IV
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ON THE ORDOVICIAN SYSTEM

OSLO-NORWAY
IV
1982

FIELD EXCURSION GUIDE

Edited by: D. L. Bruton & S. H. Williams

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FOREWORD

The enclosed articles and guides are those produced for excursions held in conjunction with the IV International Symposium on the Ordovician System held in Norway in August 1982. One pre-Symposium and two post-Symposium guides are included, together with those for three separate one-day excursions held during the Symposium. Regrettably a guide for Öland was not completed at the time of publication. Insufficient people wished to visit Scania as a fourth post-Symposium excursion, although the guide is included here. Each guide contains a wealth of information, much of it based on research done since the guides for Scandinavia were produced for the XXI International Geological Congress, Norden, 1960.

While travelling through Norway and Sweden, many participants will see for the first time classical localities previously known to them only from literature. Many names contain one of the last three letters in the Norwegian (æ, ø (=ö) and å) and Swedish (ä, ö and å) alphabets. None has exact English pronounciation equivalents, but æ approximates to the 'a' in 'cat', ø to the German ö or the French sound in 'peu' and å to a slightly shorter sound than the 'oo' in 'door'. The Swedish ä is similar to the 'e' in 'bed', while ö and å are the same as in Norwegian.

Editing the articles has not been without its problems and lack of time has unfortunately not allowed many authors to check their altered manuscripts. One reference list has been compiled to avoid repetition, while a complete separate listing is given for the 'Middle Ordovician of the Oslo Region, Norway' series published in the Norsk Geologisk Tidsskrift.

We express our warm thanks to all authors for their efforts in producing the guides and to the anonymous artists and typists who aided their production. We also thank our own artist René Jacquet for assistance in designing the cover. Finally, the production of this publication would not have been possible without the tireless help of Veronica Harrington who typed the final text.

It is suggested that either of the following alternatives should be used for future bibliographic reference to the guides:

Jaanusson, V. 1982: Introduction to the Ordovician of Sweden. *In* Bruton, D.L. & Williams, S.H. (eds.): *Field excursion guide. IV Int. Symp. Ordovician System. Paleont. Contr. Univ. Oslo 279*, 1-10.

Jaanusson, V. 1982: Introduction to the Ordovician of Sweden. *Paleont. Contr. Univ. Oslo 279*, 1-10.

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Leaders:	Valdar Jaanusson, Lars Karis, Kent Larsson (Sweden) J. Fredrik Bockelie, Robert B. Neuman, Bjørn Wandås, Olaf Schmidt (Norway)
13 August	Hotel Gillet, Dragarbrunngatan 23, Uppsala Tel. (018) 15 53 60
14 August	Siljan district Hotel Lerdahlshöjden, 79500 Rättvik Tel. (0248) 111 50
15 August	Northern Siljan, Jämtland Hotel Östbergsgården, Räntmästvägen 11, 83200 Frösön Tel. (063) 12 93 18
16 August	Östersund area, Jämtland Hotel Östbergsgården
17 August	Storsjö area, Jämtland, thereafter crossing into Norway Hotel Trønderheimen, Kongens gate 15, Trondheim Tel. (075) 27030
18 August	Løkken - Hølonda - Støren areas Sundvolden Hotel, 3452 Krokkleiva Tel. (067) 39140

LOCAL EXCURSIONS

22 August	1 OSLO - ASKER Leaders: J. Fredrik Bockelie, David L. Bruton, Bernd-D. Erdtmann, David A.T. Harper, Leif Koch
	2 RINGERIKE Leaders: Nils-Martin Hanken, Alan W. Owen
	3 VIKERSUND - KREKLING Leaders: Bjørn Wandås, Gunnar Henningsmoen, Torsten Klemm

EXCURSION 2	HADELAND - MJØSA - VÄSTERGÖTLAND
Leaders:	Alan W. Owen, Nils Spjeldnæs (Norway) Valdar Jaanusson (Sweden)
24 August	Hadeland, Eina and Gjøvik areas Grand Hotel, Gjøvik Tel. (061) 72 180
25 August	Helgøya, Furuberget, Mjøsa lake. Stops en route to Hotel Forum, Stenstorp, Sweden Tel. (0500) 50940
26 August	Västergötland Hotel Forum

EXCURSION 3	ISLAND OF ÖLAND
Leaders:	Valdar Jaanusson, Harry Mutvei
27 August	South Öland Pensjonat Sandbergen, Mörbylånga Tel. (0485) 3639 3
28 August	Northern and central Öland Pensjonat Sandbergen

TOPOGRAPHICAL MAPS (NORWAY)

Localities visited on excursions in Norway are to be found on the following 1:50 000 scale topographical maps (topografiske kart) issued by the Norwegian Geographical Survey (Norges Geografiske Oppmåling):-

TRONDHEIM REGION	
Hølonda	Blad 1521 II
Løkken	1521 III
Støren	1621 III
VESTFOSSEN-KREKLING	
Hokksund	1714 I
Kongsberg	1714 II
OSLO-ASKER	
Asker	1814 I
VIKERSUND	
Lier	1814 IV
HADELAND	
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RINGERIKE	
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TOTEN-NES-HAMAR	
Gjøvik	1816 I
Eina	1816 II
Østre Toten	1916 III
Hamar	1916 IV

INTRODUCTION TO THE ORDOVICIAN OF SWEDEN

Valdar Jaanusson

The Baltoscandian epicontinental sea covered an extensive area east and south-east of the Caledonian region in western Scandinavia. In the east, from Öland to the Moscow Basin, deposits of the sea are continuous and undisturbed tectonically (Fig. 1). West of it, on the mainland of Sweden, epicontinental Ordovician rocks are preserved in a number of

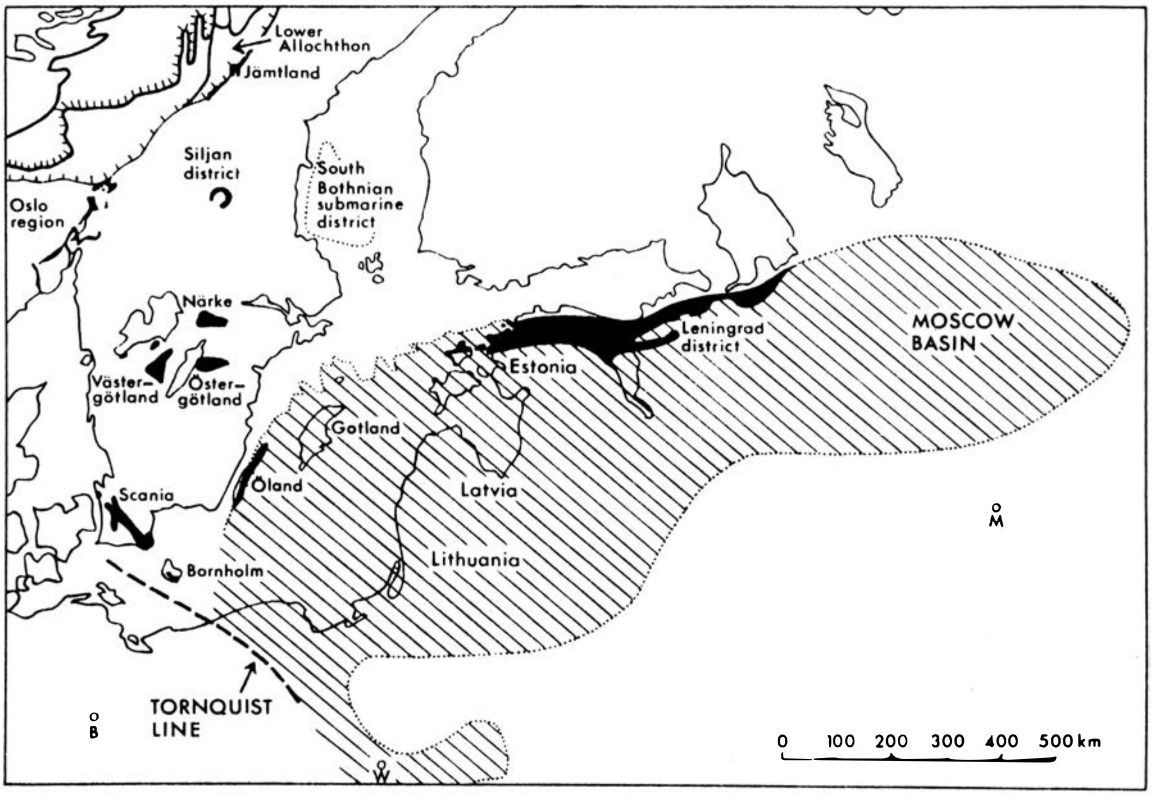


Figure 1. Map showing outcrop areas of Ordovician epicontinental deposits in Baltoscandia (black) and extent of subsurface and submarine Ordovician on the Russian platform (diagonal shading). On mainland Sweden the whole outcrop area of the Cambro-Silurian outliers is shown, of which Ordovician rocks occupy only a minor part. B, Berlin; W, Warszawa; M, Moscow.

outliers, from the autochthonous of southern Lapland in the north to Scania in the south. A further outlier is on the Danish island of Bornholm.

Recent studies have shown that in the Ordovician of the Baltoscandian region distinct, composite belts can be distinguished which differ faunally and in many cases also lithologically from each other (Männil 1966). These belts are termed confacies belts (Jaanusson 1976). Each belt may represent a single, but more commonly several contemporaneous lithofacies, and within most belts there is a second-order faunal differentiation (biofacies) which mostly follows that of lithofacies. However, the confacies belts are distinguishable faunally even in cases when differences in lithology between two adjacent belts are difficult to define. Confacies belts obviously reflect a broad ecologic zonation controlled by enviromental factors which mostly influenced also the depositional conditions. It is interesting to note that the western confacies belts, as well as lithofacies belts within the central belt, are not arranged parallel to the Caledonian front, but meet it at an angle (Jaanusson 1973).

The Siljan district, autochthonous of Jämtland, Västergötland and Öland are in the central Baltoscandian confacies belt (Fig. 2). A notable feature is that correlation is fairly easy along a confacies belt, whereas correlation between the belts frequently presents problems. For example, despite the distance apart, the sequence of the autochthonous of Jämtland is very similar to that on Öland, both lithologically and faunally, whereas several points in the correlation between the central belt and the Oslo Region, which belongs to another belt, are still uncertain. Scania is in a separate belt which consists almost exclusively of graptolitic shales.

The Ordovician epicontinental sequence in the Baltoscandian region is in many respects unusual. First of all, the average rate of deposition has been extremely low, in the order of 1-3 mm per 1 000 years. In Sweden, the total thickness of the Ordovician deposits rarely exceeds 150 m, and even in Scania, where almost the whole sequence is developed as graptolitic shales, the total thickness is normally less than 200 m. In many areas of the central and Scanian confacies belts there are numerous breaks of recognisable magnitude in the sequence; on the other hand, no portion of the sequence is known which is not developed continuously somewhere within the preserved depositional area. The possible exception is the transition from the Lower Tremadoc Dictyonema Shale to the Upper Tremadoc Ceratopyge Shale. The transition is complete in the Oslo area, but parts of it may be missing over the whole of Sweden. Experience has

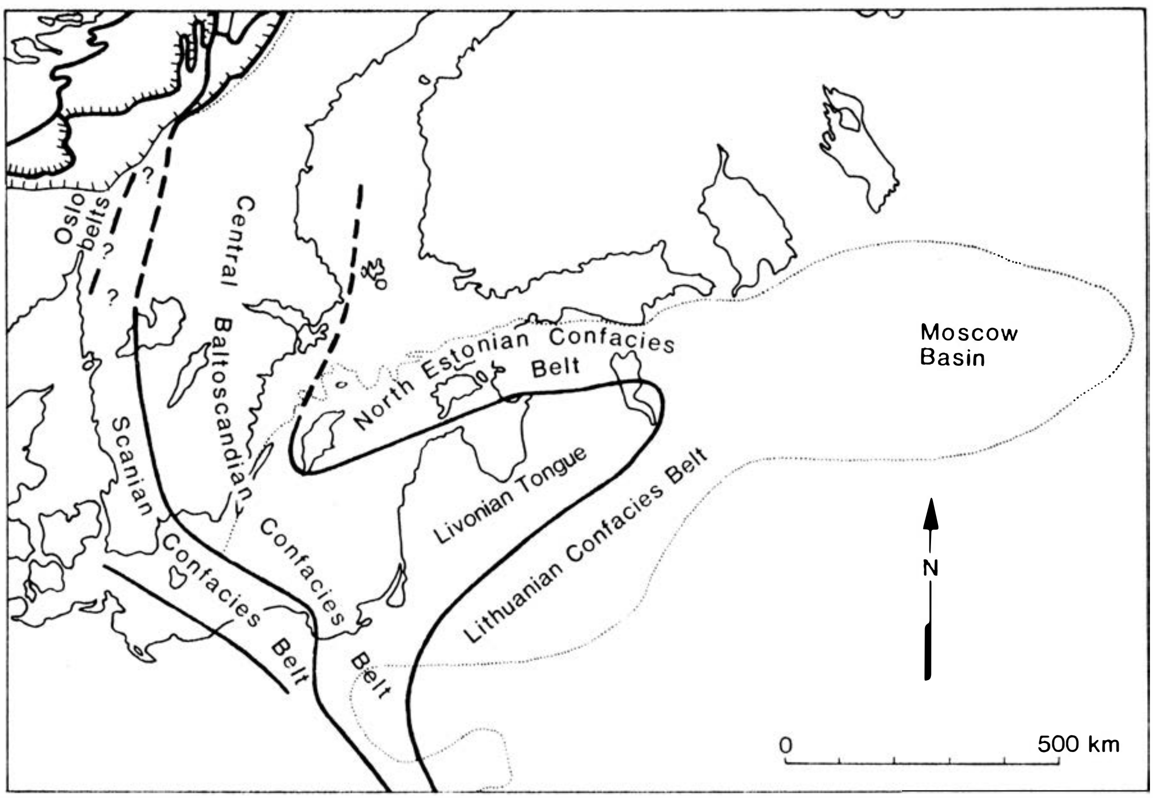


Figure 2. Map showing approximate boundaries of Ordovician confacies belts in the Baltoscandian region.

shown that the intricate pattern of breaks in the sequence represents an unfamiliar feature to many geologists from abroad. Likewise, it is not always fully understood that because of the extraordinarily low average rate of deposition, and therefore the very small thickness of many distinguishable stratigraphic subdivisions, the precision in our work with the sections is frequently in the order of centimetres. For a general example, the conodont Subzone of Prioniodus gerdae is only 4.75 m thick in its type section in the Siljan district, whereas in the southern Appalachians, in the Shenandoah Valley (Virginia), it ranges through at least 125 m (S. Bergström 1971).

The particular features of the Ordovician sequence of Sweden have led to some unconventional solutions with respect to regional stratigraphic classification. In addition to conventional lithostratigraphic units, so-called topostratigraphic units (Jaanusson 1960) are used in which one boundary is defined by lihtological and the other by biostratigraphical criteria (termed topoformations). The approach is purely pragmatic: for distinguishing stratigraphical units usefulness in practice is regarded as the main criterion, and in the Ordovician sequence of Sweden such combined bio- and lithostratigraphic subdivisions have proved to be useful. For the biostratigraphic definition of a topostratigraphic boundary, normally large and common macrofossils are used which are identifiable in the field; for this reason topostratigraphic units have proved to be mappable in the same way as lithostratigraphic units. In several cases topostratigraphic units have a certain lithostratigraphic individuality, but at one of the boundaries changes in lithology can be gradual, making it difficult to define the level of the boundary lithologically. In this case, definition of the boundary using biostratigraphic criteria increases the precision.

There are two, widely different interpretations of the depositional conditions in the central Baltoscandian confacies belt. According to Lindström (1971) deposition in the belt took place in a fairly deep sea, especially in the early Ordovician. The sedimentation is characterised as pelagic or neritic. All breaks were submarine, even those associated with coarse, clastic deposits such as conglomerates. Transport of conglomeratic pebbles and other coarse material is explained by submarine slides or sedifluction. If I understand Lindström correctly, then the Siljan district was submerged during the whole Cambrian period, and conditions for preserving sediments became favourable first in the early Ordovician. Lindström's model has the advantage of offering a fairly simple explanation for the extremely low rate of sedimentation, comparable to that of modern deep sea deposits, the origin of black, bituminous, in the Upper Cambrian uraniferous shales, and some other unusual features.

Another interpretation is shared by many geologists who work on the Ordovician sequence of Sweden. According to them, in the central belt there is conclusive evidence of emergence, not only at the base of the Ordovician but also at some levels within the system. Emergence caused some of the numerous breaks, but other major breaks may be due to submarine non-deposition. The depth of the sea fluctuated, and the sequence includes both shallow water near-shore and deeper water off-shore deposits even in the Lower Ordovician. However, the depth of the sea appears to have been rarely below the photic zone. Deposition took place on an extremely flat sea floor, in an extensive sea which was bordered in the east by a very low peneplane on which rivers had a very low transport energy. For such conditions there are almost no modern analogues, and this renders it difficult to understand some of the specific depositional factors.

With regard to the general depositional conditions, the closest analogues to the Ordovician of Baltoscandia appear to be in the Middle and Upper Ordovician sequence of the Yangtze valley of central China, and probably also in the Tarim Basin.

With the exception of the Hirnantian Stage, there are no bahamitic carbonates in the central Baltoscandian confacies belt, that is, no carbonates containing indurated pellets, calcium carbonate ooids or micritisation phenomena. In the pre-Hirnantian time, the region was probably in a temperate climatic zone, and the lack of precipitated aragonite certainly contributed to the low rate of sedimentation. The general spatial distribution of the main sediment types can probably be best explained by the model of competitive sedimentation (Jaanusson 1973). In the central belt, carbonates are dominant in the east and the importance of the terrigenous material increases towards the west. The main source of the carbonate mud was in the extensive carbonate flats east of the belt from which the mud fraction was gradually winnowed and transported westwards. It appears very unlikely that all the carbonate mud that is incorporated in the calcilutites of the belt has been produced on the spot. Terrigenous clay was produced in the west, probably on a chain of islands, and this area supplied terrigenous material eastwards. Additional supplies of terrigenous mud were located south-west of Scania, possibly on the other side of the Wendean Basin. The relative importance of these two areas in supplying terrigenous clay to the central belt is at present difficult to evaluate. The location of the divide between the carbonate and terrigenous sediments was controlled mainly by a competition between the sediment supply from the east and west, modified by factors influencing sediment transport. An important consequence is that according to this model, the distribution of carbonate mud and fine-grained terrigenous sediments was not always controlled by the depth of the sea. Terrigenous mud in the west or south-west could well have been deposited in the same depth as carbonate mud in the east, or even in shallower water.

A notable feature in the central Baltoscandian confacies belt is the frequent occurrence of widespread red deposits. In fact the red colour of the rock, caused by a haematite pigment, is almost invariably confined to this belt. The total iron content does not appear to be basically different in the grey and red rock, and thus the difference in the colour depends mainly on the mineralogy of the iron compounds. Most non-detrital iron is expected to have been transported into the sea as amorphous oxy-hydroxide. Within the sediment, due to metabolic activities of bacteria on decaying organic matter, ferric compounds became easily reduced, ultimately mostly into pyrite. This happened in most of the grey Ordovician sediments of Baltoscandia. During deposition of the red sediments either the total production of organic material was very low, or the organic material was oxidized on the sea floor before becoming embedded into the sediment. The reason why the central belt was frequently 'starved' with respect to organic material embedded in the sediment is not clear, and several explanations are possible.

The spatial distribution of Ordovician sediments at the Caledonian front in Jämtland (Fig. 3) represents, in a way, a condensed example for the model of competitive sedimentation as applied to the Baltoscandian region. In the east, extended wide carbonate mud flats of which the autochthonous outcrop area with its shale tongues (Töyen, Örå and Fjäcka Shales) obviously forms only the westernmost marginal stripe. According to the model, the shale tongues indicate periods during which the supply of fine-grained terrigenous sediment from the west grossly outweighed that of carbonate mud from the east (which might mean either a considerable increase in the supply of terrigenous mud or a decrease in the supply of carbonate mud, or both). Conversely, a tongue of the 'Orthoceratite

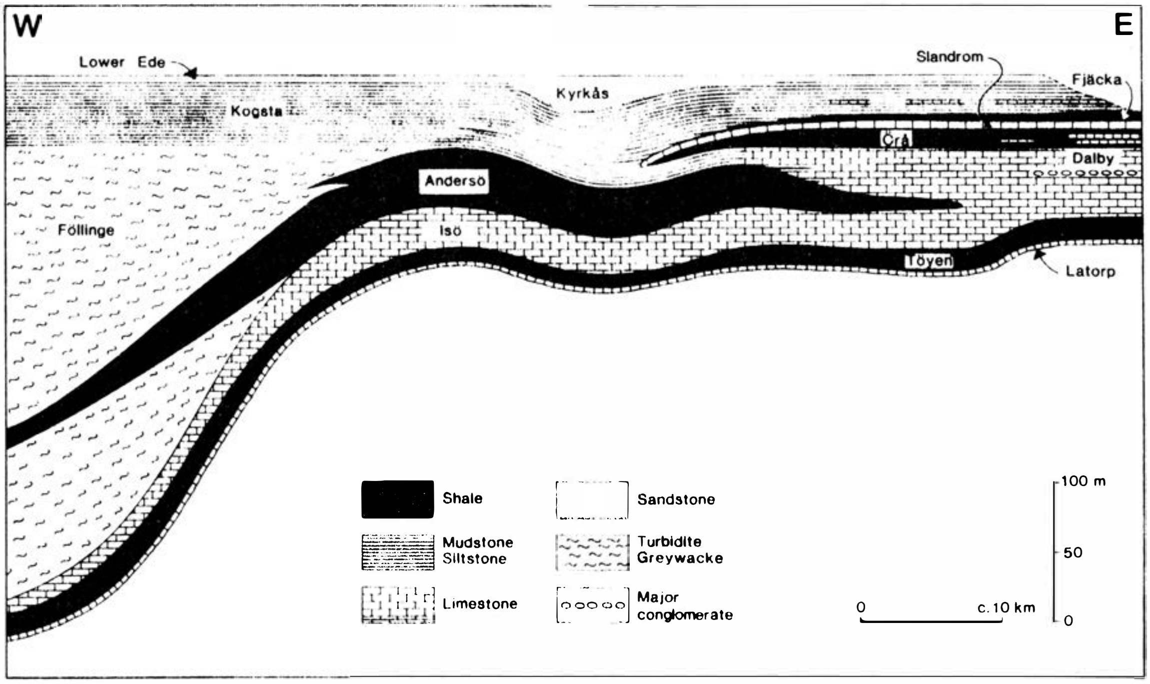
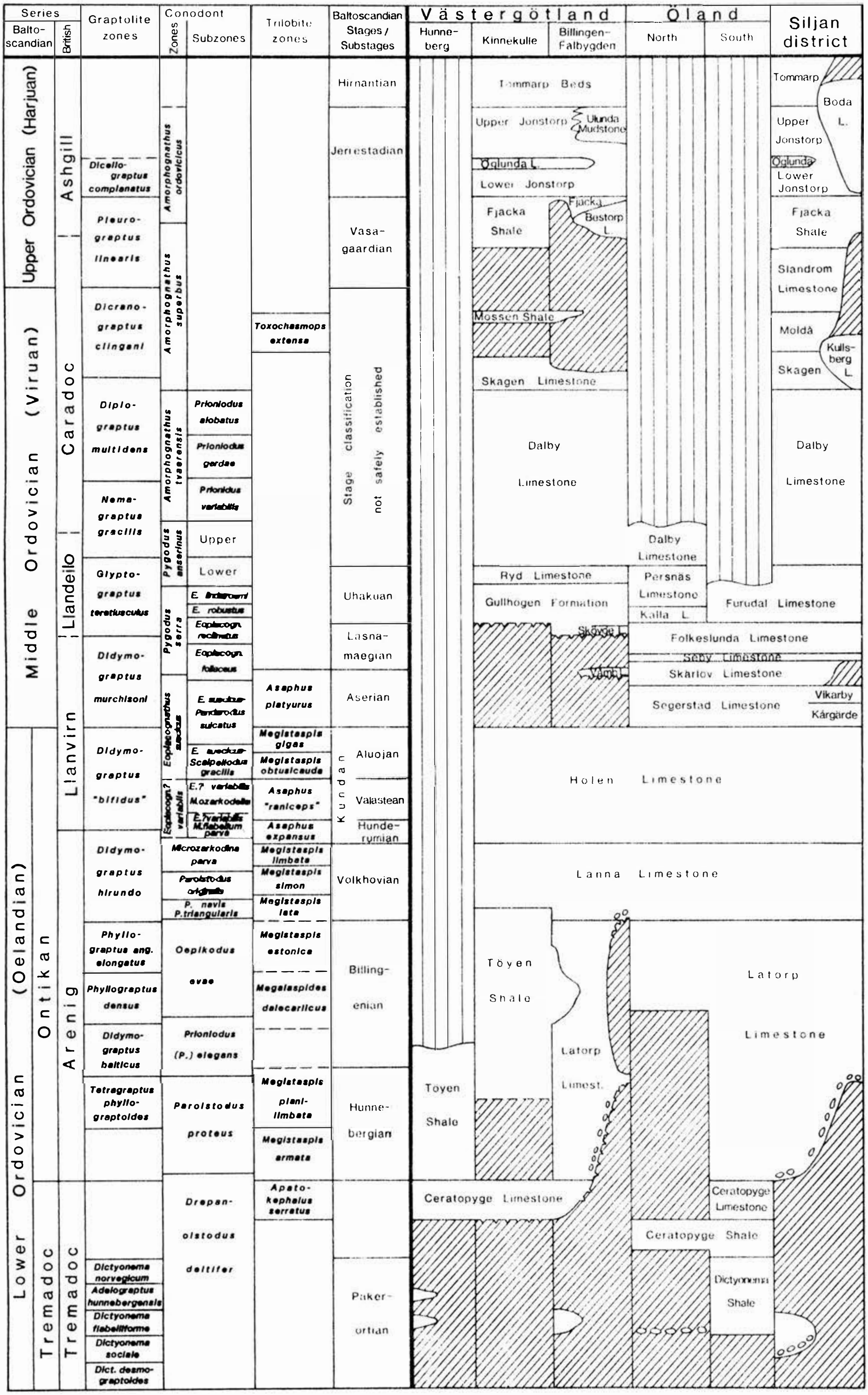


Figure 3. A diagrammatic, restored, palinspastical cross-section of the Ordovician deposits at the Caledonian front in Jämtland, approximately along a line from Brunflo-Slandrom in the autochthonous over Skute-Stengärde and Andersön to the west (V. Jaanusson, original).

Limestone' (Isö Limestone) extends far to the west, indicating a period of intense supply of carbonate mud from the east. The near-shore deposits in the autochthonous outcrop area (e.g. Kullstaberg and Lockne Conglomerates, possibly even the Upper Aserian-Lower Lasnamaegian Lunne facies) probably represent local features related to topographic highs of the basement. However, in general, the importance of terrigenous material, transported from the west, increases successively towards the west. Furthest to the west, thick turbidite sequences (mainly greywackes) were deposited (Föllinge Formation) in a series of interconnected basins east of the probable chain of islands which supplied the terrigenous sediment. The mere presence of turbidite deposits is an indication of an increased slope of the sea floor. The above version of the depositional processes is, of course, simplified. In reality the sedimentation was more complicated, not least in the lower allochthon in which the sea floor obviously had an irregular topography.

With respect to both lithofacies and fauna, the autochthonous and lower allochthonous of Jämtland belong to different confacies belts. The former area is in both repects an integral part of the central Baltoscandian belt,



Series
Balto-scandian
British
Graptolite zones
Conodont
Zones
Subzones
Trilobite zones
Baltoscandian Stages / Substages
Västergötland
Hunneberg
Kinnekulle
Billingen-Falbygden
Öland
North
South
Siljan district
Upper Ordovician (Harjuan)
Middle Ordovician (Viruan)
Lower Ordovician (Oelandian)
Ontikan
Tremadoc
Ashgill
Caradoc
Llandeilo
Llanvirn
Arenig
Tremadoc
Dicellograptus complanatus
Pleurograptus linearis
Dicranograptus clingani
Diplograptus multidens
Nemagraptus gracilis
Glyptograptus teretiusculus
Didymograptus murchisoni
Didymograptus "bifidus"
Didymograptus hirundo
Phyllograptus ang. elongatus
Phyllograptus densus
Didymograptus balticus
Tetragraptus phyllograptoides
Dictyonema norvegicum
Adelograptus hunnebergensis
Dictyonema flabelliforme
Dictyonema sociale
Dict. desmograptoides
Amorphognathus ordovicicus
Amorphognathus superbus
Amorphognathus tvaerensis
Prioniodus alobatus
Prioniodus gerdae
Prioniodus variabilis
Pygodus anserinus
Upper
Lower
Pygodus serra
Eoplacognathus suecicus
Eoplacognathus? variabilis
Oepikodus evae
Prioniodus (P.) elegans
Paroistodus proteus
Drepanoistodus deltifer
Microzarkodina parva
Paroistodus originalis
P. navis P. triangularis
Toxochasmops extensa
Asaphus platyurus
Megistaspis gigas
Megistaspis obtusicauda
Asaphus "raniceps"
Asaphus expansus
Megistaspis limbata
Megistaspis simon
Megistaspis lata
Megistaspis estonica
Megalaspides dalecarlicus
Megistaspis planilimbata
Megistaspis armata
Apatokephalus serratus
Hirnantian
Jerrestadian
Vasagaardian
Stage classification not safely established
Uhakuan
Lasnamaegian
Aserian
Kunda
Aluojan
Valastean
Hunderumian
Volkhovian
Billingenian
Hunnebergian
Pakerortian
Tommarp Beds
Upper Jonstorp
Ulunda Mudstone
Öglunda L.
Lower Jonstorp
Fjäcka Shale
Fjäcka
Bestorp L.
Mossen Shale
Skagen Limestone
Dalby Limestone
Ryd Limestone
Gullhögen Formation
Skövde L.
Våmb L.
Persnäs Limestone
Källa L.
Folkeslunda Limestone
Seby Limestone
Skärlöv Limestone
Segerstad Limestone
Furudal Limestone
Vikarby
Kårgärde
Holen Limestone
Lanna Limestone
Töyen Shale
Latorp Limest.
Latorp Limestone
Ceratopyge Limestone
Ceratopyge Shale
Dictyonema Shale
Tommarp
Boda L.
Upper Jonstorp
Öglunda
Lower Jonstorp
Fjäcka Shale
Slandrom Limestone
Moldå
Kullsberg L.
Skagen
Dalby Limestone

whereas the fauna of the lower allochthonous, still poorly known, shares several elements with that of the Oslo Region. However, the Middle and Upper Ordovician sequence of the latter has an unusually complicated spatial lithofacial and faunal pattern, and without further studies a comparison is difficult.

It is interesting to note that the basic depositional structure of the Ordovician sequence in the autochthonous and lower allochthonous of Jämtland resembles very much that of the southern Appalachians in Middle Ordovician time (for the most recent cross section see Jaanusson & Bergström 1980, Fig. 6). The autochthonous carbonate sequence of Jämtland is comparable to the Lee confacies belt of the Appalachians, a marginal stripe of the North American midcontinent region. The thick, mainly turbidite, western basinal sequence of the lower allochthon of Jämtland has a close counterpart in similar deposits (mainly Sevier Formation) in the eastern Blount belt of southern Appalachians. As in Jämtland, the main source of the terrigenous material in the Appalachians was located along the margin of the craton, and terrigenous sediment was transported towards the epicontinental, cratonic sea; the divide between the carbonate and terrigenous deposits can also here be explained in terms of competitive sedimentation.

Figure 4. Correlation table of the Ordovician of Västergötland, Öland and the Siljan district. Unpublished data by Stig M. Bergström and Anita Löfgren have been incorporated. Diagonal shading indicates breaks in succession.

THE ORDOVICIAN OF NORWAY

David L. Bruton and Alan W. Owen

Ordovician deposits in Norway outside the main Caledonian belt are restricted to the Oslo Region and Digermulen. Sedimentation extended from a stable platform in the east (Balto-Scandian area) passing into a lime mud deposition of the foreland (Oslo-Scania) and westwards for an unknown distance. Parautochthonous sediments along the edge of the fold

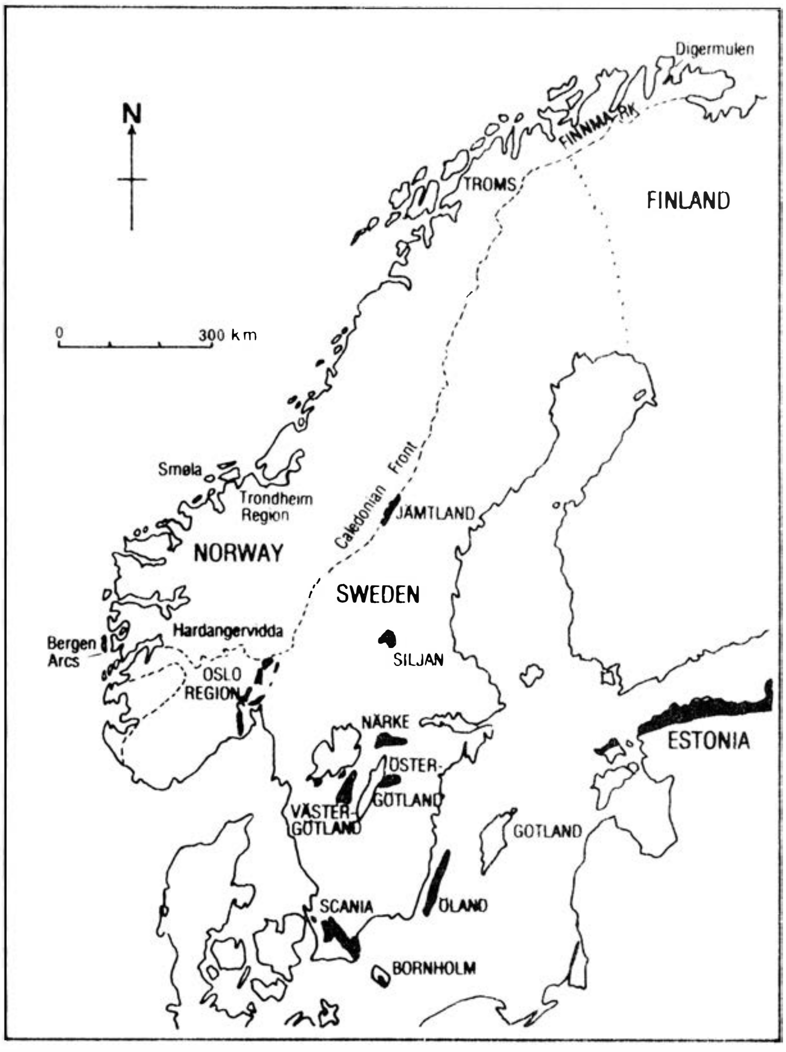


Figure 1. Map of Scandinavia showing location of Ordovician outcrops. From Bruton, Lindström & Owen, in prep.

belt show this distance to have been at least 150 km. Recent data (Nystuen 1981; Ramberg & Bockelie 1981) indicated that parts of the succession in the Oslo Region itself lie above planes of décollement and may have originated some distance to the north.

West of the present Norwegian coast lay the Iapetus Ocean of unknown width. Transport of ocean floor volcanic assemblages (Furnes *et al.* 1980) and related fossiliferous early Ordovician sediments (Bruton & Harper 1981) from west to east indicates far distant sources. The main sources of terrigenous sediments were to the north-west within the Iapetus Ocean and its Scandinavian borderland. Hypothetical sources are island chains and emergent sialic masses that either were completely detached from the main cratons or remained continuous with them at a deeper lithospheric level.

The Ordovician succession over the platform to the east is thin (commonly less than 200 m), but in the Oslo Region mean sedimentation rates were much higher (Bjørlykke 1974) and local successions approaching 1 000 m thick are known. Lateral and vertical facies changes are more marked in this region, but broadly speaking there is a series of belts which indicate a westward shallowing (Størmer 1967; Bockelie 1978). Parts of local allochthonous Ordovician successions show some similarity to the autochthonous and parautochthonous Scandinavian deposits but the overall distribution of facies and faunas is otherwise more complex.

SEDIMENTOLOGICAL AND TECTONIC HISTORY

There is a conspicuous break at the base of the system except near Oslo where the succession is complete at the Cambro-Ordovician boundary (Henningsmoen 1973; Bruton *et al.* 1982). Nevertheless, it is debatable whether there was an extensive regression in the early Tremadoc. The Tremadoc begins with Dictyonema Shale and ends with Ceratopyge Limestone containing a typical Ordovician shelly fauna. It is somewhat difficult to fit this succession into the pattern of gradual transgresssion, since the Dictyonema Shale can be regarded as a continuation of an Upper Cambrian black shale facies that is not likely to have been a shallow water deposit. However, the process of transgression may have been complex and iterative rather than gradual. The Dictyonema beds also occur in the parautochthonous successions along the Caledonian front as far north as Digermulen (Størmer 1940; Gee 1981).

The early Arenig marks a further transgression with the establishment of graptolite shales extending from Scania into the Oslo region and north into Jämtland (Erdtmann 1965). Like in Sweden, the development of limestones is seen locally along the western edge of the Oslo Region (Erdtmann 1965, text-fig. 7) while further west (palinspastically; north in present geography), in the parautochthonous successions, an arenaceous facies is developed (Skjeseth 1952, 1962; Størmer 1967, Fig. 9). As with the Whiterock regression in North America (Jaanusson 1979), there is evidence that the Oslo Region, including the Scanian confacies belt, underwent shallowing during the late Arenig—early Llanvirn (Jaanusson 1973). This may also be the explanation for the change from the graptolite shale environment of the Lower Arenig of the Oslo Region (Erdtmann 1965) to the 'Orthoceras Limestone'.

Superimposed on the Whiterock regressive event (which was possibly eustatic) there is a pattern of hiatuses and recommencement of sedimentation on the Baltic Shield which Jaanusson (1973, pp. 29-30) speculated to have been coupled to tectonic events within the Caledonian orogen. These phenomena are now thought to be related to early nappe movement in the west associated with the closing of Iapetus. Throughout the south-western and central Norwegian Caledonides, a number of ophiolite sequences occur along a belt some 1 000 km long (Furnes et al. 1980). Only in the Trondheim area is one such ophiolite associated with sediments containing late Arenig or younger fossils of North American aspect (Bruton & Bockelie 1980). The ophiolite sequences include the shelly faunas of the Hølonda Limestone (Neuman & Bruton 1974; S. Bergström 1979) and the graptolite faunas of the Bogo Shale (Skevington 1963; Ryan et al. 1980). Structural and geochemical analyses (Furnes 1980; Roberts 1980) suggest that obduction was complete by mid-Arenig times and this hypothesis has been extended to the dating of the time of obduction of other ophiolites (Sturt et al. 1980). Bruton & Bockelie (1980), however, have pointed out that this conflicts with current views on faunal provincialism, and suggest that obduction might have occurred later in the Ordovician. Irrespective of when obduction occurred, the sequences show that volcanic island environments existed either on or at some distance from the margin of the Baltic Shield during the early Ordovician (Bruton & Bockelie 1979, 1980; Roberts 1980). Sediments associated with these include serpentine conglomerates (Stigh 1980) some of which are fossiliferous (Bruton & Harper 1981; Holmquist 1980).

Following the Whiterock regression, renewed transgression set in during the Llanvirn. Evidence is that the phosphate content of the sediments high at the Volkhov—Kunda transition, is much reduced (Bjørlykke 1974, Table 3), sessile benthos disappears, the proportion of trilobite/echinoderm skeletal material rises, and particle size decreases. The succeeding history of the Middle and late Ordovician bears witness to the increasing influence of events in the fold belt. Thus Bjørlykke (1974, 1974a) has documented a progressive increase in geochemical similarity of the sediments in the Oslo region and those in the Trondheim area. Elements such as Mg, Fe, Ni and Cr, detrital minerals, notable chromite, and increasing chlorite/illite ratios, suggest derivation from volcanic island sources (or from old submarine volcanic rocks that emerged as a result of tectonic processes). If volcanic islands were involved, these may have been remnants of islands formed during the Arenig and later eroded during an early advance of the nappes, or active systems which also were responsible for the Middle Ordovician bentonites. These bentonites extend from the *Glyptograptus teretiusculus* to *Diplograptus multidens* zones and occur at various localities between Oslo and Bornholm and as far east as Estonia (Bergström & Nilsson 1974; Männil 1966). Some bentonite beds can be traced over long distances and represent explosive intermediate volcanism of apparently enormous proportions. Approximately at the same time as this volcanic activity, basement faulting occurred which influenced deposition of parts of the Ordovician succession in the Oslo Region (Bockelie 1978).

From the Middle Ordovician onwards, the distinction between the North American and Baltic faunas becomes less pronounced as a result of narrowing of the Iapetus Ocean (Shaw & Fortey 1977; Jaanusson 1979; Bruton & Owen 1979). Important regressive events are recorded in the Middle and Upper Ordovician successions of Norway, the first of these being a Caradoc event. Thus in the northern (Mjøsa, Opalinski & Harland 1981) and southern (Skien—Langesund, Harland 1980) parts of the Oslo Region, limestones, locally biohermal, are developed. Jaanusson (1973, pp. 12-13, 1979, A 148-149) noted that the Norwegian formations contain carbonate sediments of 'Bahaman type' and faunas indicating warm water conditions. At the Caradoc-Ashgill boundary, black shale deposits, the result of a very widespread transgression, covered much of Sweden and all but the Mjøsa district of the Oslo Region (Jaanusson 1963; Bruton & Owen 1979). This shale is regarded as a tongue of the Dicellograptus Shale of the Scanian confacies belt. Vogt (1928; 1945) argued that a supposed hiatus aroung the Caradoc-Ashgill boundary in the Oslo Region corresponds to the so-called Ekne disturbance in the Trondheim Region. Owen (1979) and Bruton & Owen (1979), however, have demonstrated that no break exists.

The most spectacular and widespread regression took place in the latest Ordovician with the development of coarse clastic sediments. Brenchley & Newall (1980) have argued that these deposits record glacio-eustatic changes. The late Ordovician regressive events were separated by phases of sedimentation in relatively deep water, culminating in the early Silurian with widely distributed graptolite shales on the Scandinavian part of the Baltic Shield. One can speculate that this was due to increased nappe loading on the western margin of the Shield. The regressive events, if correctly interpreted as eustatic, were in this case superimposed on a tectonically induced trend towards transgression.

In the fold belt, Middle and Upper Ordovician successions are known but not well correlated. New faunas of both Caradoc and Ashgill age are known from the Meldal and Hølonda areas of the Trondheim Region (R.B. Neuman pers. comm. 1981). These included the oldest known brachiopods and corals to occur in both autochthonous and allochthonous sequences from west to east. Characteristic Ashgill faunas are recorded from the Bergen, Trondheim and possibly Troms areas in Norway (Breivik 1975; Færseth & Ryen 1976; Ryen & Skevington 1976; Kollung 1979; Binns & Gayer 1980).

THE SILJAN DISTRICT

Valdar Jaanusson

The Siljan district is situated north of Lake Siljan, in the province of Dalarna (latinised Dalecarlia). The term is a translation of the Swedish Siljansbygden (= The Siljan district). The Palaeozoic strata occur in a complex ring-structure of downfaulted sedimentary rocks, 5-18 km wide (Fig. 1), which surrounds a central uplift of the Sub-Jotnian Dala granite. Within the ring structure, the rocks are strongly faulted, and mapping of the bed-rock is difficult because of the extensive cover of Quarternary deposits. The Ordovician sequence, with a total thickness in the intermound facies of about 100 m, consists predominantly of carbonate rocks, overlain by Silurian graptolitic shales. The youngest sedimentary rocks are represented by the Orsa Sandstone which is barren and whose age is uncertain; it may still be of Silurian (possibly Wenlock) age.

It is now generally agreed that the Siljan ring structure should be classed as a probable hypervelocity impact crater (Svensson 1971, 1973; Rondat 1975). Two melt samples from the central granite have yielded an integrated K-Ar age of 361.9 ± 1.1 m y for the impact (Bottomley *et al.* 1978).

LOWER ORDOVICIAN (OELANDIAN)

Basal Ordovician transgression Throughout the whole district, the Ordovician sediments rest on weathered Precambrian rocks. The weathering of the Precambrian basement is most intense in the granites of the eastern part of the district; it is less pronounced in the late Precambrian porphyries and sandstones to the north and west. In the south-east and in some places in the north-east the basal Ordovician beds belong to the lower Tremadoc. In the west and in other places in the north the whole

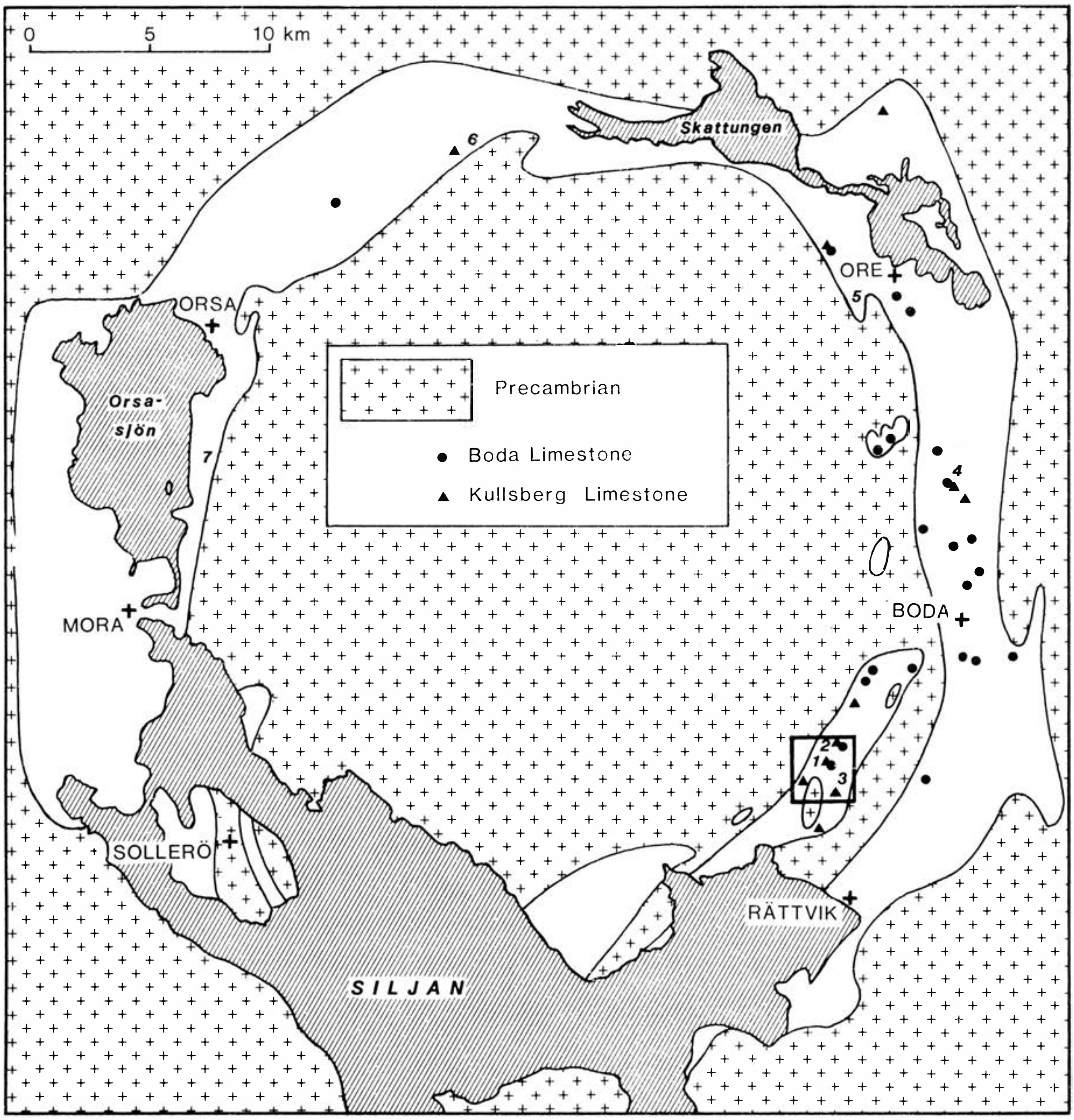


Figure 1. Map showing distribution of the Palaeozoic beds in general, and carbonate mounds in particular, in the Siljan district, Dalarna. Data on the carbonate mounds are based on Thorslund (1936), but later additions are also included. A quadrangle shows the area of the map on Fig. 2. 1, Skålberget; 2, Unskarsheden; 3, Kullsberg; 4, Osmundsberget; 5, Fjäcka; 6, Djupgrav; 7, Kärgäde.

Tremadoc is missing and Lower Arenig rests directly on the Precambrian.

Tremadoc Lower Tremadoc deposits consist of various terrigenous clastic rocks. Their thickness and composition varies from section to section, reflecting the uneven topography of the pre-Ordovician land surface. At Sjurberg, for example, the Lower Tremadoc is represented by a thin bed of conglomerate which is formed by gravel and pebbles derived from weathered granite, and includes also grains of phosphorite and worn fragments of Obolus. At Silverberg the conglomerate also contains pieces of grey, fine-grained limestone, abounding in quartz grains and indicating that several phases were involved in the formation of the conglomerate (Hadding 1927). The conglomerate is overlain by well lithified quartz sandstone which contains fragments of Obolus valves. At Gärdsjö, erratic boulders of soft quartz sandstone have been found, similar in appearance to the Obolus Sandstone (Maardu Beds) of northern Estonia, and containing well preserved valves of Obolus triangularis Mickwitz. At Djupgrav (Stop 2:2), a thin layer of shale, found close to the top of the fairly thick conglomerate, has yielded Dictyonema flabelliforme sociale. Influence of the pre-Ordovician bed-rock topography on the basal Ordovician depositional conditions is particularly obvious at Skattungbyn. In the Djupgrav section (Stop 2:2), a Lower Tremadoc conglomerate, about 3 m thick, is developed, whereas in the Talubäcken section, situated only 2 km to the east, Lower Arenig conglomeratic limestone, with scattered pebbles of porphyry, rests directly upon late Precambrian porphyry. The Upper Tremadoc is not developed in the Siljan district, and the break may comprise also the upper part of the Lower Tremadoc.

Latorp (Hunnebergian and Billengenian Stages) and Lanna (Volkhovian Stage) Limestones Latorp and Lanna Limestones are basically lithostratigraphic units and correspond roughly to the Planilimbata and Limbata Limestones in the old classification. However, the boundary between the units is transitional lithologically and therefore difficult to define precisely in terms of lithology. For this reason, the present usage is to define the location of the boundary in biostratigraphic terms, based on trilobites.

The carbonate deposition that began with the Latorp Limestone belongs to a main lithofacies, named in Sweden since 1828 the Orthoceratite Limestone. The facies is characterised by a predominantly thick bedded limestone which in parts of the sequence abounds in large orthocone cephalopod conchs. In the Siljan district the Latorp and Lanna beds are composed of red or variegated red and grey argillaceous calcilutites. They contain numerous discontinuity surfaces which have mostly a yellow, goethitic mineralisation. In these beds cephalopods are relatively uncommon, and the large macrofauna is dominated by asaphid and nileid trilobites. A hardbottom fauna is represented mainly by small pedunculate orthacean brachiopods whose adult size is just above or below the size limit (0.5 cm) between large and small macrofauna. In the Zone of Megistaspis (Ekeraspis) armata a small camerellacean brachiopod, previously referred to Lycophoria but belonging to a new genus, is fairly common. In the Siljan district, the biostratigraphy of the Lanna beds has not yet been studied in detail.

The post-Tremadoc deposition began earliest in the south-east where the lower Hunnebergian Megistaspis (Ekeraspis) armata Zone is developed. In the west not only the Tremadoc but also the armata Zone is missing; at Kårgärde (Stop 7) the earliest identifiable Ordovician beds appear to belong to the Zone of Megistaspis (Varvaspis) planilimbata (cf. Tjernvik 1956, 167-168 with regards to the nearby Holen section). In the Talu-bäcken section even most of the Hunnebergian Stage appears to be missing, because the basal Ordovician bed, formed by grey, glauconitiferous lime-stone with numerous pebbles of porphyry, probably belongs to the upper-most part of the planilimbata Zone.

In the Talubäcken section at Skattungbyn, parts of the Billingen Stage are replaced by a greyish-green graptolitiferous shale, about 2 m thick, which is a wedge of the Töyen Shale ('Lower Didymograptus Shale'). The shale is greyish-green in the lower part and red in the upper part. The exposure has been known since 1876 and is the type locality of the index fossils Phyllograptus densus Törnquist and Megalaspides dalecarlicus Holm.

Holen Limestone (Kundan Stage) In the Siljan district, the Holen Limestone (new term, see Stop 7; 'Vaginatum Limestone' in the old classi-fication) is a topostratigraphic unit. Its base is sharply defined also lithologically whereas the definition of the upper boundary is based on biostratigraphic evidence (top of the Zone of Megistaspis (Megistaspidella) gigas).

Throughout the district, the base of the Holen Limestone is normally marked by a discontinuity surface with a limonitic crust or mineralisation.

It indicates a break whose magnitude cannot be determined at present. The transition from the Lanna to Holen Limestones was associated with a considerable increase in water energy. The sediment changed from carbonate mud to skeletal sand, and also the colour of the rock changes, from red to grey. Moreover, the grey rock is oolitic, with numerous limonitic ooids which in some exposures (Leskusängen) are especially large. In the upper part of the oolitic limestone (lowermost Valastean Substage) chamosite ooids appear and chamosite also occurs as cavity fillings within small skeletal grains.

The appearance of chamosite signifies an important change in the facies of authigenic silicate minerals. In beds below that level the authigenic silicate, where present, is invariably glauconite, while above the level the mineral is chamosite, at least in high energy environments (inconsiderable quantities of glauconite occasionally occur in lutitic rocks). The change can be followed, at about the same level, over the whole Baltoscandian region. The chamosite facies persists until the middle Viruan Skagen Limestone. In higher beds of Baltoscandia authigenic silicates are rare but, where developed, they are represented by glauconite (e.g. the lower Slandrom Limestone of the Siljan district). The environmental significance of the changes in authigenic silicate facies is unknown.

The increase in the grain size of the sediment at the base of the Holen Limestone is associated with the appearance of a varied fauna, including large brachiopods which are pedunculate (*Orthis callactis*, *Antigonambonites*, *Lycophoria*, *Porambonites*, etc.), ambitopic (*Inversella*, *Ahtiella*) and recumbent (*Pseudocrania*), gastropods, hyolithids, etc. In most sections the lowermost Valastean beds are even developed as a coquina (about 40 cm thick) composed mainly of large trilobite pygidia (*Asaphus* (*Asaphus*) and *Megistaspis* (*Megistaspidella*)) and various cephalopod conchs (Jaanusson & Mutvei 1951).

The rock of the Holen Formation above the grey oolitic limestone is mostly red, calcilutitic and poor in macrofossils (mainly cephalopods and occasional asaphids). In the Siljan district this part of the sequence has not been studied in detail.

MIDDLE ORDOVICIAN (VIRUAN)

Segerstad Limestone (Aserian Stage) On exposed rock surfaces the boundary between the Ontikan Holen and the Viruan Segerstad Limestones is commonly not immediately apparent, because the red limestone on either side of the boundary is almost identical macroscopically. A closer look soon reveals that the uppermost beds of the Holen Formation abound in large pygidia of *Megistaspis* (*Megistaspidella*) *gigas* which in the lowermost Segerstad beds are replaced by abundant, equally large pygidia of *Asaphus* (*Neoasaphus*) *platyurus*. In some sections at least, the actual boundary is formed by a variously furrowed surface covered by a stromatolitic algal mat of the same type as in the Lunne Limestone of the autochthonous of Jämtland. In the Vikarby section the stromatolitic mat is 6 cm thick (Jaanusson, unpublished). The stromatolitic structures can be clearly observed after the surface is polished and etched.

The boundary between the Kundan and Aserian Stages coincides with a major change in the benthic fauna all over the whole of Baltoscandia. In the red limestones of the type of the upper Holen and Segerstad Limestone, the faunal diversity is low, and the macrofauna is composed mainly of cephalopods and trilobites; there are very few sedentary forms.

In the Segerstad Limestone two subdivisions have been distinguished, a lower red, mainly calcilutic Kårgärde Limestone (Zone of *Angelinoceras latum*) and an upper variegated red and grey, mostly calcarenitic Vikarby Limestone (Zone of *Illaenus planitrons* in the trilobite scale and Zone of *Trilacinoceras toernquisti* in the lituitid scale). In the Vikarby section the boundary is formed by a surface with probable mud cracks overlain by a thin conglomeratic layer in which the pebbles consist of red calcilutite derived from the substrate (Jaanusson & Mutvei 1953).

Skärlöv Limestone The Skärlöv Limestone is a lithostratigraphic unit which consists of red, finely nodular limestone with argillaceous intercalations and a few individual beds of red calcilutite. The unit has a wide spatial distribution within the central Baltoscandian confacies belt, from the autochthonous of Jämtland to Öland, but the finely nodular, argillaceous rock weathers easily and is therefore very poorly exposed.

In the south-eastern part of the Siljan district (Vikarby section) Skärlöv Limestone is not developed, and the Seby Limestone rests directly on the Segerstad Limestone (Jaanusson 1963a). The unit is poorly fossiliferous, and macrofossils are as a rule poorly preserved. The lower part of the Skärlöv Limestone is of Aserian and the upper part of Lasnamaegian age, but because of the rarity of fossils the level of the boundary is difficult to locate.

Seby and Folkeslunda Limestones (Lasnamaegian Stage) In the Siljan district both units are defined by lithostratigraphic criteria, but they are also distinctive faunally, especially with regard to lituitids and hyolithids. *Illaenus chiron* Holm is a common trilobite in both formations. The Seby Limestone consists of variegated grey and red, mainly calcarenitic beds; it is a thin unit but can be followed almost over the whole central Baltoscandian confacies belt. The Folkeslunda Limestone (Upper Grey Orthoceratite Limestone according to the old terminology) is grey, mainly calcarenitic. It is the uppermost unit in the Swedish orthoceratite limestone facies.

Furudal Limestone (Uhakua Stage) The Orthoceratite Limestone is overlain by a relatively thick sequence of bedded calcilutites with argillaceous intercalations, the Furudal Limestone. The calcilutitic sequence initiates a temporary stabilisation in the depositional conditions of the central Baltoscandian confacies belt, probably due to increased water depth. The thickness of individual distinguishable units increases, both lithostratigraphic and biostratigraphic (based on shelly faunas), and within the belt there are no breaks known which cannot be explained by relatively late post-depositional erosion.

The fairly dense limestone is sparsely fossiliferous. *Nileus* is the dominant trilobite, a pelophile also found elsewhere, while brachiopods are represented by small forms among which *Christiania* is normally the commonest. The soft carbonate mud was obviously an unsuitable substrate for large ambitopic and recumbent organisms. The rarity of these, in turn, contributed to the rarity of hardbottom organisms, such as encrusting and ramose bryozoans and large pedunculate brachiopods which required a hard substrate for their attachment.

In the Siljan district the Furudal Limestone is basically a lithostratigraphic unit, but its upper boundary is lithologically transitional and therefore difficult to define precisely in terms of lithology. For this reason the boundary is defined as the level where the Dalby fauna appears. The faunal change is pronounced and can be followed throughout the central Baltoscandian confacies belt. According to this definition of the upper boundary of the Furudal Limestone, and consequently also of the lower boundary of the Dalby Limestone, these two units are in practice topostratigraphic units (one boundary defined by lithological and the other by faunal criteria).

Dalby Limestone Increased water energy close above the base of the Dalby Limestone resulted in deposition of skeletal sand, and the unit consists predominantly of calcarenites. The change in substrate was accompanied by a change in benthic macrofauna, and the latter change forms an excellent example of a faunal shift (Jaanusson 1976). Numerous large ambitopic (e.g. massive trepostomate bryozoans) and several recumbent organisms appear, associated with ramose bryozoans, large pedunculate brachiopods, numerous cystoids, etc. Echinosphaerites aurantium aurantium (Gyllenhaal) is especially common (Fig. 6), and this was the reason why the division was formerly termed Cystoid Limestone. The interesting fact is that in northern Estonia many of the genera, and even a number of species, lived in a similar skeletal sand environment already in Uhakua time, that is, during the time of the deposition of the Furudal carbonate mud. When in the Siljan district, as well as in most other districts of the central Baltoscandian belt, the sediment changed to skeletal sand these forms followed the change in environment and entered the central belt. The top of the Dalby Limestone is formed by a distinctive complex of bentonitic beds which are widely distributed.

Skagen and Moldå Topoformations Lithostratigraphically, Skagen and Moldå Topoformations form a single limestone unit, Freberga Formation (new term; defined as interval 87.80-73.85 m in the Smedsby Gård boring, Östergötland). The sequence begins, both in the Siljan district (Martna 1955) and in Östergötland, by bedded calcarenitic calcilutites with thin intercalations of calcareous mudstone (rough lithostratigraphic equivalent to the upper 4bα and 4bβ of the Oslo district), in the middle part of the formation calcareous mudstone is dominant and limestone is represented by nodules or discontinuous beds (roughly equivalent to 4bγ), and the top of the sequence is formed predominantly of limestone (approximately 4bδ). However, these lithological subdivisions are difficult to define because of the fairly continuous transition between the various lithologies. The boundary between the Skagen and Moldå Topoformations is situated within the mudstone subdivision and is characterised by a fairly abrupt faunal change (Fig. 7; for palaeocope ostracode fauna see Jaanusson 1976, Fig. 9). The level of the faunal change is easily recognisable in sections where the mudstone is at least moderately fossiliferous. The faunal change is predominantly of an immigration type, because many of the faunal elements which appear at that level appear to lack close relatives in earlier beds elsewhere in the Baltoscandian region. The environmental factors that caused the faunal change are not reflected in the lithology.

