora Åsbotorp boring. These two diagrammatic sections yielded the first information about the development of the bentonitic beds on northern Billingen. No exposure of this complex of bentonitic beds and the overlying Viruan strata is so far known on this part of the mountain.

JAANUSSON (in THORSLUND & JAANUSSON 1960, pp. 15, 17) gave a brief, preliminary section of the Viruan strata in the Gullhögen quarry.

Topo-stratigraphic Classification of the Viruan Sequence of Västergötland

The lithologic and faunal development of the Viruan sequence is, on the whole, so similar in Öland, Östergötland, and the Siljan district that the same topo-stratigraphic classification can easily be applied (JAANUSSON 1960*a*, 1962, 1963). In Västergötland, on the other hand, tongues from the pelitic and graptolitic sequence of Scania (*Dicranograptus clingani* Shale) and from the mixed mudstone and carbonate sequence of the Oslo region (upper Lasnamägian and lower Uhakuan beds, upper part of the Dalby Formation) cause conspicuous lithologic and faunal differences in parts of the sequence, and several of the topo-stratigraphic subdivisions of the districts mentioned above cannot be recognized. For this reason, and on account of the fact that the description in this paper comprises also the suprabentonitic Viruan beds, the introduction of several new topo-stratigraphic and litho-stratigraphic names was found necessary for the treatment of the Västergötland sequence in terms of objective units of the region. The new terms are defined below, and comments are made on the use of the terms established in the other districts.

VIKARBY LIMESTONE (JAANUSSON 1963).—Fossils indicate that the very thin sequence of the Segerstad Limestone on northern Billingen belongs exclusively to the upper part of the formation, i.e. to the zone of *Illaenus planifrons*. In the Siljan district beds with the *Illaenus planifrons* fauna can be distinguished as a separate litho-stratigraphic member, the Vikarby Limestone, of the Segerstad Limestone. In this district the member consists of variegated, reddish-brown and grey, calcarenites with locally abundant chamositic grains (see the description of the zone of *Illaenus* aff. *sulcifrons* in JAANUSSON & MUTVEI 1953). The corresponding beds in northern Billingen are in part oölitic, but otherwise their lithology agrees closely with the Vikarby Limestone of the Siljan district. For this reason, and in order to stress the fact that the upper part only of the Seger-

Table 1.

Siljan district		Västergötland		Graptolite zones	Stages
		NE. Billingen	Kinnekulle		
"Macrourus Limestone"		HIATUS	Mossen	*Dicranograptus clingani*	
"Suprabentonitic *Ludibundus* Limestone"			HIATUS	*"Diplograptus multidens"*	
		Skagen Formation			
Dalby		Dalby Formation			
				Nemagraptus gracilis	
Furudal		Ryd Formation		*Glyptograptus teretiusculus*	Uhaku
		Gullhögen Formation			
Folkeslunda			?	?	Lasnamägi
Seby		Skövde	HIATUS	*Didymograptus murchisoni*	
Skärlöv		HIATUS			
Segerstad	Vikarby	Vikarby			Aseri
	Kårgärde	HIATUS			

stad Limestone is developed, the term Vikarby Limestone is used here also for the corresponding beds of Billingen.

SKÖVDE LIMESTONE (new name).—The basal part of the post-Aserian sequence on the south-eastern slope of northern Billingen is formed by a few beds of regularly bedded limestone with some irregular intercalations of dark-grey mudstone. The limestone is preponderantly calcarenitic and mainly variegated, reddish-brown and grey, though some beds are intensely reddish-brown. Fossils indicate that the division is of Lasnamägian age.

The litho-stratigraphic classification of this thin division has been an intricate problem. It has been found that, at present, it is scarcely possible to use for this division any of the litho-stratigraphic terms defined for the roughly corresponding beds in the other Cambro-Silurian districts of Sweden. Although the Seby Limestone has a comparable lithologic development, the composition of its fauna is different and the correlation is uncertain. On Billingen these beds are poor in ostracodes, and although a large amount of rock samples were examined, only a few identifiable palaeocopes were found. Furthermore, the beds are very poor in cephalopods which form an important constituent of the fauna in the Seby and Folkeslunda Limestones and provide some of the best index fossils.

Because of the difficulties relating to the exact correlation of these beds it has been found best for the present to regard them as representing a separate litho-stratigraphic unit, here termed the Skövde Limestone. Subsequent studies may provide a better understanding about the correlation of this part of the sequence on Billingen with the other districts of Sweden and may show this term to be superfluous.

The lower boundary of the Skövde Limestone coincides with the discontinuity surface on top of the Vikarby Limestone. The upper boundary, as defined here, is sharp and possibly represents a discontinuity surface. The type locality of the division is the Gullhögen quarry in the town of Skövde. The division has at present been recognized only on the eastern part of northern Billingen, where it attains a thickness from 0.23 (Gullhögen quarry) to 0.27 m (Stora Åsbotorp boring).

GULLHÖGEN FORMATION (new name).—On eastern Billingen the Skövde Limestone is overlain by a thick distinctive lithologic unit consisting of dark mudstone with irregular nodules and thin beds of calcilutite. Regularly bedded limestone is of subordinate importance. The mudstone is predominantly dark-grey to greenish-grey. The limestone is mostly pale-brown ("liver-coloured") but includes beds and patches which are intensely reddish-brown. On Billingen the basal part of the formation is probably of late Lasnamägian age, whereas the age of the main part of the formation is early Uhakuan. It has not been possible to make an exact distinction, either lithologically or faunally, between the Lasnamägian and Uhakuan parts of the formation.

The Gullhögen Formation is a litho-stratigraphic unit in the conventional sense. On eastern Billingen its lower boundary is defined as the level where the colour of the limestone changes from variegated, reddish-brown and grey, to grey. It should be remembered, however, that reddish-brown portions reappear higher up within the formation. On Kinnekulle the formation overlies directly the Ontikan Kunda Stage. The upper boundary of the formation is drawn at the level of the lithological change from the sequence consisting mainly of mudstone and nodular limestone to the predominantly regularly bedded calcilutite succession of the Ryd Limestone. In outcrops this boundary is not always distinct and is sometimes difficult to draw without a close examination of the rock. The formation is developed on Kinnekulle and, as far as is known, all over the Billingen-Falbygden district.

Characteristic and common species of the Gullhögen Formation are *Pseudomegalaspis patagiata*, *Ogygiocaris sarsi*, *Trinucleus foveolatus*, *Reedolithus carinatus*, *Actinochilina* sp. *A*, and *Steusloffia linnarssoni*.

In the earlier classification the formation constituted the lower part of the division of the Orthoceratite Limestone that has been termed *Leversten*. The lower part of the formation, pierced in a well-digging on northern Billingen, was designated by WESTERGÅRD (1931) as the Shale with *Trinucleus* cf. *foveolatus*.

The type locality is the Gullhögen quarry in Skövde where the formation is exposed in its entire thickness. For further information about the formation, see the Chapter on stratigraphical and lithological remarks.

RYD LIMESTONE (new name).—The Gullhögen Formation is overlain in Västergötland by a division of regularly bedded and finely nodular, grey to pale-brown calcilutites, occasionally with irregular reddish-brown portions. This division is of late Uhakuan age and resembles, lithologically as well as faunally, the Furudal Limestone of Östergötland, southern Öland, and the Siljan district. However, it corresponds to the upper part of the Furudal Limestone only and represents a tongue of the latter formation. For this reason it is better to designate these beds in Västergötland with a different name.

The Ryd Limestone is a topo-stratigraphic unit, the upper boundary being defined as the level where the species distinctive for the Dalby Limestone appear, and the lower boundary according to lithologic criteria (see the Gullhögen Formation). The formation can be distinguished on Kinnekulle and, as far as is known, in the whole Billingen-Falbygden district. It is generally poor in macrofossils other than *Nileus*.

In the earlier classification the Ryd Limestone formed the upper part of the division called *Leversten*.

The formation is named after the Ryd mansion, the type locality being a natural section through most of the formation in the valley of a brook, 1.8–1.9 km W. of the Ryd mansion, about 4 km N. of Skövde. However, it can be better defined by the portion of the Stora Åsbotorp core between the levels of 53.78 and 62.75 m. The site of the boring is only 2 km SSW of the type locality.

DALBY FORMATION (JAANUSSON 1960).—The Dalby Formation of the Billingen–Falbygden district, excepting Mösseberg, agrees with that of Öland, Östergötland, and the Siljan district. On Kinnekulle and Mösseberg the main upper part of the formation has a conspicuously different development consisting of mudstone with subordinate beds of limestone. There the formation can be divided into two well-defined members, the Lower Member exhibiting the usual lithology of the formation and the Upper Member being preponderantly in a pelitic facies. It was not found necessary to give these members special names, in part owing to the lack of suitable geographic names.

SKAGEN LIMESTONE (new name).—On Kinnekulle and in the Billingen–Falbygden district the suprabentonitic *Ludibundus* beds are developed as a well-defined unit, distinctive faunally as well as lithologically. They consist of hard, grey, thick-bedded calcilutites with subordinate beds of calcareous mudstone. The lower boundary of the formation is tentatively drawn on top of the thickest bed of bentonite, and the upper boundary is defined by the base of the overlying division. The latter varies to a considerable extent. On Kinnekulle, easternmost southern Billingen (Skultorp boring), western Mösseberg, and possibly on Varvsberget the formation is overlain by the topmost Viruan Mossen Shale; on the eastern part of northern Billingen (Stora Åsbotorp boring) and on eastern Mösseberg (Bestorp boring) the overlying formation is the Lower Harjuan Bestorp Limestone; on the south-eastern part of southern Billingen (Häggum boring) the Harjuan Fjäcka Shale rests directly upon the Skagen Limestone.

Without further detailed studies it is difficult to know whether or not the term Skagen Limestone can be used for the corresponding part of the limestone sequence in certain other Cambro-Silurian districts of Sweden. In Västergötland the formation has previously not been distinguished as a separate division.

The type locality of the formation is the Mossen section on Kinnekulle, situated within the village of Skagen. In this exposure a complete section through the formation is available (see Fig. 8). For further information about the Skagen Limestone, see the Chapter on stratigraphical and lithological remarks.

MOSSEN FORMATION (SKOGLUND 1963).—The topmost Viruan shale and mudstone of Västergötland (zone of *Dicranograptus clingani*, THORSLUND 1948). For further details, see SKOGLUND (1963, pp. 8–9).

Kullatorp Boring, Kinnekulle

The Kullatorp boring is the first of the series of borings for scientific purposes drilled for the Palaeontological Institute, Uppsala. Its location was chosen so as to penetrate the Silurian and the upper part of the Ordovician sequence of Kinnekulle down to a level which could be connected with the top of the Norra Skagen boring, situated some 1.5 km towards SSE (cf. WÆRN *et al.* 1948, Fig. 1). Particulars about the boring and its sequence can be found in WÆRN *et al.* (1948).

The Viruan portion of the core was described by THORSLUND (1948). Since that time our knowledge about the fauna of these beds has increased. This has resulted in some changes in identifications of species as given by THORSLUND as well as in the correlation within the shelly sequence of the lowermost part of the core section. JAANUSSON (in JAANUSSON & STRACHAN 1954, p. 687, Fig. 2) suggested the boundary between the *Crassicauda* (Flagkalk) and *Ludibundus* Limestones to be situated in the core at an about 10 m lower level than drawn by THORSLUND (1948). In this paper the base of the core is considered to lie within the Dalby Formation, though very close to its lower boundary.

During an earlier examination the entire Viruan portion of the core had been crushed. The macroscopic description of the core as given here is essentially an abbreviated version of the description by THORSLUND (1948) with slight alterations in order to make the description agree with the writers style as used in the treatment of the other sections. The topmost Viruan beds, the *Dicranograptus clingani* Shale (62.96–64.05 m of the core), are not included, since no new data are available.

The diameter of the core is 7 cm.

Description of the Section

Viru Series 15.60 m. +

Mossen Formation 1.09 m (see THORSLUND 1948, pp. 343, 345).

Skagen Limestone 3.30 m.

64.05–64.81 m. Grey to dark-grey, fine-grained limestones with some beds of grey to dark-grey calcareous mudstone.

Panderia sp. (64.40 m; pyg.)[1]
Oedicybele cf. *clava* (THORSL.) (64.20 m)
Pharostoma sp. (64.24–64.29 m; THORSLUND 1948, Pl. XXI, figs. 4–6)
Miraspis sp. (64.24–64.27 m; THORSLUND 1948, Pl. XXI, fig. 9)
Trinodus sp. indet. (64.44 m)
Steusloffia costata (LINNARSSON)
Hesslandella ? gunnari (THORSL.)
Oepikium ? sp. (64.36–64.42 m)
Parapyxion obesum (THORSL.)
Onniella sp.

64.81–64.90 m. Conglomeratic limestone (cf. THORSLUND 1948, Pl. XXII, fig. 3). The pebbles consist of fine-grained limestone or, rarely, of dark shale or mudstone.

Trinodus sp. indet. (64.86 m).

64.90–65.43 m. Grey to dark-grey, fine-grained limestone intercalated by grey to dark-grey calcareous mudstone. At 65.29 m *c*. 1 mm thick layer of bentonitic clay.

Asaphus (*Neoasaphus*) *glabratus* (ANG.) (THORSLUND 1948, Pl. XXI, figs. 7–8)
Remopleurides sp. (65.05–65.13 m; 65.20 m)
Phillipsinella n.sp.
Lonchodomas sp. (65.05 m; THORSLUND 1948, Pl. XXI, fig. 11)
Steusloffia costata (LINNARSSON)
Hesslandella ? gunnari (THORSL.)
Parapyxion obesum (THORSL.)
Onniella sp.
Amplexograptus cf. *fallax* BULMAN

65.43–65.75 m. Three beds of fine-grained limestone (for closer description, see THORSLUND 1948, p. 346; cf. also op. cit., Pl. XXII, fig. 2).

Steusloffia costata (LINNARSSON)
Amplexograptus cf. *fallax* BULMAN

65.75–66.50 m. Grey, fine-grained limestone and grey to dark-grey mudstone. Bentonitic material in the mudstone between 66.25–66.29 m.

Phillipsinella n.sp.
Steusloffia costata (LINNARSSON)
Sigmobolbina sp. indet.

66.50–67.0 m. Bentonite.

67.0–67.35 m. Two beds of dark, hard limestone, increasingly siliceous towards the base.

Steusloffia costata (LINNARSSON)

Dalby Formation 21.20 m. +

Upper Member 17.65 m.

67.35–69.05 m. Bentonite.

[1] Here as well as in the descriptions of the other cores the figures after the names of fossils refer to the level within the core. The vertical range of species without these data in the description of the core is given in text-figures (Figs. 1 and 2 for the Kullatorp boring).

69.05–71.50 m. Grey to dark-grey, fine-grained limestone with mostly thin partings of dark-grey calcareous mudstone. Thin layers of bentonitic clay at 71.03, 71.08, and 71.42 m.

Chasmops sp. indet. (71.40; 71.47–71.50 m)
"*Ampyx*" sp. indet. (70.30 m)
Trinodus sp. (69.58; 71.18 m)
Actinochilina suecica (THORSL.) (THORSLUND 1948, Pl. XX, fig. 8; JAANUSSON 1957, Pl. III, fig. 9)
Euprimites locknensis (THORSL.)
Steusloffia costata (LINNARSSON) (JAANUSSON 1957, Pl. X, figs. 16–18)
Conchoprimitia cf. *conchoides* (HADDING)
Sericoidea restricta (HADDING) (71.04 m)
Onniella sp.
Climacograptus sp. indet. (70.25 m, THORSLUND 1948, Pl. XX, fig. 15; 69.87–69.90 m)

71.50–71.80 m. Bentonite.

71.80–71.83 m. Dark, hard, siliceous limestone.

71.83–71.90 m. Bentonite.

71.90–71.95 m. Dark, hard, siliceous limestone.

Sericoidea restricta (HADDING)

71.95–72.05 m. Bentonite.

72.05–72.25 m. Dark-grey, hard, siliceous limestone, probably with a thin layer of bentonite at about 72.15 m.

72.25–73.15 m. Bentonitic beds with at least one intercalation, 5 cm thick, of dark, siliceous mudstone. Core poorly preserved.

73.15–73.55 m. Dark-grey to grey, hard, argillaceous limestone to calcareous mudstone, in the uppermost part siliceous. Very thin layers of bentonitic clay at 73.20 and 73.43 m.

73.55–73.70 m. Bentonite.

73.70–73.90 m. As between 73.15 and 73.55 m.

Parapyxion subovatum (THORSL.)

73.90–74.10 m. Core poorly preserved, consisting mainly of bentonitic material, probably with an intercalation of dark mudstone, about 2 cm thick.

74.10–74.45 m. Mainly dark, grey-spotted, hard mudstone with a layer of bentonitic clay, less than 1 cm thick, at 74.20 m.

Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ.
Remopleurides sp. (74.40 m)
Cybelella sp. (74.39 m)
Parapyxion subovatum (THORSL.)

74.45–74.60 m. Bentonite.

Diplograptus ? *molestus* THORSL. (THORSLUND 1948, Pl. XXI, figs. 3a, 3b; JAANUSSON & SKOGLUND 1963, Figs. 1A, B)

74.60–74.72 m. Dark, grey-spotted, hard mudstone.

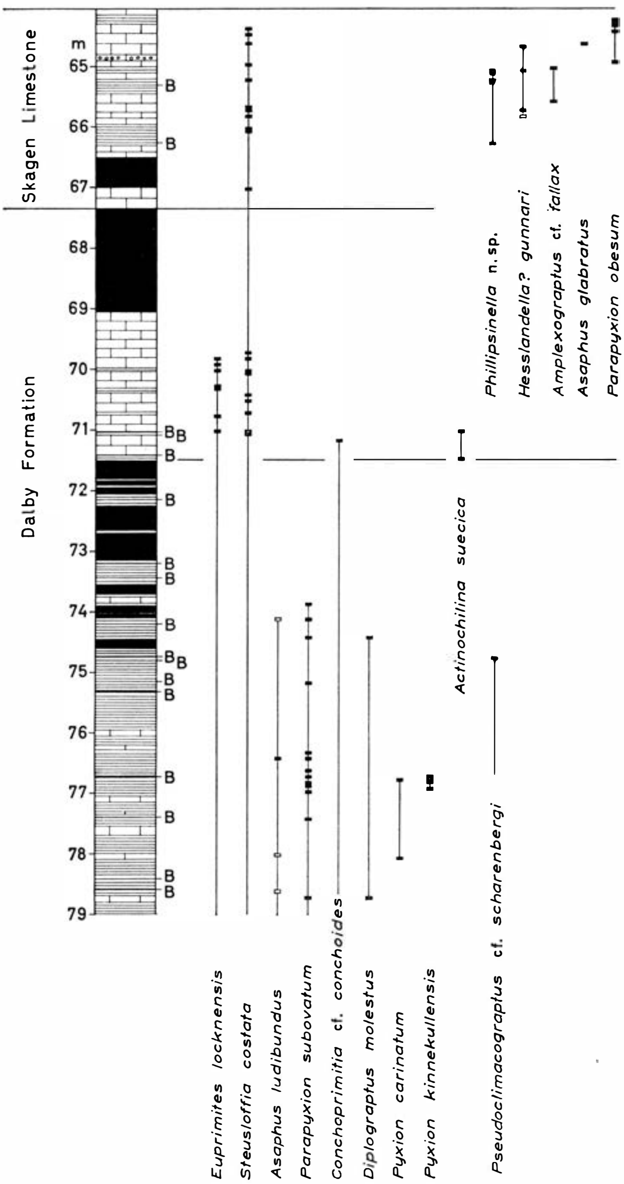


Fig. 1. Kullatorp boring, Kinnekulle. Range of selected species in the upper part of the Dalby Formation and in the Skagen Limestone. Continued on Fig. 2. For legend, see Fig. 6.

74.72–74.75 m. Bentonite.

74.75–75.30 m. Dark-grey mudstone with thin layers of bentonitic clay at 74.78, 74.81, and 75.14 m.

Robergia ? sp. (75.15 m)
Parapyxion subovatum (THORSL.)

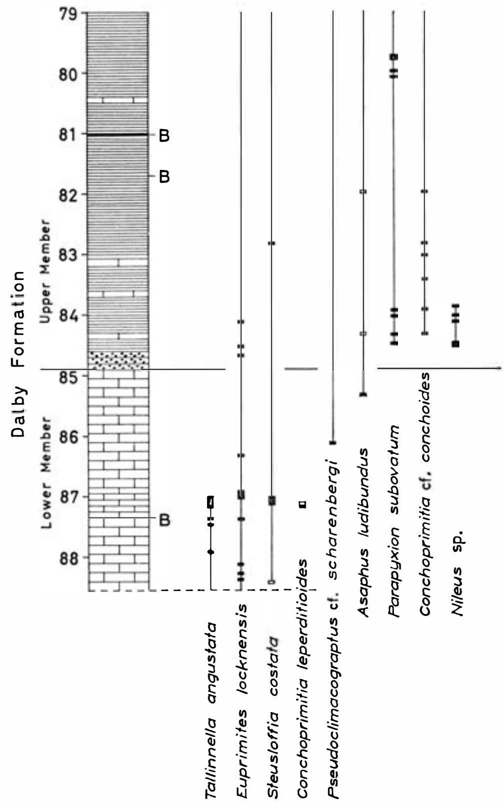


Fig. 2. Kullatorp boring, Kinnekulle. Range of selected species in the lower part of the Dalby Formation. Continued from Fig. 1. For legend, see Fig. 6.

Sericoidea restricta (HADDING) (74.78 m)
Pseudoclimacograptus cf. *scharenbergi* (LAPW.) (74.78 m)

75.30–75.34 m. Bentonite.

75.34–76.71 m. Dark-grey mudstone with some beds or lenses of fine-grained limestone.

Asaphus (*Neoasaphus*) *ludibundus* TÖRNQ.
Asaphus (*Neoasaphus*) sp. indet. (76.23 m)
Remopleurides sp. (76.60 m)
Sphaerocoryphe sp. (76.60 m)
Parapyxion subovatum (THORSL.)
Primitiella ? *spiniger* LINDSTR.
Onniella sp.

76.71–76.73 m. Bentonite.

76.73–78.58 m. As between 75.34 and 76.71 m. Thin layers, about 1 cm thick, of bentonitic clay at 77.40 and 78.42 m.

Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ.
Lonchodomas sp. (76.85; 76.98 m)
Parapyxion subovatum (THORSL.) (JAANUSSON 1957, Pl. XV, figs. 17–19)

Parapyxion n.sp.
Pyxion carinatum (HADDING)
Pyxion kinnekullensis THORSL.
Ulrichia ? reticulata THORSL.
Palaeostrophomena ? sp. (77.42, 78.38 m)
Onniella sp. indet.

78.58–78.61 m. Bentonite.

78.61–78.69 m. Dark-grey mudstone.

Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ.

78.69–78.81 m. Dark-grey, fine-grained limestone.

