THE SILJAN DISTRICT

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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

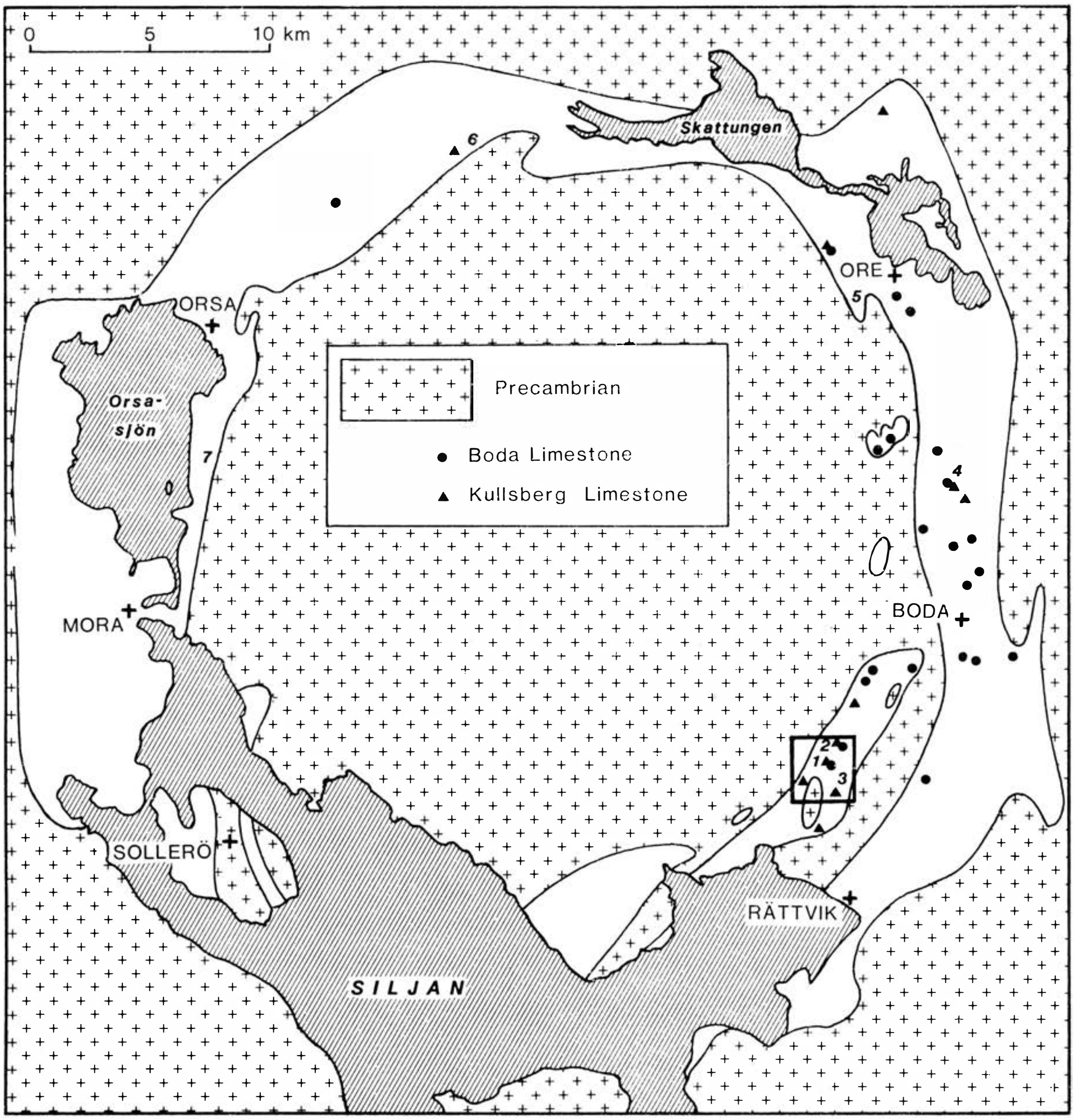

Figure 1. Map showing distribution of the Palaeozoic beds in general, and carbonate mounds in particular, in the Siljan district, Dalarna. Data on the carbonate mounds are based on Thorslund (1936), but later additions are also included. A quadrangle shows the area of the map on Fig. 2. 1, Skålberget; 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 Talubäcken section even most