In the beds between the Lower Dalby and Slandrom Limestones the faunal development in the central Baltoscandian confacies belt differs so much from that in northern Estonia that correlations are still uncertain. For this reason a classification at stage level for the whole Baltoscandian region is at present hardly possible.

UPPER ORDOVICIAN (HARJUAN)

Slandrom Limestone This is a lithostratigraphic unit characterised by beds of dense, hard, finely nodular calcilutite (in the Siljan district colloquially termed 'masurkalksten'), intercalated by bedded limestone. The unit has always been poorly exposed and, although some of the bedded limestone does not appear to be poorly fossiliferous, the rock quantity which has been available for collecting fossils has been very limited. There are some indications that the formation includes two successive benthic faunas (Jaanusson 1953). The poor knowledge of these beds in the central Baltoscandian confacies belt makes it difficult to apply a classification at stage level.

In a regional context, the dense calcilutites of the Slandrom Formation are probably wedges from the main calcilutite deposition (Lower Östersjö

Limestone) along the axis of the Baltic (northern Gotland, Gotska Sandön, the submarine South Bothnian district) where the whole equivalent sequence consists of dense, aphanitic calcilutites with a low content of terrigenous clay. The same calcilutitic development of the sequence continues eastwards into northern Estonia (Rakvere and Nabala Stages).

Fjäcka Shale This is a most distinctive lithostratigraphic unit consisting of dark brown graptolitic shale. It is a wedge from the main graptolitic shale belt as developed in Scania and on Bornholm, and has a wide, spatial extent, from Jämtland to Latvia, and even to south-eastern Estonia (Männil 1966). The graptolite fauna is that of the Zone of *Pleurograptus linearis*, and evidence from Kinnekulle in Västergötland shows that the upper boundary of the shale coincides with the base of the *Dicellograptus complanatus* Zone (Skoglund 1963). The Fjäcka Shale of the Siljan district is the type horizon for both *Diplograptus pristis* (Hisinger), the type species of *Diplograptus*, and *Tretaspis seticornis* (Hisinger), the type species of *Tretaspis*. The fauna of the shale contains both graptolites and shelly fossils, but the latter are poorly described. *Chonetoidea iduna* Öpik and *Flexicalymene trinucleina* (Törnquist) are common in some beds. Other notable species are *Triarthrus pygmaeus* Törnquist and *Raphiophorus setirostris* Angelin.

Jonstorp Formation (including the Nittsjö Beds; Jerrestad Stage) These soft beds have always been poorly exposed in the Siljan district, and most of our knowledge is derived from excavations or temporary exposures. The sequence (15.6 m at Amtjärn) consists mainly of finely nodular argillaceous calcilutite, grey in the lower and uppermost part but otherwise red. A distinct subdivision (Öglunda Limestone), consisting of hard, dense, finely nodular calcilutite is developed in some sections; where present it separates the Lower and Upper Members of the formation. The term Nittsjö Formation was originally applied to the topmost grey beds of the sequence (Jaanusson 1963b), but they differ from the underlying beds only with respect to colour. In the Siljan district, it now appears practical to include these beds, as an informal subdivision, in the Jonstorp Formation.

In the Siljan district, the Jonstorp Formation is poorly fossiliferous and its fauna is not well known. At Amtjärn the uppermost 0.42 m of the Nittsjö Beds (referred to the Staurocephalus Zone (= Alleberg Beds; see Västergötland)) have yielded Dalmanitina (Mucronaspis) mucronata (Brongn.), Staurocephalus clavifrons Ang., Phillipsinella parabola (Barr.), Tretaspis sp., etc. (Thorslund 1935).

Tommarp Formation (Hirnantian Stage) In the intermound facies the basal Hirnantian beds vary from calcareous sandstone (up to 0.5 m thick and in places with ripple marks) to hard, in places pelletal calcarenite (locally termed Klingkalk). The overlying beds, about 2 m thick, still of Hirnantian age according to fossils, consist of soft, grey, argillaceous limestone and calcareous mudstone, with occasional intercalations of calcareous sandstone or siltstone in the lower part. The remainder of the sequence between the fossiliferous Hirnantian and Llandovery graptolitic shale (Glisstjärn Formation, some 13 m thick; Stop 3) is composed of various mudstones, mostly grey but with a red portion in the upper part. These beds, as well as the underlying soft Hirnantian rocks, are very poorly exposed, and most of the available information is based on excavated sections (Thorslund 1935) where the accessible rock material for collecting fossils has been very limited. Except for a few levels the Glisstjärn Formation appears to be barren; it is overlain by Lower Llandovery graptolitic shale with the Zone of Monograptus revolutus at the base (Waern 1960). There are no indications of an appreciable break within the sequence between the fossiliferous Hirnantian and the revolutus Zone, and thus the Glisstjärn Formation is probably, for the most part at least, an equivalent to the pre-revolutus portion of the Lower Llandovery. However, based on the available material, the top of the Hirnantian cannot be adequately defined in the Siljan district. More extensive exposures may lead to a redefinition of the top of Hirnantian and the base of the Glisstjärn Formation.

Stromatactis-bearing carbonate mounds The Siljan district is well known for its Middle and Upper Ordovician stromatactis-bearing carbonate mounds which are extensively quarried and thus well exposed. The mounds occur as huge lenses of high-carbonate limestone surrounded by far thinner, argillaceous intermound deposits. The mound core is massive, that is, without evident stratification. In the peripheral part of the mounds thin, argillaceous intercalations appear, and the mound flank deposits are formed by bedded stromatactis-bearing limestones with red or green argillaceous partings. The flank deposits are very rich in skeletons of various sedentary organisms.

The mounds lack an organic frame, and no traces of an organic control on the growth of the mounds have been recognised. An important macroscopic constituent is formed by well-defined bodies of sparry calcite, elongate or laminar in cross section, which are arranged roughly parallel to the depositional plane and comprise up to 50 per cent of the volume of the mound core. Microscopic examination reveals that the calcite crystals that form the bodies have undulose extinction, highly irregular intercrystalline boundaries, and are frequently divided into subgrains. Such calcite is termed radiaxial. The central part of the calcite bodies is occasionally formed by normal, para-axial calcite which may enclose a residual cavity in the centre of the calcite body. The macro- and microscopic characteristics of the calcite bodies agree with those known as stromatactic from many Palaeozoic carbonate mounds. There is a fairly general agreement that these structures represent inorganic cavity fillings (Bathurst 1959). The origin of the cavities, on the other hand, is disputed. However, the rock of the mounds appears to have been lithified very early, and it is possible that the mounds are comparable to modern lithoherms (Jaanusson in Ross et al. 1975; Jaanusson 1979; Bathurst 1980, 1982).

In the Siljan district stromatactis-bearing carbonate mounds occur at two levels; upper Viruan (Kullsberg Limestone) and middle-upper Harjuan (Boda Limestone). Some 35 individual mounds are known in the district (Fig. 1), 11 of which represent Kullsberg Limestone. In four places a Boda mound has grown directly upon a Kullsberg mound. It should be noted that stromatactis-bearing carbonate mounds of the district represent far larger structures than the uppermost Viruan and Hirnantian organic reefs in the Oslo Region and northern Estonia and also far larger build-ups than any Silurian organic reef on Gotland. The mounds formed prominent elevations on the sea floor. When the growth of a mound had ceased, deposition on the top of the mound did not resume until the level of surrounding sediments began to approach the level of the mound top; for this reason there is a break at the top of every mound. Towards the mound flank the break is successively filled.

In the Siljan district very little is known about the geometry of the individual mounds except that in cross-section they always appear to be somewhat mushroom shaped, with the greatest areal extent of the mound core being situated in the upper part of the mound. The Kullsberg mounds appear to attain a diameter of 300-350 m and a thickness of about 40-50 m. The Boda mounds are much larger, with a maximum diameter up to 1 000 m and a maximum thickness of about 100-140 m. It is interesting to note that the dimensions of the Boda mounds are comparable to those of the modern lithoherms in the Straight of Florida.

Strain, developed because of differential compaction in the substrate, caused the rigid mound bodies to crack, and every mound has postdepositional crevices which are filled with younger sediments, mainly dark graptolitic shale (Fjäcka Shale in the Kullsberg Limestone and Llandovery shale in the Boda Limestone). Syndepositional crevices also occur, although it is difficult to recognise these.

<u>Kullsberg Limestone</u> The base of the Kullsberg Limestone coincides closely with that of the Skagen Limestone, because the Kullsberg mounds began to develop immediately above the main bentonite bed at the top of the Dalby Limestone (Jaanusson, unpublished). The main part of the Kullsberg Limestone is an equivalent to the Skagen Limestone, and there is some faunal evidence that deposition of the mounds continued into the basal Moldån equivalents. On the flanks of the Kullsberg mounds, the earliest beds that rest on the Kullsberg Limestone consist of a nodular, argillaceous calcarenite representing a wedge of the upper Moldå Limestone which is termed the Skålberg Limestone (Jaanusson 1973). The Skålberg Limestone has a somewhat greater grain size than the Moldå calcilutite, but it is otherwise similar to the equivalent interbank beds, both lithologically and faunally. Towards the summit of the Kullsberg mounds both upper Moldå and Slandrom equivalents successively thin out to nothing, and the Fjäcka Shale, with a greatly reduced thickness, rests directly on the mound.

The mound core of the Kullsberg Limestone contains a diverse, mainly vagile fauna which is poorly known, except for the trilobites (Warburg 1925) and bivalves (Isberg 1934). The bedded flank deposits abound in sedentary organisms, particularly bryozoans, cystoid (Caryocystites lagenalis, Haplosphaeronis oblonga, Heliocrinites granatum), crinoids (Cornucrinus), and articulate brachiopods (Ptychoglyptus, Nicolella, Platystrophia aff. lynx, Eoplectodonta percedens, Bimuria, Christiania cf. holtedahli, Sulevorthis, etc.). In these beds there appears also the earliest tabulate coral in Baltoscandia (Eofletcheria). The Skålberg Beds contain Toxochasmops extensa (Boeck), Nicolella, Leptestiina aff. indentata (Spjeldnæs), Trigrammaria n.sp.A, Coelostylis toernquisti Lindström, various bryozoans, etc.

Boda Limestone The Boda mounds began to develop soon after the deposition of the Fjäcka Shale had ceased (Stop 1). The greatest areal extent of the individual mounds is close to their top, in beds that contain Holorhynchus and are probably of Hirnantian age (Stop 4). However, an early generation of postdepositional crevices is filled with a grey calcareous siltstone which at Solberga contains a Hirnantian bryozoan fauna (Brood, unpublished). This may indicate that the Boda mounds ceased to grow before the end of the Hirnantian. The break at the top of the Boda mounds comprises both Lower and Middle Llandovery; the earliest recorded graptolite zone in the overlying graptolitic shale is the Zone of Monograptus sedgwicki. The available exposures do not show how the break is filled along the flanks of the mounds.

The macrofauna of the Boda Limestone is rich and diverse (e.g. 46 trilobite genera (Warburg 1925; Owen & Bruton 1980) and 40-45 genera of articulate brachiopods). Bivalves have been described by Isberg 1934 and rugose corals by Neuman (1969). As in the Kullsberg Limestone, the mound core contains mainly a vagile fauna (trilobites, gastropods, cephalopods, pelecypods) whereas sedentary macro-organisms tend to be less common. Common trilobites are Eobronteus laticauda (Wahlenberg), Stenopareia linnarssoni Holm) and Holotrachelus punctillosus (Törnq.) which frequently occur in patches containing hundreds of individuals. Other common trilobites are Sphaerexochus calvus (McCoy) and various species of Amphilichas. Ambonychinia corrugata (Lindström) is the commonest pelecypod, and among brachiopods Cryptothyrella terebratulina (Wahl.), Aphanomena luna (Lindström), Cliftonia psittacina (Wahl.) and other triplesiids tend to be more common in the mound core than on mound flanks. The bedded flank deposits abound in sedentary organisms, particularly articulate brachiopods, cystoids, bryozoans, and various corals (rugose, heliolitid and tabulate (see Stop 1:4). No undoubted stromatoporoid has ever been found in the Boda Limestone although this group is fairly common in contemporaneous bedded limestone of North Estonia and the Oslo Region.

1:1 SKÅLBERGET (Figs. 1, 2, 3) A 'twin' of stromatactis-bearing carbonate mounds. The Upper Ordovician Boda Limestone to the east rests on the Middle Ordovician Kullsberg Limestone to the west. The contact between the Boda Limestone and the Llandovery shales (Kallholn Formation; with the Zone of Monograptus sedgwicki at the base) was previously exposed farthest to the east. The strata dip almost vertically, and the carbonate mounds increase in thickness downwards. The quarry was abandoned some 25 years ago, and now parts of this instructive locality are already covered. The type locality of the Skålberg Limestone is at the old, northern entrance to the quarry (section 4 in Fig. 3).

In this quarry the mound cover beds between the Kullsberg and Boda mounds of the Kullsberg Limestone are well exposed. In the northern entrance (section 4) the sequence between the mounds is developed largely as in the intermound facies. Note the discordant contact between the Kullsberg Limestone (peripheral core facies) and the Skålberg Limestone (a similar discordant contact can be observed also in the quarries of Kullsberg and Amtjärn). The Slandrom equivalents are more coarse grained than in the intermound facies but include some thin beds of the fine grained 'masur' limestone. The Fjäcka Shale is much thinner than farther away from the mounds but part of the sequence (0.4 m) is a black shale. In the Jonstorp Formation even the Öglunda Limestone (0.9 m) is developed. The section at the southern entrance to the quarry in the Kullsberg

Limestone (section 5) is towards the top of the Kullsberg Limestone. The Skålberg Limestone has obviously thinned out to nothing, the thickness of the Slandrom equivalents has decreased, and the Fjäcka Shale is represented by a very thin unit. Equivalents to the red Jonstorp beds of section 4 are developed as a red, argillaceous rock rich in crinoid ossicles, in a facies characteristic of the flank facies of the Boda Limestone elsewhere. In the tunnel section, most of these red Jonstorp equivalents are developed in the peripheral mound core facies.

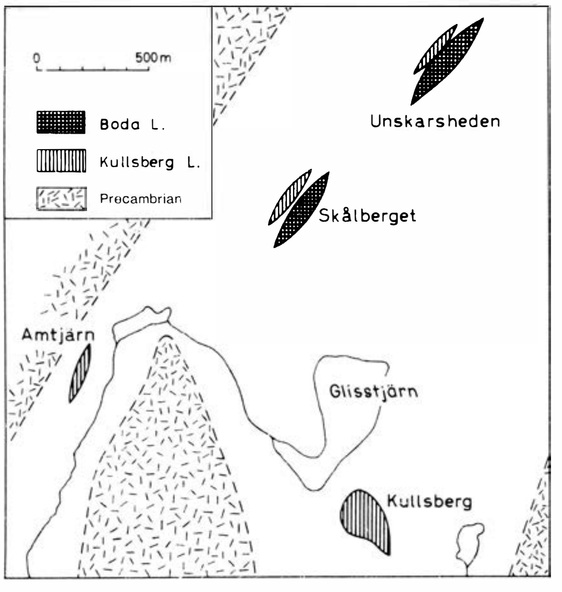


Figure 2. Carbonate mounds in the Kullsberg area. The location of the area is indicated by a quadrangle in Fig. 1.

In section 5 (northern wall) the following section, in ascending order, is exposed below the lowermost massive bank (1.3 m thick) of the peripheral core facies in the Boda Limestone (V. Jaanusson, unpublished).

Lowermost Boda flank deposits (equivalents to the lower part of the Jonstorp Formation) 8.55 m

Dark grey, nodular limestone with irregular argillaceous intercalations	0.95 m
Dark grey, breccia-like argillaceous rock with angular limestone pebbles	0.2 m
Red and variegated red and grey argillaceous rock, mostly rich in crinoid ossicles, with limestone beds and lenses. Bimuria sp, Diambonia sp., Eoplectodonta schmidti (Lindström), Christiania sp., Sulevorthis sp., Ptychopleurella emarginata Wright (type stratum and locality), Eospirigerina sp., several species of cystoid (Eucystis, etc.), etc.	6.3 m
Greenish grey calcareous mudstone rich in crinoid columnals, alternating with limestone beds	1.1 m

"Grey Jonstorp beds" 0.55 m

Regular alternation of grey argillaceous mudstone and beds of brownish grey limestone	0.55 m

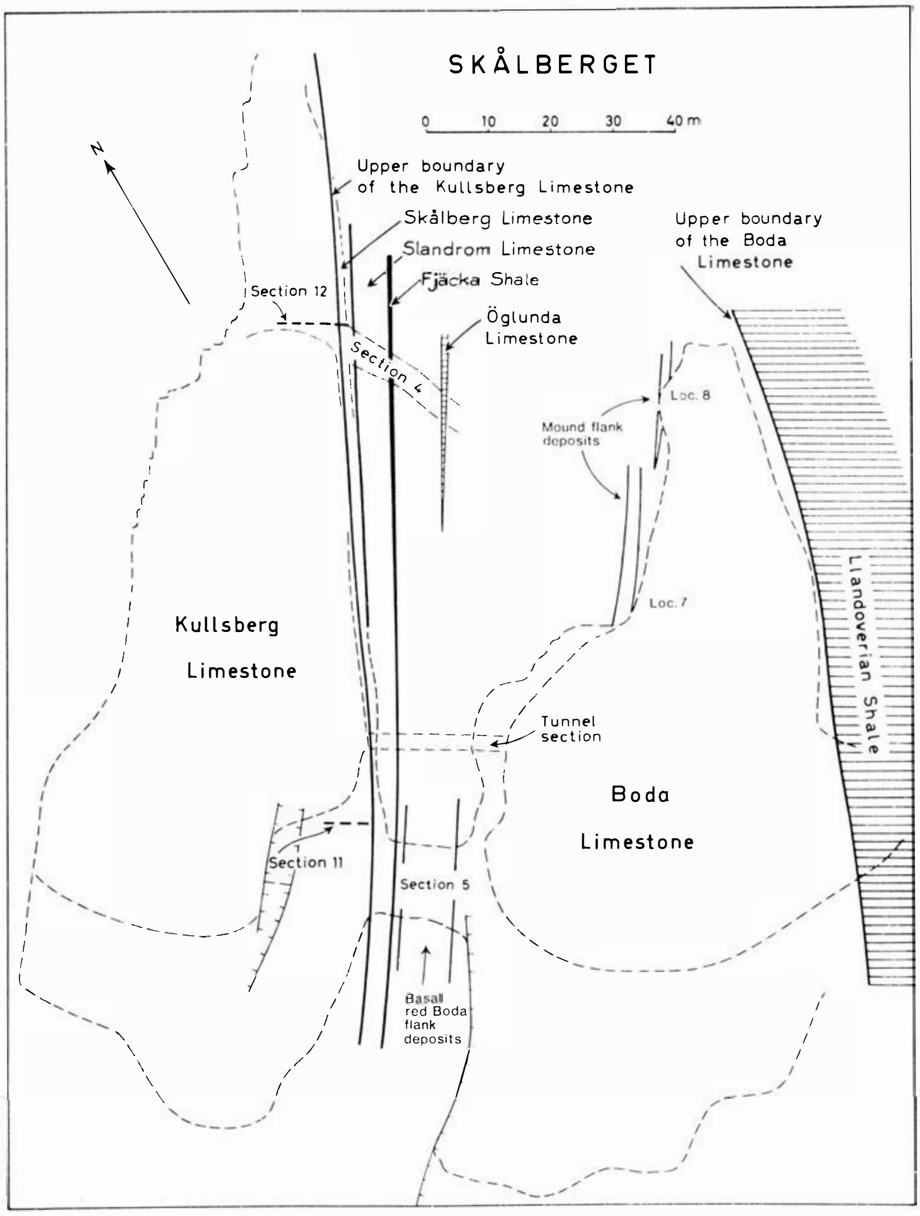


Figure 3. Map of the Skålberget quarry

Fjäcka Shale 0.25 m

Shale in the lower 6-7 cm dark brown, in the upper part grey .... 0.25 m

Slandrom equivalents 2.95 m

Dark grey, bituminous limestone .... 0.15 m

Grey, thick-bedded to nodular limestone with argillaceous intercalations. Nicolella sp. is a common brachiopod .... 2.8 m

Kullsberg Limestone (mound core)

1:2 UNSKARSHEDEN (Fig. 2) A 'twin' of stromatactis-bearing carbonate mounds which dip almost vertically: the Middle Ordovician Kullsberg Limestone to the north-west overlain by the Upper Ordovician Boda Limestone to the south-east. Llandovery graptolitic shales (Kallholn Formation) with large, rounded limestone lenses (concretions) rest upon the Boda Limestone farthest to the south-east. A thin sequence of greenish grey, thin bedded limestones between the Kullsberg and Boda Limestones belong to the mound cover of the Kullsberg Limestone; they have not yet been studied in detail, but appear to include a thin wedge of the Slandrom equivalents and Fjäcka Shale equivalents developed mainly as green mudstone. Note the crevices in the Boda Limestone filled with black Llandovery shale.

Farthest to the north-west, removal of loose drift deposits which covered the bed-rock has exposed large surfaces of the Kullsberg Limestone, polished by the Pleistocene land ice. These surfaces, approximately perpendicular to the depositional plane, show the structures of the mound core excellently. The surfaces are now exposed at the transition between the mound core and the flank deposits, and the red colour of the limestone matrix contrasts distinctly against the drusy calcite of stromatactis. These surfaces have been repeatedly figured (Jaanusson 1979; Bathurst 1980, 1982).

1:3 KULLSBERG (Fig. 2) Type locality of the Middle Ordovician Kullsberg Limestone, a stromatactis-bearing carbonate mound. The quarrying ceased when the high carbonate limestone of the mound core had been quarried away. Some of the mound core remains to the left of the entrance to the quarry, otherwise the quarry walls are in the bedded mound flank deposits. The southern wall of the quarry exposes the following section (based on unpublished data by V. Jaanusson, J. Martna, H. Mutvei and H. Neuhaus in 1945-47).

Fjäcka Shale The top of the section appears to be close to the base of the Fjäcka Shale, because pieces of this black shale occur on the ground immediately south of the quarry (see also Warburg 1910).

Slandrom equivalents

Predominantly calcarenitic, grey, thick bedded limestone with some thin portions of nodular, argillaceous limestone. Some beds in the middle contain glauconite grains .... 3.5 m +

Skålberg Limestone

Predominantly calcarenitic, grey, mostly nodular argillaceous limestone. Toxochasmops extensa (Boeck), Trigrammaria n. sp. A, Leptestiina aff. indentata (Spjeldnæs), Nicolella sp., etc. .... 1.7 m

Kullsberg Limestone

Thick bedded to massive limestone belonging to the peripheral facies of the mound core .... 3.5 m

Thin bedded calcarenite with green argillaceous partings. Upper boundary transitional. These beds still appear to be Skagen equivalents. Eoplectodonta percedens, Platystrophia cf. lynx, Christiania holtedahli, etc. .... 1.0 m

Red to variegated red and greenish grey limestone of varying thickness of individual beds and with argillaceous intercalations. Asaphus (Neoasaphus) cf. ludibundus Törnq., Eoplectodonta percedens (Holtedahl), E. cf. acuminata (Holt.), Bimuria sp., Ptychoglyptus sp., Christiania holtedahli Spjeldnæs, Oepikina sp., Platystrophia aff. lynx (Eichw.), Nicolella sp., Dolerorthis sp., Sulevorthis sp., Caryocystites lagenalis Regnéll, Haplosphaeronis oblonga (Ang.), etc. .... 7.8 m

Greenish grey argillaceous limestone with argillaceous intercalations .... 0.5 m +

OVERTHRUST PLANE

The Kullsberg mound has been thrust over another Kullsberg carbonate mound which was situated below the level of the present quarry floor. The core of this mound was also quarried, but the pit is now filled. Parts of the thrust plane are visible at the entrance to the quarry, and also to the right within the quarry. At the entrance, the upper Kullsberg mound was thrust over steeply dipping Upper Ordovician intermound beds and Lower Llandovery mudstones (this section is the type locality of the Glisstjärn Formation). This section is now poorly exposed but is still accessible in part and represents the best available section of the intermound Hirnantian beds in the Siljan district. The following description of the section is based on Thorslund (1935; his material has since been re-examined, and the identifications of fossils have been updated).

LLANDOVERY

Kallholn Formation
Dark graptolitic shale with limestone concretions .... 7 m

Glisstjärn Formation 13.0 m
Grey mudstone with thin beds of finely nodular limestone ... 1.5 m
Red mudstone .... 4.1 m
Dark grey, soft mudstone with some beds of calcareous mudstone. Encrinurus sp., Flexicalymene? sp., Harpidella sp. The base of the division, as defined by Thorslund (1935) may be within the Hirnantian .... 7.4 m

UPPER ORDOVICIAN

Tommarp Formation (Hirnantian Stage) 2.35 m
Grey, argillaceous limestone with thin intercalations of grey mudstone .... 0.95 m
Dark grey, thin bedded mudstone with some thin intercalation of grey argillaceous limestone .... 0.35 m
Grey, calcareous mudstone. Flexicalymene sp., Leptaena cf. rugosa Dalman, Foliomena sp., Leangella (Leptestiina) sp., Hindella cf. crassa incipiens (Williams) (= ?Hindella cassidea (Dalman)), Loxonema sp. indet., Streptelasma unicum Neuman .... 0.9 m
Grey, hard calcarenite (= Klingkalk) with sparse, rounded quartz grains (maximum diameter 0.3 mm) in the basal 2 cm Dalmanitina (Mucronaspis) mucronata (Brongn.), Flexicalymene sp., Hindella cf. crassa incipiens (Williams), Loxonema sp., Gyronema? n. sp., Clathropora bifurcata (Brood), Streptelasma unicum Neuman .... 0.15 m

Jonstorp Formation
Upper Member. Grey, in some beds variegated red and grey, finely nodular argillaceous limestone grading into grey mudstone with limestone nodules (probably Ålleberg beds). Atractopyge sp., Phillipsinella parabola (Barr.) .... 0.8 m
Red, in the lowermost part grey finely nodular limestone .... c. 9 m
Öglunda Limestone. Grey, hard, very fine grained finely nodular limestone (masur-kalk) .... c. 1 m
Lower Member. Grey finely nodular limestone. Thickness uncertain.

Fjäcka Shale
Black shale, distorted during faulting, thickness unknown.

On the way to the north, we pass Boda church on the left side, situated on the top of a carbonate mound, the type locality of the Boda Limestone.

1:4 OSMUNDSBERGET (Figs. 2, 4) A large quarry in another 'twin' of stromatactis-bearing carbonate mounds. The Middle Ordovician Kullsberg Limestone to the south is overlain by the Upper Ordovician Boda Limestone. At the northern entrance to the quarry, Llandovery deposits rest upon the Boda Limestone with thick-bedded light grey limestone beds at the base. This limestone forms the immediate mound cover here. The boundary between the Boda Limestone and the Llandovery sequence is not always immediately obvious macroscopically. However, the Llandovery limestone lacks stromatactis and associated carbonate mound structures, and its development was obviously associated with particular depositional conditions close to the top of an elevation on the sea floor. Higher up, the Llandovery sequence continues as graptolitic shale containing rounded limestone concretions of various size, and a complex of bentonite beds. The mound cover of the Kullsberg Limestone, between the Kullsberg and Boda mounds, includes thin equivalents of both the Slandrom Limestone and Fjäcka Shale, but these beds have not been studied in detail.

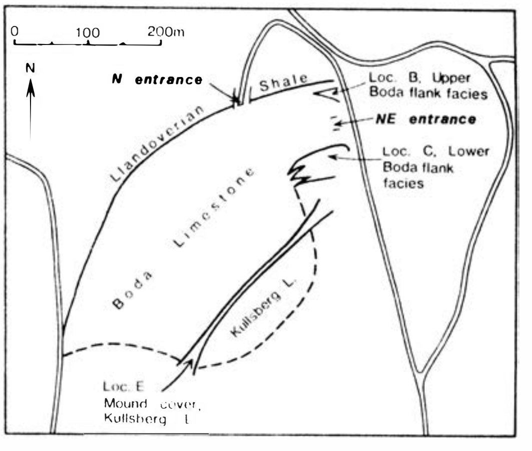


Figure 4. Sketch-map of the Osmundsberget quarry.

In the eastern part of the quarry the transition between the Boda mound core and the argillaceous, red and green, bedded mound flank deposits are exposed. North of the northeastern entrance to the quarry the mound flank deposits of the uppermost Boda Limestone contain *Holorhynchus* and are obviously of Hirnantian age. There, the bedded limestone and marl are rich in various sedentary macrofossils. Common articulate brachiopods include *Eospirigerina expansa* (Lindström), *Hyattidina? portlockiana* (Reed), *Christiania* sp., *Bimuria* sp., *Eoplectodonta schmidti* (Lindström), *Diambonia* sp., *Dicoelosia indenta* (Cooper), *Epitomyonia glypha* Wright, *Nicolella oswaldi* (Roemer), *Sulevorthis* sp., and *Dolerorthis* sp. A common rugose coral is *Bodophyllum osmundense* Neuman. Heliolithid and tabulate corals are represented by *Acantholithus lamellosus* (Lindström), *Catenipora* and other forms. Cystoids, (*Eucystis*, Tetreucystis, Caryocystites, etc.) form an important macrofaunal constituent.

2:1 FJÄCKA SECTION (Fig. 5) A continuous section from the upper part of the Furudal Limestone to the Upper Jonstorp Formation. The lowermost part of the section, in the Furudal Limestone and the lower half of the Dalby Limestone, is exposed in a small, long abandoned quarry, whereas the remainder of the section is a natural outcrop along the slope of the Moldå valley. The locality was first described by Törnquist in 1867, but a complete section was first obtained through excavations in 1945-1946 by Valdar Jaanusson, Jüri Martna, Harry Mutvei and Henrik Neuhaus, who initiated what is informally termed Project Fjäcka. The whole section was described by Jaanusson & Martna (1948), the lithology of the Skagen and Moldå topoformations by Martna (1955), and the Furudal and Dalby Limestones, with particular emphasis on the succession of palaeocope ostracode faunas, by Jaanusson (1963a). Laufeld (1967) described the chitinozoan succession, S. Bergström (1971) the conodont succession and Jaanusson (1976) summarised the information on Middle Ordovician ostracode ranges. Additional work is in progress (e.g. see Figs. 6, 7). The whole section was re-excavated by courtesy of the Kopparberg County Government in 1976, and the area now forms a protected Nature Reserve.

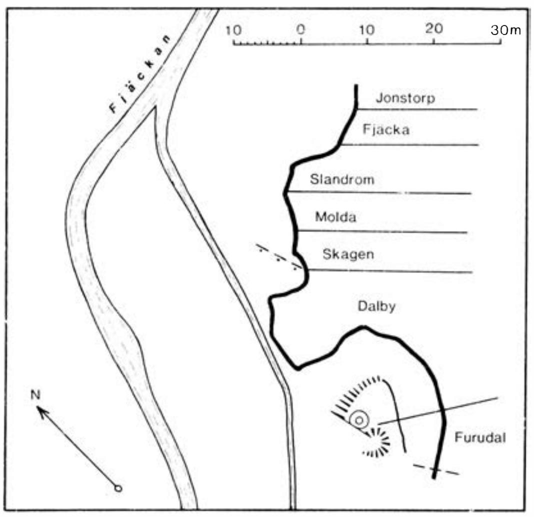


Figure 5. Sketch-map of the main exposures along the Fjäcka brook at Moldå. Based on a map of the Fjäcka area by J. Martna.

The Fjäcka section is the type locality for Furudal, Dalby, Moldå and Fjäcka Formation, and for the North Atlantic conodont zones of *Pygodus anserinus*, *Amorphognathus tvaerensis* (and its three subzones) and *Amorphognathus superbus*.

Please note that the area is a Nature Reserve and that according to law no collecting is permitted without special permission from Skogsvårdstyrelsen (Forestry Protection Council) of the Kopparberg County (applications for this should be submitted preferably through Lars Karis at the Geological Survey of Sweden). Permission has been granted for the excursion. Collecting for Project Fjäcka is being done with bed-by-bed precision, and as the available quantity of rock for each bed is limited, every specimen of most species is important. It is also important that the level of each specimen found should be determined by measuring the stratigraphical distance (perpendicular to the strike and dip) from the closest formational boundary or other index level (such as a bentonite bed).

The section at Fjäcka is as follows:

UPPER ORDOVICIAN (HARJUAN SERIES)

Jonstorp Formation 6.5 m +

Red, finely nodular, argillaceous limestone .... 4.1 m +
Greyish-green, finely nodular, argillaceous limestone ...... 3.8 m
Öglunda Limestone. Very fine grained, hard, finely nodular calcilutite .... 0.8 m
Greyish-green, finely nodular, argillaceous limestone ...... 3.0 m

Fjäcka Shale 5.8 m

Black shale. Some beds (especially in the lowermost part) are rich in fossils, such as _Tretaspis seticornis_ (Hisinger), _Flexicalymene trinucleina_, _"Onniella" argentea_ (His.), _Chonetoidea iduna_ Öpik, _Actinomena? arachnoidea_ (Lindström), etc. .... 5.8 m

Slandrom Limestone 8.4 m

Hard, very fine-grained ('lithographical'), finely nodular limestone ('masur' limestone), alternating with fairly thick bedded, mostly calcarenitic calcilutite. The 'masur' limestone has been regarded as especially characteristic for this formation but in fact it occupies only about 30% of the total thickness of the formation. Poor in fossils. _Toxochasmops_ cf. _wesenbergensis_ has been recorded from the lower part (Jaanusson 1953), and _Tretaspis seticornis_ occurs in the upper part .... 8.4 m

MIDDLE ORDOVICIAN (VIRUAN SERIES)

Moldå Topoformation 5.8 m (for the macrofauna see Fig. 7)

Grey, thin bedded, argillaceous calcilutite, in the lower half with intercalations of calcareous mudstone ...... 3.6 m

Regularly bedded, grey, argillaceous calcilutite with thick intercalations of calcareous mudstone .... 2.2 m

Skagen Topoformation 5.6 m (for the macrofauna see Fig. 7)
Regularly bedded, grey argillaceous calcilutite with thick intercalations of calcareous mudstone .... 0.5 m
Grey, thin bedded, argillaceous calcilutite with regular intercalations of calcareous mudstone .... 2.4 m
Grey, thick bedded, argillaceous calcilutite with argillaceous partings .... 2.7 m

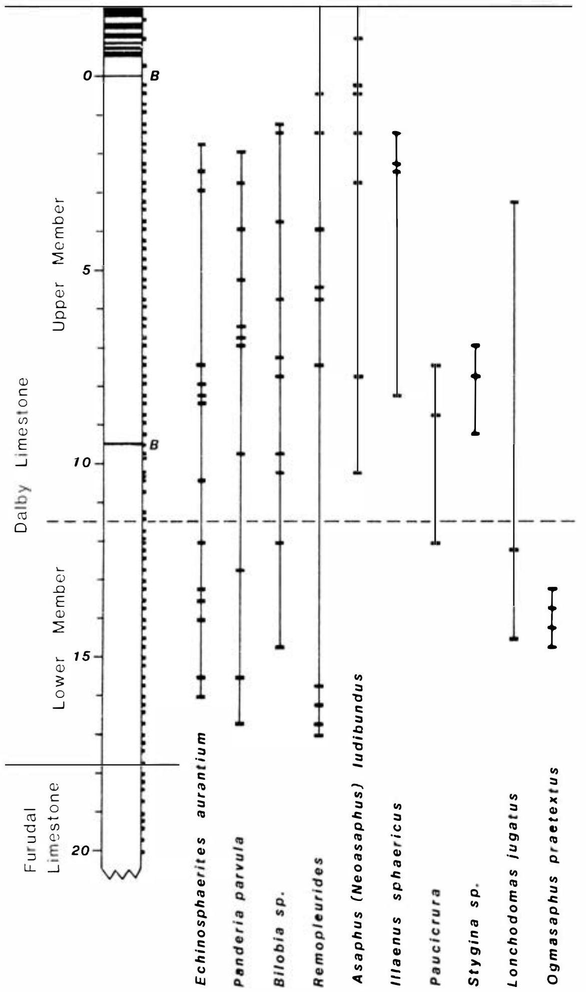


Figure 6. Sample-frequency distribution of the common species in the large macrofauna (excluding bryozoans) in the Dalby Limestone of the main Fjäcka section (V. Jaanusson, original). The figure shows species which were found in a series of c. 2.5 kg samples; the level of each sample is indicated by black quadrangles along the rock column. Species which occurred in less than three samples are excluded. It should be emphasised that for most of the species the figure does not show the known vertical range based on all available material (selective collecting included).

Dalby Limestone 19.9 m (for common forms in the macrofauna see Fig. 6)
Upper Member (13.3 m). A complex of 7 bentonite beds, with the thickest bed (26 cm) on the top, intercalated by beds of grey, calcarenitic calcilutite. The basal bentonite bed (1 cm thick), separated from the other beds of the complex by 50 cm of limestone, is taken as a reference level (0 m) within the Dalby Limestone below the bentonitic complex .... 1.8 m
Grey, somewhat nodular limestone (calcarenitic calcilutite to calcarenite) with irregular argillaceous intercalations. A bentonite bed (3-5 cm thick) at the base of the unit forms a convenient index horizon ... 9.5 m

Somewhat nodular limestone, indistinguishable from the rock above. Beds adjacent to the boundary between the Lower and Upper Members of the Dalby Limestone are poorly exposed	c. 2	m
Lower Member (c. 6.6 m). Thick bedded, grey calcarenite	c. 4	m
Grey, fairly thick bedded limestone, mainly calcilutitic	c. 2.6	m
Furudal Limestone 5 m +		
Grey, fairly thick bedded calcilutite	5	m +

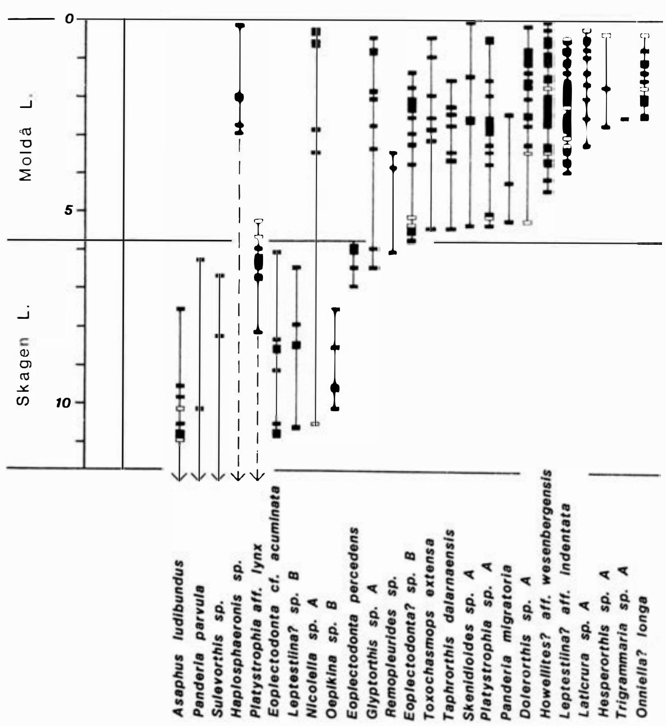


Figure 7. Macrofaunal log (excluding bryozoans) from the Skagen and Moldå Topoformations of the main Fjäcka section (M.G. Bassett and V. Jaanusson, original). With the exception of Trigrammaria sp. A, species which have been found at a single level are excluded. The log is in many respects preliminary because a monographic study of the fauna is not yet completed.

2:2 DJUPGRAV (Loc. 6, Fig. 1) Road cut in the basal Ordovician conglomerate, resting on the Jotnian sandstone. The beds dip almost vertically. The conglomerate is c. 3 m thick and consists of rounded pebbles of various Precambrian rocks, mostly sub-Jotnian porphyries, embedded in a matrix of coarse sandstone. As a result of faulting, the sequence is repeated along the road. The topmost c. 30 cm of the conglomerate is somewhat darker than the unerlying beds, and has a very thin layer of a greyish shale at the base. In the western exposure the shale is black and contains Dictyonema sociale (Thorslund & Jaanusson 1960). The conglomerate is overlain by the Latorp Limestone which contains numerous discontinuity surfaces and has a sandy glauconitic clay at the base.

2:3 KÅRGÄRDE (Loc. 7, Fig. 1) A continuous section from the Precambrian to the top of the Middle Ordovician Dalby Limestone. In the immediate vicinity small exposures covering most of the sequence have been known for a long time (Törnquist 1883). A continuous section from the Lanna Limestone to the Furudal limestone was exposed by excavation in 1947 (described by Jaanusson & Mutvei 1953 and Jaanusson 1963a). The present section was prepared by the Government of the Kopparberg County in 1976 and is protected as a Nature Reserve.

At Kårgärde are the type sections of the Holen and Kårgärde Limestones, and the North Atlantic conodont Zone of *Pygodus serrus* as well as its subzones of *Eoplacognathus suecicus*, *E. foliaceus*, *E. reclinatus* and *E. lindstroemi* (S. Bergström 1971).

The new exposure has not yet been studied in detail. The following description of the section was prepared by Lars Karis. West of the major fault on the top of the Dalby Limestone the sequence is repeated and continues in the Furudal Limestone which is also exposed in a small, abandoned quarry farther to the west. In the whole Kårgärde area the beds dip almost vertically.

MAJOR FAULT

MIDDLE ORDOVICIAN

Dalby Limestone 18.1 m

A complex of bentonitic beds separated by beds of grey, somewhat nodular, argillaceous limestone. The uppermost bentonitic bed is c. 15 cm thick, and 3 thin additional beds can be recognised lower down		0.5	m
Grey, bedded to nodular limestone with irregular argillaceous intercalations. *Echinosphaerites aurantium* is a conspicuous macrofossil		11.1	m
Grey, thick bedded calcarenite	c.	5.0	m
Grey, fine grained, mainly calcilutitic limestone	c.	1.5	m

Furudal Limestone 9.2 m	
Uniform sequence of thick bedded, grey calcilutites with argillaceous intercalations	9.2 m
Folkeslunda Limestone 2.4 m	
Fairly thick bedded, grey calcarenite	1.4 m
Fairly thick bedded, grey calcilutite with argillaceous intercalations	0.85 m
One bed of grey calcarenite	0.15 m
Seby Limestone 1.55 m	
Variegated red and grey, finely nodular calcilutite	0.5 m
Variegated red and grey, mainly fairly thick bedded limestone	1.05 m
Skärlöv Limestone 3.40 m	
Red, finely nodular to nodular calcilutite	3.40 m
Segerstad Limestone 3.1 m	
Vikarby Beds (Zone of _Illaenus planifrons_). Variegated red and grey, thick bedded limestones	0.7 m
Kårgärde Beds (Zone of _Angelinoceras latum_). Red, thick bedded limestone with some intercalations of red, finely nodular limestone. There are traces of stromatolitic algal mats in the lowermost beds	2.4 m
LOWER ORDOVICIAN	
Holen Limestone (type locality) 7.1 m	
Thick bedded calcilutites, in the upper part red, in the lower part variegated red and grey	4.8 m
Grey, thick bedded limestone, mainly calcarenitic	0.7 m
Grey, thick bedded coquinoid limestone, abounding in disarticulated trilobites carapaces and fragmentary cephalopod conchs	0.4 m
Grey, oolitic limestone with limonitic ooids, particularly in the lower 0.8 m. The base is formed by a discontinuity surface with limonitic mineralisation	1.2 m
Lanna and Latorp Limestones (not yet studied)	
Grey, medium to thick bedded limestone with discontinuity surfaces	0.8 m
Pale red, thick bedded limestone with numerous discontinuity surfaces	1.4 m
Red, thick bedded calcilutite with a few discontinuity surfaces	2.0 m
MINOR FAULT	
Dark red mudstone	0.7 m
Red, thick bedded calcilutite with goethitic mineralisation at some levels; basal 15 cm nodular	0.6 m

Alternating beds of red or variegated red, grey and yellow calcilutite and red mudstone	1.8 m
Red mudstone	0.75 m
Variegated red, green and yellow, nodular calcilutite	0.1 m
Green glauconitic clay	0.3 m
Glauconite sandstone	0.25 m
Conglomerate with a calcite matrix. The pebbles are mostly formed by porphyry, derived from the substrates, but granite and limestone pebbles also occur	0.25 m

JOTNIAN PORPHYRY

INTRODUCTION TO THE ORDOVICIAN IN JÄMTLAND

Valdar Jaanusson and Lars Karis

The general distribution of Ordovician deposits along the Caledonian front in Jämtland has been reviewed briefly in the introduction to the Ordovician of Sweden, and illustrated by a rough palinspastic restoration of a cross-section from the autochthonous sequence to the west (Jaanusson, Fig. 3).

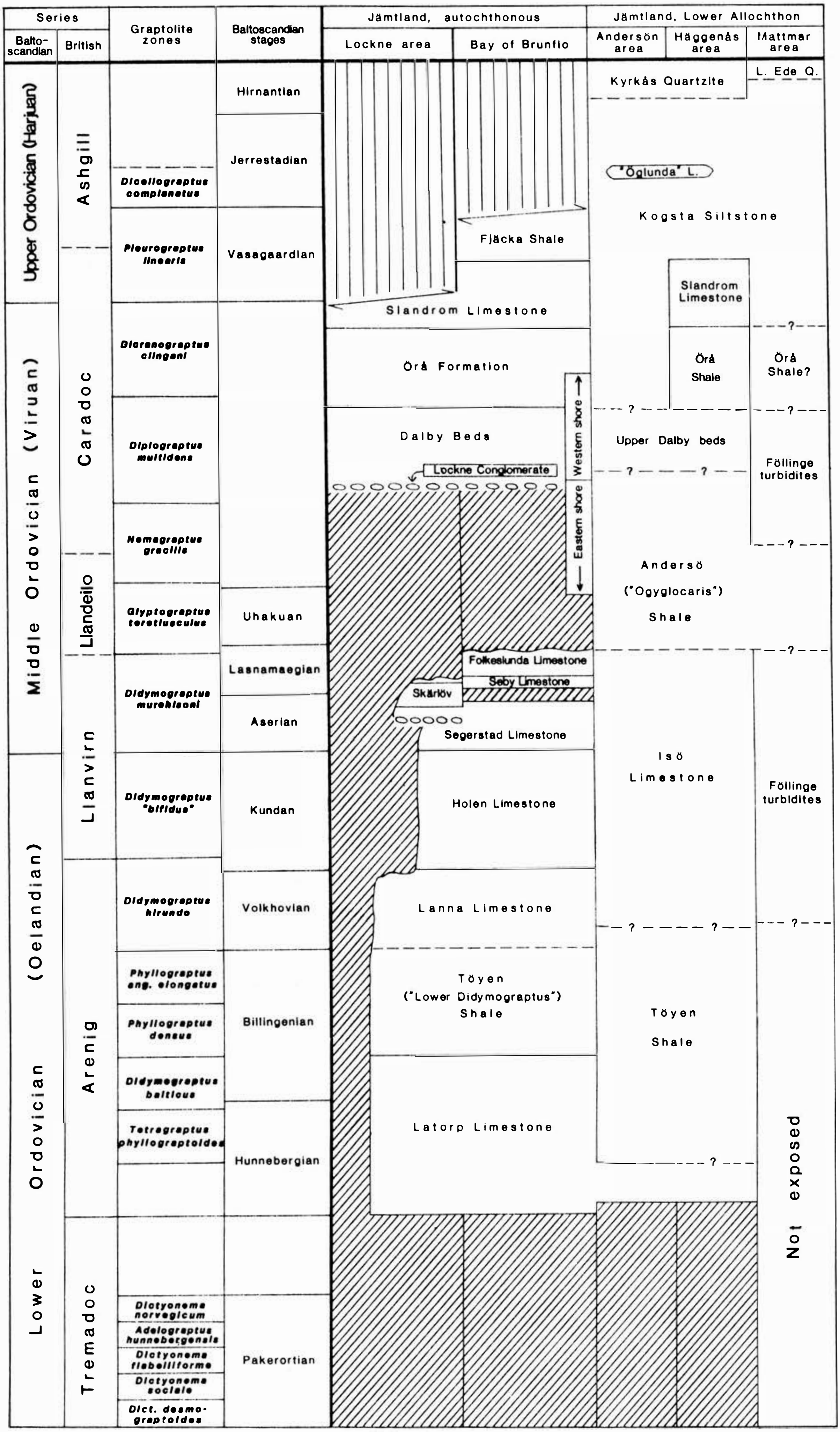
As a result of the Caledonian orogeny, the rock sequence is tectonically deformed, the deformation increasing in intensity towards the west. The tectonic style that characterizes the structure of the Caledonian front appears to be cover shortening over a passive basement. In many cases the Middle and Upper Cambrian shales provided a plane of décollement near to the Precambrian crystalline basement, over which the overlying Ordovician and Silurian rock pile was thrust eastwards. The transported sequences became folded, thrust and stacked both on each other and on the Cambrian and Ordovician sedimentary cover which remained autochthonous farthest to the east. See also Gee & Zachrisson (1979); Gee & Wolff (1981).

In central and northern Jämtland the main tectonic unit of the Caledonian front, previously termed parautochthonous but now generally referred to as the Lower Allochthon, has an extensive outcrop area (Karis & Larsson, road log, Fig. 1). This tectonic unit is composed of thrusted rocks of Late Precambrian and Early Palaeozoic age with low grade metamorphism (at the most lower greenschist facies). Along the eastern margin of the Caledonian front the Cambrian and Ordovician sedimentary cover of the Precambrian crystalline basement is exposed in a more or less autochthonous position below the thrusted rocks of the Lower Allochthon and east of the thrust front. This sedimentary sequence is termed the Autochthon. The forces involved in the eastward thrusting of the allochthonous sequence have also affected the autochthonous rocks to varying degrees. In many places the autochthonous rocks are folded and cut by climbing minor displacements or thrust-planes.

Previous reconstructions of the structure of the Caledonian front in Jämtland emphasised the tectonic and lithofacial discontinuity between the Autochthon and Lower Allochthon (Asklund 1938; Thorslund 1940). Even the basal thrust units of the Lower Allochthon were assumed to have been transported considerable distances eastward, thus bringing different contemporaneous facies into close proximity. The Autochthonous sequence, as then defined, coincided with the distribution in Jämtland of what is now termed the central Baltoscandian confacies belt.

Recent studies during mapping of the bed-rock for a new geological map of Jämtland County have shown that in practice the distinction between the Autochthon and the Lower Allochthon is not always sharp, and in places is even arbitrary. The thrust front of the Lower Allochthon in some areas is situated farther to the east than previously thought. For example, in the Autochthon of the north-western Bay of Brunflo area, which includes the Slandrom section, at least one significant thrust-plane with associated climbing displacements has now been recorded (L. Karis, unpublished). Tectonically this area should thus be classified as Lower Allochthon. Also the discontinuity between the Autochthon and Lower Allochthon is not always as sharp as previously believed. In the basal Lower Allochthon of the area south-east of Storsjön, Asklund (1938) suggested a tectonic structure with successive thrust units, termed the Skute, Bjärme and Sunne Nappes, each having a distinctive stratigraphical composition. This interpretation was important in forming the current usage of the concepts autochthon and allochthon. Recent studies appear to indicate that the differences between these nappes are to a large extent due to rapid spatial change in lithofacies rather than to longer transport for the individual tectonic units.

Figure 1. Correlation table of the Ordovician in some selected areas of Jämtland. Diagonal shading indicates breaks in the sequence. Compiled by V. Jaanusson and K. Larsson (Autochthon), and L. Karis (Lower Allochthon). Unpublished data from Stig M. Bergström are incorporated.


Series
Balto-scandian
British
Graptolite zones
Baltoscandian stages
Jämtland, autochthonous
Lockne area
Bay of Brunflo
Jämtland, Lower Allochthon
Andersön area
Häggenås area
Mattmar area
Upper Ordovician (Harjuan)
Middle Ordovician (Viruan)
(Oelandian)
Lower Ordovician
Ashgill
Caradoc
Llandeilo
Llanvirn
Arenig
Tremadoc
Dicellograptus complanatus
Pleurograptus linearis
Dicranograptus clingani
Diplograptus multidens
Nemagraptus gracilis
Glyptograptus teretiusculus
Didymograptus murchisoni
Didymograptus "bifidus"
Didymograptus hirundo
Phyllograptus ang. elongatus
Phyllograptus densus
Didymograptus balticus
Tetragraptus phyllograptoides
Dictyonema norvegicum
Adelograptus hunnebergensis
Dictyonema flabelliforme
Dictyonema sociale
Dict. desmograptoides
Hirnantian
Jerrestadian
Vasagaardian
Uhakuan
Lasnamaegian
Aserian
Kundan
Volkhovian
Billingenian
Hunnebergian
Pakerortian
Kyrkås Quartzite
L. Ede Q.
"Öglunda" L.
Kogsta Siltstone
Fjäcka Shale
Slandrom Limestone
Slandrom Limestone
Örå Formation
Örå Shale
Örå Shale?
Dalby Beds
Upper Dalby beds
Föllinge turbidites
Lockne Conglomerate
Western shore
Eastern shore
Andersö ("Ogygiocaris") Shale
Folkeslunda Limestone
Seby Limestone
Skärlöv
Segerstad Limestone
Holen Limestone
Isö Limestone
Föllinge turbidites
Lanna Limestone
Töyen ("Lower Didymograptus") Shale
Töyen Shale
Latorp Limestone
Not exposed

A consequence of these studies is that the tectonic concepts Autochthon and Lower Allochthon no longer coincide with the distribution of the confacies belts. The confacies type characteristic of the central belt continues in some areas into what should be tectonically classified as Lower Allochthon. However, pending comprehensive description of the Caledonian front structure in Jämtland, the accustomed usage of the term Autochthon (Asklund 1938) is followed in this guide. The geographical distribution of the main tectonic units in the region west of Östersund, the Föllinge and Olden Nappes (Asklund 1938), is also disputed. For that reason very few tectonic elements are indicated in Karis & Larsson, Road log, Fig. 1.

The autochthonous Lower Palaeozoic epicontinental deposits crop out in a narrow strip along most of the Caledonian front. Ordovician rocks are preserved from Härjedalen in the south to Lake Malgomaj area in southernmost Lapland. The outcrop area is widest in central Jämtland, south-east of Östersund, on both sides of the Bay of Brunflo.

Along its whole extent from Härjedalen to southernmost Lapland, the Ordovician of the Autochthon belongs to the central Baltoscandian confacies belt. Much of the sequence is lithologically as well as faunally very similar to the Siljan district. However, the clearly nodular upper Dalby Limestone and, locally, Örå Shale resemble contemporaneous beds of the Oslo Region as does the persistent development of the Töyen Shale.

THE SEQUENCE IN THE AUTOCHTHON OF JÄMTLAND

Valdar Jaanusson, Kent Larsson and Lars Karis

LOWER ORDOVICIAN (OELANDIAN)

Latorp Limestone No Tremadoc rocks have been recorded in the autochthonous sequence, and the lowermost Arenig Latorp Limestone rests directly on Upper Cambrian shales. At Kloxåsen (road log, Fig. 3) and Tossåsen the limestone comprises almost the whole Hunnebergian Stage (Tjernvik 1956) whereas in the Flåsjön area, northern Jämtland, the limestone below the Töyen Shale is thin and restricted to the Lower Hunnebergian Zone of *Megistaspis* (*Ekeraspis*) *armata*. In the Flåsjön area the Latorp Limestone, of late Billingenian age and developed as calcilutite with intercalations of grey shale, continues above the Töyen Shale (based on conodont data; Löfgren 1978). This may also be the case in some other areas.

Töyen Shale The shale is developed throughout the autochthonous outcrop area, but varies in vertical extent. The lowermost graptolite zone is the Zone of *Tetragraptus phyllograptoides* in the Kalkberget section, Flåsjön area, and the Zone of *Didymograptus balticus* at Skålan in the Åsarna area. In several other sections (Kloxåsen, Tossåsen) the shale seems to begin in the Zone of *Phyllograptus densus*. At Kalkberget the upper boundary of the shale is within the Billingen Stage, whereas at Kloxåsen the boundary appears to coincide with the base of the Volkhovian Lanna Limestone (Löfgren 1978).

Lanna Limestone In the autochthonous sequence the Lanna Limestone is developed almost everywhere as a uniform sequence of thick-bedded, grey to pale red calcilutites, 8 to 15 m thick. The Zone of *Megistaspis* (*Megistaspis*) *lata* has been proved at the base of the unit. In the Brunflo area the topmost beds of the unit are grey and calcarenitic, and have yielded Dysplanus acutigenia Jaanusson and other trilobites which indicate the Zone of Megistaspis (Megistaspis) limbata limbata, which corresponds to the East Baltic Zone of Asaphus (Asaphus) lepidurus. Löfgren (1978) described the conodont succession of the Lanna equivalents in several sections; according to the conodont zonation the Lanna Limestone corresponds to the Havsnäs Limestone and the lower part of the Flåsjö Limestone in the Kalkberget sections of the Flåsjö area.

Holen Limestone Over almost the whole autochthonous outcrop area two lithostratigraphical members can be distinguished in the Holen Limestone, a lower member, consisting of grey, nodular limestone with irregular argillaceous intercalations (Flåsjö Limestone in Löfgren 1978) and an upper member, composed of thick bedded calcilutite, grey in the lower part, pale red in the middle and red in the upper part (Järvsand Limestone in Löfgren 1978, definition of the top uncertain). The nodular limestone has yielded a rich fauna of the Zone of Asaphus (Asaphus) expansus. The upper member is less fossiliferous and has not yet been studied in detail except for conodonts (Löfgren 1978). The uppermost beds have yielded Megistaspis (Megistaspidella) gigas in several localities.

MIDDLE ORDOVICIAN (VIRUAN)

Segerstad Limestone The autochthonous basal Middle Ordovician of Jämtland shows many similarities to the contemporaneous strata of the Siljan District. Thus, both subdivisions of the Segerstad Limestone distinguished in the Siljan (i.e. the lower Kårgärde Limestone and the upper Vikarby Limestone) are present in Jämtland (Larsson 1973). The zones of Angelinoceras latum and Illaenus planifrons may also be distinguished. The Kårgärde Limestone cannot be separated lithologically from the underlying Kunda Holen Limestone, but as in the Siljan District, two distinct trilobite faunas characterize the Lower/Middle Ordovician boundary (i.e. Megistaspis (Megistaspidella) gigas at the top of the Holen Limestone, and Asaphus (Neoasaphus) platyurus at the base of the Segerstad Limestone). Commonly these two trilobite species occur accumulated into distinct, narrow bands. In all principal districts of Jämtland, the boundary interval between these two faunas amounts to about 0.5 m.

The Kårgärde Limestone consists of an intensely reddish-brown calcarenitic calcilutite, while the Vikarby Limestone is mostly composed of variegated, recrystallised calcarenites. Irregular grains of chamosite are characteristic. The boundary between the two members is generally developed as an irregular discontinuity surface showing overhanging portions. The limestone beneath is generally bleached. A local intraformational conglomerate, the Kullstaberg Conglomerate, is developed in the Lockne area. This polymict conglomerate appears in the upper part of the Kårgärde Member and rapidly varies in thickness laterally.

Both members of the Segerstad Limestone exhibit numerous discontinuity surfaces. These appear as irregular haematite-stained surfaces, and are frequently developed as mud crack surfaces. Such surfaces are particularly abundant in the Vikarby Member.

Stromatolites also form a characteristic feature of the Segerstad Limestone (Larsson 1973). These are developed above the discontinuity surfaces with fossil fragments and appear as algal mats or laterally linked domes. The Vikarby Member is particularly rich in stromatolites. Oncolites have recently been proved in the Segerstad Limestone at Högfors, north-east of Östersund.

The Kårgärde Limestone is generally poor in macrofossils, except for some thin accumulations of trilobites and cephalopods. The Vikarby Limestone occasionally shows coquina-like accumulations of trilobites and cephalopods. Many cephalopods of this limestone have been drifted onto the mud cracked surfaces and are arranged along the polygonal pattern of these surfaces.

Skärlöv Limestone The Skärlöv Limestone consists of nodular to finely nodular, reddish-brown calcilutites. The unit is well represented in southern Jämtland, while it is considerably reduced in the Lockne area and totally absent in the Brunflo area (Fig. 1). In the Lockne area, the lower boundary coincides with a discontinuity surface. The Skärlöv Limestone is very poor in macrofossils.

Seby Limestone In the Brunflo area, the lower division of the Seby Limestone is lithologically indistinguishable from the underlying Aserian Vikarby Limestone. The Skärlöv Limestone is not developed in the area, and the Seby and Vikarby Limestone are in direct contact. Thus the Aserian/Lasnamägian boundary can only be defined by means of faunal criteria (Larsson 1973). *Illaenus planifrons* and *Geisonoceras? centrale* occur immediately below and *Illaenus chiron* above the discontinuity surface separating the two units. This surface is partly developed as a mud crack surface with overhanging portions.

