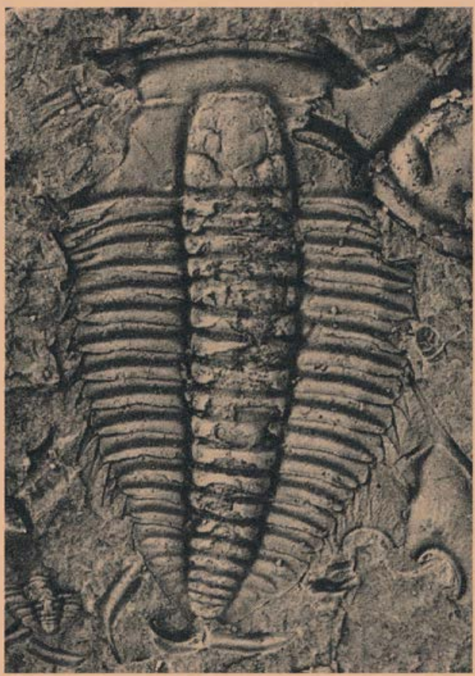
IV FIELD CONFERENCE OF THE
CAMBRIAN STAGE SUBDIVISION WORKING GROUP

INTERNATIONAL SUBCOMMISSION ON CAMBRIAN STRATIGRAPHY

SWEDEN, 24-31 AUGUST 1998

GUIDE TO EXCURSIONS IN SCANIA AND VÄSTERGÖTLAND, SOUTHERN SWEDEN



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Lund Publications in Geology
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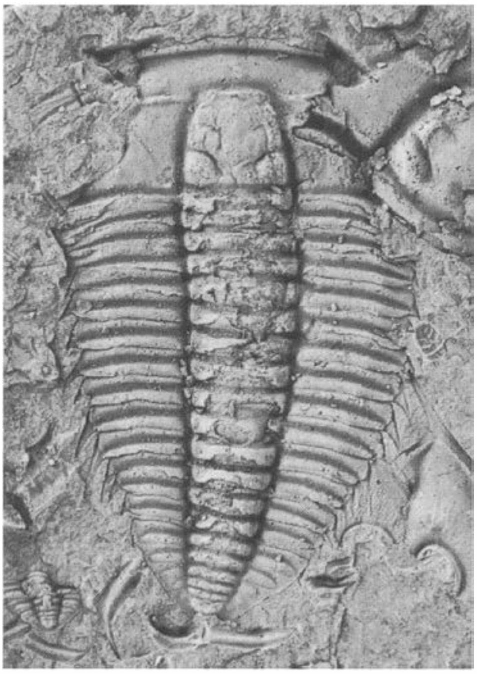

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Cambrian deposits of southern Scandinavia. From Bergström & Gee (1985, fig. 1).

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Cambrian shelly faunas and biostratigraphy of Scandinavia

PER AHLBERG

Lower Cambrian

The biostratigraphy of the Lower Cambrian platform deposits of Scandinavia is based mainly on the succession of trilobites in the Mjøsa area, southern Norway, and in Scania (Skåne), southern Sweden (e.g. Bergström 1980*b*, 1981; Bergström & Gee 1985; Ahlberg 1991). A number of non-trilobite zones have also been distinguished, but it is worth noting that several of the non-trilobite fossils (e.g. *Platysolenites antiquissimus* and *Volborthella tenuis*) are fairly long-ranging. As currently interpreted, the Lower Cambrian of Scandinavia can be subdivided into six biozones (Fig. 1). In ascending order these are the *Sabellidites cambriensis* Zone, the *Platysolenites antiquissimus* Zone, the *Schmidtiellus mickwitzi* Zone, the *Holmia inusitata* Zone, the *Holmia kjerulfi*-group Zone, and the *Proampyx* (or *Ornamentaspis*; Geyer 1990) *linnarssoni* Zone. The *S. cambriensis* Zone is generally regarded as basalmost Cambrian, but there is now evidence for a late Vendian age (e.g. Moczydlowska & Vidal 1986; Moczydlowska 1991). The *Holmia inusitata* and *Holmia kjerulfi*-group Zones have recently been united in a new concept, the *Holmia kjerulfi* Assemblage-zone (Moczydlowska 1991; Ahlberg & Bergström 1993).

In general, each zone is characterised by an assemblage of taxa. The base of each zone can be defined by the first appearance of the zonal index or by an assemblage of fossils characteristic of the zone, and the top can be placed at the first appearance of fossils characteristic of the next overlying zone. However, in the Lower Cambrian of Scandinavia the fossil record is generally scanty, particularly in the arenitic units. In addition, fossiliferous beds are generally separated by sparsely fossiliferous or barren strata (barren interzones). Thus, there is generally no precise control of zonal boundaries.

The *Sabellidites cambriensis* Zone forms the lowermost zone in the Cambrian of the East European Platform (see, e.g., Mardla et al. 1968; Arén & Lendzion 1978; Arén et al. 1979; Føyn & Glaessner 1979). The status of the zone is, however, unclear and in the Lublin area of Poland it has recently been assigned to the *Sabellidites-Vendotaenia* Interval-zone and regarded as late Vendian in age (Moczydlowska 1991). The *S. cambriensis* Zone appears to be poorly represented in Scandinavia. The nominate species is, however, reported from the lower Breivik Formation and correlative strata in eastern Tana, Finnmark, northern Norway (Føyn & Glaessner 1979; see also Farmer et al. 1992), and *Sabellidites* sp. is reported from the Dividal Group of northern Sweden (Jensen & Grant 1998).

