ORDOVICIAN IN VÄSTERGÖTLAND

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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.

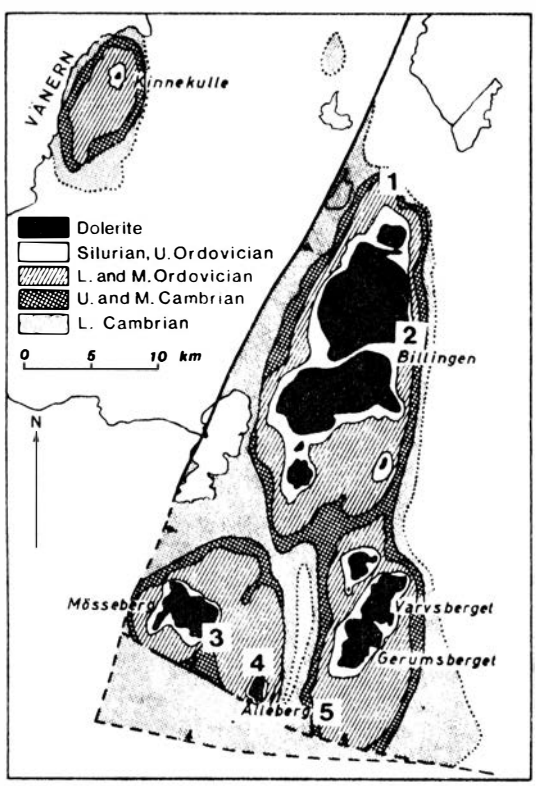


Figure 1. Geological map of Kinnekulle and the Billingen-Falbygden district. Italic numbers refer to stops in the road log (Stop 2 coincides roughly with the location of the town of Skövde).

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 Important unpublished data, provided by Jan Bergström, Lars Holmer and Jan Johansson, are incorporated in the following text.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

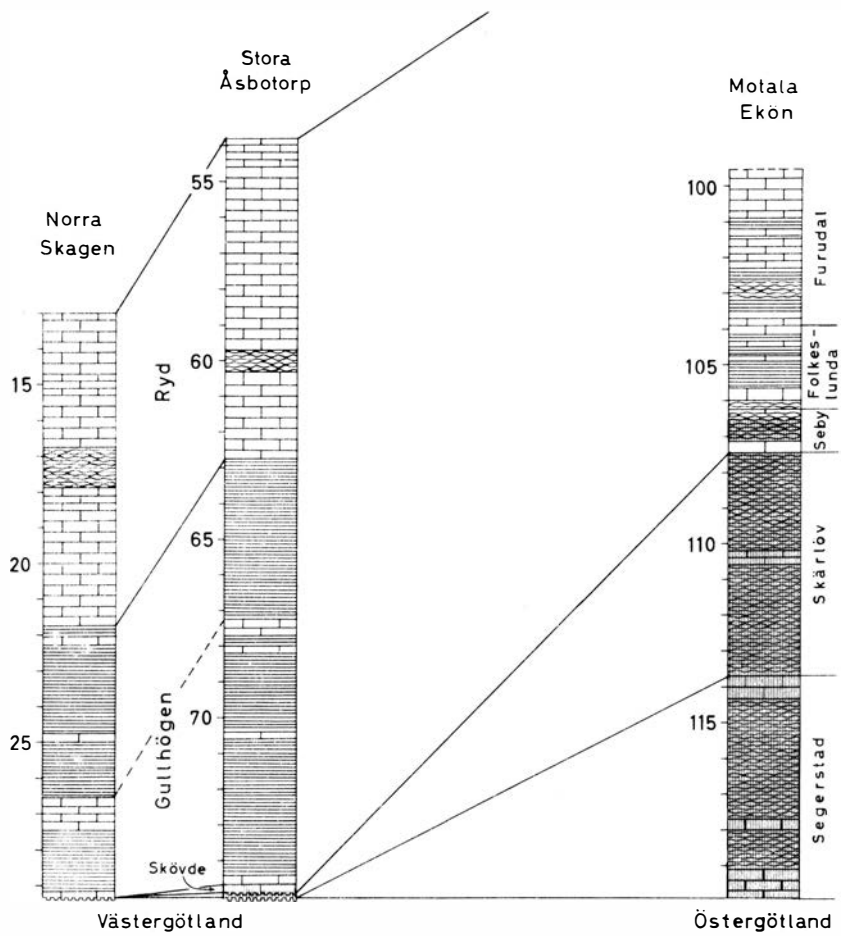


Figure 2. A comparison of the Aserian, Lasnamägian, and Uhakuan sections on Kinnekulle (Norra Skagen boring), northern Billingen (Stora Åsbotorp boring) and in Östergötland (slightly modified after Jaanusson 1964).