The lower division of the Seby Limestone can be defined as a mottled, partly sparitic calcarenite, with mud crack surfaces and stromatolites. This development is found both in the Brunflo and the Lockne area. In the former area, the upper divisions of the Seby Limestone are developed as grey calcarenites with stromatolites, but without the haematite staining typical for the lower division. The higher divisions are also more argillaceous and show fewer discontinuity surfaces. Probably this reflects increased water depth towards the end of the deposition of the Seby Limestone.

In southernmost Jämtland, the Seby Limestone is somewhat differently developed as the lower divisions consist of reddish-brown and mottled fine-grained limestone without stromatolites. In the upper part, reddish-brown, nodular, fine-grained beds and thick-bedded calcarenites with haematite-stained stromatolites dominate.

The Seby Limestone has yielded a rich fauna comparable to the faunas found on Öland and in the Siljan districts. Among the trilobites are *Illaenus chiron*, *Pseudobasilicus? brachyrachis* and *Pseudoasaphus tecticaudatus*. Species of *Remopleurides* are also common.

Folkeslunda Limestone The most complete development of the Folkeslunda Limestone is found in southern Jämtland, while it is much reduced in the Brunflo area, and probably missing in the Lockne area. This is probably the result of erosional events in Kukrusean time when the higher areas of the Autochthon were severely denuded. Compared to the Siljan district, the Folkeslunda Limestone in Jämtland is much finer grained, and most of the formation consists of grey, calcilutitic

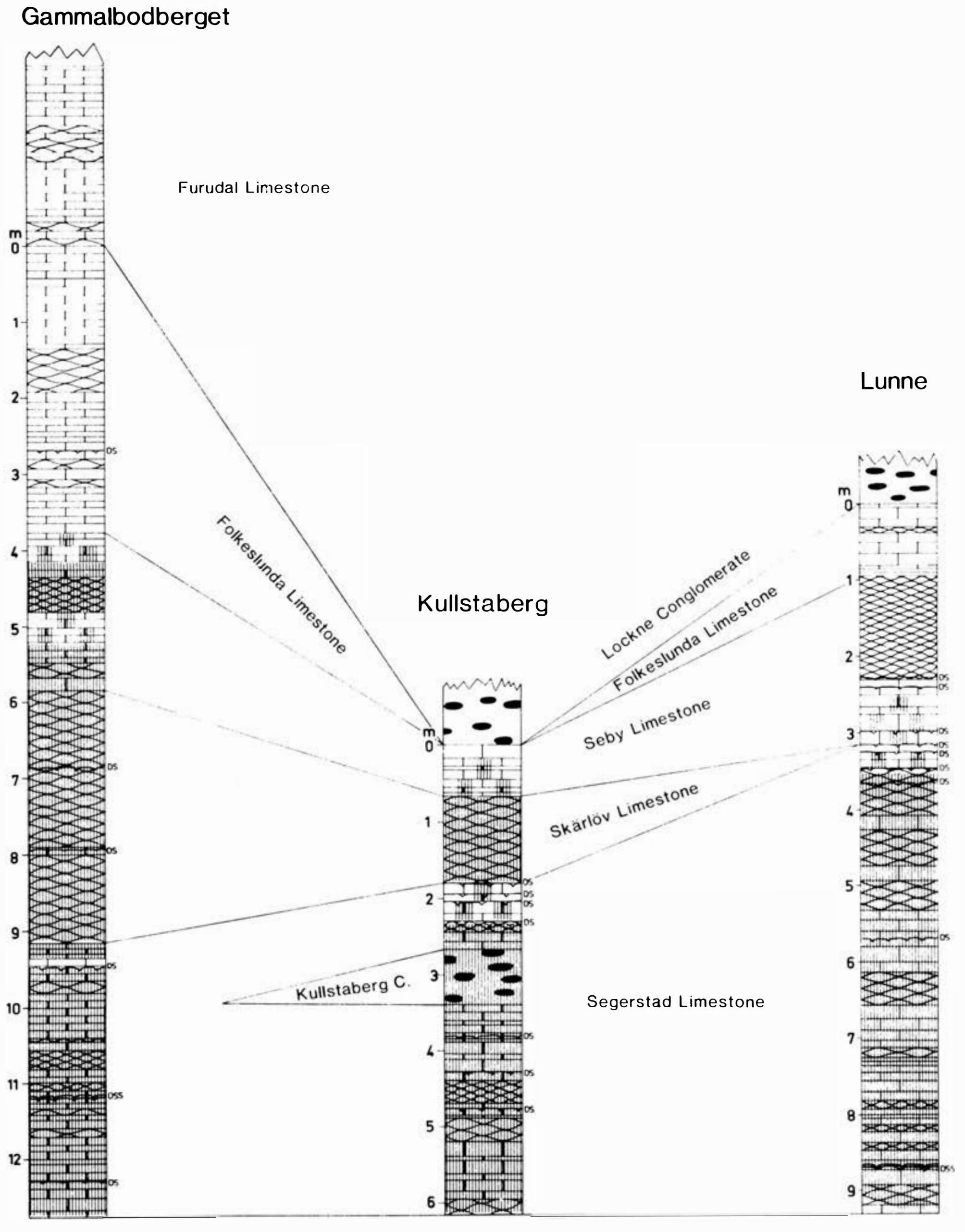


Figure 1. A comparison of the Aserian, Lasnamägian and Uhakuan beds in the Åsarna (Gammalbodberget), Lockne (Kullstaberg) and Brunflo (Lunne) areas (after Larsson 1973).

limestones. The upper limit of the formation is drawn on palaeontological criteria (i.e. where Euprimites effusus disappears) as the lithology is the same as the succeeding Furudal Limestone.

Occasionally some beds are rich in macrofossils, including Illaenus chiron, Pseudomegalaspis patagiata, Plectasaphus plicicostis and Paraceraurus cf. exsul.

Furudal and lower Dalby Limestones In the autochthonous sequence the Furudal and lower Dalby Limestones are preserved only in the Åsarna area in the south-west and the Häggenås area in the north. Between these two areas, erosion prior to the deposition of the Lockne Conglomerate has removed deposits of Uhakuan and Kukrusean age, although in places these may never have been deposited. To the south and north of these areas the Lower Allochthon rests on older autochthonous beds.

In the Åsarna and Häggenås areas the Furudal-lower Dalby limestone are developed as a monotonous sequence of grey, thick-bedded calcilutites, poor in macrofossils. In the Storhallen section of the Åsarna area the Lockne Conglomerate rests on limestones which yield conodonts of the Subzone of Prioniodus gerdae (S. Bergström, pers. comm.). In the uppermost metre Echinosphaerites aurantium is a fairly common macrofossil. In other localities of the Åsarna area (e.g. Gammalbodberget; Fig. 1) the Lockne Conglomerate rests on the Furudal Limestone. At Högfors, Häggenås area, a Furudal-Dalby calcilutite sequence, about 18 m thick, reaches into the middle part of the Dalby Limestone. In this area no Lockne Conglomerate has been observed. The uppermost 2 m of the exposed Dalby Limestone has yielded Echinosphaerites aurantium, Asaphus (Neoasaphus) ludibundus, Illaenus sphaericus and other macrofossils.

Lockne Conglomerate and the upper Dalby Limestone The Lockne Conglomerate at the base of the upper Dalby Limestone is a spectacular unit in the autochthonous sequence. It is a polymict conglomerate of appreciable but variable thickness, in places even containing large boulders derived from the crystalline basement. It is mostly overlain by a thin unit of a distinctive calcareous sandstone, locally termed 'Loftarsten'. The conglomerate can be followed from the northernmost exposures of the Brunflo Bay area in the north to the Åsarna area in the south. It has not been observed in the lower Allochthon as usually defined.

The base of the Lockne conglomerate is at various levels. In the Åsarna area it overlies Dalby beds of the Subzone of Prioniodus gerdae, in the northern part of its distributional area the Folkeslunda Limestone, and in the vicinity of the Lockne high it frequently rests on the Lanna Limestone. In some sections (e.g. Lillå and Hackås) the conglomerate, with a red, haematitic clay at the base, fills channels up to 2-3 m deep eroded into the Lanna Limestone (L. Karis, unpublished). At Målingen a discontinuous section, 800 m long (stop 2:4), shows the conglomerate to overlie various levels, such as the Lower Ordovician Latorp Limestone, Middle and Upper Cambrian shales, and locally (no longer exposed) even weathered crystalline basement. In the Tandsbyn area, the central area of the Lockne high, it rests on crystalline basement; the geology of this area in general, and the Lockne conglomerate in particular, has been described in detail by Thorslund (1940). The distribution of the conglomerate was clearly associated with the Lockne high which formed an emergent area during the early Middle Ordovician.

The limestone beds above the conglomerate commonly yield conodonts of the Subzone of Prioniodus gerdae (S. Bergström, pers. comm.), indicating that the Lockne conglomerate was of approximately the same age over the whole of its distributional area.

The upper Dalby beds tend to be developed as a high calcium limestone immediately above the conglomerate. Higher up these beds consist mostly of grey, nodular, argillaceous limestone with intercalations of mudstone. The appearance of this rock is similar to that of approximately contemporaneous beds in the Oslo district. The lower metre of the upper Dalby beds is normally very rich in fossils, including Asaphus (Neoasaphus) ludibundus Törnquist, Cnemidopyge costata (Boeck), and Echinosphaerites aurantium (Gyllenhaal).

The Örå Shale In the autochthonous sequence the development of the Örå Shale (Upper Chasmops Beds in Thorslund 1940) is similar to that in the Lower Allochthon except that limestone beds are more numerous; in some sections (e.g. at the Slandrom rivulet) dark limestone is the dominant rock type at least in the upper part of the formation. The boundary between the Dalby and Örå beds is poorly exposed but appears to be transitional. The shelly fossils obtained from the autochthonous Örå beds are almost exclusively from the upper part of the formation and include Toxochasmops extensa (Boeck) and Tretaspis ceriodes (Angelin).

UPPER ORDOVICIAN (HARJUAN)

Slandrom Limestone This formation, about 5 m thick at its type locality, the Slandrom rivulet, consists of a hard, dark, very fine grained, finely nodular limestone, and some bedded limestone intercalated with thin layers of black shale. In the autochthonous sequence the formation also occurs in the central Lockne area where it forms the top of the preserved sequence. The limestone is poorly fossiliferous. *Tretaspis seticornis* has been recorded from the upper part.

Fjäcka Shale The youngest beds preserved in the autochthonous sequence, in the area around Slandrom, belong to the Fjäcka Shale, developed as black shale with beds or lenses of black limestone. The shale has at best been poorly exposed and at present is scarcely accessible. A few identifiable graptolites found indicate the Zone of *Pleurograptus linearis*.

THE SEQUENCE IN THE LOWER ALLOCHTHON OF JÄMTLAND

Lars Karis

Tremadoc In places where black shales are strongly folded or tectonically disturbed, it is difficult to distinguish between Upper Cambrian and Tremadoc shales. However, in several areas the presence of the Tremadoc has been proved. The recorded maximum thickness of the Tremadoc black shales is about 5 m but mostly the thickness is less than 1.5 m; whether these figures represent the primary thickness or not cannot be safely established. In the Dictyonema Shale only the Zone of *Dictyonema flabelliforme* has been proved, with *D. flabelliforme*, *Bienvillia wimani* and *Boeckaspis mobergi*. In the Moholmen section, central Storsjön area, the presence of the Upper Tremadoc Ceratopyge Shale (Zone of *Platypeltoides incipiens*) is indicated by *Peltocare* cf. *norvegicum* and *Parabolinella* n.sp. (with a pronounced ocular ridge) (Karis, unpublished).

Recently a thin (0.3 m) black bituminous limestone was found between the Upper Cambrian dark shale and the Latorp Limestone in a road-section about 1 km west of Oviken new church, south-west Storsjön area. The fossil content has still to be fully studied, but appears similar to the Upper Tremadoc at Moholmen (Karis, unpublished).

Latorp Limestone In the Lower Allochthon of Jämtland, the Lower Arenig Latorp Limestone is generally thin. It varies from about 1.5 m in the south-west Storsjön area (Österåsen and Fjällsågen, 10-15 km west of Oviken) to about 0.5 m in the Andersön section. This unit seems persistent across large areas and can be identified in sections as far west of the Caledonian thrust front as Föllinge and at localities on the western shore of Storsjön 20 km due west of Östersund. In the eastern Lower Allochthon the zones of *Megistaspis* (*Ekeraspis*) *armata* and *Megistaspis* (*Varvaspis*) *planilimbata* are present, while in the western sections (Andersön) only the former has been recognised (Tjernvik 1956). The base of this limestone is glauconitic in many localities.

Töyen Shale This shale is apparently developed throughout the Lower Allochthon and in places attains an estimated thickness of about 15 m. The shale facies evidently began earlier in the Lower Allochthon than in many areas of the Autochthon. The zones of *Tetragraptus phyllograptoides* and *Didymograptus balticus* have been recorded from Andersön (Tjernvik 1956), where higher zones are probably missing. In adjacent localities, graptolites of the Zone of *Didymograptus hirundo* have been found (e.g. the Bynäset section, west Frösön, 7 km west of Östersund). The Töyen Shale occurs through a comparable interval in the south-west Storsjön area (Österåsen and Svartbodarna road, west of Oviken).

The dating of this unit is generally difficult since the shale is strongly folded and cleaved, and fossils can only be obtained from a very few levels. Specimens of the trilobite *Gog* have been found at several localities, (e.g. at Sanne, Hackås and on Andersön (Fortey 1975) and Frösön, from the zones of *Tetragraptus phyllograptoides* and *Phyllograptus densus*).

Isö Limestone The grey, generally thick-bedded, calcilutitic Isö Limestone is widely distributed in the Lower Allochthon, from the lowermost nappes in the east, to the vicinity of Ås and Aspås in the western part of the central Storsjön area, and Föllinge north of Östersund (similar, undated rocks appear in the antiforms west of Åre). The type area is the island of Isön, in Storsjön immediately south-west of Andersön. There the whole sequence is strongly folded, in parts inverted, but without any major breaks. The upper and lower boundaries, with the Andersö and Töyen Shales respectively, are exposed. The estimated thickness is about 40 m.

Only a few levels within the Isö Limestone have yielded diagnostic faunas. The basal part of the limestone in the type area falls within the Zone of *Didymograptus hirundo*, and in a nodular calcilutite about 5 m above the base, trilobites from the Zone of *Asaphus (Asaphus) expansus* have been recovered. In the uppermost 2 m of the Isö Limestone, *Paraceraurus exsul* (Beyrich) and *Pseudomegalaspis patagiata* (Törnquist) are common, indicating beds equivalent to the Folkeslunda Limestone. The Isö Limestone has the same age range throughout most of the central Storsjön area.

To the north of Östersund in the Lower Allochthon of the eastern Häggenås area, the Holen, Segerstad, Folkeslunda and lower Dalby equivalents can be recognized within the Isö Formation in the Örån section upstream of the road to Storhögen. An almost identical development is seen in the Autochthon of Högfors section (Stop 3:4) about 3 km south-east of Häggenås.

In the south-west Storsjön area the thickness of the Isö Limestone decreases rapidly. Across a distance of approximately 2 km within a tectonic unit, the thickness changes from about 12 m to 1.2-0.8 m; in sections through the same interval about 800 m further north-west, the unit is missing. This thinning-out can be seen from the village Kläppe along the road to Svartbodarna, about 12 km WNW of Oviken. The thin limestone wedge is rich in macrofossils (trilobites, brachiopods), which indicate the Zone of *Asaphus* (*Asaphus*) *expansus* (Karis, unpublished). To the west the limestone is replaced by the Föllinge Turbidites.

Andersö Shale This formation, formerly termed Ogygiocaris Shale, is widely distributed in the Lower Allochthon. In the type area on the northern shore of Andersön the formation rests on the probable Folkeslunda equivalent of the Isö Limestone. According to Hadding (1913) the lower part comprises a dark shale with limestone lenses (Zone of *Glyptograptus teretiusculus*, about 6 m), the middle is dark, bedded limestone (1.5-2 m), and the upper part is dark shale with lenses of limestone and sandy intercalations becoming particularly common towards the top (more than 10 m; Zone of *Nemagraptus gracilis* and Zone of *Dicranograptus clingani* in the upper part). The identification of the Zone of *Dicranograptus clingani* has been questioned and seems improbable.

West, north-west and north of the central Storsjön area the shale is generally thinner. The Zone of *Glyptograptus teretiusculus* is the most widely developed. Throughout the outcrop area, the formation commonly shows graded bedding indicating turbidite sedimentation. The thinly laminated units of the central Storsjön area represent more distal turbidites. Limestone lenses or layers commonly separate graded units on Andersön and Norderön. On Andersön and especially on northern Norderön, cycles of graded siltstone 1-5 cm thick occur throughout the sequence. On Norderön there are also thicker cycles 10-15 cm thick in the lower part, and a few beds of greywacke 0.5-0.8 m thick in the upper part of the formation. On Norderön channel-fillings, 1 m wide and filled with cross-bedded coarse silt, have been observed. The turbidite sedimentation in the Andersö Shale appears to be related to the Oviken and other antiforms (see also Föllinge formation).

In the beds of the Zone of Glyptograptus teretiusculus some limestone lenses are rich in shelly macrofossils, particularly trilobites such as Ogygiocaris sarsi regina Henningsmoen, O. sarsi lata Hadding, Pseudomegalaspis patagiata (Törnquist), Nileus sp., Botryoides bronni (Sars), Triarthrus humilis Hadding, Robergia microphthalma (Linnarsson), and Telephina (Telephina) bicuspis (Angelin). In the lower part of the Zone of Nemagraptus gracilis, the dark bedded limestone contains a mixed shelly and graptolite fauna, characterized by Telephina (Telephops) biseriata (Asklund) and was previously referred to as Biseriata Limestone. From the shaly equivalents of the Zone of Nemagraptus gracilis, Ogygiocaris sarsi lata, Botryoides efflozescens (Hadding), Robergia microphthalma, Telephina (Telephops) granulata (Angelin) and other trilobites have been recorded.

In the area west and north-west of Hammerdal, 30-40 km north of Östersund, a sequence of dark shales resting on Isö Limestone has recently been shown to contain graptolites of the Zone of Didymograptus murchisoni, and thus comparable to the Upper Didymograptus Shale. However, on lithological criteria this shale is difficult to distinguish from the Andersö Shale and it is mapped within this formation. The fairly soft shale is isoclinally folded throughout the area. In sections along a road south-east of Björvallen, 12-15 km west of Hammerdal, the thickness of the unit is estimated to be at least 12 m. There are indications of a comparable shale in the lower part of the Lower Allochthon in the Östersund area. The lateral facies relationships of the shales with limestone and turbidite developments are not yet studied (L. Karis, unpublished).

The upper boundary of the Andersö Shale is at present difficult to define. In some areas the shale is overlain by Dalby equivalents (see below) while in other areas, for example at Lugnvik in Östersund, the Andersö Shale grades into the Örå Shale without an intervening limestone (Stop 3:6).

Dalby equivalents On the islands of Frösön and Andersön, and probably also on Verkon farther to the west, the Andersö Shale is overlain by a limestone unit of argillaceous bedded and nodular calcilutites. The lower, bedded part is very poor in fossils whereas the upper, nodular limestone has yielded fossils indicating a correlation with the upper Dalby Limestone. The limestone is overlain by Örå Shale. In the western Lit-Häggenås area, about 15 km north of Östersund, the Andersö Shale is overlain by bedded, dark grey limestone with distinct argillaceous intercalations. The limestone, at least 5.4 m thick, contains *Asaphus* (*Neoasaphus*) cf. *ludibundus* and *Echinosphaerites aurantium*. The apparently limited distribution of upper Dalby equivalents may chiefly be a reflection on the generally poor exposure through this interval.

At Lugnvik (Stop 3:6), the complex of bentonitic beds, which in the central confacies belt marks the boundary between the Dalby and Skagen Limestones, occurs within a continuous sequence of dark shales. A few tephra layers from the same complex have recently been recorded in the Örån section (Stop 3:3).

Örå Shale The Örå Shale consists of dark grey to black, partly calcareous, silty, graptolitic shale with intercalations of dark grey limestones. In the type section, about 100 m downstream from the bridge where the Storhögen road crosses the river of Örån (Häggenås area; Stop 3:3), the unit is at least 9 m thick. The lower boundary is not exposed, and the contact with the overlying Slandrom Limestone is obscured by folding and thrusting. In the central Lockne area, shales of similar lithology and fauna overlie Dalby Beds, and there are also largely comparable relationships in the Lower Allochthon.

The Örå Shale occurs widely in the central and northern Storsjön areas without significant lithological variation. Thorslund (1940) used the term Upper Chasmops Beds for this unit. Its equivalents in the Siljan district and in Östergötland are the Skagen and Moldå topoformations.

A silty shale-mudstone in approximately the same stratigraphical position as the Örå Shale occurs beyond the area where the Slandrom Limestone is developed (e.g. at Lugnvik, Stop 3:6 and localities 15 and 25 km north-west of Lugnvik). However, the stratigraphical range of this mudstone facies is uncertain, and it may incorporate equivalents to the Fjäcka, Slandrom and upper Dalby Formations. For practical purposes these shales are included in the Kogsta Formation.

The graptolite fauna in the Örå Shale indicates the Zone of Dicranograptus clingani (Thorslund 1940 recorded the index fossil itself) and possibly also the upper part of the Zone of Diplograptus multidens. Trilobites are not uncommon in the interbedded limestones, particularly Triarthrus linnarssoni Thorslund, Ampyxella cf. aculeata (Angelin), and others.

Slandrom Limestone The lithology is similar to that in the autochthonous sequence. In the Lower Allochthon the Slandrom Limestone occurs mainly in two regions, in the Skute and Lit-Häggenås areas. In intermediate areas the corresponding portion of the sequence is developed as a dark silty shale with thin intercalations of dark limestone. At Örån the thickness of the formation is 7.3 m (Thorslund 1940).

Föllinge greywackes and turbidites The formation is composed of a monotonous sequence of greywackes and silty mudstones, mostly showing graded bedding (Stop 4:2). In some areas the thickness is in the order of several hundreds of metres. The formation has its maximum development and coarsest sediments (locally including conglomerates) in the south-west, around the Oviken antiform, and in the north towards the Olden and other antiforms (Förlling-Holmsö area north of Östersund and in the Tåsjö area, north Jämtland and south Lapland). Between these areas is a belt extending roughly from Östersund to Offerdal along Lake Näldsjön in which equivalent beds are considerably finer grained.

The oldest dated Föllinge beds occur east of the Oviken antiform. At Iffelnäs, approximately 4 km south-east of Hallen church, basal Föllinge greywackes resting on the Töyen Shale have yielded graptolites of the Zone of Phyllograptus angustifolius elongatus. On the road from Kläppe to Svartbodarna, approximately 12 km WNW of Oviken, the Föllinge beds rest on Töyen Shale of Didymograptus hirundo Zone age. Over large areas the Föllinge turbidites are divided by a tongue of Andersö Shale (mainly the Zone of Glyptograptus teretiusulus) into a lower and an upper part. The tongue of shale can be seen at Hallen church, 28 km west of Östersund, and about 10 km west of Föllinge, where it divides the Föllinge turbidites into parts of approximately equal thickness. In the transition from turbidites to shaly siltstones of the Kogsta Formation in the Mattmar area a fossiliferous shale is developed. This shale development has not been observed elsewhere. The shale is less than 10 m thick, and graptolites indicate the Zone of Diplograptus multidens. In the Alsen area 15 km north of Mattmar and 3 km north-west of Kogsta the transition from the Föllinge greywackes to the Kogsta Siltstone covers about 3 m of beds, and the basal Kogsta Formation has yielded graptolites indicating the Zone of Dicranograptus clingani.

Kogsta Siltstone In the west the Kogsta Siltstone rests on the Föllinge turbidites, and is developed as a monotonous sequence of dark, shaly siltstones, about 30-40 m thick. The type section is in the Alsen area, about 12 km south-west of Offerdal, where the basal part of the formation has yielded graptolites indicating the Zone of Dicranograptus clingani and the top is overlain by the Ede Quartzite. Recent collections here suggest that the upper Kogsta beds contain a Hirnantian brachiopod fauna (M.G. Bassett, pers. comm.), and similar faunas are now known from several localities across the Lower Allochthon. About 12 km south-west of Ånge, Tretaspis seticornis and Diplograptus pristis have been found in the lower part of the Kogsta Formation.

In western areas where the Slandrom Limestone is developed, silty Kogsta beds rest directly on the limestone. However, in eastern areas (e.g. in the railway section at Stengårde, Skute area), a dark shale is developed above the Slandrom Limestone and within the basal Kogsta Formation. This shale is equivalent to the Fjäcka Shale and the higher siltstones are roughly equivalent to the Jonstorp Formation in the Siljan district, except that they probably also include beds of early Hirnantian age.

The lower Kogsta Formation in siltstone facies is mostly poor in fossils; in addition to Tretaspis seticornis and Diplograptus pristis, it includes

Tretaspis latilimbus (Linnarsson) and Dionide euglypta (Angelin). The upper part of the formation is known to contain Dalmanitina (Mucronaspis) mucronata (Brongniart) together with Hirnantian brachiopod faunas.

Within the Upper Ordovician part of the Kogsta Siltstone a conspicuous limestone unit is developed locally. It has its maximum development in and immediately north of Östersund. In the north-eastern outskirts of Östersund Dicellograptus complanatus has been recorded from underlying beds which suggests that the limestone may be roughly equivalent to the Öglunda Limestone of the Jonstorp Formation.

The Kyrkås and Ede Quartzites Coarse quartzite siltstones of two different developments conclude the Ordovician sequence. The Kyrkås Quartzite occurs in the east; its westernmost occurrences are at Landsom, approximately 15 km north-west of Östersund, and on the islands of Andersön and Frösön. The main development of the Ede Quartzite is in the west; a similar thin quartzite unit is known from south-east of the westernmost occurrences of the Kyrkås Quartzite, for example at Stengårde in the Skute area. West of its major outcrop area, Ede quartzite is present below the Middle Allochthon Åre amphibolites. Törnebohm's (1896) interpretation of nappe displacement in Jämtland involved his recognition of this quartzite unit here.

The maximum known thickness of the Kyrkås Quartzite is 45 m. Of the 35 m at Rannåsen (Stop 3:5), at least the lower 15 m is Ordovician. The formation is composed mainly of grey, thin bedded, coarse, quartzitic siltstones with intercalations of fine, shaly siltstone. The bedding is disturbed by occasional shallow channels filled with mudflake conglomerates. Sedimentary structures include oscillation and current ripples, megaripples in some thicker bedded portions of the sequence, cross-bedding and mud cracks. At Storhögen, west of Kyrkås, large-scale slumping has been observed about 12 m above the base of the formation.

The Ede Quartzite (Stop 4:1) is a much thinner unit, usually not more than 6 m thick. Generally its lower part, 1.5 to 2 m thick (rarely up to 3.8 m, e.g. Mattmar), is a bluish-grey, massive (primarily thick bedded) quartzite. The upper part consists of thin bedded siltstones, quartzites and limestones, showing sedimentary structures such as cross-bedding and ripples.

The stratigraphical relationship between these two clastic formations has been disputed. The Kyrkås Quartzite has been regarded as partly Ordovician and partly Silurian, and Ede Quartzite as exclusively Silurian (Thorslund in Thorslund & Jaanusson 1960). Recently, useful marker horizons have been discovered which aid in the correlation. The markers consist of three or (westwards) more beds of porphyry-rich sediments. North-west of Offerdal and above dated Kogsta Siltstone there are coarse porphyry-rich sandstones and conglomerates among dark bedded quartzites, the Rönnöfors Conglomerate, best exposed at Rönnöfors (20 km north-west of Offerdal) where its total thickness is 10-15 m. The marker horizons appear to be feather-edge deposits derived from the same source, fining and thinning towards the east. At Ede and other nearby localities, the markers occur as argillaceous intercalations in the uppermost 0.5 m of the Kogsta Shale and in the basal metre of the Ede Quartzite. In the Kyrkås Quartzite they are developed in the basal part (e.g. in the Storhögen Quarry 1.5 km west of Kyrkås) at a level below the fossiliferous siltstone with Dalmanitina (Mucronaspis) mucronata and Brongniartella sp. as developed at Rannåsen (for fauna, see Stop 3:5) (L. Karis, unpublished). Thus the basal parts of the Ede and Kyrkås Quartzites appear to be roughly contemporaneous. The available evidence indicates that the Ordovician-Silurian boundary falls within both the Kyrkås and Ede Quartzites, but the level of the boundary is at present difficult to define.

It was supposed previously that the silt and sand of the Kyrkås Quartzite was supplied from a land area east of the Autochthon. However, recent studies indicate that the sediment for both the Kyrkås and Ede Quartzites was, to a great extent, derived from local western sources (L. Karis, unpublished).

JÄMTLAND ROAD-LOG

Lars Karis and Kent Larsson

2:4 MÅLINGEN (Loc. 1, Fig. 1) Outcrops along minor road about 1 km ESE of the Näcksta farms, 2.5 km east of Hackås. Topographical map sheet 18 E, Hackås NO 697970/143675.

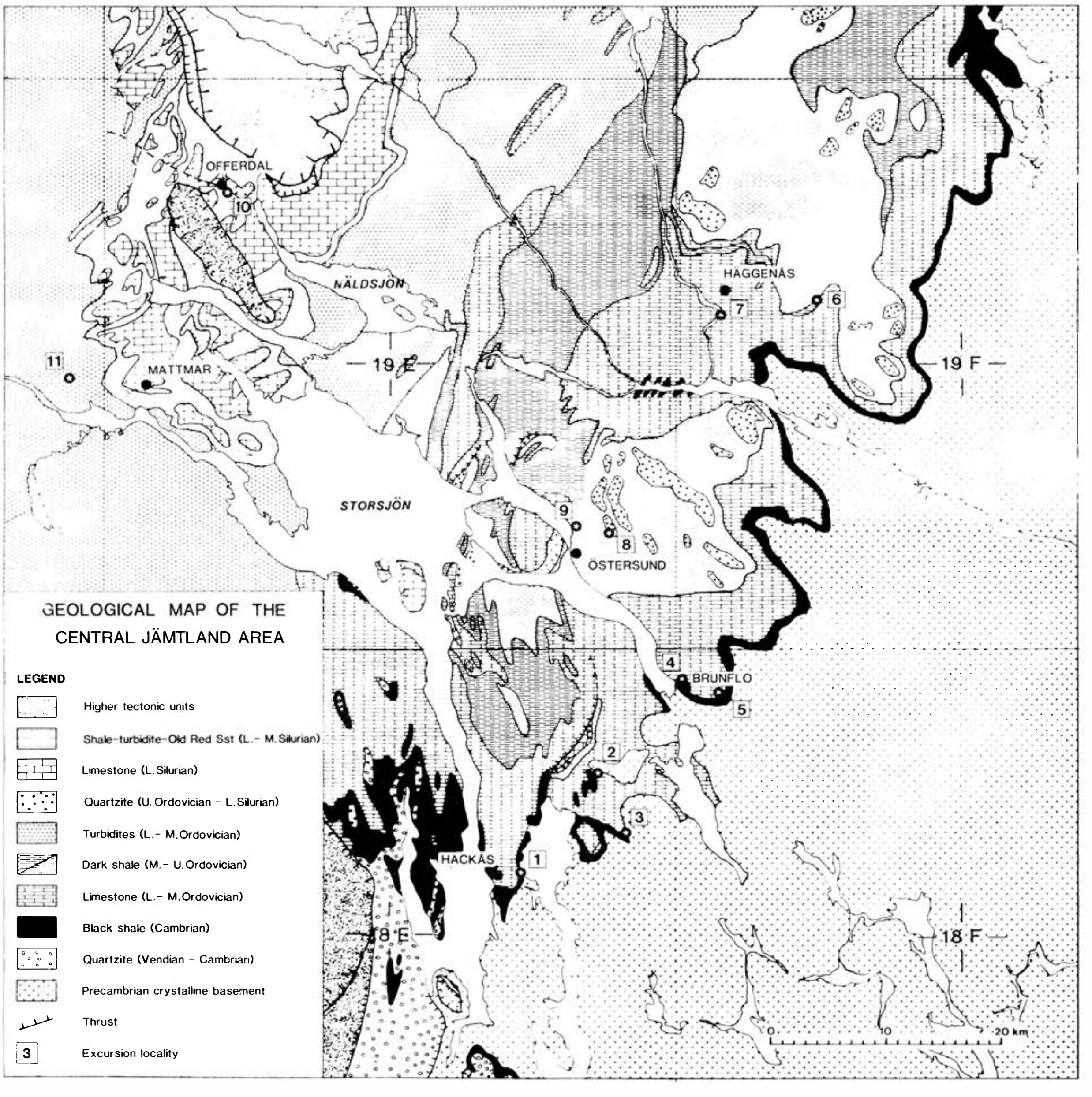
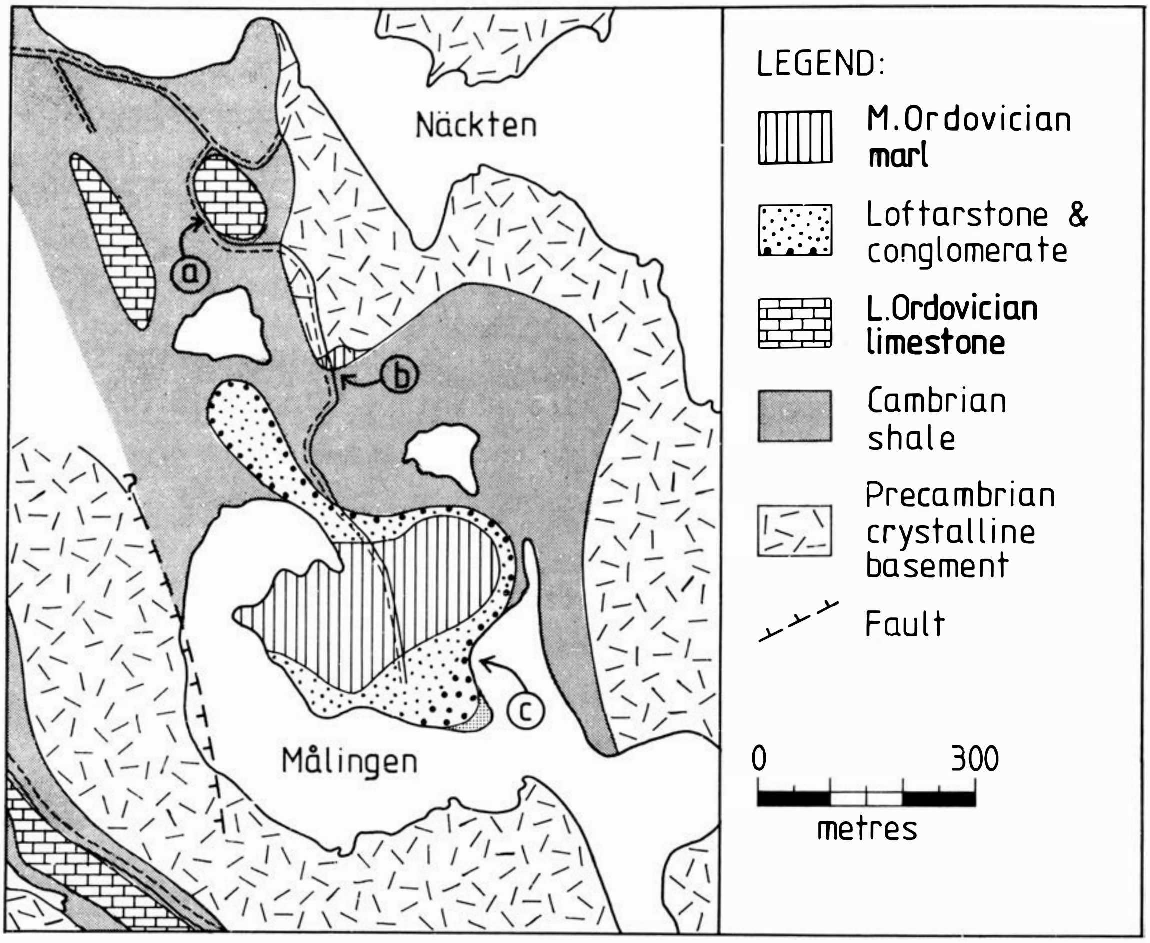


Figure 1. Simplified geological map of central Jämtland based on one of the areas currently being prepared by the Geological Survey of Sweden. The boundary between the Autochthon and Lower Allochthon is not indicated.

At locality (a) on Fig. 2 (redrawn with minor modifications from Thorslund 1940, p. 63, Fig. 37), on the north side of the road, grey-green and dark Middle Cambrian shales with occasional limestone lenses are overlain by bituminous limestones and black shales with an upper Middle Cambrian (Paradoxides forchhammeri Stage) and Upper Cambrian (Agnostus pisiformis, Olenus and Parabolina spinulosa zones) fauna. Lower Ordovician limestones overlie the P. spinulosa Zone stinkstones. Following the section about 20 m to the south-east along the road, these limestones are downfolded into the Middle Cambrian shales. The hinge of the syncline in the limestones is well exposed with a fold axis N 20^{o} E, a steep west limb, a flat east limb and development of a prominent cleavage.

About 50 m south-east along the road, the P. spinulosa Zone is overlain by Lower Ordovician bedded limestones and Middle Ordovician limestone-pebble conglomerates. At locality (b) of Fig. 2, the irregular surface of the granitic Precambrian basement is exposed. The palaeorelief appears to have been in the order of 15-20 m in the Målingen area, with Cambrian shales filling the deeper pockets in the basement and Ordovician limestones, conglomerates and mudstones being deposited on the higher parts. Locally, on the east side of the road (east of Högtjärn), marly shales and limestones equivalent to the Dalby Limestone were deposited directly on the weathered granitic basement. These relationships are interpreted as indicating the existence of an archipelago in the Målingen area from the Middle Cambrian to the Late Ordovician which caused extensive deposition and reworking of the Ordovician strata. On the road to locality (c) of Fig. 2 are a number of small exposures of Cambrian shales and stinkstones ranging in age into the P. spinulosa Zone.

At locality (c) along the north shore of Målingen, dark Cambrian shales are overlain by Lockne conglomerates. Clasts in the latter are usually composed of Lower Ordovician limestones; they decrease in size upwards and pass into the so-called 'Loftarstone' within the Lockne formation (Thorslund 1940), a fine to medium-grained calcareous sandstone derived from the Lower Ordovician limestones and underlying granitic basement.



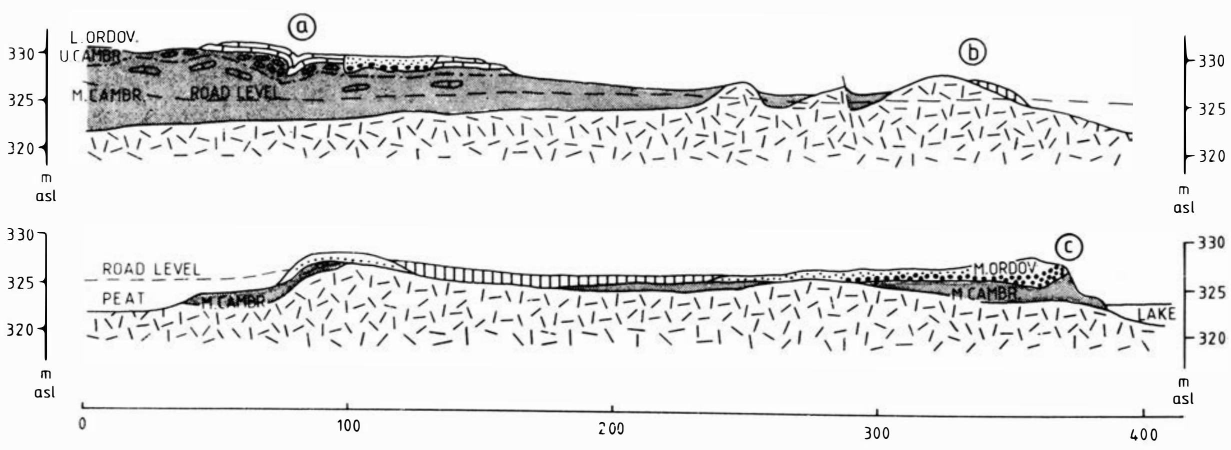


Figure 2. Geology of the area around Målingen. From Gee & Kumpulainen 1980.

2:5 KLOXÅSEN (Loc. 3, Fig. 1) Exposures along the road at the Kloxåsen farm. Topographical map sheet 18 E Hackås NO 698430/144445.

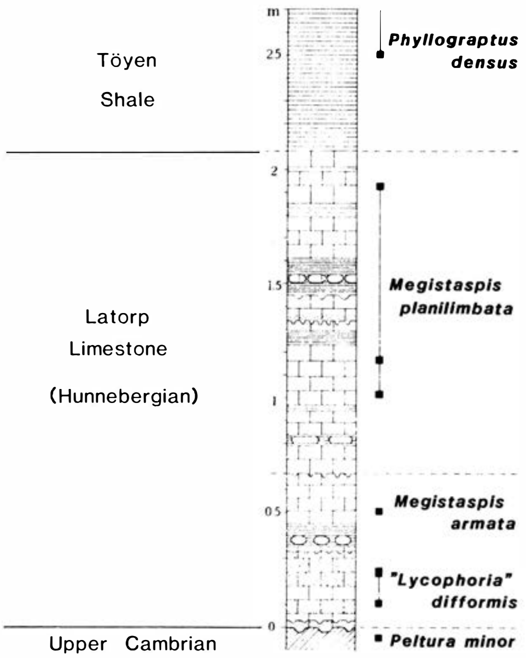


Figure 3. Section through the Lower Ordovician at Kolxåsen (after Tjernvik 1956).

Road section through Middle and Upper Cambrian shales overlain by Lower Ordovician Latorp Limestone and Töyen Shale. The stratigraphy of the Ordovician rocks occur in NW-SE trending synclines which plunge at about 5^{o} to the north-west. The area is situated on the south-western slope of the Lockne basement high.

In addition to the index species, the Zone of Megistaspis (Varvaspis) planilimbata has yielded Megalaspides (Lannacus) nericiensis Wiman, Promegalaspides (Borogothus) stenorhachis (Angelin), Niobella bohlini Tjernvik, Cyclopyge gallica Tjernvik and other trilobites (Tjernvik 1956).

2:6 TAND (Loc. 2, Fig. 1) Road cuts on the north side of the main-road (81), about 11 km south of Brunflo. Topographical map sheet 18 E Hackås SO 698910/144355.

The Precambrian basement surface in the Lockne area is approximately 70 m higher than the peneplain to the south-west and north-east. Various Ordovician sediments were deposited on this basement high and the conglomeratic facies contains clasts of most of the underlying units, including basement lihtologies, Cambrian shales and stinkstones, and Lower and Middle Ordovician limestones.

The Tand locality comprises two sections 200 m apart. These two sections demonstrate the upper Kundan—lower Aserien sequence and the type of deformation commonly found at the transition zone between the Autochthon and Lower Allochthon.

The westernmost road-cut exposes steeply dipping beds of reddish-brown Holen and Segerstad Limestones. The exact level of the Lower—Middle Ordovician boundary is not determined, but it may be assumed to occur within a 1.33 m thick limestone sequence between the last occurrence of the Kundan Megistaspis (Megistaspidella) gigas and the earliest Aserian Asaphus (Neoasaphus) platyurus. The Segerstad Limestone consists of reddish-brown, bedded and nodular, fine-grained limestone with occasional coarse-grained limestone beds. Some haematite-stained discontinuity surfaces are developed, The top of the sequence consists of a polymict conglomerate, the Kullstaberg Conglomerate. This unit forms a significant intraformational horizon in many parts of the Lockne area. The pebbles consists of red and grey Lower/Middle Ordovician limestones and Precambrian granite, all in a reddish-brown, calcareous matrix. The exposed Aserian sequence measures about 4 m in thickness.

The second, easternmost road-cut demonstrates beds of Skärlöv, Seby and Dalby ages. The eastern half of the section comprises a slightly overturned sequence which is overthrust onto a brecciated granite. The oldest unit in this part of the section is a reddish-brown nodular limestone with grey intercalations. This unit may be comparable to the Skärlöv Limestone. The contact between this unit and the beds immediately west of it occurs in badly dislocated strata. The top of the Skärlöv Limestone is concordant with a dark grey, coarse-grained, fossiliferous limestone with haematite-stained stromatolites. The rich trilobite fauna, including Illaenus chiron, Pseudomegalaspis patagiata, Pseudobasilicus? brachyrachis, combined with the lithological properties, indicate a Seby age of this unit. It is succeeded by a thin, grey limestone and 0.5 m of nodular, reddish-brown, fine-grained limestone. Their stratigraphical position is uncertain, but they can probably also be referred to the Seby Limestone. The uppermost (eastern) part of the inverted sequence consists of a polymict conglomerate containing pebbles of reddish-brown and grey limestone and granite. The pebble size increases upwards. This unit can be referred to the Lockne Conglomerate.

The western part of the section exhibits a grey, dense limestone comprising the eastern limb of a small N-S anticline. Overlying this limestone is a strongly polymict conglomerate which partly seems to cut into the limestone. This conglomerate contains pebbles and boulders of grey limestone, alum shale, granite and dolerite. The largest boulder observed is 24 x 15 cm in cross-section. The matrix of the conglomerate is grey and calcareous. No fossils indicating the age of the described westernmost part of the road-cut have, so far, been found, but the strata may be assumed to belong to the Dalby Beds.

3:1 BRUNFLO (Loc. 4, Fig. 1) Section along the main road E 75 in the north-western part of Brunflo. Topographical map sheet 18 E Hackås NO 699793/144980.

This is the only section through a lower part of the Holen Limestone easily accessible at present. The very locally flat-lying grey nodular calcilutite with subordinate bedded units represent an interval 1.8-c. 6 m above the Lanna/Holen boundary, previously exposed in additional sections towards the east. The exposed interval belongs to the basal part of the Zone of _Asaphus_ (_Asaphus_) _expansus_ and the overlying Zone of _A._ (_A._) '_raniceps_'.

The fauna at the base of the section is dominated by trilobites including _Asaphus_ (_A._) _expansus_ and closely related species, _Ptychopyge augustifrons_, _Niobella_ sp. and ostracodes such as _Glossomorphites_, _Aulacopsis_ and _Conchoprimitia_. The Zone of _A._ (_A._) '_raniceps_' contains trilobites, cephalopods, brachiopods, bryozoans and ostracodes.

3:2 LUNNE (Loc. 5, Fig. 1) Quarry on the hill-top Lundbomberget, about 2 km north-east of Brunflo church. Topographical map sheet 18 F Bräcke NV 699700/145320.

This abandoned quarry cut in slightly undulating Ordovician strata exposes a section from the uppermost Kundan, through the Aserian Segerstad Limestone, Lasnamägian Seby and Folkeslunda Limestones and is terminated by the polymict Lockne Conglomerate of upper Dalby age. Most of the Folkeslunda Limestone and the conglomerate are accessible in a narrow trench. Immediately above, on the top of the hill, some small exposures of the Dalbyan 'Loftastone' sandstone have been observed previously. Nowadays only loose boulders can be seen. The exposed sequence demonstrates clearly the weak folding and overthrusting which may be seen in this part of the Autochthon. Some small overthrusts are visible on one of the walls in the middle of the quarry. Many bedding planes also show slickensides which indicate W-NW tectonic direction.

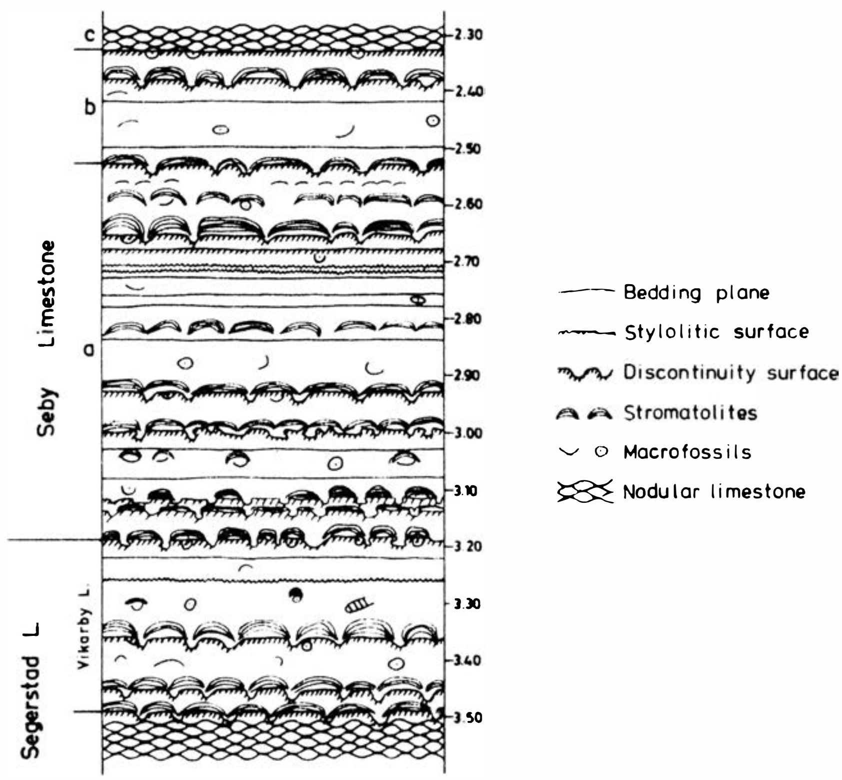


Figure 4. Section of the upper Segerstad and Seby Limestones in the Lunne section to show the distribution of stromatolitic algal mats (from Larsson 1973).

<u>Description of the section (from the top downwards)</u> (see also Fig. 4; Jaanusson, Larsson & Karis, Fig. 1)

Lockne Conglomerate 2.0 m +
Polymict conglomerate with pebbles of Lower/Middle Ordovician limestone and Precambrian granite. The size and sphaerocity of the pebbles increase upwards. The matrix is dark grey and calcareous .... 2.0 m +

Folkeslunda Limestone 0.99 m
Grey to dark grey, fine-grained limestone .... 0.99 m

Seby Limestone 2.22 m

(c) Finely nodular, fine-grained, variegated pale reddish-brown to reddish-grey limestone .... 1.36 m

(b) Grey, thick-bedded, coarse-grained limestone with stromatolites. Two dessiccation surfaces occur, 5 and 20 cm from the top. The top is a smooth discontinuity surface .... 0.20 m

(a) Grey to brownish-grey, thick-bedded, coarse-grained limestone with numerous stromatolites strongly stained with haematite. Numerous dessication surfaces occur. The lower boundary is formed by an uneven discontinuity surface .... 0.66 m

Macrofauna of (b) and (a): Illaenus chiron, Pseudobasilicus? brachyrachis, Pseudomegalaspis sp., Pseudoasaphus tecticaudatus, Plectasaphus plicicostis, Asaphus (Neoasaphus) sp., Remopleurides sp., Lituites sp., 'Conorthoceras' conicum, Ancistroceras sp.

Segerstad Limestone 6.12 m

Vikarby Limestone. Grey and red mottled, coarse-grained limestone, rich in haematite-stained stromatolites. The uppermost surface is irregular with overhanging portions. Parts of the surface show dessication polygons with cephalopods arranged along the cracks. The lower boundary is very rough and irregular. It is covered by a stromatolitic algal mat stained by haematite. Illaenus planifrons, Remopleurides sp., Geisonoceras? centrale, Cameroceras sp., Dorsolinevites dispar. .... 0.30 m

Kårgärde Limestone. Alternating beds of reddish-brown, fine-grained, bedded and nodular limestone. The uppermost bedding surface is rough and irregular with overhanging portions. Irregular, haematite-stained discontinuity surfaces occur 2.30, 5.28 and 5.30 m below the top. The two lowermost surfaces are covered by small stromatolitic domes, intensely haematite stained. The lowermost boundary of the Segerstad Limestone is placed immediately above the last find of Megistaspis (M.) gigas. Asaphus (Neoasaphus) platyurus, Remopleurides sp., Angelinoceras latum, 'Orthoceras' nilssoni .... 5.82 m

Holen Limestone 0.8 m +

Brownish-red, thick-bedded, fine-grained limestone. Megistaspis (Megistaspidella) gigas .... 0.8 m

3:3 ÖRÅN (Loc. 6, Fig. 1) Section along the western side of the stream Örån, approximately 100 m south of the bridge on the Storhögen road. Topographical map sheet 19 F Häggenås NV 703003/146255.

Scattered outcrops of the same units as those exposed in the main section occur in the vicinity clearly indicating a continuous isoclinal (shales) open (massive limestone) fold system approximately parallel to the stream. The sequence here is generally younging eastwards. In the partly excavated section three formations are exposed, in ascending order the Örå Shale, Slandrom Limestone and Kogsta Siltstone. There is a general dip of strata towards the south-west and the Örå Shale occupies the larger part of the section.

The Örå Shale has an estimated thickness of 9 m, of which approximately 6 m is exposed in this section. This unit, or parts of it, is repeated several times in the slope, and twice in the exposed section. The upper boundary is obliterated by a thrusted fold axis. The Örå Shale is here very fossiliferous throughout. There is a strong domination of graptolites and inarticulate brachiopods in the lower part but a mixture of graptolites and trilobites (Triarthrus) in the upper 2 m of the unit.

The most common graptolites are Dicranograptus clingani, Amplexograptus vasae, Corynoides sp., Amplexograptus cf. pulchellus, Climagraptus cf. brevis, Neurograptus margaritatus, Orthograptus sp. and Climacograptus bicornis. The most common trilobites are Triarthrus linnarssoni and Triarthrus skutensis. It should also be noted that four very thin metabentonites occur in the lower part of the Örå Shale.

Above the disturbed contact there follows a very thin (less than 10 cm) strongly compressed black shale and the Slandrom Limestone. The Örån section is one of the best exposures of this unit. The basal part is nodular calcilutite, 0.6 m thick, with argillaceous intercalations followed by bedded calcilutites with shaly interbeds and a grey, finely nodular calcilutite. The uppermost metre of the unit is again a bedded calcilutite. Very few fossils have been found in this formation although Tretaspis cf. seticornis has been recorded from the uppermost part.

The contact with the overlying poorly exposed Kogsta Siltstone is sharp and is probably tectonic. No fossils have been found in this unit at this locality.

3:4 HÖGFORS (Loc. 7, Fig. 1) River exposures about 3 km south-east of Häggenås church. Topographical map sheet 19 F Häggenås NV 70295/14542.

Large exposures of flat-lying and folded autochthonous Lower and Middle Ordovician limestones occur around the River Hårkan below the dam at Högfors. The river has cut down several metres into the limestone.

The limestones are mainly grey, but some reddish tints are present in the lower Segerstad and upper Kundan Limestone. Most beds are calcilutitic. The macrofauna is very sparse and so far only one specimen of Asaphus (Neoasaphus) platyurus has been found, indicating the presence of the Segerstad Limestone. Of special interest is the presence of oncolites. These attain a diameter up to 6 cm and are formed around small limestone fragments and are strongly stained with haematite. Some beds are almost completely composed of the oncolites. At the bottom of the oncolite-bearing horizon some stromatolitic algal mats have been observed. One deeply corroded discontinuity surface forms the top of the basal oncolite-bearing bed.

South of the visited exposure, dislocated beds of Dalby Limestone and Middle-Upper Cambrian shales occur. The latter are overthrust onto the limestones.

3:5 RANNÅSEN (Loc. 8, Fig. 1) Quarry, about 3.5 km NE of Östersund. Topographical map sheet 19 E Östersund NO 701020/144425.

This operational quarry is cut in a folded and faulted sequence, composed predominantly of quartzites, dark shales and mudstones which belong to the Kyrkås Formation of Ashgill and possibly of early Silurian age. The exposed sequence is about 35 m thick. The lower part of the sequence includes two prominent dark mudstone units, 1.30 m and 3.30 m, separated by two beds, 0.75 and 0.17 m thick, of a lighter calcareous siltstone. The upper half of the quarried sequence is composed of massive quartzite and alternating beds of dark shale and quartzite.

The Kyrkås Formation shows a variety of sedimentary structures characteristic of shallow water environments. The lower mudstone contains bedding surfaces with mudcracks, ripple marks and load casts. A thin conglomeratic horizon occurs within this mudstone with pebbles of quartz and granite. This bed is no longer exposed. The quartzites are commonly cross-bedded.

The lower mudstone unit has yielded Hirnantian fossils, including the trilobites Dalmanitina (Mucronaspis) mucronata and Brongniartella platynota, Leptaenopoma trifidium and other brachiopods, lamellibranchs, cephalopods and hyolithids. The upper mudstone has yielded Climacograptus, which were previously thought to be of early Silurian age (Thorslund in Thorslund & Jaanusson 1960). Current studies on these graptolites show that the age relationship of the upper Kyrkås Beds remains open.

3:6 LUGNVIK (Loc. 9, Fig. 1) Exposures at the railway, about 2 km north of central Östersund. Topographical map sheet 19 E Östersund SO 701057/144156.

In this area, north of Östersund, a new traffic system (road and railway) was constructed from 1976 to 1978, giving excellent exposures of the bedrock over large areas. In the remaining section on the railway the uppermost Andersö Shale and the Örå Shale are exposed in a gently folded sequence. The temporary sections exposed an almost complete sequence from the Isö Limestone (south-west Lugnvik) to the Öglunda Limestone (north-west Lugnvik) in a distance of approximately 1 km.

The two units in the visited section are very similar in lithology, although the Örå Shale is richer in minor silts and carbonates. The boundary between these two units has been placed at the base of the thickest metabentonite occurring in this section. Thus the Andersö Shale has a wider stratigraphic range here than on the islands of Frösön, Andersön and Norderön, where a limestone unit (Dalby equivalent) separates the two.

The beds below the metabentonite are at present poorly exposed and strongly compressed. In the Örå Shale, however, very fossiliferous beds occur and contain the same fauna as in the Örån section but with additional elements including hyolithids, inarticulate brachiopods (common in some beds) and sponge spicules.

The Slandrom Limestone is completely absent here; in sections towards the north-west the shaly siltstone sequence continues into the Zone of *Pleurograptus linearis* within the Kogsta Siltstone.

4:1 EDE (Loc. 10, Fig. 1) Exposures on the south-eastern side of a small hill, about 1 km south-east of Offerdal church. Topographical map sheet 19 E Östersund NV 704020/141115.

This is the type locality for the Ede Quartzite (Thorslund in Thorslund & Jaanusson 1960). The quartzite is well exposed towards the top of the hill which is capped by the Silurian Berge Limestone. The dark Ashgill Kogsta Siltstone underlies the quartzite. The sequence dips gently north-west and is folded and cleaved. It is thought to be thrust over the Berge Limestone which is exposed at the road along the eastern base of the hill (Thorslund in Thorslund & Jaanusson 1960).

The Ede Quartzite is composed of 2-3 m of bluish-grey and white quartzites which pass upwards into calcareous sandstones with thin shales. The latter in turn pass gradationally into the Berge Limestone which contains a Lower Llandovery fauna. The cross-bedded and ripple-bedded Ede Quartzite contains corals and brachiopods in the calcareous upper part but has not as yet yielded a diagnostic fauna. Transitional relationships with the Berge Limestone suggest an early Llandovery age.

The dark shales and mudstones of the Kogsta Siltstone underlying the Ede Quartzite contain thin sandy beds and laminations in the uppermost part. A number of pale grey, thin laminations are composed of talus from porphyritic rocks. The contact between the Kogsta Siltstone and the Ede Quartzite is sharp and the latter concordantly overlies the shales. A Hirnantian fauna occurs 1-6 m below this contact with, mostly decalcified, brachiopods, trilobites and crinoid ossicles.

4:2 MÖRSIL (Loc. 11, Fig. 1) Roadsection on E 75, about 4 km east of Mörsil. Topographical map sheet 19 D Åre SO 702430/149590.

This exposure shows a typical development of the Lower to Middle Ordovician turbidites of the Föllinge Formation, each cycle consisting of 8-40 cm coarse silt and sand grading in to 2-10 cm fine silt and clay (shale). It also demonstrates the style of deformation in this unit, with gentle N 20° W plunging folds. In general the beds young north-eastwards.

Rare pendant didymograptids in the eastern part of the section indicate a stratigraphic interval of the *Didymograptus bifidus*—*D. murchisoni* zones.