In the Lower Cambrian of the East European Platform, the *Sabellidites cambriensis* Zone is succeeded by the *Platysolenites antiquissimus* Zone. This extends from the first appearance of the zonal index to the base of the ranges of *Volborthella*, *Mobergella*, or trilobites of the *Schmidtiellus mickwitzi* Zone (Bergström 1981). *P. antiquissimus* Eichwald, 1860 is recorded from a number of localities in Scandinavia (Føyn & Glaessner 1979). It appears, however, to have a long stratigraphical range; e.g. in southern Norway it probably ranges into trilobite-bearing strata (cf. Ahlberg

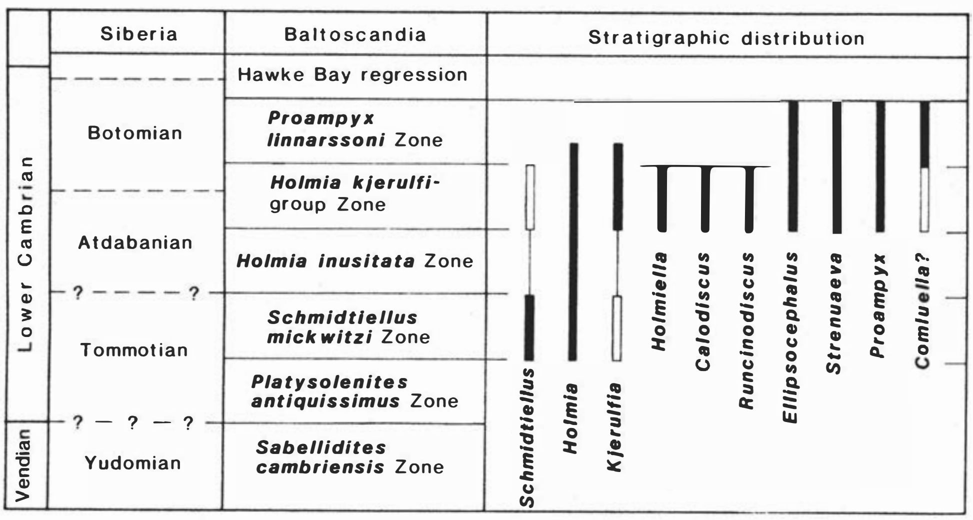


Fig. 1. Composite ranges of trilobite genera in the Lower Cambrian of Scandinavia. An open symbol indicates uncertainty. The record of *Holmia* and *Kjerulfia* in the lower part of the *Proampyx linnarssoni* Zone is based on Nikolaisen (1986) and Ahlberg (unpublished data from a section at Skyberg, about 3.5 km east of Tømten, Ringsaker, southeast Norway). Acritarch evidence indicates that the Tommotian Stage in Siberia is in part equivalent to the Talsy (Lükati) "horizon", which is correlated with the *Schmidtiellus mickwitzi* Zone (Moczydlowska & Vidal 1988). From Ahlberg (1991).

& Bergström 1978, fig. 1; Vidal 1981*a*, 1981*b*, p. 192, 1981*c*, p. 40; Vidal & Nystuen 1990, p. 214). The record of *P. antiquissimus*, *Spirosolenites spiralis* Glaessner, 1979, and *Aldanella kunda* (Öpik, 1926) well below the first trilobites in the Dividal Group and Breivik Formation of northern Norway (Føyn & Glaessner 1979) may suggest a correlation with at least the upper part of the *P. antiquissimus* Zone as recognised on the East European Platform.

The *Schmidtiellus mickwitzi* Zone is characterised by olenellid trilobites such as *S. mickwitzi* (Schmidt, 1888), *Holmia mobergi* Bergström, 1973, and *Kjerulfia*? *lundgreni* (Moberg, 1892). Additional fossils of biostratigraphic potential include *Mobergella* spp., *Mickwitzia monilifera* (Linnarsson, 1869), and the trilobite trace fossil *Rusophycus dispar* (Bergström 1980*b*, 1981). In Scandinavia, faunal assemblages of the *Schmidtiellus mickwitzi* Zone are known from the Norretorp Formation of Scania, southern Sweden, the "Green Shales" (Broens Odde Member) of Bornholm, Denmark, the Mobergella beds of the West Baltic area, and from the Brennsæter Shale (unit 1aα_1) in the Mjøsa area, southeast Norway. Acritarchs recovered from the above-mentioned units also suggest that they are roughly equivalent (Vidal 1981*a*, 1981*b*; Moczydlowska & Vidal 1986; Vidal & Nystuen 1990; Moczydlowska 1991). The Scandinavian faunas of the *Schmidtiellus mickwitzi* Zone seem to be time-equivalent with those from the Talsy (= Lükati) "horizon" of the East Baltic area and the upper part of the Klimontovian Stage (Zawiszyn Beds) of the East European Platform in Poland.

In the Mjøsa area of southeast Norway, beds referable to the *Schmidtiellus mickwitzi* Zone are overlain by the sparsely fossiliferous Bråstad Sandstone and Shale (1aα_2 and 1aβ). The Bråstad Shale has yielded *Volborthella tenuis* Schmidt, 1888 and *Holmia inusitata* Ahlberg & Bergström, 1986 (originally identified as *Callavia* n. sp.; Skjeseth 1963), and it is assigned to the *Holmia inusitata* Zone (Ahlberg et al. 1986). It has not been recognised outside the Mjøsa area, but the Rispebjerg Sandstone in Scania, southern Sweden, and on Bornholm, Denmark, may occupy this zone (Ahlberg & Bergström 1978, fig. 1; Bergström 1980*b*, 1981). It has recently been suggested that the *H. inusitata* Zone should be considered as a subzone of the *Holmia kjerulfi*-group Zone (Ahlberg & Bergström 1993; see also Moczydlowska 1991).

The standard zones for the uppermost Lower Cambrian in Scandinavia are based on the section at the classical locality of Tømten and adjacent areas close to Lake Mjøsa, southeast Norway (Kiær 1917). However, the vertical ranges of the faunal elements in this area are not known in detail. Therefore, a careful biostratigraphical study of equivalent beds (the Gislöv Formation) in Scania, southern Sweden, forms a valuable contribution to our knowledge of the faunal succession through this interval. In contrast with the underlying zones, the uppermost zones in the Lower Cambrian of Scandinavia (the *Holmia kjerulfi*-group and *Proampyx linnarssoni* Zones) contain well differentiated faunas. The faunal elements include, among others, a variety of ellipsocephalid and olenellid trilobites, generally rare eodiscids, various lingulate brachiopods, rare articulate brachiopods (*Nisusia*), hyoliths, helcionellid molluscs, hyolithelminthids, lapworthellids, rare bradoriid arthropods, and *Volborthella tenuis*.