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

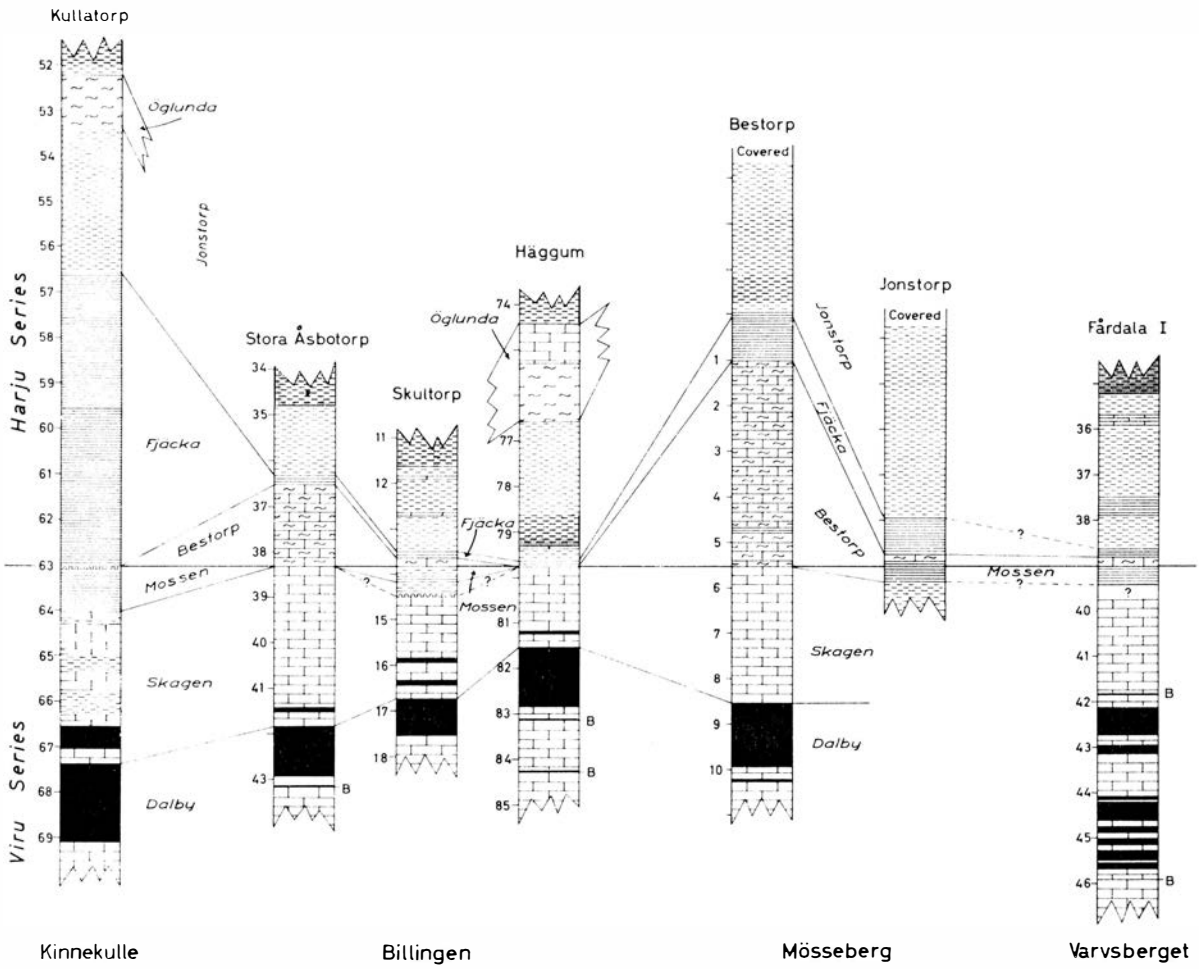


Figure 3. Diagrammatic sections of the uppermost Viruan and the lower part of the Harjuan sequence in Västergötland. Bentonitic beds are black and thin layers marked with the letter B. (From Skoglund 1963)

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.