THE LØKKEN-HØLONDA-STØREN AREAS

David L. Bruton and J. Fredrik Bockelie

INTRODUCTION

The region around Løkken, Hølonda and Støren, south and south-west of Trondheim (Fig. 1) is classical ground for the interpretation of the Lower Palaeozoic stratigraphy of western Trøndelag. In fact it is the only area in the entire Caledonian belt in which fossils are present in sufficient number, variety and preservation to allow detailed palaeontological and stratigraphical work. Even so, knowledge of the faunas is still incomplete and fossil localities so far recorded are limited to a narrow east-west belt from Løkken to Hovin, a distance of approximately 30 km. The fossils are Ordovician in age and include graptolites (Blake 1962; Berry 1968; Skevington 1963), brachiopods (Reed in Kiær 1932; Neuman & Bruton 1974), trilobites (Strand 1948; Neuman & Bruton 1974), cephalopods (Foerste in Kiær 1932), echinoderms (Bockelie 1974) and conodonts (Bergström 1971, 1979). Early Ordovician (Arenig-Llanvirn) shelly faunas are of North American type, while the graptolites show strong Australian affinities and a zonal scheme based on this has been introduced by Skevington (in Ryan et al. 1980). These facts led Wilson (1966), Dewey (1969) and Dewey et al. (1970) to suggest a two-fold division of the Scandinavian Caledonides into eastern and western parts, each developed independently on opposite sides of a proto-Atlantic (Iapetus) Ocean. The junction between the two is now represented by a major low angled thrust (Nicholson 1971) separating the Gula and Støren nappes (Fig. 1). Evidence for the two-fold division is structural (Nicholson 1971, 1979), faunal (Bruton & Harper 1981) and geo-chemical (Gale & Roberts 1974). Basaltic greenstones in the area of Løkken and Hølonda have been interpreted as representing either a marginal or a major ocean basin (Pearce & Gale 1974; Grenne et al. 1980), while a back-arc volcano-sedimentary basinal environment has been inferred for the overlying Lower and Upper Hovin Groups (Bruton & Bockelie 1980). However, there is no

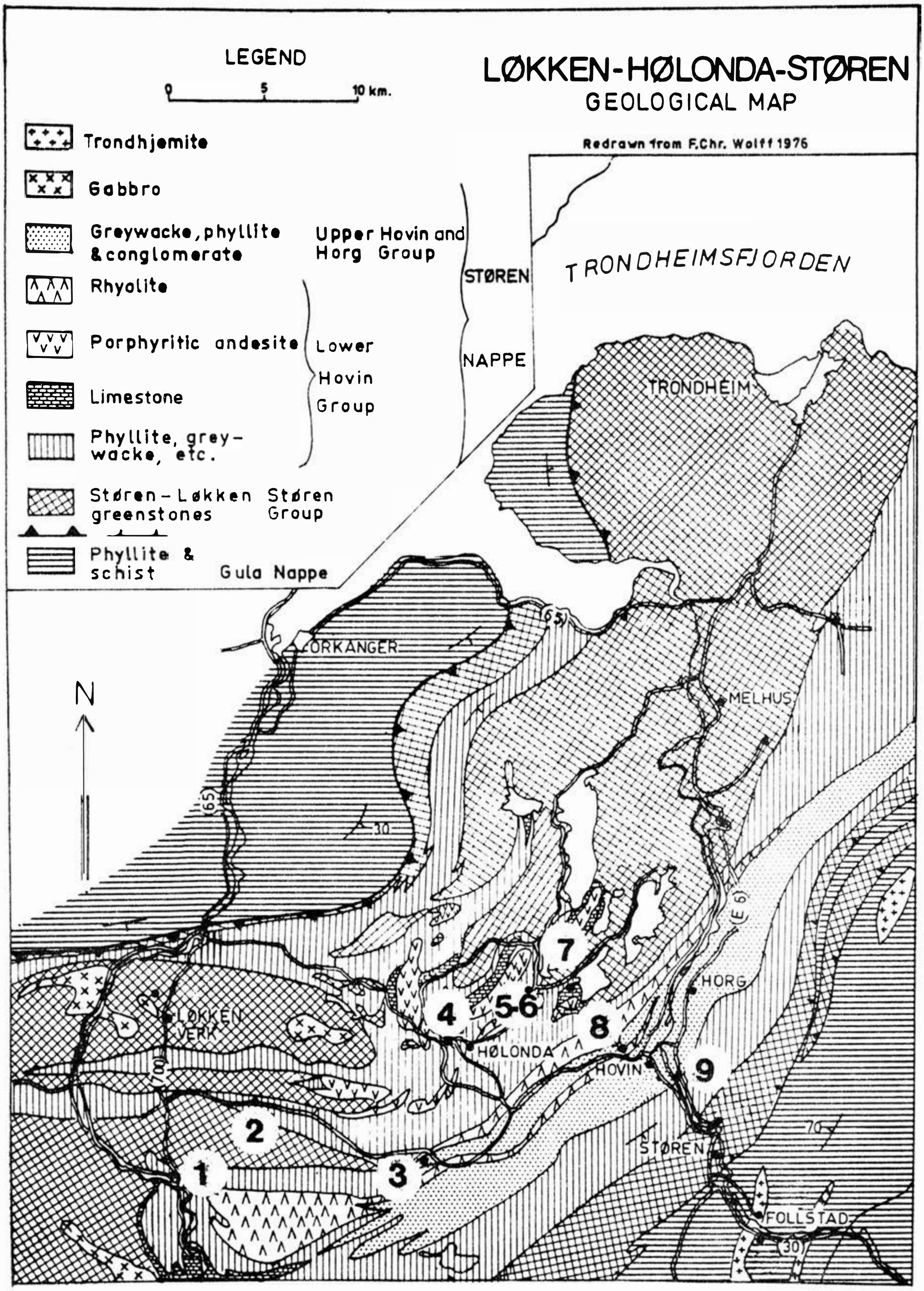


Figure 1. Geological map of the excursion area with marked stops (Modified after Gee & Wolff 1981).

WESTERN TRØNDELAG - STØREN NAPPE	
HORG GROUP	Greywackes and conglomerates (age uncertain)
UPPER HOVIN GROUP	Greywackes and conglomerates. Subord lst and rhyolitic tuffs. (Mid Ordovician and possibly younger)
LOWER HOVIN GROUP	Black phyllites greywackes and conglomerates. Andesites and rhyolites. Limestones. Basal volcaniclastic conglomerates. (Mid Arenig to Upper Caradoc)
STØREN GROUP	Pillow lavas, cherts and very subord. phyllites. Other units of ophiolites (sheeted dykes and layered gabbro) also present locally. (pre-Mid Arenig)
GULA NAPPE COMPLEX	

Figure 2. Stratigraphy of the Støren Nappe (modified after Gee & Wolff 1981).

agreement on the direction of subduction related to the development of the basin. The North American affinity of the fossils suggests westward-dipping subduction, while the reverse has been suggested by Ryan _et al_. (1980) because the Lower Hovin Group sediments are considered to contain continental detritus derived from the margin of Baltoscandia. Recent geochemical studies by Roberts (1980) suggest deposition in a basin marginal to Baltoscandia or to a ? microcontinent with associated back-arc spreading. These apparently conflicting interpretations need further examination.

STRUCTURE

The structure of the area is complex and a variety of interpretations are illustrated in Fig. 3. Recent work shows that the basaltic greenstones in the Løkken area occur in a synformal anticline which can be followed further west (Grenne _et al_. 1980). In the Hølonda area, Vogt (1945) considered the structure to be a simple syncline with the sedimentary rocks capped by the Hølonda porphyrites (andesites). Bockelie & Bruton (1980) have shown all sedimentary units to be diachronous and the andesites to be penecontemporaneous intrusions and extrusions. The rocks strike NE-SW, folds being overturned towards the south-east. A series of low-angled thrusts occur, running parallel or cross-cutting the strike and separating distinct sedimentary units from the north-west to south-east. A major thrust, identified by the authors (t-t, Fig. 4), separates

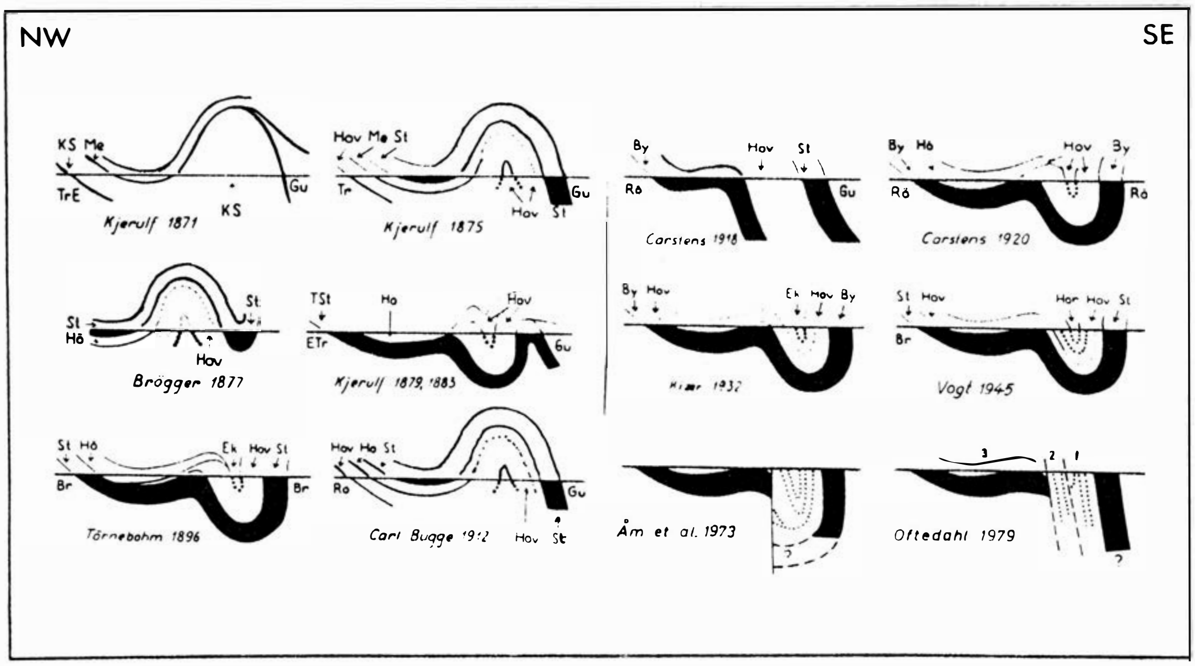


Figure 3. Historical review of structural interpretation in the Hølonda-Horg-Støren region (see Vogt 1945). Gu - Gula Group; St - Støren Group (black); Hov (3,1) - Lower and Upper Hovin Groups; Hor (2) - Horg Group. (After Gee & Wolff 1981)

the succession of Arenig-Caradoc rocks in the north-west form a younger Caradoc-Ashgill succession in the south-east. These two units are recognised by Oftedahl (1980) who agrees that they are separated by a thrust and are not limbs of what was formally known as the Horg Syncline.

STRATIGRAPHY OF THE STØREN NAPPE

Vogt (1945) divided the succession into four series, now known as the Støren, Lower Hovin, Upper Hovin and Horg groups (Figs. 2, 6), separated from each other by conglomerates marking three diastrophic events. He also identified a number of formations which have since been redefined and modified by Chaloupsky (1970). Mapping carried out by the present authors has shown that many of Vogt's formations in the Lower Hovin Group are diachronous (Fig. 5) and that the Upper Hovin Group belongs to a separate thrust unit.

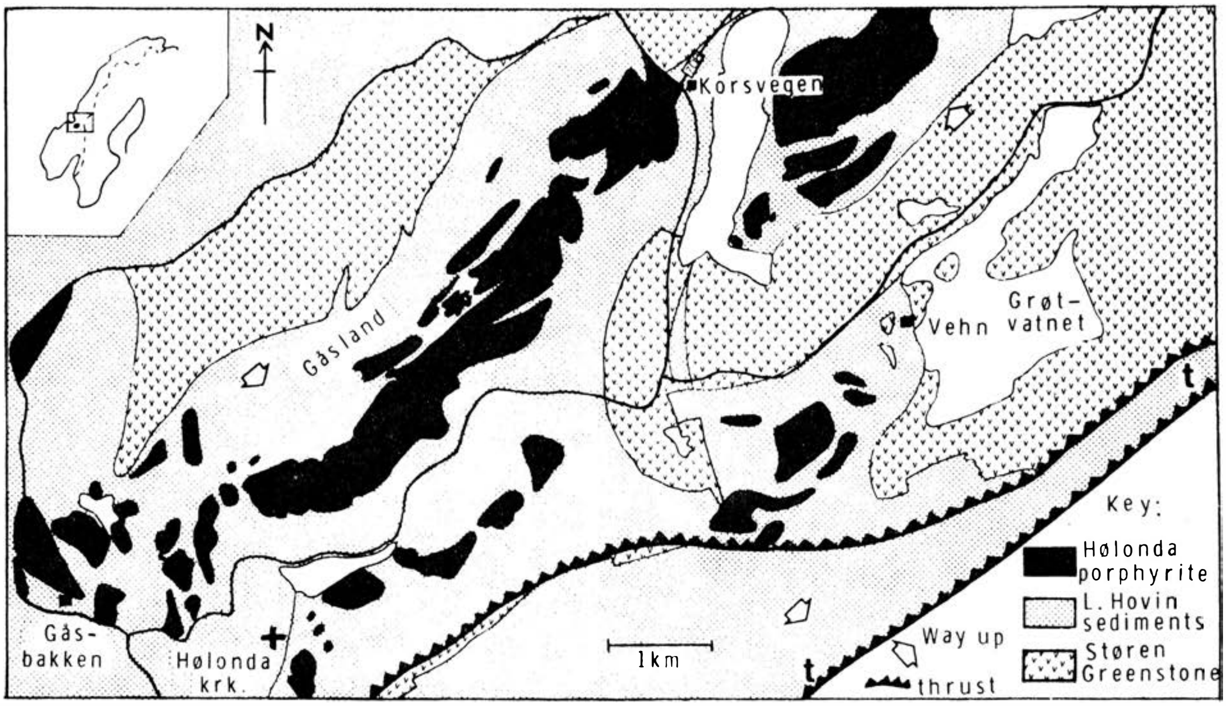


Figure 4. Simplified geological map of the Hølonda area based on the authors' own mapping. Inset map shows position of area in the Trondheim region. Many of the contacts between Støren Greenstone and Lower Hovin sediments are tectonic. Major faults are indicated by dashed lines. Line t-t is a major thrust separating the succession of Arenig-Caradoc rocks in the north-west from a younger Caradoc-Ashgill succession in the south-east. (After Bruton & Bockelie 1980.)

The Støren Group is about 3 km thick and is dominated by basaltic lavas of tholeiitic composition and ocean floor affinities. Pillow basalts are common and the association of cherts, sheeted dykes and layered gabbros allows the recognition of part of an ophiolite suite (Grenne *et al.* 1980). The copper mineralisation of the Løkken Mine is associated with these rocks. Some authors correlate the basalts in the type area of Støren with those at Løkken and regard both to be of pre-middle Arenig age (Furnes *et al.* 1980), while others, including Ryan *et al.* (1980), regard the Løkken unit as middle to late Arenig. This is based on associated graptolite bearing shales in the Meldal area south and west of Løkken (Fig. 6).

In the Hølonda area, Bruton & Bockelie (1980) have shown that folding, accompanied by uplift and erosion of the Støren Group, allowed the formation of locally thick conglomerates prior to deposition of sediments of the Lower Hovin Group. Rapid changes in sediment type and thickness suggests that local faulting produced NE-SW troughs in which the conglomerates were deposited. The conglomerates contain blocks of the immediately underlying greenstones and cherts but towards the top, red conglomeratic sandstones have been interpreted as being of continental origin (Vogt 1945) or near shore shallow marine (Furnes *et al.* 1980).

The Lower Hovin Group Bruton & Bockelie (1980) have shown that erosion of the greenstones in the Hølonda area continued at the same time as black graptolitic shales, including the Bogo Shales, were being deposited 20 km farther west. The top of the Bogo Shale is topmost Arenig (late *Didymograptus hirundo* Zone) and is equivalent in age to part of the Hølonda Limestone dated using trilobite-brachiopod associations (Neuman & Bruton 1974) and conodonts (Bergström 1979).

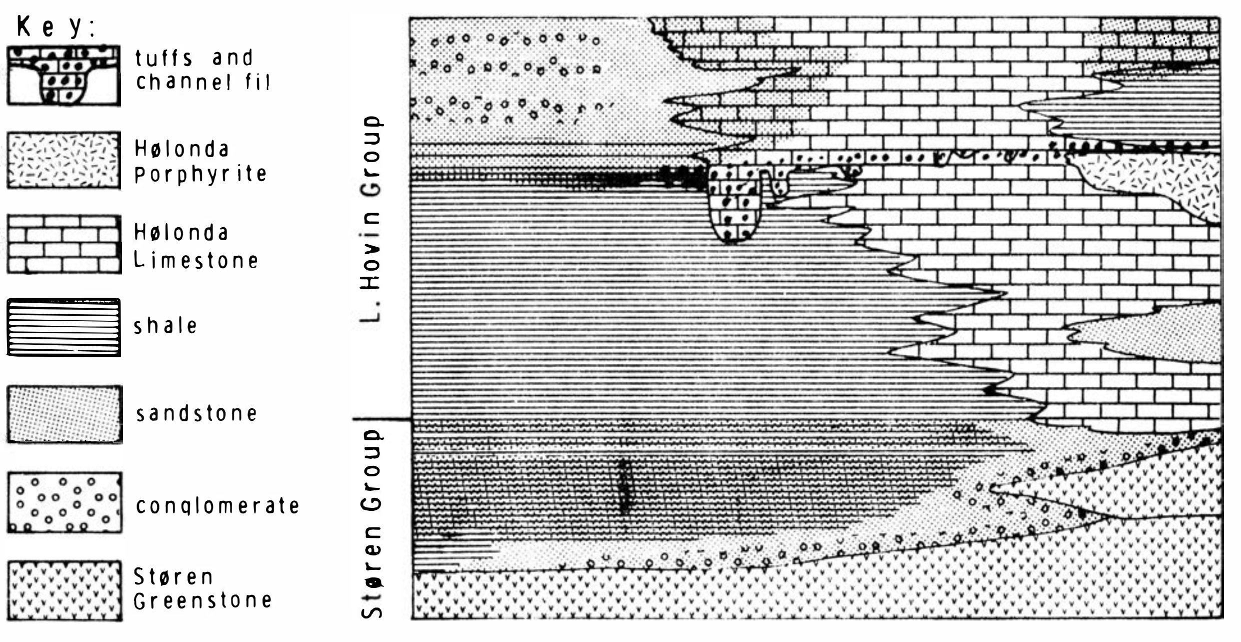


Figure 5. Lithostratigraphic synthesis of Lower Ordovician (Arenig-Llanvirn) rocks in the Hølonda area. Note the complex facies changes in the Lower Hovin Group. Silt influx is shown in shales and limestones where appropriate. (From Bruton & Bockelie 1980.)

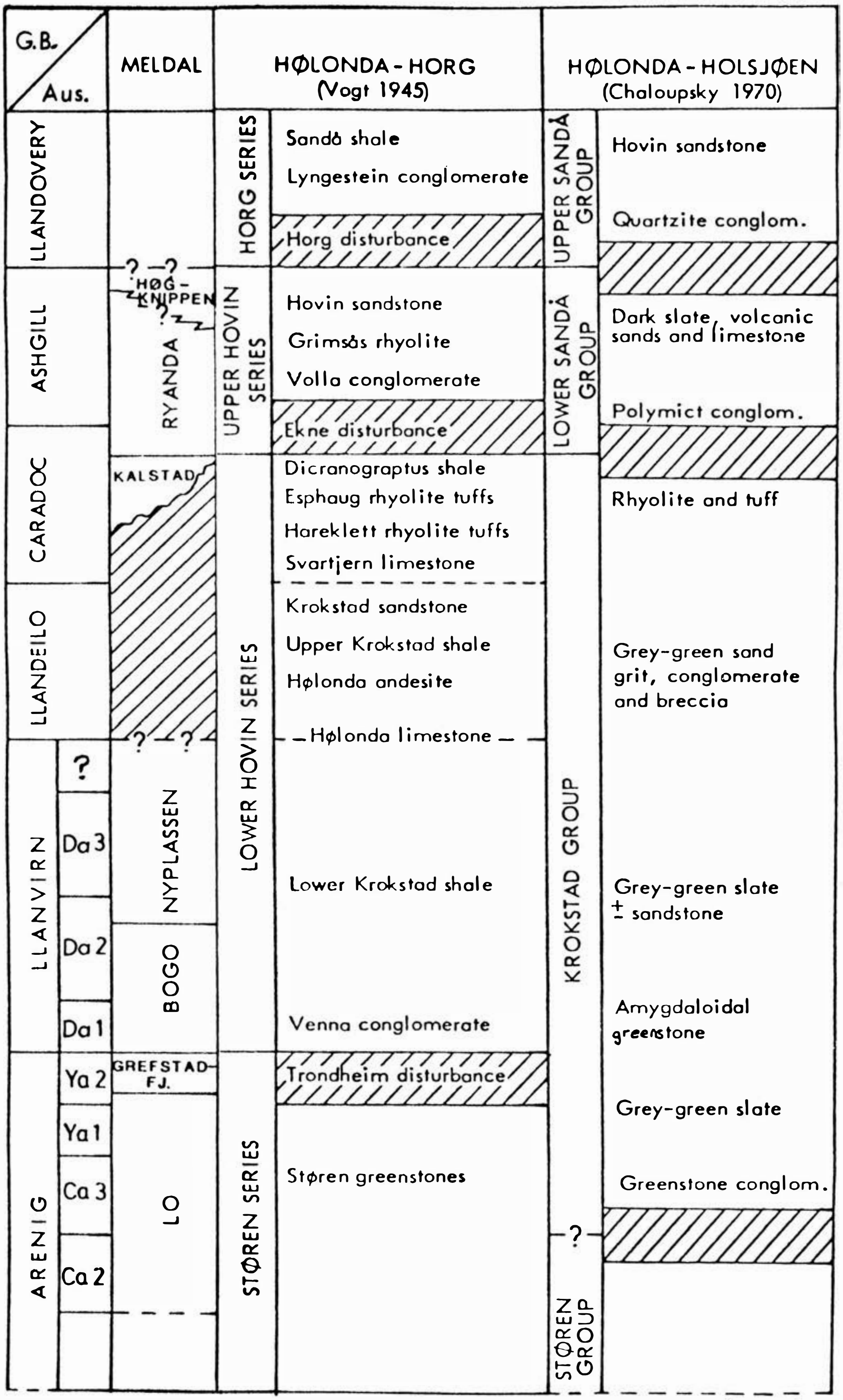


Figure 6. Stratigraphical schemes for the region based on Ryan et al. (1980), Vogt (1945) and Chaloupsky (1970). Modified from Ryan (MS).

A series of limestones, including the Hølonda Limestone, were deposited locally around 'greenstone islands' with a succession of deeper water sediments off-shore. In addition, penecontemporaneous intrusion of the Hølonda andesites caused uplift and island formation in previously deeper areas of the basin. Both limestone breccias and limestone-andesite conglomerates filled channels off these volcanic islands (Fig. 7).

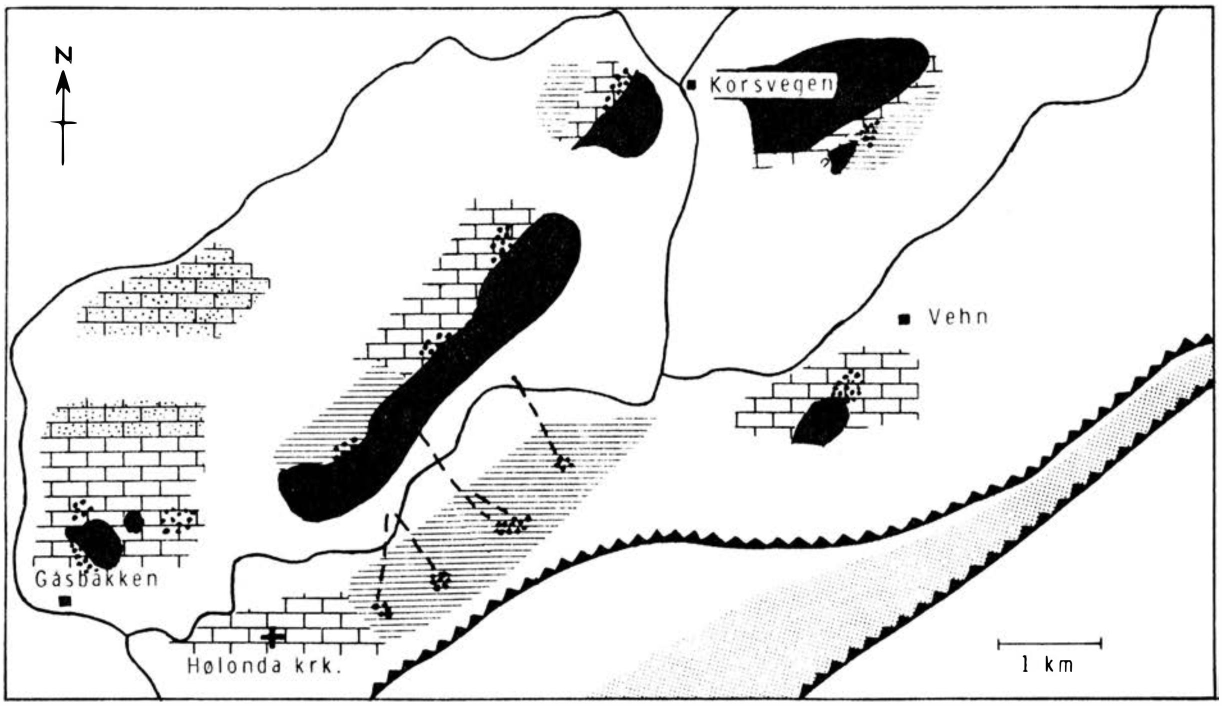


Figure 7. Simplified palaeogeographic map for the early Ordovician (Arenig-Llanvirn) of the Hølonda area after the formation of the Hølonda Porphyrite (black). Those porphyrite bodies shown formed local islands around which the different sediment types were deposited. Erosional channels (direction illustrated by dotted lines), filled with blocks of porphyrite, extend from some of the islands out into the deeper shaly parts of the basin. Note the deposition of clastic sediments on the northwestern and southeastern margins of the basin. Symbols as in Fig. 5. (From Bruton & Bockelie 1980)

Fossils in sediments pre- and post-dating intrusion of the andesites show that the geological evolution of the island arc system (Fig. 8) took place in a relatively short period of time from late Arenig to early Llanvirn (Bruton & Bockelie 1980).

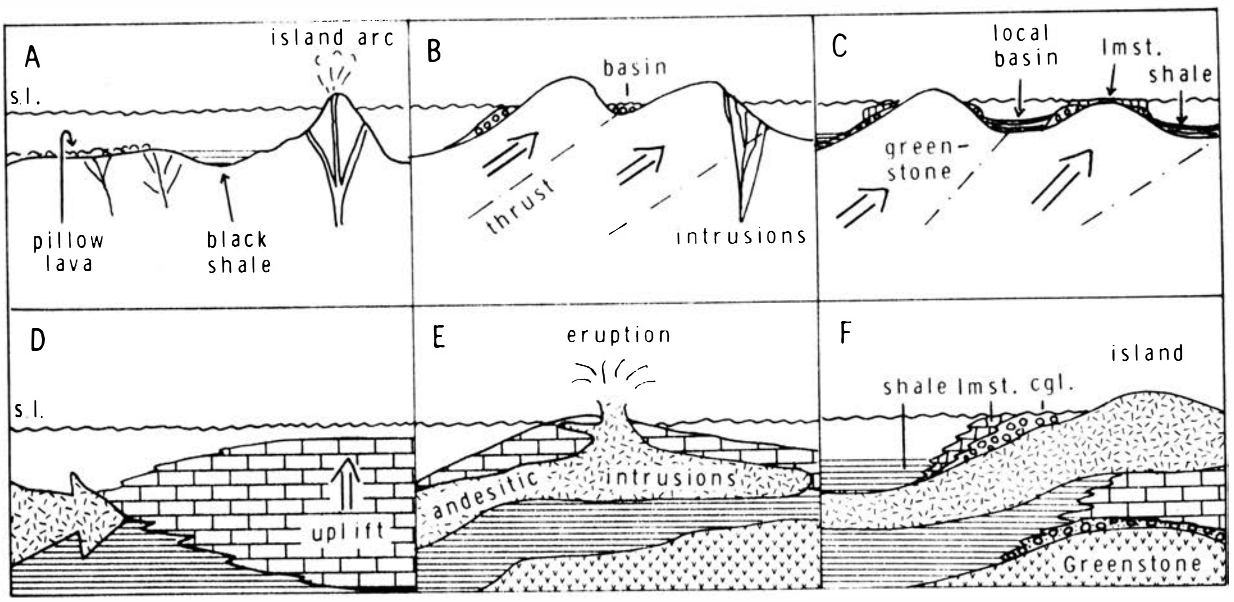


Figure 8. Geological evolution of the Hølonda area during the early Ordovician (Arenig-Llanvirn). A, Pre-Arenig. Ocean floor spreading with the formation of pillow lavas (Støren Greenstones) and an immature island arc. B, Middle Arenig. Uplift associated with thrusting and erosion of the greenstones and arc, and formation of local basins. C-F, Late Arenig - early Llanvirn. C, Development of local basins. D, Injection of some Hølonda porphyrites with formation of explosive breccias, tuffs and islands. Shape of bodies possibly influenced by the underlying sediments, greenstones and reactivated thrusts. F, Erosion of islands and formation of concentric facies belts. (From Bruton & Bockelie 1980)

Younger brachiopod faunas of possible Caradoc age occur between Løkken and Hølonda in successions previously mapped as Lower Hovin Group, although they may belong to the Upper Hovin Group. Graptolites belonging to the Dicranograptus clingani Zone (late Caradoc) have recently been identified from shales below the Volla Conglomerate which defines the base of the Upper Hovin Series at the type locality north of Støren.

The Upper Hovin Group consists of a succession of greywackes, intraformational conglomerates, limestones, light coloured volcaniclastic sandstones, rhyolites and rhyolitic tuffs, which are best seen near Hovin. Some units contain brachiopods suggestive of a Caradoc age, while one might be Ashgill (Neuman, written comm. 1981). All localities yielding Caradoc and younger faunas are on the lower, south-east side of a major thrust (t-t, Fig. 4) separating older rocks to the north-west.

In the Meldal area (Fig. 6) a lime-mud mound, known as the Kalstad Limestone, is in contact with the Løkken greenstones (Ryan *et al*. 1980). Ryan (pers. comm.) regards the contact to be an erosional unconformity, while the present authors believe it to be a fault contact. Brachiopods from bedded sediments associated with the carbonate mound suggest a Caradoc age for these while crinoid ossicles and the corals (Kiær 1932) suggest an Ashgill one.

The Horg Group The status of this group is uncertain (Chaloupsky 1970) and the age is uncertain. The unit consists of greywackes and shales (phyllites) with a monomict quartz conglomerate at the base. No fossils have been recorded from the area and the once supposed Llandovery age (based on correlation with the Slågån Group in Meråker 80 km to the north east) is far from certain.

ROAD LOG

Leader: J. Fredrik Bockelie (assisted by Robert B. Neuman, Bjørn Wandås and Olaf Schmidt)

5:1 MELDAL (1521 III Løkken, 360915). Section on north side of road. 1 km north of Meldal.

This section, described in detail by Kiær (1932, p. 17), is an inverted sequence, dipping north. The bedded limestones and tuffaceous shales, known as the Kalstad Limestone (Ryan *et al*. 1980), are thought to be of Caradoc-Ashgill age. At the south end of the outcrop (top of sequence) dark weathering, tuffaceous shales are underlain by alternating nodular limestones and shales, separated by a minor thrust from the more compact coral, algal bryozoan limestone. Stratigraphically below, a small roadside limestone quarry contains silty beds which have yielded fragments of a trinucleid trilobite. Stratigraphically down section, a thick series of silty shales contain abundant crinoid ossicles of ?Ashgill age (Bockelie in prep).

About 800-1000 m to the north-west, a shale, underlying a massive partly brecciated limestone, contains a brachiopod fauna, including *Dalmanella* sp., *Dinorthis*, *Glyptorthis*, *Rafenesquina* and *Sowerbyella* (Neuman pers. comm. 1981).

5:2 BOGO RIVER (1521 II Hølonda, 396964). East side of bank, Bogo river, 20 m downstream from the waterfall.

This locality, first reported by Blake (1962), has since become widely known because it yields one of the few Pacific Province, Early Ordovician graptolite faunas in Europe (Berry 1968; Ryan *et al*. 1980). The graptolites occur in the black, rusty-weathering Bogo shales. Massive, resistant tuffs form prominent features and thinner, well bedded tuffs, often calcareous, occur within the black shales at this locality and at another about 75 m down stream on the west bank of the river. Cooper (1973) reported the occurrence in the Bogo Shale of Isograptus caduceus australis, a species characteristic of the Australian Yapeenian Stage which is generally correlated with the Didymograptus hirundo Zone. Other graptolites include: Tetragraptus bigsbyi (Hall), Isograptus caduceus spp and Didymograptus similis (Hall).

The section has recently been cleared by dipl. geol. Olaf Schmidt (University of Göttingen) who will be present to explain his work.

5:3 SVARTSÆTRA (1521 II Hølonda, 494922). Section in track leading to Svartsætra.

This section shows at least 140 m of tuffs, interbedded with fossiliferous grey limestone, pale weathering shales and dark banded siltstones. The limestones contain gastropods, a rugose coral and algal structures. The shales contain abundant crinoid ossicles together with brachiopods including Dalmanella sp., Glyptorthis sp., Leptaena sp., P. multicostella sp., Oxoplecia sp., Skenidioides sp. and Sowerbyella sp. (Neuman pers. comm. 1981). This succession occurs on the south-east side of the major thrust which crosses the area. The relationship of the limestone at Svartsætra to the Kalstad Limestone in the west and the Hølonda Limestone in the north is unknown. The fauna suggest a Caradoc age.

5:4 GÅSBAKKEN (1521 II Hølonda 507986). Road section 500 m east of Gåsbakken.

This locality shows well-bedded Hølonda Shales overlying Hølonda Limestone and penecontemporaneous porphyrites. The massive limestone contains blocks of porphyrites near the base, but is intruded by porphyrite near the top. At Trotland, approximately 2 km to the north-west, the limestone contains a rich trilobite, brachiopod and crinoid fauna (Neuman & Bruton 1974) of Arenig-

Llanvirn age. The limestone is diachronous and varies considerably in thickness in the Hølonda area (Bruton & Bockelie 1980).

5:5 ALMÅS (1521 II Hølonda 552012). Road-section 600 m south-west of Stenset cross-roads.

A recent road-cut showing more than 200 m of well-bedded, dark siltstone. The coarse tuffs contain scour markings and graded bedding is common. These beds belong to the Hølonda Shale and are thought to have been deposited in the deeper portion of a small basin. From this locality, observe the distinctive hills of Högåsen and Middagsåsen, formed of porphyrite, with Lower Hovin sediments in the lower ground.

5:6 STENSET (1521 II Hølonda 553013). North-west side of road Hølonda-Kvål, at Stenset cross-roads.

This stop, 600 m north of Stop 5, shows a small outcrop of Gaustadbakk breccia (Vogt 1945), thought by the leaders to be basal sediments, eroded from and deposited on the Støren Greenstone Complex. The beds consist of alternating green and red conglomeratic siltstones containing bands of red jasper and greenstone clasts. The sediments show cross-bedding and grading, indicating way-up to the north. No fossils are known from these beds. The locality is next to a major NW-SE trending fault.

5:7 KATUGLEÅSEN (1521 II Hølonda 566008). South side of hill. Steep climb (15 mins).

This locality was first described by Brøgger (1875) and has since yielded a rich, shelly fauna (Kiær 1932; Strand 1948) consisting of trilobites, brachiopods, gastropods and cephalopods from the Hølonda Limestone which forms the top and steep southern slope. Recently, a new brachiopod assemblage has been identified by R.B. Neuman in cleaved calcareous siltstones near the base of this section. These siltstones form a good marker horizon and can be traced westwards at least 1 km along strike to Damtjernet, 0.6 km south-west of Vehn farm.

The brachiopods (Neuman pers. comm. 1981) include:
Aporthophyla stoermeri Neuman, 1974
"Chonetoidea" triangularis Reed in Kiær, 1932
?Desmorthis sp.
Idiostrophia sp.
Rhysostrophia sp.
?Taffia sp.
Trondorthis strandi Neuman, 1974
Syndielasma sp.
Dr. E.L. Yochelson (pers. comm.) has identified the gastropod Loxoplocus (Lophospira) sp. (see also Yochelson 1977, p. 383).

The locality is one of several in the area from which Bergström (1979) has obtained conodonts. These are moderately well preserved with a colour alteration index (Epstein et al. 1977) of 5, which indicates a heating in excess of 300 ^{o}C. Bergström concluded that the conodonts are of Whiterock age and equivalent to part of the Anomalorthis Zone. Trilobites and brachiopods from the Hølonda Limestone at Trotland (Neuman & Bruton 1974) support this.

5:8 SJURSMOEN (M711/1521 I Hølonda 606986). New road-cut ca. 400 m east of Sjursmoen on road from Hølonda to Hovin.

This section shows representative lithologies in the Upper Hovin Group: rhyolites, acidic tuffs, conglomerates containing well-rounded ?ejecta, and interbedded fossiliferous limestones containing brachiopods, gastropods, rugose and tabulate corals, Solenopora algae and crinoid debris. The limestone also contains well-rounded blocks of volcanic material. According to Vogt (1945) these beds may belong to the Espehaug tuffaceous unit of the Lower Hovin Group, but they probably belong to the Upper. The fauna resembles that of the Kalstad Limestone. In the middle of the section a large block of bedded fossiliferous limestone is included within the conglomerate as a giant slump horizon.

5:9 GYLLAN (M711/1621 III Støren 632965). E6 road section ca. 4 km north-west of Haga bridge and Gaula river exposure.

A new road-cut shows a section of dark, pyrite-rich shales with interbedded calcareous beds and tuffaceous siltstones belonging to the so-called Dicranograptus Shales. Beds dip south but are inverted. This locality is one of several in the area from which Getz (1887) collected graptolites later briefly described, but not figured, by Hadding (Kiær 1932). He concluded that although the material was badly deformed, identifications indicated the zones of *D. clingani* or *P. linearis*. New collections made by Bruton and Wandås in May 1982 have since been examined by S.H. Williams. The specimens are badly cleaved with little thecal detail, but have been tentatively identified as *Dicellograptus forchhammeri* (*s.l.*), *Climacograptus spiniferus* (? = *bicornis* of Hadding) and diplograptid spp indet. Both the two named taxa and others listed by Hadding do not occur above the *D. clingani* Zone as defined by Williams (in press) at Dob's Linn, southern Scotland, and the strata may belong to this zone. The Dicranograptus shales and overlying greywackes contain limestone erratics and grade into the polymict Volla Conglomerate (Vogt 1945) taken as the base of the Upper Hovin Group. The conglomerate is best exposed below the small cabin beside the river 100 m north. Clasts up to 1 m in size include granites, trondhjemites, basalts, quartzites, limestones and greywacke.

From here the bus will stop at the Støren Hotel for refreshment before continuing the long drive to Sundvolden (estimated time of arrival: around midnight).

THE ORDOVICIAN OF THE OSLO REGION
A SHORT HISTORY OF RESEARCH

Gunnar Henningsmoen

INTRODUCTION

The Oslo Region (Oslofeltet) is not an administrative unit but a term introduced by geologists. At first referred to as 'Christianias Overgangs-Territorium' (the 'overgang' or transition relating to geological age) or 'Christiania-territoriet' (Keilhau 1826), it later became known as 'Kristianiafeltet' and finally 'Oslofeltet' when the old name of Oslo was reintroduced for the capital in 1925.

The Oslo Region varies in width from 40 to 75 km and extends a distance of approximately 115 km both north and south of Oslo, which is situated at its eastern border. The region is fault controlled (Oslo Graben) and covers an area of roughly 10 000 square km. It is bordered by Precambrian in the west and east and by the Caledonian nappe region in the north. Within the region, Upper Palaeozoic, mostly igneous, rocks are slightly greater in areal extent than the Lower Palaeozoic sedimentary rocks. Ordovician rocks cover around 2 000 square km and crop out in eleven districts established by Størmer (1953).

THE ORDOVICIAN SYSTEM IN THE OSLO REGION

In the early 1800's, strata now assigned to the Ordovician were not distinguished as a separate unit, but were included in the 'Uebergangsgebirge' (transitional rocks), a concept introduced in Germany in the late 1790's by Abraham G. Werner for rocks between the 'Urgebirge' (ancient rocks) and the 'Flötzgebirge' (Coal Measures and younger). Thus the German geologist von Buch (1810), after having travelled in Scandinavia, assigned all the rocks of the Oslo Region to the 'Uebergangsformation'. Heyerdahl (1811), curate in Toten, correspondingly called such rocks the 'Overgangs-Bjergene'. In 1844, Murchison visited Christiania (Oslo) and recognized the presence of both the Lower and Upper division of his newly erected Silurian System, the Lower Silurian including what was later to become the Ordovician and most of the Cambrian. Kjerulf (1855) adopted the terms Upper and Lower Silurian and soon after (Kjerulf 1857) gave reasons why the 'Uebergangsformation' should be discarded and British terms introduced. In a later text-book, Kjerulf (1878) listed three formations, viz. Primordial or Cambrian (including also late Precambrian strata north of the Oslo Region), Lower Silurian and Upper Silurian. Brøgger (1882) continued to regard the Primordial as Silurian and following Barrande, distinguished between the first Silurian or Primordial (= Cambrian), second Silurian (= Ordovician) and third Silurian fauna. In 1887, he loosely applied the term 'Middle Silurian' to beds with the second Silurian fauna and only later (Brøgger 1896) did he advocate the use of the names Cambrian and Ordovician. Following this example, Bjørlykke (1898) used the name Cambrian but regarded the overlying Lower Palaeozoic strata as 'true Silurian'. Thus arose the term Cambro-Silurian still used figuratively today. The term Middle Silurian was reintroduced by Kiær (1901), now in a restricted sense (= uppermost Ordovician). Holtedahl was the first Norwegian geologist to use the term Ordovician, in a publication dealing with fossils from the Canadian Arctic, and later (Holtedahl 1916) applied it to rocks from the Oslo Region.

The boundaries applied to the Ordovician System in Scandinavia developed from boundaries used before the system was accepted. Brøgger (1882) placed a major boundary above the Dictyonema Shale, at the transition from the first to the second Silurian fauna as perceived by him. In Sweden, Moberg (1901) suggested a boundary between the Cambrian and 'Lower Silurian' at the base of the Dictyonema Shale. This is the lower boundary of the Ordovician applied in Scandinavia today. International agreement is still awaited on this boundary as well as that of the upper. Until now the latter has remained remarkably stable and uncontroversial in the Oslo Region, being that between the Lower and Upper Silurian as recognized by Murchison in 1844.

A tripartite division of the Ordovician in the Oslo Region into Lower, Middle and Upper was consolidated by Størmer (1953), who grouped the

Ordovician units of the Etage classification into five local series (Fig. 1), admitting that an earlier attempt (Størmer 1934) to make use of British nomenclature had been premature. In later years, attempts have been made to correlate with the British Standard sections or with that established for eastern Baltoscandia more directly, abandoning the Etage units.

THE ETAGE CLASSIFICATION

'Etage', from French ētage (level, floor), was adopted as a stratigraphical term in various European countries in the last century, and for the Lower Palaeozoic succession in the Oslo area by Kjerulf (1857). The etage classification as applied to the Oslo Region was adjusted and refined through the years to comprise ten main etage units with numerous sub-units. They were given 'shorthand symbols' of Arabic numerals followed by Roman and Greek letters (e.g. the Ceratopyge Limestone was given the symbol 3aγ, denoting that it was the third unit (indicated by γ) of the Ceratopyge Beds (3a) of the Lower Ordovician (Etage 3) — see Fig. 1. Some etage units are lithostratigraphical, such as a limestone (e.g. Megistaspis Limestone, 3cα) between two shales. In other cases, one or both boundaries are defined on palaeontological evidence. Thus the Lower Didymograptus Shale (3b) was subdivided into smaller units (3bα-3bδ) according to fossil content.

Upper Ordovician 4c–5b	Tretaspis Series (4c-5b)
Middle Ordovician 4a-4b	Chasmops Series (4aβ- 4bδ) Ogygiocaris Series (4aα)
Lower Ordovician 2e–3c	Asaphus Series (3b-3c) Ceratopyge Series (2e-3a)

Figure 1. Outline of the etage classification of the Ordovician in the Oslo Region.

The unit symbols, first used within restricted areas, were later applied to other parts of the Oslo Region. Outside the type areas, the symbols were normally used in a chronostratigraphical sense. Where originally applied to biostratigraphical units, especially in the Cambrian, the symbols are still practical. In the Ordovician and Silurian, where many symbols were originally based on lithostratigraphical units, changing views on correlation and other factors have led to confusion, and the etage symbols are now being discarded. Nevertheless, their extensive use in literature, on museum labels and in notebooks can hardly be ignored, and with critical use they can convey important locality and stratigraphical information.

EXTRACTS FROM THE HISTORY OF RESEARCH

An Ordovician fossil from the Oslo Region was the first of its kind to be described from Norway. In a publication from 1781, the Danish scientist Morten Thrane Brünnich (1737-1827) described a trilobite species named Trilobus dilatatus (= Ogygiocaris dilatata) and assigned it to the Trilobita, a name introduced only ten years earlier by Walch (1771). Brünnich did not figure any of his specimens but his description of a dorsal shield from Fossum near Skien was so detailed that the specimen could be recognised and selected as a lectotype (Henningsmoen 1960). The specimen is now in the collections of the Geological Museum, Copenhagen. At this time the kingdoms of Denmark and Norway were united, Denmark being the leading nation and Copenhagen the administrative centre. Civil servants were moved from one country to the other and Brünnich spent much of his life as an administrator at the Kongsberg Silver Mines in Norway. However, he longed to do research at the University of Copenhagen and returned there as soon as the union between Norway and Denmark was broken in 1814.

The first illustrations of Norwegian fossils, two trilobites and two 'orthoceratites' from the Ordovician of Eiker, were published in 1784 by Professor in Theology Hans Strøm (1726-1797). He remarked that cephalopods "are seen in thousands sitting on the outside of limestone rocks in a disorderly and criss-cross fashion" (transl.), a vivid description of certain surfaces of the Orthoceras Limestone.

Little else was published on the Ordovician at that time, the Kongsberg Bergseminar (1757-1814) restricting its attention to the mining value of the Oslo Region (Dons 1978).

In the early 1800's, rising national pride in Norway led to the foundation in 1811 of the first Norwegian university (Det kongelige Fredriks Universitet, Universitetet i Oslo from 1939). Until then, the University of Copenhagen (founded 1478) had been the only university in Denmark and Norway. At the new university, geological research expanded rapidly in spite of severe economic problems. In relation to studies in the Oslo Region, Balthazar Mathis Keilhau (1797-1858), Professor in 'The Rock Sciences', published the first geological map of the Region in 1838. There was no chair in palaeontology, but trilobites were described by Christian Peter Bianco Boeck (1798-1877), Professor in Physiology, Comparative Anatomy and Veterinary Sciences from 1840, Hans Morten Thrane Esmark (1801-1882), Minister in Brevik, and by Michael Sars (1805-1869), clergyman and from 1854 Professor in Zoology (see Størmer 1940).

The early 1800's were stormy years. Following the Napoleonic Wars, the Kiel peace treaty of 1814 required the King of Denmark and Norway to cede Norway to Sweden. After negotiations, Norway entered a union with Sweden in the same year, which lasted until 1905, when Norway became independent. Friendships between Nordic countries slowly grew and a meeting of Scandinavian scientists held in Gothenburg in 1839 was the first of many. Roderick I. Murchison was invited to a similar meeting held in Christiania (Oslo) in 1844 and "On an excursion in the vicinity of Oslo he was struck by the striking similarity in stratigraphy and tectonics between the Oslo Region and Wales" (Størmer 1953, 46).

Theodor Kjerulf (1825-1888) succeeded Keilau as professor in 1858. He and Tellef Dahll (1825-1893), Superintendent of Mines from 1872, did much to unravel the geology of southern Norway. They took the initiative to establish the Norwegian Geological Survey in 1858, with Kjerulf as director and Dahll as his only full-time member of staff. Kjerulf (1857) laid the foundation of the Lower Palaeozoic stratigraphy in Norway which included contributions by Dahll.

The first comprehensive study of the Ordovician of the Oslo Region was by Waldemar Christopher Brøgger (1851-1940) who, having already published on Middle Cambrian fossils and sections at Krekling, Eiker (Brøgger 1878), turned his attention to the younger parts of the section. A comprehensive study (Brøgger 1882) on the Upper Cambrian and Lower Ordovician was completed before moving to Stockholm in the same year to become Professor of Geology and Mineralogy, a position he held until 1890 when he returned to a similar office in Oslo. Although most of his studies concentrated on other fields in geology, later papers included one on the Lower Palaeozoic stratigraphy and tectonics of the Skien-Langesund area (Brøgger 1884) and another covering in detail the Ordovician stratigraphy of islands near Oslo. His last Ordovician paper (Brøgger 1896), on the distribution of the Euloma-Niobe fauna in Europe, was written while temporarily in bed!

A contemporary of Brøgger was Hans Reusch (1852-1922) who became director of the Norwegian Geological Survey in 1888. Although his research was concentrated on areas outside the Oslo Region, he published several small 'notes' on the stratigraphy and tectonics of Ordovician strata (e.g. Reusch 1883). It has been said that Brøgger saw the outcrops in two dimensions and Reusch in three, referring to the latter's many published block diagrams. Reusch founded a geological club which, in 1905, became the Geological Sociey of Norway with himself as the first president.

Johan Aschehoug Kiær (1869-1921) became the first Professor of Palaeontology and Historical Geology in Norway in 1909, and a few years later became Director of the University Palaeontological Museum. His work included several publications on Ordovician stratigraphy and palaeontology (e.g. Kiær 1901), but he is best known for his work on the Silurian (Kiær 1908) and early vertebrates. Olaf Holtedahl (1885-1975) became Professor of Historical Geology in 1920. Covering most aspects of geology, an early work of his (Holtedahl 1910) dealt with the Ordovician of the Mjøsa district where he worked out a local stratigraphy. He thus took into account Brøgger's early (1887) warning (forgotten by many subsequent workers) that the classification of Etage 4 on the islands near Oslo cannot be applied uncritically to other areas. A later paper by Holtedahl (1916) was on Ordovician and Silurian strophomenid brachiopods of the Oslo Region.

The foundation in 1916 of the University Palaeontology Museum, installed shortly after in its present building, led to an increase in the number of palaeontologists. This was followed in 1935 by the establishment of an Institute of Palaeontology, first housed in the Museum at Tøyen but later incorporated in the reorganized Institute of Geology on the university campus at Blindern. The leader of the former institute was Leif Størmer (1905-1979), Professor in Historical Geology from 1946. Contributing numerous articles, especially on trilobites and merostomes, many of Størmer's papers are on Ordovician stratigraphy and palaeontology. Størmer was the founder of what has become known as the 'Middle Ordovician Project', carried out by a research team including foreign specialists. The background for the project, its stratigraphical starting-point and objectives were outlined by Størmer (1953) in the first of what has since become 30 contributions (see reference list), forming a magnificent monument to his memory.

THE TREMADOC IN EXTRA-CALEDONIAN SCANDINAVIA: ITS STRATIGRAPHIC RANGE AND ITS DEPOSITIONAL HISTORY

Bernd-Dietrich Erdtmann

Henningsmoen (1973, pp. 430-432), representing the Scandinavian point of view, provided an authoritative summary of the history of discussion of the Cambrian-Ordovician boundary. Certain salient points may usefully be re-emphasized here. Brøgger (1882) first emphasized the concept of a Tremadoc Stage (or a Tremadocian fauna) in discussions of Scandinavian stratigraphy. He took it to include the range of the Ceratopyge Series ('Etage 3a': a combination of the 'Ceratopyge Shale', 3aα and 3aβ, and the 'Ceratopyge Limestone', 3aγ) known in the Oslo Region in extra-Caledonian Sweden and on the Danish island of Bornholm. There is no detectable break, lithological or faunal, separating the Ceratopyge Series from the underlying "Dictyonema Shales", termed 2e and regarded by Brøgger (1882) as belonging in the Upper Cambrian Olenid Series (his "Etage 2"). Moberg (1890) took the base of the Ceratopyge Limestone as marking the Cambrian-Ordovician boundary. Later, discovery of the ceratopygid trilobite Hysterolenus within the Dictyonema Shales (Moberg 1898) caused him to change his opinion and to propose that the system boundary be taken at the base of the Dictyonema Shales. He advanced this opinion again (Moberg 1900) when, impressed by (among other evidence) the lithological continuity of the sequence from the Dictyonema Shale into the Ceratopyge Series, he referred the Dictyonema Shale to the Ordovician.

Since these times there has been general agreement within Scandinavia that the system boundary should be taken at the base of the Dictyonema Shales. Further, with regard to the Upper Cambrian it subsequently came to be accepted that beds containing nodules with the olenid trilobites Westergaardia scanica, Parabolina acanthura and Acerocare ecorne should be included with the Cambrian (on the Swedish platform the Upper Cambrian sequence ends slightly earlier, in the Peltura scarabaeoides Zone,

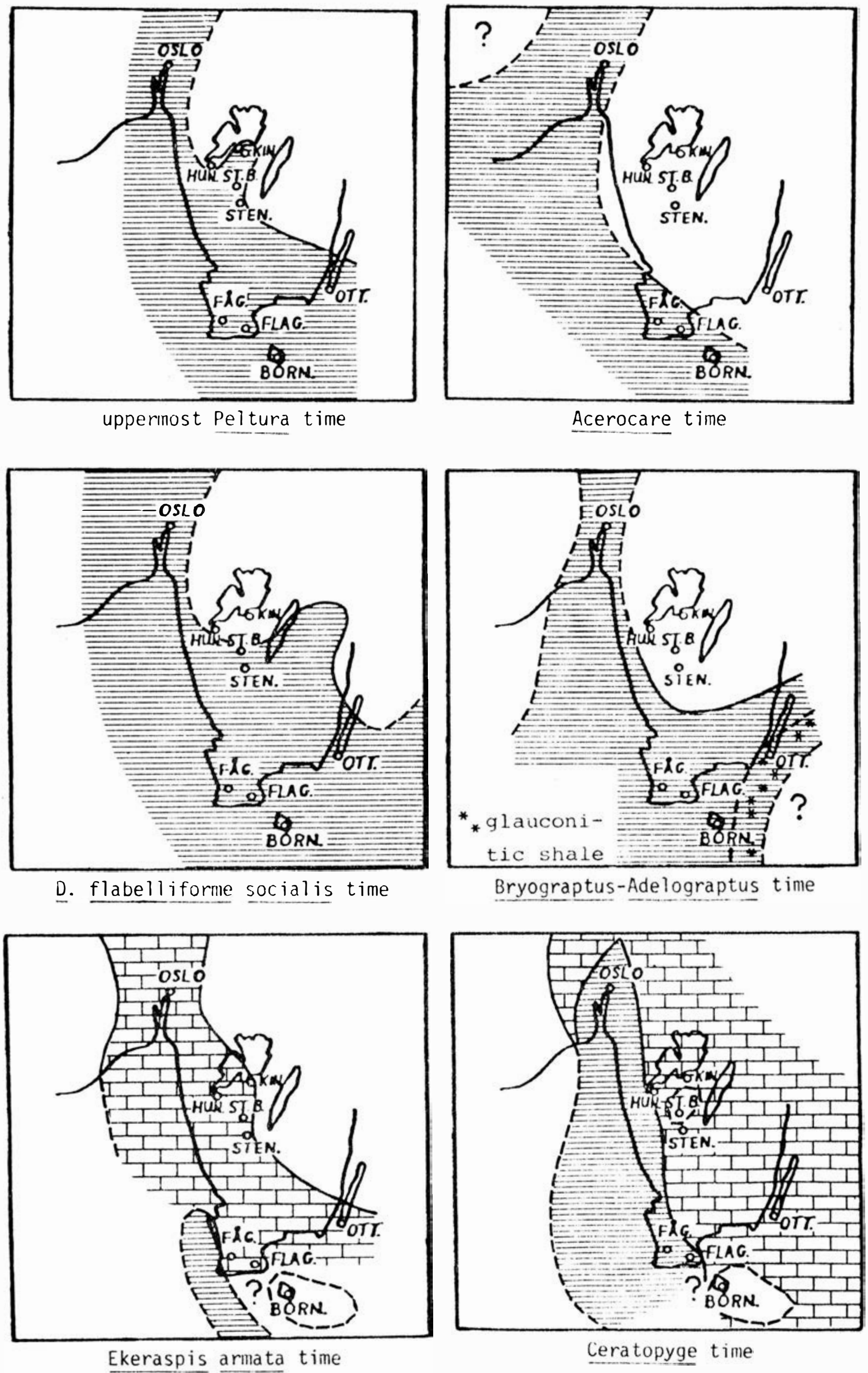


Figure 1. Paleogeography and facies of **southern** Scandinavia during the Upper Cambrian and Tremadoc (after Erdtmann in Bruton & Erdtmann 1980).

(Henningsmoen 1957). Considerable interest therefore attaches to the road section south of Nærsnes Church (SW of Oslo), which exposes the complete sequence from beds containing nodules with Acerocare ecorne, through an occurrence of Boekaspis hirsuta into the range of Jujuyaspis keideli (see Fig. 4 , p. 111). All of these occur only in limestone nodules separated by a few decimetres of black shales. In the shales in which the nodules are set the first graptolites occur at a horizon 45 cm above the Boekaspis-bearing nodule and approximately 35 cm below the anthraconite rim of a large nodule with Jujuyaspis. The graptolites are found in a 5 cm thick black shale unit which is crowded with excellent specimens of Dictyonema flabelliforme parabola and, less abundantly, D. flab. sociale. This part of the section is not tectonically disturbed. Lower, below the Boekaspis nodule, stratigraphic control is poorer because of strong folding and thrusting.

The Upper Cambrian—Mid-Ordovician black shales seem to represent a continuously developed, stable environment, with the limestone nodules (Bjørlykke 1973, 1974) or concretions (Henningsmoen 1974) allowing intermittent glimpses of the sequence of (probably non-benthic) trilobite faunas. The sudden appearance of planctic D. flab. parabola and related forms may be taken to indicated a special happening within this otherwise stable environment. Questions concerning the depositional history, and of the likelihood of stratigraphic continuity, are of immediate consequence. Considerations to be borne in mind are:

1 Black shale sequences of this character are widespread in the Oslo-Scania region from mid-Cambrian to Llandeilo.
2 Within these sequences there are occurrences of limestone concretions or nodules or nodular limestones, such as the Ceratopyge Limestone, Limbata Limestone, Endoceras Limestone, etc. These represent primary accumulations of biogenic material with varying degrees of superimposed diagenetic carbonate overgrowth (see Bjørlykke 1973, 1974 and Henningsmoen 1974 for two different views of the history of development of the carbonates in the Nærsnes section).
3 It is probably useful to think of these sporadic occurrences of shell material within the black shales in terms of variations in the position of a chemocline within the waters covering the broad, stable platform on which these sediments accumulated.

4 The faunas preserved in the nodules (and also the dictyonemids) are not benthic. The lack of trace fossils in the black shale sequences is a further indication of the exclusion of benthic communities. In contemporaneous carbonate bank or shelf deposits faunal control would involve a different range of factors.

The nature of these Scandinavian sections - their consistently fine-grained lithological character maintained over a wide areal extent and through a long span of time, their consistent, if intermittent occurrences of pelagic faunas (probably controlled by chemocline variations), should be emphasized when attempting comparisons with the original Tremadoc in North Wales. Henningsmoen (1973, table 1) has already pointed to the less stable environments and the greater likelihood of syndepositional tectonic effects that are characteristic of the British case and has suggested that almost everywhere in Great Britain, the Tremadoc Series is likely to be bounded above and below by depositional breaks. Recent assessment of new information (A.W.A. Rushton, 1980, written comm.) indicated that the gap at the lower limit might be closed in certain sections in North Wales (Ogof-ddu and Bryn-llyn-Fawr). Parabolina acanthura (contemporary of Acerocare ecorne) and Parabolina heres (contemporary of the other underlying 'missing' trilobite zones) have now been found at those sections mentioned above in North Wales. It therefore appears that, in terms of the Acado-Baltic facies development, a continuous sequence may also exist in Britain across the interval between the Upper Cambrian Merioneth and Tremadoc Series.

A continuous and conformable section across the Tremadoc-Arenig interval, documented by overlapping fossil ranges, has not yet been demonstrated from Britain. This author has read reports submitted by P.M. Allen (Rushton, 1980, written comm.) which suggest existence of a continuous transition from the Amnodd Shales (Upper Tremadoc of Fearnsides 1905) and the Erwent Limestone (Arenig according to Fearnsides 1905) in a stream section at Caunant-y-gareg ddu on the western slope of Arenig Mountain in North Wales. Similar sections are available at the Croes-y-ddwy afon and Bryn Glas quarries along the northern flanks of Harlech Dome. However, the stratigraphical short-comings of all these sections, (i.e. in the Ceunant-y-gareg ddu-"Black Rock Gorge", where 38 m of section between the Amnodd Shales and Erwent Limestone are unfossiliferous where a several metres thick dolerite sill intervenes, and where the lowermost Arenig - in Fearnsides' view - Llyfnant Flags are entirely missing), and the numerous faults , make it difficult to achieve a good resolution of depositional history in this area. Further, the earliest known Arenig graptolite in the type area around Arenig Fawr is Didymograptus cf. D. simulans (a rather 'non-descript' form related to D. extensus and D. nitidus), reported from the Llyfnant Flags, indicated a rather high post-T. approximatus position in terms of the Lake District (northern England) and Scandinavian graptolite sequences. With only one somewhat questionable occurrence of T. approximatus from the Skiddaw Slates of the Lake District (Jackson 1964, p. 530; Erdtmann 1965, p. 532) and the abscence, so far, of any finely-tuned graptolite zonation for the Arenig of Britain (Jackson 1962) there is practically no detailed evidence on graptolites in Britain between the Clonograptus tenellus - Adelograptus hunnebergensis zones (Stubblefield & Bulman 1927; Cope, Fortey & Owens 1978) and Tetragraptus approximatus. This range spans at least 3 recognizable graptolite zones (Henningsmoen 1973, table 1) or 15 m (out of 20 m for the Ceratopyge Series plus Hagastrand Member) of the post-Dictyonema flabelliforme/pre-T. approximatus sequence in the Oslo—Skåne region (see Fig. 2).