of the Hunnebergian Stage appears to be missing, because the basal Ordovician bed, formed by grey, glauconitiferous limestone with numerous pebbles of porphyry, probably belongs to the uppermost 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 classification) 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.

Kullsberg Limestone 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.

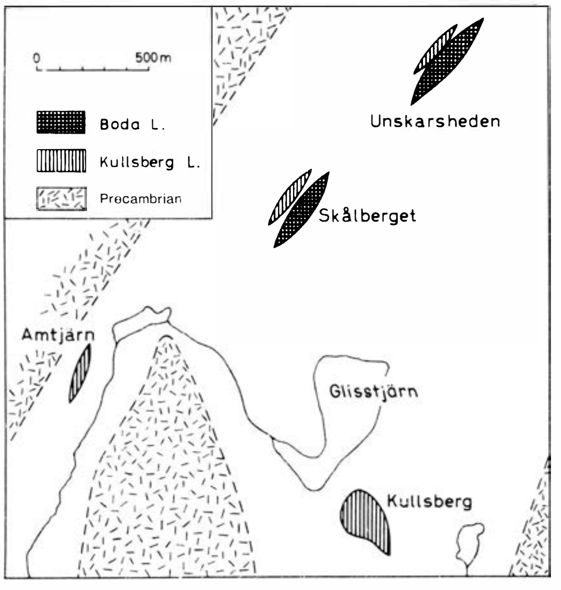

Figure 2. Carbonate mounds in the Kullsberg area. The location of the area is indicated by a quadrangle in Fig. 1.