Parapyxion subovatum (THORSL.)
Parapyxion n.sp. (78.73 m)
Primitiella ? spiniger LINDSTR.
Diplograptus ? molestus THORSL.

78.81–80.41 m. Dark-grey mudstone.

Lonchodomas sp. (79.70–79.80; 80.15 m)
Parapyxion subovatum (THORSL.)
Parapyxion n.sp. (79.57 m)
Palaeostrophomena ? sp. (78.96–80.15 m)

80.41–80.50 m. Grey, fine-grained limestone.

Asaphus (*Neoasaphus*) sp. indet.

80.50–81.0 m. Dark-grey mudstone.

81.0–81.04 m. Bentonite.

81.04–83.07 m. Dark-grey mudstone. A layer, less than 0.5 cm thick, of bentonitic clay at 81.72 m.

Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ.
Asaphus (*Neoasaphus*) sp. indet. (82.30; 82.36–82.44; 82.72 m)
Lonchodomas sp. (81.67; 82.69–82.76 m)
Steusloffia costata (LINNARSSON)
Conchoprimitia cf. *conchoides* (HADDING)
Palaeostrophomena ? sp. (82.73 m).
Onniella sp. indet.
Diplograptus ? sp. indet.

83.07–84.60 m. Dark-grey mudstone with beds and lenses of grey, dense, argillaceous limestone.

Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ.
Nileus sp.
Lonchodomas sp. (83.75; 84.34 m)
Euprimites locknensis (THORSL.)
Sigmobolbina sp. (84.26; 84.46 m)
Conchoprimitia cf. *conchoides* (HADDING)
Parapyxion subovatum (THORSL.)
Onniella sp.
Climacograptus sp. (83.96–84.08 m)

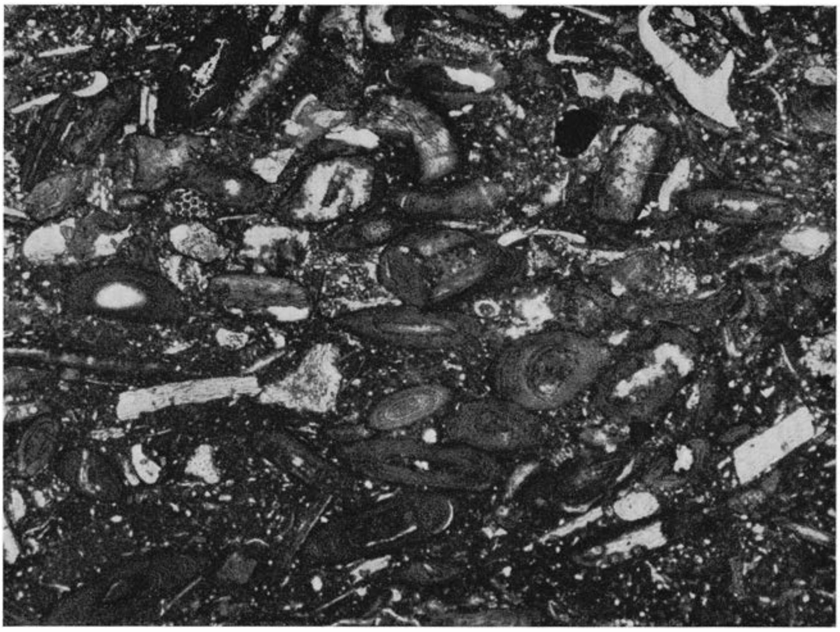


Fig. 3. Calcareous, oölitic mudstone with chamositic oöids at the base of the Upper Member of the Dalby Formation in the Kullatorp core (between the levels 84.72–84.74 m). Thin section, ordinary light. × 20. Photo N. HJORTH.

84.60–84.90 m. Dark, calcareous, oölitic mudstone with lenses or layers of argillaceous limestone. The oöids consist of chamosite and are up to 1.5 mm long (Fig. 3).

Euprimites locknensis (THORSL.)

Lower Member 3.66 m. +

84.90–88.56 m. + Grey and dark-grey limestone with intercalations of mostly thin layers of dark-grey, calcareous mudstone. A very thin layer, less than 1 mm thick, of bentonitic clay at 87.35 m.

Asaphus (*Neoasaphus*) *ludibundus* TÖRNQ.
Remopleurides sp. (86.14 m)
Lonchodomas sp. (86.14 m)
Telephina sp. (86.50–86.52 m; THORSLUND 1948, Pl. XXI, fig. 10)
Sphaerocoryphe sp. (87.17 m)
Laccochilina (*Laccochilina*) sp. indet. (86.50; 86.51; 87.04; 87.07; 87.09; 87.18; 87.90 m)
Uhakiella granulifera (ULRICH & BASSLER) (86.47 m, JAANUSSON 1957, Pl. V, fig. 6; 86.50 m)
Euprimites locknensis (THORSL.)
Tallinnella angustata (KRAUSE)
Steusloffia costata (LINNARSSON)
Steusloffia sp. indet. (86.31; 86.51; 86.86; 87.90; 88.04 m)
Sigmobolbina sp. (87.06; 88.10; 88.12; 88.38; 88.54 m)
Oecematobolbina sp. (87.90 m)

Conchoprimitia leperditioides THORSL.
Palaeostrophomena ? sp. (87.28 m)
Onniella sp.
Glyptograptus cf. *teretiusculus* (HIS.) (87.23–87.32 m)
Pseudoclimacograptus cf. *scharenbergi* (LAPW.) (86.14 m)
Echinosphaerites sp. (86.44; 86.46–86.48 m)
Clisospira sp. (87.32 m)

Norra Skagen Boring, Kinnekulle

The Norra Skagen boring (for its location, see WÆRN *et al.* 1948, Fig. 1) was drilled for the Geological Survey of Sweden in 1941. It penetrated the Ordovician sequence below the middle of the Dalby Formation, the Upper and Middle Cambrian strata, and the topmost Lower Cambrian sandstone. WESTERGÅRD (1943, Fig. 27) depicted the Cambrian sequence of the core and gave information about the thickness of the main Ordovician divisions. It should be noted that the boundary between the "*Chasmops* Shale" and the Orthoceratite Limestone as drawn by him corresponds to the base of what in this paper is termed the Upper Member of the Dalby Formation.

The thickness of the main Ordovician divisions of the Norra Skagen boring is as follows:

Viru Series (2.80–29.36 m)		26.56 m +
Ontika Subseries		40.33 m
"Orthoceratite Limestone" (29.36–58.65 m)	29.39 m	
Lower *Didymograptus* Shale (58.65–70.69 m)	12.04 m	
? Tremadoc Subseries (? *Ceratopyge* Limestone, 70.69–71.00 m)		0.31 m

The Ontikan and the possible Tremadocian portions of the boring have not been described so far. The data from the Kullatorp and Norra Skagen borings give, together, 42.2 m as the total thickness of the Viru Series on Kinnekulle.

THORSLUND (1948, pp. 359–361, Fig. 5) gave preliminary data about the upper 15 m of the core and also about the occurrence of certain species lower down in the Viruan part of the section. On comparison of THORSLUND's data with those of this paper attention should be paid to the fact that the zero level in THORSLUND's section corresponds here to the 2.8 m level. In his section the top level of the bed-rock is taken as the zero level, the quaternary deposits not being included in the section.

The upper part of the core down to about 12 m was examined for fossils by THORSLUND, then at the Geological Survey of Sweden. In this part the entire core is crushed, and it was not possible to draw the sedimentary structures in the manner done here for the remaining Viruan part of the core. The macroscopical description of this part of the sequence is based mainly on the diagrammatic columnar section given by THORSLUND (1948, Fig. 5). The core below *c.* 12 m was examined for fossils by the present writer (the Viruan beds) and Dr. H.

MUTVEI (the Ontikan limestones above the Lower *Didymograptus* Shale). In this part the core is split, and only one half of it has been crushed in the search for fossils. The other half is kept for further reference.—The diameter of the core is 7 cm.

Description of the Section

0–2.80 m. Quaternary deposits.

Dalby Formation 10.17 m. +

Upper Member 6.55 m. +

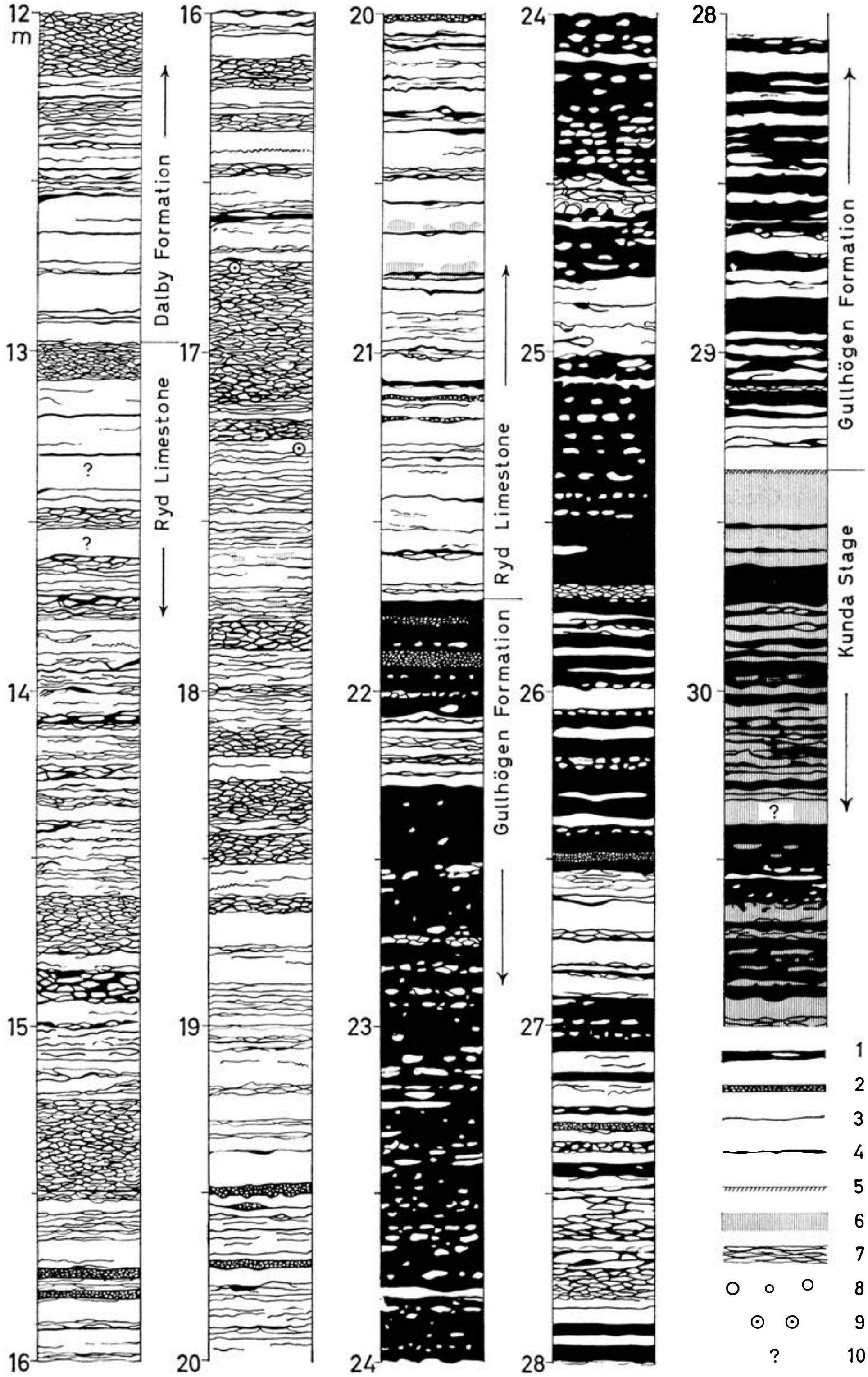
2.80–3.30 m. Dark-grey mudstone.
Lonchodomas sp. (3.05 m)
Conchoprimitia cf. *conchoides* (HADDING)
Parapyxion n.sp. (2.90; 3.02; 3.05; 3.08; 3.10; 3.20; 3.23 m)
Pyxion kinnekullensis THORSL.
Primitiella ? spiniger LINDSTR.
Onniella sp. (2.82; 2.90; 2.97 m)

3.30–3.42 m. Dark-grey, fine-grained limestone.
Chasmops sp.
Sigmobolbina sp. indet.

3.42–4.55 m. Dark-grey mudstone.
Remopleurides sp. (3.23; 3.98 m)
Lonchodomas sp. (3.60; 3.65; 3.82 m)
Conchoprimitia cf. *conchoides* (HADDING)
Parapyxion subovatum (THORSL.)
Parapyxion n.sp. (3.80; 3.90–4.05; 4.41 m)
Pyxion kinnekullensis THORSL.
Palaeostrophomena ? sp. (3.45; 4.30; 4.48 m)
Diplograptus ? *molestus* THORSL.

4.55–4.65 m. Grey, fine-grained limestone.

4.65–7.40 m. Dark-grey mudstone.
Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ.
Remopleurides sp. (6.60; 7.36 m)
Lonchodomas sp. (4.98; 5.30; 7.15 m)
Actinochilina suecica (THORSL.)
Steusloffia sp. indet. (6.40 m)
Conchoprimitia cf. *conchoides* (HADDING)
Parapyxion subovatum (THORSL.)
Pyxion kinnekullensis THORSL.
Palaeostrophomena ? sp. (5.01; 6.40; 6.59 m)
Diplograptus ? *molestus* THORSL.
Glyptograptus cf. *teretiusculus* (HIS.) (6.67–6.85 m)
Pseudoclimacograptus vestrogothicus JAAN. & SKOGL.
Pseudoclimacograptus sp. (5.86–6.08 m)
Climacograptus sp. (6.08–6.16 m)
Hyolithes sp. (5.55 m)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Dalby Formation
Ryd Limestone
Gullhögen Formation
Kunda Stage
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7.40–9.05 m. Dark-grey mudstone with beds and lenses of grey, fine-grained, argillaceous limestone.

Nileus sp.
Remopleurides sp. (8.10; 8.50 m)
Lonchodomas sp. (7.92; 8.65 m)
Hemisphaerocoryphe sp. (8.50 m)
Sphaerocoryphe sp. (7.64; 8.30 m)
Oecematobolbina sp. (7.95 m; JAANUSSON 1957, Pl. XII, fig. 22)
Conchoprimitia cf. *conchoides* (HADDING)
Parapyxion subovatum (THORSL.)
Palaeostrophomena ? sp. (7.78; 7.45 m)
Onniella sp. indet.
Pseudoclimacograptus vestrogothicus JAAN. & SKOGL.

9.05–9.35 m. Dark, calcareous, oölitic mudstone with chamositic oöids.

Asaphus (*Neoasaphus*) *ludibundus* TÖRNQ.
Nileus sp.
Euprimites locknensis (THORSL.)
Uhakiella granulifera (ULRICH & BASSLER)

Lower Member 3.63 m.

9.35–11.92 m. Grey and dark-grey limestone with intercalations of mostly thin layers of dark-grey, calcareous mudstone. A thin layer of bentonitic clay at 11.54 m.

Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ.
Remopleurides sp. (9.38 m)
Raymondaspis ? sp. (11.55 m)
Chasmops sp. indet. (11.89 m)
Laccochilina (*Laccochilina*) sp. indet. (11.42; 11.55 m)
Euprimites locknensis (THORSL.)
Uhakiella granulifera (ULRICH & BASSLER) (10.88 m)
Tallinnella angustata (KRAUSE)
Steusloffia cf. *costata* (LINNARSSON)
Steusloffia sp. indet. (10.20; 10.88; 11.52; 11.56; 11.60 m)
Oecematobolbina sp. (10.88 m)
Conchoprimitia cf. *leperditioides* THORSL.
Conchoprimitia cf. *conchoides* (HADDING)
Onniella sp. indet.
Skenidioides ? sp.
Clisospira sp. (11.55; 11.60 m)

11.92–12.19 m. Finely nodular, fine-grained, grey limestone.

Conchoprimitia sp. indet.

Fig. 4. Norra Skagen boring, Kinnekulle. Diagrammatic representation of sedimentary structures in the Viruan portion of the core below 12 m. Legend: *1*, mudstone (with an inclusion of limestone); *2*, speckled mudstone; *3*, bedding plane covered with argillaceous matter; *4*, stylolitic bedding plane; *5*, discontinuity surface; *6*, reddish-brown limestone; *7*, finely nodular limestone; *8*, cystoids; *9*, cephalopods; *10*, loss of the core, sequence uncertain.

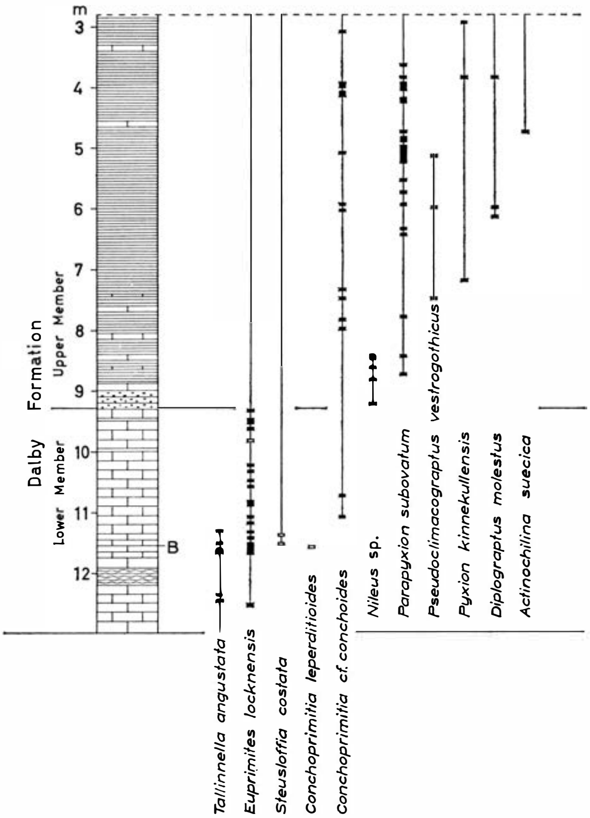


Fig. 5. Norra Skagen boring, Kinnekulle. Range of selected species in the Dalby Limestone. Continued on Fig. 6. For legend, see Fig. 6.

12.19–12.97 m. Grey, fairly thick-bedded, fine-grained limestone with some thin intercalations of calcareous mudstone.

Euprimites locknensis (THORSL.)
Euprimites sp. indet. (12.97 m)
Tallinnella angustata (KRAUSE)
Sigmobolbina sp. (12.91 m)
Oecematobolbina sp. (12.75 m)
Palaeostrophomena ? sp. (12.75 m)

Ryd Limestone 8.77 m.

12.97–13.08 m. Very finely nodular, fine-grained, grey limestone.

13.08–13.30 m. Thick beds of grey, fine-grained limestone with some thin intercalations of grey mudstone.

Euprimites cf. *eutropis* (ÖPIK)
Sigmobolbina sp. (13.30 m)

[13.30–13.41 m. Core poorly preserved.]

Nileus sp.
Laccochilina (*Laccochilina*) sp. indet.

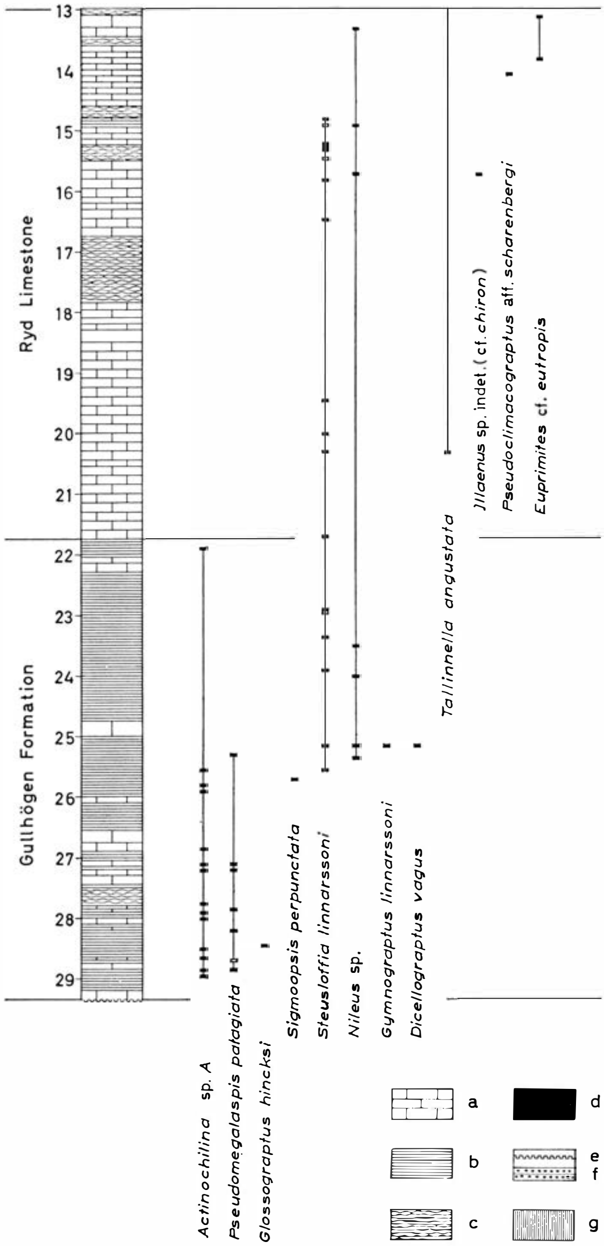


Fig. 6. Norra Skagen boring, Kinnekulle. Range of selected species in the Gullhögen Formation and Ryd Limestone. Legend: *a*, regularly bedded limestone; *b*, mudstone and shale; *c*, finely nodular limestone; *d*, bentonitic rock; *e*, discontinuity surface; *f*, oölitic mudstone; *g*, reddish-brown rock.

13.41–13.46 m. Two beds of grey, fine-grained limestone.
Laccochilina (*Laccochilina*) sp. indet.

13.46–13.52 m. Finely nodular, grey, fine-grained limestone.

[13.52–13.61 m. Core poorly preserved.]

13.61–14.62 m. Thin-bedded to nodular, fine-grained, grey limestone.
Euprimites cf. *eutropis* ÖPIK
Pseudoclimacograptus aff. *scharenbergi* (LAPW.)
Clisospira sp. (14.12 m)

14.62–14.79 m. In the upper part finely nodular, in the lower part nodular, grey, fine-grained limestone.

14.79–14.86 m. One bed of grey, fine-grained limestone.
Steusloffia linnarssoni (KRAUSE)
Clisospira sp.

14.86–14.93 m. Dark-grey mudstone with inclusions of grey, fine-grained limestone.
Nileus sp.
Steusloffia cf. *linnarssoni* (KRAUSE)

14.93–15.23 m. Thin-bedded, grey, fine-grained limestone.