If one accepts Tetragraptus approximatus, with its short range and cosmopolitan occurrence, as indicating the base of the Arenig Series, the entire Scandinavian sequence between the Kiaerograptus kiaeri (and the enclosed Ceratopyge Limestone, Erdtmann 1965a) and Temnograptus to Tetragraptus phyllograptoides beds (lower part of Tjernvik's 1956 Hunneberg Substage) has no firm representation anywhere in Great Britain (Skevington 1966, p. 115). Only the lower half (approximately) of the British Tremadoc Series can be correlated to the Scandinavian sequences (see Fig. 2). This gap is neither closed nor cancelled by Tjernvik's (1956, 1960), Erdtmann's (1965a, 1965b - tentative!) and Jaanusson's (1979) inclusion of all post-Ceratopyge beds in the Arenig Series. Such procedure demonstrates instead the great uncertainty of the above authors as to the means of applying this British term (in a chrono- or biostratigraphical sense!) to the Scandinavian case (Fig. 2).

Skevington (1966, p. 115) and Henningsmoen (1973, p. 430) have pointed

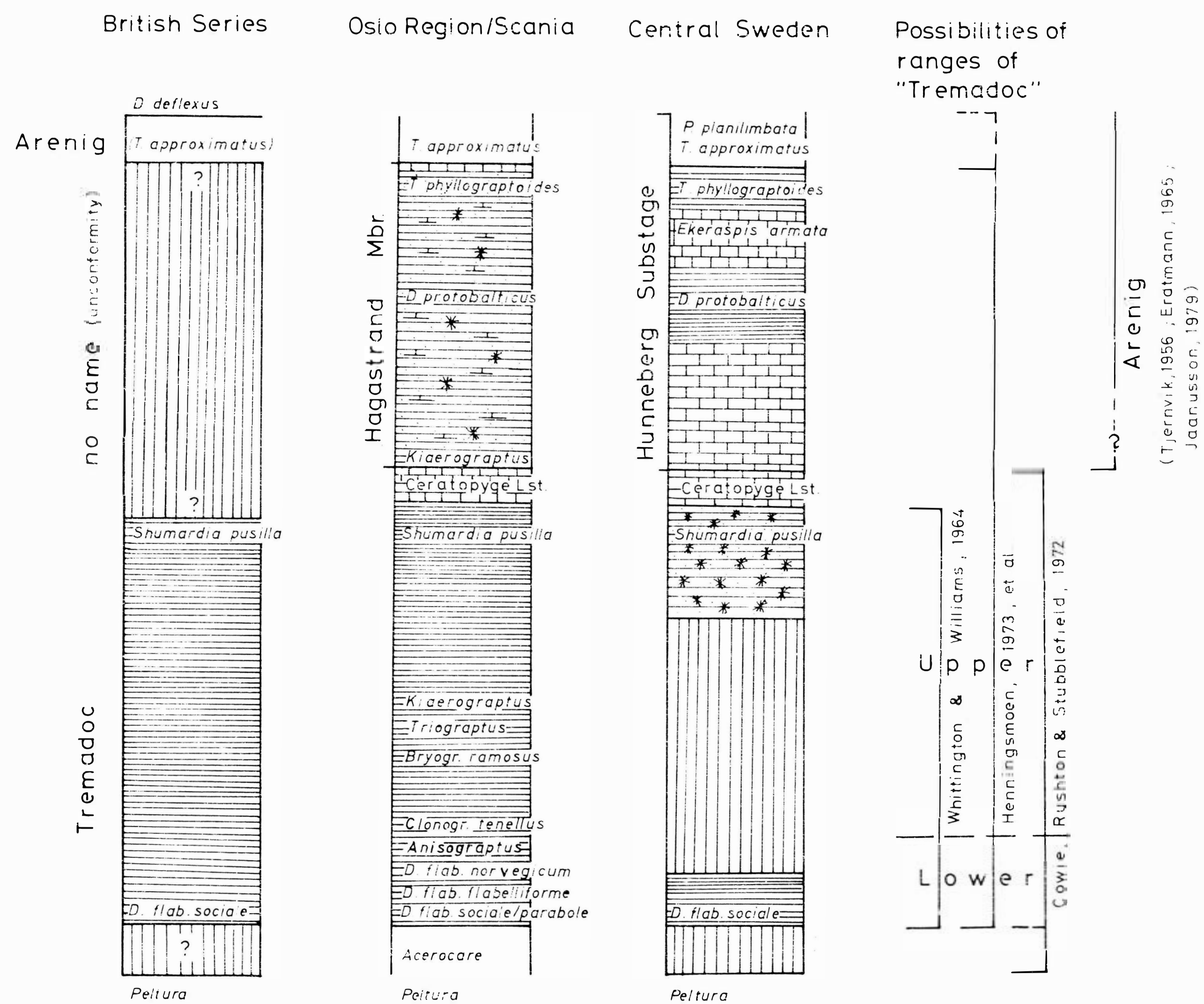


Figure 2. Correlation of Tremadoc rocks in Britain and Scandinavia. The right column shows the various definitions of the Tremadoc and Arenig Series (after Erdtmann in Bruton & Erdtmann 1980).

this out as an argument against taking the intersystem boundary between the Tremadoc and Arenig Series.

In addition to the poor correlation of horizons in the Tremadoc-Arenig range between Great Britain and Scandinavia, there is the evidence from most extra-European areas, which again supports the observation that a large fraction of depositional time represented elsewhere is missing in all British sections. The 'Pacific' trilobites and graptolite zones of North America, Siberia, Northern China, and Australia do not conform with the British concepts of Tremadoc and Arenig.

Article first appeared *in* Bruton & Erdtmann (1980)

THE ORDOVICIAN OF OSLO - ASKER

J. Fredrik Bockelie

The Lower Palaeozoic succession of the Oslo—Asker District is folded and contained in a complex dêcollement and splay thrust system with listric faults (Bockelie & Nystuen in prep.). This deformation is primarily the result of Caledonian deformation which is responsible for some shortening of the sequence (Ramberg & Bockelie 1981). A sole thrust is regionally present in the Cambrian sequence, generally 1-2 m above the Precambrian basement. The black Alum shale of the Cambrian is an ideal lithology for a thrust plane. Sediments below this thrust plane are influenced by Permian block faulting only by being tilted, whereas the sediments above this sole thrust are folded.

The Ordovician rocks of Oslo—Asker (Fig. 1) comprise approximately 400 m of alternating limestone and shale units, richly fossiliferous, with frequent occurrences of clastics in the Upper Ordovician. Details of the depositional history are to be found in Bjørlykke (1974). The Tremadoc immediately succeeding the Cambrian consists of black Alum shales with Stink-stone lenses, grading into shallow water limestones and grey-black shales in the Upper Tremadoc—Arenig.

The tri-partite Orthoceras Limestone containing the Arenig—Llanvirn boundary (Kohut 1972) is very fossiliferous, particularly in its middle part. The unit represents the second phase of shallowing in the Balto-scandian Basin. The Llanvirn—Caradoc succession consists of alternations between shales and nodular limestone, terminating with a shallow water bioclastic Upper Chasmops Limestone. Detailed analyses of the fossil content of this unit in the Oslo—Asker and adjoining Districts have recently been made. (Bruton & Owen 1979; Qvale 1980; Owen & Bruton 1980). Present investigations indicate shallow water conditions in Asker/Bærum with local synsedimentary breccias (Bockelie in prep.).

		OSLO REGION Series	Stages & substages	Correlation with Great Britain	Thickness in m	OSLO-ASKER		
Ordovician	U.O.	Tretaspis series (4c—5b)	5b	Ashgill	max. 30	5b	Calcareous sandstone formation	
			5a		45-80	5a	Gastropod limestone, etc.	
			4d			$4d\alpha$-γ	Isotelus shales ($4d\alpha$, γ) & limestone ($4d\beta$)	
			$4c\beta$-γ		55-90	$4c\beta$-γ	Upper Tretaspis sh. ($4c\gamma$) & Tretaspis lst. ($4c\beta$)	
			$4c\alpha$			$4c\alpha$	Lower Tretaspis shale	
	M.O.	Chasmops series ($4a\beta$—4b)	$4b\delta_2$	Caradoc	120-165	$4b\delta_2$		
			$4b\delta_1$			$4b\delta_1$	Upper Chasmops limestone (10—25 m)	
			$4b\gamma$			$4b\gamma$	Upper Chasmops shale	
			$4b\beta$			$4b\beta$	Lower Chasmops limestone	
			$4b\alpha$			$4b\alpha$	Lower Chasmops shale	
			$4a\beta$			$4a\beta$	Ampyx limestone	
		Ogygiocaris series ($4a\alpha$)	$4a\alpha_{3-4}$	Llandeilo	70	$4a\alpha_{3-4}$	Ogygiocaris shale	
			$4a\alpha_{1-2}$	Llanvirn		$4a\alpha_{1-2}$	Upper Didymograptus shale	
	L.O.	Asaphus series (3b—c)	$3c\gamma$	Arenig	10	$3c\gamma$	Endocerarid limestone	Orthoceras limestone
			$3c\beta$			$3c\beta$	Asaphus shale	
			$3c\alpha$			$3c\alpha$	Megistaspis limestone	
			3b		10	$3b\alpha$-ε	L. Didymograptus sh. (= Phyllograptus sh.)	
		Ceratopyge series (2e—3a)	$3a\gamma$	Tremadoc	20	$3a\gamma$	Ceratopyge limestone	
			$3a\alpha$-β			$3a\alpha$-β	Ceratopyge shales	
			2e			$2e\alpha$-δ	Dictyonema shale	Alum shale with stinkstone concretions
Cambrian	U.C.	Olenid series (2a—d)	$2d\varepsilon$	Olenus series	45	$2d\varepsilon$	Acerocare	
			$2d\alpha$-δ			$2d\alpha$-δ	Peltura	
			2c			2c	Leptoplastus & Eurycare	
			2b			2b	Parabolina spinulosa	
			$2a\beta$			$2a\beta$	Olenus & Agnostus obesus	
			$2a\alpha$			$2a\alpha$	Agnostus pisiformis	
	M.C.	Paradoxides series (1c—d)	1d	Paradoxides series	20	1d	Paradoxides forchhammeri	
			$1c\beta$-δ			$1c\beta$-δ	Paradoxides paradoxissimus	Basal cgl.
			$1c\alpha$			$1c\alpha$		
	L.C.	Holmia series (1a—b)	$1b\beta$	Olenellus series		$1b\beta$		
			$1b\alpha$			$1b\alpha$		
			$1a\beta$			$1a\beta$		
			$1a\alpha$			$1a\alpha$		
Underlying:							Precambrian (Pre-Sparagmitian)	

Figure 1. Stratigraphical succession of the Ordovician in the Oslo—Asker district (after Henningsmoen in Strand & Henningsmoen 1960). For modifications of Upper Ordovician succession see Fig. 10.

The black Tretaspis Shale, succeeding the Upper Chasmops Limestone, indicates an extensive transgression close to the Caradoc/Ashgill boundary. A progressive shallowing of the Oslo—Asker District took part in the Upper Ordovician, ending with local supratidal conditions in Asker and Bærum.

The increase in sedimentation rates throughout the Upper Ordovician is probably related to Caledonian movements and proximity to source areas supplying coarse clastic sediments. Microtectonic triggering mechanisms have been suggested for several of the sandstone beds in the Upper Ordovician (Brenchley & Newall 1977). Irregularities in the basement with differential movements of blocks of Pre-Cambrian rocks may account for some of the recurrencies of topographic highs and lows during the Cambro-Silurian.

A sharp boundary between the Upper Ordovician Langøyene Sandstone and the Lower Silurian shale (etage 6 of Kiær 1906) is locally interpreted as an erosional contact. The presence of a Climacograptus apparently of the normalis group in the Husbergøya shale (Brenchley & Newall 1975) suggests that the Ordovician—Silurian boundary may be within the 'Calcareous Sandstone' unit generally referred to as Ordovician (etage 5: see Brenchley & Newall 1975).

ITINERARY

The route goes from Sundvollen to Nærsnes by bus, passing through the Permian lavas of Krokskogen, further in areas of folded Ordovician and Silurian rocks. On the west side in Røyken and parts of Asker we will see Permian intrusives (granite). The bus will join the E18 (Drammensveien) at Sandvika and follow the western part of the fjord to Holmen, leaving the E18 here and taking route 167 to Slemmestad and Nærsnes. In Asker good sections of Middle and Upper Ordovician and Lower Silurian will be seen from the bus. Also good views of the Precambrian faultline down the eastern side of the Oslo fjord. At Nærsnes we shall study a potential Cambrian/Ordovician boundary section (Bruton *et al*. 1982).

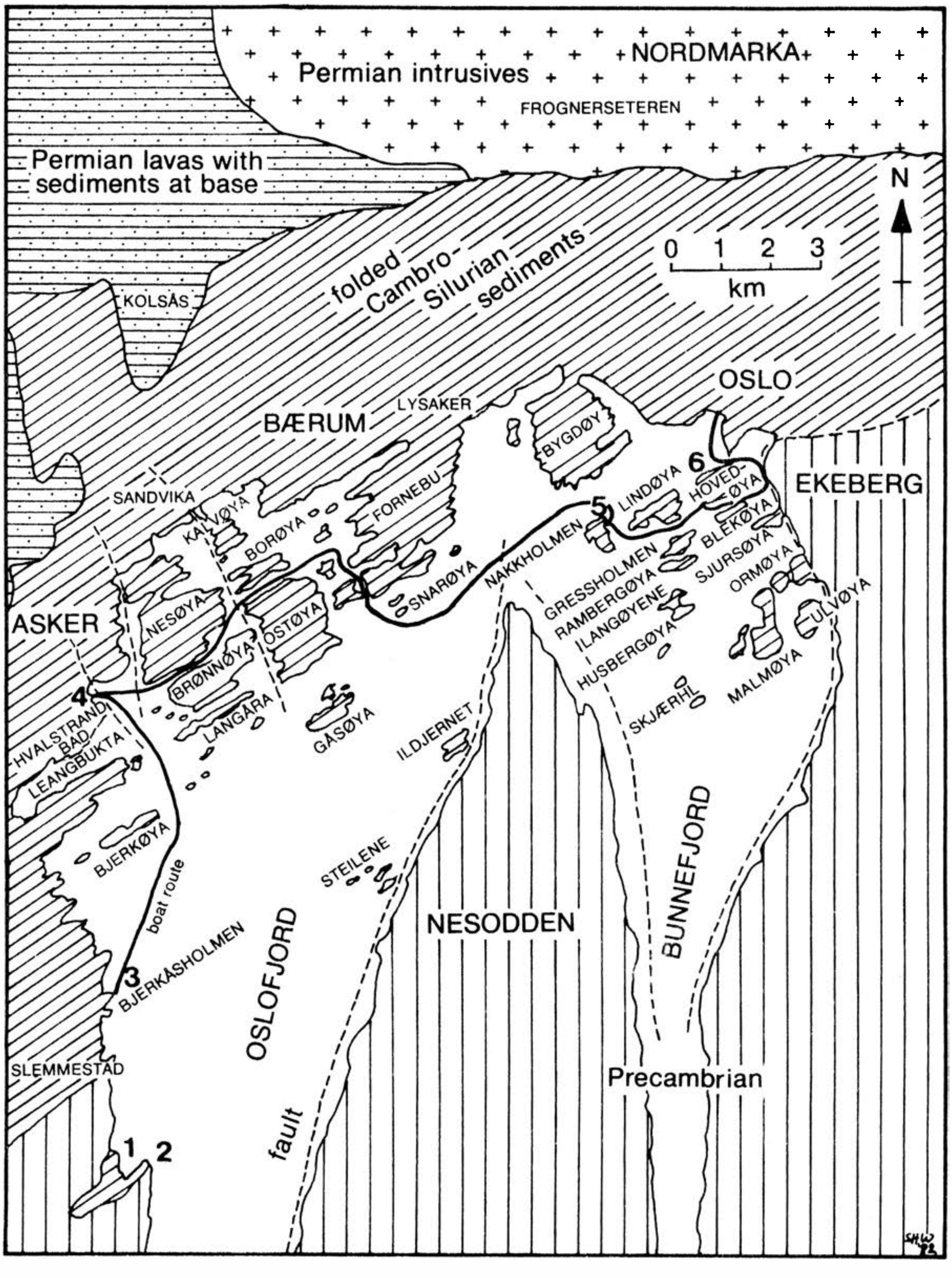


Figure 2. Map of Oslofjord showing boat route after locality 3.

After STOP 3, the excursion will travel by boat on the Oslofjord (Fig. 2).

STOP 1 NÆRSNES TYPE PROFILE (Fig. 3) (David L. Bruton, Bernd-D. Erdtmann & Leif Koch). Henningsmoen (1957, 41, Fig. 6) briefly described this locality and provided a composite section. The locality has since been cleared, and carefully logged for fossils (Bruton et al. 1982).

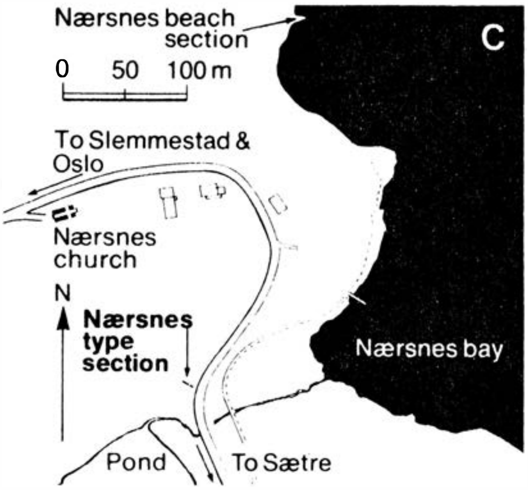


Figure 3. Location of the Nærsnes type section

Folded Upper Cambrian alum shales and limestone of the Olenid Series (pars) crop out at the roadside 400 m south-south-east of Nærsnes Church (Fig. 3). Approximately 47 m north of a small bridge and 2.3 m in the section above the footpath, limestone concretions contain well preserved Peltura scarabaeoides scarabaeoides (Wahlenberg, 1821), Ctenopyge bisulcata (Phillips, 1848) and Sphaerophthalmus humilis (Phillips, 1848), characteristic of the Upper Cambrian P. scarabaeoides Zone 2dγ. If traced south along strike and under scree approximately 8 m above the footpath, this zone would crop out 2 m below a limestone concretion in the northernmost of two profiles. This concretion contains abundant Acerocare ecorne Angelin, 1854 and Parabolina acanthura (Angelin, 1854) of the Upper Cambrian A. ecorne Zone 2dε. This zone can be identified in two more concretions 8 m along strike to the base of the southern profile (concretion 1, Fig. 4). This profile is the one proposed as a candidate for the Cambrian—Ordovician boundary stratotype at the base of the Tremadoc Series.

Above concretion 1 occur two successive concretions (2 and 3, Fig. 4) each containing Boeckaspis hirsuta (Brøgger, 1882). Graptolites first occur 52 cm above the base of concretion 2 and are a new form of Dictyonema. D. flabelliforme sociale occurs sparsely 35 cm

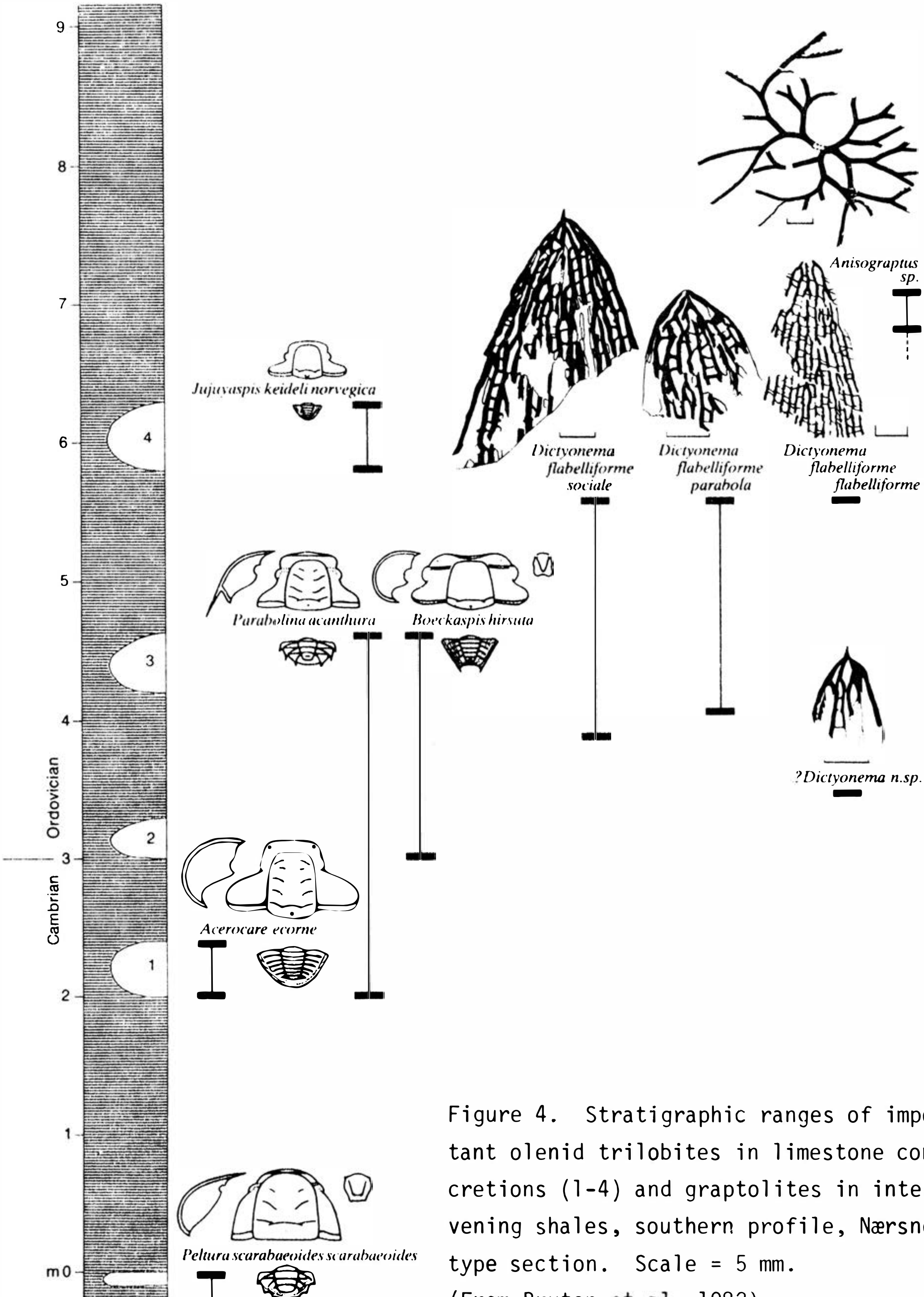


Figure 4. Stratigraphic ranges of important olenid trilobites in limestone concretions (1-4) and graptolites in intervening shales, southern profile, Nærsnes type section. Scale = 5 mm.
(From Bruton et al. 1982)

higher. Abundant D.f. parabola and a few D.f. sociale occur 75 cm above concretion 2 and below concretion 3. The succeeding shales are undisturbed and have yielded abundant D.f. parabola and a few D.f. sociale in a 6 cm thick band 30 cm below concretion 4 which contains the trilobite Jujuyaspis keideli norvegica Henningsmoen, 1957. A higher horizon 20 cm below concretion 4 has yielded D.f. parabola, D.f. sociale and D.f. flabelliforme. Stipes of a large Anisograptus sp. occur at two levels repectively 50 and 65 cm above concretion 4. Shales in the remaining 2.15 m of the section contain abundant, though incomplete specimens of a phyllocarid crustacean and inarticulate brachiopods. The profile is terminated further north by a diabase sill.

The boundary between the Cambrian and the Ordovician is defined at the base of concretion 2 (Fig. 4), the first of two concretions containing Boeckaspis hirsuta within a graptolite succession of the Tremadoc acmezone of D.f. parabola. The lowest concretion 1 (Fig. 4) contains A. ecorne and P. acanthura, representing what in Scandinavia is accepted as the topmost zone of the Upper Cambrian (Martinsson 1974; Henningsmoen 1957, 1973). The Nærsnes section therefore fulfils the following criteria which Henningsmoen (1973) considered important in choosing a suitable boundary stratotype between the Cambrian and the Ordovician systems:

1 The boundary is placed in a uniform sedimentary sequence.
2 The sequence contains cosmopolitan fossils in the form of non-benthonic graptolites and abundant, well defined and documented species of probably non-benthonic olenid trilobites.
3 Fossiliferous horizons occur above and below the boundary in a continuous sedimentary sequence.

To these may be added:

4 The boundary is defined within the same general development of the biostratigraphic succession as the British (Welsh) succession, which for so long has been used as the standard

reference.

5 The boundary stratotype section is easily accessible.

STOP 2 NÆRSNES BEACH SECTION (Fig. 3) Here a succession of alum shales and concretions occurs to the north and south of a metre thick Permian sill. A section south of the sill (Fig. 5)

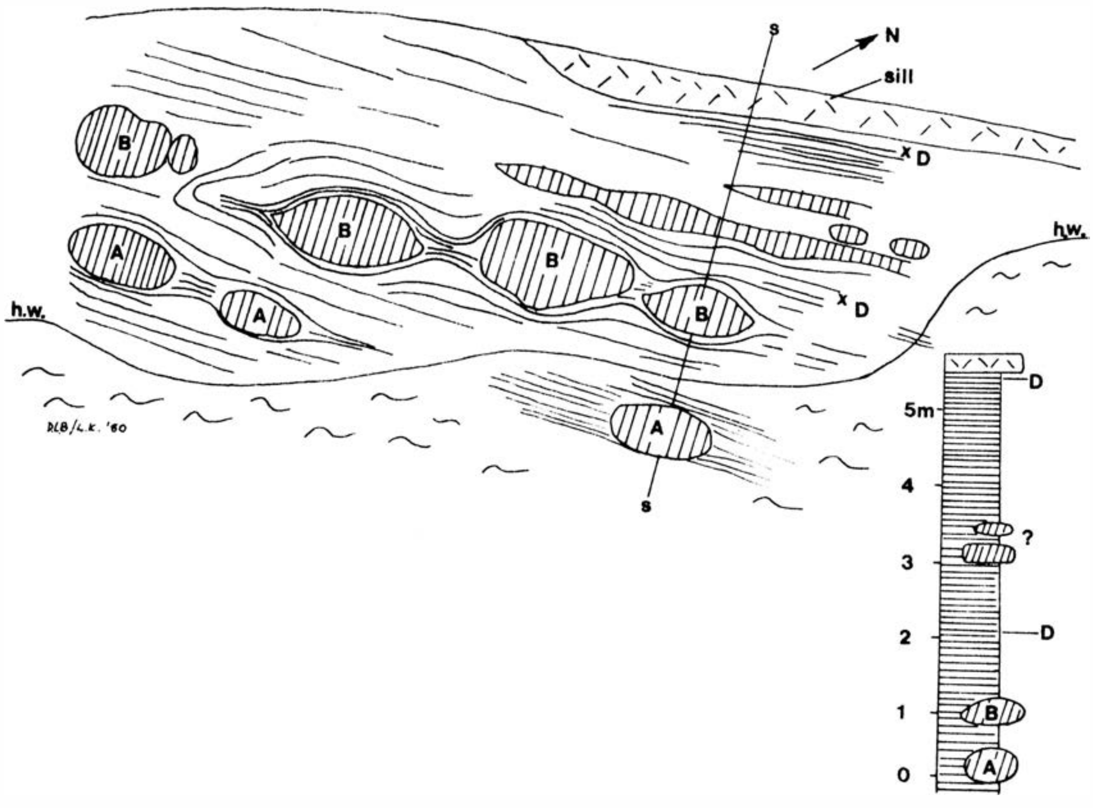


Figure 5. Sketch of Nærsnes beach section south of sill (from Bruton & Erdtmann 1980). Limestone concretions with cross-hatching contain A - Acerocare, B - Boeckaspis. D - Dictyonema vertical section along line s—s.

shows concretions containing Acerocare ecorne and Parabolina acanthura on the beach just below high water mark, succeeded by an horizon of large concretions containing Boeckaspis hirsuta. Dictyonema flabelliforme parabola occurs in the shales at three levels, 2 metres and 2 m 10 cm above the Acerocare layer, and at

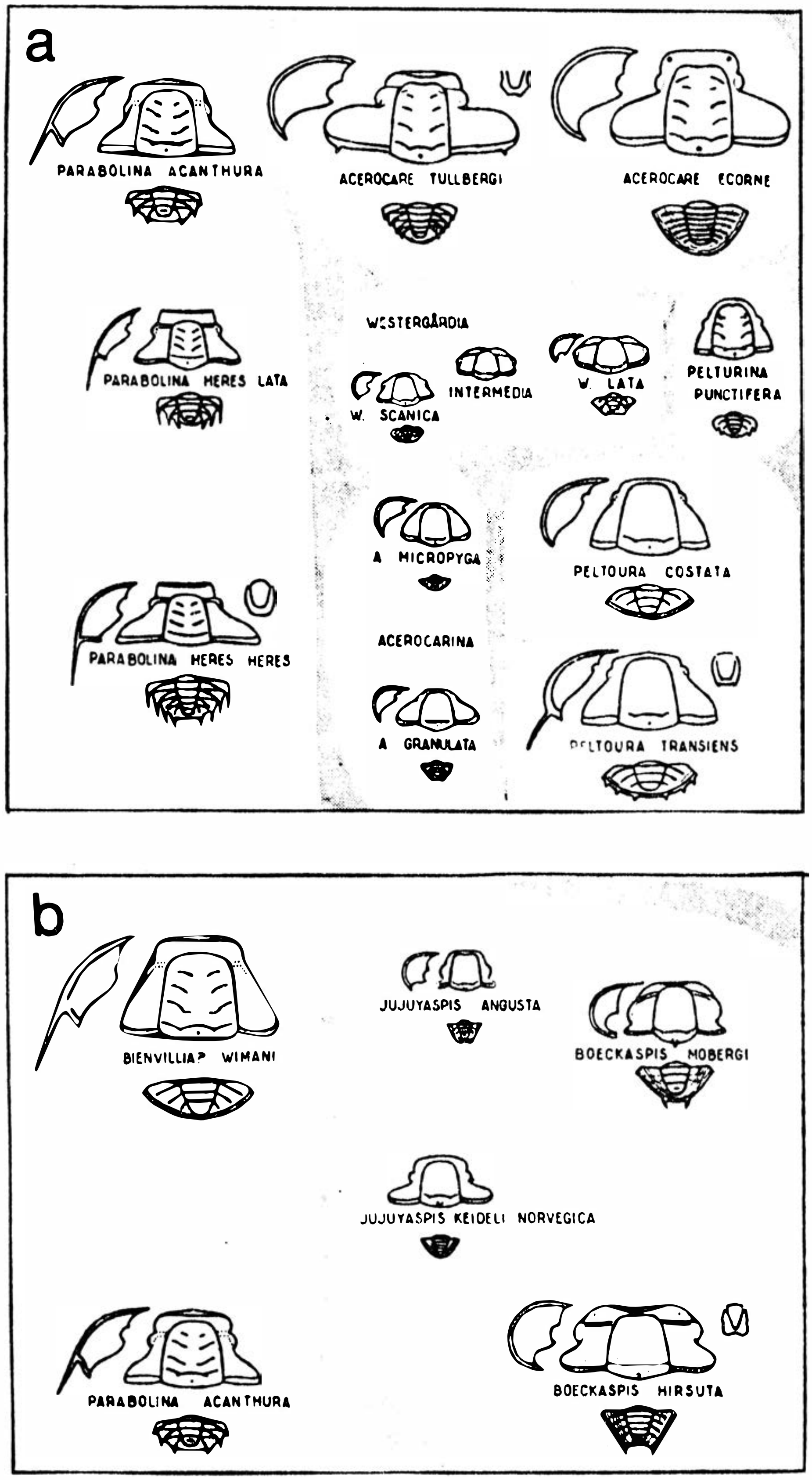


Figure 6. Olenid trilobites common in a, Upper Cambrian and b, Lower Tremadoc, at Nærsnes (from Henningsmoen 1957).

10 cm below the sill. Two irregular limestone beds and associated concretions occur between the lower and upper Dictyonema horizons but so far they have not yielded trilobites. These compact beds might correspond to the second Boeckaspis horizon in the northern section at the Nærsnes Type Profile.

North of the sill, at about high water mark, is a succession of tightly folded alum shale containing Dictyonema at 6 different horizons. Dictyonema flabelliforme parabola has been identified at 2.2 metres above the sill and approximately 1 metre above a concretion containing Boeckaspis hirsuta. The highest beds contain Dictyonema flabelliforme sociale. At the top of the section is an horizon of concretions similar in appearance to those containing Jujuyaspis at the Nærsnes Type Profile. Thus, despite the folding, the succession is thought to be a normal one though thicknesses of shales are difficult to estimate. In terms of the boundary, the sill and the succession north of it is of less significance, though it provides an ideal parastratotype section.

STOP 3 BJERKÅSHOLMEN, ASKER (Fig. 7) (J. Fredrik Bockelie)

The peninsula consists of a sequence of Lower Ordovician fossiliferous limestone and shales (Ceratopyge Limestone, Lower Didymograptus Shale (Arenig) and Orthoceras Limestone (Arenig—Llanvirn). The section dips about 45^{o} north-west. On the southern side of the peninsula is a strongly folded sequence of Lower Didymograptus Shale, eroded to sea-level. Fold axes with north-eastern plunges can be measured directly, and individual limestone beds (2-5 cm thick) can be traced in the intricate fold pattern. A thrust plane can be observed close to the cliff.

The Ceratopyge Limestone contains a varied shelly fauna of trilobites including Ceratopyge forficula, Euloma ornatum, Symphysurus angustatus and Niobe insignis. One of the earliest articulate brachiopods, Archaeorthis christianae, is found here. Note the dark concretions at the base containing the 'last' olenid, Triarthrus. The limestone is glauconitic and contains arrow-like

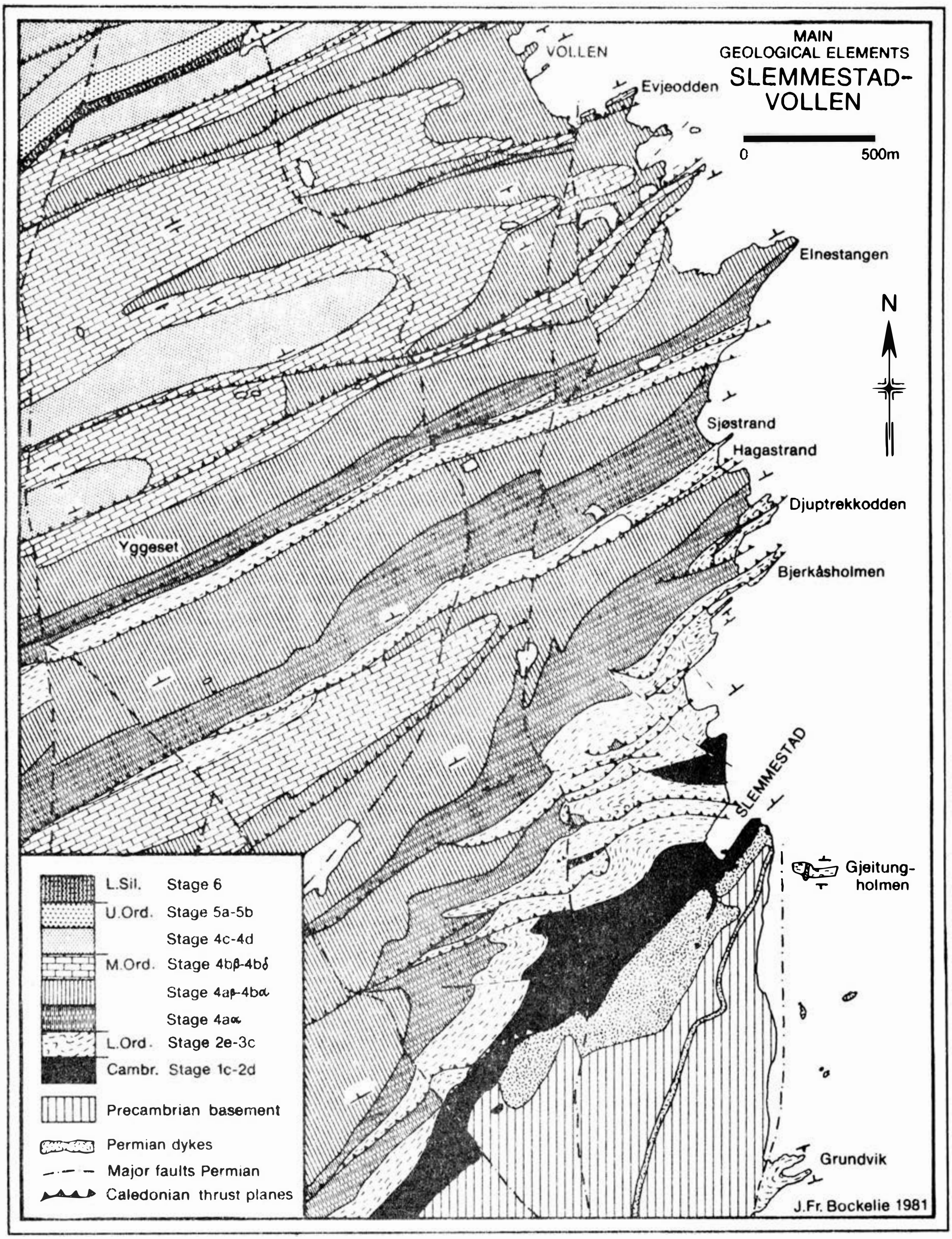


Figure 7. Geological map of the Slemmestad—Vollen area (after J.F. Bockelie MS).

pseudomorphs of gypsum(?). The overlying Didymograptus Shale is not particularly fossiliferous here and the base shows a green-grey-black colour transition. The tri-partite division of the Orthoceras Limestone is best seen along the northern flank of the peninsula. All units are very fossiliferous and contain trilobites (Brøgger 1882), brachiopods (Øpik 1939), cephalopods (Sweet 1958), echinoderms (Bockelie 1981), conodonts (Kohut 1972), bryozoa and ostracodes. The Megistaspis Limestone is partly dolomitic and the Endoceratid Limestone contains several hard grounds with phosphate (Skaar 1972). The unit is interpreted as having been deposited in shallow water.

From here the excursion will join the boat for lunch.

STOP 4 HOLMENSKJÆRET (J. Fredrik Bockelie) A sequence of low energy Palaeoporella Limestone (Ashgill) with a rich fauna of trilobites, brachiopods, gastropods and corals, but dominated by the codacean algae Palaeoporella. The frequency of Palaeoporella increases throughout the unit and reaches a maximum density at the top. A sharp boundary to the overlying Holorhynchus shale can be studied on a small peninsula. This locality has the highest faunal diversity in the Upper Ordovician with more than 80 taxa recorded.

From Holmenskjæret the boat will pass several islands in the western part of the fjord and various features, particularly the folding, will be pointed out.

STOP 5 ISLAND OF NAKHOLMEN (A. Owen, F. Bockelie, D. Harper) This island is one studied and mapped by Brøgger (1887). Fig. 8 has been adapted from Brøgger's map to show the outcrops of the Caradoc—Ashgill units to be examined. The boat will land at 'Loffen' (Stop A) and examine the richly fossiliferous uppermost bed of the Upper Chasmops Limestone containing abundant Stenopareia glaber, Platylichas laxatus, Lonchodomas aff. pennatus and Ampyxella aculeata (for references see Owen & Bruton 1980). The dark, bioturbated limestone 0.85-1.02 m above this bed locally contains trilobites (including Tretaspis ceriodes angelini) which only occur in the upper parts of the Upper Chasmops Limestone in Bærum and Asker. The occurrence of rare Triarthrus linnarssoni may suggest a deeper water environment than further west. About 10 cm above this bed is the 'phosphorite conglomerate' once thought to indicate a substantial break in deposition (but see Bruton & Owen 1979).

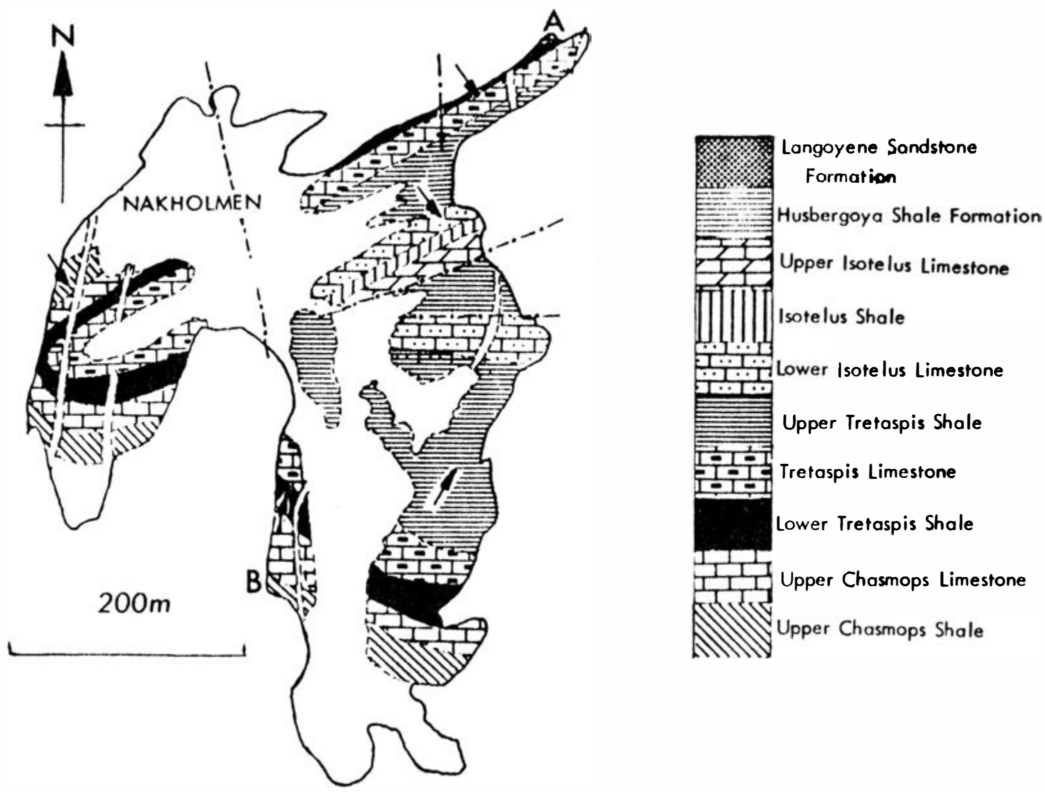


Figure 8. Geological map of the island of Nakholmen, Oslo, locality 5 with stops A and B (after Brøgger, 1887 and Owen, 1977).

The overlying Lower Tretaspis Shale is about 7 m thick and shows the characteristic planar limestones in the upper part. Fossils are difficult to collect here but localities in Oslo have yielded a linearis Zone graptolite fauna. The base of the overlying Tretaspis Limestone is distinctive, showing the characteristic small, tightly packed limestone nodules. These pass up into larger nodules and more planar limestone beds. A more or less complete profile from the Upper Chasmops Limestone through the underlying Upper Chasmops Shale (9-10 m thick), Lower Chasmops Limestone (10 m) and Lower Chasmops Shale, is best exposed on the south west coast. If time allows, we shall walk there (stop B).

The Upper Chasmops Shale is composed almost entirely of thinly bedded, dark grey to black shales although there are a few calcareous nodules, some septarian. The formation is locally fossiliferous and contains a low diversity fauna including _Broeggerolithus discors_, _Lonchodomas_ aff. _rostratus_, lingulids and species of _Onniella_, _Chonetoidea_ and _Sericoidea_. These and the underlying beds will be ideal for a discussion on the formation of the limestone nodules (Bjørlykke 1973, 1974) or concretions (Henningsmoen 1974).

STOP 9 ISLAND OF HOVEDØYA (J.F. Bockelie & A.W. Owen) The boat will moor on the west side of the island and we shall walk to the south-west corner. Fig. 9 has been adapted from Brøgger 1887 to show the Middle and Upper Ordovician units. We shall concentrate on the Upper Ordovician (Ashgill) Husbergøya Shale and Langøyene Sandstone (Brenchley & Newall 1975; see Fig. 10).

The Lower Isotelus Limestone (15.4 m) is exposed by the track and contains well developed siltstones-sandstones and shales. The Isotelus Shale (7 m) is also exposed in the track while the overlying Upper Isotelus Limestone crops out both by the track and along the foreshore. It comprises some 18.7 m of limestones, siltstones-sandstones and shales. Some (but not many) of the limestones contain pockets of shelly fossils including _Tretaspis latilimbus norvegicus_, _Brachyaspis_ sp. and cepahlopods. The overlying succession exposed along the foreshore was described by Brenchley & Newall (1975, Fig. 5) while Spjeldnæs (1957) discussed the upper parts.

Husbergøya Shale Formation contains a silty shale thought to have been deposited in an offshore environment with periodic storms causing deposition of 1-3 cm thick siltstone beds. At the base of this formation is a zone with numerous 'Trichophycus'. Individual silt beds can be traced for several hundred metres, occasionally some kilometres. The formation is relatively poor in fossils, but the faunal frequency and diversity increases from

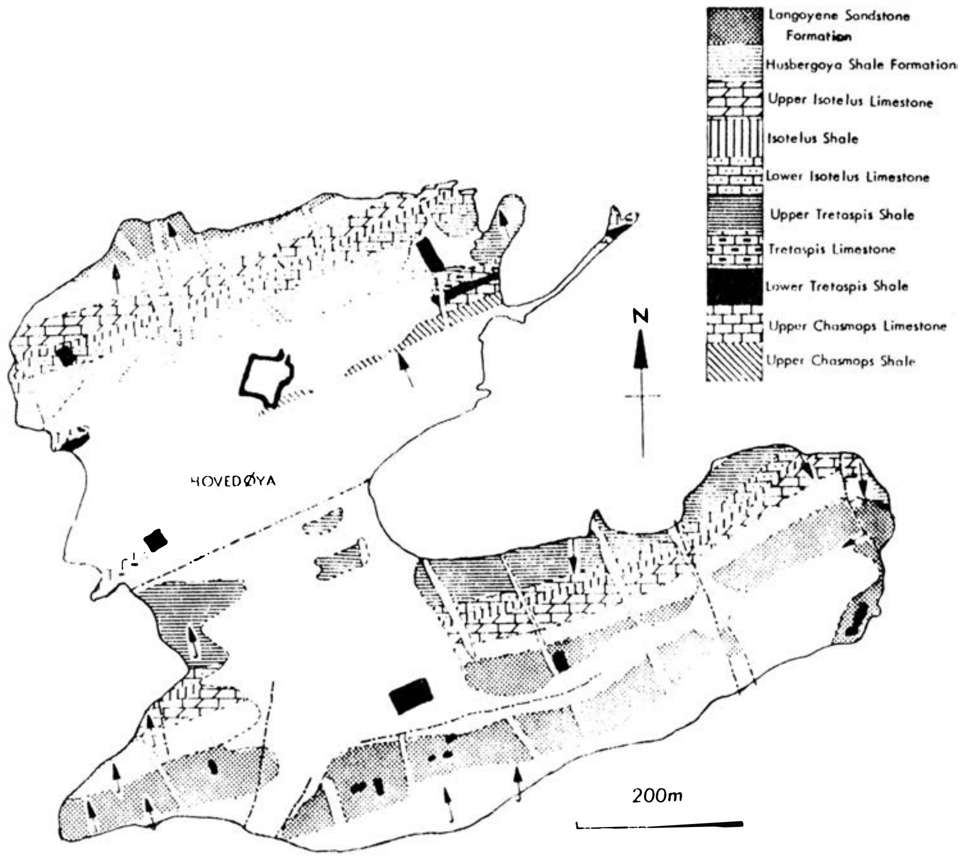


Figure 9. Geological map of the island of Hovedøya, Oslo (after Brøgger 1877 and Owen 1977).

east to west. The top of the formation is marked by a bioturbated fine sandstone which is a good marker. It can be traced on all the islands both in Oslo and Asker. This bed contains a fairly rich fauna of trilobites (Owen 1981), brachiopods, bryozoa and echinoderms (Bockelie, in press). A Climacograptus sp. of the normalis group has been found at this level on one of the nearby islands (Bockelie, in press). Even in this bed the diversities and frequencies of the fauna increases from east to west.

The Langøyene Sandstone represents a sequence of coarse sandstones with quartz grains up to 5 mm in diameter. Rapid changes in facies related to inshore, foreshore, intertidal and subtidal conditions make detailed correlations difficult. The most conspicuous units in this formation are the oolite shoal deposits in Asker (up to 11 m thick) and the thick sequences of beds showing cross-stratification and large scale ball-and-pillow structures (Brenchley & Newall 1977, 1979). The former are regarded as inshore, intertidal to subtidal deposits, the latter as seismically triggered. They are more common in Oslo than in Asker probably because of different sedimentation rates and the lower carbonate content of rocks in Oslo. At the top of the formation is an intraformational channel, infilled with large blocks of calcareous sandstones from near-by areas and overlain by Silurian shales.

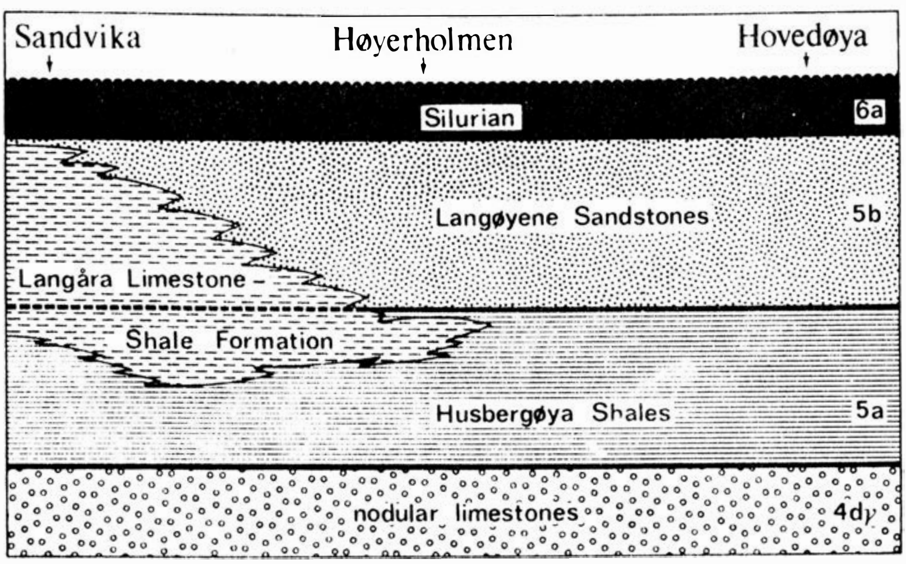


Figure 10. Stratigraphy of Upper Ordovician in Oslo—Asker (from Brenchley & Newall 1975).

From here the boat will return to the Oslo city hall quay where the buses will be waiting. Estimated time of arrival at Sundvolden is 18 00.

THE UPPER ORDOVICIAN (ASHGILL) OF RINGERIKE

Nils-Martin Hanken and Alan W. Owen

The Lower Palaeozoic succession in Ringerike is gently folded and youngs southeastwards (Fig. 1). The very open folds contrast strongly with the much tighter style of folding in Hadeland to the north.

The Ordovician rocks of Ringerike comprise alternating limestone and shale units with an interfingering of sandstone and limestone facies in

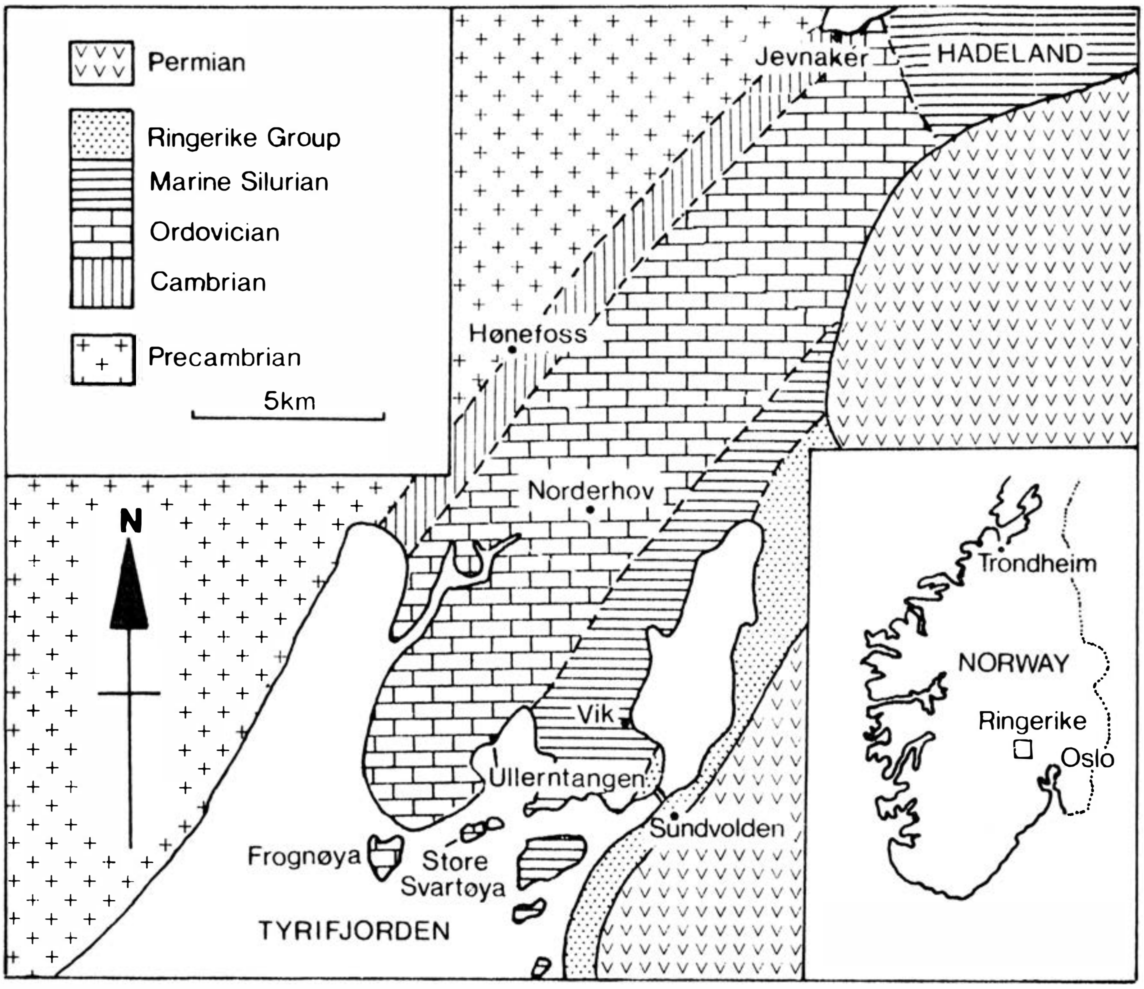


Figure 1. Simplified geological map of Ringerike (from Owen 1979).

the uppermost Ordovician. Only the upper Caradoc and Ashgill formations have been described in any detail to date (Kiær 1897; Hanken 1974, 1979; Owen 1979) although Størmer (1953) outlined the Middle Ordovician sequence and the whole succession is currently being mapped in terms of a modern lithostratigraphy (Owen and Harper in prep.).

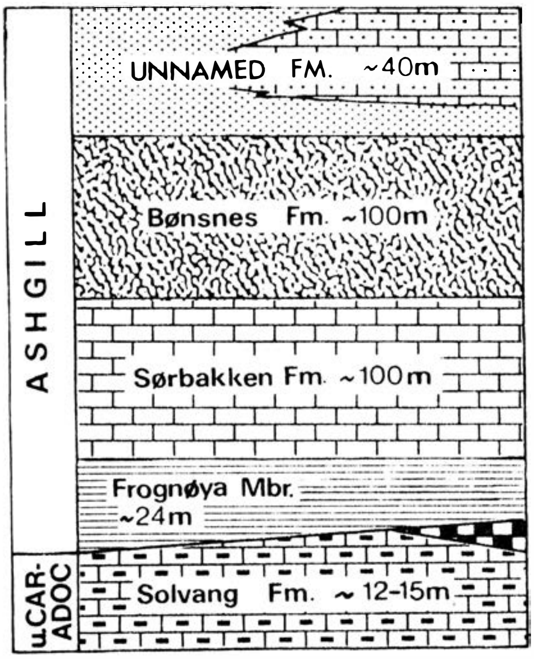


Figure 2. Summary of the Upper Ordovician succession in Ringerike.

The Ashgill succession is approximately 270 m thick (Fig. 2) and is dominated by shelf limestones although the lowest Ashgill is marked by the development of shales (the Frognøya Member of the Venstøp Formation). Latest Ashgill regression and transgression episodes resulted in the development of siliciclastic horizons as well as a very shallow water carbonate facies. Various elements of the Ashgill faunas of Ringerike have been described. The trilobites were described by Owen (1980, 1981) and the brachiopods are being revised by Harper (in prep.) following studies by Holtedahl (1916) and Öpik (1933) on the Strophomenida. Some taxonomic attention has also been given to the bivalves (Toni 1979), cephalopods (Strand 1933; Sweet 1958), gastropods and monoplacophorans (Koken 1925, Yochelson 1977), bryozoans (Brood 1980), conodonts (Hamar 1966), corals (Bassler 1950; Hanken 1979a; Kiær 1899, 1903, 1929; Neumann 1969, 1975; Scheffen 1933), ostracods (Henningsmoen 1954) and algae (Kiær 1920). In addition, Kaljo et al. (1963) have compared the late Ashgill corals and stromatoporoids of the Oslo Region (including Ringerike) with those of Estonia.

The route from Sundvolden passes over the causeway at the south end of Steinsfjord from where the boat will depart for Frognøya (Fig. 1). The red sandstones and shales on the beach and on the stretch of road beyond are described by Whittaker (1977) and show non-marine redbeds of the

Ringerike Group (Ludlow).

STOP 1 FROGNØYA (NM 65205825) (Fig. 3)

The section on the north-west coast of this island contains the stratotypes for the Høgberg Member of the Solvang Formation, the Frognøya Member of the Venstøp Formation and the base of the Sørbakken Formation in a cliff some 35 m high. The gentle northeastward dip of the succession enables the complete 65 m of this section to be examined at or about beach-level around the northwest promontory.

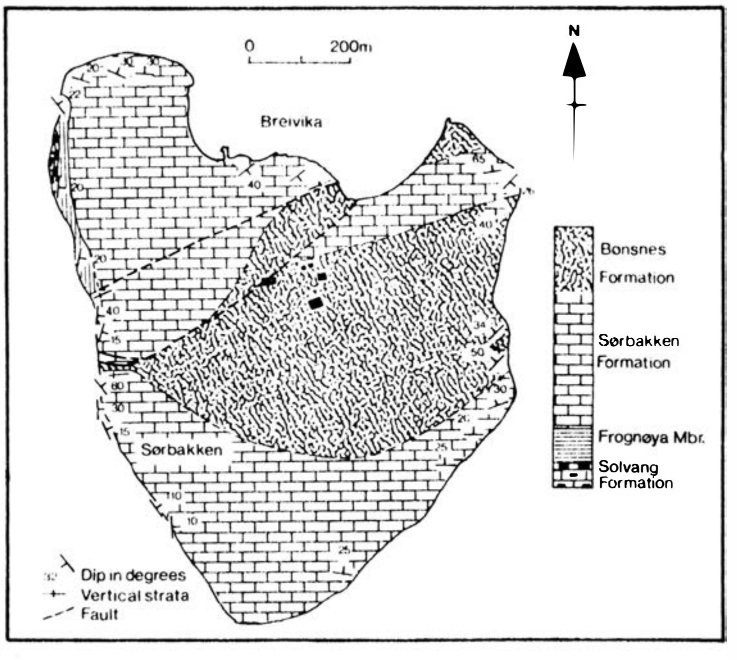


Figure 3. Geological map of Frognøya (from Owen 1979).

Solvang Formation 7.5 m of the Solvang Formation is exposed here. Abundant calices of the cystoid Echinosphaerites occur at about fjord-level in the lowest exposed part of 4.6 m of nodular and massive limestone. These beds also contain a 14 cm zone of imbricated nodules indicating dislocation parallel to bedding. The upper 2.9 m of the formation is composed of planar limestones and shales (The Høgberg Member) and a lens (now quarried out) in the lower part of this has yielded a very diverse trilobite fauna dominated by Tretaspis kiæri, Phillipsinella preclara and Lonchodomas aff.

pennatus (Bruton 1976; Owen & Bruton 1980). These and other elements of the fauna also occur elsewhere in the member but are rare and are interpreted as representing the final phase in the progressive immigration of a carbonate facies fauna into the central Oslo Region. The distinctiveness of this fauna led some earlier workers to suggest an hiatus at equivalent levels elsewhere in the region. The recent recognition, however, of a marked faunal shift associated with the diachronous base of the overlying Venstøp Formation makes such an hypothesis unnecessary (Bruton and Owen 1979).

Venstøp Formation The Frognøya Member of the Venstøp Formation comprises friable dark shales with thin beds of limestone and laminated siltstone. The bases of some of the latter horizons show sole markings. The trace fossil Chondrites is seen on some bedding planes. The fauna shows low diversity, although in the upper part the trilobites Tretaspis anderssoni and Flexicalymene trinucleina? and the brachiopod Chonetoidea iduna are abundant. Other trilobites include:
Tretaspis hisingeri, Remopleurides spp., Stenopareia aff. glaber, Cybeloides (Paracybeloides) aff. girvanensis, Calymene (s.l.) aff. holtedahli, Calyptaulax norvegicus, Toxochasmops aff. extensa, Primaspis (P.) bucculenta.