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

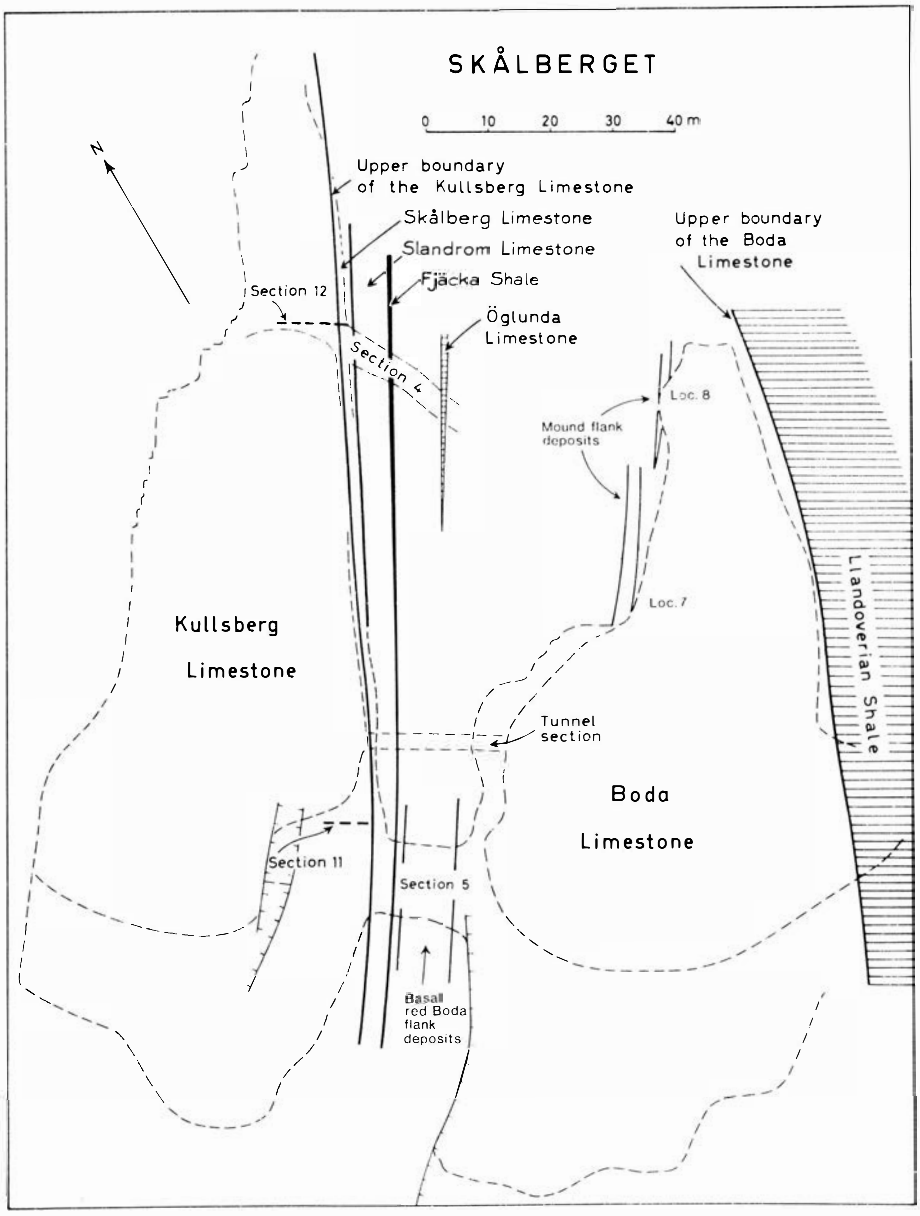

Figure 3. Map of the Skålberget quarry

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 reexamined, 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.

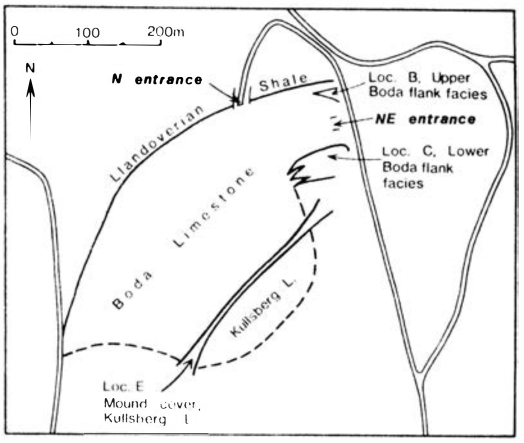

Figure 4. Sketch-map of the Osmundsberget quarry.

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.

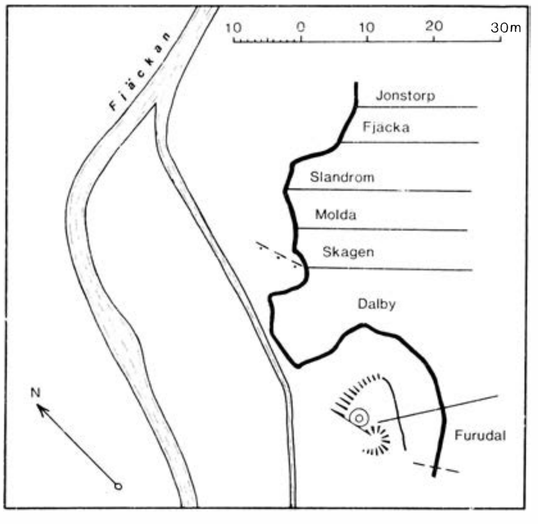

Figure 5. Sketch-map of the main exposures along the Fjäcka brook at Moldå. Based on a map of the Fjäcka area by J. Martna.