15.23–15.52 m. Finely nodular, grey, fine-grained limestone.
Remopleurides sp. (15.25; 15.37; 15.42 m)
Steusloffia linnarssoni (KRAUSE)

15.52–16.74 m. Mostly thick-bedded, fine-grained to dense, grey limestone, finely nodular between 16.13–16.23, 16.30–16.35, and 16.45–16.48 m.
Nileus sp.
Illaenus sp. indet. (cf. *chiron*)
Laccochilina (*Laccochilina*) *paucigranosa* JAAN. (16.35 m)
Laccochilina (*Laccochilina*) sp. (16.45 m)
Laccochilina (*Laccochilina*) sp. indet. (15.72; 15.86; 16.55 m)
Steusloffia linnarssoni (KRAUSE)

16.74–17.26 m. Finely nodular, grey, fine-grained limestone.

17.26–17.79 m. Thin-bedded, grey, fine-grained limestone with reddish-brown spots in the lower part.
Lonchodomas sp. (pyg., 17.67 m)
Bolbina sp. *B* JAAN. (17.75 m)

17.79–17.87 m. Finely nodular, grey, fine-grained limestone.

17.87–18.12 m. Thin-bedded to nodular, grey, fine-grained limestone.
Remopleurides sp. (17.88 m)

18.12–18.20 m. Finely nodular, fine-grained, grey limestone.

18.20–18.28 m. One bed of fine-grained, grey limestone.

18.28–18.52 m. Finely nodular, fine-grained. grey limestone.

18.52–21.74 m. Mostly thick-bedded, fine-grained limestone with occasional thin intercalations of grey mudstone; finely nodular between 18.61 and 18.66 m. The limestone is variegated intensely reddish-brown and grey between 20.56 and

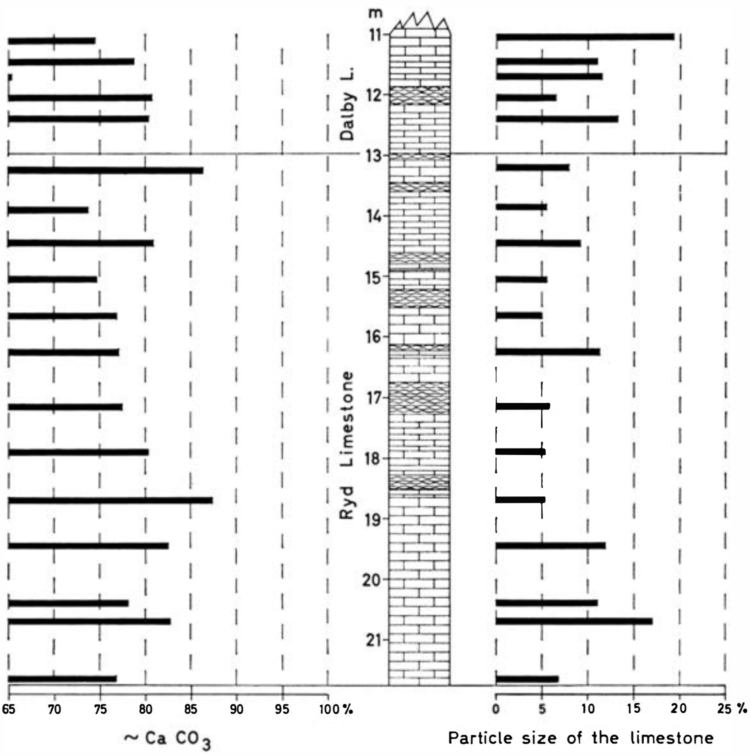


Fig. 7. Norra Skagen boring, Kinnekulle. Ryd Limestone and the lower part of the Lower Member of the Dalby Formation. To the right, particle size of the limestone according to the method of JAANUSSON (1952). To the left percentage of the substance soluble in dilute acetic acid (roughly the content of calcium carbonate). For legend, see Fig. 6.

20.78 m, otherwise grey to pale brown. An intensely yellow, goethitic zone of impregnation upon a layer of grey mudstone at the level of 21.09 m.

Lonchodomas sp. (cran., 19.10 m)
Telephina sp. (19.28 m)
Trinucleus sp. (19.15 m)
Laccochilina (*Laccochilina*) sp. indet. (20.60; 21.57 m)
Tallinnella angustata (KRAUSE)
Steusloffia linnarssoni (KRAUSE)
Steusloffia sp. (20.70 m)
Sigmoopsis sp. indet. (19.70 m)

Gullhögen Formation 7.62 m.

21.74–22.07 m. Greyish-green mudstone with irregular inclusions of limestone.

Sphaerocoryphe sp.
Laccochilina (*Laccochilina*) sp. indet.
Actinochilina sp. *A* JAAN.
Tallinnella sp. indet.
Steusloffia linnarssoni (KRAUSE)

22.07–22.29 m. Thin-bedded, grey, fine-grained limestone.

22.29–24.77 m. Greyish-green mudstone with inclusions and irregular beds of fine-grained limestone. The limestone is grey to very pale brown except between 24.02 and 24.04 m. where it is faintly reddish-brown with a narrow layer coloured yellow by goethite in the middle. A goethitic zone of impregnation occurs also at the level of 24.34 m. Flakes of mica between 23.22 and 23.26 m.

Nileus sp.
Remopleurides sp. (22.88; 22.95 m)
Bronteopsis sp. (22.80 m)
Trinucleus cf. *foveolatus* ANG. (23.45 m)
Laccochilina (*Laccochilina*) sp. indet.
Steusloffia linnarssoni (KRAUSE) (JAANUSSON 1957, Pl. X, fig. 7)
Sigmobolbina sp. indet. (23.08 m)
Sigmoopsis sp. indet. (23.96 m)
Glyptograptus cf. *teretiusculus* (HIS.) (23.22–23.27 m)
Clisospira sp. (23.25 m)

24.77–25.02 m. Thick beds of grey, fine-grained to dense limestone. Spots of goethite at 24.85 m and a goethitic zone of impregnation at 24.93 m.

25.02–25.77 m. Greyish-green mudstone with irregular inclusions of limestone.

Pseudomegalaspis patagiata (TÖRNQ.)
Nileus sp.
Actinochilina sp. *A* JAAN.
Steusloffia linnarssoni (KRAUSE)
Sigmoopsis perpunctata (ÖPIK) (JAANUSSON 1957, Pl. XI, fig. 6)
Dicellograptus vagus HADDING
Gymnograptus linnarssoni (MOBERG)
Clisospira sp.

25.77–26.53 m. Greyish-green mudstone with intercalations of beds of grey, fine-grained to dense limestone.

Estoniops sp. (25.84 m)
Actinochilina sp. *A* JAAN.
Steusloffia sp. indet. (26.06 m)
Sigmobolbina sp. (26.08; 26.23; 26.25 m)
Sigmobolbina sigmoidea JAAN. (26.23 m)
Conchoprimitia sp. (25.92 m)
Clisospira sp. (26.18; 26.21; 26.26 m)

26.53–26.91 m. Thick beds of grey, fine-grained limestone with thin intercalations of greyish-green mudstone. Chamositic grains between 26.62 and 26.64 m.

Actinochilina sp. *A* JAAN.

26.91–27.07 m. Greyish-green mudstone with some irregular inclusions of grey limestone.

27.07–27.52 m. Beds of grey, fine-grained to dense limestone intercalated with beds of greenish-grey mudstone occasionally containing inclusions of limestone.

Pseudomegalaspis patagiata (TÖRNQ.)
Actinochilina sp. *A* JAAN.

27.52–27.82 m. In the lower and upper part finely nodular, grey limestone, in the middle some irregular beds of grey, fine-grained limestone.

Actinochilina sp. *A* JAAN.

27.82–29.16 m. Alternating beds of greyish-green mudstone, occasionally with small inclusions of limestone, and grey fine-grained limestone.

Pseudomegalaspis patagiata (TÖRNQ.)
Nileus sp.
Trinucleus sp. (28.36; 28.93; 28.97 m)
Trinodus sp. (28.45 m)
Actinochilina sp. *A* JAAN. (JAANUSSON 1957, Pl. III, figs. 11–12)
Sigmobolbina sp. (28.11; 28.55 m)
Glossograptus hincksi (HOPKINSON)
Clisospira sp. (28.64 m)

29.16–29.29 m. Grey, thin-bedded, medium- to coarse-grained limestone with chamositic grains in some beds.

Telephina sp. (29.25 m)

29.29–29.36 m. One bed of greenish-grey, fine-grained limestone with numerous chamosite oöids and small nodules of phosphorite in the lowermost 1 cm.

29.36 m. Discontinuity surface with a thin, yellow, phosphoritic zone of impregnation. The surface is uneven in a small scale and without burrows (Fig. 28).

Kunda Stage.

29.36–29.53 m. Thick beds of intensely reddish-brown limestone.
Euprimites aff. *effusus* JAAN.
Aulacopsis n.sp.
Glossomorphites n.sp.

Skagen Limestone in the Mossen Section, Kinnekulle

In 1945 a small mine was opened at Mossen on the eastern slope of Kinnekulle for the exploitation of the thick bed of bentonite discovered a year before in the Kullatorp boring. At the entrance to the mine a section was exposed extending from the complex of the bentonitic beds of the Dalby Formation up to the lower part of the Harjuan Fjäcka Shale. A diagrammatic drawing of this section was given by THORSLUND (1948, Fig. 2; cf. also BYSTRÖM 1956, Fig. 1) based on measurements by Mr. H. RUDBERG. A new detailed section through the Skagen Limestone above the double thick beds of bentonitic clay was measured in 1954 by Dr. J. MARTNA, and the section described in this paper is based upon his field notes (except for the lowermost 0.61 m which are taken from the columnar section published by THORSLUND). The bentonite mine has now been abandoned, and the parts of the section which consist of soft rock are no longer visible. The uppermost Viruan shale and mudstone (the Mossen Formation) of the section were described by SKOGLUND (1963).

For the lithologic description of the Skagen Limestone two series of samples were available, one taken by Dr. J. MARTNA in 1954 and the other by the present writer in 1957.

Description of the Section

Harju Series.
Fjäcka Shale 0.30 m. +

Viru Series.
Mossen Formation 1.57 m (see SKOGLUND 1963).
Skagen Limestone 3.95 m.

0.70 m. Thin-bedded, greyish-green, calcareous mudstone with numerous shell fragments. The upper boundary against the overlying shale is sharp; the base of the shale has in part a rusty colour, evidently due to a concentration of disintegrated pyrite. A thin layer of dark-violet clay occurs 45–50 cm from the upper boundary.

Remopleurides sp.
Pharostoma sp.
Oedicybele cf. *clava* (THORSL.)
Trinodus sp.
Actinochilina sp.
Piretella triebeli (SCHALLREUTER)
Parapyxion obesum (THORSL.)
Onniella sp.
Sericoidea sp.

0.60 m. Light-grey, fine-grained limestone with intercalations of greenish-grey calcareous mudstone. The thickness of the limestone beds averages 7 to 8 cm and that of mudstone 2 to 3 cm. A bed in the lower part of the division shows the structures of an intraformational conglomerate.

0.25 m. Thin-bedded, greyish-green, soft calcareous mudstone with occasional inclusions of limestone.

Lonchodomas sp. indet.
Steusloffia costata (LINNARSSON)
Hesslandella ? *gunnari* (THORSL.)
Primitiella ? *spiniger* (LINDSTR.)
Sericoidea sp.

0.20 m. Light-grey, fine-grained limestone.

0.25 m. Dark-grey calcareous mudstone rich in shell fragments and with nodules of dark-grey limestone.

Hesslandella ? *gunnari* (THORSLUND)

0.40 m. Three beds of grey, fine-grained limestone, 10, 18, and 10 cm thick, separated by thin layers of mudstone.

Asaphus (*Neoasaphus*) *ludibundus* TÖRNQ.
Chasmops cf. *conicophthalmus* (BOECK)
Steusloffia costata (LINNARSSON)

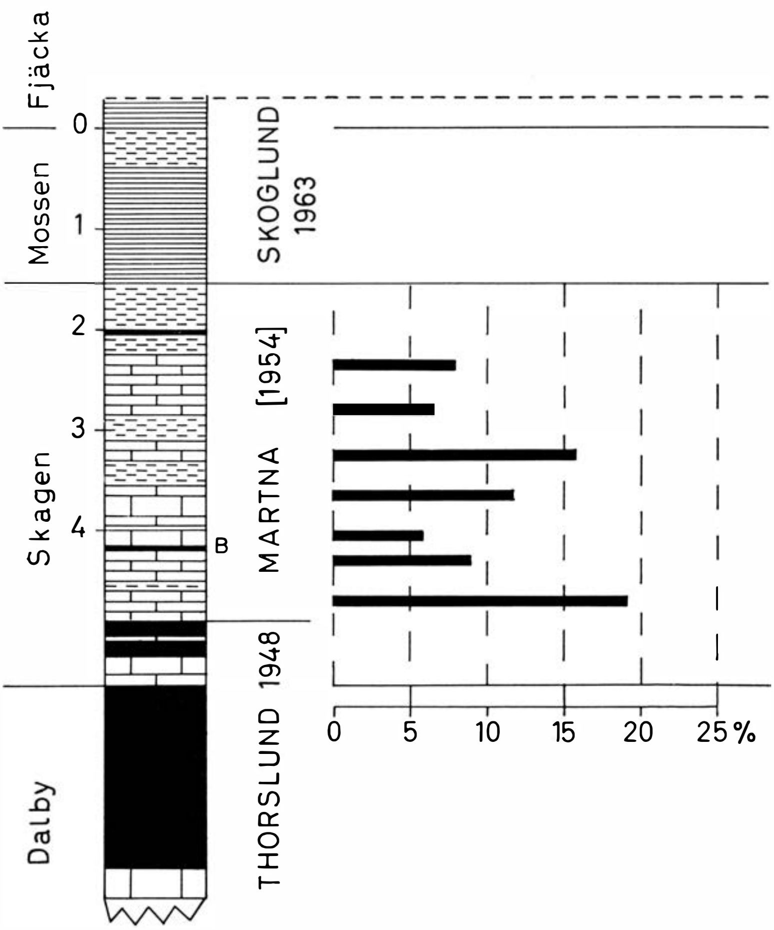


Fig. 8. Mossen section, Kinnekulle. The column is compiled from the section published by THORSLUND (1948, Fig. 2), and the description of the section by MARTNA (published herein) and SKOGLUND (1963). Dashed horizontal lines refer to mudstone, and closely spaced horizontal lines to black shale. For the other symbols, see Fig. 6. To the right, particle size of the limestone in the Skagen Formation according to the method of JAANUSSON (1952).

0.05 m. Greenish-grey mudstone.

Steusloffia costata (LINNARSSON)
Hesslandella ? gunnari (THORSLUND)

0.15 m. Grey, fine-grained limestone.

Chasmops cf. *conicophthalmus* (BOECK)
Steusloffia costata (LINNARSSON)

0.04 m. Light, greenish-yellow, bentonitic clay.

0.30 m. Grey, fine-grained limestone with intercalations of greenish-grey mudstone.

Hesslandella ? gunnari (THORSLUND)

0.10 m. Greenish-grey mudstone with nodules and irregular beds of grey, fine-grained limestone.

Steusloffia costata (LINNARSSON)

0.40 m. Grey, fine-grained limestone with intercalations of greenish-grey mudstone.

0.15 m. Light-grey bentonitic clay.

0.04 m. Limestone.

0.14 m. Bentonitic clay.

0.28 m. Limestone.

In addition to the species listed in the above description of the section the following species have been found in the Skagen limestone in loose boulders among the debris quarried from the entrance of the mine.

Asaphus (*Neoasaphus*) *glabratus* (ANG.)
Remopleurides sexlineatus (ANG.)
Remopleurides sp.
Lonchodomas sp.
Illaenus gigas HOLM
Chasmops n.sp.
Platylichas cf. *laxatus* (MC COY)
Platylichas validus (LINNARSSON)
Amplexograptus cf. *fallax* BULMAN
Climacograptus skagensis JAAN. & SKOGL.
Climacograptus cf. *bicornis* HALL
Internal moulds of gastropods.

Stora Åsbotorp Boring, Billingen

The Stora Åsbotorp boring was carried out in 1945 by the Geological Survey of Sweden in cooperation with the Gullhögens Kalkbruk AB. Its site is on the eastern slope of Mt. Billingen, c. 1.5 km N. of the Gullhögen Quarry. The boring pierced the Llandoverian shales, the entire Ordovician sequence, and the topmost Upper Cambrian stinkstone. A diagrammatic section of the bentonitic beds, the suprabentonitic Viruan limestones, and the basal Harjuan beds of the boring has been given by THORSLUND (1958, Fig. 3, *Bill.*). SKOGLUND (1963) has briefly described the Harjuan sequence, and the entire Viruan sequence is described in this paper. The remaining parts of the core have not been studied so far. The thickness of the Ontikan Subseries, here consisting exclusively of limestones and resting directly on Upper Cambrian beds, is 21.08 m.

The Viruan sequence of the core down to the level of 46.5 m was examined for fossils by Dr. B. WÆRN for the Geological Survey of Sweden. The macroscopical description of this part of the section is based on the information in his diary in the Geological Survey. When the present writer began his study of the Viruan sequence of Billingen, the entire core of this part of the boring had been crushed, and it was not possible to give a drawing of the sedimentary structures like that given for the remaining part of the Viruan sequence. The core below 46.5 m had been split into two halves, and only one half of the core was available to the writer. The other half had been used up by the Gullhögens Kalkbruk AB for laboratory analyses of the rock.

In the Stora Åsbotorp core the Harjuan Bestorp Limestone (cf. SKOGLUND 1963) overlies directly the Viruan Skagen Limestone. No *Dicranograptus clingani* Shale (Mossen Formation) is developed here. Thus in this section the Viru and Harju Series are separated by a hiatus comprising the Mossen Formation and, if the correlation of the Bestorp Limestone with the lower part of the Fjäcka Shale (SKOGLUND 1963) is correct, also the Slandrom Limestone. Unfortunately the core is poorly preserved at the level of the boundary between these series, and details of the contact are obscure.—The diameter of the core is 7 cm.

Description of the Section

Viru Series 36.58 m.

Skagen Limestone 3.29 m.

38.48–41.40 m. Light-grey, fine-grained limestone with intercalations of grey to dark-grey calcareous mudstone. The topmost half a metre of the core is strongly destroyed by the boring process, and it is difficult to reconstruct details of the section. In the lower part the main intercalations of mudstone occur between the following levels: 38.90–38.91 m, 39.52–39.54 m, 39.84–39.92 m, 40.11–40.17 m, 40.28–40.32 m, and 41.38–41.40 m. Flakes of mica at 40.96, 40.99, 41.36, and 41.38 m.

Remopleurides sp. (40.94 m)
Flexicalymene ? sp. indet. (cran., 38.7 m)
Steusloffia costata (LINNARSSON)
Steusloffia sp. indet. (39.52 m)

41.40–41.45 m. Light-grey bentonitic clay abounding in flakes of mica.

41.45–41.77 m. Grey, fine-grained limestone with intercalations of greyish-green mudstone between the levels of 41.45–41.47 m, 41.54–41.56 m, 41.58–41.63 m, 41.69–41.73 m, 41.765–41.77 m.

Steusloffia sp. indet. (41.60 m)

Dalby Limestone 12.01 m.

41.77–42.92 m. Greyish-green bentonite.

42.92–43.16 m. Grey, fine-grained limestone with intercalations of greyish-green calcareous mudstone between the levels of 42.92–42.96 m, 43.06–43.10 m, and 43.15–43.16 m. Flakes of mica at 43.15 m.

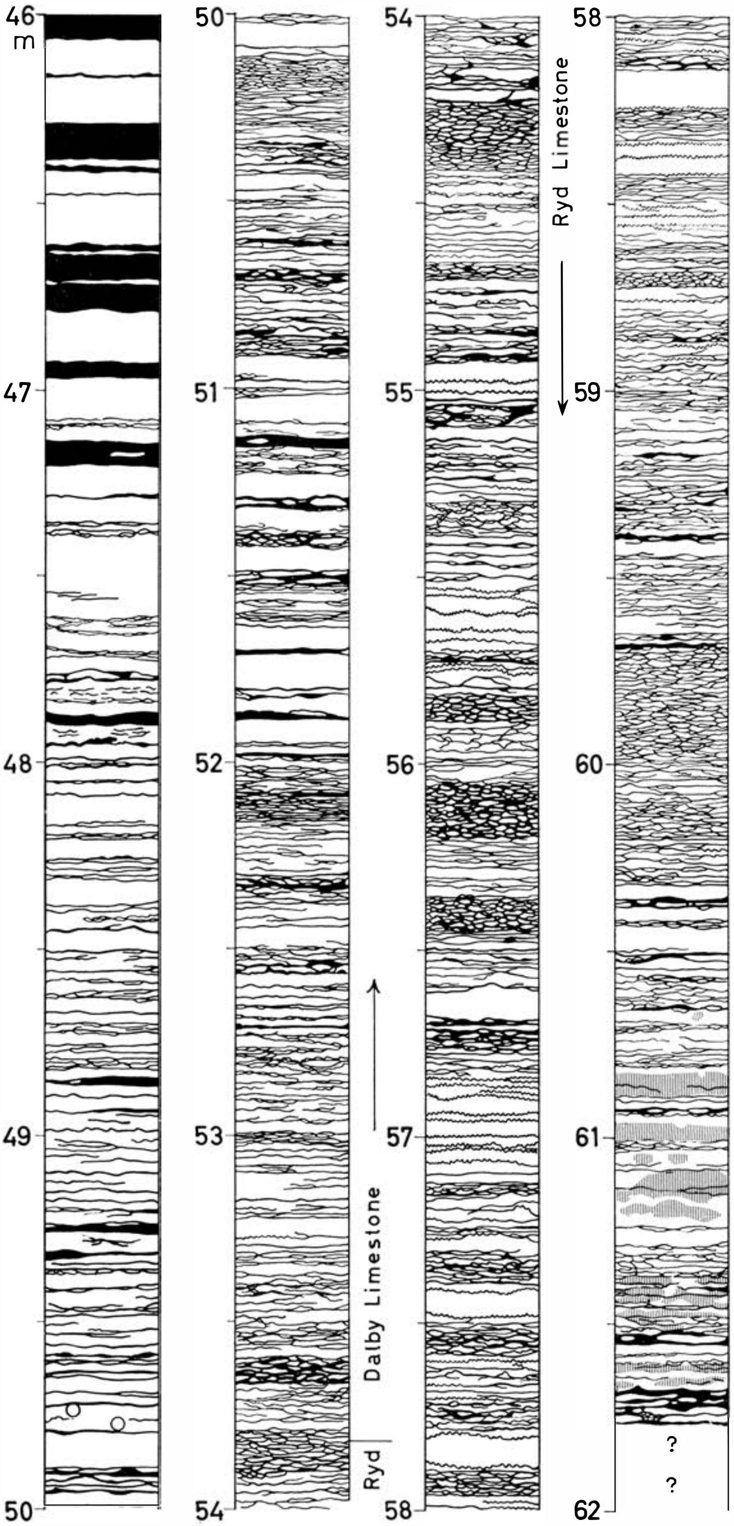
43.16 m. Thin layer of bentonitic clay rich in flakes of mica.