Other elements of the fauna include bivalves, small gastropods, inarticulate brachiopods, the articulate brachiopod Gunnarella and linearis Zone graptolites (including Dicellograptus cf. johnstrupi), some in full relief.

Sørbakken Formation 34 m of micritic limestones and calcareous shales of the Sørbakken Formation are exposed along the north-west coast of Frognøya. These beds contain a diverse fauna dominated by trilobites and brachiopods but also gastropods, nautiloids, bryozoans and rare graptolites. The trilobite fauna is similar to that of the underlying unit although species of Toxochasmops and Cybeloides are absent, the Remopleurides is close to R. aff. dalecarlicus Warburg and Illaenus (Parillaenus) cf. roemeri and Holotrachelus cf. punctillosus appear. The brachiopod fauna is more diverse than that of the Venstøp Formation and includes species of Gunnarella, Dalmanella, Triplesia, Oxoplecia, Eoplectodonta and Cyclospira.

The uppermost part of the Sørbakken Formation can be examined along the central part of the west coast of Frognøya. The cliff line between here and the Solvang Formation outcrop shows the effect of faulting and thrusting. The uppermost beds of the Sørbakken Formation are somehwat darker limestones than those seen on the north-west promontory and locally contain a trilobite fauna dominated by Tretaspis anderssoni, Stenopareia aff. glaber, Illaenus (Parillaenus) cf. roemeri and Isotelus frognoensis. The base of the overlying Bønsnes Formation is marked by the development of dark, platy limestones packed with fragments of the calcareous alga Palaeoporella. Elsewhere on Frognøya the Palaeoporella-bearing strata are overlain by limestone containing silicified corals.

STOP 2 STORE SVARTØYA (NM 67855835) The highest Ordovician unit in Ringerike, so far unnamed (Fig. 2), is about 40 m thick and reflects a complex pattern of depositional environments (Fig. 4). The only complete section is exposed here on Store Svartøya where the upper 13 m of the Bønsnes Formation, all the unnamed Formation, and the lower 18 m of the Silurian Sælabonn Formation are exposed. The upward change in lithology from the shaly Bønsnes Formation to sandstones of the unnamed Formation is gradual (Kiær 1897). The sandstone sequence is about 15 m thick and thickens northwards. The boundary between the sandstone unit and the overlying limestone is erosional with development of a basal sandstone conglomerate. The clasts are angular to subrounded and contain the same faunal elements as the underlying sandstone, indicating that they have been derived locally.

The overlying strata are dominated by crinoidal biosparites with occasional small unbedded mounds. The mounds attain their greatest size here and on Lille Svartøya where their visible height may be more than 3 m; in the Ullerntangen area they are generally much less. The lateral change from the bedded crinoidal biosparite to the

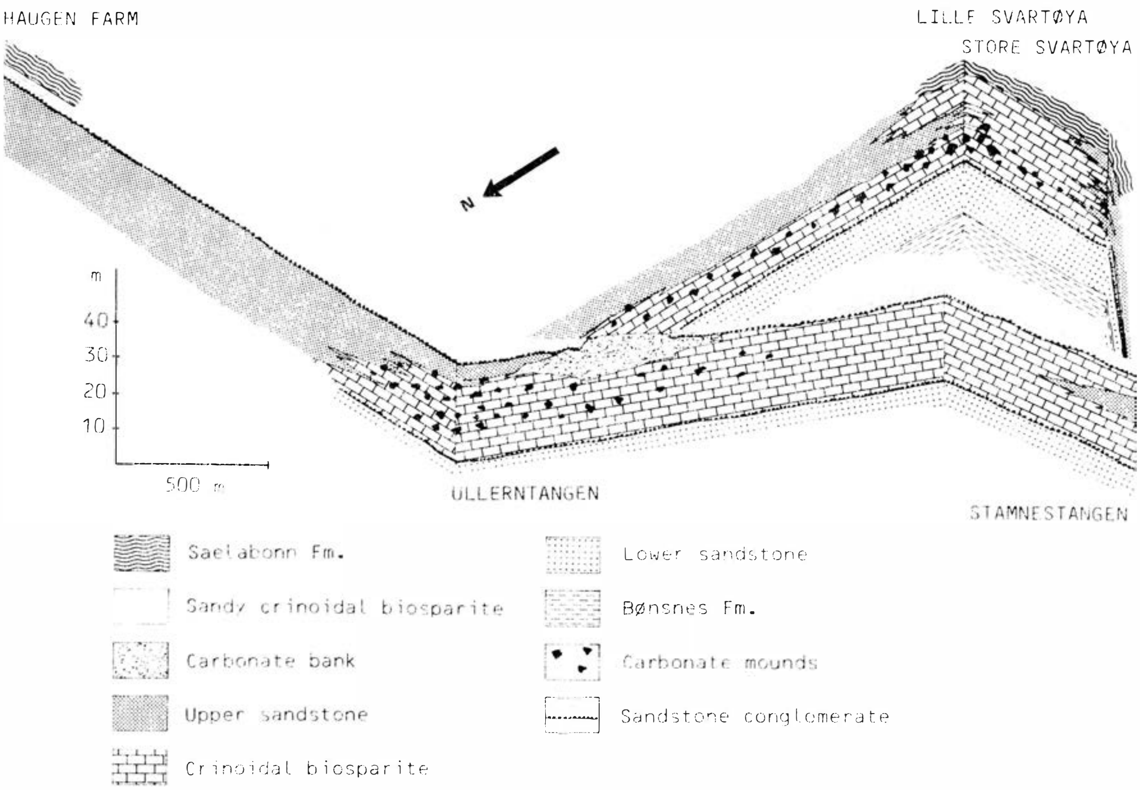


Figure 4. Fence diagram showing the lithofacies distribution within unnamed Formation at the top of the Ordovician in the central Ringerike area.

unstratified limestone of the mounds is fairly abrupt, but marly intercalations can be followed into some of the mounds with only slight deflection indicating that they did not protrude very much above the contemporary sea-floor. The lithology of the mounds includes discontinuous argillaceous intercalations and pockets of argillaceous limestone with scattered colonies of tabulate corals and sheet-like stromatoporoids.

Dislodged blocks with a typical mound biota are fairly common in the intermound facies close to the mounds. They are of variable size, the largest being more than one metre in diameter. The presence of these blocks indicates cementation penecontemporaneous with mound growth. The crinoidal biosparites have yielded a single trilobite specimen, an extremely large cephalon of Eobronteus aff. laticauda. The Ordovician-Silurian boundary in Ringerike is only exposed here on Store Svartøya. It is marked by a karst surface with north-south trending runnels infilled with Silurian shale/siltstone. Further north the hiatus is developed as a fairly smooth surface cutting straight through fossil fragments and oolites. Investigation of the brachiopods in the basal Silurian deposits seems to indicate that the lowermost part of the Rhudannian is missing in Ringerike and with a significant hiatus between the Ordovician and Silurian (Thomsen 1982).

STOP 3 ULLERNTANGEN (NM 68506100) (Fig. 1) On the southern part of Ullerntangen the small argillaceous mounds are overlain by an extensive carbonate bank which is at least 350 m long and 100 m wide. Kiær (1897) regarded this structure as a large reef, but Hanken (1974) reinterpreted it as an extensive carbonate bank because it lacks a framework and has a very high percentage of transported fauna (Fig. 5). The bank is very fossiliferous and

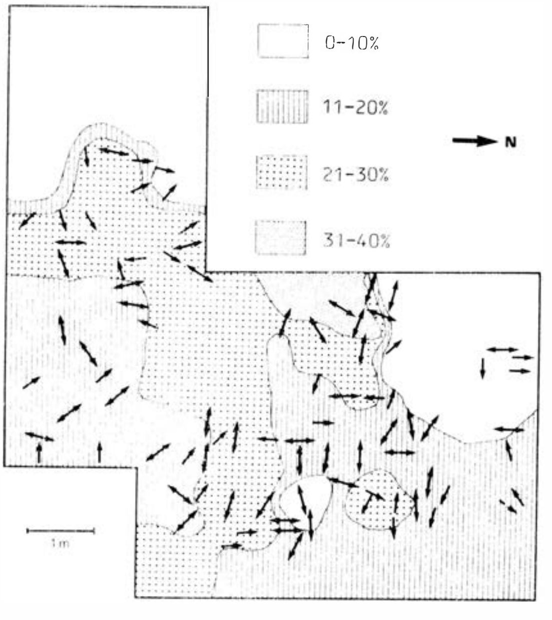


Figure 5. Slightly oblique section through a part of the surface of the carbonate mound at Ullerntangen showing the percentage of the surface occupied by corals and stromatoporoids. Arrows indicate the growth direction of coral colonies and stromatoporoid coenostea; (a double arrow has been used in cases where way up is uncertain). Highly variable growth directions indicate that most of the organisms are not *in situ*.

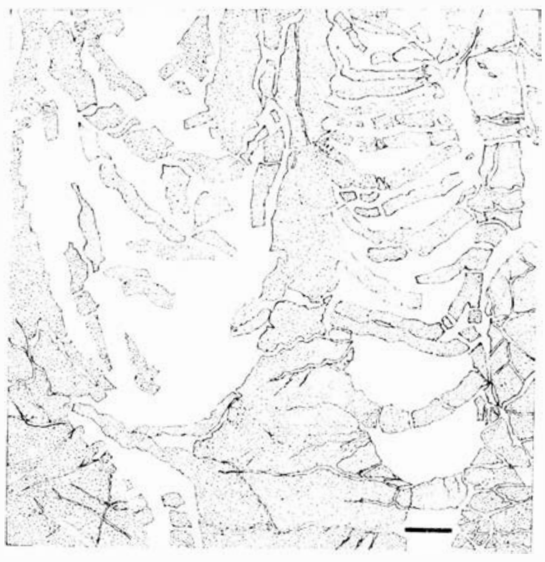
is dominated by the stromatoporoid *Pachystylostroma* sp., the colonial rugose corals *Palaeophyllum insertum*, *Cyathophylloides* sp., *Tryplasma* sp. and the tabulate corals *Saffordophyllum kiaeri*, *Rhabdotetradium frutex*, *Lyopora incerta*, *Reuschia* sp., *Catenipora* sp., *Proheliolites* sp. and *Plasmopora* sp. Locally isolated parches of cystoids and inarticulate brachiopods of the family Trimerellidae are found in great numbers.

The matrix of the carbonate bank consists of microspar with abundant skeletal fragments. Point counts of thin sections have shown that the skeletal components comprise up to 40-50%. The skeletal sand is mostly composed of echinoderm, brachiopod, and bryozoan debris and the calcareous algae Vermiporella sp., Girvanella sp. and Hedstroemia sp.

The carbonate bank at Ullerntangen is of highly variable thickness because of extensive erosion prior to deposition of an overlying sandy crinoidal biosparite facies. Fissures up to 5-6 m deep have steep, sometimes vertical to overhanging sidewalls indicating subaerial erosion of the already lithified bank.

Most fossils with large primary cavities (e.g. corals and cephalopods) have collapsed after deposition on the carbonate bank. In some cases the whole fossil is affected while in others only certain zones in the fossils are broken, the intervening parts not being affected (Fig. 6). With the aid of cathodoluminescence microscopy,

Figure 6. Drawing of longitudinal section through the colonial rugose coral Tryplasma sp. The coralite wall is transected by numerous cracks and the tabulae are fragmented. Stippled, coral; white, secondary sparry infilling. Carbonate bank, Ullerntangen. Scalebar - 1 mm.



the presence of several distinct calcite generations in the fractured fossils can be demonstrated (Fig. 7). The first calcite generation is an isopachyous rim of small, non-luminescent, equant crystals of calcite which are never found on the broken surfaces. However, the broken surfaces of the fossils are directly imbedded in a thin veneer of brightly luminescent second generation calcite cement. The small cracks in the walls of the fossils are also infilled with second generation calcite. These observations indicate that the fracturing took place subsequent to deposition of the first generation calcite, but prior to deposition of the second. The extensive fracturing is probably a result of the early emergence of the partly cemented carbonate bank. Emergence would be accompanied by stress set up by loss of the support provided by hydrostatic pressure.

The rocks in the upper part of the unnamed formation commonly have a somewhat dark appearance due to a high content of solid hydrocarbons; a fact which was pointed out by Kjerulf (1862). In the carbonate bank on Ullerntangen the hydrocarbons are restricted to primary cavities in fossils or in thin cracks. Fig. 7 shows the relationship between the hydrocarbons and the deposition of different cement generations. The hydrocarbons, probably derived from the Alum shale (Middle Cambrian—Lower Ordovician), have filled late diagenetic cracks and the remaining cavities in fossils after

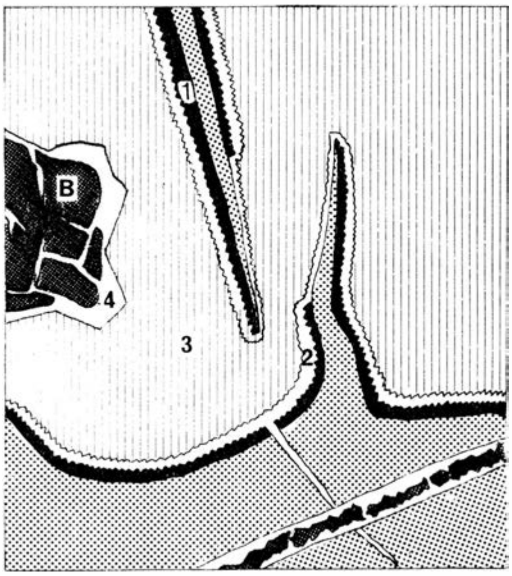


Figure 7. Relationships of cement generations and solid bitumen (B) in a coral (stippled) as revealed by cathodoluminescence microscopy. The numbers refer to the different cement generations. There are two different generations of cracks; the last is infilled with both solid bitumen and secondary calcite of the 4th generation.

deposition of the third calcite generation. During a later diagenetic stage the originally fluid hydrocarbons have lost their most volatile constituents and the remaining part has gradually turned to solid bitumen. This transition has been accompanied by a reduction in volume so that the solid bitumen shows numerous cracks from the later stage of this conversion. The cracks are later filled with a fourth generation of sparry calcite.

The carbonate bank passes northwards into a sandstone facies which contains a rich fauna close to the bank (the faunal diversity diminishes northwards). The fauna is dominated by transported disarticulated brachiopods including species of *Plaesiomys*, *Schizophorella*, *Hirnantia*, *Katastrophomena*, *Sowerbyella* and *Hypsiptycha*. The brachiopods commonly show signs of bioerosion. Other elements of the fauna include the solitary rugose coral *Ullernelasma svartoeei* and the gastropods *Phragmolites* sp., *Tropidodiscus* sp., *Clathrospira* sp., *Loxoplocus* (*Lophospira*) sp. and *Globonema* sp. A species list of the bryozoans is given by Brood (1980).

Sandstone pseudomorphs of aragonite fossils are highly characteristic of the uppermost Ordovician sediments in the central Ringerike area (Hanken 1979). Moulds of gastropods and cephalopods have been filled with well sorted clastic sand giving a fairly good cast in sandstone of the original organism. The fossil moulds are thought to have been formed by selective dissolution of aragonite shell by groundwater during early emergence of the semiconsolidated sediment.

THE AREA AROUND VIKERSUNDBAKKEN, MODUM

Bjørn Wandås

The area is situated approximately 40 km west of Oslo, on the SW-extension of Tyrifjorden. The river system from Drammenselva in this area forms a long, narrow lake called Bergsjø. The Palaeozoic rocks are situated along the eastern shoreline, continuing uphill to the Permian Finnemarka granite complex which makes up the major part of the area south of Tyrifjorden. On the west side of Bergsjø Precambrian rocks are separated by a monoclinal flexure from the Palaeozoic sediments. The flexure is here located within the river system and continues northwards along the western shoreline of Tyrifjorden (Ramberg & Larsen 1978). Precambrian rocks also occur on the east side of Bergsjø in the area of low ground near Vikersund. However, the boundary with the Palaeozoic is covered by Quaternary sand and gravel.

Southwards from Vikersund the main road (RV 35) continues up a steep hill of Carboniferous mænaite sills and Cambrian alum shale. The mænaite sills follow a N-S trend with a slight easterly dip, and continue along strike for a total length of at least 30-40 km. In this area there are two 10-20 m thick and two 1-2 m thick sills. The intrusives are acidic with a high feldspar content. They have been dated to 296 ±6 million years by the Rb/Sr-method (Sundvoll & Wandås in prep.) and are thus amongst the oldest intrusives in the Oslo Region. In this area the alum shale below and between the sills is composed of horizontally bedded shale which apparently lacks limestone nodules and is of probable Middle Cambrian age (*Ptychagnostus* sp. (1c-1d) has been identified).

Southwards the road is located on top of the mænaite sills. The fields to the east are mostly situated on strongly folded and faulted Upper Cambrian alum shale in contrast to the relatively undisturbed shale below and between the sills.

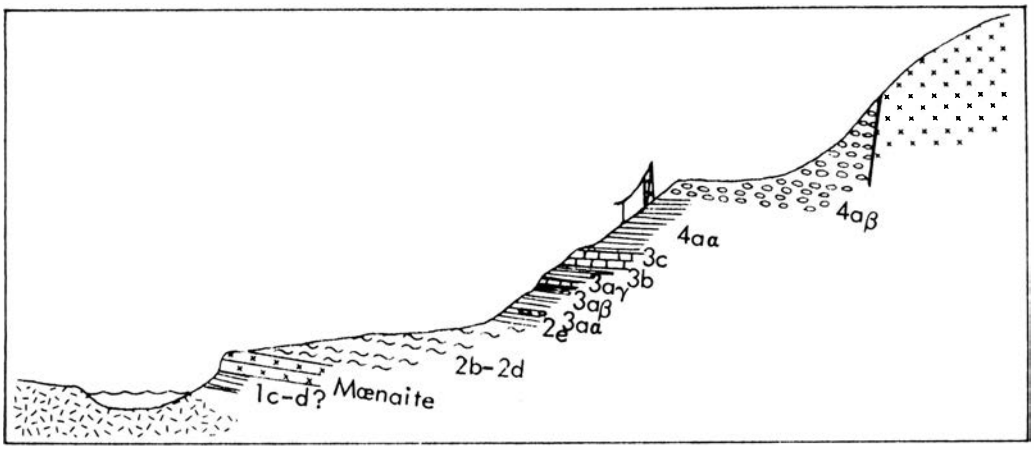


Figure 1. Simplified profile from Bergsjø to Finnemarka granite complex.

The remaining Palaeozoic sediments (Upper Cambrian-Middle Ordovician) between the top of the mænaite sills and the Finnemarka granite complex crop out in a series of tight, strike-faulted, E-W folds. The faults have a maximum throw of approximately 100 m. The folding and faulting was initiated during the Caledonian Orogeny, but the major part of the fault system was activitated (reactivated?) during the penetration of the Finnemarka granite complex. This is shown by the fact that some of the faults cut across the mænaite sills.

STOP 1 ROAD TO ØVRE ØREN/HOVLAND FARMS The embayment of Bergsjø is caused by two larger faults which have lowered the mænaite sills below present water level and caused more extensive erosion of the alum shale inside Sponevika. The stream on the west side of the fields runs on top of the mænaite sills. The contact with the strongly folded and faulted alum shale is exposed to the south where the stream turns northwards. Further upstream (eastwards) there are several exposures of the alum shale. Limestone nodules are packed with trilobites of Upper Cambrian age including: Ctenopyge fletcheri, Sphaerophthalmus humilis and Peltura scarabaeoides of zone 2dγ.

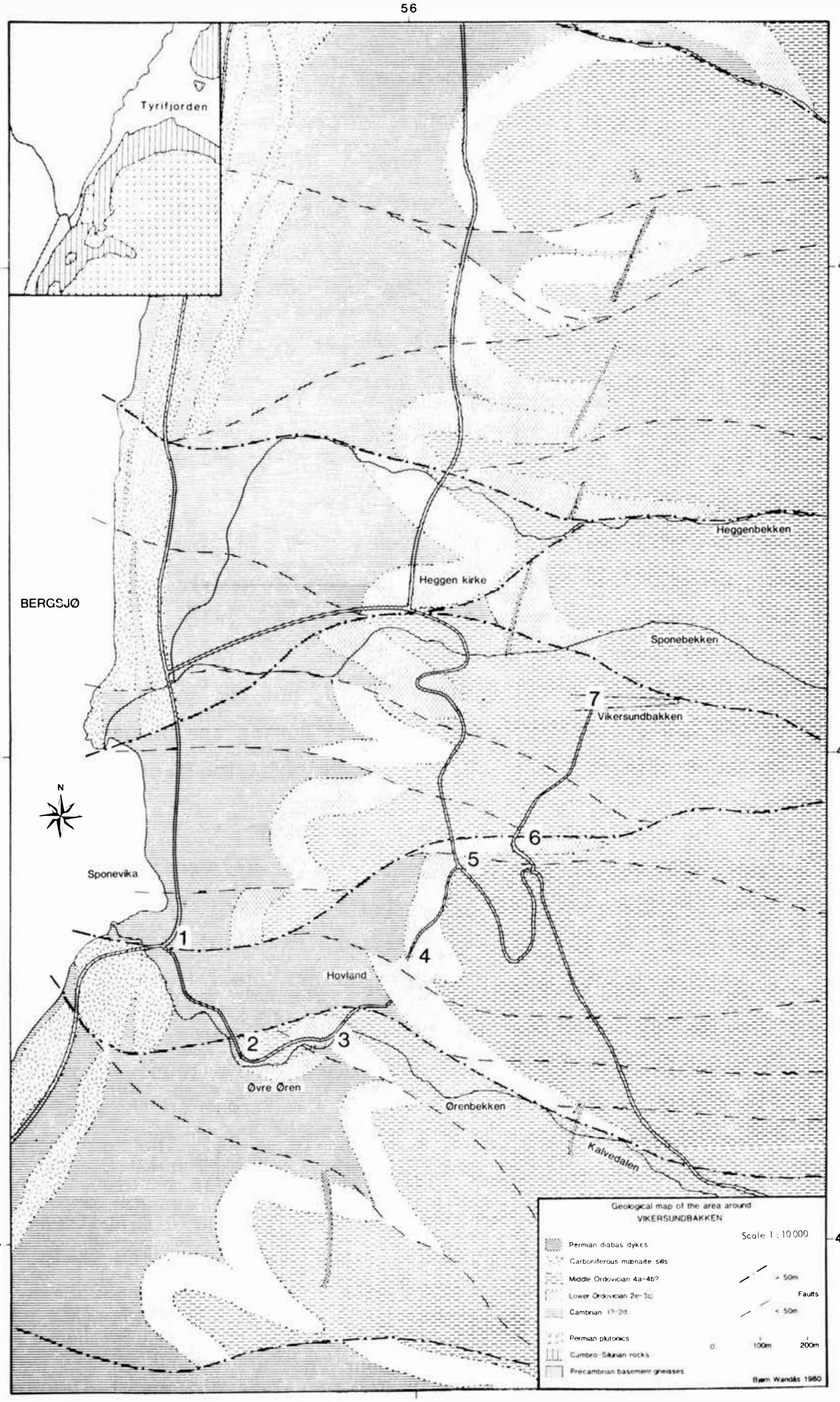


Figure 2. Geological map of the area around the Vikersund ski-jump with stops shown.

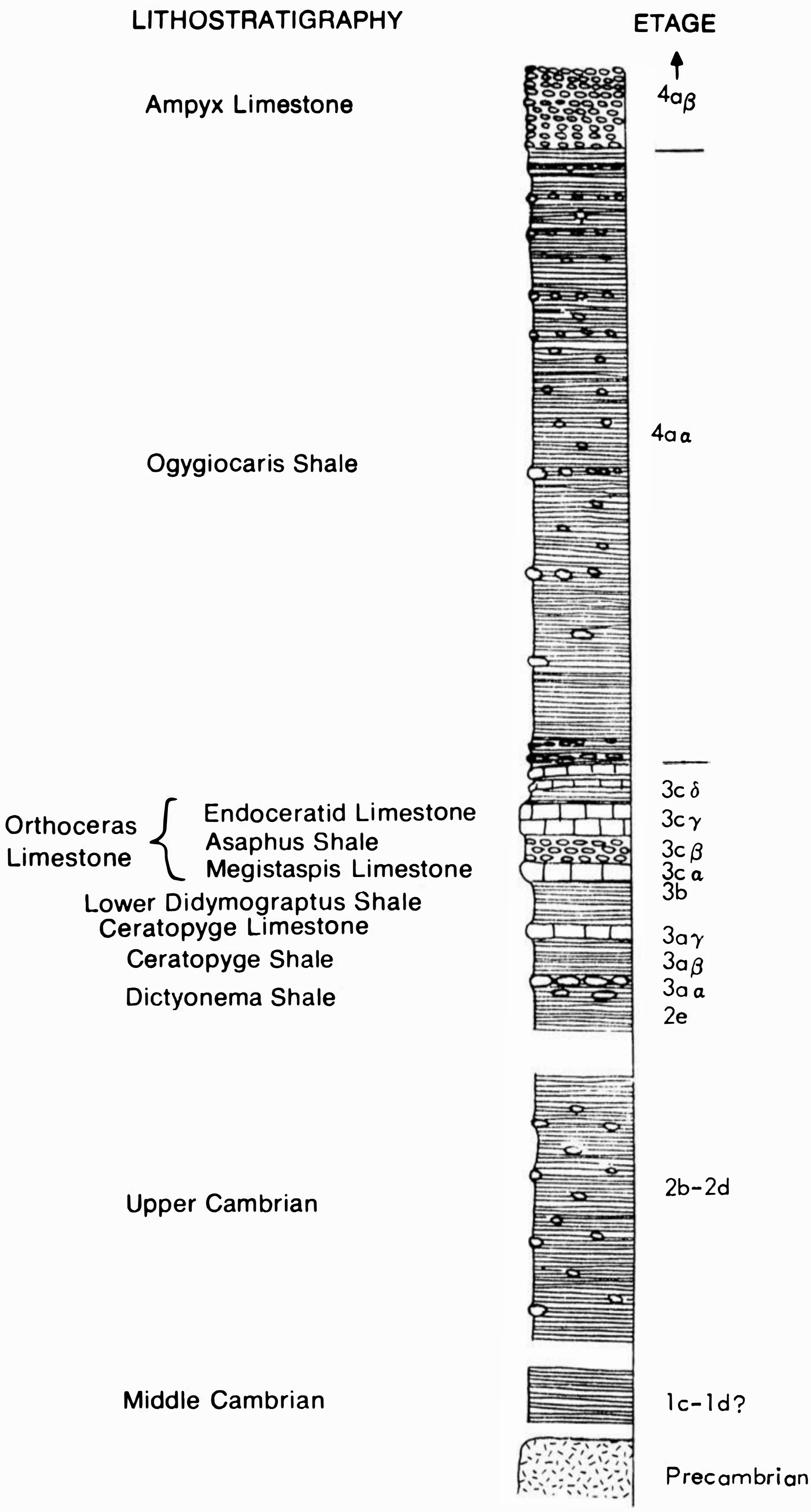


Figure 3. Simplified stratigraphy of the area around Vikersund ski jump.

STOP 2. SHARP BEND ON ROAD TO ØVRE ØREN FARM A continuous profile from the Dictyonema Shale to the Orthoceras Limestone is present. In the Dictyonema Shale, Dictyonema flabelliforme flabelliforme occurs in a thin zone 22.15 m below the Orthoceras Limestone and 5.85 m below a large limestone nodule belonging to the Zone of Platypeltoides. However, the Dictyonema Shale is better exposed at Hovland farm (STOP 4). The large limestone nodule has so far only yielded Peltocare norvegicum but at other localities within the map area equivalent beds have yielded Bienvillia tetragonalis broeggeri? and Platypeltoides incipiens. The limestone nodule is overlain by 7.5 nm of shale

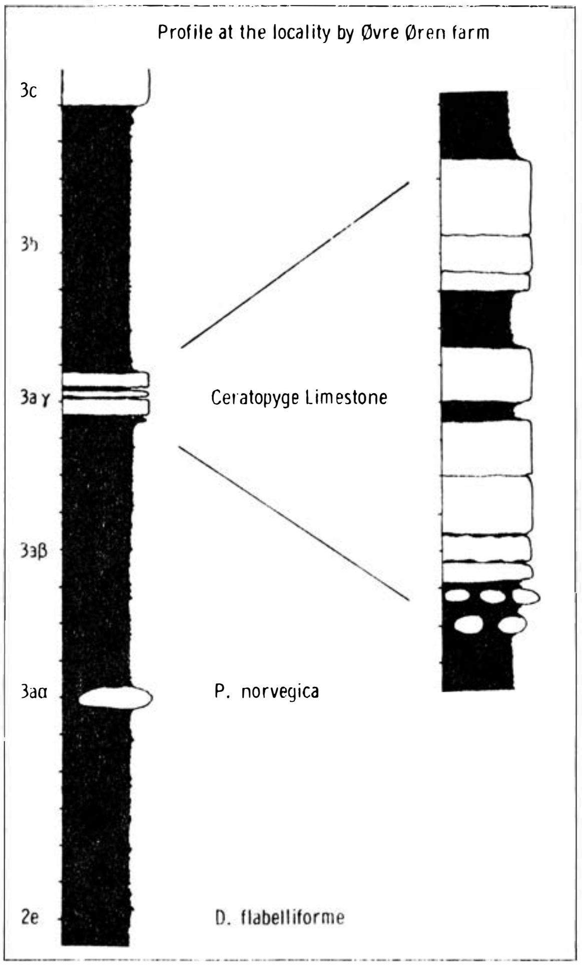


Figure 4. Profile at Øvre Øren.

belonging to the Ceratopyge Shale. The shale is exposed at only a few localities in the area, and is usually poorly fossiliferous. So far only specimens of Obulus sp. and sponge spicules have been recovered in a section above Hovland farm.

The Ceratopyge Limestone at Øvre Øren farm consists of several 5-20 cm thick limestones with interbedded thin shales. The total thickness, including two nodular limestone beds, is 1.3 m. The limestone nodules and the two lowest limestone beds are especially rich in well preserved fossils, including: Ceratopyge forficula acicularis, Euloma ornatum, Apatokephalus serratus, Niobe insignis, Trinodus mobergi, Harpides rugosus, Triarthrus sp., Shumardia sp., and at least two species of brachiopods. The limestone sequence is followed by 7.5 m of Lower Didymograptus Shale without limestone nodules. The shale contains horizons with abundant graptolites, Didymograptus and Phyllograptus species being particularly common. The sequence is capped by a 0.9 m limestone bed of the succeeding unit, the Megistaspis Limestone.

STOP 3 ROAD BEND SOUTH OF HOVLAND FARM A fault line is crossed and the Lower Didymograptus Shale—Orthoceras Limestone sequence is repeated. Here the Megistaspis Limestone is 0.8 m thick, while the Asaphus Shale is 2.55 m thick.

STOP 4 HOVLAND FARM Another fault line has been crossed and the sequence from the Dictyonema Shale is again repeated. Below the barn bridge a few large limestone nodules are exposed - the most northerly one having yielded Boeckaspis mobergi. Fragments of Dictyonema may be found in the shale just south of the barn bridge, but a 20-30 cm thick zone 4-5 m north of the bridge contains abundant D. flabelliforme flabelliforme. The boundary between the Cambrian and the Ordovicium is not exposed.

STOP 5 PATH TO ROAD INTERSECTION NORTH OF HOVLAND At the road intersection is a good exposure of the Asaphus Shale and Endoceratid Limestone with the succeeding transition beds. The Endoceratid Limestone here is 5.2 m thick (because of faulting?) and the transition beds are 2.7 m. The beds here are on the southern limb of a large fold that continues uphill and crosses the road the road at STOP 6. Along the road to STOP 6 are several exposures of the Ogygiocaris Shale which is a black and grey shale sequence with numerous small limestone nodule beds and many small scale faults and folds.

STOP 6 ROAD TO THE VIKERSUND SKI JUMP Exposed here are the limbs of the fold mentioned above. The core of the fold consists of Lower Didymograptus Shale with graptolites, and the southern limb shows the tripartite division of the Orthoceras Limestone. A few exposed beds of Asaphus Shale on the southern limb of the fold contain Ranorthis norvegica, and a few ostracods. The southern limb of the fold is slightly overturned, and the transition beds are 3.3 m thick. These and the succeeding 10 m of shale contain an interesting fauna with many large trilobites: Asaphus (Asaphus) striatus (-6 m), Megistaspis (Megistaspidella) sp. (-6 m), Metopolichas celorrhin? (0.2-3.5 m), Geragnostus hadros (0.2-5.4 m), Cyrtometopus clavifrons (0.4-5.5 m), Ampyx nasutus (1.15-11.85 m), Pliomera fischeri (1.28-13.9 m), Megistaspis (Heraspis) laticauda (2.35-5.4 m), Niobe frontalis (2.5-6.7 m), Pseudobasilicus brevicostatus (3.1-4.5 m), Megistaspis (Megistaspidella) maximus (7-14 m), Botrioides? bucculentus (7.9-12,5 m), and Ogygiocaris sarsi ((8?) 10-13 m).

STOP 7 VIKERSUND SKI JUMP The Ogygiocaris Shale is exposed in the roadside and contains abundant specimens of Ogygiocaris. From the ski-jump it is possible to follow some of the beds and faults in the lower terrain. Note the different vegetation of pines growing on the mænaite sills and thornbushes on the limestones. Further uphill there is a marked increase in the degree of contact metamorphism, although the Ampyx Limestone is identifiable to the right of the ski jump scaffold. The total thickness of the Ogygiocaris Shale is 120 m while at least 150 m of nodular limestone succeeds this.

THE ORDOVICIAN SUCCESSION AT VESTFOSSEN AND KREKLING

Torsten Klemm

The object of this part of the day's excursion will be to demonstrate a Tremadoc-Llanvirn succession deposited along the south-west margin of the Oslo Region (Skjeseth 1952; Erdtmann 1965, Fig. 3). Of interest is

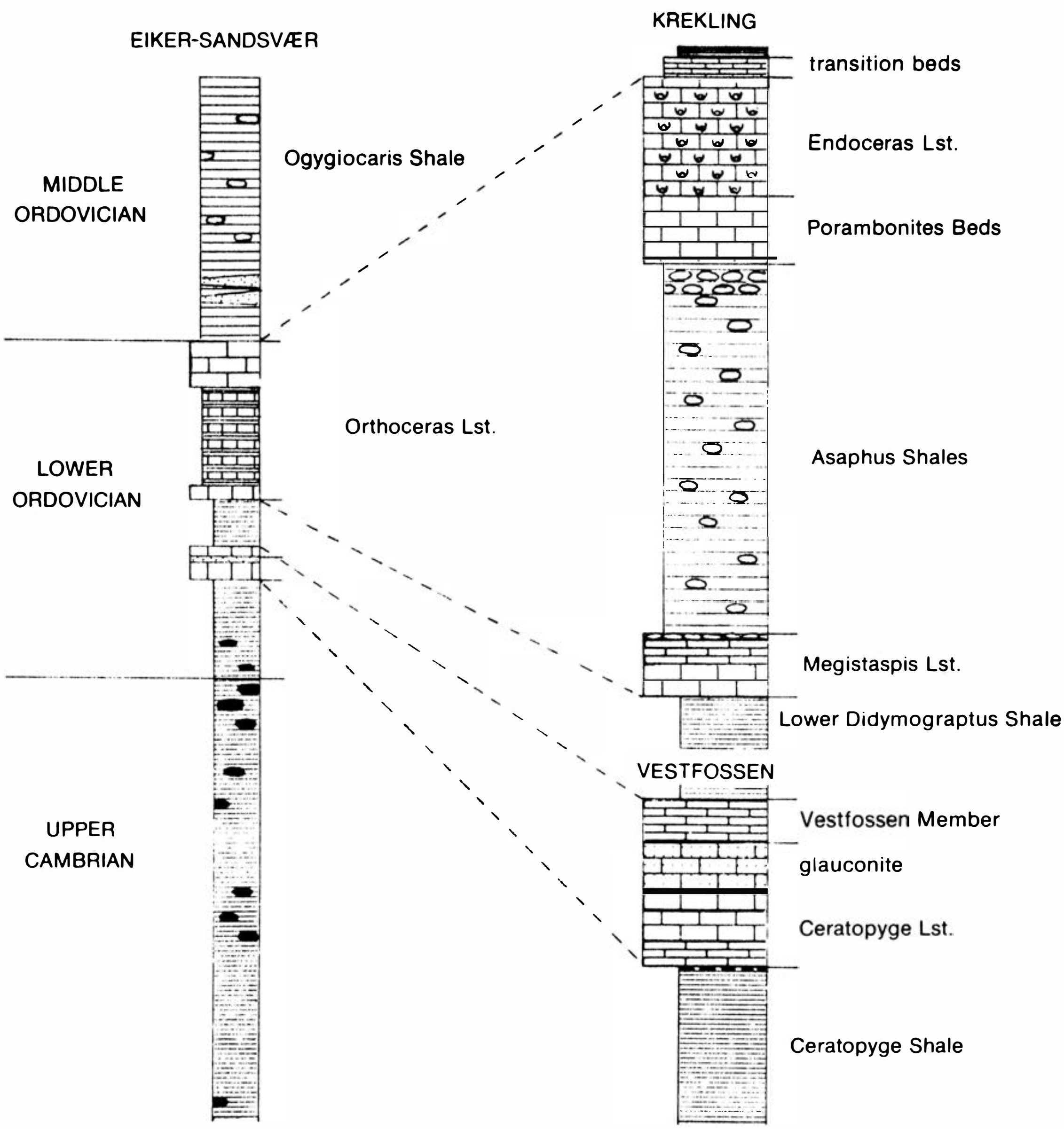


Figure 1. Generalised stratigraphy in Vestfossen-Krekling area (after Henningsmoen, unpubl.)

the development in the area of limestones approximately 0.5 m thick at the base of the Lower Didymograptus Shale. The limestones (Vestfossen Member, Fjelldal 1966) belong to the Hunnebergian Zone of Megistaspis (Ekeraspis) armata. Below them is the Ceratopyge Limestone and above are black shales of the Lower Didymograptus Shale equivalent to only part (Galgeberg Member, Erdtmann 1965) of its development at the type locality of Tøyen in Oslo.

The area was described in detail by Brøgger (1882). Since this time sections in the area have been discussed by Skjeseth (1952), Tjernvik (1956), Erdtmann (1965), Fjelldal (1966), Størmer (1967) and Skaar (1972). The author has remapped the area (scale 1 : 5 000) and the map, together with detailed descriptions of trilobites from the Vestfossen Member, will form the basis of a thesis to be submitted in 1982 to the University of Hamburg, Germany.

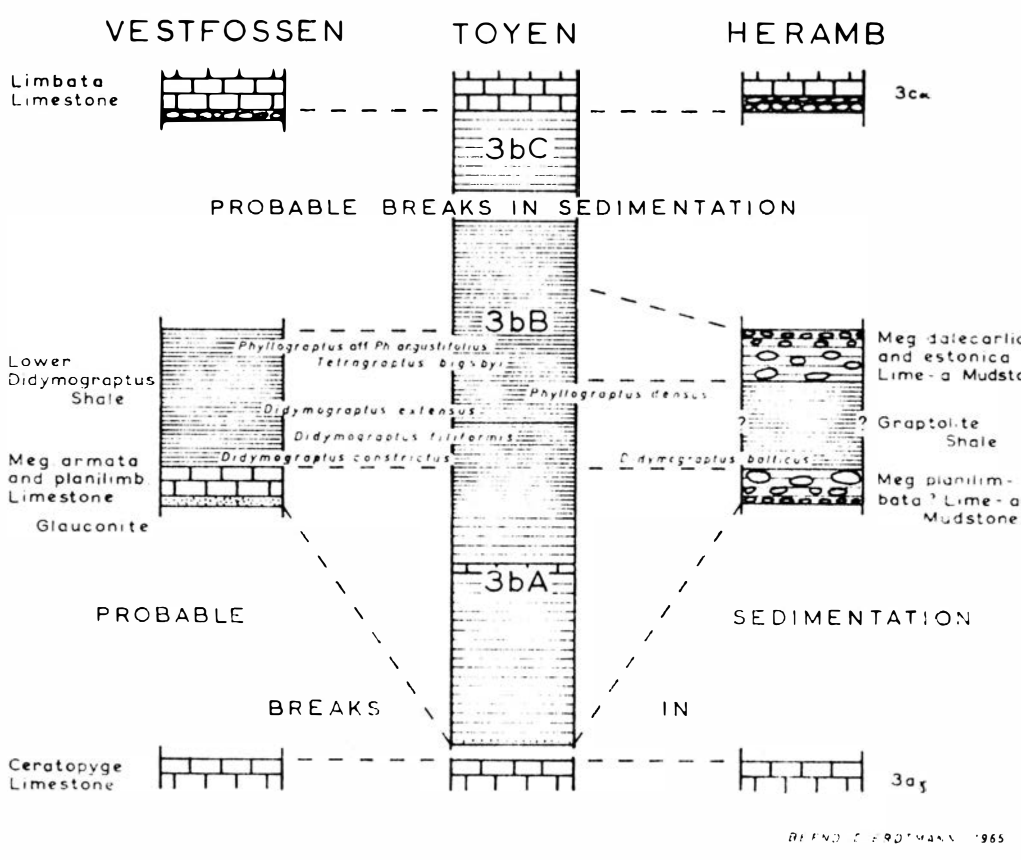


Figure 2. Correlation of the Vestfossen, Tøyen (Oslo) and Heramb localities (after Erdtmann 1965).

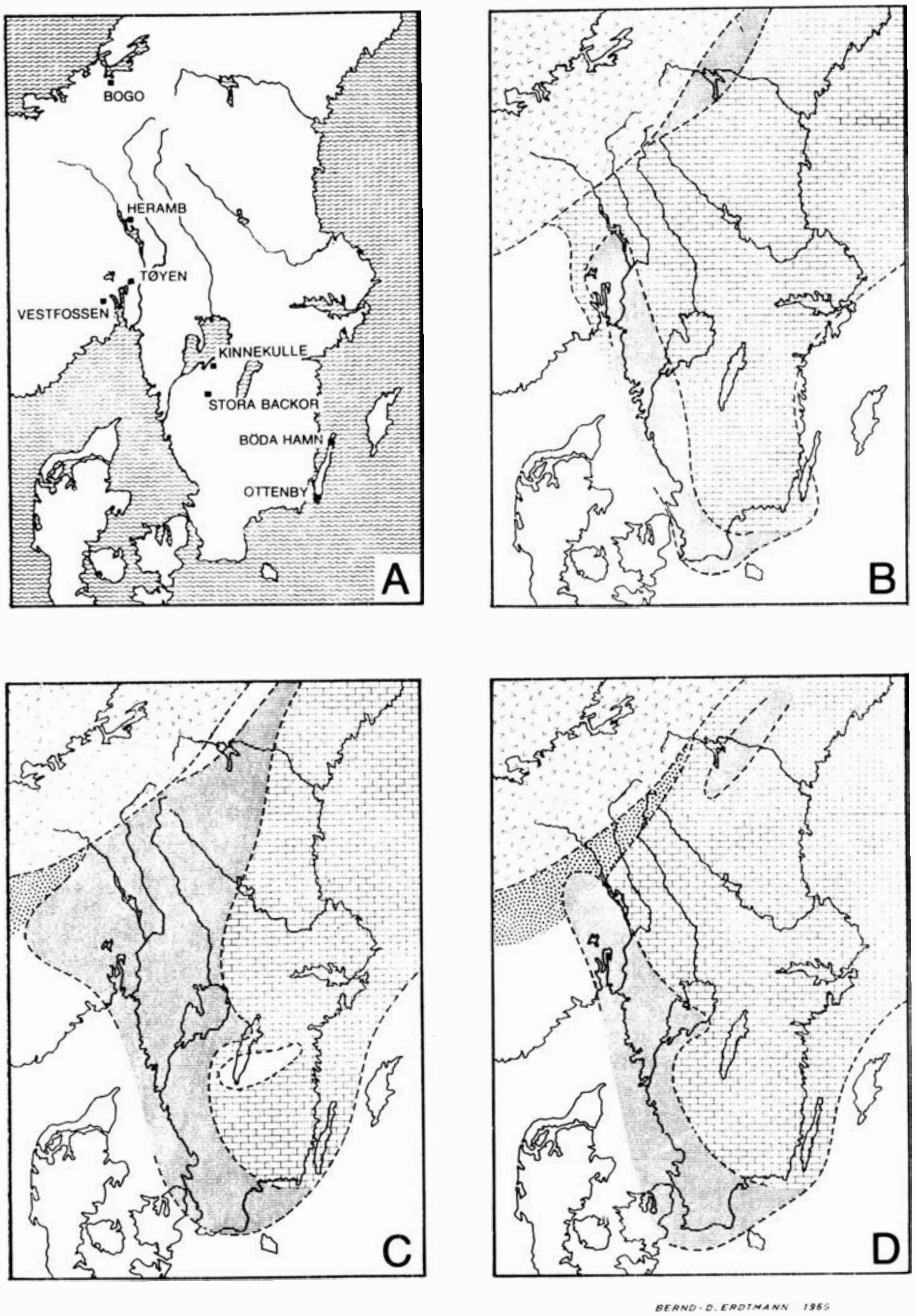


Figure 3. The palaeogeography of southern Scandinavia during deposition of Lower Didymograptus Shale and facies. A, important Norwegian and Swedish localities; B, Hunneberg Stage; C, Billingen Stage; D, Volkov Stage. White - areas of no deposition, lst. blocks - shelly facies, horizontal shading - graptolite facies, stipple - clastic facies, v - Caledonides (modified after Erdtmann 1965).

STOP 1 HALS, NEAR SKARA (NM 486230) This locality (Figs. 2, 5a) is more accessible than the type locality of the Vestfossen Member at Skara cross roads (Fjelldal 1966). The succession on the north-west limb of a fold is:

Ceratopyge Limestone (0.5 m) Compact, light blue limestone in lower half with light, partly recrystallised upper half. The uppermost 0.1 m is developed as an horizon of alternating calcite and glauconite laminae in a clay matrix. The limestone is poorly fossiliferous but contains *Ceratopyge forficula*, *Euloma ornatum* and *Triarthrus angelini*.

Vestfossen Member (0.57 m) A tripartite grey-blue limestone, in places nodular and pyritic, and shale intercalations. Trilobites included: *Megistaspis* (*Ekeraspis*) *armata*, *Niobella* sp., *Varvia* sp., and *Symphysurus* sp.

Lower Didymograptus Shale Dark grey to black rusty weathering shales with *Didymograptus constrictus*, *D. filiformis*, *D. extensus* (Erdtmann 1965, 524).

STOP 2 On the south-east limb of the above fold (Fig. 5b), a continuous section through the tripartite Orthoceras Limestone with a 1.58 m thick nodular limestone (transition beds) at the base of the Ogygiocaris Shale. At this locality, the Asaphus Shale is unusually thick, being approximately 10 m.

STOP 3 HAUGNES NEAR KREKLING This locality was described in detail by Skaar (1972). It shows a north easterly dipping limb of an anticline with Dictyonema Shale, Ceratopyge Limestone and Lower Didymograptus Shale in the core and the tripartite Orthoceras Limestone on the northern limb. Of interest is a bedding plane near the top of the Endoceras Limestone with numerous oriented conchs of *Endoceras*, some up to 10 cm in diametre (Fig. 4). This bedding plane can be

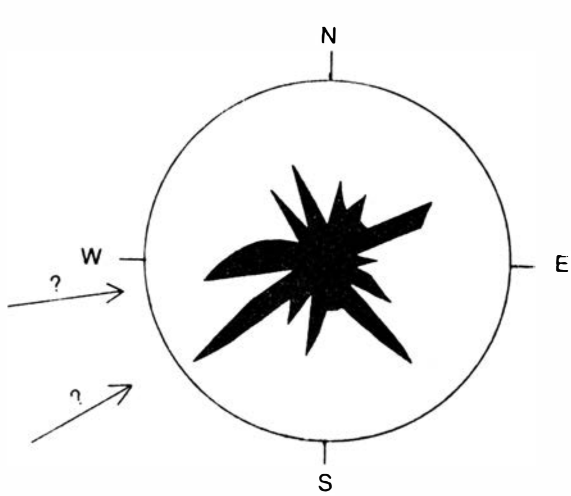


Figure 4. Rose diagram showing orientation of *Endoceras* conchs, Haugnes. No clear pattern is obvious. n = 194

traced at least 15 km to the west and forms a valuable marker horizon.

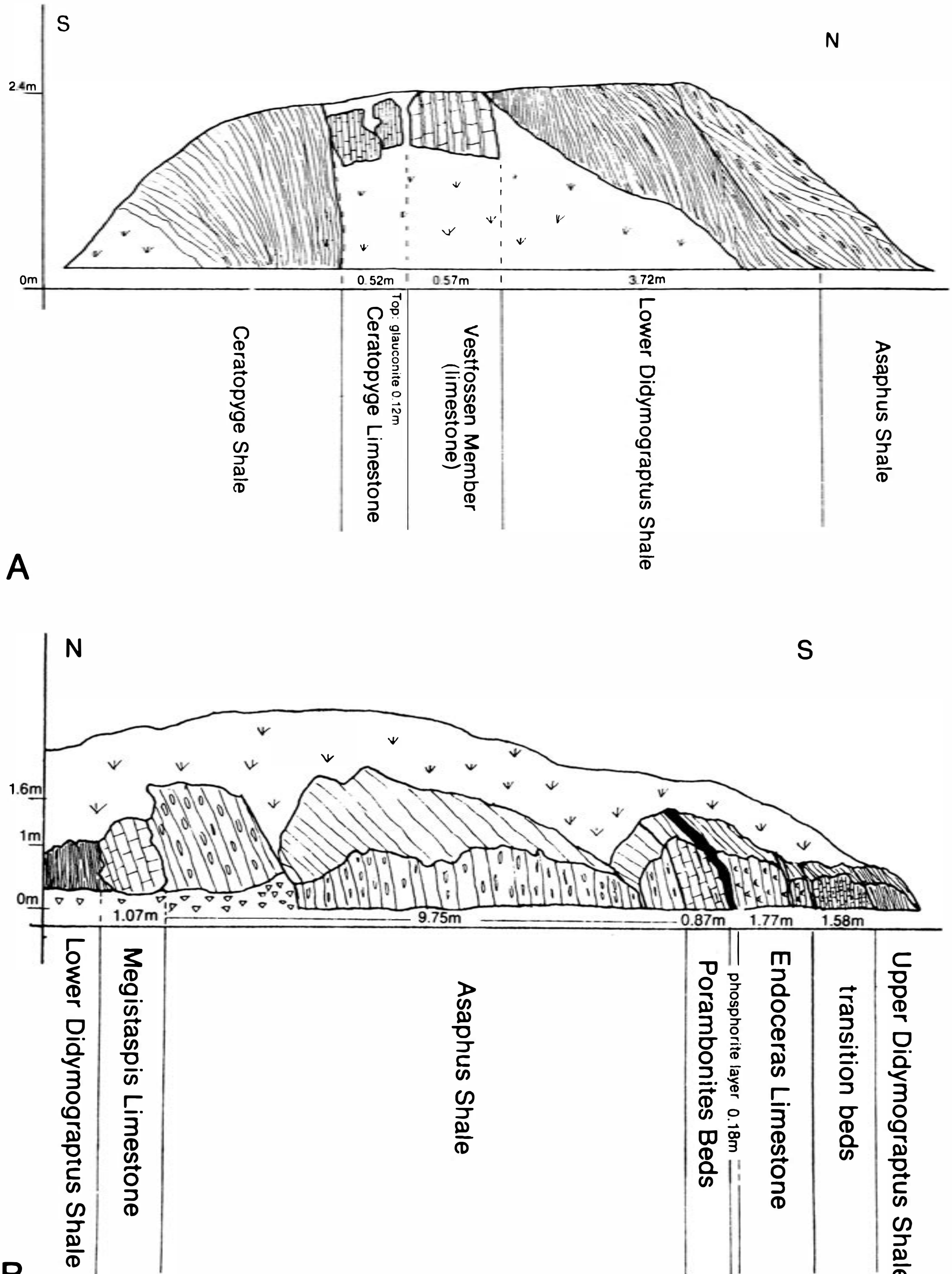


Figure 5. Profile at Hals. A, north-west limb of fold, stop 1; B, south-east limb of fold, stop 2.

THE UPPER ORDOVICIAN OF HADELAND

Alan W. Owen

The Ordovician stratigraphy of Hadeland bears few similarities to that around Oslo and thus caused problems when attempts were made to force the Oslo stratigraphical scheme upon it. The dominantly shaly Cambrian to middle Ordovician succession is tightly folded, whereas more open folds plunging westwards characterise the upper Ordovician and Silurian

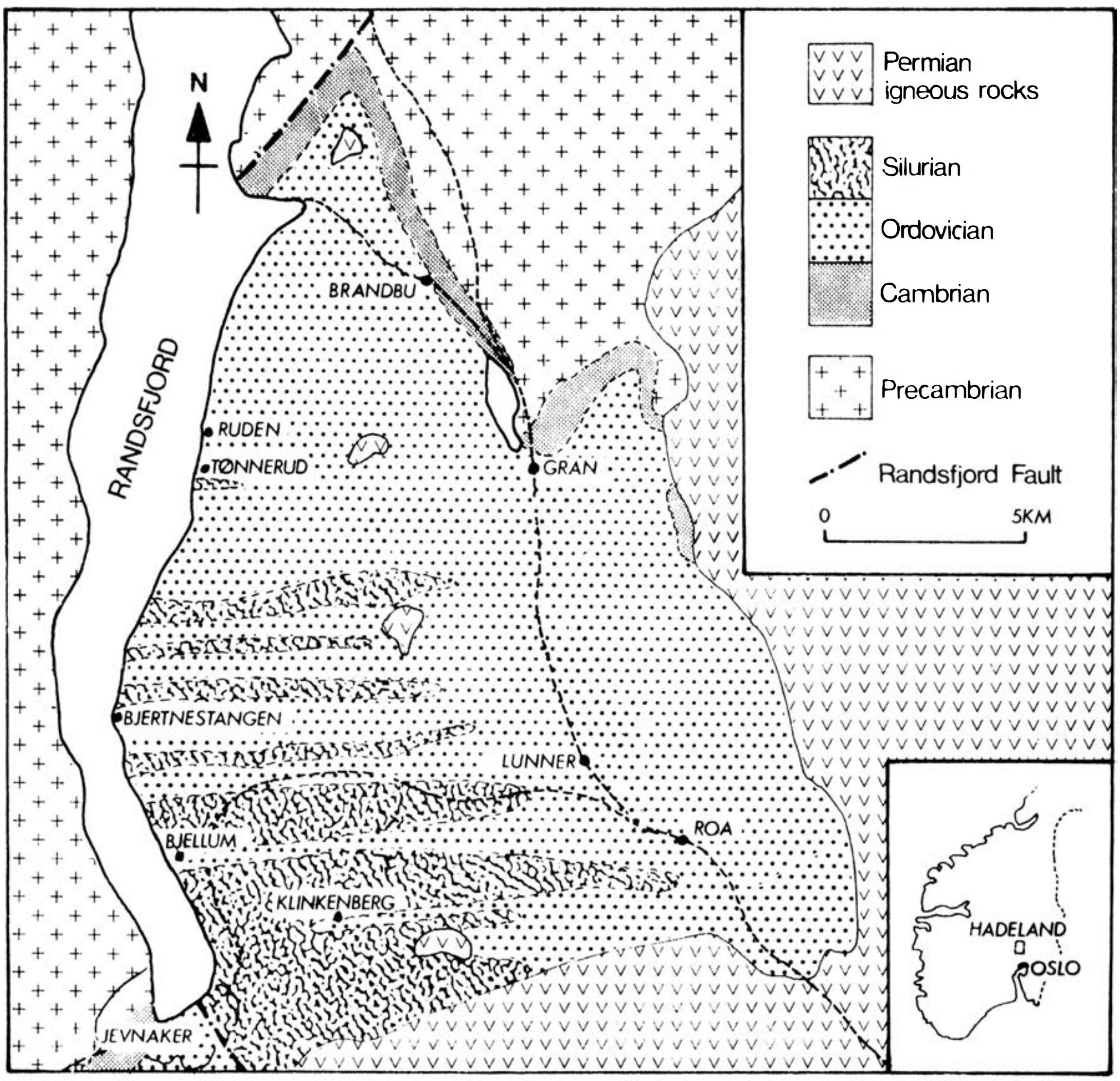


Figure 1. Simplified geological map of Hadeland (modified after Owen 1978).

sequence. This part of the succession comprises several thick, competent units and has been affected by extensive stike faulting, some of which is high angle reverse, and by a set of wrench faults. There is an overall younging of the Lower Palaeozoic succession towards the south-west (Fig. 1). The aim of this excursion is to examine briefly the upper Caradoc to lower Llandovery succession in Hadeland in order to establish a broader context for the very spectacular development in the Mjøsa area.

The history of research on the Ordovician of Hadeland was summarised by Owen (1978), who introduced a modern lithostratigraphical terminology (Fig. 2). The Llanvirn to middle Caradoc sequence is composed largely of shales, the Kirkerud group. The upper part of this is similar lithologically and in some faunal elements to the Furuberg Formation which underlies the Mjøsa Limestone to the north. The Kirkerud group

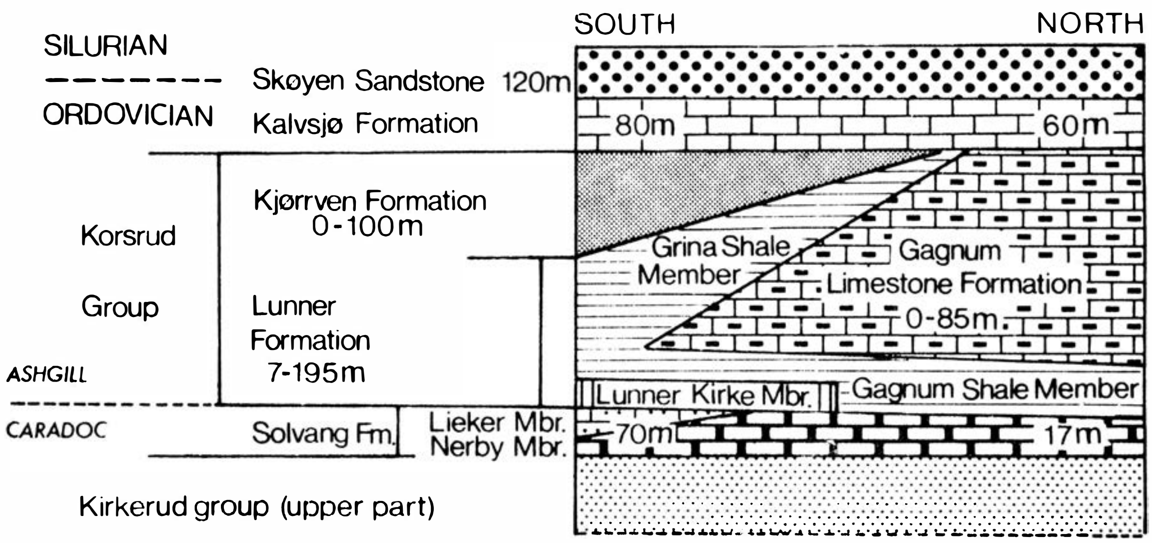


Figure 2. The upper Ordovician stratigraphy of Hadeland. Note that the Kirkerud group extends down to the lower Llanvirn.

in Hadeland is overlain by the Solvang Formation which comprises nodular limestone (the Nerby Member) over most of the area. The uppermost part in the south is, however, developed as bedded limestones and shales (Lieker Member) similar to the development around Oslo (= 'Upper Chasmops Limestone'). The Solvang Formation has a late Caradoc (to lowest Ashgill in part of Ringerike) fauna (Bruton & Owen 1979) and is a partial lateral equivalent of the Mjøsa Limestone (see Opalinski & Harland 1981). The Ashgill succession in Hadeland shows a dominantly limestone sequence in the north passing southwards into a thicker, more shaly succession (Fig. 2). It is capped over the whole district by the Skøyen Sandstone, a supraformational unit which extends into the Silurian. Much of the Ashgill is absent in the Mjøsa area but the Llandovery arenaceous unit overlying the Mjøsa Limestone is a lateral equivalent of the upper Skøyen Sandstone.

The itinerary follows the Randsfjord which lies along the fault-line here marking the western edge of the Oslo Graben. Outcrops of Llandovery sandstones and red and green marine shales are seen en route.

1:1 BJELLUM (NM 78058280) The Skøyen Sandstone is well exposed here. The strata are vertical and locally tectonised but show the thick calcareous sandstones near the base of the unit passing up into thinner bedded sandstones with shale division. These are succeeded by bioclastic limestones of the overlying formation which are packed with comminuted brachiopod and bryozoan debris and overlain by banks composed largely of pentamerid brachiopods. The Skøyen Sandstone is one of the best exposed units in Hadeland and shows a wide variety of sedimentary structures indicating high-energy shallow marine deposition. Brachiopods, crinoids, gastropods, corals and rare trilobites occur at various levels in the unit. Several other roadside outcrops of the Skøyen Sandstone and the overlying units are seen on the 10 km between Bjellum and the second locality, Tønnerud.