The *Holmia kjerulfi*-group Zone was introduced by Bergström & Ahlberg (1981) for strata yielding *H. kjerulfi* or closely related species. It is the most widely recognised zone in the Lower Cambrian of Scandinavia, and at many localities the fauna consists predominantly of trilobites. In the *H. kjerulfi*-group Zone, and correlative strata (the *Holmia* Zone) in Poland, olenellid trilobites are generally associated with ellipsocephalid trilobites. The olenellids are dominated by species of *Holmia* and *Kjerulfia*, and the ellipsocephalids include species of *Ellipsocephalus*, *Strenuaeva*, and *Proampyx* (or *Ornamentaspis*; Geyer 1990, p. 127). In addition, *Calodiscus lobatus* (Hall, 1847) is known from Scania, southern Sweden (Bergström & Ahlberg 1981; Ahlberg & Bergström 1993) and Jämtland, central Scandinavian Caledonides (Ahlberg 1984*a*), and *Runcinodiscus* cf. *index* Rushton, 1976 is described from the Mjøsa area, southeast Norway (Ahlberg 1984*b*). The presence of these eodiscid trilobites in the *Holmia kjerulfi*-group Zone suggests a correlation with strata containing representatives of the *Hebediscus attleborensis* assemblage (Robison et al. 1977) in the North Atlantic region and in Siberia, i.e. with the top of the "*Callavia*" Zone in Avalonia, and with the top of the Atdabanian in Siberia. Acritarchs recovered from the *Holmia kjerulfi*-group Zone are indicative of the *Heliosphaeridium dissimilare-Skiagia ciliosa* Assemblage-zone (Vidal 1981*b*; Vidal & Nystuen 1990; Moczydlowska 1991).

The youngest Lower Cambrian zone in Scandinavia, the *Proampyx* (or *Ornamentaspis*) *linnarssoni* Zone (previously referred to as the *Strenuella linnarssoni* Zone), was established by Kiær (1917) for a sequence of shales and intercalated limestone beds (Evjevik Limestone; 1bβ) overlying the Holmia Shale in the Mjøsa area. It is recorded with certainty only in southern Norway and in Scania, southern Sweden. In the latter area, the base of the zone is placed at the lowest occurrence of *P.* cf. *linnarssoni* (see Bergström & Ahlberg 1981). The top of the zone is marked by a regional unconformity (Bergström 1980*b*, 1981; Berg-

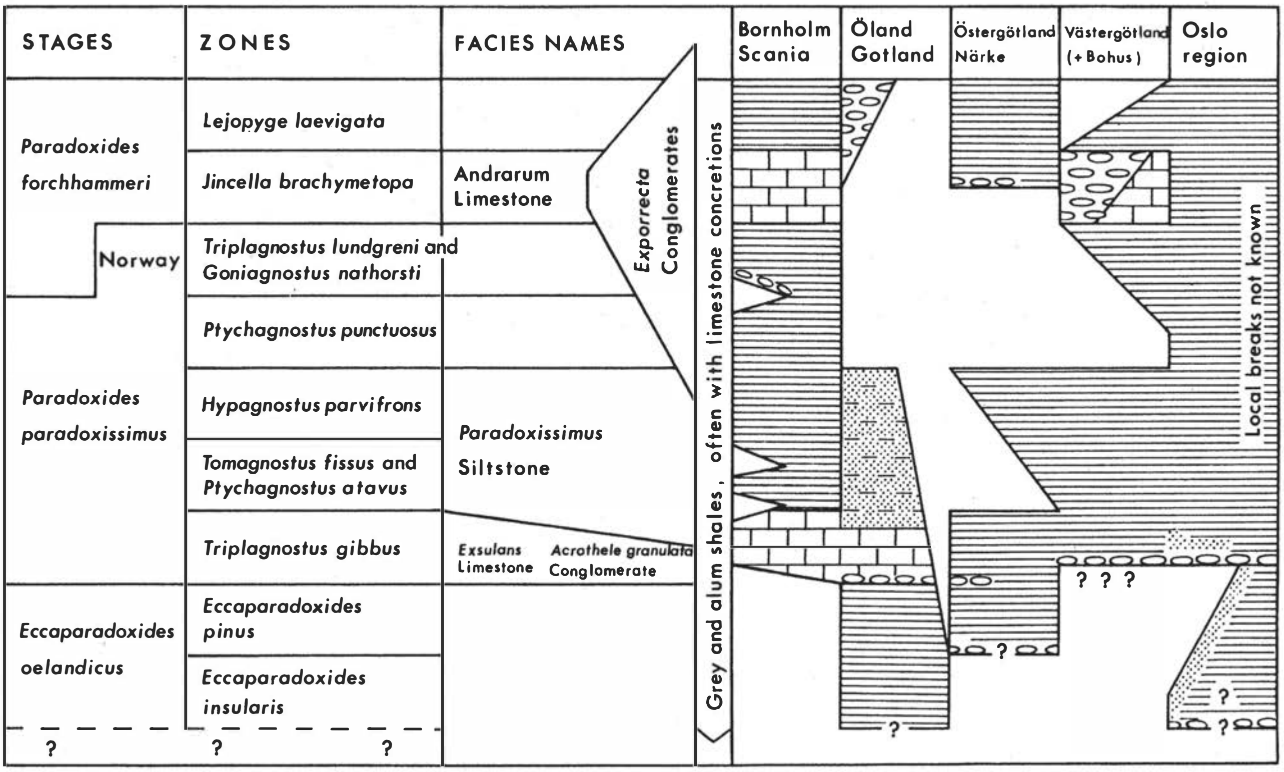


Fig. 2. Correlation and zonation of the main Middle Cambrian districts in Scandinavia. The validity of the *Ptychagnostus lundgreni—Goniagnostus nathorsti* Zone appears to be questionable, and it is now generally included in the *P. punctuosus* Zone (Berg-Madsen 1985). From Martinsson (1974, fig. 4).

ström & Ahlberg 1981). The trilobite faunas of the *P. linnarssoni* Zone are dominated by various ellipsocephalid trilobites, but also include rare specimens of olenellids (*Holmia kjerulfi* and *Kjerulfia lata*; Ahlberg & Bergström 1978, p. 28; Nikolaisen 1986). The zone may be correlated tentatively with the *Protolenus* Zone in Poland.