43.16–44.10 m. Grey, fine- to coarse-grained limestone with abundant flakes of mica in the uppermost part and with sparse chamositic grains below 43.55 m.

Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ. (pyg., 43.23 m)
Steusloffia sp. indet. (43.34 m)
Sigmobolbina sp. (44.08 m)

44.10–44.29 m. Dark-grey, argillaceous, coarse-grained limestone and calcareous mudstone with inclusions of light limestone. Numerous chamositic grains.

Parapyxion subovatum (THORSL.)


46 m
47
48
49
50
50
51
52
53
54
54
55
56
57
58
58
59
60
61
62
Ryd Limestone
Dalby Limestone
Ryd
?
?

44.29–44.84 m. Grey mudstone with irregular lenses and beds of grey, fine-grained limestone.

Euprimites locknensis (THORSL.)
Steusloffia costata (LINNARSSON)
Steusloffia sp. indet.
Parapyxion subovatum (THORSL.)

44.84–44.97 m. Grey, fine-grained limestone.

Asaphus (*Neoasaphus*) sp. indet.

44.97–45.18 m. Dark-grey calcareous mudstone with irregular inclusions of limestone.

Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ. (pyg., 45.06 m)
Parapyxion subovatum (THORSL.)
Onniella sp. indet.

45.18–45.37 m. Grey, fine- to coarse-grained, nodular to finely nodular limestone with intercalations of dark, calcareous mudstone and with chamositic grains, especially between 45.25–45.27 m.

Onniella sp. indet.

45.37–45.47 m. Dark-grey calcareous mudstone.

45.47–47.96 m. Thick beds of grey, fine-grained limestone with intercalations of dark-grey calcareous mudstone. Chamositic grains between the levels of 46.98–47.14 m and 47.21–47.28 m. Flakes of mica at 45.79 m.

Asaphus (*Neoasaphus*) cf. *ludibundus* TÖRNQ. (pyg., 47.38 m)
Nileus sp.
Illaenus sp. (pyg.)
Euprimites locknensis (THORSL.)
Pseudoclimacograptus vestrogothicus JAAN. & SKOGL. (JAANUSSON & SKOGLUND 1963, Figs. 1 C, 1 D, 4 E–F)

47.96–50.12 m. Preponderantly thin-bedded, mostly coarse-grained, grey limestone. Chamositic grains between the levels of 48.02 and 48.30 m. Flakes of mica between 48.78 and 48.82 m.

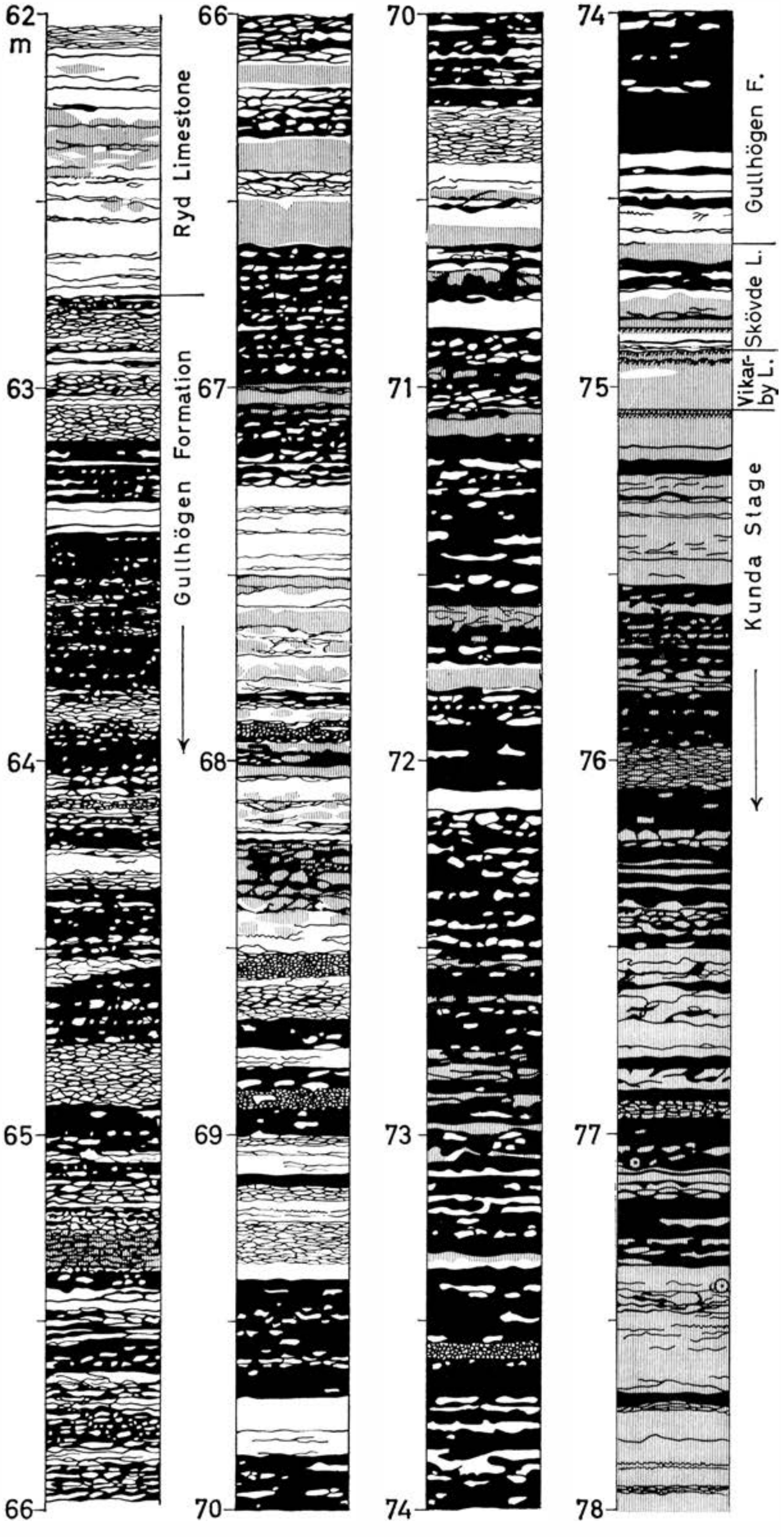
Laccochilina (*Laccochilina*) sp. *A* JAAN. (50.01 m; JAANUSSON 1957, Pl. II, fig. 1)
Euprimites locknensis (THORSL.)
Sigmobolbina sp. (49.49 m)
Conchoprimitia leperditioides THORSL.

Cystoids, gen. et sp. indet. (49.71–49.78 m).

50.12–51.93 m. Finely nodular to nodular, fairly coarse-grained, grey limestone with occasional intercalations of dark-grey calcareous mudstone. Chamositic grains between 51.09–51.13, 51.24–51.29, and 51.77–51.79 m.

Lonchodomas sp. (50.99 m)
Laccochilina (*Laccochilina*) cf. sp. *A* JAAN. (51.82 m)
Laccochilina (*Laccochilina*) sp. indet. (51.53 m)
Euprimites locknensis (THORSL.)

Fig. 9. Stora Åsbotorp boring, Billingen. Diagrammatic representation of sedimentary structures in the Viruan portion of the core between 46 and 62 m. Continued on Fig. 10. For legend, see Fig. 4.


62 m
63
64
65
66
Ryd Limestone
Gullhögen Formation
66
67
68
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71
72
73
74
74
75
76
77
78
Gullhögen F.
Skövde L.
Vikarby L.
Kunda Stage

51.93–53.60 m. Thin-bedded to nodular, fine-grained, grey limestone, fairly coarse-grained between 52.85–53.03 m.

Euprimites locknensis (THORSL.)
Steusloffia sp. indet. (52.30; 52.33 m)
Sigmobolbina sp. (53.04 m)
Baltonotella sp. (52.48 m)

53.60–53.67 m. Finely nodular, grey limestone.

Steusloffia cf. *multimarginata* ÖPIK

53.67–53.78 m. Thin-bedded to nodular, grey limestone.

Steusloffia cf. *multimarginata* ÖPIK

Ryd Limestone 8.97 m.

53.78–53.90 m. Finely nodular, grey limestone.

Laccochilina (*Laccochilina*) cf. sp. *A* JAAN. (53.80 m)

53.90–54.22 m. Thin-bedded to nodular, fine-grained, grey to pale-brown limestone.

Nileus sp.
Laccochilina (*Laccochilina*) cf. sp. *A* JAAN. (53.94 m)

54.22-54.42 m. Finely nodular, grey limestone.

54.42–54.50 m. Grey, nodular, fine-grained limestone.

Steusloffia linnarssoni (KRAUSE)

54.50–56.06 m. Light-brown, mostly thin-bedded to nodular, occasionally thick-bedded and with stylolitic structures, fine-grained limestone with intercalations and irregular laminae of greyish-green argillaceous matter. Grey, finely nodular limestone between 54.56–54.60 m and 55.82–55.88 m.

Illaenus sp. indet. (cf. *chiron*)
Illaenus sp. (juv. pyg.)
Nileus sp.
Euprimites cf. *eutropis* (ÖPIK)

56.06–56.20 m. Finely nodular, grey limestone.

56.20–56.37 m. Thin-bedded to nodular, light-brown, fine-grained limestone.

56.37–56.45 m. Finely nodular, light-brown limestone with irregular green argillaceous layers.

56.45–58.14 m. Mostly thin-bedded to nodular, occasionally thick-bedded and with stylolitic structures, dominantly light-brown, fine-grained limestone.

Remopleurides sp. (57.77 m)
Panderia sp. (pyg., 57.73 m)
Laccochilina (*Laccochilina*) *paucigranosa* JAAN. (57.04, 57.54, 57.83, 57.98, 58.00 m).
Sigmoopsis sp. *B* JAAN. (57.82; 57.85 m, cf. JAANUSSON 1957, Pl. XI, fig. 10)

58.14–58.73 m. Three well-defined cycles (58.14–58.22, 58.22–58.49, and 58.49–58.73 m), each beginning with a thin division of brown, finely nodular limestone

Fig. 10. Stora Åsbotorp boring, Billingen. Diagrammatic representation of sedimentary structures in the lowermost Viruan and the uppermost Ontikan part of the core. Continued from Fig. 9. For legend, see Fig. 4.

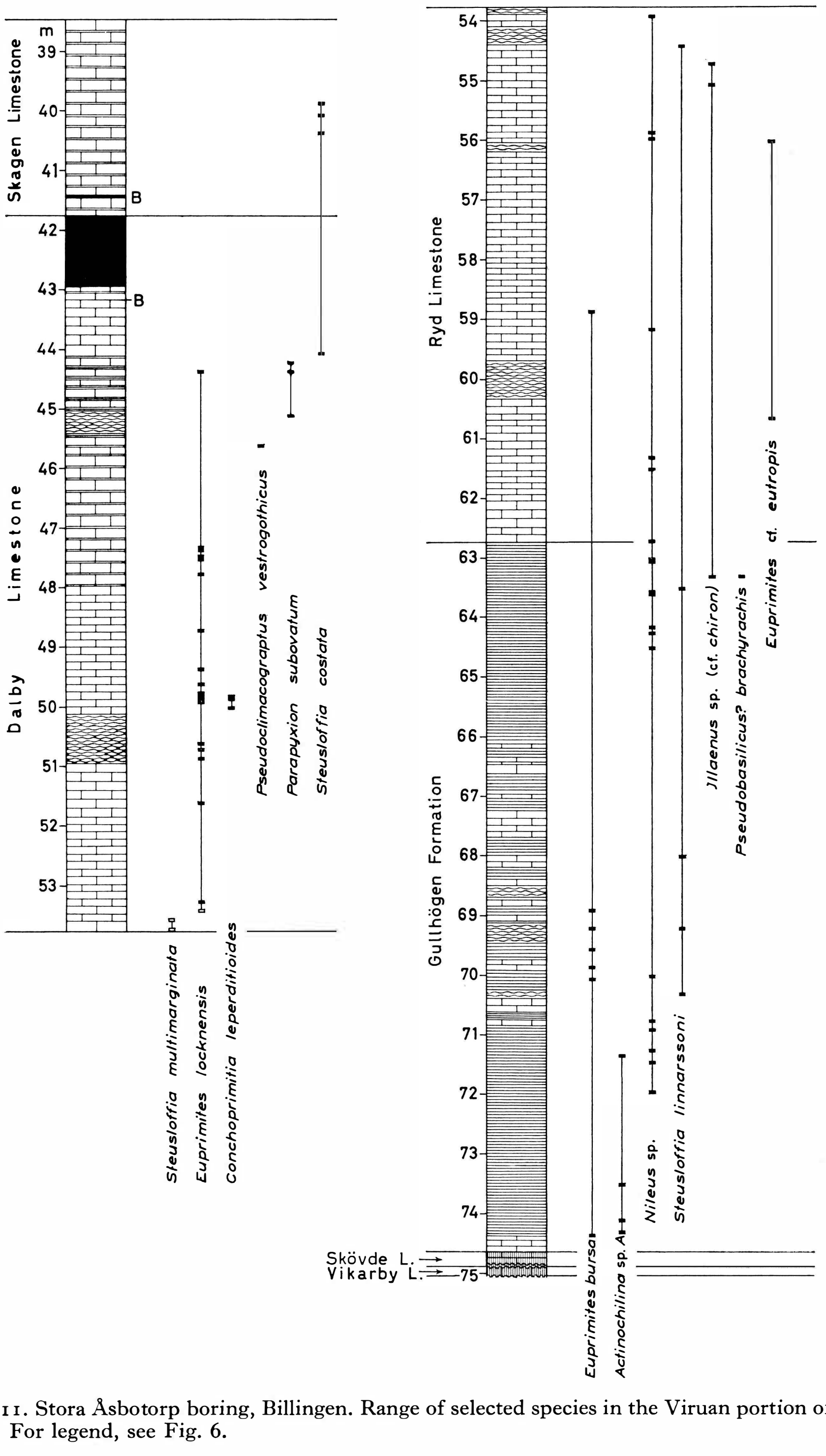

Fig. 11. Stora Åsbotorp boring, Billingen. Range of selected species in the Viruan portion of the core. For legend, see Fig. 6.

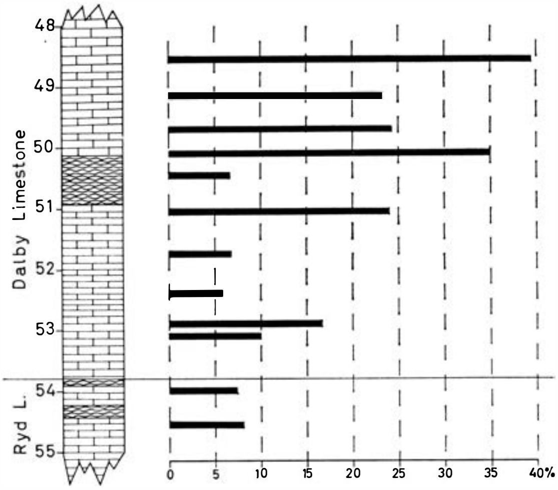

Fig. 12. Stora Åsbotorp boring, Billingen. Uppermost Ryd Limestone and lower Dalby Formation. Particle size of the limestone according to the method of JAANUSSON (1952).

merging upwards into thick-bedded, brown, fine-grained limestone. The argillaceous intercalations are always greenish-grey.

Laccochilina (*Laccochilina*) *paucigranosa* JAAN. (58.59 m)
Steusloffia sp. indet.

58.73–59.70 m. Thin-bedded and brown, to nodular and light-grey, fine-grained limestone.

Nileus sp.
Trinodus sp.
Laccochilina (*Laccochilina*) *paucigranosa* JAAN. (59.46 m)
Euprimites bursa (KRAUSE)

59.70–60.33 m. Finely nodular, light-brown limestone with larger nodules between 60.00–60.10 m.

60.33–60.80 m. Thin-bedded to nodular, light-brown, fine-grained limestone.

Euprimites cf. *eutropis* (ÖPIK)

60.80–61.76 m. Thin- to thick-bedded, variegated reddish-brown and grey, fine-grained limestone.

Nileus sp.
Laccochilina (*Laccochilina*) *paucigranosa* JAAN. (60.87 m)

[61.76–62.03 m. Core poorly preserved.]

62.03–62.10 m. Finely nodular, grey limestone.

62.10–62.75 m. Thick-bedded, grey, in the middle variegated reddish-brown and pale-brown, fine-grained limestone.

Nileus sp.
Remopleurides sp. (62.10 m)

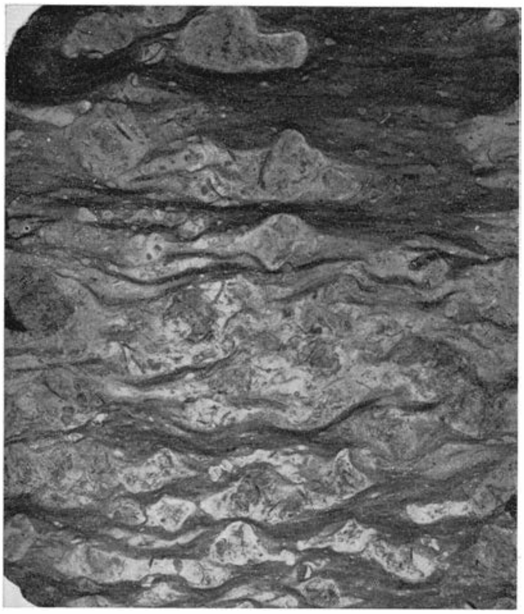

Fig. 13. Stora Åsbotorp boring, polished and slightly etched surface of the core between the levels of 64.72 and 64.80 m. Upper part of the Gullhögen Formation. In the lower part finely nodular limestone which merges upwards into a grey mudstone with limestone nodules. Natural size. Photo N. HJORTH.

Gullhögen Formation 11.89 m.

62.75–66.12 m. Grey mudstone with limestone nodules and with intercalations of finely nodular limestone and thin beds of fine-grained, grey limestone. Between 65.24 and 65.37 m the nodules in the mudstone are reddish-brown. The alternation of beds of mudstone and limestone gives an impression of cyclical sedimentation, each cycle beginning with more or less pure mudstone and ending in a finely nodular limestone or a continuous bed of limestone. These cycles are best developed in the intervals 63.30–63.52 m, 63.52–63.80 m, 63.80–64.02 m, and 64.02–64.23 m.

Pseudobasilicus ? *brachyrachis* (TÖRNQ.)
Nileus sp.
Illaenus sp. indet. (cf. *chiron*)
Laccochilina (*Laccochilina*) sp. indet. (63.54 m)
Laccochilina (*Laccochilina*) sp. (63.80 m)
Steusloffia linnarssoni (KRAUSE)

66.12–66.20 m. One bed of fine-grained reddish-brown limestone, pale red in the lowermost 1 to 1.5 cm.

66.20–66.34 m. Grey mudstone with nodules of grey limestone, merging upwards into finely nodular, fine-grained limestone.

66.34–66.43 m. One bed of fine-grained, reddish-brown limestone, grey in the upper 1 cm.

66.43–66.47 m. Grey, nodular to finely nodular limestone.

66.47–66.62 m. One bed of reddish-brown, fine-grained limestone.

66.62–66.97 m. Greenish-grey mudstone with nodules of grey, fine-grained limestone.

66.97–67.04 m. Two beds of reddish-brown, fine-grained limestone.

67.04–67.26 m. Greenish-grey mudstone with nodules of limestone, reddish-brown in the upper 6 cm, otherwise grey.

67.26–67.50 m. Fairly thick-bedded, grey, fine-grained limestone with occasional light-red spots.

67.50–67.71 m. As above, but variegated, reddish-brown and grey. The upper boundary is formed by a distinct surface with a strong concentration of haematite below it.

67.71–68.01 m. Greenish-grey mudstone intercalated by irregular beds of fine-grained, variegated, reddish-brown and grey limestone.

Sigmobolbina sp. indet.

68.01–68.04 m. One bed of reddish-brown, fine-grained limestone.

Steusloffia linnarssoni (KRAUSE)

68.04–68.20 m. Medium- to thin-bedded, fine-grained limestone with irregular reddish-brown spots.

68.20-68.40 m. Greyish-green mudstone with irregular nodules of reddish-brown, fine-grained limestone.

68.40–68.51 m. One bed of fine-grained, variegated reddish-brown and grey limestone.

68.51–68.69 m. In the upper 6 cm very finely nodular limestone to speckled mudstone, in the middle 3 cm one bed of grey, fine-grained limestone, and in the lower 9 cm finely nodular, grey limestone.

68.69–68.76 m. Greenish-grey mudstone with irregular nodules of fine-grained limestone.

68.76–68.83 m. One bed of grey, fine-grained limestone.

68.83–69.00 m. Greyish-green mudstone with some irregular nodules of fine-grained limestone. The middle part of the mudstone is densely spotted with pale grey.

Euprimites bursa (KRAUSE)

69.00–69.10 m. In the uppermost part finely nodular, otherwise thin-bedded, grey, fine-grained limestone.

69.10–69.13 m. Greyish-green mudstone.

69.13–69.47 m. Finely nodular grey limestone with two continuous beds of grey, fine-grained limestone.

Euprimites bursa (KRAUSE)
Steusloffia linnarssoni (KRAUSE)

69.47–69.74 m. Greyish-green mudstone with sparse irregular nodules of fine-grained limestone.

Euprimites bursa (KRAUSE)
Sigmobolbina sp.

69.74–69.92 m. Two beds of fine-grained, faintly red limestone.
Euprimites bursa (KRAUSE)

69.92–70.24 m. Greyish-green mudstone with nodules and irregular beds of fine-grained, grey limestone.
Nileus sp.
Euprimites bursa (KRAUSE)

70.24–70.40 m. Finely nodular, grey limestone.
Steusloffia linnarssoni (KRAUSE)
Sigmobolbina sp. indet.

70.40–70.62 m. Thick-bedded, fine-grained limestone, intensely reddish-brown between 70.47–70.50 and 70.55–70.62 m, otherwise faintly brown.

70.62–70.77 m. Greyish-green mudstone with irregular beds and nodules of limestone, faintly reddish-brown in the upper part and intensely reddish-brown in the lower part.

70.77–70.85 m. One bed of fine-grained, variegated, grey and faintly reddish-brown limestone.
Nileus sp.

70.85–74.37 m. Greyish-green mudstone with grey nodules and irregular, mostly reddish-brown beds of fine-grained limestone.
Nileus sp.
Remopleurides sp.
Trinucleus sp. indet.
Actinochilina sp. *A* JAAN.
Pseudoclimacograptus aff. *scharenbergi* (LAPW.)

74.37–74.64 m. Medium- to coarse-grained, grey limestone with some intercalations of grey mudstone. Spots with chamositic grains occur between 74.53 and 74.58 m.
Ogygiocaris sarsi ANG. (74.42 m)
Euprimites bursa (KRAUSE) (JAANUSSON 1957, Pl. VII, fig. 17)

Skövde Limestone 0.27 m.