1:2 TØNNERUD (NM 8259225) The road cutting here affords a continuous section from the upper Kirkerud group to the Gagnum Limestone Formation and is part of the most northerly outlier of late Caradoc and younger rocks in Hadeland. A similar profile on the nearby shore of the Randsfjord was described by Kiær (1926) and has been studied in detail recently by Dr. J.F. and Mrs. T. Bockelie.

Some 20 m of the upper Kirkerud group crops out in the northern part of the road section and yields a diverse fauna dominated by the trilobites Toxochasmops extensus, Lonchodomas aff. rostratus and Stenopareia glaber, the brachiopods Leptestiina indentata, Sowerbyella hadelandica and Leptaena strandi and the bryozoan Diplotrypa sp . Corals, crinoids and gastropods also occur. A 1.2 m thick bed of tightly nodular limestone within shales and limestones of the uppermost part of the group is seen here and throughout Hadeland, and is anticipatory of the lithology of the overlying Nerby Member of the Solvang Formation. This unit constitutes the lowest part of Kiær's 'Sphaeronid Limestone' - a tripartite unit now viewed in terms of the lithostratigraphical scheme applied to the rest of Hadeland.

The Solvang Formation at Tønnerud is 16-17 m thick and is poorly fossiliferous. The overlying Gagnum Shale Member of the Lunner Formation is 7 m thick and contains a fauna including the cystoid Haplosphaeronis kiaeri, the brachiopod Leptaena minuta and the trilobites Tretaspis ceriodes angelini, Platylichas cf. laxatus and Atractopyge progemma. Bryozoans, gastropods and bivalves are also known. The Tretaspis species suggests that the base of the Lunner Formation is diachronous and is older here than elsewhere in Hadeland. Approximately 25 m of the Gagnum Limestone Formation is exposed at Tønnerud and contains a diverse but generally sparse fauna dominated by cystoids, trilobites and brachiopods. The top of the formation is not exposed at Tønnerud but limestones of the overlying Kalvsjø Formation crop out a short distance to the south.

THE ORDOVICIAN OF THE DISTRICTS AROUND MJØSA

Nils Spjeldnæs

The object of this part of the excursion is to study the late Ordovician strata in the Toten and Nes-Hamar areas represented by a ca. 100 m thick predominantly carbonate sequence, named the Mjøsa[1] Limestone, and its various members (Harland 1981; Opalinski & Harland 1981). This formation is distinct from underlying and overlying clastic units (Furuberg Formation and Helgøya Quartzite) of respectively Middle Ordovician and Silurian age. Time does not allow us to examine other parts of the succession; for details of this and references to older papers the reader is referred to Størmer (1953) and Skjeseth (1963).

HISTORY OF RESEARCH

The first real scientific paper describing the Ordovician of the Mjøsa districts was that of Kjerulf (1857). The classical, and still fundamental papers are by Kiær (1897, 1908); the latter is on the Silurian but contains valuable information on the youngest Ordovician. This includes the naming of the Mjøsa Limestone and the first attempt to subdivide it formally. Holtedahl (1909, 1912) supplied information on the lower part of the Middle Ordovician and additional data on the lower beds was given by Bjørlykke (1905). Raymond (1916) suggested that the Mjøsa Limestone was of Middle, not Upper Ordovician age as believed at

[1] Following a decision by the Norwegian Language Council in 1981, the author maintains that the correct spelling is Mjøs Limestone, and consequently drops the definite article -a-ending. The editors disagree and maintain that Mjøsa, the name of the lake and that to be found on all maps, is the more correct. Moreover, the name Mjøsa has been used in all standard works published in English since 1908, and it appears in Strand & Størmer (1956 Lexique stratigraphique international Vol. 1, Fasc. 2a Norvege, 44). The law of priority would therefore seem to apply. In addition, retention of the name Mjøsa would lead to nomenclatorial stability.

that time. This was accepted and elaborated on in a number of papers by Kiær (1920, 1921, 1922, 1926). Rosendahl's study (1929) was concentrated on the Brumunddal area (Ringsaker district). Reference to publications on fossils from the Mjøsa Limestone are given in the following text or are to be found in the cited 'Middle Ordovician Series' and general reference lists.

STRUCTURAL SETTING

The early Palaeozoic rocks around Lake Mjøsa occur in four districts, namely Toten, Nes and Hamar in the south and Ringsaker (sometimes regarded to be outside the Oslo Region proper) north of the Solbergås horst. The area is a deeply eroded rift which was infaulted during Permo-carboniferous times with possibly some movement continuing into the Triassic (Ramberg & Spjeldnæs 1978). The area was faulted into a number of blocks which now dip gently in a variety of directions.

The early Palaeozoic beds were intensely folded during the Caledonian Orogeny, the maximum probably occurring in the Lower Devonian. There are two models for the tectonic history of the area, both focussing on the several kilometre thick, late Precambrian Hedemark Group found to the north of the Mjøsa district. In the commonly accepted model (Bjørlykke 1978 and others), the Hedemark Group is regarded as para-autochthonous having been deposited in the basin where it is now found, but compressed into an imbricate structure by pressure from the north. The Ordovician beds now found in the southern districts must have been deposited on top of the Hedemark Group, but were later peeled off by thrusting onto the crystalline Precambrian basement where they are now found. The Ordovician of the Ringsaker district must be allochthonous or para-autochthonous in relation to the underlying Hedemark Group, in the same way as the Ordovician of the southern districts is para-autochthonous in relation to its present basement.

The second model has been proposed by Nystuen (1981) who suggests that the whole of the Hedemark Group is allochthonous, and was originally deposited in a northern basin before being transported into its present position as part of a huge thrust sheet, the Osen-Røa Nappe Complex. In this model it is suggested that the Ordovician of the southern districts was deposited on the Precambrian basement, or on unknown sediments now depressed deeply under the Hedemark Group, and was scraped off during the advance of the nappe complex. The Ordovician of the Ringsaker district is therefore basically autochthonous on the Hedemark Group, but allochthonous in relation to the common basement of the nappe complex.

Regardless of which tectonic model is chosen, there are two features which are important:

1 The Ordovician has been considerably shortened due to décollement folding over the Precambrian basement. The Ordovician rocks found in the southern districts must therefore have been deposited at least 100-150 km to the north, a fact which must be considered in palaeogeographical and palaeoecological studies of the area.

2 The Ordovician sediments of the southern districts and those of the Ringsaker district were probably deposited in two different basins under rather different structural conditions, even if the distance between the basins was not necessarily much greater than the present one.

The Furuberg Formation consists of shale, with siltstone and limestone bands, mostly thin, but in the upper part more than 10 cm thick. The siltstones show many sedimentary structures, lamination, crossbedding and deformation structures, indicating that they were not bioturbated after deposition. The limestone beds contain a rich fauna of bryozoans, brachiopods, echinoderms, trilobites, molluscs and calcareous algae, which together with the sediment have been transported during periodic storms from a near-by carbonate platform. Very few, if any, of the fossils in these beds appear to have lived in the area. The same appears to be the case with the fossils in the siltstone beds, with the exception of some beds with a *Sowerbyella*-dominated association, which may be in life position. The shales are mostly unfossiliferous, but at some localities (Furuberget N) there are numerous hat- or bun-shaped trepostome bryozoans, and brachiopods thought to be *in situ*.

In the Hamar-Nes Districts, the cross-bedding of the silt- and limestone beds indicates current directions from north or south, in some cases towards the axis of the present synclines from both sides. The pure carbonate beds often show a transport direction from the west. In the upper part of the Furuberg Formation, and the Mjøsa Limestone, the transport direction shows a wider spread, and it is difficult to discern a consistent pattern. The cross-bedding pattern observed in the lower part of the Furuberg Formation is interpreted as indicating a palaeoslope from west to east. A carbonate platform to the west formed the source of carbonate material which was occasionally washed into the eastern, clay-dominated areas, transport possibly being concentrated in broad channels.

Series	Toten - Nes - Hamar Mjøsa south	Ringsaker Mjøsa north
Tretaspis Series	HIATUS	HIATUS
Chasmosp Series	Mjøsa Limestone (reef and algal limestone Furuberg formation { Cyclocrinus beds, Coelosphaeridium beds } Hovinsholm Shale	Mjøsa Limestone (red and shaly in upper part) Furuberg formation { Cyclocrinus beds, Coelosphaeridium beds } Hovinsholm Shale (= Robergia beds)
Ogygiocaris Series	Cephalopod shale Ogygiocaris shale Upper Didymograptus shale	Ogygiocaris shale Upper Didymograptus shale
Asaphus Series	Helskjær shale and limestone Endoceratid limestone Asaphus shale Megistaspis limestone Lower Didymograptus shale	Stein Limestone (= Orthoceras limestone Heramb Shale and limestone Lower Didymograptus Shale Stein Shale and limestone
Ceratopyge Series	Ceratopyge limestone Ceratopyge shales Dictyonema shale	Ceratopyge limestone Ceratopyge shales Dictyonema shale

Figure 1. Stratigraphy of the area visited (modified after Skjeseth 1963).

The carbonate beds, now found in the synclines, are therefore not the remains of continuous sediment cover but are 'fingers' from the western carbonate platform. These have escaped intense folding because of their relative competence. This model applies only to the Furuberg Formation; the upper part of the Mjøsa Limestone may have been a blanket deposit covering the whole area.

Correlation between the typical section of the Mjøsa Limestone at Bergevika south and the type section of the Furuberg Formation at Furuberget south indicates that, at the latter, the upper half of the Furuberg Formation corresponds to the lower half of the Mjøsa Limestone at Bergevika south. Based on the contained fauna both can be correlated with the Oandu Stage of Estonia (for example, there are 16 species of bryozoa common in Norway and Estonia), and more indirectly with the Upper Chasmops Limestone in the Oslo district. The lower part of the Furuberg Formation may be older, and at Sund (Einavann) in the Toten area they contain Kullervo sp. and Christiania holtedahli, known from the Lower Chasmops Shale in the Oslo district.

Mjøsa Limestone This formation was first named "der Mjøsen-Kalk" by Kiær (1908, p. 405), who supposed it to be Upper Ordovician. The lithology is highly variable (Opalinski & Harland 1981; Harland 1981). Because of the rapidly changing facies it is difficult to apply formal lithostratigraphy in a meaningful way and the author has attempted to use a series of informal units, based on rhythmic changes in sea level, which are supposed to be contemporaneous in the different localities. This system has been worked out in the Hamar—Nes districts. In the Toten district the limestones were deposited in shallower water and are to a large extent represented by intertidal, recrystallised and sparsely fossiliferous rocks, possibly originally calcareous muds. The shallow water units in the eastern districts of Toten contain surfaces of erosion, some with karst features.

The section at Bergevika south (Fig. 2, loc. 7) is regarded by the author as being the type section for the Mjøsa Limestone which is contrary to that of Opalinski & Harland 1981. [In doing this the author follows Størmer 1953 and Skjeseth 1963. Skjeseth 1963 p. 66 refers to Helgøya

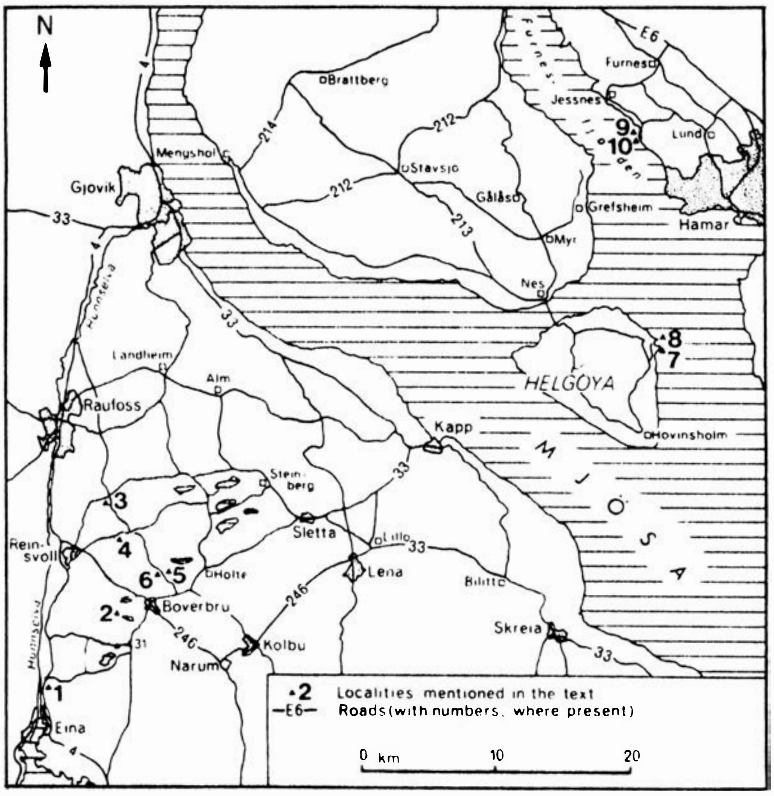


Figure 2. Map of the Toten and Nes—Hamar areas with stops marked (modified after Opalinski & Harland 1981).

and Furuberget as type localities while Størmer 1953 p. 106 refers to these as "classical". Strand and Størmer 1956, do not define a formation stratotype for the Mjøsa Limestone. Eds.]

In the section at Bergevika south the following units can be recognised:
Unit I is developed in the Furuberg Formation facies and consists of shales with dense, 3-8 cm beds of silt and limestone. These were probably storm-generated, containing upward-fining sequences and a number of sedimentary structures. The upper boundary is sharp but mostly deformed by slumping.

Unit II A limestone unit with massive *Solenopora* beds at the base. These beds are partly slumped and contorted. Higher up the bedding is irregular and the initial stages of mound and roof formation are common, although well developed structures are absent. Small, irregular lenses of unbedded limestone alternate with bedded, washed limestone. Typical features are large (up to 1 m high and 2 m wide) colonies of a *Catenipora* sp. and occasional rugose corals. The stromatoporoids are better preserved here than in Unit IV, the unit from which Webby's (1979) described material originated, and are mostly crustose forms, although some branching forms occur in sheltered, mud-filled cavities. The large 'bun-shaped' colonies from reefs in Unit IV are very rare in Unit II. The fauna is dominated by bryozoans which include 16 species known also from the Oandu Stage of Estonia. Some of these and others are known from Unit I and from the Furuberg Formation at Furuberg. This unit is a veritable

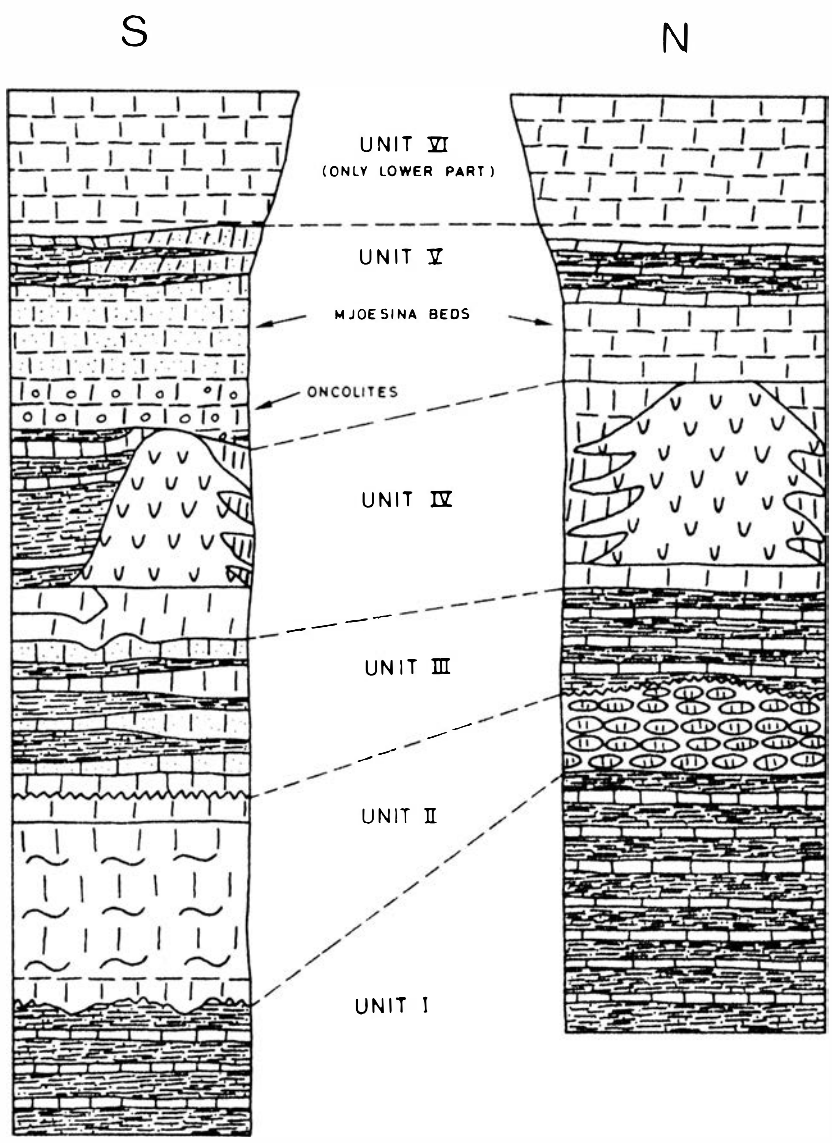


Figure 3. Sections through Units I-IV of Mjøsa Limestone and Furuberg Formation from Bergevika N and S. For explanation of the individual units, see text.

museum of sedimentary structures both primary ('tadpole nest' ripple marks) and secondary (vertical stylolites). Dolomite rhombs occur with stylolites and bedding planes. Both horizontal and vertical stylolites are common. Reconstructions of fossils to their original shape show that they lost more than 60% of their original volume during compaction. In contrast to Unit I, which was probably deposited below wave-base and eroded only during rare, periodic storms, Unit II was evidently deposited above wave-base and probably in the highest subtidal to low intertidal areas.

Unit III This is a dolomitic silt with fining-upwards carbonate beds 1-6 cm thick. The boundary with Unit II is sharp and erosive; both in the upper and lower parts there are thicker carbonate beds. This type of deposition resembles that of Unit I but the facies changes more rapidly in less than 1 km lateral distance, from dominantly silty, current bedded carbonate with small amounts of shales at the eastern tip of the southern peninsula at Bergevika, to dark shales with silt-stone-carbonate beds (Furuberg Formation lithology) in the eastermost road section. In the more shaly parts, the fauna is dominated by a *Sowerbyella* association, while in the more carbonate-rich beds bryozoans are dominant. Algae are rare except for a few scattered *Solenopora* specimens in the lowest and upper beds, and all but a few rugose corals are absent. The environment was probably similar to that in Unit I, with the possibility of an east-west gradient, although this could also be due to changes in supply of clastic material.

Unit IV This reef horizon sits directly on a massive *Solenopora* lime-stone which, as in Unit II, contains prominent slump structures. The reefs consist of fairly large, 'bun-shaped' stromatoporoids and several species have been identified (Webby 1979). Corals are few in number in the reef mass itself, most being found on the flanks in a more impure, argillaceous limestone. The corals include bushy colonies of *Eofletcheria* which hosted a rich epifauna with an infauna in the interlying sediment. The reef mass has been exposed to intense pressure solution which has altered its original morphology and reduced the volume by more than half. This must be taken into consideration when reconstructing the topography of the reefs, and has resulted in the loss of any cryptic faunas and epifaunas. A few mud-filled cavities however contain a fauna including brachiopods and stromatoporoids. Lateral equivalents to the reef occur in the steep cliff section and are similar in lithology to the main part of Unit II.

Unit V The contact between this and the reef unit is sharp. The lower part contains a massive bedded limestone with oncolites, oolites and numerous calcareous algae including Dimorphosiphon rectangulare Høeg. The presence of oncolites suggests deposition in the intertidal zone. It is overlain by fine-grained limestones, the 'Mjoesina beds' of Spjeldnæs (1957) of shallow water origin, and dolomitic siltstones with carbonate beds, similar to those of Unit III. The lower bed contains both in situ faunas and transported ones derived from a purer carbonate environment. The transported faunas are similar to those found in the shallow water carbonates, while the in situ fauna is dominated by Sowerbyella, Vellamo dalmanellids, rhynchonellids and large bivalves, often alone or in low-diversity assemblages. Spjeldnæs (1957, text-fig. 22) showed that no appreciable size-sorting had occurred in populations of Sowerbyella, although disarticulation and current orientation was present. Laterally, the lower part of Unit V grades into peloidal limestones, resembling those of the overlying unit but without the reticulate structure. Some of these beds are extremely rich in recrystallised mollusc shells.

Unit VI This is a uniform limestone, at least 60 m thick, consisting of peloidal limestone with a characteristic reticular structure resulting from internal solution. This is probably one of the best examples of the formation of nodular limestones according to the model suggested by Bjørlykke (1973). The fauna appears to be poor in comparison to the other units as fossils are difficult to extract. However, large gastropods, cephalopods, bryozoans and (?)sponges occur. The fauna appears to be uniform throughout the unit and there is no visible horizontal change related to facies. Superficially, this limestone looks rather homogeneous, but this is partly an illusion because of the secondary reticulation. Detailed examination reveals 'nests' of fossils, small-scale chanelling and variations in clastic content and grain size. The boundary with the overlying Silurian Helgøya quartzite is a sharp, erosive one. The contact is not exposed at Bergevika, but at Furuberget and Snipsand there is a thin (0.5-0.7 m) sandy carbonate horizon between the typical Unit VI and the typical Silurian sandstone. This unit contains, amongst others, colonies of Solenopora and Palaeofavosites. In the author's opinion, these beds are of Silurian age but contain reworked Ordovician fossils.

At Bergevika north (Fig. 2, loc. 8) Unit I is the same as at Bergevika south, but Unit II is much thinner and developed as a nodular limestone. Its fauna includes numerous small, globular colonies of Nyctopora. Unit III contains current-bedded carbonates, including some spectacular beds with isolated ripples of pure carbonate sand in silty shale. The ripples are 5-10 cm high with a crest distance of 70-100 cm and indicate a current from the west. Unit IV contains reefs which are similar to those at Bergevika south. However, the interreef facies resembles that of Unit II at the southern locality, with many encrusting stromatoporoids, some corals (including a different Catenipora from Unit II) and horizons of massive carbonate. The reef-like rocks interfinger with massive, clastic carbonates. The basal Solenopora limestone is much thinner here than at Bergevika south, as are the basal oncolitic beds of Unit V. The 'Mjoesina beds' are similar to those of the southern locality, as are the silty dolomitic beds and the succeeding limestones of Unit VI.

The classical section of the Mjøsa Limestone is at Furuberget. Here beds equivalent to the lower part of the section at Bergevika south are developed as the upper part of the Furuberg Formation at the type section in the railway cutting at Furuberg south. This is shown both in the resemblance of the faunas, especially the bryozoans, and in a lithological correlation with the upper parts of the formation. A series of thick, closely spaced silty limestone beds in the middle part of the upper Furuberg Formation may represent Unit II. Beds equivalent to the reefs of Unit IV are developed as massive limestones containing Solenopora and rhynchonellid brachiopods. These beds are followed by more massive silty limestones, which grade into the typical reticulate peloidal limestones of Unit VI. This unit is more than 60 m thick and the reticulation is often less marked than at the other localities. Near the top of the limestone some beds are rich in fossils but identification is hindered by strong recrystallisation.

Model of deposition It is suggested here that the Mjøsa Limestone was formed on an eastward dipping slope with a carbonate platform dominated by intertidal conditions in the west and soft-bottom (clay) conditions in the east. Gradually, the amount of carbonate supplied to the eastern region increased, first in rare, periodic storms, and later in large channels where reef development occurred along the edges. Because of differential compaction of the argillaceous and carbonate sediments, the channels developed as rather thick bodies which 'preformed' the present synclines. The final step appears to have been a massive, uniform deposit of peloidal carbonates representing Unit IV.

Units II and IV represent periods of shallowing with reef and near-reef conditions, water depth in the Hamar—Nes districts ranging between upper sub-tidal and low intertidal to partly hypersaline lagoons. These two periods may be represented in the Toten district by periods of karst erosion (Skjeseth 1963, text-fig. 23; Jørgensen & Spjeldnæs 1964, p. 438).

Most modern studies on carbonate platforms are made in regions where the platforms are bounded by steep slopes towards the deep ocean, or in regions with a very sparse supply of terrigenous clastics. Analogies with such deposits must be used with some reservations when applied to the Mjøsa Limestone, deposited on a gentle palaeoslope, where the carbonate platform graded into a clay-filled, slowly sinking intra-cratonic basin. This is reflected particularly in the Furuberg Formation, with its dominantly transported fauna, and in the argillaceous beds lateral to the stromatoporoid reefs in Unit IV at Bergevika south.

1:3 EINA (Fig. 2, loc 1) A series of old, partly overgrown limestone quarries in the Mjøsa Limestone. The rock types (Fig. 4) are those described in Opalinski & Harland (1981).

1:4 HOLE KALKVERK (Fig. 2, loc. 2) A group of quarries located within a complex of westward plunging, tightly folded synclines of Mjøsa Limestone. Here rock types are the same as seen at 1:3, but the erosional terrestrial karst surface contact with the Silurian Helgøya Quartzite is exposed. Karst surfaces occur elsewhere within the Mjøsa Limestone and these probably correspond to periods of low sea level (see Units II and IV in the Hamar—Nes districts). The boundary between the Mjøsa Limestone and the underlying Furuberg

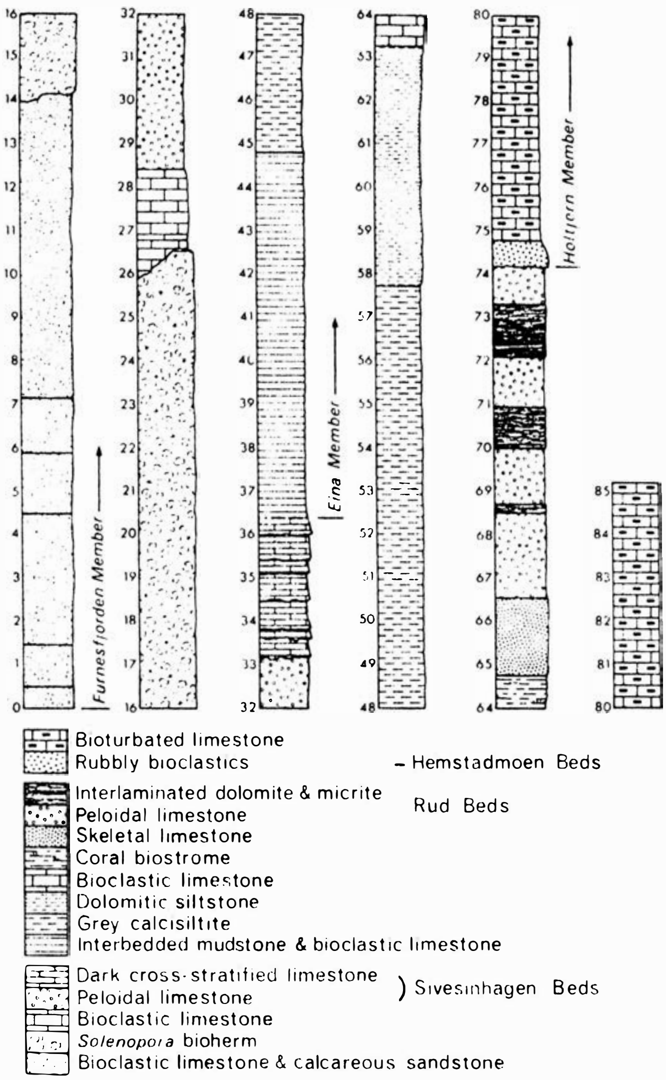


Figure 4. Detailed section through the middle part of the Mjøsa Limestone at Eina (Loc 1, Fig. 2) (from Opalinski & Harland 1981).

Formation is also exposed near these quarries.

1:5 Karst surfaces will be studied in greater detail at either Ånnerud (Fig. 2, loc. 3), Kyset (Fig. 2, loc. 4) or Rud (Fig. 2, locs. 5, 6) depending on quarrying activity.

If time permits, we will stop at a section of 'Mjøsa Limestone' (Kiær 1908, 407-408) before proceeding to Gjøvik. To the west of this locality is the (?)Permian Hundselv fault line which forms the western boundary of the Oslo Graben. This fault continues south and forms the boundary between the Lower Palaeozoic sediments and the crystalline Precambrian. The sediments were probably deposited a considerable distance to the west. Immediately to the north of Gjøvik is the 'Caledonian Front' where the dêcollement-folded sediments and the imbricate thrust-faulted rocks meet in a rather complex structure. The Permo-Carboniferous and (and ?Triassic) rifting adds to the tectonic complexity as some of the major faults, including the Hudselv fault, the Solbergås horst (see below) and the Brumunddal fault, cut obliquely through the critical area.

NIGHT AT GJØVIK

In the morning the ferry will be taken from Gjøvik across the lake to Mengshoel at the northern side of the Precambrian Solbergås horst and then south-east to Helgøya (Holy Island). The landscape clearly reflects the underlying geology, and farms are situated on ridges formed by the Orthoceras Limestone (Arenig—Llanvirn). The Mjøsa Limestone and the overlying Silurian forms broad, open synclines which appear as tree-covered ridges of pine and spruce. The cultivated land is mainly on the flat terrain formed by the deeply weathered Ordovician shales. A thin veneer of glacial sediments covers most of the area which is among the richest and most fertile agricultural areas in Norway.

2:1 BERGEVIKA SOUTH (Fig. 2, loc. 7) The road section (Fig. 5, loc. 9) shows the reef (Unit IV) and 'backreef' facies of marl beds in mudstone. The reef is rather recrystallised but the basal beds of Solenopora limestone are well exposed. The latter and the lower part of the reef seem to grade laterally into Unit III, developed in the same facies as the Furuberg Formation. Dendroid graptolites occur in shale partings near the top of the reef. En route to the quarry, two small sections (Fig. 5, locs. 7, 5) show the reticulate peloidal limestone of Unit VI, and Unit III. In the quarry the lowest beds are the basal Solenopora limestone of Unit IV with some slump structures. The reef contains large, dome-shaped stromatoporoids with little matrix or other organisms. The original shape of the colonies is destroyed because of secondary solution. The marl-mudstone lateral facies is seen between two reef mounds and on the

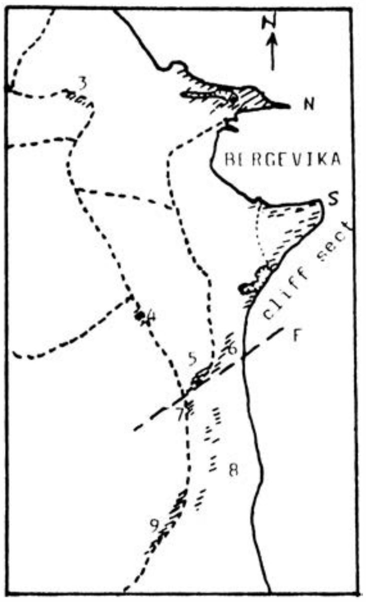


Figure 5. Sketch map of Bergevika, Helgøya, Mjøsa. Main exposures are hatched. The localities are (except for the northern peninsula (N), and the southern peninsula with the cliff section): 3 = Northern road section (Units IV-V), 4 = small road section (Unit VI), 5 = road section (Unit III in Furuberg Formation lithology), 6 = inland cliff section (Unit II, with base of III at top), 7 = road section (Unit VI), 8 = scattered smaller cliff sections (Units II-III), 9 = long road section (Unit IV, with parts of II and V). F = prominent fault. Drawn from aerial photograph.

eastern flank of one of the reefs there is a rubbly limestone rich in corals and more complete stromatoporoids. The reefs are overlain by an oncolite-algal limestone belonging to the base of Unit V, which contains oncolites, ooliths and a number of transported fossils, mainly bryozoans, brachiopods, and fragments of Dimorphosiphon rectangulare Høeg, 1927, an Halimeda-like algae. This is the type locality for this taxon. The oncolitic limestone grades upwards into a dark, partly peloidal limestone, the 'Mjoesina beds', containing bryozoans and thin-shelled brachiopods. These grade into silty dolomitic beds and occasional carbonates which were apparently storm generated. The transition to Unit VI with reticulate-peloidal limestone is seen along the old railway tracks leading to the disused kiln at the southern shore of

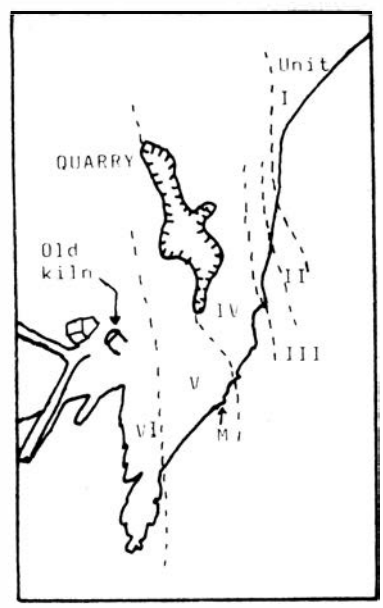


Figure 6. Sketch of Bergevika North. The distribution of the units of the Mjøsa Limestone is shown. From an oblique aerial photograph.

Bergevika.

2:2 BERGEVIKA NORTH (Fig. 2, loc. 8, Fig. 6) We shall endeavour to examine this section, lake level permitting, in order to compare and contrast the equivalent units at the previous localities (see text).

On leaving Bergevika, the bus will drive north, back to the mainland <u>via</u> Nes and cross the inner end of Furnesfjord to join route E6 south. From here the road passes through Brumunddal to Furnes. Roadcuts of folded Orthoceras Limestone (Arenig—Llanvirn) will be pointed out from the bus. Leaving the E6, the bus follows a route past Furnes Church to Furuberget (Pine Mountain; Fig. 2, locs. 9-10).

2:3 FURUBERGET (Figs. 7, 8) Shore line and road sections along the railway line provide the only complete sequence through the Furuberg Formation. The railway section itself is not accessible for field parties. At the type section, the lower

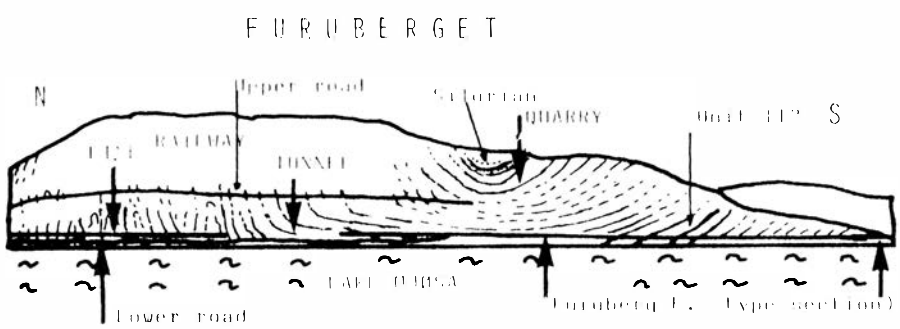


Figure 7. Sketch of the Furuberget section, looking east approximately along axis of syncline. The northern part of the section, north of the railway tunnel, is tectonically disturbed. The section of Holtedahl (1909, p. 18, fig. 8) is only from the railway section.

part is more shaly than the upper, which contains more massive limestone thought to be equivalent to Unit II at Bergevika south. The fossils in the type Furuberg Formation, especially the bryozoans, are the same as those in the lower part of the Mjøsa Limestone at Bergevika south. At the northern end of the quarry above the railway-line, a section shows the junction between the Furuberg Formation and the lower part of the Mjøsa Limestone represented by Solenopora limestone with some cross bedding and slump structures. In the quarry proper, the contact between the Ordovician and Silurian will be demonstrated along the south-west rim.

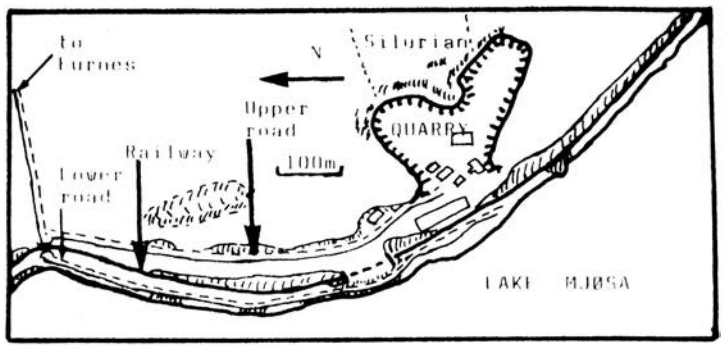


Figure 8. Sketch of the Furuberg locality. Main exposures are hatched (modified after Hamar MS).

ORDOVICIAN IN VÄSTERGÖTLAND

Valdar Jaanusson

The Cambro-Silurian areas of Västergötland (latinised Vestrogothia) include a main district (the Billingen-Falbygden district), which comprises Mount Billingen in the north and Falbygden with its numerous small mountains in the south. In addition are a few outliers to the west, Halleberg and Hunneberg at the southern end of Lake Vänern, Kinnekulle at the coast of the same lake to the north, and Lugnås north of Billingen. The mountains are capped by a thick sheet of dolerite, originally intruded as sills. The Cambro-Silurian rocks are preserved mainly due to the protective cover of the dolerite, but downfaulting has also contributed to their preservation.

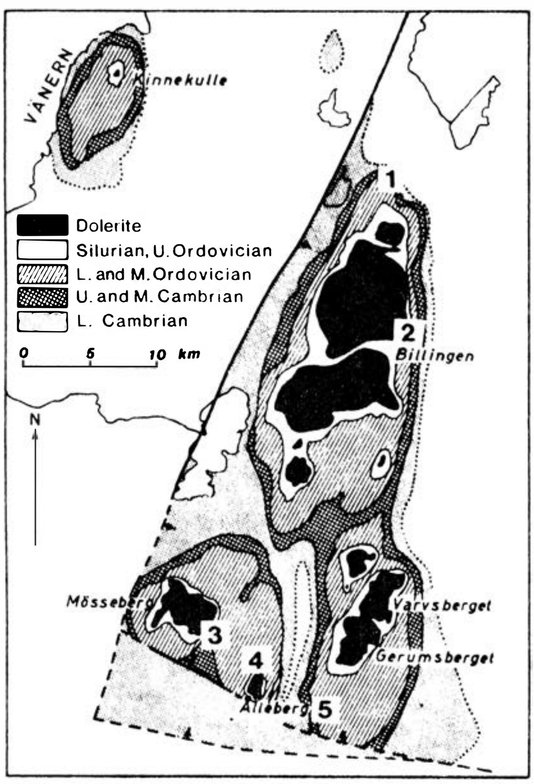


Figure 1. Geological map of Kinnekulle and the Billingen-Falbygden district. Italic numbers refer to stops in the road log (Stop 2 coincides roughly with the location of the town of Skövde).

The dolerite caps rests on various levels; on Halleberg it is on Upper Cambrian shale, while on Hunneberg it is on Lower Arenig Tøyen Shale. In the Billingen-Falbygden district the youngest beds belong to the Llandovery Zone of *Spirograptus turriculatus*, while on Kinnekulle they belong to the Zone of *Cyrtograptus lapworthi*. On the low Lugnås no dolerite cap is preserved, and the top of the sequence is within the Upper Cambrian Shales.

In Västergötland the Lower Cambrian

consists of sandstones, the Middle and Upper Cambrian of black shales, the Ordovician mainly of carbonate rocks but also with mudstones and some graptolitic shale, and the Silurian of graptolitic shales. The total thickness of the Ordovician sequence is 104 m on Kinnekulle and 84 m on eastern Billingen.

Kinnekulle can be regarded as the cradle of research on the early Palaeozoic in Sweden. The general lithostratigraphic succession was described by Kalm (1746) and Linnaeus (1747a, b), and it continued to be a reference section for a long time. It is worth noting that Pehr Kalm (a pupil of Linnaeus) was the first to record Ordovician fossils from the Champlain Valley of New York State in 1749. Kinnekulle is the type area of the Orthoceratite Limestone (Hisinger 1828). Important unpublished data, provided by Jan Bergström, Lars Holmer and Jan Johansson, are incorporated in the following text.

LOWER ORDOVICIAN (ONTIKAN)

There is a break at the base of the Ordovician over the whole of Västergötland. In the few areas where the Lower Tremadoc Dictyonema Shale is developed, the lowermost zones are missing and, except at Kinnekulle, the break comprises also the uppermost Upper Cambrian Zone of *Acerocare* and *Parabolina heres*. The magnitude of the break varies; it is largest on the eastern side of Varysberget where the upper Hunnebergian Zone of *Megistaspis (Varvaspis) planilimbata*, only 10 cm thick, rests on the Upper Cambrian *Peltura* beds (Tjernvik 1956). The break is commonly associated with an impressive discontinuity surface at the top of the Upper Cambrian bituminous limestone which is bleached to a depth of several centimetres. In places the basal Ordovician bed contains small pebbles of phosphorite.

Tremadoc This series is poorly developed in Västergötland. The Lower Tremadoc Dictyonema Shale is only about 1 m thick, and where most fully developed includes only the middle two graptolite zones. The shale is known only from Hunneberg and southern Falbygden.

The Upper Tremadoc is represented by the Ceratopyge Limestone, which has a maximum thickness of 1.5 m at Hunneberg, the type locality of the unit. The rock is mostly very rich in glauconite. The Ceratopyge Limestone is developed only on Hunneberg, Kinnekulle and southern Falbygden. On Billingen and northern Falbygden the Ordovician sequence begins with the Lower Arenig Latorp Limestone.

The large macrofauna of the Ceratopyge Limestone consists almost exclusively of trilobites of which the most common are: Ceratopyge forficula, Euloma ornatum, Apatokephalus serratus, Niobe insignis, Niobella obsoleta, Symphysurus angustatus and Nileus limbatus.

Latorp Limestone and its Tøyen Shale equivalents (Hunnebergian and Billingenian Stages In the lower Arenig of Västergötland a wedge of the Tøyen Shale (Lower Didymograptus Shale) reaches far to the east. The shale development is most complete on Hunneberg (at least to a level within the Zone of Didymograptus balticus; higher beds are not preserved) and on Kinnekulle where the shale facies reaches into the Didymograptus hirundo Zone (Tjernvik 1956). The importance of the shale decreases to the east; the most persistent zone is that of Phyllograptus densus, which in places is represented in a thin shale unit on eastern Billingen and in southern Falbygden. In some other places on eastern Billingen (e.g., Stop 3:1) the whole sequence is developed as limestones. The shale is black on Hunneberg and greyish-green in other areas; it is mostly graptolitic. The Latorp Limestone is a grey calcilutite which contains trilobites but few other large macrofossils. Megistaspis (Varvaspis), Megalaspides (Megalaspides), Niobe, Niobella, Varvia and Symphysurus are common genera.

Lanna and Holen Limestones (Volkhovian and Kundan Stages) Although these units are excellently exposed in Västergötland they have never been studied in detail. The common rock type is a regularly bedded calcilutite. On Kinnekulle a tripartite subdivision of the Orthoceratite Limestone has been used based on the colour of the lithologies. A lower, pale red limestone is separated from an upper, red limestone by a few metres of grey (locally termed 'Täljsten'). It should be remembered that on Kinnekulle tha Latorp and lowermost Lanna equivalents are developed as Tøyen Shale. On Billingen the equivalents of Kinnekulle's lower red limestone are grey.

Except for some beds, the Lanna and Holen Limestones appear to be fairly poor in large macrofossils. The commonest forms are trilobites while orthocone cephalopod conchs also form a conspicuous macrofaunal element in many beds. In the Lanna beds Megistaspis (Megistaspis) and Nileus are widespread, whereas in the lower part of the Holen Limestone, Megistaspis heros and Ptychopyge applanata are common in some beds. The uppermost metre or so of the Holen Limestone is fairly rich in trilobites. These red, calcilutitic beds belong to the Zone of Megistaspis (Megistaspidella) gigas and also contain Asaphus (Neoasaphus) n. sp., Niobe frontalis Dalman, Pseudoasaphus perstriatus Bohlin, Illaenus glabriusculus Jaanusson, Pliomera fischeri (Eichwald) and other trilobites.

MIDDLE ORDOVICIAN

Våmb Limestone (Aserian Stage) On eastern Billingen the Aserian beds, some 9-10 m thick in Östergötland 70 km to the east, are represented by a thin 16 cm thick wedge which is of uppermost Aserian age (Fig. 2). The conodonts show that the wedge belongs to the Subzone of Eoplacognathus foliaceus (S. Bergström 1971), and that its beds are equivalent to the lower part of the Skärlöv Limestone as developed on Öland and in the Siljan district. The wedge was earlier termed Vikarby Limestone (Jaanusson 1964), but because of the lack of spatial continuity with the Vikarby beds in the Siljan district and because of a somewhat different age, a separate name for the unit on Billingen is useful. The type section of the Våmb Limestone is in the Gullhögen quarry (Vikarby Limestone in Jaanusson (1964) but with the lower boundary drawn at the discontinuity surface 2-3 cm lower down; Lars Holmer, pers. comm.) which is situated in Våmb parish. The top and base of the Våmb Limestone is defined by a discontinuity surface, and the variegated red and grey limestone in places abounds with chamosite ooids. For details see Stop 3:2.

On Kinnekulle, not only are the Aserian equivalents completely missing but also the overlying sequence begins at a somewhat higher level than on Billingen.

Gullhögen (including Skövde Limestone) and Ryd Formations On Kinnekulle the Gullhögen and Ryd Formations were referred to by Linnaeus (1747a, b) as 'Gorsten'; later the local name 'Leversten' was used (Holm 1901). The Gullhögen Formation is a lithostratigraphic unit in which calcareous mudstone forms an important component in the lithology. In the basal part small chamosite ooids occur in some limestone beds. Both lithologically and faunally (Ogygiocaris sarsi, Botryoides foveolatus, Reedolithus carinatus, etc.) the division can be considered to be a wedge from the general facies of the Oslo Region. Trilobites (Pseudomegalaspis patagiata, Nileus, etc.) are dominant elements in the large macrofauna; sedentary forms are rare.

The Skövde Limestone, a thin (20-30 cm) unit of variegated limestone at the base of the Gullhögen Limestone on eastern Billingen, contains Illaenus chiron and can be considered a wedge from the Folkeslunda Limestone. It now appears more practical to include the Skövde Limestone in

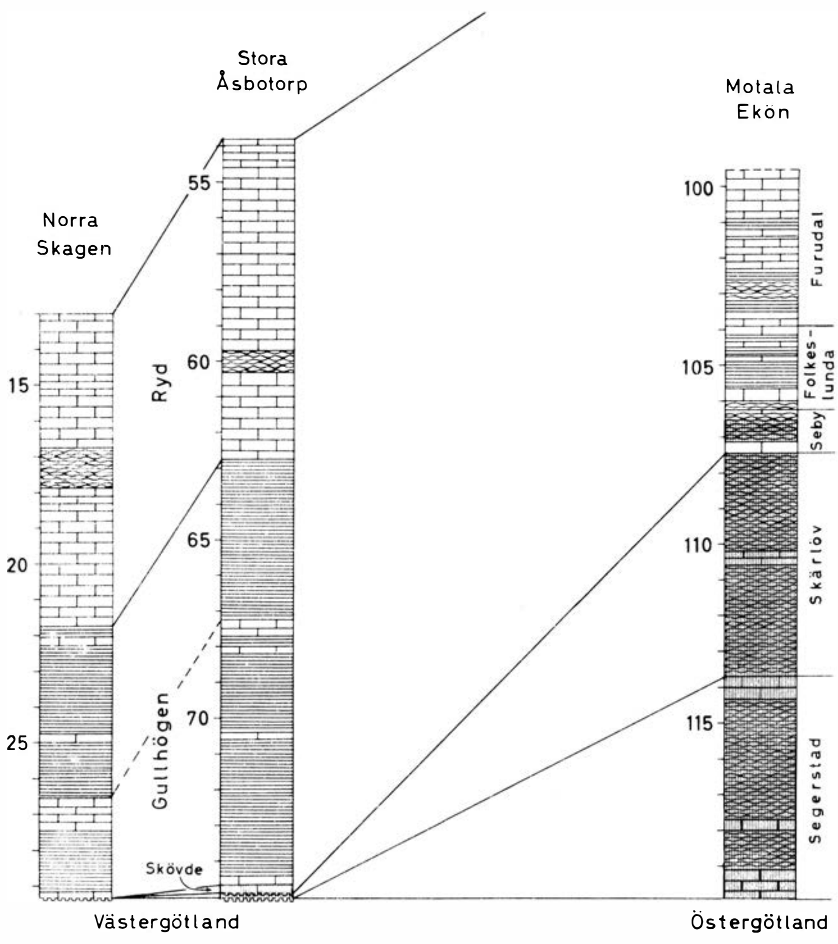


Figure 2. A comparison of the Aserian, Lasnamägian, and Uhakuan sections on Kinnekulle (Norra Skagen boring), northern Billingen (Stora Åsbotorp boring) and in Östergötland (slightly modified after Jaanusson 1964).

the Gullhögen Formation, as an informal basal subdivision. On Kinnekulle the Skövde equivalents are included in the break at the base of the Middle Ordovician (Fig. 2).

The Ryd Limestone consists of bedded and finely nodular calcilutites and forms a wedge from the Uhakuan Furudal Limestone. Nileus is again a common trilobite, but otherwise the Ryd beds tend to be poor in macrofossils. The transition between the Ryd Limestone and the overlying Dalby Formation is gradual, and the boundary is drawn at the level of the first appearance of the Dalby fauna. Thus in a strict sense both units are topostratigraphical.

Dalby Formation The lower member of the Dalby Formation consists of fairly thinly bedded to finely nodular, grey limestone, predominantly calcilutitic in the lower part and calcarenitic in the upper part. The development of the upper member is different on Kinnekulle and Billingen. On Billingen, as well as on Mösseberg, dark mudstone prevails with subordinate beds of mainly fine grained limestone. The base of the member is formed by some beds of dark, oolitic, calcareous mudstone with chamosite ooids. The mudstone development can be regarded as an influence from the prevailing lithofacies in the Oslo region (mainly 4aβ). On Billingen, thick bedded limestone prevails with intercalations of dark mudstone. In both members many limestone beds contain chamosite. The upper part of the uppermost member contains a distinctive set of bentonites which are thickest and most numerous on Kinnekulle where water energy during deposition of this part of the sequence was lower than elsewhere in Västergötland.

Dalby beds have been poorly exposed in Västergötland and their fauna is not well known. Asaphus (Neoasaphus) ludibundus is a fairly common species in the upper member, and Echinosphaerites occurs in both members. Large sedentary macro-organisms are rare.

Skagen Limestone In Västergötland the Skagen Limestone forms a distinctive lithostratigraphic unit which consists mainly of fairly thick bedded, grey calcilutites. Its base coincides with the top of the spectacular, main bentonitic bed (1.8 m thick in the Mossen section on Kinnekulle). The thickness of the Skagen Limestone is mostly 3-4 m.

In the Häggum boring on southern Billingen, it is only 1.8 m thick, where it is overlain by a thin (0.14 m) unit of dark shale and mudstone, which may represent the Fjäcka Shale at the base of the Jonstorp Formation (Fig. 3; Skoglund 1963). Thus, in the Häggum boring there is a considerable break at the top of the Skagen Limestone, and the break probably also involves the upper part of the Skagen Formation as developed elsewhere. It is possible that the uppermost part of the Skagen Formation is also missing at several other places in Västergötland.

In the Skagen Limestone of Västergötland sedentary macrofossils are rare, and large macrofauna is composed mainly of trilobites, Asaphus (Neoasaphus) ludibundus being the most common species.

Mossen Mudstone The Mossen Formation is a thin lithostratigraphic unit (maximum thickness on Kinnekulle 1.6 m, and in the Billingen-Falbygden district 0.4 m). It is composed mainly of calcareous mudstone but in places includes dark graptolitic shale which has yielded graptolites belonging to the Zone of Dicranograptus clingani. In Sweden, the formation can only be distinguished in Västergötland, but a comparable thin mudstone-shale wedge is widely distributed in Latvia and even reaches southernmost Estonia (Männil 1966).

The fauna of the formation is poorly known. In the Mossen section on Kinnekulle the commonest macrofossil is Estoniops n.sp., but Lonchodomas minutus Thorslund, Pharostoma sp. and other trilobites also occur. On Kinnekulle Tretaspis ceriodes (Angelin) has been recorded from the top bed of the formation, and this species is common in the Mossen beds of eastern Billingen (Jan Johansson, pers. comm.).

The correlation of the Mossen Formation presents problems because the unit appears to be bounded by breaks and there is no obvious lithological or faunal continuity with the other districts in Sweden. A further problem is that the trilobite fauna in the type section appears to differ considerably from that of the ceriodes-bearing beds on Billingen (Jan Johansson, pers. comm.). Männil (1966) regarded the Mossen beds as a probable equivalent to the lower Slandrom Limestone, whereas Jaanusson (1973) preferred a correlation with the upper part of the Moldå beds.

UPPER ORDOVICIAN

Bestorp Limestone The distribution and lithology of this lithostratigraphic unit is unusual. The formation is composed of thick bedded, high carbonate, extremely fine grained calcilutite with argillaceous partings. The thickness at the type locality on eastern Mösseberg is 4.5 m but only 5 km to the north-west, at Jonstorp on the western slope of Mösseberg, it is reduced in places to barely 0.1 m (Skoglund 1963). The thickness also fluctuates elsewhere in Västergötland, and in some places the unit is missing. The formation is not known outside the Billingen-Falbygden district. The Bestorp Limestone is sparsely fossiliferous, and the commonest trilobite, Primaspis bestorpensis Bruton, has not been found elsewhere.

The correlation of the Bestorp Limestone is unclear. Skoglund (1963) regarded the formation as a possible equivalent to the lower Fjäcka Shale, and recent evidence from chitinozoans corroborates this correlation to some extent (Grahn 1981). According to Männil (1966) the Bestorp Limestone may correspond to the upper Slandrom Limestone.

Fjäcka Shale On Kinnekulle the black Fjäcka Shale is even thicker (6.45 m) than in the Siljan district and Östergötland. In the Billingen-Falbygden district, on the other hand, the division is thin, and the thickness fluctuates within wide limits (from 1.0 to 0.1 m); in some places it is even questionable whether the formation is developed at all. This poor development of the Fjäcka Shale is exceptional because otherwise this division is known to have a marked spatial continuity (Männil 1966). The shale is normally graptolitic, with species indicating the Zone of Pleurograptus linearis.

Break at the transition from the Middle to the Upper Ordovician All over Västergötland there is an extensive break between the Middle and Upper Ordovician. In the districts of the central Baltoscandian confacies belt where the transition from the Middle to the Upper Ordovician appears to be continuous (the Siljan district, autochthonous of Jämtland) a distinctive lithostratigraphic unit - the Slandrom Limestone - is developed between the Moldå beds and the Fjäcka Shale. In Östergötland the Slandrom Limestone is developed, with a reduced thickness in some

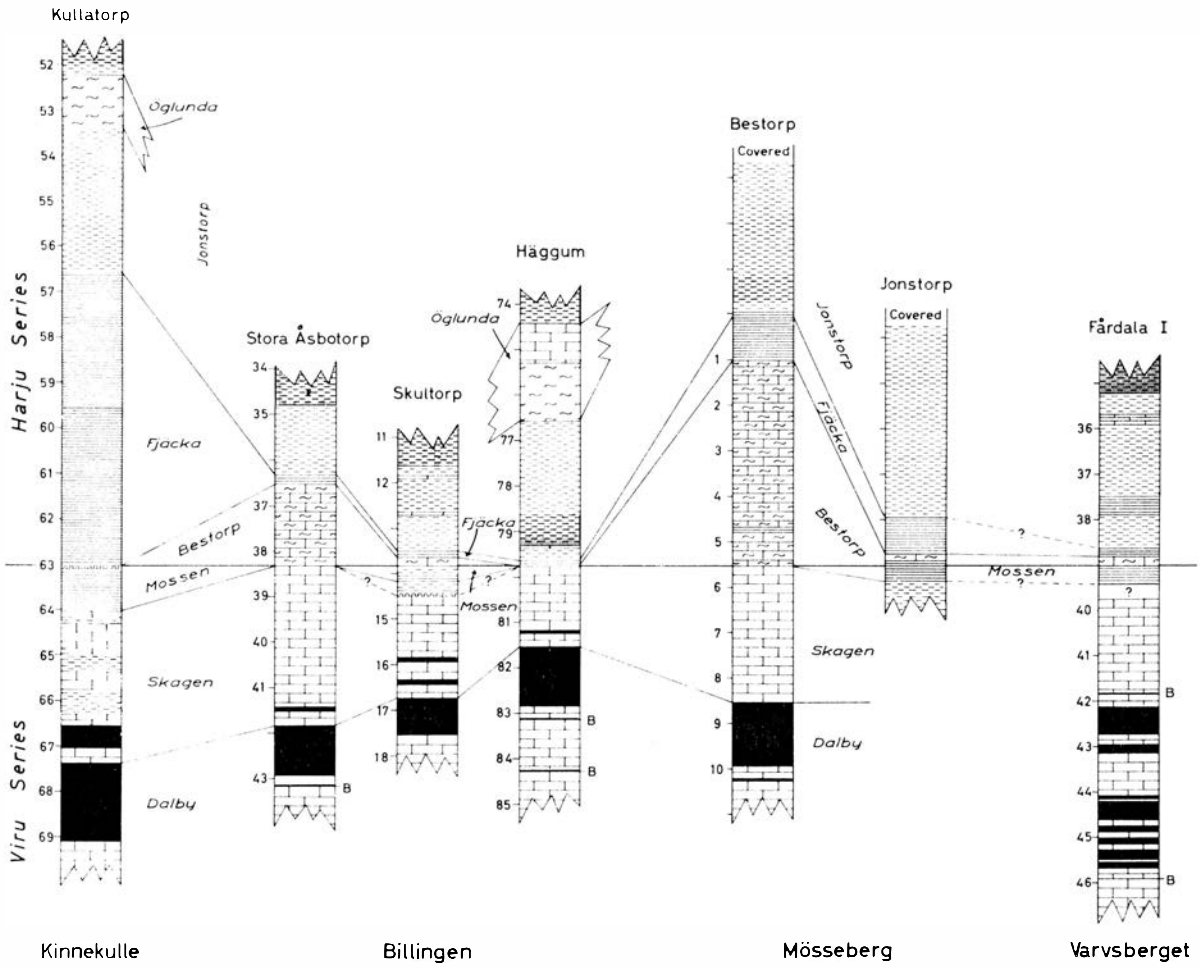


Figure 3. Diagrammatic sections of the uppermost Viruan and the lower part of the Harjuan sequence in Västergötland. Bentonitic beds are black and thin layers marked with the letter B. (From Skoglund 1963)

places, whereas in other places the Fjäcka Shale rests directly on the Moldå beds. There the lack of the Slandrom Limestone cannot be due to a lateral change into another lithology because there is no space in the adjacent units to incorporate the missing portion of the sequence. The magnitude of the break is still larger in Västergötland, some 60-70 km to the west. On southern Billingen, where the break is largest, the lowermost Jonstorp Formation rests on the lower Skagen Limestone, with a very thin shale unit at the base. This may represent a remnant of the Fjäcka Shale. The extent of the break varies (see Fig. 3), and no regular pattern can be recognised. However, although a partial Slandrom equivalent may possibly be represented in the Bestorp Limestone, the principal break appears to correspond to the Slandrom

Limestone and its Estonian equivalents, the Rakvere and Nabala Stages.

According to the model presented by Bruton & Owen (1979) for correlation of the transitional strata between the Middle and Upper Ordovician within the central Oslo Region, the limestone facies changes diachronously into the Lower Tretaspis Shale. However, the condition at this boundary in Östergötland and Västergötland can be interpreted as supporting the previous model in which the base of the Lower Tretaspis Shale (in this case essentially an equivalent to the Fjäcka Shale) is largely synchronous. Thus in the east, the break at the base (where the Fjäcka equivalents would rest on Moldå equivalents) is represented to the west by successively younger limestone units.

Jonstorp Formation (including 'Nittsjö Beds' and Ulunda Mudstone (Jerrestadian Stage) Conditions of deposition stabilised during the Jerrestadian Age. There is little variation in the total thickness of the deposits, and no breaks of recognisable magnitude are known in the central Baltoscandian confacies belt.

In Västergötland, deposits of Jerrestadian age are represented mainly by mudstones. The Jonstorp sequence begins with a greyish green mudstone ('Green Tretaspis Shale' in the old terminology) and continues in a red mudstone ('Red Tretaspis Shale'). At about the transition between the green and red mudstones a distinctive limestone unit, the Öglunda Limestone (up to 3 m thick), consisting of an extremely fine grained, hard, finely nodular calcilutite, is developed in many sections. Jaanusson (1963b) included the topmost greyish green pre-Hirnantian mudstones on Kinnekulle (2.65 m thick) in the Nittsjö beds, but these beds may belong, at least partly, to the Hirnantian Stage (J. Bergström, pers. comm.). In the Billingen-Falbygden district, equivalents to the upper part of the Upper Jonstorp Formation, as developed on Kinnekulle, consists of a dark grey to black mudstone, the Ulunda Formation.

The fauna of the Ulunda Mudstone does not differ appreciably from that of the Upper Jonstorp Mudstone (J. Bergström 1973). In both formations trilobites are the most common component of the macrofauna (for the Ulunda beds see J. Bergström 1973). The trilobite fauna (some 40 species, many revised by Kielan 1959) is basically of the Mediterranean type. Tretaspis latilimbus (Linnarsson) and Nankinolithus granulatus (Wahlenberg) are particularly common, other forms include Lonchodomas porlocki (Barrande), Cybeloides loveni (Linnarsson), Dindymene ornata Linnarsson, Phillipsinella parabola (Barrande), Cyclopyge speciosa (Hawle and Corda), Dionide euglypta (Angelin), and Liocnemis recurvus (Linnarsson). Articulate brachiopods are represented by a few small species, such as Rugosowerbyella rosettana (Henningsmoen), Foliomena folium (Barrande), and Christiania nilssoni Sheehan.