Middle and Upper Cambrian

The Middle and Upper Cambrian of Scandinavia consists predominantly of dark grey or black, kerogen-rich mudstones and shales with lenses or beds of dark grey limestone (anthraconite or stinkstone). The mudstones and shales are generally parallel-laminated with a high content (2-28%) of organic carbon (e.g. Andersson et al. 1985; Buchardt et al. 1997), and they are referred to as alum shales. They have been extensively quarried in the past, providing many exposures from which rich faunas have been collected. The alum shale successions are condensed and accumulated over long periods of time under dominantly dysoxic, anoxic or euxinic conditions in an epicontinental sea (e.g. Thickpenny 1984, 1987). The net rate of accumulation was very low, about 1-10 mm/1000 years. Low organic carbon accumulation rates (0.02-0.5 g/cm^2/1000 years) exclude high productivity as a major cause of the anoxia, and no equivalent environments seem to exist today (Buchardt et al. 1994). The successions are very condensed and generally interrupted by several minor and a few major hiata. The palaeontology, stratigraphy, and geochemistry of the alum shales have been extensively studied (see, e.g., Westergård 1922, Martinsson 1974, Bergström & Gee 1985, Andersson et al 1985, and Buchardt et al. 1997 for general reviews).

The Middle Cambrian is generally in the order of 20-30 m thick and dominated by grey and black mudstones and shales. It is subdivided into three stages (Fig. 2), the *Acadoparadoxides oelandicus* Stage (two zones), the *Paradoxides paradoxissmus* Stage (four zones), and the *Paradoxides forchhammeri* Stage (two or three zones). Important limestone beds in the Middle Cambrian are the Exsulans Limestone of the *Ptychagnostus gibbus* Zone, locally developed as the *Acrothele granulata* Conglomerate, and the Andrarum Limestone of the *Solenopleura brachymetopa* Zone. These limestones may reflect regressive events (e.g. Bergström & Gee 1985; Conway Morris & Rushton 1988; Nielsen 1996). The Andrarum Limestone is remarkable for its particularly rich faunas. In Scandinavia, the Middle Cambrian-Upper Cambrian boundary is drawn at the top of the *Lejopyge laevigata* Zone.

The Scandinavian Middle Cambrian faunas are well-diversified and with few exceptions dominated by trilobites, which form the basis for the zonation. Agnostids as well as paradoxidid, solenopleurid, and cono-

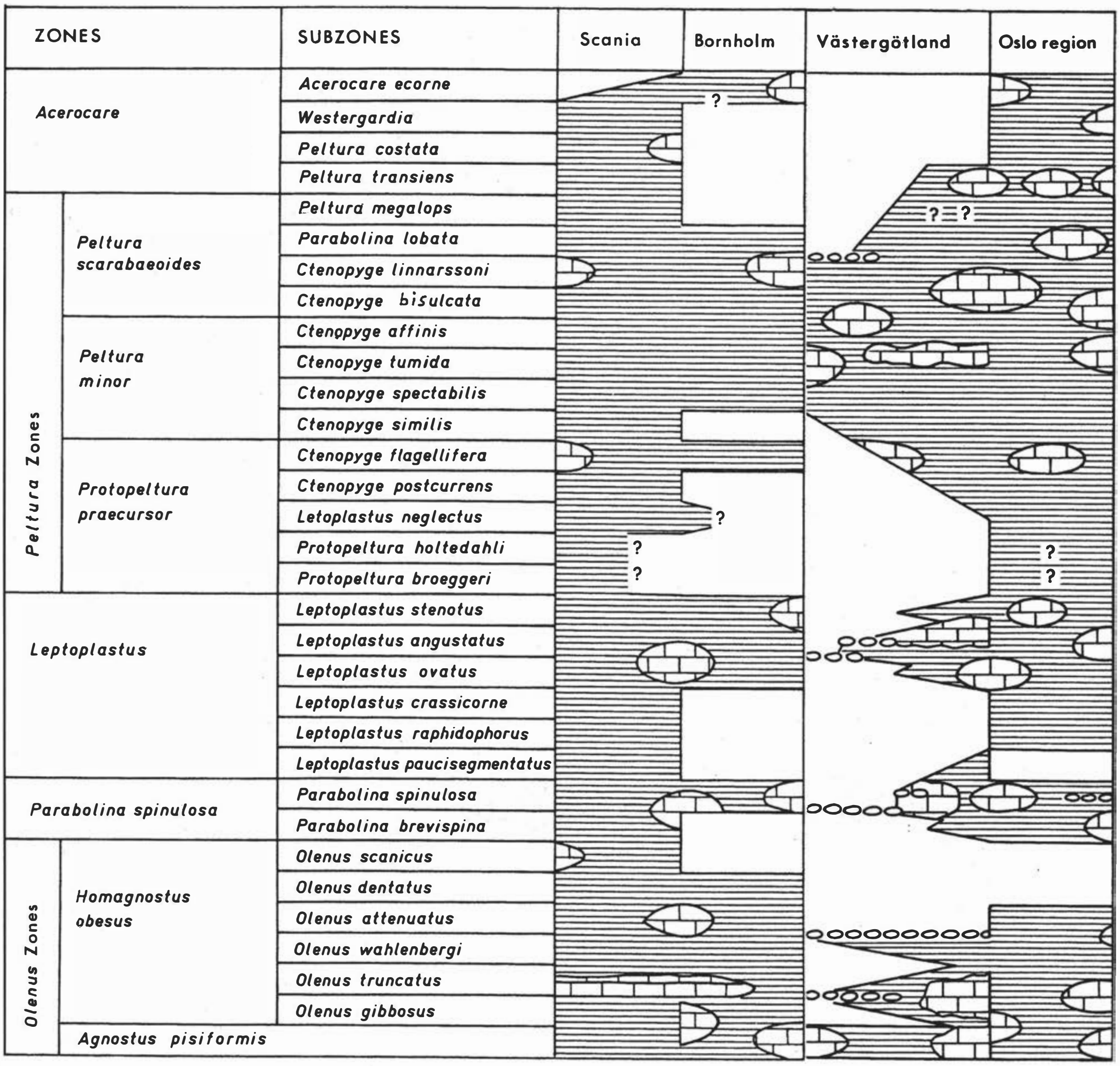
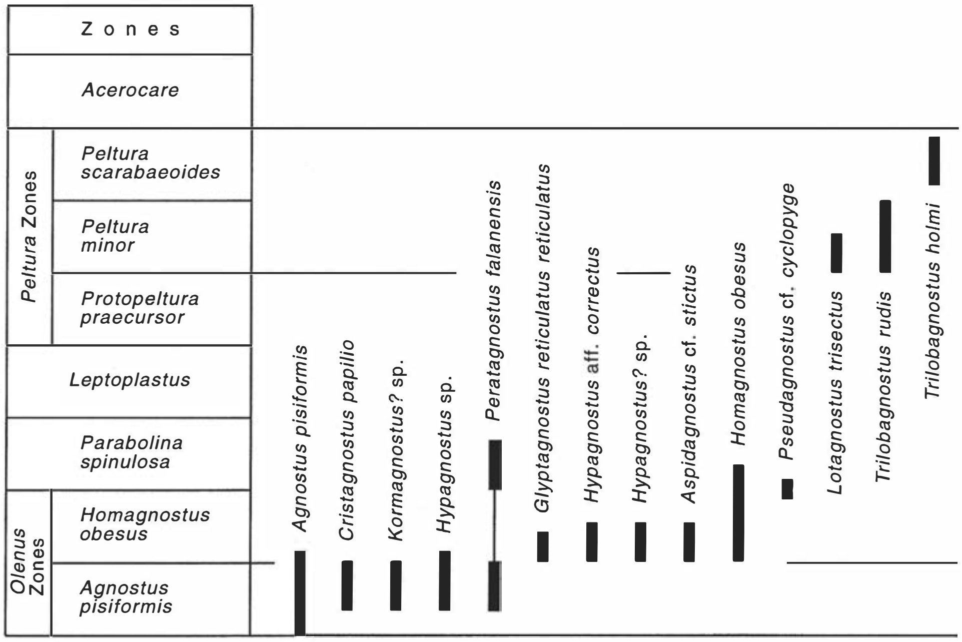