D. 74.64–74.67 m. Reddish-brown, coarse-grained limestone, oölitic in the upper part. The upper boundary is distinct, fairly smooth, and may represent a discontinuity surface.

C. 74.67–74.74 m. Grey mudstone with irregular intercalations of grey, fine-grained limestone.

B. 74.74–74.84 m. Medium- to coarse-grained limestone, grey in the upper 2 cm, otherwise reddish-brown. An intercalation of grey mudstone at 74.81-74.82 m. Oöid-like grains on the top of the reddish-brown limestone. The upper boundary of the reddish-brown limestone is sharp and undulating, but does probably not represent a discontinuity surface.

74.84 m. Discontinuity surface, smooth and without borings. The surface is underlain by a concentration of haematite, up to 0.5 cm thick and partly of oölitic nature.

A. 74.84–74.91 m. In the lower part grey and somewhat nodular, fine-grained limestone, in the upper part (74.84–74.88 m) reddish-brown, medium-grained limestone with occasional chamositic grains; the uppermost 0.5 cm is intensely red.

74.91 m. Discontinuity surface with broad, up to 0.7 cm deep furrows. No distinct zone of impregnation.

Vikarby Limestone 0.15 m.

B. 74.91–74.93 m. Intensely red, coarse-grained, oölitic limestone.

74.93 m. Discontinuity surface, very uneven (Fig. 25 B) and with a narrow yellowish zone of impregnation.

A. 74.93–75.06 m. Reddish-brown oölitic limestone, between 74.96–74.97 m variegated reddish-brown and grey. An uneven, indistinct surface at the level of 74.97 m, immediately below the variegated limestone, may represent a weak discontinuity surface.

75.06 m. Discontinuity surface, smooth and without borings. No distinct zone of impregnation.

Oeland Series, Ontika Subseries.

Kunda Stage.

75.06–75.07 m. Intensely reddish-brown, fine-grained limestone.

75.07 m. Discontinuity surface, smooth and without borings. The rock below the surface is to a depth of 1 cm of a somewhat lighter colour (with a yellowish tint) than the rock farther down.

Gullhögen Quarry, Billingen

The large Gullhögen quarry in Skövde, on the south-eastern slope of northern Billingen, exposes a section from the Upper Cambrian to about the middle of the Ryd Limestone (see the brief description of the entire section in THORSLUND & JAANUSSON 1960, pp. 14, 17). The total thickness of the exposed beds is about 45 m of which about 36 m are within the Ordovician strata. In this quarry the Kundan *Gigas* Limestone and the Aserian and Lasnamägian beds were for the first time available in Västergötland for examination in an extensive outcrop. The quarrying in the Viruan strata began first in the early fifties; previously the series was not exposed there.

The Viruan sequence in the quarry is almost identical with that of the Stora Åsbotorp boring, situated some 1.5 km towards N. For this reason a description of the whole Viruan section is not repeated here. A special, detailed section is given through the Skövde, Vikarby, and uppermost *Gigas* Limestones.

The Gullhögen Formation is exposed in its entire thickness (about 12 m). Its upper boundary against the Ryd Limestone is not so distinctly marked in the exposure as in the Stora Åsbotorp boring. The formation is poor in fossils, and only few specimens have been found *in situ* in the rock wall. In the loose boulders of limestone derived from these beds the following species have been found:

Pseudomegalaspis patagiata (TÖRNQ.)
Pseudoasaphus sp.
Nileus sp.
Remopleurides sp.
Illaenus sp. (cf. *chiron*)

Loose boulders of mudstone from the lower 3.5 m of the formation have yielded the following species:

Pseudomegalaspis patagiata (TÖRNQ.)
Remopleurides sp.
Nileus sp.
Trinucleus foveolatus ANG.
Actinochilina sp. *A*
Clisospira sp.

A thorough collecting during a period of years will certainly yield much additional information of stratigraphic importance about the fauna of the Gullhögen Formation, especially if attention is directed to the lowermost beds of the division.

In the section described by JAANUSSON (in THORSLUND & JAANUSSON 1960) the two reddish-brown beds between discontinuity surfaces above the Vikarby Limestone were included in the *Platyurus* Limestone. At that time no identifiable fossils had been found in this interval. Subsequent finds of *Illaenus chiron* in loose boulders, with a high degree of certainty derived from these beds, suggest that the upper boundary of the Aserian (*Platyurus*) beds must be drawn at the lower discontinuity surface.

Section of the Vikarby Limestone and Adjacent Beds

Gullhögen Formation 0.25 m. +

0.25 m. Grey, mostly coarse-grained limestone with intercalations of greyish-green mudstone.

Ogygiocaris sarsi ANG.
Remopleurides sp.

Skövde Limestone 0.23 m.

D. 0.03 m. Reddish-brown, fine-grained limestone. The upper boundary is distinct, fairly smooth and may represent a discontinuity surface.

C. 0.05 m. Grey mudstone with nodules of grey, fine-grained limestone.

B. 0.08 m. One bed of medium-grained limestone, grey in the upper 0.03 m and reddish-brown in the lower 0.05 m. The boundary between the reddish-brown and the grey limestone is sharp and undulating, but does not seem to mark a distinct break.

Illaenus chiron HOLM

Discontinuity surface, perfectly smooth and without borings. It is occasionally overlain by a layer of reddish-brown mudstone, up to 1 cm thick.

A. 0.07 m. Two beds of intensely reddish-brown limestone separated by what appears to be a normal bedding-plane. The limestone immediately above the bedding-plane as well as that adjacent to the overlying discontinuity surface contains haematitic oöids. The lower bed is occasionally grey or variegated grey and brownish-red.

Illaenus chiron HOLM
Nileus sp.
Conchoprimitia n.sp.

The pygidia of *I. chiron* have not been found in the section *in situ*, but in loose boulders which according to lithological criteria are almost certainly derived from these beds.

Discontinuity surface, occasionally smooth but mostly furrowed (Fig. 25).

Segerstad Formation, Vikarby Member 0.07 m.

B. 0.02–0.03 m. Reddish-brown, oölitic limestone, very rich in oöids.

Asaphus (*Neoasaphus*) *platyurus* ANG. (well-preserved pygidia, up to 9 cm long)
Lituites (*Lituites*) cf. *toernquisti* HOLM
Conchoprimitia n.sp.

Discontinuity surface, very uneven and with a haematitic crust (Fig. 26A).

A. 0.04–0.05 m. Reddish-brown, oölitic limestone, very rich in large oöids (Fig. 17).

Asaphus (*Neoasaphus*) *platyurus* ANG.
"*Orthoceros*" *nilssoni* (BOLL) sp. coll.

Discontinuity surface, quite smooth and without borings (Figs. 23, 24).

Kunda Stage

0.025 m. Reddish-brown, occasionally grey, fine-grained limestone.

Discontinuity surface, quite smooth and without borings (Fig. 23).

0.50 m. Intensely reddish-brown, fine-grained limestone.

Megistaspis (*Megistaspidella*) *gigas* (ANG.)
Asaphus (*Neoasaphus*) n.sp.
Niobe laeviceps DALM.
Pseudoasaphus perstriatus BOHLIN
Illaenus glabriusculus JAAN.

The bed of limestone immediately below the lower discontinuity surface has yielded the following ostracodes:

Euprimites aff. *effusus* JAAN.
Tallinnella n.sp.
Glossomorphites n.sp.
Aulacopsis n.sp.
Conchoprimitia erratica (KRAUSE)
Pinnatulites procera (KUMMEROW)

Loose boulders, derived from reddish-brown limestones immediately below the beds of the zone of *Megistaspis* (*Megistaspidella*) *gigas*, have yielded some pygidia of *Megistaspis* (*Megistaspidella*) *obtusicauda* (BOHLIN). This indicates that the zone of *M.* (*Megistaspidella*) *obtusicauda* can obviously be distinguished also in Västergötland. In the Gullhögen quarry the beds with this index fossil are generally poor in fossils.

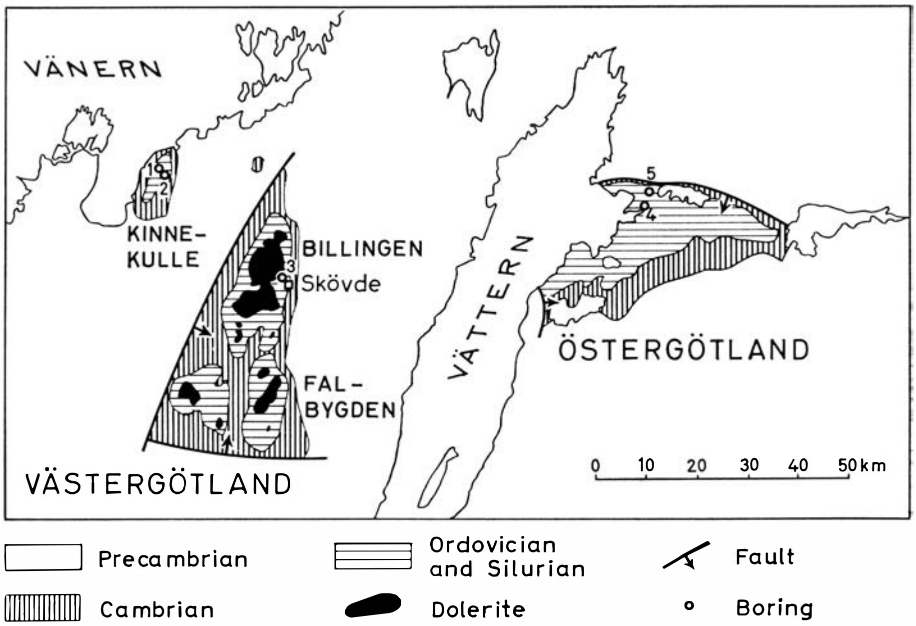

Fig. 14. Map showing the locations of borings on Kinnekulle, northern Billingen, and in Östergötland described or discussed in the present paper. *1*, Kullatorp boring; *2*, Norra Skagen boring; *3*, Stora Åsbotorp boring; *4*, Ekön boring (Motala); *5*, Smedsby Gård boring.

Stratigraphical and Lithological Remarks

ASERI STAGE.—On eastern Billingen the Segerstad Limestone is considerably thinner than at Motala, Östergötland, some 70 km towards ENE (cf. Fig. 14). In the Motala boring the thickness of the formation is 6.2 m (JAANUSSON 1962), whereas in the Stora Åsbotorp boring and in the Gullhögen quarry it amounts to only 0.15 and 0.07 m, respectively. The occurrence of *Lituites* (*Lituites*) cf. *toernquisti* and the large size of pygidia of *Asaphus* (*Neoasaphus*) *platyurus* in these beds of the Gullhögen quarry strongly indicate that the part of the formation developed on eastern Billingen belongs to the zone of *Illaenus planifrons*, i.e. to the upper zone of the Aseri Stage of Sweden. The lithology of these beds suggests that the term Vikarby Limestone for the upper part of the Segerstad Limestone of the Siljan district (JAANUSSON 1963) can be used also for the corresponding beds on Billingen.

The base of the Vikarby Limestone on eastern Billingen coincides with a considerable break in the sequence. In comparison with the Siljan district, this break comprises equivalents to the Kårgärde Limestone (the zone of *Angelinoceras latum*) and, possibly, to the lowermost Vikarby Limestone. The Vikarby Limestone is separated from the overlying beds by another pronounced break (see below). Thus the Aseri Stage on eastern Billingen is represented by a thin sequence belonging to the upper part of the stage and is preceded and succeeded by considerable breaks. The thin sequence itself includes discontinuity surfaces.

On Kinnekulle, some 30 km towards NW (cf. Fig. 14), the Aseri Stage is entirely missing, and the break is indicated by a conspicuous discontinuity surface (Figs. 28–30).

On eastern Billingen the rock of the Vikarby Member is predominantly an oölite with chamositic oöids (cf. Fig. 17). In the Gullhögen quarry it is almost exclusively oölitic, whereas in the Stora Åsbotorp core, where the member attains a somewhat greater thickness, parts of the sequence lack oöids and consist of a partly recrystallized calcarenite. Most of the oöids show a well-developed concentric structure of thin laminae consisting of a light green substance which agrees in its colour and optical properties with chamosite in the wider sense of the term. The colour of some oöids is brownish in transmitted and yellow in incident light evidently due to oxidation. In many oöids chamosite is partly replaced by calcite (and, possibly, also by siderite). Large oöids usually have a diameter of about 1.5 mm, but some reach up to *c.* 2 mm. No detailed study of the oöids has been attempted.

In the oölitic portions of the rock the matrix between the oöids contains fragments of shells and is in spots strongly pigmented by haematite which gives the rock an intensely reddish-brown colour. Non-oölitic parts of the rock are frequently variegated reddish-brown and grey.

The following species have been found in the Vikarby Limestone of the Gullhögen quarry:

Asaphus (*Neoasaphus*) *platyurus* Ang.
Conchoprimitia n.sp.
"*Orthoceros*" *nilssoni* (Boll.) *sp. coll.*
Lituites (*Lituites*) cf. *toernquisti* Holm

Lasnamägi and Uhaku Stages.—The Lasnamägian sequence of eastern Billingen has an extensive break at its base. There is no evident counterpart to the Skärlöv Limestone, 6.3 m thick in the Motala boring, Östergötland (Jaanusson 1962), although the possibility is not quite excluded that the corresponding beds are present but developed in a different lithofacies. In the Gullhögen quarry the sequence above the Vikarby Limestone begins with intensely reddish-brown and variegated reddish-brown and grey calcarenite, 0.23 m thick, which contains scattered concentrations of small oöids. This thin calcarenitic division includes a discontinuity surface close to the base and a possible discontinuity surface at the top. It is poorly fossiliferous and has yielded only *Illaenus chiron*, *Nileus* sp., and *Conchoprimitia* n.sp. These reddish-brown and variegated beds might correspond to the Seby Limestone, but the correlation is uncertain until some species distinctive for that formation has been found on Billingen. For this thin unit the term Skövde Limestone is used in the present paper. The Skövde Limestone differs from the probably contemporaneous calcarenitic beds of the other districts of Sweden by the almost complete lack of cephalopods, a circumstance which makes its exact correlation

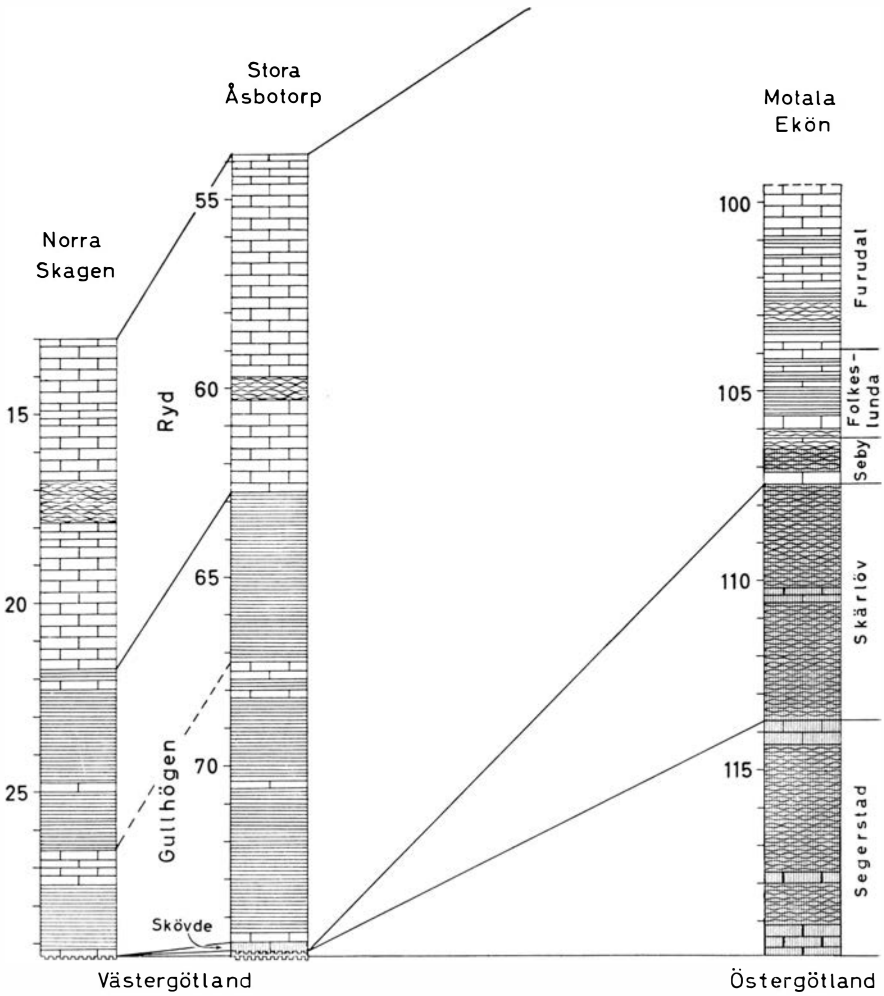

Fig. 15. A comparison of the Aserian, Lasnamägian, and Uhakuan sections on Kinnekulle, northern Billingen, and in Östergötland.

difficult. Otherwise it can be regarded as an extension, possibly a tongue, of the Lasnamägian calcarenitic sequence north and east of Västergötland.

On Kinnekulle the Skövde Limestone or beds corresponding to it are missing at the base of the Viruan sequence.

In Västergötland the sequence above the Skövde Limestone and below the Dalby Limestone falls into two well-defined and distinctive lithological subdivisions. The lower division consists predominantly of mudstone with mostly irregular inclusions and nodules of calcilutite. Intercalations of regularly bedded or finely nodular limestone are usually of subordinate importance. The limestone is frequently intensely reddish-brown or variegated reddish-brown and grey. This division, 11.9 m thick on the south-eastern part of northern Billingen

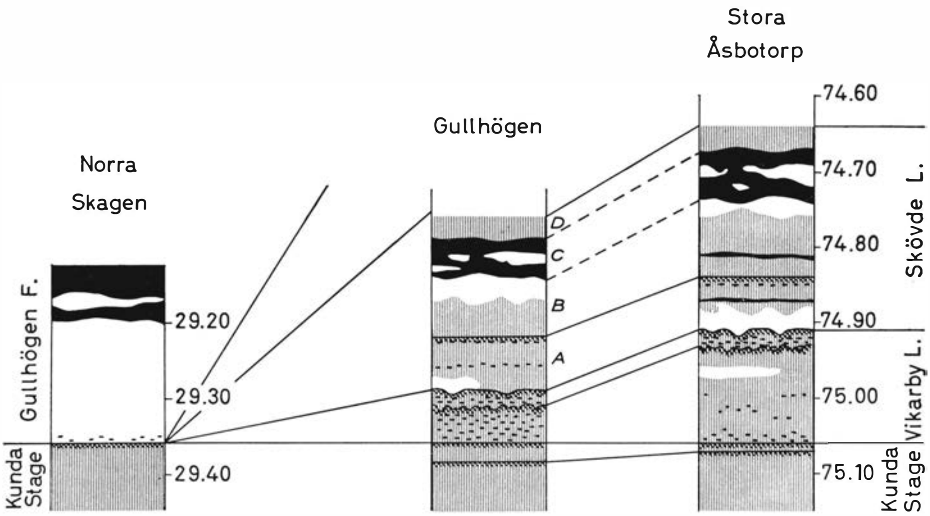

Fig. 16. A comparison of detailed sections of the basal Viruan beds in the Stora Åsbotorp boring, in the Gullhögen quarry, and in the Norra Skagen boring.

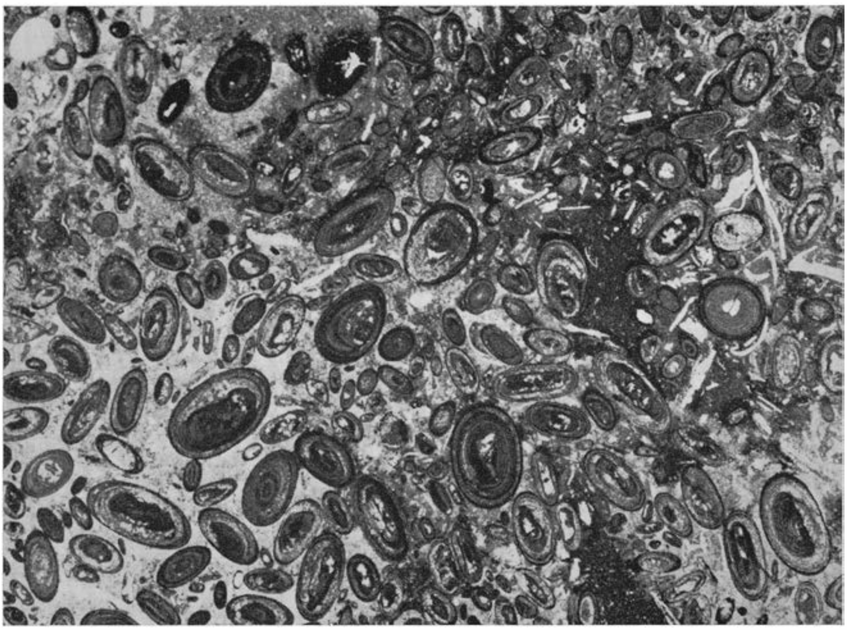

Fig. 17. Oölitic limestone with chamosite oöids. Vikarby Limestone, division *A*. Thin section, ordinary light. × 10. Photo N. HJORTH.

Table 2. Comparison of the thickness of Viruan topo-stratigraphic subdivisions on Kinnekulle (combined section of the Norra Skagen and Kullatorp borings) and south-eastern part of northern Billingen (Stora Åsbotorp boring).

Formation	Kinnekulle (Kullatorp + Norra Skagen) (m)	N. Billingen (Stora Åsbotorp) (m)
Mossen Formation	1.05	0
Skagen Limestone	3.30	3.29
Dalby Formation	21.28	12.01
Ryd Limestone	8.77	8.97
Gullhögen Formation	7.62	11.89
Skövde Limestone	0	0.27
Vikarby Limestone	0	0.15

and 7.6 m on Kinnekulle, is termed here the Gullhögen Formation. The upper division is formed by bedded calcilutites and finely nodular limestones and is here referred to as Ryd Limestone.

On Kinnekulle the Gullhögen Formation rests directly upon the Ontikan Kunda Stage. The basal Viruan discontinuity surface is overlain by a bed of limestone, 4 to 7 cm thick, which is an oölite at the base (for a description of this oölitic portion, see p. 71) but otherwise a calcilutite with few shell fragments. This bed of calcilutite is overlain by a calcarenitic limestone, some 20 cm thick, with numerous chamositic grains in some beds and with irregular thin intercalations of argillaceous matter rich in shell fragments. On the south-eastern part of northern Billingen the Skövde limestone is overlain by a similar calcarenitic limestone, some 25 cm thick. Otherwise the limestone of the Gullhögen Formation is a calcilutite though some thin beds rich in shell fragments occur also higher up in the sequence and occasionally contain chamositic grains. The insoluble residue of the limestone has not been studied yet.