The topmost Ulunda beds at Ålleberg were distinguished by Linnarsson (1869) as Staurocephalus Shale. Dalmanitina (Mucronaspis) mucronata (Brongniart) enters in these beds, and is here associated with Staurocephalus clavifrons Angelin, Nankinolithus granulatus (Wahlenberg), Phillipsinella parabola (Barrande) among others. Brachiopods are represented mainly by small forms. In a chronostratigraphic sense, these beds, about 0.5 m thick at Ållebergsände and about 0.9 m at Stommen, are termed the Ålleberg Beds (Jaanusson 1963b).

Tommarp Beds (Hirnantian Stage) In a chronostratigraphic sense the equivalent of the Hirnantian was first distinguished by Angelin (1854; Regio Harporum). In the intermound facies of Sweden, these beds have subsequently been termed Dalmanites or Dalmanitina Beds, used both in a chrono- and topostratigraphic sense. This generic name is unsuitable for several reasons, and Jaanusson (1963b) replaced it by the locality name Tommarp. However, in the chronostratigraphical sense Tommarpian can now be shown to be a junior synonym of the Hirnantian, and therefore the use of Tommarp is now restricted to topostratigraphic classification. In Sweden, the intermound Hirnantian sequence has a varied lithology, from mudstones to various limestones and siltstones, but lithological relationships are complex, both within a district (not least in Västergötland) and between districts. For the time being it appears preferable to use the term Tommarp in the Scanian and central Baltoscandian confacies belts wherever the division can be defined litho- or topostratigraphically.

In the Tommarp Beds of the Billingen-Falbygden district mudstone is the dominant rock at localities where the division is thickest (Stommen, 4.1 m), whereas in places where the total thickness of the division is thinnest the sequence is formed predominantly of limestone (Skultorp, 1.7 m; Ulunda, 2.0 m). In this district almost all sections display a tripartite lithologic subdivision: a middle limestone unit is underlain and overlain by a mudstone unit (Stridsberg 1980). The lithology of the limestone varies. It is finely nodular on North Billingen, pelletal on western South Billingen and on Mösseberg, oolitic (with calcium carbonate ooids) on eastern South Billingen, Plantaberget and Varvsberget, and partly conglomeratic on Ålleberg (Stridsberg 1980). Siltstone layers also occur in several places.

In areas where the limestone is finely nodular the whole Tommarp sequence tends to be poorly fossiliferous. In the other areas not only the limestone but also the mudstone are mostly fairly rich in macrofossils. Among trilobites Dalmanitina (Mucronaspis) mucronata (Brongniart) and Brongniartella platynotus (Dalman) are common. The brachiopod fauna has recently been described by J. Bergström (1968); it is Hirnantia fauna with a high taxonomic diversity. Hirnantia sagittifera (McCoy), Eostropheodonta hirnantensis (McCoy), Kinnella kielanae (Temple), and Plectothyrella crassicosta (Dalman) are widely distributed in the Hirnantia fauna. Leptaena rugosa Dalman is the type species of the genus Leptaena (type locality Fårdalaberg). Brood (1980) has recently described the Hirnantian bryozoans from Kinnekulle.

It is at present popular to associate the distribution of the Dalmanitina-Hirnantia fauna with the maximum extent of the Upper Ordovician glaciation, and to regard this assemblage as a cold water fauna. However, in Västergötland this assemblage is associated with bahamitic sediments which normally indicate tropical-subtropical temperatures.

3:1 STORA STOLAN (Loc. 1, Fig. 1; Fig. 4) A quarry in the Upper Cambrian alum shales and lowermost Ordovician limestones and shales. On Billingen, the lower part of the Upper Cambrian Subzone of Peltura scarabeoides contains 300 g uranium per tonne of shale, and it is thus an important source of uranium. At Stolan these beds are especially rich in small lenses of an argillaceous coal (in Swedish 'kolm') which contains on average 1.5 mg $RaBr_2$ per tonne of kolm. This radium ore has been quarried at Stolan.

A key to the Lower Ordovician sequence in the quarry is given in Fig. 4, based on a detailed study of the section by Tjernvik (1956). At this locality the lower Billingenian Zone of Megalaspides (Megalaspides) dalecarlicus is replaced by Tøyen Shale (Lower Didymograptus Shale; Zone of Phyllograptus densus).

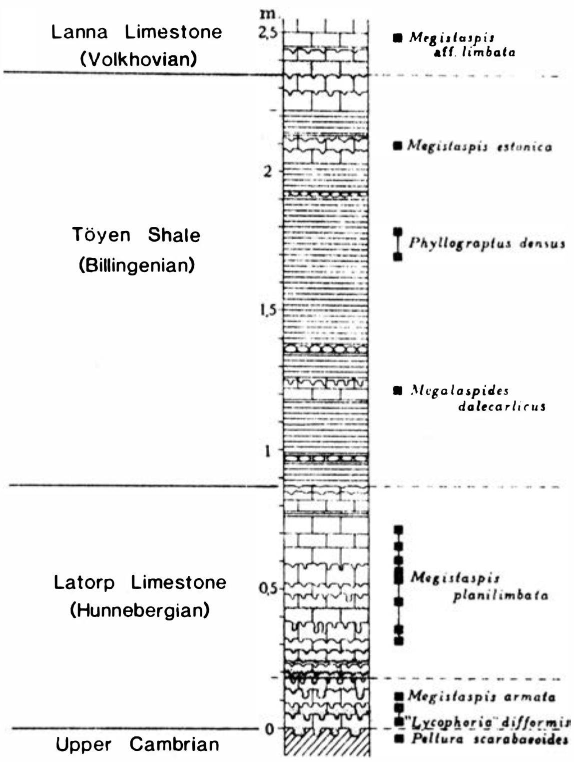


Figure 4. Section through the early Ordovician limestones and shales at Stora Stolan, Billingen (after Tjernvik 1956).

3:2 GULLHÖGEN QUARRY (Loc. 2, Fig. 1) A continuous section from the Upper Cambrian bituminous shale to the Upper Ordovician Jonstorp Formation. The total thickness of the exposed beds is almost 70 m. This is the type locality of the Våmb Limestone, Skövde Beds, Gullhögen Formation and, in practice, the Ryd Limestone (the latter division was originally defined with reference to the Stora Åsbotorp boring about 1.5 km north of the Guulhögen quarry, and the section in the quarry is the closest exposure). The section in the quarry below the Våmb Limestone and above the Ryd Limestone has not yet been studied in detail. The section is as follows:

UPPER ORDOVICIAN (HARJUAN SERIES) 4.0 m +

Jonstorp Formation 2.0 m +
Red mudstone .... 0.5 m +
Greenish grey mudstone with some limestone lenses .... 1.5 m

POSSIBLE BREAK, comprising at least some of the Fjäcka Shale (represented by 0.2 m black shale in the Stora Åsbotorp core and 1.0 m at Bestorp)

Bestorp Limestone 1.8 m
Thick bedded, very fine frained calcilutite, in the lower part with intercalations of dark mudstone .... 1.8 m

BREAK, comprising at least a major part of the Slandrom equivalents (may be situated below the thin shale unit underlying the Bestorp Limestone)

MIDDLE ORDOVICIAN (VIRUAN SERIES)

Formation uncertain 0.05 m (may be Harjuan)
Black shale with abundant sponge spicules .... 0.05 m

BREAK?

Mossen Formation 0.15 m
Grey calcareous mudstone. The commonest fossils are Tretaspis ceriodes (Angelin), Flexicalymene sp. and Lonchodomas sp. (Jan Johansson, pers. comm.) .... 0.15 m

BREAK, comprising the equivalents of almost the entire Moldå and possibly also the upper Skagen

Skagen Limestone 2.8 m
Grey, fairly thick bedded calcilutite with some intercalation of calcareous mudstone. A layer of bentonite, 5 cm thick, 30 cm above the base. Relatively poor in macrofossils; Asaphus (Neoasaphus) ludibundus is the commonest species. From the Skagen Limestone of the Mossen section, Kinnekulle, which is identical lithologically, the following estimate of the composition of the large macrofauna is available from the limestone beds 1.65-2.05 m above the base of the formation (N = 38; V. Jaanusson, unpublished): Trilobita 80%, Gastropoda 13%, Cephalopoda 5%, Brachiopoda Articulata 2%. The commonest species are Asaphus (Neoasaphus) ludibundus Törnquist (35%), Lonchodomas sp. (13%) and Scolopochasmops sp. (7%) .... 2.8 m

Dalby Limestone 11.9 m
Upper Member 6.3 m
A thick bed of bentonite .... 1.1 m
Thick bedded grey limestone (predominantly calcarenite) with regular intercalations of fairly thick beds of grey calcareous mudstone. A 20-25 cm thick argillaceous limestone close to the base of the member is rich in fossils. Jan Johansson (pers. comm.) has made the following estimate of the composition of the large macrofauna (N = 350): Trilobita 78%, Gastropoda 6%, Brachiopoda 5%, Torellella 5%, Cephalopoda 4%, Echinosphaerites 1% and Conulariida 1%. The commonest species are: Asaphus (Neuasaphus) ludibundus Törnquist (21%), Cnemidopyge costata (Boeck) (9%), Chasmops sp. (8%), Sphaerocoryphe sp. (7%), Lonchodomas sp. (6%), and Telephina sp. (6%). Higher up in the sequence

Echinosphaerites aurantium (Gyllenhaal) is a conspicuous macrofossil in some beds .... 5.2 m
In the bed below those rich in fossils, at the lower boundary of the member, large macrofossils are surrounded by thick calcium carbonate incrustations (Jan Johansson, pers. comm.). The enveloping structures may represent stromatolites but they have not yet been studied.
Lower Member 5.6 m
Thick bedded to finely nodular, in the upper part mainly calcarenitic, in the lower part predominantly calcilutitic limestones. Poor in macrofossils except occasional *Echinosphaerites* .... 5.6 m

Ryd Limestone 9.0 m
Thin bedded to finely nodular calcilutites, mostly grey, but with some red beds in the lower part. Poor in macrofossils except occasional specimens of *Nileus*. .... 9.0 m

Gullhögen Formation 12.1 m
Dark calcareous mudstone to finely nodular limestone with sparsely spaced continuous beds of grey or red calcilutite. *Pseudomegalaspis patagiata* (Törnquist) and *Nileus* sp. are common especially in the lower part .... 11.9 m

Skövde Beds
Some beds of variegated grey and red limestone. A discontinuity surface at the top of the unit indicates a minor break .... 0.2 m

BREAK, comprising strata of early and middle Lasnamägian age. The level is defined by a distinct discontinuity surface furrowed in places, the furrows arranged in a polygonal pattern suggesting mud cracks

Våmb Limestone 0,0.09 m
Red or variegated red and grey limestone with large chamosite ooids. *Asaphus (Neoasaphus) platyurus* Angelin is the commonest macrofossil. The thin sequence includes several intraformational discontinuity surfaces. In parts of the quarry the division pinches out over swells in the basal Viruan discontinuity surface, and here the uppermost Lasnamägian Skövde Beds rest directly on Kunda Stage (Lars Holmer, pers. comm.) .... 0-0.09 m

BREAK; the Aserian Stage is in places completely missing and represented in other places only by a few topmost beds (Våmb Limestone). The basal Viruan discontinuity surface is in most places completely smooth; large orthocone cephalopods are truncated at the surface. The surface is buckled in several places into very low mounds. On some of these, truncated dome-shaped laminated structures occur which probably represent stromatolites (Lars Holmer, pers. comm.)

LOWER ORDOVICIAN (OELANDIAN SERIES) 21.2 m

Holen and Lanna Limestones 20.5 m

Red, fairly thick bedded, argillaceous calcilutite .... 0.6 m
These beds, together with the upper part of the underlying finely nodular limestone, belong to the Zone of Megistaspis (Megistaspidella) gigas and are fairly rich in trilobites. They also contain large orthocone cephalopods but almost no other macrofossils. Common species are Megistaspis (Megistaspidella) gigas (Angelin), Asaphus (Neoasaphus) n.sp., Niobe laeviceps Dalman, Pseudoasaphus perstriatus Bohlin and Illaenus glabriusculus Jaanusson.

Finely nodular red calcilutite .... 1.5 m
Red, bedded calcilutite .... 8.1 m
Alternating grey and pale red calcilutite .... 2.2 m
Light grey limestone .... 8.1 m

Latorp Limestone (Billingen Stage) 0.7 m

Grey limestone, in part rich in glauconite, in the lowermost part with pebbles derived from the underlying beds. Lower and upper boundary defined by discontinuity surfaces .... 0.7 m

BREAK, comprising the Tremadoc Subseries, Hunneberg Stage and most of the Billingen Stage. The basal Ordovician discontinuity surface is spectacular, with deep solution pits and a bleached zone below the surface.

UPPER CAMBRIAN 8 m +

BREAK, comprising the uppermost Upper Cambrian zone and two subzones of the Peltura Zone

'Alum Shale Formation' 8 m +

Dark, bituminous shale with lenses of 'stinkstone' (= bituminous limestone, 'orsten' in Swedish) .... 8 m +

3:3 BESTORP (Loc. 3, Fig. 1) Almost complete section from the Upper Ordovician Bestorp Limestone to the basal Silurian shales. The main, upper part of the section is exposed in a deep ravine cut into the slope of Mösseberg. Collections have been made at this well known exposure since the beginning of the 19th century; for example, both Wahlenberg and Dalman collected here. It is the type locality of such well-known Hirnantian species as Dalmanitina (Mucronaspis) mucronata (Brongniart) and Lichas laciniatus

(Wahlenberg) (type species of *Lichas*).

LOWER LLANDOVERY

Mudstone and shale .... 3 m

UPPER ORDOVICIAN

Tommarp Beds (Hirnantian Stage) 2.8 m
Grey mudstone .... 0.55 m
Pelletal calcisiltite .... 0.3 m
Siltstone with irregular limestone lenses .... 0.35 m
Pelletal calcisiltite .... 0.3 m
Grey mudstone .... 1.3 m

Ulunda Mudstone 8.15 m
Dark grey to black mudstone, speckled close to the top .... 8.15 m

Jonstorp Formation about 18.3 m
Red mudstone with some greyish green intercalations .... 10.1 m +
COVERED INTERVAL .... 4.8 m
Greyish green mudstone .... 1.7 m +
Dark, speckled mudstone. *Dicellograptus complanatus* Lapworth, *Orthograptus gracilis* (Roemer) and other graptolites .... 0.15 m
Greenish grey mudstone, in part speckled .... 0.75 m
Red mudstone .... 0.6 m
Greenish grey mudstone, in part speckled .... 0.15 m
Dark grey calcilutite .... 0.08 m

Fjäcka Shale 1.01 m
Dark grey to black mudstone. *Dicellograptus johnstrupi* Hadding, *Climacograptus angustus* Perner and other graptolites close to the base .... 1.01 m

Bestorp Limestone 3.6 m +
Dark, very fine grained, regularly bedded limestones with thin intercalations of shale. *Primaspis bestorpensis* Bruton .... 3.6 m +

3:4 ÅLLEBERGSÄNDE (Loc. 4, Fig. 1) A section from the Upper Ordovician Jonstorp Formation to the basal Silurian shales. Another well known locality visited by Dalman, Wahlenberg and many others. Ållebergsände is the type locality of the Dalmanitina and Staurocephalus Beds (Linnarsson 1869), the latter now termed Ålleberg Beds (Jaanusson 1963b). The following section is accessible.

LOWER LLANDOVERY

Mudstone and shale .... 3 m +

UPPER ORDOVICIAN

Tommarp Beds (Hirnantian Stage) 2.5 m

Mudstone, in the middle part speckled, with a thin calcilutitic bed in the uppermost part. Streptolasma linnarssoni common in the lower part; Dalmanitina (Mucronaspis) mucronata (Brongniart) has been recorded up to the top of the unit (J. Bergström pers. comm.) .... 0.7 m

Grey, in part conglomeratic limestone, displaying cross-bedding in places. Streptelasma linnarssoni (Lindström) abundant in some beds .... 0.4 m

Grey to yellowish mudstone, in the upper part calcareous. Dalmanitina (Mucronaspis) mucronata (Brongniart), Brongniartella platynota (Dalman), Leptaena rugosa Dalman, etc. .... 1.4 m

Ulunda Mustone 2.55 m

Ålleberg Beds (Zone of Staurocephalus clavifrons; type locality). Grey, speckled mudstone. Staurocephalus clavifrons Angelin (type locality) Dalmanitina (Mucronaspis) mucronata (Brongniart), Nankinolithus granulatus (Wahlenberg), etc. .... 0.5 m

Black mudstone, speckled in some beds. Very poor in macrofossils .... 2.05 m

Jonstorp Formation

Red mudstone with some greenish intercalations .... 4.0 m +

According to data from J. Bergström (1968), the commonest brachiopods in the Tommarp Beds of this locality are: Coolinia dalmani Bergström (44%), Hirnantia sagittifera (McCoy) (9%), Kinnella kielanae (Temple) (9%), Eostropheodonta hirnantensis (7%), and Plectothyrella crassicosta (Dalman) (6%) (N = 610).

3:5 STENBROTTET (ORREHOLMEN) (Loc. 5, Fig. 1; Fig. 5) A quarry in the Upper Cambrian bituminous shales and Lower Ordovician beds. The sub-Ordovician surface was uneven, and the thickness and development of the basal Ordovician varies considerably in different parts of the quarry. In the north-eastern corner of the quarry (the left column in Fig. 5) the Dictyonema Shale is overlain by Ceratopyge Limestone which is missing in the south-western corner (the right column in Fig. 5). Here limestone of the Hunnebergian

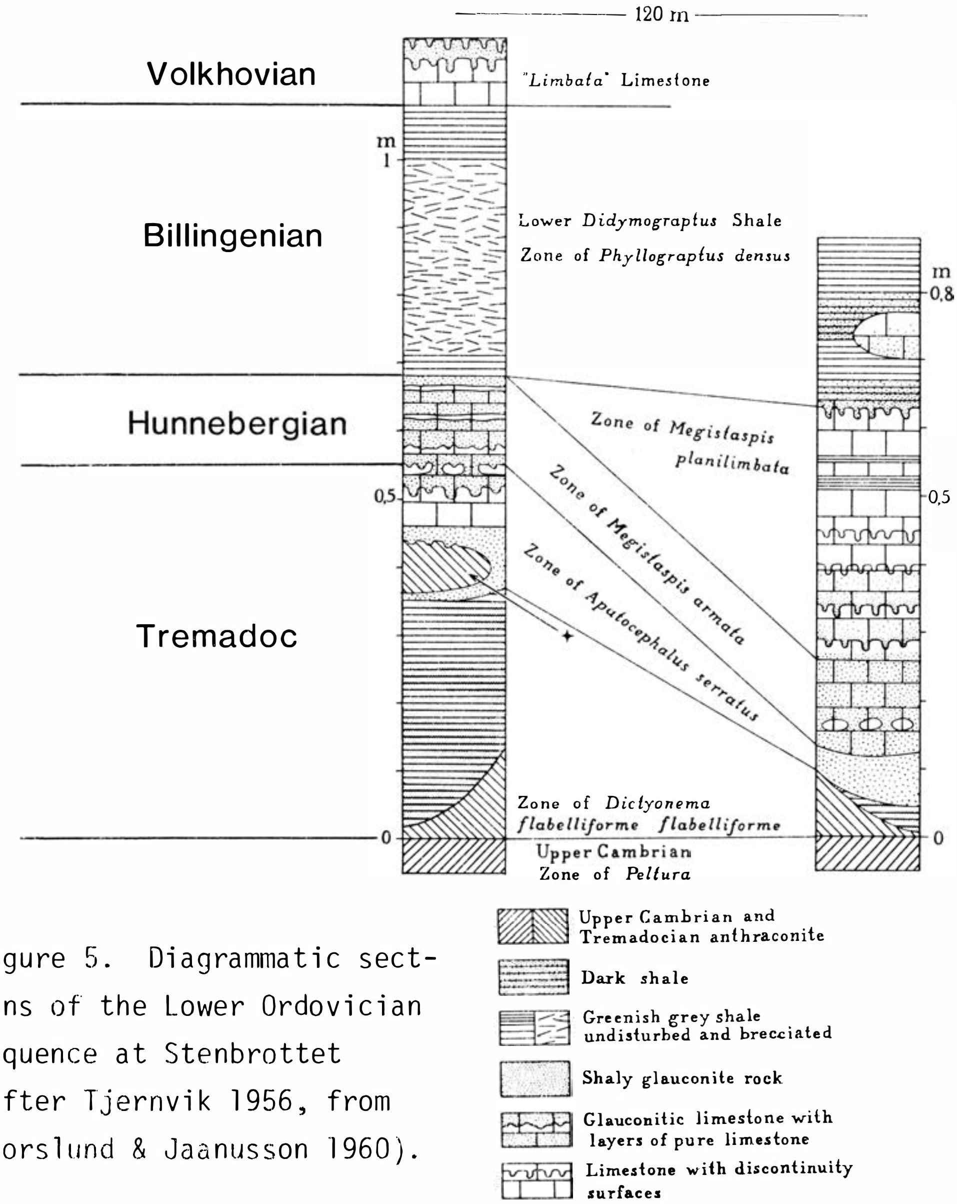


Figure 5. Diagrammatic sections of the Lower Ordovician sequence at Stenbrottet (after Tjernvik 1956, from Thorslund & Jaanusson 1960).

Zone of Megistaspis (Varvaspis) planilimbata rests on the Zone of Megistaspis (Ekeraspis) armata, while in the north-eastern corner of the quarry the Billingenian Tøyen Shale directly overlies the Hunnebergian Zone of Megistaspis (Ekeraspis) armata.

This quarry can be regarded as the type locality of the Zone of Megistaspis (Ekeraspis) armata. This and the following fossils have been recorded from the armata beds: Hunnebergia retusa Tjernvik, Lapidaria tenella Tjernvik, Varvia falensis Tjernvik, Symphysurus angustatus (Sars & Boeck), Saltaspis viator Tjernvik, Falanaspis aliena Tjernvik, Orometopus grypos Tjernvik, *Geragnostus lepidus* Tjernvik, and other trilobites (Tjernvik 1956).

The Ceratopyge Limestone and the Zone of *Megistaspis* (*Varvaspis*) *planilimbata* also contain numerous trilobites, whereas the Tøyen Shale (Lower Didymograptus Shale in Fig. 5) has a limited faunal diversity (mainly *Phyllograptus*). Common species in the Ceratopyge Limestone are *Ceratopyge forficula* (Sars), *Euloma ornatum* Angelin, *Orometopus elatifrons* (Angelin), *Apatokephalus serratus* (Boeck), *Symphysurus angustatus* (Sars & Boeck), and *Nileus limbatus* Brøgger. In the Zone of *Megistaspis* (*Varvaspis*) *planilimbata*, *Megalaspides* (*Lannacus*) *nericiensis* Wiman, *Promegalaspides* (*Borogothus*) *stenorhachis* (Angelin), *Niobe emarginula* Angelin, *Varvia breviceps* (Angelin), *Symphysurus angustatus* (Sars & Boeck), and *Apatokephalus pecten* Wiman occur in addition to the index species.

SCANIA

Jan Bergström

GEOLOGICAL SETTING

Scania is the southernmost province of Sweden, lying on the boundary between the Fennoscandian Shield and west central Europe. The buffer zone is known as the Fennoscandian Boundary Zone and extends in a NW-SE direction through Scania.

Much of the Early Palaeozoic was tectonically quiet, and Cambrian to middle Silurian deposits were laterally uniform. Considerable faulting occurred during the Ludlow and a thick pile of Colonus Shale accumulated in an elongated trough. Tension and volcanism around the Permo-Carboniferous boundary led to the formation of very numerous dolerite dykes trending NW-SE to WNW-ESE. Subaerial remains of this event have been completely removed. New tectonic activity throughout much of the Mesozoic led to sedimentation over various parts of Scania. A second volcanic event started around the early-middle Jurassic and resulted in numerous basaltic necks, mostly in central Scania. Here the early Jurassic landsurface is now exposed, revealing pockets of residual kaolin and volcanic remains. The geology is much more complex than can be shown on a small-scale map, and due to the Quaternary cover is known only in outline in many areas.

The following text has gained from data and comments given by Kristina Lindholm, Anita Löfgren, Ragnar Nilsson, and Valdar Jaanusson.

The Ordovician of Scania (Fig. 2) belongs to a south-west Scandinavian confacies belt characterized by graptolite shales. It overlies the Upper Cambrian alum shale, which is dominated by olenid and agnostid trilobites and almost devoid of distinctly benthic faunas. The Ordovician is normally some 150-200 m thick.

Dictyonema Shale and Ceratopyge Beds (Tremadoc) Continuous sedimentation appears to have occurred at least locally at the Cambrian-Ordovician transition. The base of the Ordovician is marked by the Dictyonema Shale; although its alum shale is similar to that of the underlying shale, there is a striking contrast in fauna content. The monotonous trilobite faunas of the Upper Cambrian indicate adverse bottom conditions

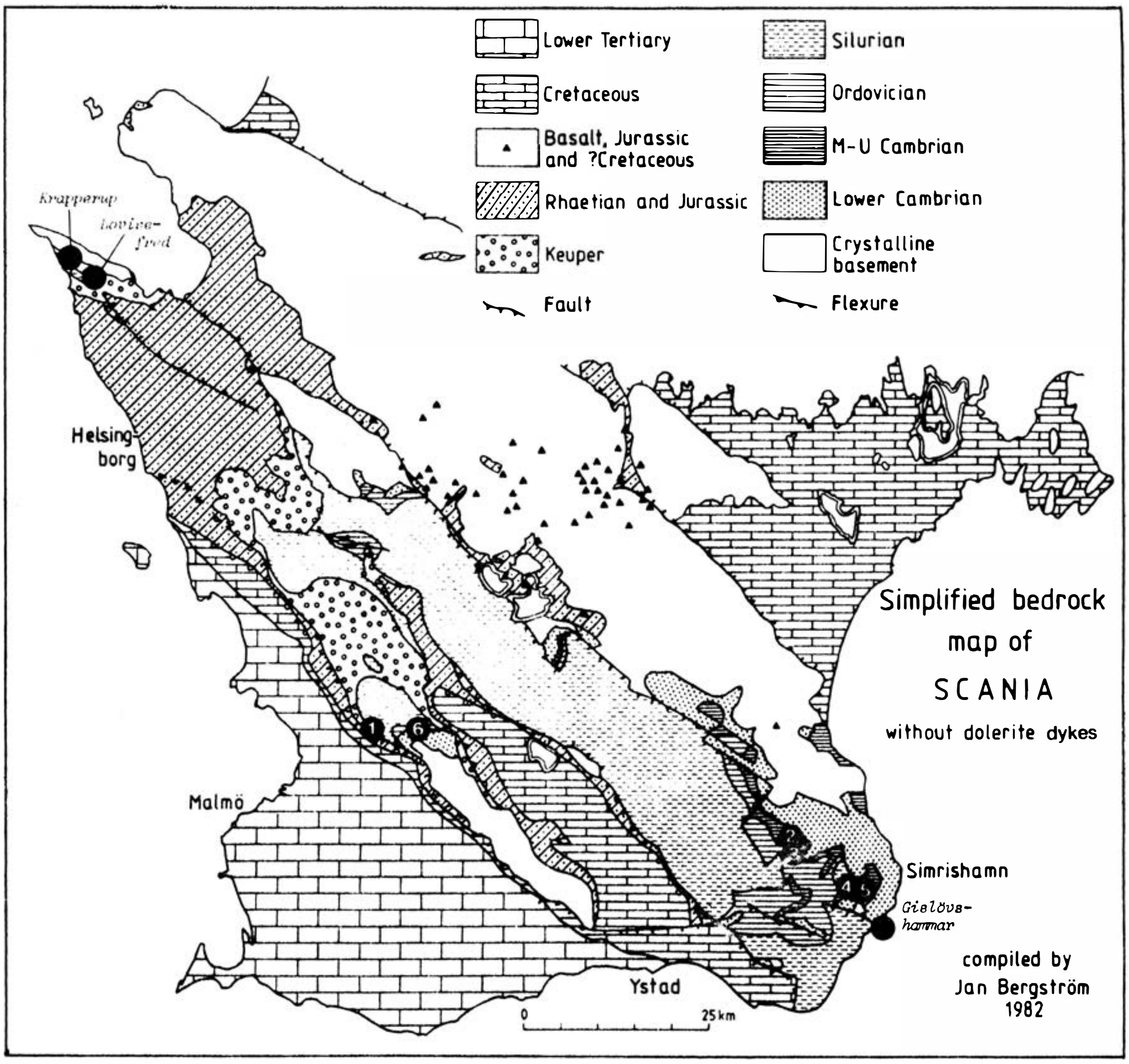


Figure 1. Bedrock map of Scania. The numerous Permo-Carboniferous dolerite dykes, trending NW-SE, are omitted for clarity. Excursion stops marked with white number in filled circle: 1, Department of Geology, Lund; 2, Flagabro; 3, Killeröd; 4, Tommarp; 5, Jerrestad; 6, Fågelsång. Krapperup, Lovisefred and Gislövshammar are sites for important borings referred to in the text.

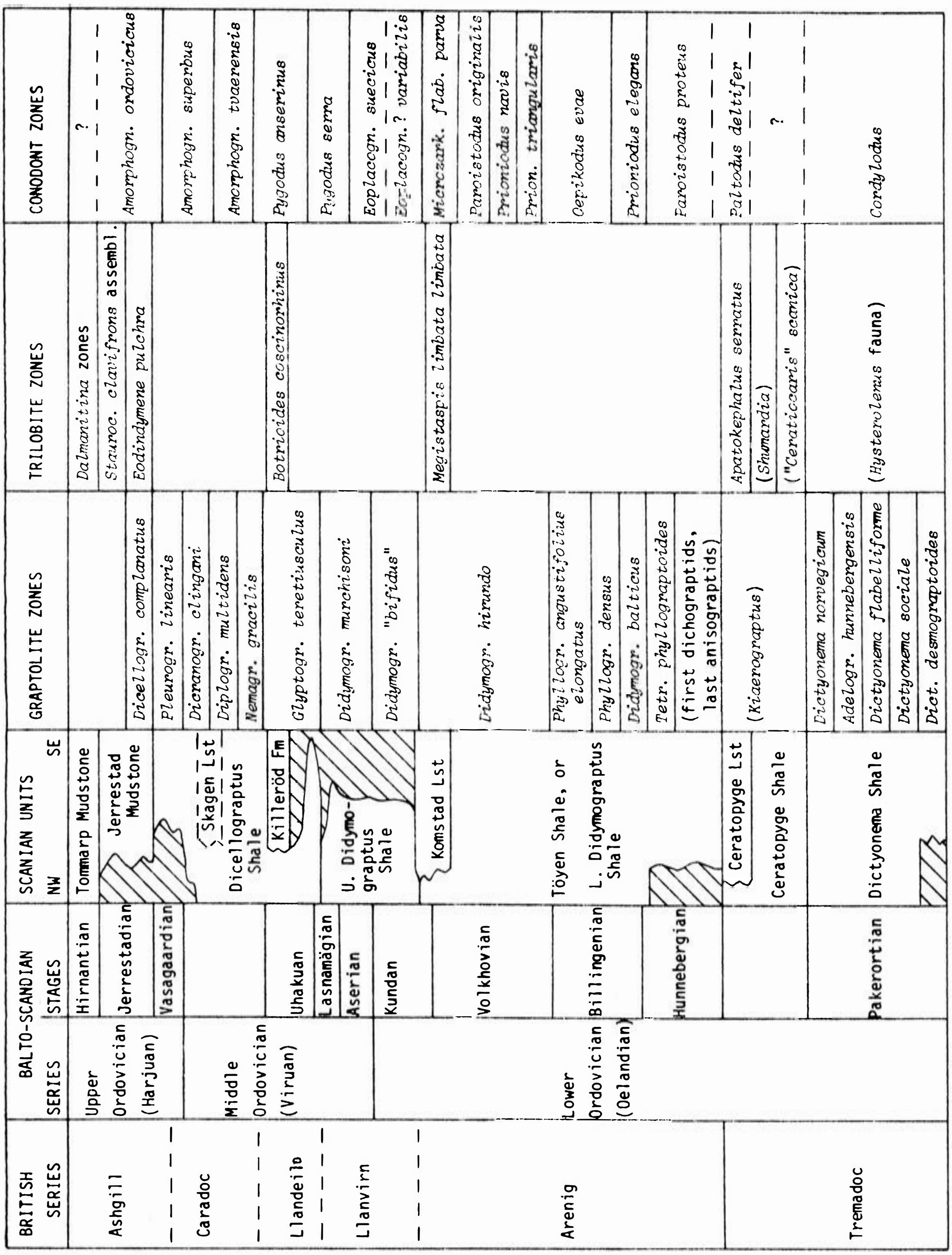


Figure 2. The Ordovician of Scania.

with only rare benthic invertebrates. The Dictyonema Shale carries a much more varied fauna, including dendroid graptolites (*Dictyonema* spp, *Clonograptus tenellus*, *Adelograptus hunnebergensis*, *Bryograptus kjerulfi*) and a benthos of inarticulate brachiopods, various trilobites (e.g. *Hysterolenus toernquisti*) and conodonts.

The Dictyonema Shale varies in thickness from 5.3 to 16.5 m, the highest value being found at Gislövshammar in the extreme south-east corner of Scania. It is rich in silica and contains kerogen and pyrite with some uranium. The Dictyonema Shale is particularly rich in vanadium, which reaches up to 4500 ppm. This may have been organically enriched as some living organisms (holothurians) can enrich vanadium up to 280 000 times relative to sea water.

The top few tens of centimetres of the alum shale sequence lack graptolites but are rich in the crustacean "*Ceratiocaris*" *scanica* Moberg & Segerberg in addition to brachiopods. This unit is regarded as the base of the Ceratopyge Limestone and Shale. At Fågelsång east of Lund the alum shale is overlain by a shale with a thin limestone band. The limestone contains an interesting trilobite fauna which includes *Shumardia dicksoni* Moberg, *Ceratopyge forficula* (Sars), *Symphysurus angustatus* (Sars & Boeck), *Euloma ornatum* Angelin, and *Orometopus elatifrons* (Angelin).

The top of the Ceratopyge Beds is normally developed as the Ceratopyge Limestone, which is around 0.25-1.0 m thick. This limestone is grey and microcrystalline, with splintery fracture, and is rich in pyrite. The fauna includes *Geragnostus sidenbladhi urceolatus* (Moberg & Segerberg), *Shumardia dicksoni*, *Ceratopyge forficula*, *Apatokephalus serratus* (Boeck), *Niobe insignis* Linnarsson, *Niobella obsoleta* (Linnarsson), *Symphysurus angustatus*, *Nileus limbatus* Brögger, *Euloma ornatum*, *Harpides rugosus* (Sars & Boeck), and *Orometopus elatifrons*.

Evidence from the Krapperup drilling in north-west Scania indicates that where the sequence is less condensed it may consist of grey graptolite shale with *Kiaerograptus* sp (Kristina Lindholm, unpublished).

Lower Didymograptus Shale or Tøyen Shale (Arenig) The graptolite shale unit overlying the Ceratopyge Beds has long been known as the Lower Didymograptus Shale, a name now regarded as a synonym of Tøyen Shale. The latter term was introduced for the corresponding sequence in the Oslo area. There is considerable variation in the development of this unit in Scania; the sequence is incomplete and measures only a few metres in the Fågelsång area (Hede 1951), while 75 m in the drillcore from Krapperup in northwestern Scania apparently represents only part of the Lower Didymograptus Shale of that area (Kristina Lindholm, unpublished). Other areas tend to be intermediate in thickness. As in the overlying parts of the Ordovician, there is considerable variation inside Scania not only in thickness but also in faunal composition. The zonation of the basal part of the sequence is currently poorly understood. There seems to be a lowest interval with Dictyonema sp and the last anisograptid fauna, overlain by one with the earliest dichograptid fauna, both of which correspond to the Megistaspis (Ekeraspis) armata Zone in the trilobite zonal system (Kristina Lindholm, unpublished).

The subsequent zones generally occur in graptolite shales. The Tetragraptus phyllograptoides Zone is poor in fossils (Tjernvik 1960), but the zones of Didymograptus balticus, Phyllograptus densus, P. augustifolius elongatus, and Didymograptus hirundo contain varied graptolite faunas. The zones of T. phyllograptoides and P. densus are missing at Fågelsång. In north-west Scania (Lovisefred drillcore) the D. hirundo Zone has yielded an Australasian graptolite fauna with species of Isograptus, Pseudisograptus, Maeandrograptus, and Apiograptus indicative of the Yapeenian Stage in Australia (Ragnar Nilsson, unpublished).

Komstad Limestone (Arenig-Llanvirn boundary) The Lower Didymograptus Shale (Tøyen Shale) is normally overlain by the Komstad Limestone, which may be considered as a tongue of the northern and north-eastern orthoceratite limestone. The Komstad Limestone thins accordingly in a westerly direction from around 10 m in south-east Scania to 2 m at Fågelsång. In the Lovisefred drilling core in north-west Scania the Komstad Limestone is not developed (Ragnar Nilsson, unpublished). The trilobite fauna in the Komstad Limestone includes species of Megistaspis (Megistaspis), Asaphus (Asaphus), Ptychopyge, Cyclopyge, Raymondaspis, Illaenus, Cyrtometopus, and Pterygometopus. Cephalopods are common. This fauna is badly in need of revision but is regarded to indicate the zones of Megistaspis (Megistaspis) limbata limbata (formerly called the Zone of Asaphus lepidurus) and Asaphus (Asaphus) expansus. The position relative to the boundary between the D. hirundo and D. 'bifidus' zones is debatable. However, the limestone appears to range from the Zone of Microzarkokodina flabellum parva to the lowest part of the Zone of Eoplacognathus? variabilis in the conodont zonal scheme (Anita Löfgren, Ragnar Hedvall and Sara Nyman, unpublished).

Upper Didymograptus Shale (Llanvirn) The Komstad Limestone is succeeded by the Upper Didymograptus Shale. This unit is encompassed within the zones of D. 'bifidus' and Didymograptus murchisoni (Pterograptus elegans Zone in north-west Scania). The Upper Didymograptus Shale is best developed in north-west Scania where it measures 49.5 m in the Lovisefred drillcore (Ragnar Nilsson, unpublished). The unit decreases to 18 or 16 m at Fågelsång. In south-east Scania there is a break on top of the Komstad Limestone, the Upper Didymograptus Shale measuring only 1.2 m at Flagabro and missing at Tommarp. The D. 'bifidus' Zone has not been reported in south-east Scania, and in places the whole Upper Didymograptus Shale is missing. In the latter case the Glyptograptus teretiusculus Zone equivalents (Killeröd Formation) rest directly on the Komstad Limestone. The break has its greatest known extent on Bornholm to the south-east, where beds belonging to the upper part of the Diplograptus multidens Zone rest on the Komstad Limestone (S.M. Bergstrom & Nilsson 1974). In addition to many graptolite species, the Upper Didymograptus Shale has yielded a number of inarticulate brachiopods together with phyllocarids, sponge spicules and conodonts in the shales (e.g. Hede 1951).

Dicellograptus Shale (Llandeilo-Caradoc) This was formerly divided into Lower and Middle Dicellograptus Shale, but is here taken as one unit consisting of graptolite shales with siltstones and thin limestone beds. Although the shales are dominated by graptolites, they also contain a shelly fauna (Hadding 1913; Nilsson 1952, 1960). The Dicellograptus Shale is about 62 m thick at Fågelsång (Hede 1951; Nilsson 1977) and around 40 m at Lovisefred (Ragnar Nilsson, unpublished). In south-east Scania equivalents to parts of the G. teretiusculus Zone are developed as a thin sequence of alternating limestone and mudstone beds. These beds were formerly termed the Coscinorhinus or Bronni beds (after the trilobite Botryoides coscinorhinus (Angelin) which is regarded as a senior synonym of B. bronni (Sars & Boeck), but a more appropriate term is needed. At Killeröd the basal bed, which belongs to the top of the Pygodus serra Zone, is conglomeratic and contains chamosite ooids. The remainder of the formation has yielded a conodont fauna of the lower part of the Pygodus anserinus Zone (S.M. Bergström 1973).

The Diplograptus multidens Zone is characterized by a number of thin, metabentonite beds and associated silicification of mudstones, resulting in the so-called Sularp shale. The Sularp shale has a comparatively rich shelly fauna including trilobites such as Asaphus (Neoasaphus) ludibundus Törnquist, Platycalymene dilatata(Tullberg), Lonchodomas "rostratus" (Sars) and Cnemidopyge costata (Boeck), brachiopods such as Onniella bancrofti M. Lindström and Sericoidea restricta (Hadding), further ostracodes, molluscs, machaeridians, and echinoderms (Lindström 1953). Graptolites are few.

In south-east Scania a thin limestone unit is developed, bounded by shales belonging to the D. multidens and Dicranograptus clingani zones respectively. This limestone has previously been termed the Ampyx limestone (after a species of Lonchodomas) but is actually a tongue of the Skagen Limestone developed to the north. The Skagen Limestone is overlain by the Cystoid shale with a shelly fauna including the echinoderms Heliocrinites granatum (Wahlenberg), Echinosphaerites? sp and Haplosphaeronis oblonga (Angelin).

The Pleurograptus linearis Zone is represented by graptolite shale in south-east Scania but seems to be absent in the Fågelsång area and in north-west Scania. In the latter area the hiatus also comprises the Jerrestadian and probably part of the D. clingani Zone.

Jerrestad and Tommarp Mudstones (Ashgill) These mudstones form one lithological unit representing the top of the Ordovician. Despite detailed work the thickness is still poorly known. It is around 45 m in the Fågelsång area (Glimberg 1961; Grahn 1978; Nilsson 1977, 1979) but decreases to 9 m or less in north-west Scania, where the Jerrestad Mudstone appears to be absent (Ragnar Nilsson, unpublished). The basal part of the Jerrestad Mudstone was formerly termed the Upper Dicellograptus Shale. The fauna contains several zonal indices including Dicellograptus complanatus and Nankinolithus granulata (Wahlenberg) in western Scania and Opsimasaphus latus (Angelin), Lonchodomas portlocki (Barrande) and Eodindymene pulchra (Olin) in south-east Scania (e.g. Kielan 1959; Regnéll 1960). Nilsson (1977) listed 114 species from this level.

Higher parts of the Jerrestad Tommarp Mudstone unit contain a poorer fauna, graptolites in particular being virtually absent (Nilsson 1979). The zonation appears to be strongly influenced by local ecological conditions. Thus the Staurocephalus clavifrons Zone is difficult to delimit from the Eodindymene pulchra Zone and from the Dalmanitina beds. The latter have been separated into three zones, viz. the Dalmanitina (Mucronaspis) olini Zone, the Dalmanitina (M.) mucronata Zone, and the Brongniartella platynota Zone. The two forms of Dalmanitina (Mucronaspis) as well as Brongniartella platynota (Dalman) may be strongly influenced by local ecological conditions. D. olini Temple is missing in Västergötland although there is probably no hiatus. B. platynota appears to be a shallow-water species occurring at slightly different levels and with varying frequency. The author found it at Nyhamnsläge (close to Klapperup) in north-west Scania, where the corresponding 'zone' has been regarded as absent, and possibly below the Dalmanitina beds in the Ulunda Mudstone in Västergötland.

1:1 DEPARTMENT OF GEOLOGY, LUND UNIVERSITY Due to the Quarternary cover, exposures of Ordovician rocks are generally both rare and small. In order to give a more complete picure of the local Ordovician, Mr. Ragnar Nilsson and Ms. Kristina Lindholm of the Department will demonstrate interesting drillcore material whose results have not yet been published.

2:1 FLAGABRO (Figs. 3, 4) The base of the Ordovician (Tremadoc) is accessible along a small rivulet at the farm Flagabro, run by Mr. Julius Jönsson. Just east of a small bridge there is the 1 m thick, grey-coloured and calcilutitic Ceratopyge Limestone, which forms the top of the Tremadoc. This limestone has yielded a fauna including trilobites (*Ceratopyge forficula*, *Euloma ornatum*, and *Symphysurus augustatus*) and brachiopods (Tjernvik 1958). The limestone is underlain by a thin sheet of dark Ceratopyge Shale with the phyllocarid crustacean *Ceratiocaris* and brachiopods. This is in turn underlain by the 11 m thick Dictyonema Shale, an alum shale forming the base of the Tremadoc. This shale is highly bituminous and contains concretions of stinkstone (= bituminous limestone), baryte and pyrite. The total carbon content is 11% and the sulphur content is 2%, while the uranium content is low, only some 50-60 g/t (0.005%). The Dictyonema Shale is known for its content of vanadium (around 0.4%); a water-filled digging 100 m NE of the bridge is the remains of an attempt at extraction. The fauna is dominated by *Dictyonema*, but the upper part, exposed at Flagabro, is poorly fossiliferous. Towards the south-west the section is terminated by a Permo-

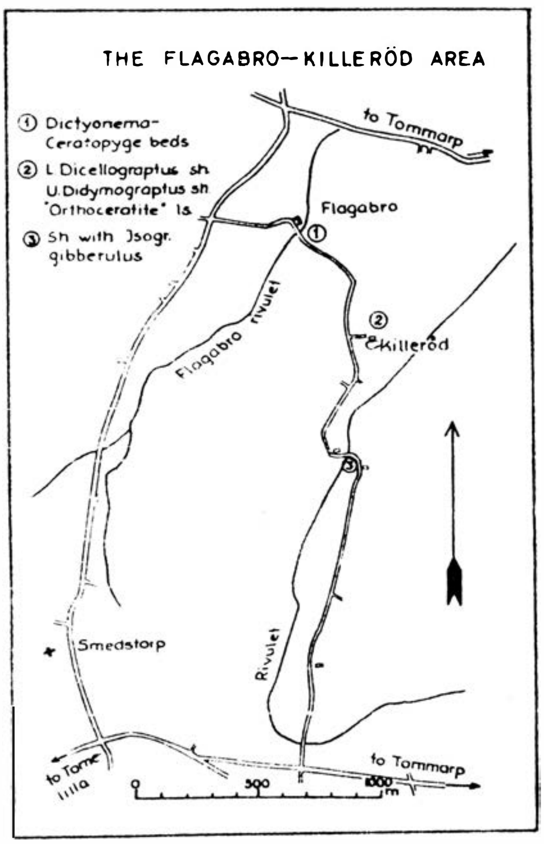


Figure 3. Map of Flagabro-Killeröd area (from Tjernvik in Regnéll 1960)

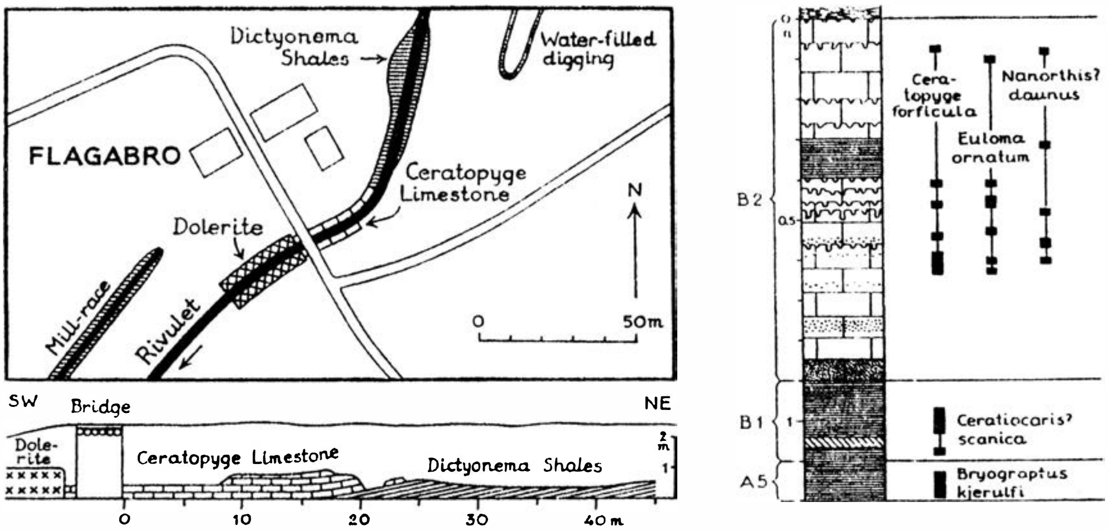


Figure 4. Map of exposures at Flagabro Farm and section through the top of the Tremadoc. A5, top of Dictyonema Shale; B1 Ceratopyge Shale; B2 Ceratopyge Limestone. (From Tjernvik 1958)

Carboniferous dolerite dyke just on the other side of the bridge.

2:2 KILLERÖD (Figs. 5, 6) Some 550 m SSE of Flagabro is a small limestone quarry at Killeröd. The limestone overlies 23 m of Lower Didymograptus Shale (Tøyen Shale; Tjernvik 1960), which in turn overlies the Ceratopyge Limestone. The limestone itself belongs to the Upper Arenig and is called the Komstad Limestone. Here, in its type area, it is around 10 m thick and is considered to be a tongue of the thick orthoceratite limestone characteristic of Öland, Gotland and south-central Sweden. It thins to the west to around 2 m east of Lund. Tectonic disturbances are seen in the western wall of the quarry at Killeröd, and in the north-east the limestone is bounded by a 27 m wide Permo-Carboniferous dolerite dyke. Fossils are rare and poorly preserved but include trilobites and orthoconic cephalopods.

On the north-west side of the dolerite dyke is a small exposure of a condensed sequence overlying the Komstad Limestone (Nilsson 1952; S.M. Bergström 1973; S.M. Bergström & Nilsson 1974). At the base is 1.2 m of Upper Didymograptus Shale (Fig. 5) overlain by 0.12 m of similar Lower Dicellograptus Shale. This sequence is fairly rich in graptolites, including species of Didymograptus, Glyptograptus and

Climacograptus. There are also brachiopods and conodonts. The top of the sequence is formed by 0.7 m of so-called Bronni beds, which are only distinguished in south-east Scania (Nilsson 1952; S.M. Bergström 1974). The rocks are alternating grey mudstones and hard, grey, finely crystalline limestones and contain a number of trilobites and brachiopods.

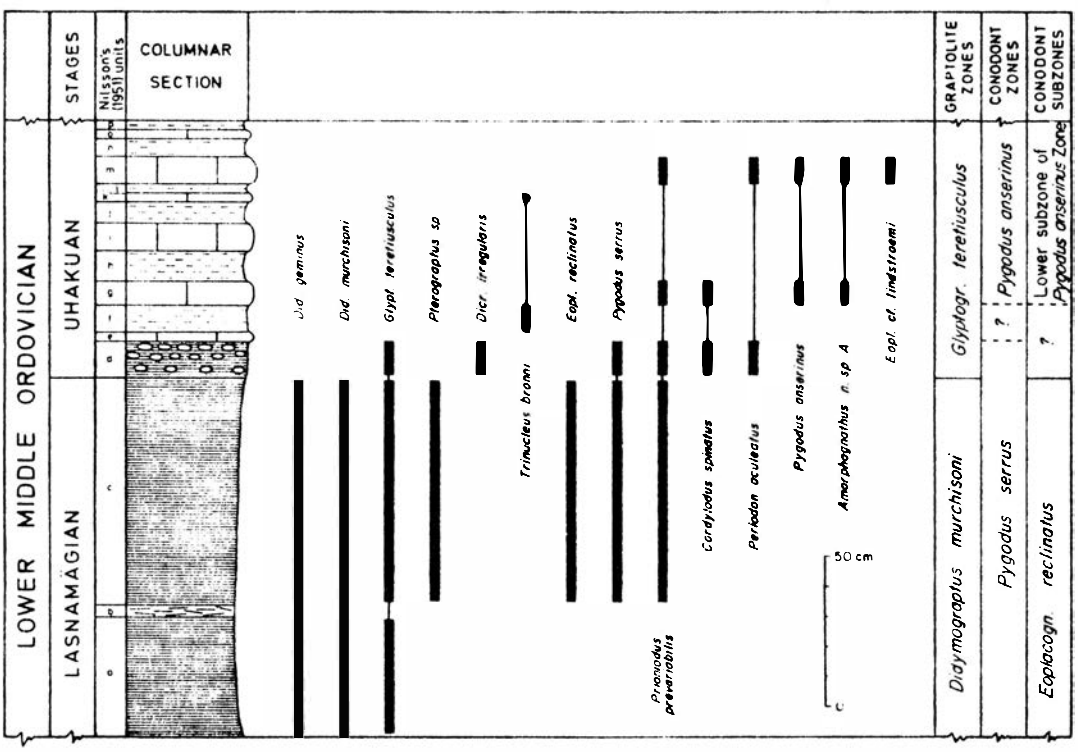


Figure 5. Lithologies, zonation and vertical distribution of selected fossils in the Killeröd section through lower Middle Ordovician strata. Trinucleus bronni stands for Botrioides coscinorhinus (Angelin). (From S.M. Bergström 1973)

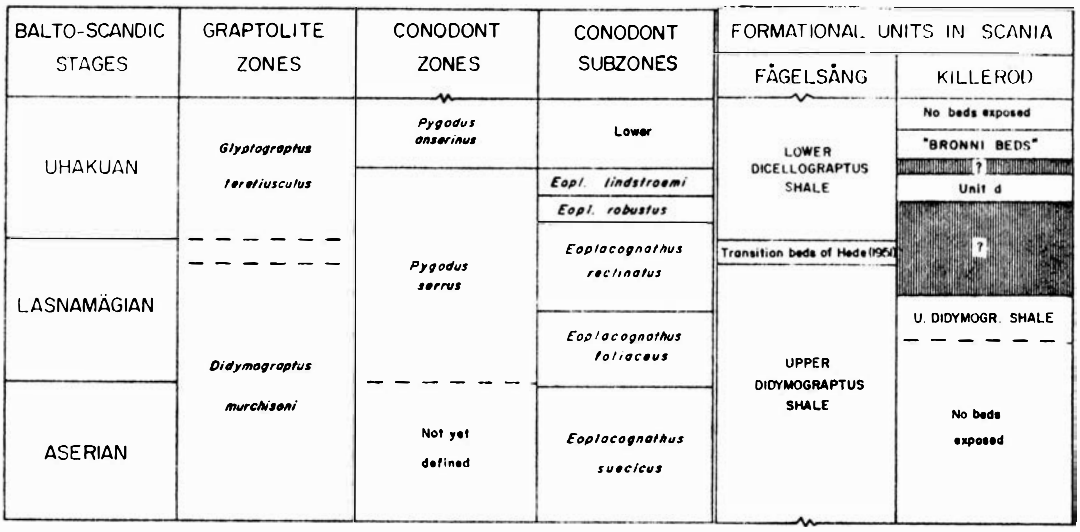


Figure 6. Comparison between lower Middle Ordovician stratigraphy at Killeröd and Fågelsång to illustrate the incomplete and condensed state of the Killeröd sequence. 'Bronni beds' are now recognized as the Killeröd Formation (beds d-p in Fig. 4). (From S.M. Bergström 1973)

2:3 TOMMARP (Fig. 7) On the south side of Jerrestad rivulet, south-

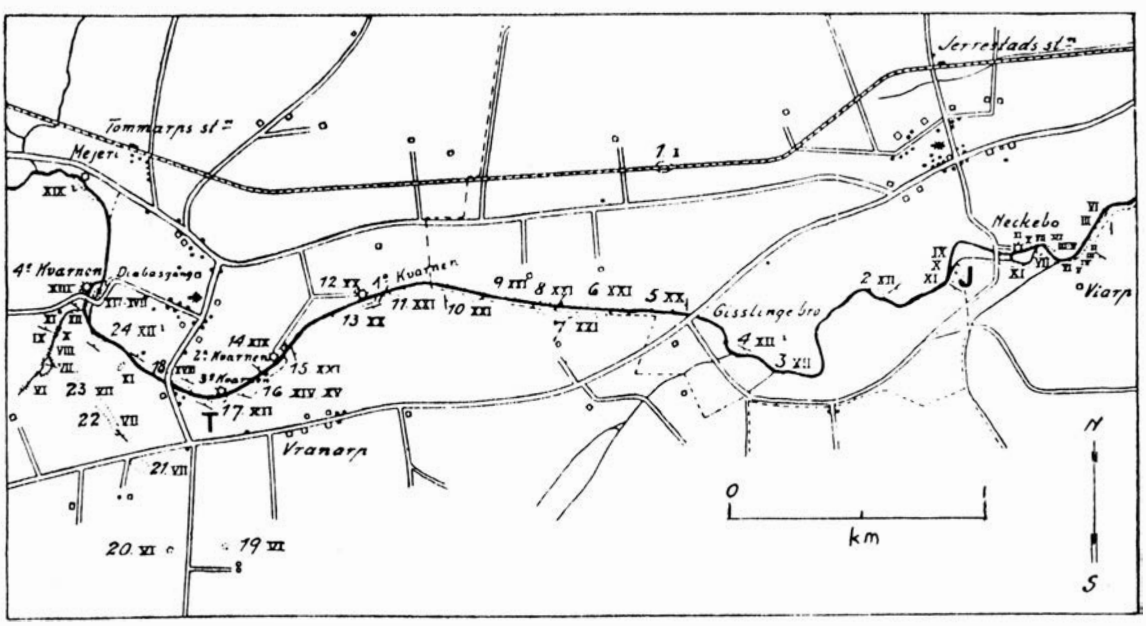


Figure 7. Map of sections along the Tommarpsån stream. T, stop 4 at Tommarp; J, stop 5 at Jerrestad. (From Moberg 1910)

east of Tommarp Church is an exposure of the hard, grey, poorly bedded Tommarp Mudstone (Dalmanitina beds). Fossils are rare but include Dalmanitina olini Temple. A section from a temporary exposure in Tommarp Mudstone west of Tommarp Church was described by Grahn (1978).

2:4 JERRESTAD A small road extending south from the church in Jerrestad ends at a bridge over the Jerrestad rivulet. Over the bridge and about 150 m west along the rivulet is a small section in the upper part of the (middle) Dicellograptus Shale, the Pleurograptus linearis Zone.

3:1 FÅGELSÅNG (Fig. 8) Ordovician graptolite shale is exposed along the Sularp rivulet in the classical Fågelsång area east of Lund. The exposures of the entire area were described in connection with the International Geological Congress in Stockholm 1910 (Moberg 1910). At the mouth of the Fågelsång rivulet is an exposure of Sandby Shale (Upper Didymograptus Shale) yielding graptolites, phyllocarids and inarticulate brachiopods. A few hundred metres further east along the Sularp rivulet are exposures of (lower and middle) Dicello-

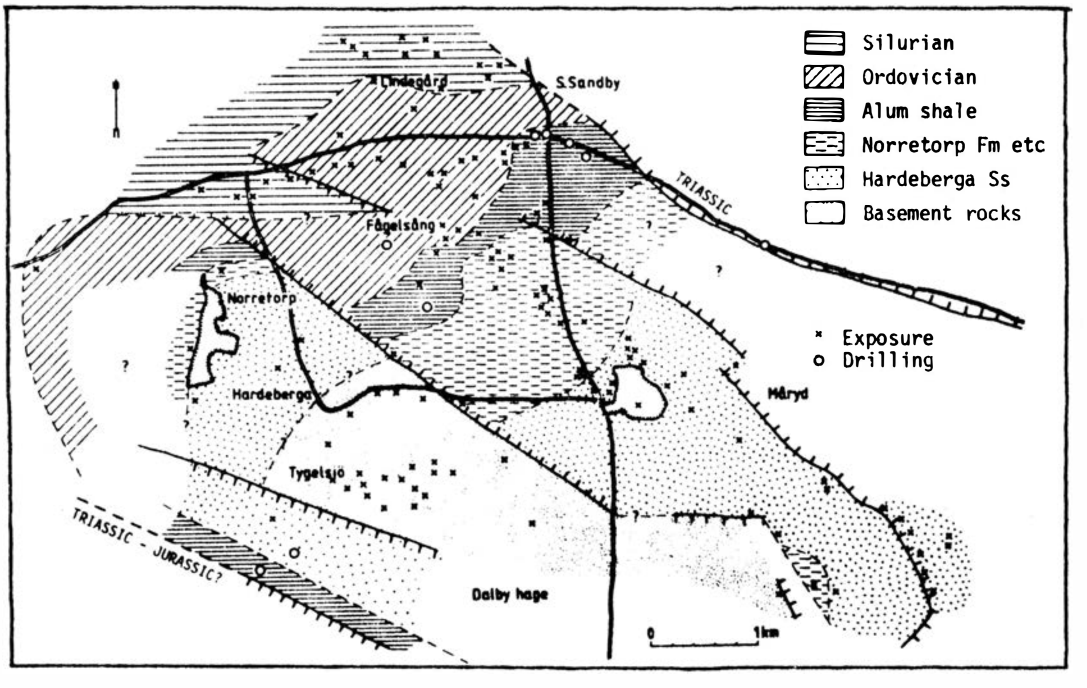


Figure 8. Geology around stop 6 at Fågelsång on the north-west end of Romleåsen Horst.

graptus Shale which yield graptolites and, more rarely, some shelly fossils. The base of the *Nemagraptus gracilis* Zone is marked by a phosphorite bed. Metabentonites occur, particularly in the *Diplograptus multidens* Zone.

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