Fig. 3. Correlation and zonation of the Upper Cambrian in selected parts of Scandinavia (Scania, Bornholm, Västergötland, and the Oslo region). From Martinsson (1974, fig. 5).

coryphid trilobites are particularly common and easily recognisable. A high-resolution biostratigraphy based on agnostids was established by Westergård (1946). Current knowledge on the occurrences and ranges of fossils in the Middle Cambrian of Scandinavia are based mainly on papers by Westergård (1936, 1946, 1948, 1950, 1953). Subsequent studies have been carried out by, e.g., Berg-Madsen (1981, 1985, 1986, 1987), Berg-Madsen & Peel (1978, 1986, 1987), Bengtson & Urbanek (1986), Ahlberg (1989), and Hinz-Schallreuter (1993, 1995).

The Upper Cambrian alum shales are finely laminated and characterised by intervals with very abundant, but low-diversity trilobite faunas, with brachiopods and bradoriid arthropods as minor faunal constituents. The trilobite faunas are generally dominated by olenid trilobites. In the lowermost part of the succession agnostids may occur in abundance. The few documented occurrences of large trilobites and brachiopods are generally restricted to more light-coloured limestone intercalations (Bergström 1980*a*), and it is possible that these limestones represent regressive events with occasional episodes of ventilation (cf. Nicoll et al. 1992, pp. 387-388). The Upper Cambrian trilobites of Scandinavia were elegantly monographed by Westergård (1922) and Henningsmoen (1957*a*). Intensive research in recent years on stemline crustaceans and *Agnostus pisiformis*, isolated from limestone nodules and extremely well preserved, have given an added dimension to the study of the alum shales (e.g. Müller & Walossek 1985, 1987, 1988; Walossek 1993). A recent, comprehensive study on conodonts from the Upper Cambrian of Sweden is also noteworthy (Müller & Hinz 1991).

Fig. 4. Occurrences of agnostids in the Upper Cambrian of Västergötland, south-central Sweden. From Ahlberg & Ahlgren (1996, fig. 2).



Species turnover rate is high in the Upper Cambrian and allows a refined biostratigraphical framework, in which currently eight biozones and 32 subzones are recognised (Martinsson 1974). The system of eight zones was introduced by Westergård (1922). Westergård finally (1947) worked with 24 subzones altogether, and after Henningsmoen's (1957*a*) revision on the Norwegian olenids there are 32 subzones (Fig. 3). The status of at least two of the subzones (the *Protopeltura holtedahli* and *P. broeggeri* Subzones) appears, however, to be unclear, and it is sometimes difficult to fully apply the system introduced by Henningsmoen (Bergström & Gee 1985, p. 254).

The lowest zone of the Upper Cambrian is dominated almost entirely by the zonal index, *Agnostus pisiformis*. Polymerid trilobites here are generally very rare, but *Proceratopyge nathorsti* and *Schmalenseeia amphionura* may be fairly common at certain horizons. Unfossiliferous intervals generally occur between rocks containing the *L. laevigata* and *A. pisiformis* faunas, and in most sections there is an interval of uncertainty concerning the zonal and series boundaries. Following the *A. pisiformis* Zone, trilobites of the family Olenidae dominate the sequence until the base of the Tremadoc. *Agnostus* (*Homagnostus*) *obesus* is abundant at some horizons in the *Olenus/Agnostus obesus* Zone, but above this level agnostids become relatively uncommon. The diversity of the agnostids is also considerably lower in the upper part of the Upper Cambrian (Fig. 4). Thus, at least fourteen species of agnostids have been recognised in the lower part of the succession, whereas only five species seem to be present above the *Leptoplastus* Zone (e.g. Westergård 1947; Ahlberg & Ahlgren 1996). The olenid trilobites are generally extraordinarily abundant, but commonly are found as monospecific assemblages, which suggests a stressed environment (Clarkson & Taylor 1995*a*). There are never more than three olenid genera present at each level, and the co-occurring genera are of very different morphology and were surely adapted to specialised niches within the same general environment (Clarkson & Taylor 1995*b*).

Lower Cambrian acritarch biochronology in Baltoscandia

MALGORZATA MOCZYDLOWSKA

Acritarchs are organic-walled microfossils of photoautotrophic protists (marine phytoplankton) representing resting cysts in their life cycles. The group is polyphyletic, including probably ancestors of green algae (mainly prasinophytes), dinoflagellates and other microorganisms of unknown biological affinities. The morphology of acritarchs, used in the phenetic classification, is diverse and, in general, individuals consist of vesicle enclosing the internal cavity and bearing ornamentation elements as processes, membranes, crests or fine sculpture on the surface. The excystment structure, suggesting that the vesicle is an algal cyst, is occasionally preserved. The vesicle diameter is usually 10-100 μm but it may vary up to 1000 μm.