It is probable that on eastern Billingen a lower part of the Gullhögen Formation corresponds to the Lasnamägian Folkeslunda Limestone. In Östergötland beds comparable to the Folkeslunda calcarenite of Öland consist to a large extent of mudstone and finely nodular limestone (JAANUSSON 1962) reminding one of the Gullhögen Formation. In this respect they seem to form a transition between the calcarenitic facies of the Folkeslunda Formation and the mixed calcilutite and mudstone facies of the Gullhögen Formation. However, at present no certain faunal criteria support this correlation. The top of the Folkeslunda Formation is characterized by the disappearance of *Euprimites effusus*, but this otherwise common species has hitherto not been found in the Viruan of Västergötland. Species, such as *Actinochilina* sp. *A*, which are distinctive for the Gullhögen Formation, have not been found outside that division. *Trinucleus foveolatus* may indicate a Lasnamägian age, but its vertical range is poorly known, and on Kinnekulle it or a very closely related species occurs in beds which are unquestionably of Uhakuan age. In fact, there exist at present no faunal or lithological criteria which can be used for determination of the boundary between the lower, probably Lasnamägian part and the upper, undoubtedly Uhakuan part of the Gullhögen Formation. This agrees with the experience from some other districts that, in pelitic and lutitic facies, the faunal differences between Lasnamägian and Uhakuan beds are slight, and the boundary between the stages is difficult to draw. It is possible that this boundary is better defined in the conodont faunas.

On Kinnekulle the Gullhögen Formation is 4.27 m thinner than in the Stora Åsbotorp core of Billingen (cf. Table 2). The overlying Ryd Limestone has about the same thickness on Kinnekulle (8.77 m) and on eastern Billingen (8.97 m in the Stora Åsbotorp boring). Thus the differences in the thickness of the Gullhögen Formation cannot be explained by an earlier change into a Ryd Limestone lithofacies on Kinnekulle. Both Norra Skagen and Stora Åsbotorp sections contain a conspicuous division of regularly bedded limestone within the Gullhögen Formation, beginning at the levels of 26.53 and 62.75 m, respectively. The distance of these levels from the upper boundary of the Gullhögen Formation is nearly identical in both sections (4.79 m in the Norra Skagen core and 4.51 m in the Stora Åsbotorp core). This and comparable lithological features indicate that, if there is a break in the Gullhögen sequence of Kinnekulle, it evidently involves beds that correspond to the lowermost part of the formation as developed on northern Billingen. Thus also beds corresponding to the lower *c.* 4 m of the Gullhögen Formation of eastern Billingen might be included in the hiatus at the base of the Viru Series on Kinnekulle. If this is the case, the question arises, whether or not the Gullhögen Formation of Kinnekulle includes any beds of Lasnamägian age at all, i.e. whether or not the Uhakuan beds there overlie directly the Kunda Stage. In the Motala boring, Östergötland, the thickness of the beds corresponding to the Folkeslunda Formation is 2.76 m (JAANUSSON 1962). Although the transition westwards of these beds into the Gullhögen Formation of eastern Billingen evidently involves some increase in thickness, the total thickness of the Lasnamägian portion of the Gullhögen Formation there may not exceed 4 m. In this case the Lasnamägian strata might have completely wedged out towards Kinnekulle. However, the correlation of the strata in question of Billingen and Östergötland is not sufficiently exact yet and additional faunal evidence is needed for solving this problem. Conodonts, in particular, may be useful in this connection. In the Norra Skagen section the occurrence of *Sigmoopsis perpunctata*, *Gymnograptus linnarssoni*, and *Dicellograptus vagus*[1] (cf. Fig. 6) indicates that beds 3.5 to 4 m above the base of the Viruan strata are of Uhakuan age. Lower down in the Gullhögen Formation no species

[1] This specimen was referred to by JAANUSSON & STRACHAN (1954, p. 686) as *Dicellograptus divaricatus salopiensis*. Further preparation of this tolerably well preserved rhabdosome in limestone revealed that it belongs to *D. vagus* HADDING.

Fig. 18. Norra Skagen boring, polished and slightly etched surface of the core between the levels of 24.31 and 24.39 m. Upper part of the Gullhögen Formation. Limestone inclusions in a greenish-grey mudstone. Natural size. Photo N. HJORTH.

have been found which are known to be confined to either Lasnamägi or Uhaku Stage. At present state of our knowledge, the basal beds of the Viru Series of Kinnekulle belong either to the Uhaku or the uppermost Lasnamägi Stage.

The mudstone of the Gullhögen Formation characteristically contains irregularly shaped calcilutite nodules (Figs. 18, 19). Orientation and state of preservation of shell fragments within the nodules, and lamination of the mudstone around the nodules witness of an early lithification of the nodules, before any noticeable compaction had taken place. The mudstone around the nodules is, on the other hand, considerably compacted as is seen also from the flattened and distorted shells within the mudstone. The origin of the nodules requires further study. However, they cannot be explained to have originated as a sort of "sedimentary boudinage" formed by compaction (cf. McCROSSAN 1958).

Parts of the sequence show well-defined cyclical sedimentation. A well-developed cycle begins with mudstone with or without a few limestone nodules continues upwards into mudstone with numerous nodules and subsequently into finely nodular limestone, and ends in a more or less continuous bed of limestone, or a group of limestone beds. The top of the limestone unit against the base of the overlying cycle is mostly sharp.

The fauna of the Gullhögen Formation of Kinnekulle and Billingen is listed in Table 3. Lithologically the formation is close to that prevailing in the Viruan deposits of the Oslo district, and also the fauna shows affinities to that district. *Ogygiocaris sarsi* and *Trinucleus foveolatus* are common in the Oslo district, and

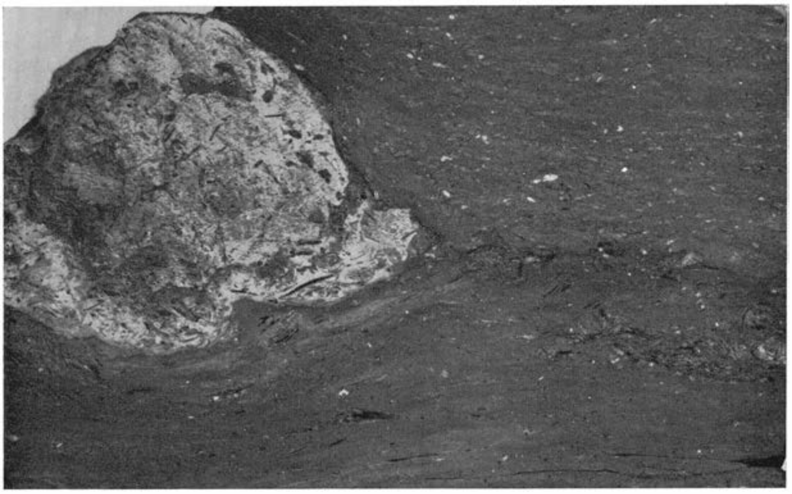

Fig. 19. Stora Åsbotorp boring, polished and slightly etched surface of the core between the levels of 74.22 and 74.28 m. Lower part of the Gullhögen Formation. A large limestone nodule in grey mudstone. Notice the irregular orientation of shell fragments within the limestone. × 1.5. Photo N. HJORTH.

although *Pseudomegalaspis patagiata* occurs also on Öland and in the Siljan district its ubiquity in the Gullhögen Formation agrees with that of the Oslo district.

In this connection a fauna from the Gullhögen Formation in a quarry at the western slope of Mösseberg is of a certain interest, although the locality lies outside the region treated in this paper. The quarry is situated in Viske-Kleva, close to the road which traverses Mösseberg, just before the road joins the highway from Floby to Ugglum. In it a section some 3 m high is exposed in the upper part of the Gullhögen Formation. The lower part of this sequence has yielded the following species;

Pseudomegalaspis patagiata (TÖRNQ.)
Ogygiocaris sarsi ANG.
Nileus sp.
Remopleurides sp.
Cybelella sp.
Paraceraurus sp. indet.
Sphaerocoryphe sp.
Lonchodomas sp.
Reedolithus carinatus (ANGELIN)
Actinochilina sp. *A* JAAN.
Tallinnella elongata (KRAUSE)
Steusloffia linnarssoni (KRAUSE)
Conchoprimitia sp.
Alwynella sp.
Clisospira sp.
Didymograptus sp. (extensiform type)

The exposed sequence belongs to the Uhakuan portion of the formation. Of special interest is the occurrence of *Reedolithus* low down in the Uhakuan strata.

The Ryd Limestone can be considered as a tongue of the Furudal Limestone. It consists of bedded and finely nodular calcilutites (cf. Fig. 7), and the lithology and fauna agree with the Furudal Limestone as developed in Öster-

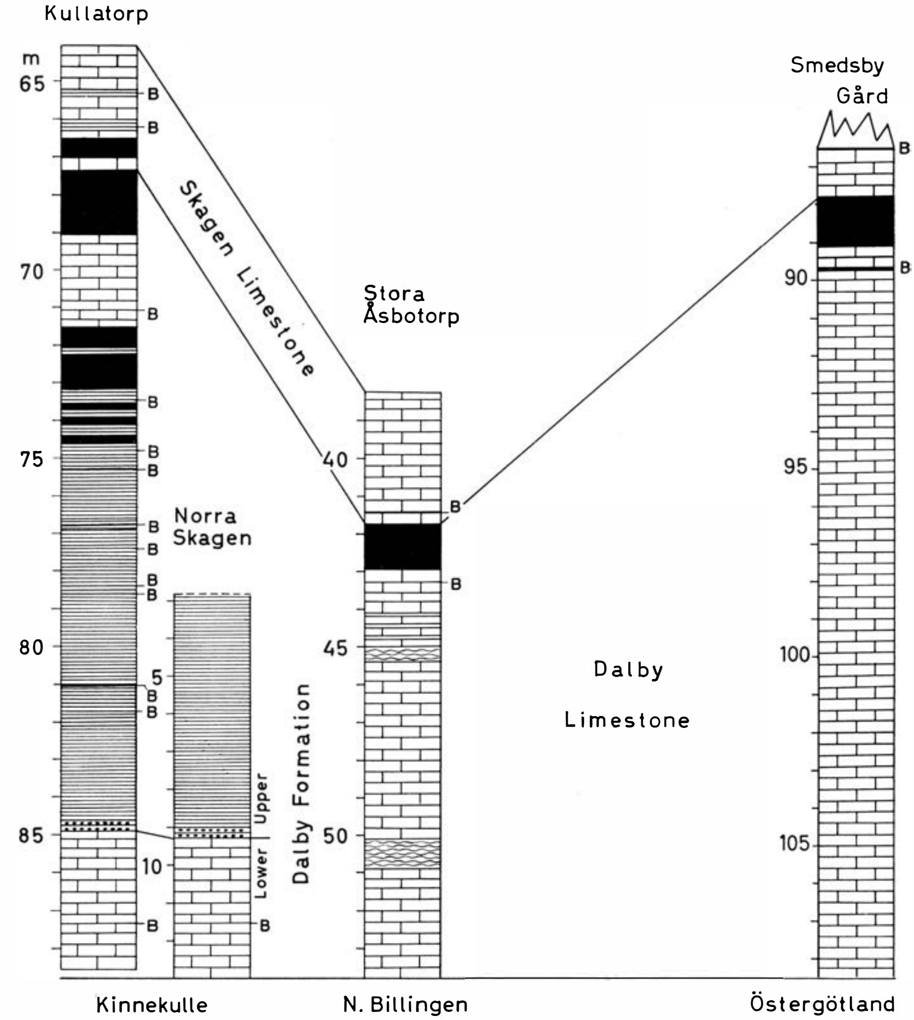

Fig. 20. A comparison of sections through the Dalby Formation on Kinnekulle, northern Billingen, and in Östergötland.

götland. Portions of the sequence consist of faintly reddish-brown to variegated, intensely reddish-brown and grey limestones. Occasional beds with a reddish-brown colour are known also in the Furudal Limestone of Östergötland (JAANUSSON 1962). Parts of the sequence show a cyclic sedimentation similar to that in the Gullhögen Formation. Here the cycles usually begin with a finely nodular limestone with thick argillaceous intercalations. Upwards the argillaceous intercalations become thinner, and the top of the cycle is usually formed by one or a few continuous beds of calcilutite.

The fauna of the Ryd Limestone is listed in Table 3.

DALBY FORMATION.—The lowermost part of the formation has, in the main, a fairly similar development in all known sections of Kinnekulle and the Billingen–Falbygden district. The basal beds are calcilutitic (cf. Figs. 7 and 12), and do not differ lithologically from the underlying Ryd Limestone. The lower boundary can be drawn upon faunal evidence only. Higher up in the section the grain size of the limestone increases until the rock becomes preponderantly a calcarenite, and chamositic grains occur in some beds.

On Kinnekulle and Mösseberg the development of the main upper part of the formation differs conspicuously from that on eastern Billingen and Varvsberget. On the former mountains this part consists predominatly of dark mudstones, whereas on eastern Billingen and Varvsberget the whole formation is composed of limestones. The sequence of the formation on Kinnekulle and Mösseberg can thus be divided into two well defined members. The Lower Member, 3.7 m thick on Kinnekulle, has the same development as the corresponding part of the sequence on eastern Billingen. The Upper Member on Kinnekulle as well as on Mösseberg has a distinctive oölitic mudstone (cf. Fig. 3) at its base and is formed by dark mudstone in the lower part and by a complex of bentonitic beds in the upper part. The mudstone has some intercalations of beds and lenses of calcilutite, and the bentonitic beds alternate with beds of calcilutite which is in part siliceous. The thickness of the Upper Member amounts to 17.65 m on Kinnekulle and 10.39 m on Mösseberg (Bestorp boring, cf. SKOGLUND 1963). This difference in thickness depends in part upon the greater total thickness, about 2.2 m, of the bentonitic beds on Kinnekulle.

The predominatly pelitic development of the Upper Member on Kinnekulle and Mösseberg contrasts with the preponderantly calcarenitic lithofacies of the corresponding beds not only on eastern Billingen and Varvsberget, but also in Östergötland (JAANUSSON 1962), on Öland (JAANUSSON 1960a), and in the Siljan district (JAANUSSON 1963). On the other hand, it shows similarity with the corresponding beds of the Fågelsång district in Scania (Sularp Shale and the underlying sequence of the *Dicellograptus* Shale) and of the Oslo district (division 4 bα below the thickest bentonitic bed). Lithologically the lower part of the member agrees with the mudstones of the Oslo district rather than with the graptolitic shale of the Fågelsång district, whereas the upper part is more calcareous than in either of these districts. The majority of common species in the mudstone of Kinnekulle is known also in the sequence in question of the Fågelsång district. Such species are *Pyxion carinatus*, *Actinochilina suecica*, *Conchoprimitia* cf. *conchoides*, *Primitiella* ? *spiniger*, and *Sericoidea restricta*. In addition specimens of *Parapyxion* and *Asaphus* (*Neoasaphus*) *ludibundus* have been examined by the present writer from the corresponding beds of the latter district. The ostracode fauna of the division 4 bα is still poorly known, and the presence there of at least some of these species is not excluded.

On the whole, the Upper Member of the Dalby Formation on Kinnekulle and Mösseberg can be considered as a tongue of the facies prevailing in the contemporaneous beds of the Oslo district, and the Lower Member as a similar tongue from the main calcarenitic facies of the formation in the mainland of Sweden north of Scania and south of Jämtland. The latter lithofacies dominates the sequence of the formation on eastern Billingen and on Varvsberget.

On Kinnekulle the macrofauna of the Dalby Formation is poorly known, since these beds have never been accessible in good exposures. On northern Billingen our present knowledge about the macrofauna of the formation is derived chiefly from collections in two small outcrops, viz. about 1 km WNW of Ryd on the eastern slope of the mountain and at Jättedalen in Öglunda on the western slope of Billingen. From the former locality extensive collections have been made, in 1941, by Professor BIRGER BOHLIN. The following species have been encoutered:

Asaphus (*Neoasaphus*) *ludibundus* TÖRNQ.
Nileus sp.
Remopleurides sp.
Lonchodomas sp.
Ampyx costatus (BOECK)
Illaenus cf. *sphaericus* HOLM
Panderia parvula (HOLM)
Raymondaspis ? *nitens* (WIMAN)
Niezkowskia variolaris (LINNARSSON)
Chasmops sp.
Platylichas sp. (hypostoma)
Euprimites locknensis (THORSL.)
Euprimites n.sp.
Sigmobolbina sp.
Echinosphaerites aurantium aurantium (GYLL.)
Pseudoclimacograptus cf. *scharenbergi* (LAPW.)

From the Dalby Limestone at Jättedalen in Öglunda Dr. JÜRI MARTNA has, in 1951 and 1952, brought together the following species:

Asaphus (*Neoasaphus*) *ludibundus* TÖRNQ.
Ogmasaphus sp.
Nileus sp.
Illaenus sphaericus HOLM
Panderia parvula (HOLM)
Chasmops sp.
Echinosphaerites aurantium aurantium (GYLL.)
Orthoceracone cephalopods
Clathrospira sp.
Torellella taenia HOLM

WESTERGÅRD (1931, p. 59) listed a faunule from the Dalby Limestone from a well-digging at Karstorp on the eastern side of northern Billingen. A revised list of the fossils found by him, in 1924, at this locality is as follows:

Asaphus (*Neoasaphus*) *ludibundus* TÖRNQ.
Nileus sp.
Remopleurides sp. (recorded by WESTERGÅRD as *R. sexlineatus* but belonging to some other species)
Steusloffia costata (LINNARSSON)
Echinosphaerites aurantium aurantium (GYLL.)
Internal moulds of gastropods
Orthoceracone cephalopods
Pseudoclimacograptus cf. *scharenbergi* (LAPW.)

WESTERGÅRD recorded also *Illaenus avus* HOLM (= *Stenopareia* sp.) from this assemblage. However, this trilobite was found by him, in 1919, in an erratic boulder at Karstorp. It is difficult to ascertain, whether it comes from the Dalby or the Skagen Limestone.

In comparison with Öland, Östergötland, and the Siljan district the Dalby Limestone of Billingen is very poor in large sedentary organisms, excepting *Echinosphaerites*. Articulate brachiopods and bryozoans which form an important constituent of the fauna of the formation in the other districts are almost entirely missing. *Nileus* is, on the other hand, fairly common in the lower part of the formation in Västergötland. This genus has never been found in these beds of the other districts.

The number and thickness of bentonitic beds in the upper part of the Dalby formation show an irregular distribution. On Kinnekulle the number of individual bentonitic beds as well as their total thickness are great in comparison with the other Cambro-Silurian districts of Sweden north of Scania. This may have a certain connection with the small grain size of the intercalated pelitic and calcilutitic sediments on this mountain. It indicates that the transportation velocity of the currents during the deposition of these beds has in general been low and favourable for the deposition of clay particles. In the Oslo district (Sinsen section) the development of the complex of bentonitic beds is similar to that of Kinnekulle (HAGEMANN & SPJELDNÆS 1955), and the whole sequence is developed in a comparable pelitic facies. In the Fågelsång district, Scania, the depositional conditions of the corresponding graptolitic shales have evidently been still more tranquil than in the above districts. The number of observed individual bentonitic layers is much higher than elsewhere in Sweden (cf. NILSSON 1960). On the other hand, in the districts where the comparable part of the Dalby Formation has a predominantly calcarenitic development only few bentonite beds are developed. Often only the thickest bentonite bed and two to three additional thin beds are distinguishable (Billingen, cf. SKOGLUND 1963; Östergötland, cf. THORSLUND 1958, Fig. 3). In some sections the number of individual bentonite beds is somewhat greater (Varvsberget, cf. SKOGLUND 1963; File Haidar, Gotland, cf. THORSLUND 1958, Fig. 3; Siljan district, cf. JAANUSSON & MARTNA 1948), but in these cases none of the beds attains a considerable thickness. Thus it seems that the distribution of the bentonitic beds has been controlled by depositional conditions rather than by the distance of the area of deposition from the source of the bentonitic material. An exception from the described pattern is the sequence on Mösseberg (Bestorp boring. cf. SKOGLUND 1963) where, in a pelitic and calcilutitic environment, only four bentonitic beds can be distinguished. Only the thickest bentonite bed of Kinnekulle (the topmost bed of the Dalby Formation) can be correlated with that in the other Cambro-Silurian districts of Sweden with any degree of certainty (cf. THORSLUND 1958, Fig. 3).

In Västergötland the total thickness of the Dalby Formation is at present known only on Kinnekulle (combined sections of the Kullatorp and Norra Skagen borings) and on the eastern part of northern Billingen (Stora Åsbotorp boring). The whole formation has been pierced also in the Häggum boring on south-eastern Billingen, but the infrabentonitic part of the core has not yet been examined. The thickness of the formation on Kinnekulle (cf. Table 2) is about equal to that in Östergötland and the Siljan district, although the prevailing type of the rock is different. In the Stora Åsbotorp boring, on the other hand, the thickness of the formation is only about half of that in the districts mentioned above. This is the known minimum thickness of the formation in Sweden. There are indications that the comparatively small thickness of the Dalby Formation is a feature common to the whole Billingen–Falbygden district. In the Bestorp boring, Mösseberg (cf. SKOGLUND 1963), the base of the boring is evidently not much above that of the Dalby Formation, and the thickness of the formation cannot be expected greatly to exceed that in the Stora Åsbotorp boring. The reason of the comparatively small thickness of the Dalby Formation in the Billingen–Falbygden district is not evident. No lithological indications of a break within the limestone sequence have been observed.

SKAGEN LIMESTONE.—The fauna of the *Ludibundus* beds above the thickest bed of bentonite differs from that below the complex of bentonitic beds and within this complex. Several of the species which are distinctive for, and common in the Dalby Limestone disappear, and several species not found in the Dalby Limestone make their entrance. Among the former species *Euprimites locknensis* can be particularly mentioned. The species distinctive for the Skagen Limestone include *Asaphus* (*Neoasaphus*) *glabratus*, *Phillipsinella* n.sp., *Illaenus gigas*, *Platylichas validus*, *Chasmops* n.sp., *Chasmops* cf. *conicophthalmus*, *Remopleurides sexlineatus*, and *Hesslandella* ? *gunnari*. Several species continue from the Dalby Limestone, among them *Asaphus* (*Neoasaphus*) *ludibundus* and *Steusloffia costata*. This faunal change makes it necessary to distinguish the suprabentonitic *Ludibundus* beds as a separate formation.

The fauna of the Skagen Limestone consists preponderantly of vagile organisms, such as trilobites, ostracodes, and gastropods, whereas sedentary groups are rare. Brachiopods are few and are represented by small species only, and bryozoans and cystoids are almost completely lacking.