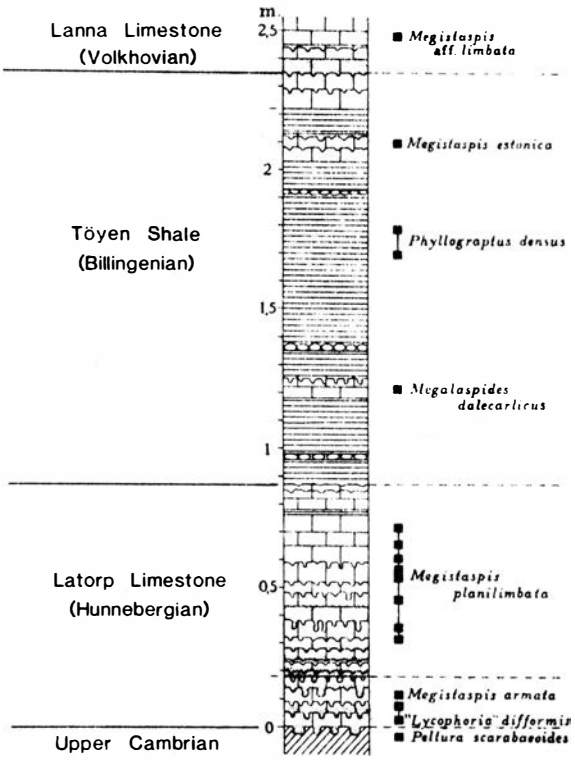
In the Tommarp Beds of the Billingen-Falbygden district mudstone is the dominant rock at localities where the division is thickest (Stommen,

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

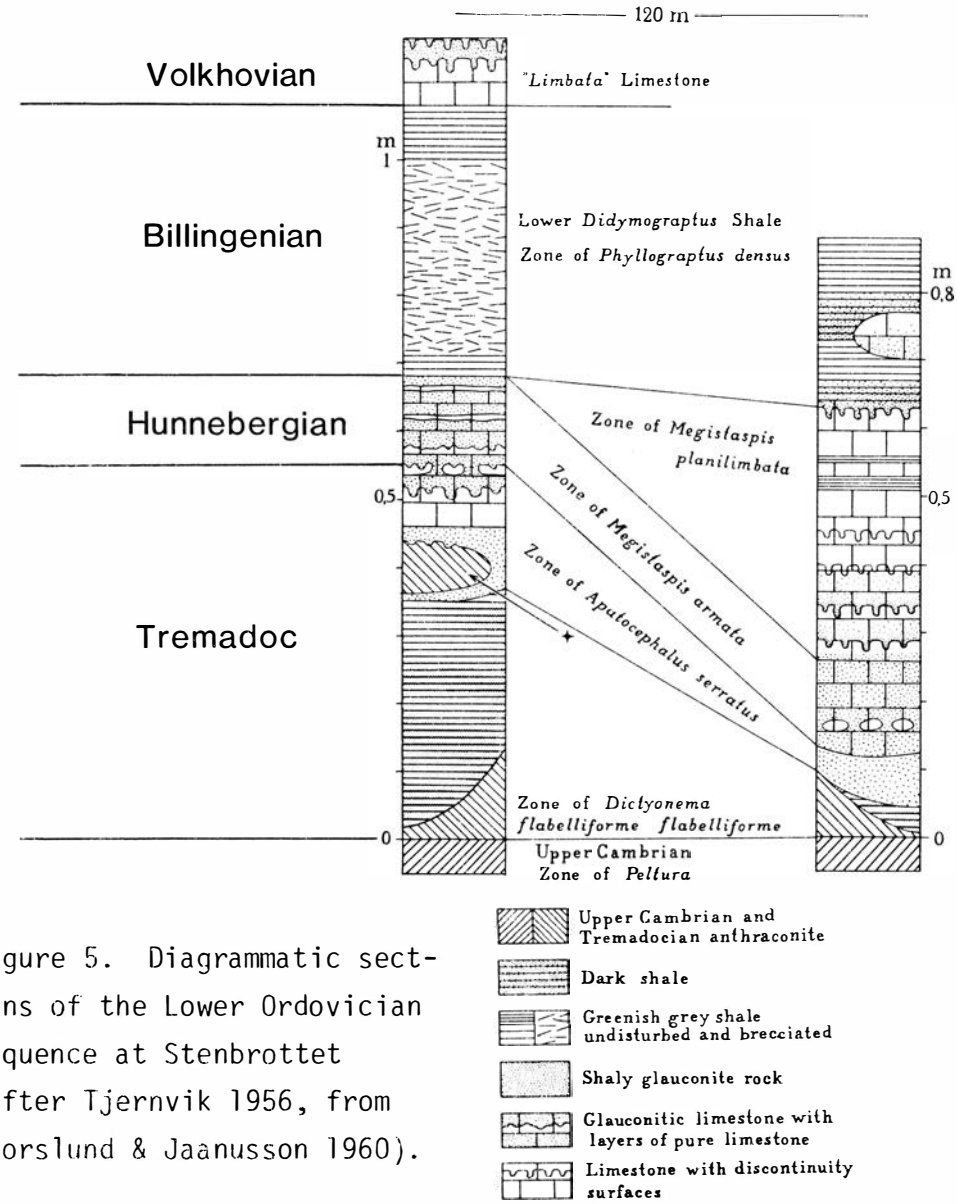


Figure 5. Diagrammatic sections of the Lower Ordovician sequence at Stenbrottet (after Tjernvik 1956, from Thorslund & Jaanusson 1960).

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.