# INTRODUCTION TO THE ORDOVICIAN OF SWEDEN

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

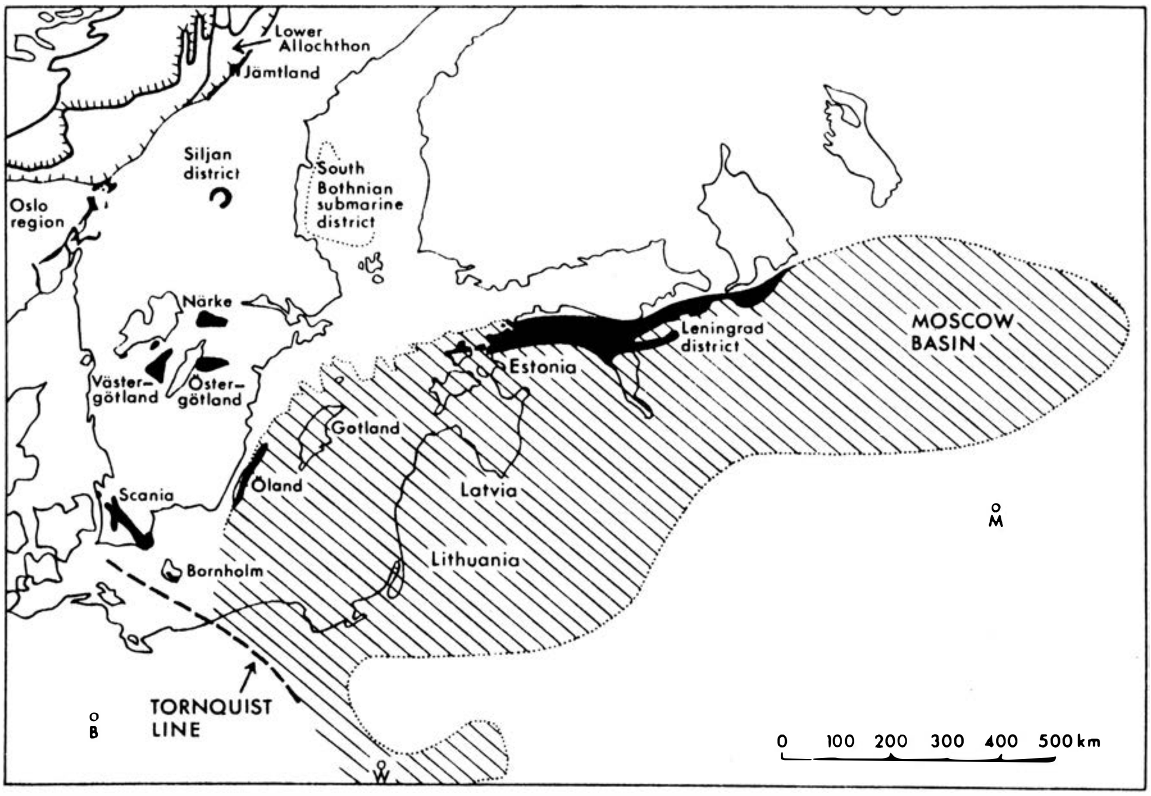


Figure 1. Map showing outcrop areas of Ordovician epicontinental deposits in Baltoscandia (black) and extent of subsurface and submarine Ordovician on the Russian platform (diagonal shading). On mainland Sweden the whole outcrop area of the Cambro-Silurian outliers is shown, of which Ordovician rocks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

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

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

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

The Ordovician epicontinental sequence in the Baltoscandian region is in many respects unusual. First of all, the average rate of deposition has been extremely low, in the order of 1-3 mm per 1 000 years. In Sweden, the total thickness of the Ordovician deposits rarely exceeds 150 m, and even in Scania, where almost the whole sequence is developed as graptolitic shales, the total thickness is normally less than 200 m. In many areas of the central and Scanian confacies belts there are numerous breaks of recognisable magnitude in the sequence; on the other hand, no portion of the sequence is known which is not developed continuously somewhere within the preserved depositional area. The possible exception is the transition from the Lower Tremadoc Dictyonema Shale to the Upper Tremadoc Ceratopyge Shale. The transition is complete in the Oslo area, but parts of it may be missing over the whole of Sweden. Experience has shown that the intricate pattern of breaks in the sequence represents an unfamiliar feature to many geologists from abroad. Likewise, it is not always fully understood that because of the extraordinarily low average rate of deposition, and therefore the very small thickness of many distinguishable stratigraphic subdivisions, the precision in our work with the sections is frequently in the order of centimetres. For a general example, the conodont Subzone of Prioniodus gerdae is only 4.75 m thick in its type section in the Siljan district, whereas in the southern Appalachians, in the Shenandoah Valley (Virginia), it ranges through at