The lower and main part of the Skagen Limestone has a fairly uniform development all over Västergötland. It consists of thick-bedded, grey calcilutites with argillaceous intercalations of varying thickness. The lithology of the upper part of the formation is more diversified. On Kinnekulle, western Mösseberg (Jonstorp exposure, cf. SKOGLUND 1963), and possibly also in the eastern part of northern Billingen (Stora Åsbotorp boring) calcareous mudstone forms an important constituent of the sequence. On southern Billingen, western Mösseberg (Bestorp boring, cf. SKOGLUND 1963), and on Varvsberget the whole sequence of the formation consists of thick-bedded calcilutites, and intercalations of mudstone are inconspicuous. The significance of the intraformational

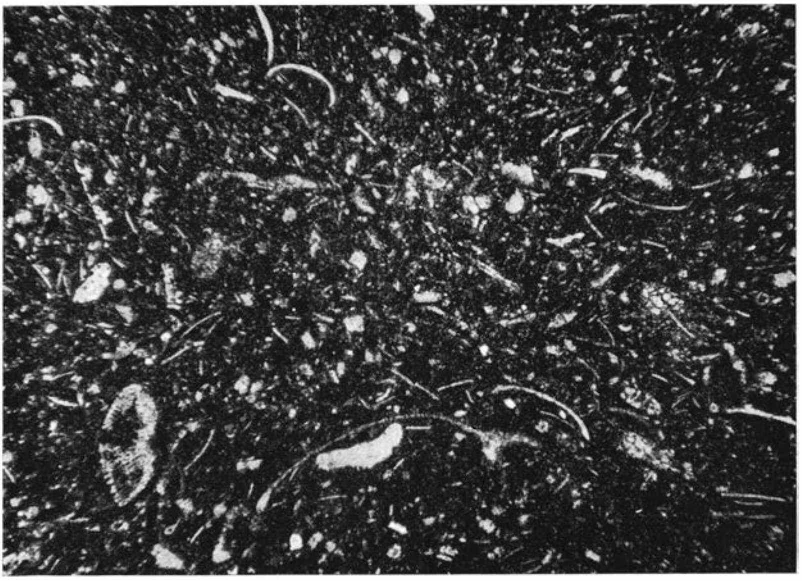

Fig. 21. Skagen Limestone, Mossen section, 2.65–2.70 m from the top of the formation. A calcilutite with a moderate content of shells and shell fragments (this thin section contains 9 % of shell fragments longer than 0.1 mm). Ordinary light. × 40. Photo N. HJORTH.

conglomerate in the upper part of the Skagen Limestone of Kinnekulle (THORSLUND 1948, Pl. XXII, fig. 3) requires further study.

The limestone of the formation is a calcilutite, usually with 5 to 15 % of shell fragments longer than 0.1 mm in thin section (Fig. 8). The matrix is fine-grained to cryptocrystalline, shell fragments have usually a well preserved outline (Fig. 21), and recrystallization phenomena are inconspicuous. The insoluble residue of the limestone has not been studied yet.

The following data about the thickness of the formation are known:

Kullatorp boring, Kinnekulle	3.30 m
Mossen section, Kinnekulle	3.95 m
Stora Åsbotorp boring, eastern slope of northern Billingen	3.29 m
Skultorp boring, eastern slope of southern Billingen (SKOGLUND 1963)	2.28 m (? + 0.31 m)
Häggum boring, southeastern slope of southern Billingen (SKOGLUND 1963)	1.80 m
Bestorp boring, eastern slope of Mösseberg (SKOGLUND 1963)	2.95 m
Fårdala boring I, Varvsberget (SKOGLUND 1963)	1.51 m (? + 0.24 m)

According to the diagrammatic section given by BYSTRÖM (1957, Fig. 1) of the Rosenlund core on the southwestern slope of northern Billingen, the thickness of the Skagen Limestone seems there to be only about 1.7 m.

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SPJELDNÆS (in HAGEMANN & SPJELDNÆS 1955, pp. 46–48) suggested that on Kinnekulle beds corresponding to the Mossen Formation and the *Ludibundus* beds are separated by a hiatus which comprises equivalents to the divisions 4bβ, 4bγ, and almost the whole of 4bδ of the Oslo-Asker sequence. JAANUSSON (1960 b, p. 350) pointed out that there certainly is a hiatus on Kinnekulle at the base of the *Dicranograptus clingani* Shale, but that the magnitude of this hiatus, though not yet exactly determinable, is in no way comparable to that suggested by SPJELDNÆS. SPJELDNÆS (loc. cit.) also hinted at the possibility that the hiatus may be indicated by the intraformational conglomerate between the levels of 64.81 and 64.90 m in the Kullatorp core. However, at that level no conspicuous faunal change can be observed, and the break at the base of the conglomeratic bed is probably of a minor importance.

It is difficult to give a satisfactory idea about the magnitude of the hiatus between the Mossen and Skagen Formations on Kinnekulle before the suprabentonitic Viruan sequences of Östergötland and the Siljan district have been described in some detail. For this reason some general remarks only are given here. In Östergötland and in the Siljan district the sequence is apparently continuous from the top of the Dalby Limestone to the top of the *Macrourus* Limestone. In the inter-reef facies no lithological or faunal indications of a break are known in this part of the sequence. In the Smedsby Gård boring the total thickness of the suprabentonitic *Ludibundus* beds and *Macrourus* beds is 14.35 m. Owing to the paucity of determinable fossils in this part of the core it is difficult to determine the exact level of the boundary between these beds. Still, the fossils indicate that at least half of suprabentonitic Viruan sequence of the core (about 7 m) belongs to the suprabentonitic *Ludibundus* beds. This is almost twice the known maximum thickness of these beds (the Skagen Limestone) in Västergötland (3.95 m at Mossen). The sedimentation intensity during the deposition of this part of the sequence may, of course, have been much lower in Västergötland than in Östergötland, but the general type of the rock is fairly similar in both districts, and great differences in the sedimentation intensity seem to be improbable. In case the sedimentation intensity during the deposition of the suprabentonitic *Ludibundus* beds has been about equal in Östergötland and Västergötland, deposits corresponding to about the upper half of these beds are missing on Kinnekulle. In the Billingen–Falbygden district the break is still greater, since the thickness of the Skagen Limestone is smaller, and in several places this formation is directly overlain by the Harjuan beds (Fig. 22). On the south-eastern slope of southern Billingen (Häggum boring) and the south-western slope of northern Billingen (Rosenlund boring) the small thickness of the Skagen Limestone (1.7 to 1.8 m) indicates that beds corresponding to the upper part of this formation of Kinnekulle are probably involved in the extensive hiatus at the top of the Viru Series and the base of the Harju Series. In the Häggum boring the formation is overlain by the uppermost beds of the Harjuan Fjäcka Shale (SKOGLUND 1963).

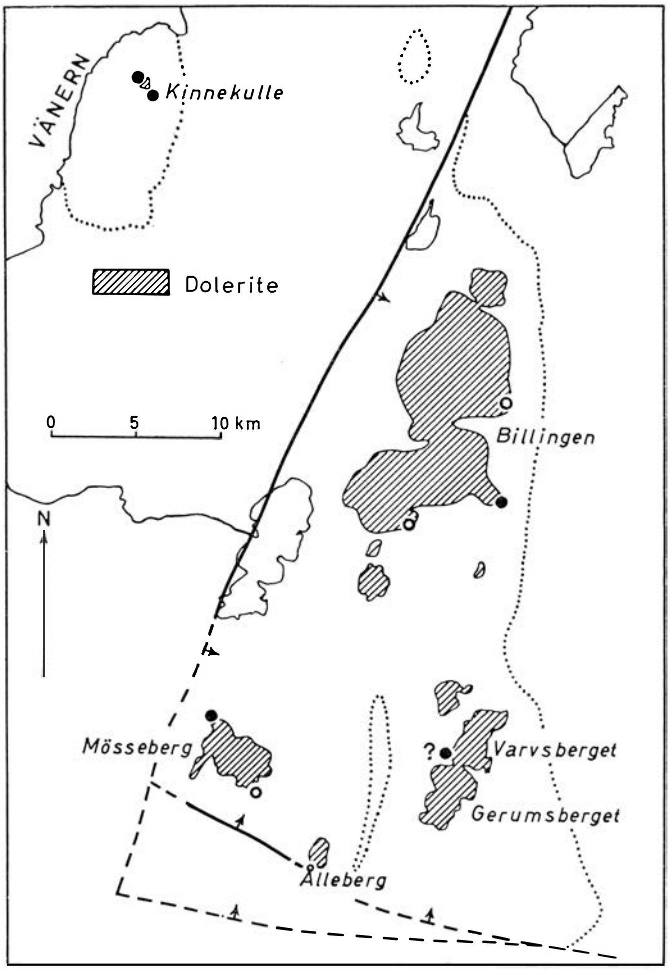


Fig. 22. Map showing, where in Västergötland the presence of beds belonging to the Mossen Formation has been established (black dots), and where the corresponding beds are missing (circles). In the latter places the Skagen Limestone forms the top of the Viru Series.

MOSSEN FORMATION.—In several areas of the Billingen–Falbygden district the Viruan sequence terminates with the Skagen Limestone, and the topmost Viruan beds are missing. Such areas are the eastern part of northern Billingen (Stora Åsbotorp boring), south-eastern Billingen (Häggum boring), and eastern Mösseberg (Bestorp boring) (cf. Fig. 22). In some other areas of the district and on Kinnekulle the Skagen Limestone is overlain by a thin sequence of shale and mudstone belonging to the topmost Viruan division in Västergötland (SKOGLUND 1963). This division, first distinguished by THORSLUND (1948) on Kinnekulle, has been termed the Mossen Formation (SKOGLUND 1963). In the Billingen–Falbygden district it has been identified (SKOGLUND 1963) on Varvsberget (Fårdala boring I), western Mösseberg (Jonstorp excavation), and the easternmost part of southern Billingen (Skultorp boring). Its occurrence on Varvsberget requires however, in the present writer's opinion, further confirmation. The shale contains graptolites distinctive for the zone of *Dicranograptus clingani* (THORSLUND 1948; SKOGLUND 1963). For further information about these beds, see SKOGLUND (1963).

Examination of the syntype material of *Tretaspis cerioides* in the Riksmuseum in Stockholm showed that the topmost calcareous mudstone of the Mossen Formation of Kinnekulle (cf. SKOGLUND 1963) is the type stratum of this species. The specimens occur in the kind of rock characteristic for these beds and are associated with the ostracode species distinctive for the upper part of the Mossen Formation.

That the zone of *Dicranograptus clingani* is comparable to the *Macrourus* beds (*s. str.*) has been conclusively shown already by THORSLUND (1940, 1948).

The known maximum thickness of the Mossen Formation in Västergötland (1.57 m in the Mossen section on Kinnekulle, cf. SKOGLUND 1963) is much smaller than that of the *Macrourus* Limestone in Östergötland (at least about 5 m in the Smedsby Gård boring) and in the Siljan district (about 5.7 m in the main section of Fjäcka). However, the sedimentation intensity of the graptolitic shale of the Mossen Formation has evidently been considerably inferior to that of the calcarenitic calcilutite of the *Macrourus* beds in the inter-reef facies. In the graptolitic facies of southern Scandinavia the known thickness of the zone of *Dicranograptus clingani* is 2.95 m (Fågelsång district, Scania; GLIMBERG 1961) to 3.2 m (Bornholm; HADDING 1915). This suggests that the part of the *clingani* Shale as developed on Kinnekulle may correspond to only about a half of the total extent of this zone. The main part of the hiatus corresponding to the missing portion of the zone is probably confined to the base of the Mossen Formation (cf. also SPJELDNÆS in HAGEMANN & SPJELDNÆS 1955), but the evidence is not quite conclusive.

The Basal Viruan Discontinuity Surfaces

The level of the breaks in the basal Viruan strata of the described sections is indicated by discontinuity surfaces. According to their morphology three different types of discontinuity surfaces can be distinguished, viz. (1) the smooth type, (2) the furrowed type, and (3) the type with an irregularly rough surface.

The basal discontinuity surface of the Vikarby Limestone on the south-eastern part of northern Billingen can be taken as an example for the first type.

Macroscopically the surface is quite smooth (Fig. 23) without any trace of organogenic borings or solution phenomena and with only a narrow and very faint zone of impregnation. The impregnation is haematitic, and the concentration of haematite in the matrix is only slightly stronger below the surface than in the rock lower down. Thin sections reveal that the surface is rough on a

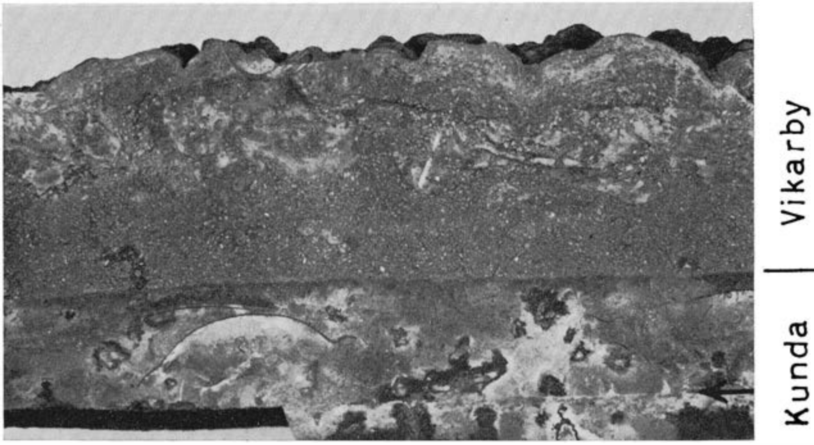
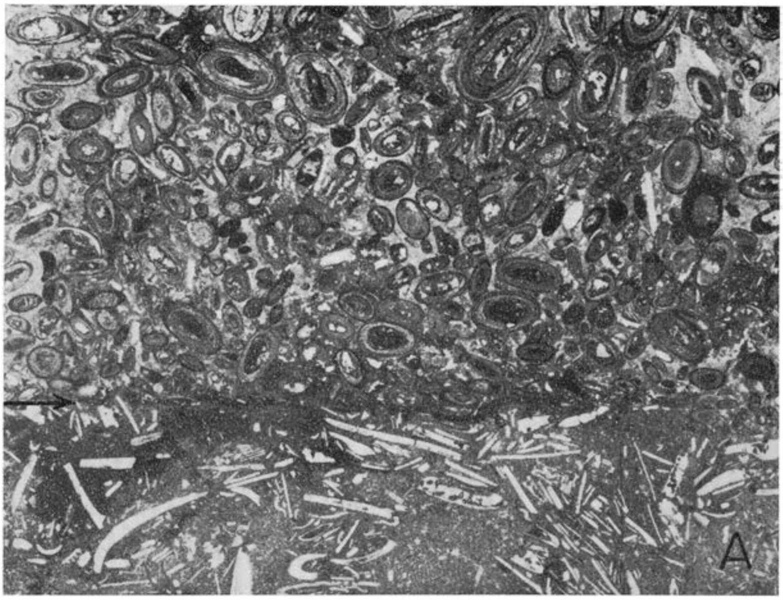


Fig. 23. Polished and slightly etched surface of the bed *A* of the Vikarby Limestone and the uppermost bed of the Kunda Stage showing the plane discontinuity surface at the base of the Viru Series. An arrow points to a plane discontinuity surface close to the top of the Kunda Stage. The upper surface of the sample is formed by the irregularly furrowed discontinuity surface between the beds *A* and *B* of the Vikarby Limestone (see Fig. 26A). Gullhögen quarry. × 2/3. Photo N. HJORTH.

microscopical scale, with irregular pits (Fig. 24B) which are up to 0.2 mm deep and occasionally pierce parts of shell fragments. The surface is locally coated, and the pits are in part filled with haematite. When the surface lacks a coating of haematite it becomes frequently indistinct in thin section already under moderate magnification (cf. Fig. 24A to the right). This is due, in part at least, to recrystallization phenomena — mostly grain growth (BATHURST 1959) — since in this case the grain size of the matrix tends to be fairly coarse. The minute pits in the surface are probably originated by corrosion, and the preservation of their shape is due to protecting action of the haematite coating. Such protecting properties against recrystallization of thin films of ferric compounds are known in the contemporaneous rocks of Sweden also in other connections (cf. JAANUSSON & MUTVEI 1953).

To this smooth type of discontinuity surface belong the basal surface of the Vikarby Limestone, a surface in the uppermost Kunda beds 1 to 2.5 cm below the Vikarby Limestone (cf. Fig. 23, lower surface), and a surface in the Skövde Limestone, 7 cm above the Vikarby Limestone, all on eastern Billingen. These surfaces resemble very much the smooth discontinuity surfaces described by HEIM (1908, Pl. VI, fig. 30; 1913) from the Cretaceous and basal Tertiary sequence of the Swiss Alps.

The basal discontinuity surface of the Skövde Limestone in the Gullhögen quarry is mainly of the furrowed type. It is occasionally smooth and resembles then the basal surface of the Vikarby Limestone. More often it is sculptured by fairly broad furrows which surround irregular subpolygonal areas of varying size (Fig. 25). In the latter case the surface resembles the contact between the



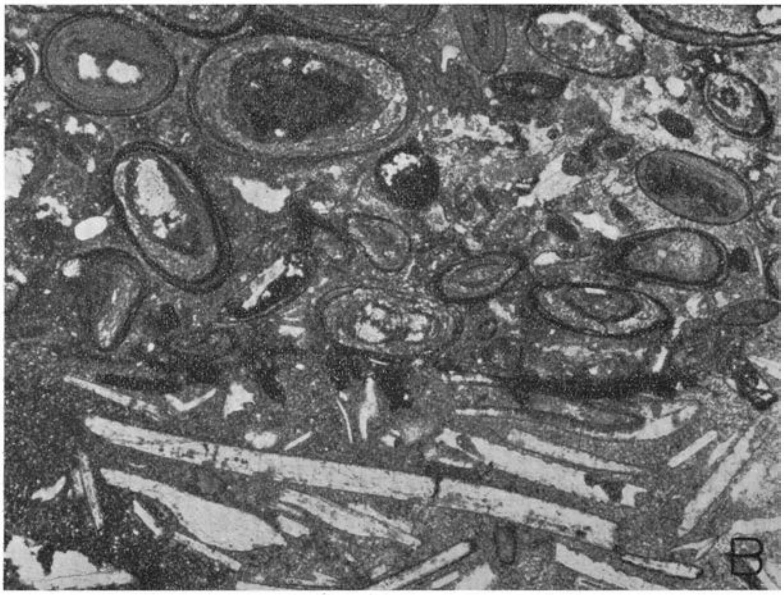


Fig. 24. Two photographs of a thin section showing the discontinuity surface at the contact between the Kunda limestone and Vikarby oölite. Gullhögen quarry. Photo N. HJORTH. *A*, × 7,5; an arrow points to the level of the discontinuity surface. *B*, × 30; notice the irregular small pits, filled with haematite, in the surface.

Kårgärde and Vikarby Limestones in the Vikarby section, Siljan district (JAANUSSON & MUTVEI 1953, Pl. 1, fig. 2) and the surface within the *Planifrons* zone on southern Öland (JAANUSSON 1960*a*, Pl. 5, fig. 2). No organogenic borings have been observed, and there does not seem to exist a distinct zone of impregna-

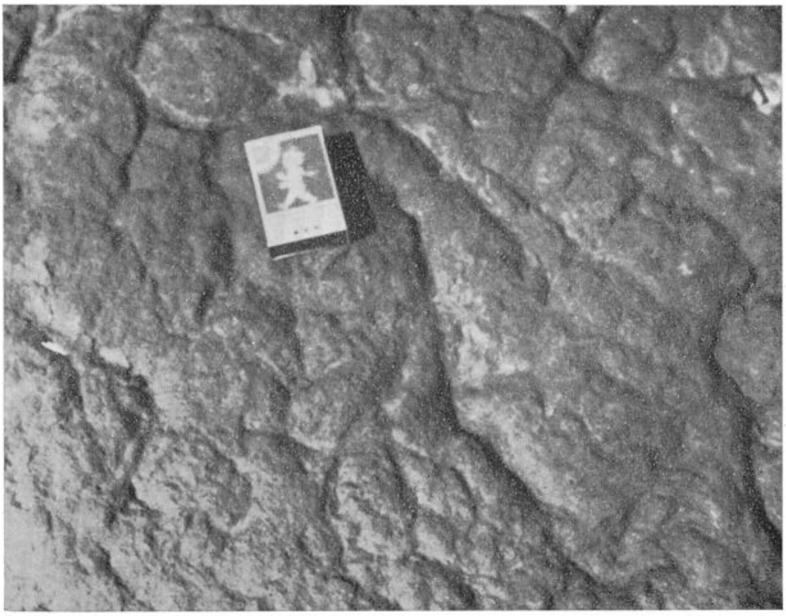


Fig. 25. The discontinuity surface at the base of the Skövde Limestone in the Gullhögen quarry. The length of the matchbox is 5 cm. Photo by the author.

tion apart occasionally from a slightly stronger concentration of haematite in the matrix immediately below the surface.

The discontinuity surface 6 cm above the base of the Vikarby Limestone in the Gullhögen quarry is rough and irregular, but can still be regarded as an extreme variant of the furrowed type. In some cases it shows a system of furrows which surround subpolygonal areas of about 5 to 7 cm diameter (cf. Fig. 26A). The furrows, as seen from transverse sections, are up to 1.2 cm deep (cf. Fig. 26B). The surface, especially in its protruding parts, is covered by a haematitic crust, some tenths of mm thick. In the Stora Åsbotorp core a narrow zone of the rock below the surface is yellow whereas in the Gullhögen quarry the bed underlying the surface is reddish-brown throughout. This surface resembles very much the basal discontinuity surface of the Aseri Stage in parts of northern Estonia (cf. ORVIKU 1940, Pl. XIII, fig. 4) except that the irregular system of furrows has not been observed there, and that no undoubted borings have been ascertained in the discontinuity surface of eastern Billingen.