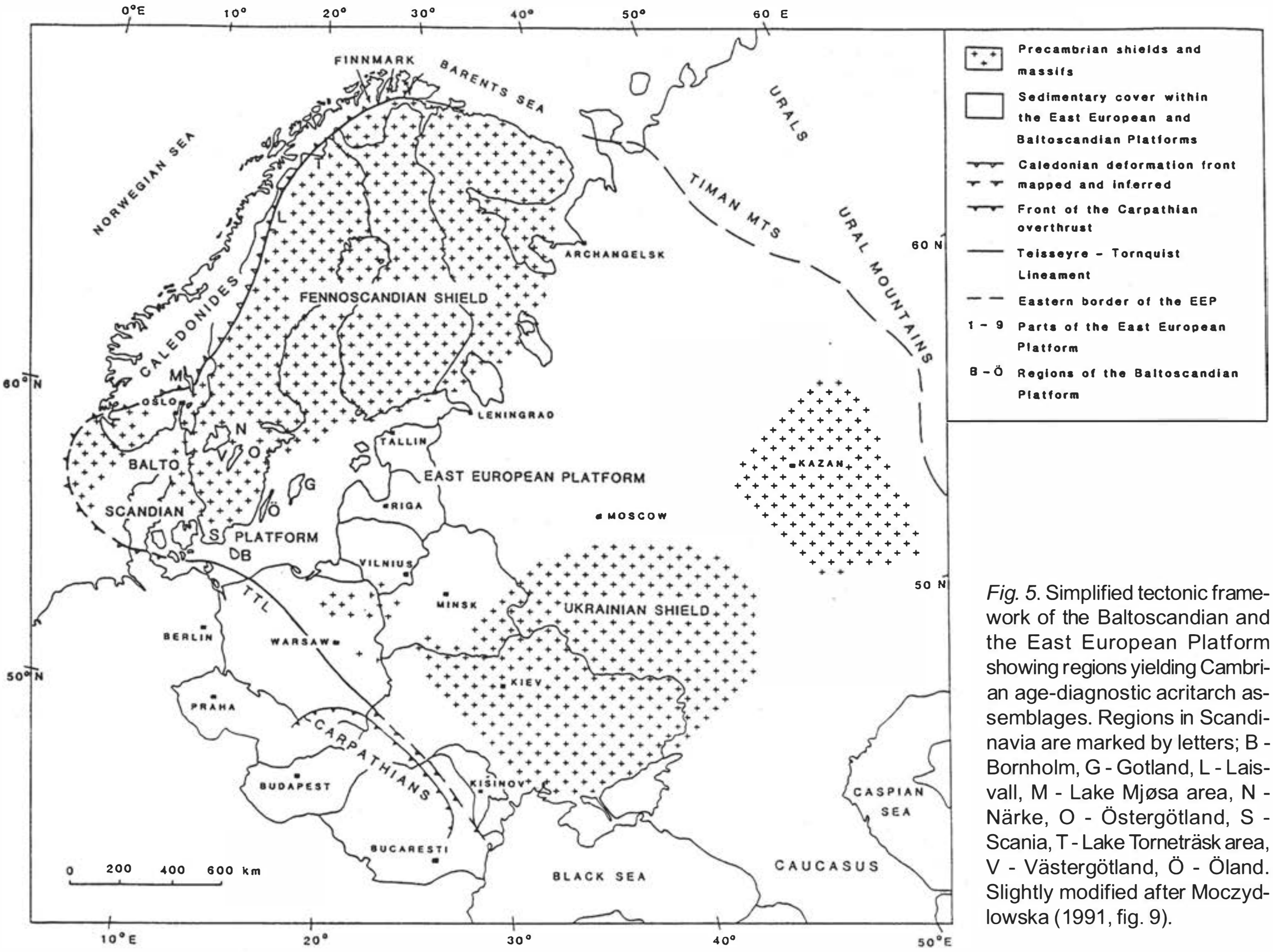


Fig. 5. Simplified tectonic framework of the Baltoscandian and the East European Platform showing regions yielding Cambrian age-diagnostic acritarch assemblages. Regions in Scandinavia are marked by letters; B - Bornholm, G - Gotland, L - Laisvall, M - Lake Mjøsa area, N - Närke, O - Östergötland, S - Scania, T - Lake Torneträsk area, V - Västergötland, Ö - Öland. Slightly modified after Moczydlowska (1991, fig. 9).

Acritarchs are widespread in various depositional settings, from nearshore to offshore shelf and basinal environments, and occur through the Middle Proterozoic to the Tertiary. Their greatest value in biostratigraphy is in terminal Neoproterozoic and Lower Palaeozoic strata. The Cambrian acritarch biodiversity, counting over 330 species, and the consistent pattern of acritarch assemblages changes allow recognition of several biozones in each series. The Lower Cambrian acritarch zones were established in the East European Platform (EEP) and recognised in Baltoscandia and other areas worldwide, and their stratigraphic relationships to faunal zones are getting better understood (Figs. 5-7). Furthermore, the homogeneous distribution of early Cambrian acritarch assemblages along the shelves of Baltica, the Avalonian and Armorican margins of Gondwana, and Laurentia facing the Iapetus Ocean and the Avalonian seaway suggests that these basins were still relatively narrow at the time, i.a. at the initial opening stage (Fig. 8).

Studies on acritarchs in Baltoscandia were initiated about twentyfive years ago and carried out up to the last year by the late Gonzalo Vidal, and have been continued by his students (including myself). Among them were Svenolov Lindgren, the late Krister Eklund, Stefan Hagenfeldt, Joakim Samuelsson, and the recent doctoral students Nina Talyzina and Mónica Martí, both in Uppsala.

The acritarch biochronology of the Lower Cambrian in Scania and its extension in Bornholm, and in Västergötland and Östergötland, the areas of interest during this field conference, and the interregional correlation with the stratotype successions of acritarch zones in the EEP, can be summarised as follows.

Scania

In Scania, southern Sweden, Lower Cambrian rocks rest unconformably on the Proterozoic crystalline basement and are overlain by the Alum Shale Formation (Bergström & Gee 1985). The generally shallow marine deposits consist of, in ascending order, the Hardeberga Formation, the Norretorp Formation, the Rispebjerg Sandstone, and the Gislöv Formation (Fig. 6).