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

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

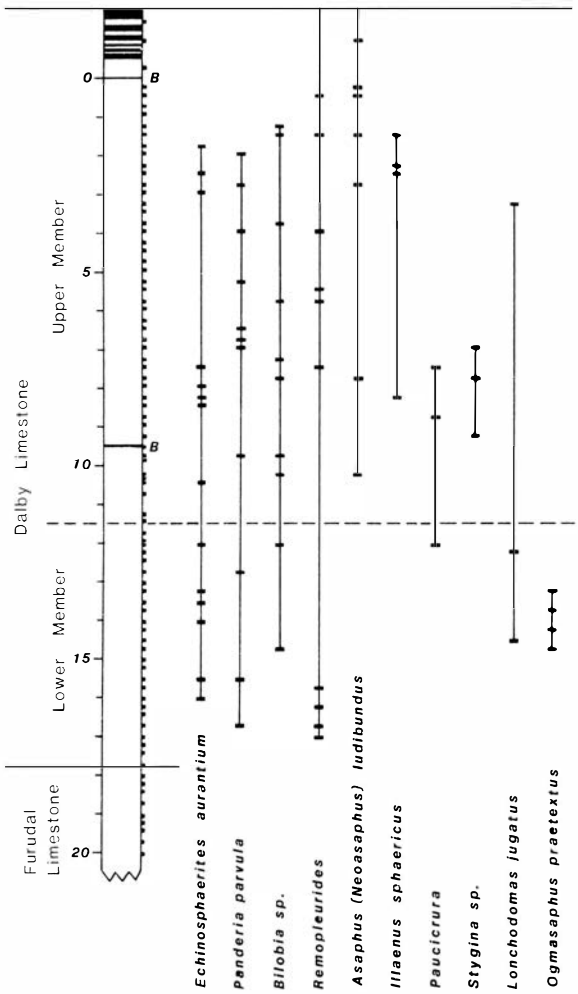

Figure 6. Sample-frequency distribution of the common species in the large macrofauna (excluding bryozoans) in the Dalby Limestone of the main Fjäcka section (V. Jaanusson, original). The figure shows species which were found in a series of c. 2.5 kg samples; the level of each sample is indicated by 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 +

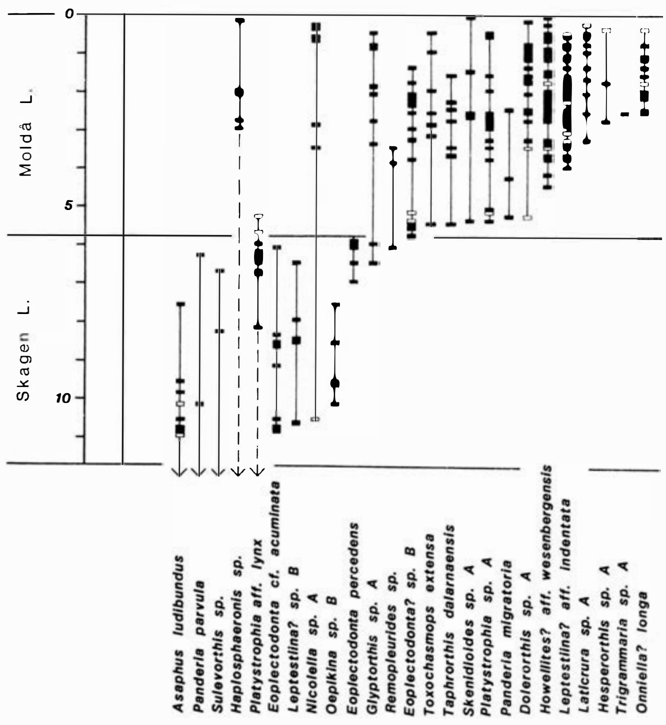

Figure 7. Macrofaunal log (excluding bryozoans) from the Skagen and Moldå Topoformations of the main Fjäcka section (M.G. Bassett and V. Jaanusson, original). With the exception of Trigrammaria sp. A, species which have been found at a single level are excluded. The log is in many respects preliminary 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