There seem to exist all transitions from furrowed to completely smooth discontinuity surfaces. If the furrows have been formed by a subaerial desiccation (JAANUSSON 1960*a*, p. 252), the surface had been subaerially exposed. On reworked surfaces with desiccation cracks the polygons in carbonate sediments are often irregular and incomplete owing to a subsequent obliteration of some cracks here and there (cf. Fig. 27). The occasional occurrence of pebbles derived from the substratum above furrowed discontinuity surfaces (JAANUSSON &

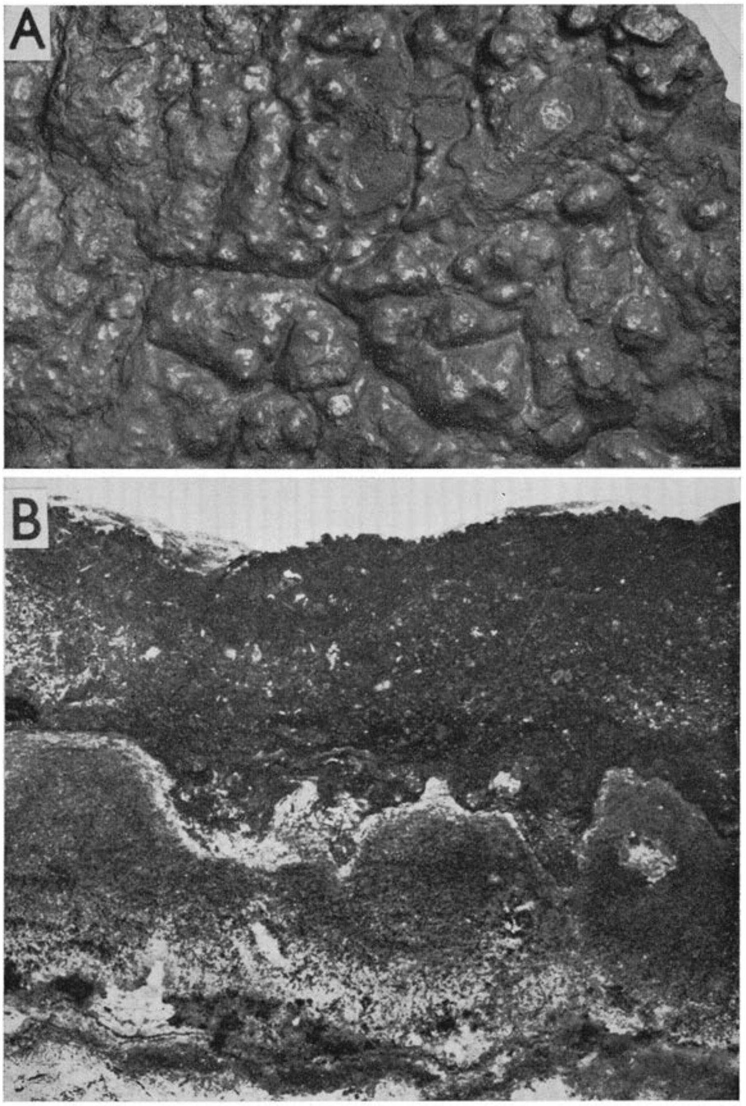


Fig. 26. *A*, the irregularly furrowed discontinuity surface at the contact between the beds *A* and *B* of the Vikarby Limestone. Gullhögen quarry. × 2/3. *B*, the same surface in cross-section. Stora Åsbotorp boring between the levels of 74.91 and 74.96 m, polished and slightly etched surface of the core. The bed above the discontinuity surface is the bed *B* of the Vikarby Limestone, and the upper surface of this bed is formed by the furrowed discontinuity surface at the contact between the Vikarby and Skövde Limestones (cf. Fig. 25). × 1.5.

MUTVEI 1953, Pl. I, fig. 1) is a phenomenon often associated with mud cracks. If the surface with desiccation cracks had become lithified to a certain extent during the subaerial exposure, subsequent erosion, subaerial as well as submarine, initiated a general levelling of the surface. When the erosion has acted for a sufficiently long time, or has been especially effective, the levelling may have

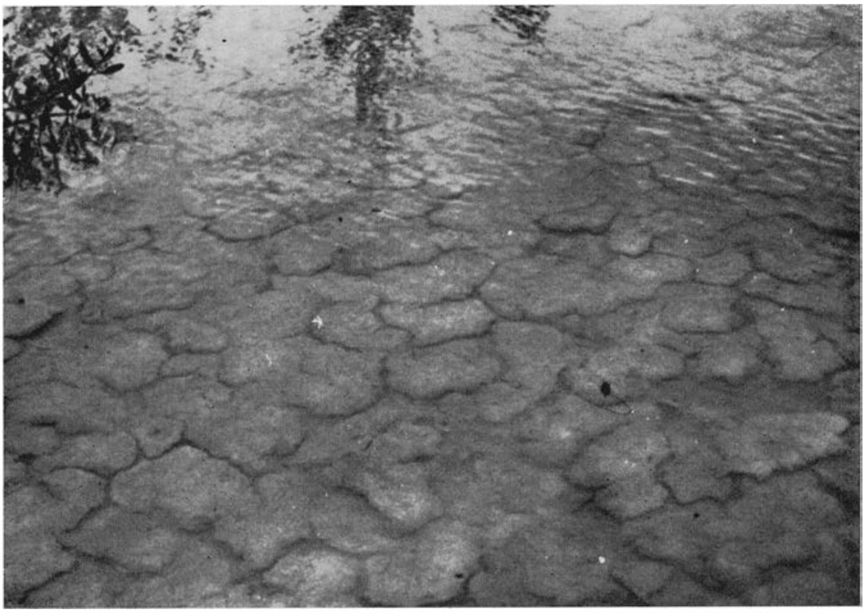


Fig. 27. Desiccation furrows in Recent calcareous mud, subsequently flooded and somewhat reworked. Bay of Florida, the largest of the Crane Keys. Photo by the author.

resulted in completely smooth surfaces. The final smoothness is probably due to polishing action of calcareous shell fragments or oöids in suspension (cf. JAANUSSON 1961). Subsequent deposition has preserved the surfaces at different stages of levelling, from those with slightly reworked desiccation cracks to completely smooth surfaces. A probable intermediate stage is described by JAANUSSON (1960*a*, p. 250) from the Seby Limestone of central Öland. However, not all smooth discontinuity surfaces are necessarily preceded by furrowed surfaces, and as to the described basal discontinuity surface of the Vikarby Limestone there is at present no evidence that its origin is connected with a furrowed surface.

The described discontinuity surfaces are now much better exposed in the Gullhögen quarry than at the time of the field-work for the present paper. A study of the horizontal changes in the morphology of these surfaces along the quarry would give important information towards the understanding of the origin of these structures.

The described surfaces differ from most other discontinuity surfaces by the complete absence of traces of organogenic borings. This may be due to infavourable conditions for boring organisms while the surface was submerged but still not covered by subsequent deposits. Scarcity of nutriment may have been one of the reasons for unfavourable conditions. Within the reddish-brown sediments adjacent to these discontinuity surfaces evidently little organic material has

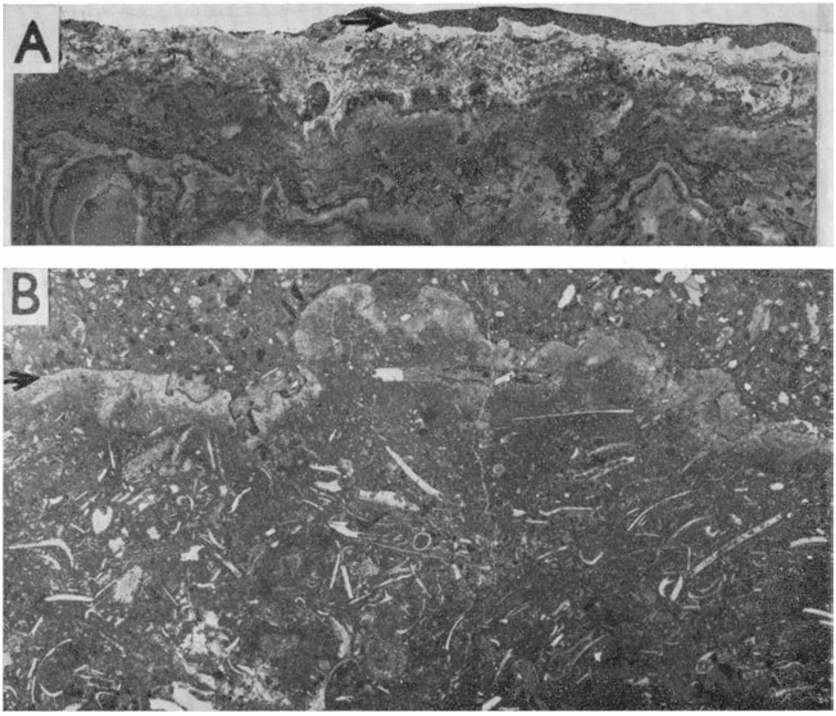


Fig. 28. The discontinuity surface at the base of the Viru Series in the Norra Skagen boring. *A*, polished and slightly etched surface of the core between 29.36 and 29.38 m. A cross-section of the uneven discontinuity surface can be traced, at the level of the arrow, on the right half of the figured portion of the core. Here the surface is seen to be overlain by an oölitic limestone at the base of the Gullhögen Formation (a thin, grey band on the photograph). Note the peculiar undulating banding in the rock below the discontinuity surface caused by a laminated arrangement of haematitic pigment within the reddish-brown limestone. × 1.5. *B*, thin section through the discontinuity surface and adjacent rock; the arrow points to the level of discontinuity. Note the distinct, light, phosphoritic zone of impregnation immediately below the discontinuity surface. × 12. Photo N. HJORTH.

been embedded, since otherwise its decomposition would, at least locally, have caused a reduction of ferric compounds into sulphide.

Discontinuity surfaces without organogenic borings and without a conspicuous zone of impregnation are often recognized with difficulty only. It is possible that within the Ontikan and Lower Viruan sequence of Sweden such surfaces are more numerous than what is evident from the published information.

The basal discontinuity surface of the Viru Series of Kinnekulle is irregular and rough. In the Norra Skagen boring it is uneven on a small scale (cf. Fig. 28A), the height of the irregularities of the surface not exceeding 2 mm. It differs from the described surfaces of eastern Billingen also by having a conspicuous zone of impregnation. The latter consists of a collophane-like phosphoritic substance which has replaced calcium carbonate in a narrow, somewhat irregular zone at and below the surface. This zone is usually about 0.3 to 0.4 mm

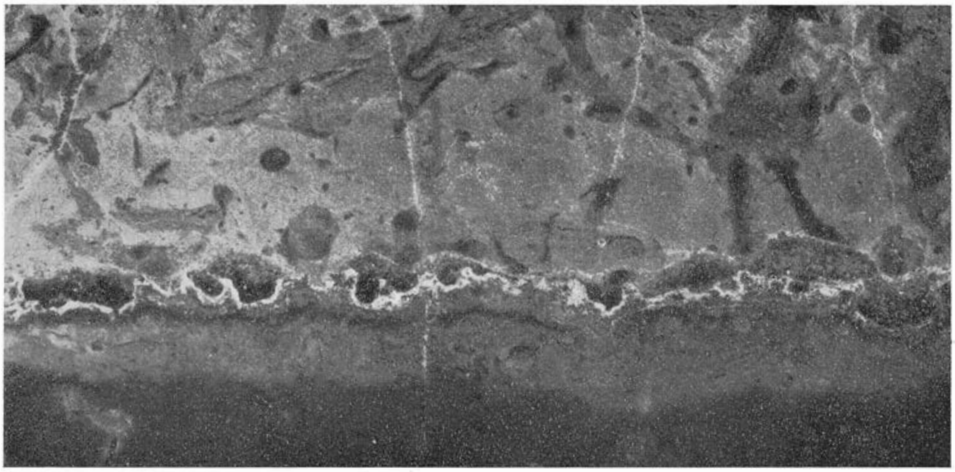


Fig. 29. The discontinuity surface at the base of the Viru Series in the Hällekis quarry on Kinnekulle. Polished and slightly etched surface of the topmost Kunda limestone and the lowermost Gullhögen Formation. The discontinuity surface at the contact between these divisions is marked by the top of the irregular, white, phosphoritic zone of impregnation. See also Fig. 30. Natural size. Photo N. HJORTH.

thick, but its lower boundary is not strictly parallel to the surface, and the thickness of the zone varies accordingly (cf. Fig. 28 B). The Kundan calcilutite below the zone of impregnation has to a depth of 0.5 to 1 cm a greenish-grey tint, and contains, locally, an impregnation of a pale green to yellow substance and small spots coloured reddish-brown by haematite. Below this light zone the calcilutite shows a peculiar irregular, undulating, reddish-brown banding (Fig. 28 A) caused by laminar arrangement of haematite pigment within the rock. The origin and significance of this banding is not obvious.

The discontinuity surface is overlain by a bed, 1 cm thick, which consists of

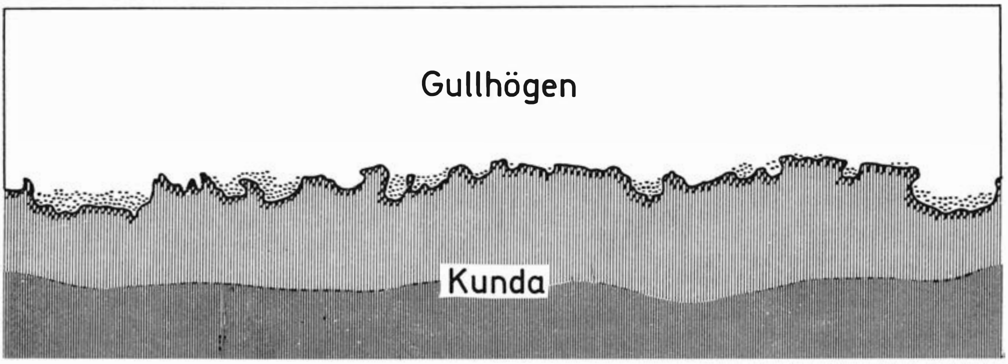


Fig. 30. Diagrammatic drawing of the section through the discontinuity surface shown on Fig. 29. The area marked by dark shading represents the intensely reddish-brown limestone which is overlain by a yellow zone — light shading. Black dots above the discontinuity surface show the distribution of chamosite oöids. Natural size.

Table 3. List of the species found in the Gullhögen, Ryd, Dalby, and Skagen Formations on Kinnekulle and northern Billingen.

The list includes only the species the identification of which was considered reliable at least at the generic level or could be checked by the writer. "L" and "U" denote that the species has been found in the lower or upper part of the formation, respectively.

Species	Gull-högen	Ryd	Dalby	Skagen	Kinne-kulle	N. Bil-lingen
TRILOBITA						
Asaphus (Neoasaphus) ludibundus TÖRNQ.	–	–	+	+	+	+
Asaphus (Neoasaphus) glabratus (ANG.)	–	–	–	+	+	–
Ogmasaphus cf. *praetextus* (TÖRNQ.)	–	–	+	–	–	+
Pseudomegalaspis patagiata (TÖRNQ.)	+	–	–	–	+	+
Pseudoasaphus sp.	+	–	–	–	–	+
Pseudobasilicus ? brachyrachis (TÖRNQ.)	+	–	–	–	–	+
Ogygiocaris sarsi ANG.	+	–	–	–	+	+
Nileus ssp.	+	+	+	–	+	+
Remopleurides sexlineatus (ANG.)	–	–	–	+	+	–
Remopleurides ssp.	+	+	+	+	+	+
Robergia ? sp.	–	–	+	–	+	–
Telephina ssp.	+	+	+	–	+	–
Lonchodomas ssp.	–	+	+	+	+	+
Ampyx (Cnemidopyge) costatus (BOECK)	–	–	+	–	+	+
Ampyx (Cnemidopyge) n.sp.	L	–	–	–	+	–
Illaenus sp. indet. (cf. *chiron* HOLM)	+	+	–	–	+	+
Illaenus sphaericus HOLM	–	–	+	–	–	+
Illaenus gigas HOLM	–	–	–	+	+	–
Panderia parvula (HOLM)	–	–	+	–	–	+
Panderia ssp.	–	+	–	+	+	+
Stenopareia sp.	–	–	?	?	–	+
Raymondaspis ? nitens (WIMAN)	–	–	+	–	–	+
Raymondaspis sp.	–	–	+	–	+	–
Bronteopsis sp.	+	–	–	–	+	–
Phillipsinella n.sp.	–	–	–	+	+	–
Trinucleus foveolatus ANG.	+	–	–	–	cf.	+
Reedolithus carinatus ANG.	+	?	–	–	+	–
Trinodus ssp.	+	+	+	+	+	+
Pharostoma sp.	–	–	–	+	+	–
Flexicalymene ? sp.	–	–	–	+	–	+
Cybelella sp.	–	–	+	–	+	–
Oedicybele cf. *clava* (THORSL.)	–	–	–	+	+	–
Hemisphaerocoryphe sp.	–	–	+	–	+	–
Sphaerocoryphe ssp.	+	–	+	–	+	–
Nieszkowskia variolaris (LINNARS.)	–	–	+	–	–	+
Estoniops sp.	+	–	–	–	+	–
Chasmops sp. A	–	–	+	–	+	+
Chasmops sp. B	–	–	–	+	+	–
Chasmops cf. *conicophthalmus* (BOECK)	–	–	–	+	+	–
Miraspis sp.	–	–	–	+	+	–

Table 3. (*continued*)

Species	Gull-högen	Ryd	Dalby	Skagen	Kinne-kulle	N. Bil-lingen
Platylichas sp.	–	–	+	–	–	+
Platylichas validus (LINNARSS.)	–	–	–	+	+	–
Platylichas cf. *laxatus* (MCCOY)	–	–	–	+	+	–
OSTRACODA PALAEOCOPA						
Laccochilina (*Laccochilina*) *paucigranosa* JAAN.	–	+	–	–	+	+
Laccochilina (*Laccochilina*) cf. sp. *A* JAAN.	–	U	L	–	–	+
Laccochilina (*Laccochilina*) ssp.	+	+	–	–	+	+
Actinochilina suecica (THORSL.)	–	–	+	–	+	–
Actinochilina sp. *A* JAAN.	+	–	–	–	+	+
Actinochilina sp.	–	–	–	+	+	–
Uhakiella granulifera (ULR. & BASSL.)	–	–	+	–	+	–
Piretella sp.	–	–	–	+	+	–
Euprimites locknensis (THORSL.)	–	–	+	–	+	+
Euprimites bursa (KRAUSE)	+	+	–	–	–	+
Euprimites cf. *eutropis* (ÖPIK)	–	+	–	–	+	+
Euprimites n.sp.	–	–	+	–	–	+
Tallinnella angustata (KRAUSE)	–	+	L	–	+	–
Steusloffia linnarssoni (KRAUSE)	+	+	–	–	+	+
Steusloffia cf. *multimarginata* ÖPIK	–	–	L	–	–	+
Steusloffia costata (LINNARS.)	–	–	+	+	+	+
Sigmoopsis perpunctata (ÖPIK)	+	–	–	–	+	–
Sigmoopsis sp. *B* JAAN.	–	+	–	–	–	+
Sigmobolbina cf. *sigmoidea* JAAN.	+	–	–	–	+	–
Sigmobolbina ssp.	+	+	+	–	+	+
Hesslandella ? *gunnari* (THORSL.)	–	–	–	+	+	–
Oecematobolbina sp.	–	–	+	–	+	–
Oepikum ? sp.	–	–	–	+	+	–
Conchoprimitia leperditioides THORSL.	–	–	L	–	cf.	+
Conchoprimitia sp.	+	–	–	–	+	–
Conchoprimitia cf. *conchoides* (HADDING)	–	–	+	–	+	–
Baltonotella sp.	–	–	+	–	–	+
Parapyxion subovatum (THORSL.)	–	–	+	–	+	+
Parapyxion obesum (THORSL.)	–	–	–	+	+	–
Parapyxion n.sp.	–	–	+	–	+	–
Pyxion carinatum (HADDING)	–	–	+	–	+	–
Pyxion kinnekullensis (THORSL.)	–	–	+	–	+	–
Primitiella ? *spiniger* LINDSTR.	–	–	+	–	+	–
Ulrichia ? *reticulata* THORSL.	–	–	+	–	+	–
CEPHALOPODA						
Curtoceras teres (EICHW.)	?	?	–	–	+	–
Trocholites cf. *orbis* SCHRÖDER	?	?	–	–	+	–

Table 3. (*continued*)

Species	Gull-högen	Ryd	Dalby	Skagen	Kinne-kulle	N. Bil-lingen
Ancistroceras undulatum (BOLL)	?	?	–	–	+	–
Lituites sp.	?	?	–	–	+	–
GASTROPODA						
Clisospira ssp.	+	+	+	–	+	+
Clathrospira sp.	–	–	+	–	–	+
HYOLITHIDA						
Hyolithes sp.	–	–	+	–	+	–
BRACHIOPODA ARTICULATA						
Skenidioides ? sp.	–	–	+	–	+	–
Onniella ssp.	–	–	+	+	+	+
Palaeostrophomena ? sp.	–	–	+	–	+	–
Sericoidea restricta (HADDING)	–	–	+	–	+	–
Sericoidea sp.	–	–	–	+	+	–
GRAPTOLOIDEA						
Pseudoclimacograptus cf. *scharenbergi* (LAPW.)	–	–	+	–	+	+
Pseudoclimacograptus aff. *scharenbergi* (LAPW.)	+	+	–	–	+	+
Pseudoclimacograptus vestrogothicus JAAN & SKOGL.	–	–	+	–	+	+
Pseudoclimacograptus sp.	–	–	+	–	+	–
Climacograptus cf. *bicornis* HALL	–	–	–	+	+	–
Climacograptus skagensis JAAN. & SKOGL.	–	–	–	+	+	–
Climacograptus sp.	–	–	+	–	+	–
Diplograptus ? *molestus* THORSL.	–	–	+	–	+	–
Amplexograptus cf. *fallax* BULMAN	–	–	–	+	+	–
Glyptograptus cf. *teretiusculus* (HIS.)	+	–	+	–	+	–
Gymnograptus linnarssoni (MOBERG)	+	–	–	–	+	–
Dicellograptus vagus HADDING	+	–	–	–	+	–
Glossograptus hincksi (HOPK.)	+	–	–	–	+	–
CYSTOIDEA						
Echinosphaerites aurantium aurantium (GYLL.)	–	–	+	–	+	+
Echinosphaerites sp. (REGNÉLL 1945, p. 152)	–	–	?	?	+	–
Sphaeronites globulus (ANG.)	–	–	+	–	+	–
Haplosphaeronis oblonga (ANG.)	–	–	?	?	+	–
HYOLITHELLIDA						
Torrellella taenia HOLM	–	–	+	–	–	+

chamosite oöids, phosphoritic nodules, and shell fragments embedded in a fine-grained calcilutitic matrix (Fig. 28 B). The sand fraction in this bed appears to be moderately well sorted. The shell fragments are often rounded, and in many of them calcium carbonate has been replaced by phosphorite. The chamosite oöids are small, as a rule not exceeding 0.5 mm in diameter, but occasionally up to 1 mm long. Scattered grains with haematitic pigment or consisting of haematite also occur. The phosphoritic nodules are occasionally up to 1.5 mm in diameter, but most of them are smaller and of about the same size range as the oöids. The nodules give the impression of having been eroded from the zone of impregnation of the discontinuity surface. Some such nodules can be seen almost *in situ* at the surface. Also some other features, e.g. somewhat overhanging projections on the surface (cf. Fig. 28 B), indicate that the surface had been hardened before the deposition of the oöidiferous layer began. No organogenic borings have been observed in the discontinuity surface.

The same surface is now well exposed in the new part of the Hällekis quarry. There the surface has a much more irregular and rough appearance than in the Norra Skagen core, the height of the irregularities of the surface being up to 7 mm (Fig. 29). The distribution of the chamosite oöids is confined to pits within the surface (Fig. 30). The rock below the surface is yellow to a depth up to 2 cm and intensely reddish-brown lower down, without any trace of the peculiar undulating banding of the corresponding part in the Norra Skagen core. No organogenic borings have been observed in the surface. The characters of the zone of impregnation agree with those in the Norra Skagen core.

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