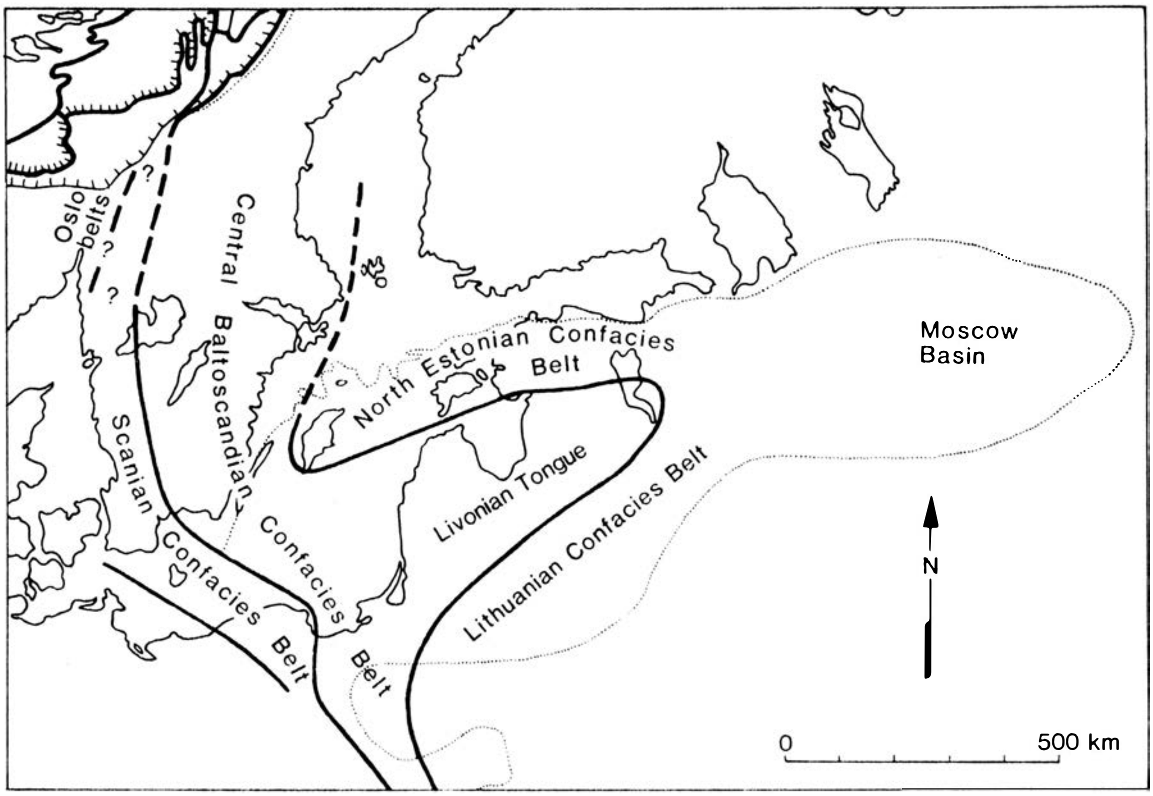


Figure 2. Map showing approximate boundaries of Ordovician confacies belts in the Baltoscandian region.

least 125 m (S. Bergström 1971).