The Hardeberga Formation consists of arkosic and quartz-arenitic sandstones and reaches a maximum thickness of about 120 m. The formation is sparsely fossiliferous and contains ichnofossils, hyoliths and acritarchs. The acritarch assemblage is stratigraphically significant and includes *Granomarginata squamacea, Lophosphaeridium tentativum, Asteridium*

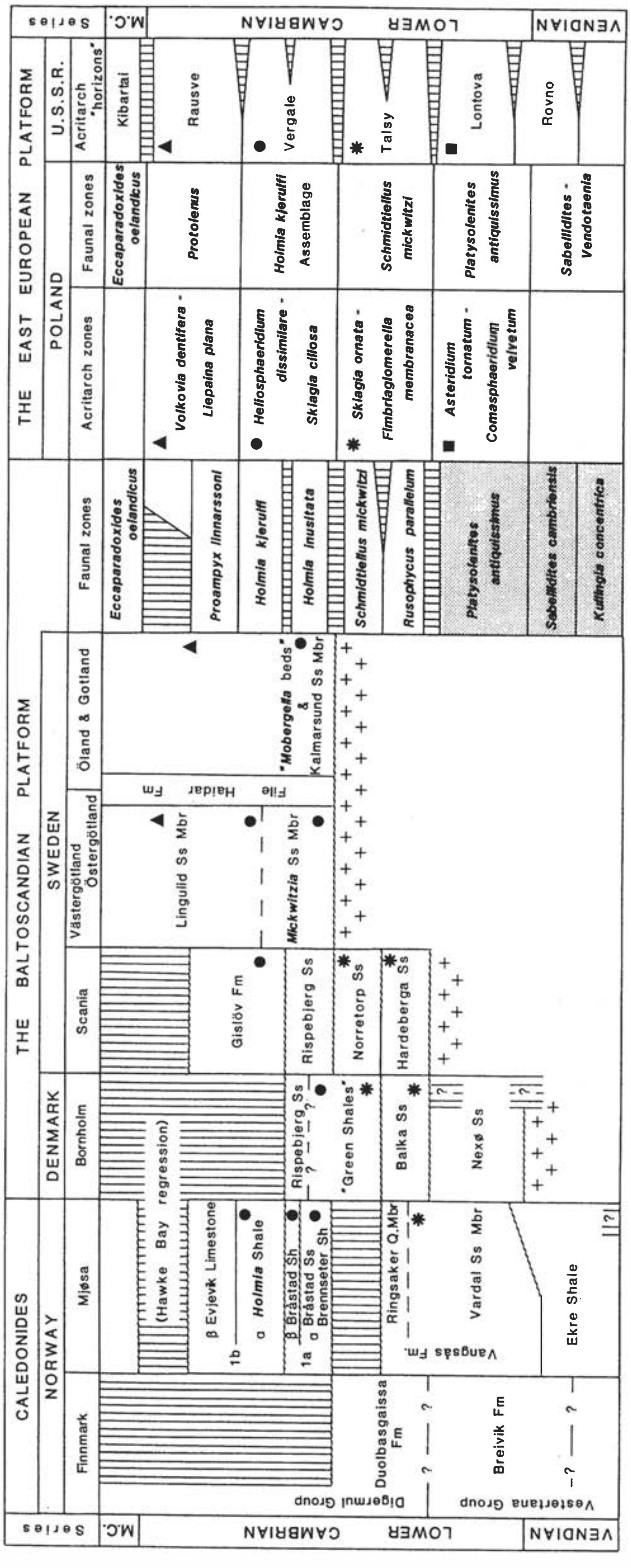


Fig. 6. Interregional acritarch-based correlation of Lower Cambrian strata in the East European Platform, the Baltoscandian Platform, and the Scandinavian Caledonides. Broken lines are for uncertain or approximate boundaries, vertical stripes indicate hiati, wavy line unconformities and crosses mark stand for crystalline basement. The square, asterisk, circular and triangle symbols indicate occurrences of acritarch assemblages defining acritarch zones established in Poland. From Moczydlowska (1991, fig. 11).

lanatum, A. tornatum, Comasphaeridium strigosum, C. brachyspinosum (Fig. 9A-B)*, Globosphaeridium cerinum, Fimbriaglomerella membranacea, Dictyotidium birvetense*, and *Tasmanites tenellus*. The assemblage is diagnostic for the *Skiagia ornata - Fimbriaglomerella membranacea* acritarch Zone and the time equivalent *Schmidtiellus mickwitzi* trilobite Zone (Vidal 1981*a*, 1981*b*; Moczydlowska & Vidal 1986; Moczydlowska 1991; Fig. 5).

The Norretorp Formation overlies the Hardeberga Formation with a transitional lithologic contact or, in some localities (the Simrishamn area), with a discontinuous boundary at the bottom of a conglomerate and sedimentary breccia indicating a sedimentary break and probably short lasting hiatus. The formation consists of alternating glauconitic sandstones and siltstones with phosphorite nodules. It ranges in thickness from about 4 to 20 m, and has yielded trilobites of the *Schmidtiellus mickwitzi* Zone, and additionally hyoliths, brachiopods and ichnofossils (Bergström 1981; Bergström & Gee 1985; Ahlberg et al. 1986). The acritarch assemblage recovered from the lower part of the Norretorp Formation includes *Archaeodiscina umbonulata, Granomarginata squamacea, Globosphaeridium cerinum, Lophosphaeridium dubium, L. tentativum, Skiagia orbiculare* and *S. ornata*. The assemblage is comparable to the one defining the *Skiagia ornata - Fimbriaglomerella membranacea* Zone, and thus indicates the same zone as the Hardeberga Formation (Vidal 1981*a*, 1981*b*, 1985; Moczydlowska 1991).

The overlying Rispebjerg Sandstone consists of coarse-grained sandstones rich in pyrite and phosphorite, and displays discontinuity surfaces. The thickness of the unit is only 1-3 m, and it was first recognised on the island of Bornholm, Denmark, and subsequently in Scania (Bergström & Gee 1985). The Rispebjerg Sandstone in Scania rests disconformably on the Norretorp Formation and is also disconformably overlain by the Gislöv Formation (Lindström & Staude 1971; Bergström & Ahlberg 1981). It has yielded only indeterminable fragments of shelly fossils and ichnofossils (Bergström & Gee 1985). Acritarchs have not yet been found (Vidal 1981*a*, 1981*b*).