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

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

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

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

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

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

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

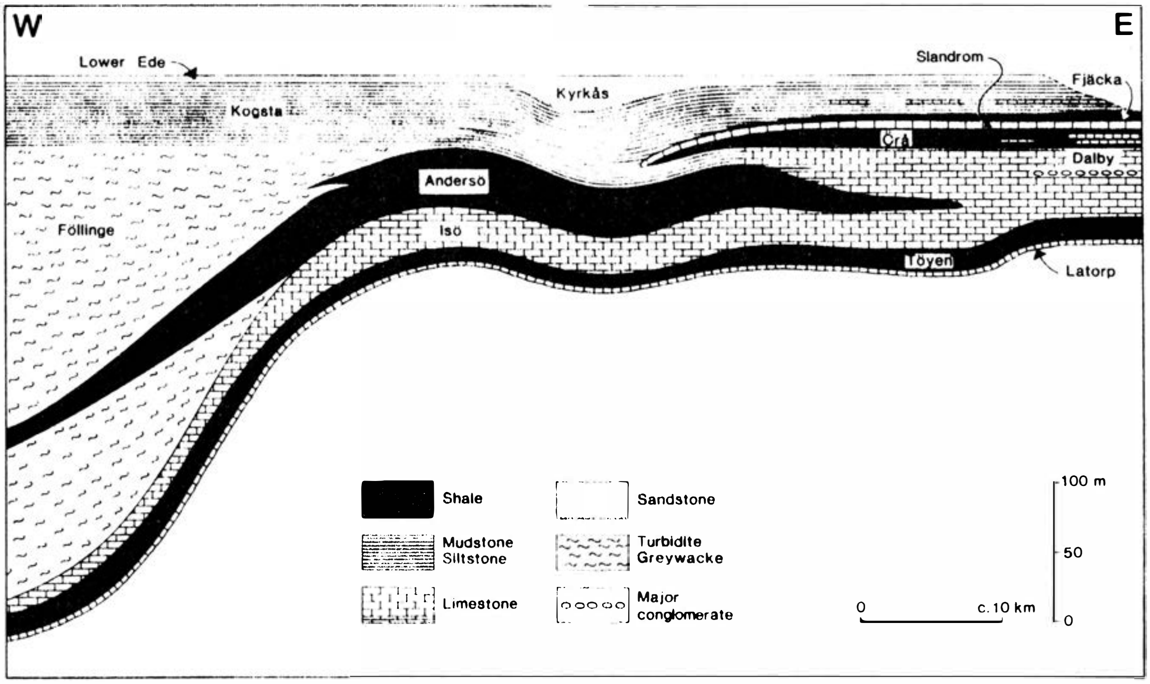
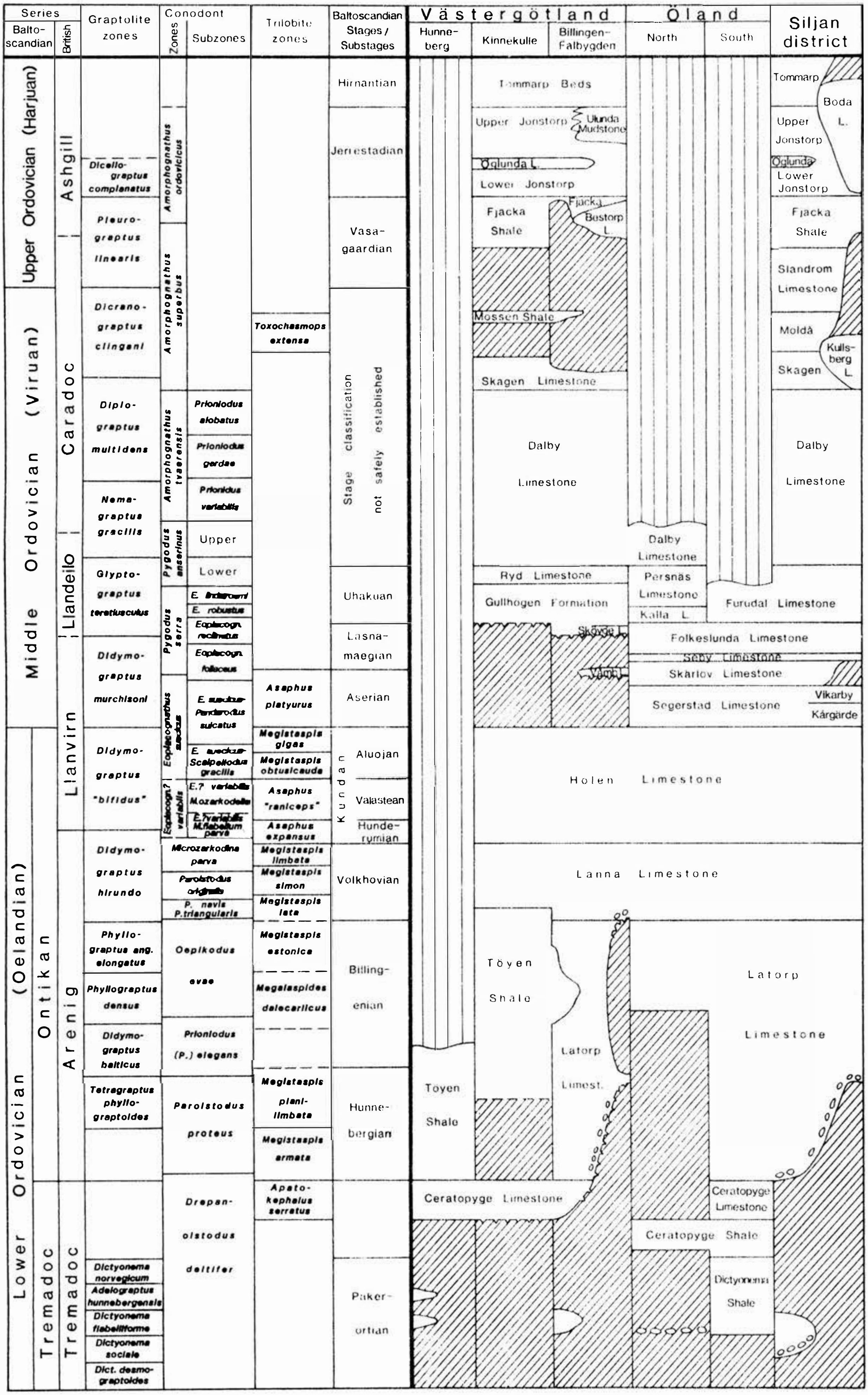


Figure 3. A diagrammatic, restored, palinspastical cross-section of the Ordovician deposits at the Caledonian front in Jämtland, approximately along a line from Brunflo-Slandrom in the autochthonous over Skute-Stengärde and Andersön to the west (V. Jaanusson, original).

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

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


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

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

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

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