The Gislöv Formation is a condensed sequence of silty limestone, siltstone and phosphatic shale attaining a thickness of about 2 m. It contains a diverse fossil fauna including trilobites and various small shelly fossils. Based on the trilobite evidence the formation has been referred to the *Holmia kjerulfi* and *Proampyx linnarssoni* Zones (Bergström & Ahlberg 1981; Ahlberg & Bergström 1993). Acritarchs are scattered and limited to specimens of *Skiagia ciliosa* and *Leiosphaeridia* sp. However, *Skiagia ciliosa* is known to occur in the *Heliosphaeridium dissimilare - Skiagia ciliosa*

Fig. 7. Succession of microfossil assemblages across the Upper Vendian and Lower Cambrian in the East European Platform in Poland, and the acritarch zonal subdivision. Additional occurrences in time equivalent zones are indicated by a vertical-line bar for Scandinavia, and a dashed-line bar for Estonia and Ukraine. From Moczydlowska (1991, fig. 5).

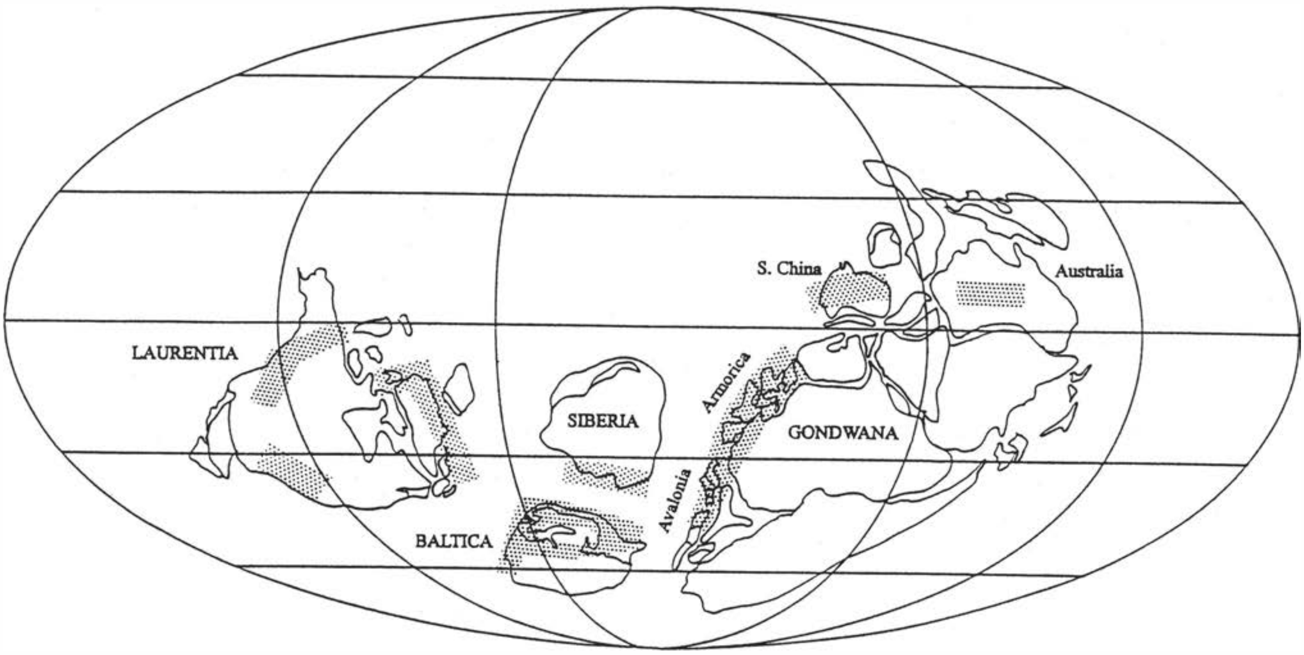


Fig. 8. Early Cambrian palaeogeographic reconstruction showing distribution of comparable acritarch assemblages (shaded) in the shelf basins extending along the margins of the Cambrian palaeocontinents. From Moczydlowska (1995).

and *Volkovia dentifera - Liepaina plana* assemblage Zones that correspond to the *Holmia kjerulfi* and *Protolenus* Zones in the EEP, respectively (Vidal 1981*a*, 1981*b*; Moczydlowska 1991).

Bornholm

The Lower Cambrian succession in Bornholm is comparable to that in Scania, with the exception of the basal Nexø Sandstone, and the discrete formations are regarded time-equivalent. The unfossiliferous Nexø Sandstone is an at least 100 m thick continental-fluvial, red arkosic unit. The transitionally overlying Balka Sandstone is the counterpart of the Hardeberga Formation, and the "Green Shales" (Broens Odde Member) correspond to the Norretorp Formation. Acritarchs derived from the Balka Sandstone are few and referred to *Lophosphaeridium tentativum* and *Comasphaeridium brachyspinosum*. These species occur in the *Skiagia ornata - Fimbriaglomerella membranacea* acritarch Zone (Vidal 1981*a*, 1981*b*; Moczydlowska & Vidal 1986; Moczydlowska 1991; Fig. 6).

The "Green Shales" yielded two diverse acritarch assemblages. The assemblage from the lower part of the formation consists of *Asteridium tornatum, A. lanatum, A. pallidum, Granomarginata squamacea, Lophosphaeridium tentativum, Comasphaeridium brachyspinosum, C. molliculum*, *Fimbriaglomerella membranacea, Globosphaeridium cerinum, Tasmanites bobrowskae, T. volkovae, Skiagia ornata, S. pura,* and *Alliumella baltica*, and it is consistent with the *Skiagia ornata - Fimbriaglomerella membranacea* acritarch Zone. In the middle part of the formation additional species such as *Lophosphaeridium truncatum, L. dubium, Fimbriaglomerella minuta, Skiagia orbiculare, ciliosa, S. insigne, Dictyotidium priscum*, and *Archaeodiscina umbonulata* occur, and together the acritarch assemblage is indicative of the *Heliosphaeridium dissimilare - Skiagia ciliosa* Zone (Vidal 1981*a*, 1981*b*; Moczydlowska & Vidal 1986, 1992; Moczydlowska 1991; Fig. 6).

Västergötland and Östergötland

In south-central Sweden, the File Haidar Formation comprises the Mickwitzia Sandstone Member and the Lingulid Sandstone Member, ranging from 16 to 38 m in thickness. The formation consists of fine-grained sandstones and siltstones resting on the crystalline basement and being overlain by Middle Cambrian rocks (Bergström & Gee 1985; Eklund 1990).

In Västergötland, the basal part of the Mickwitzia Sandstone yielded an acritarch assemblage with *Comasphaeridium brachyspinosum, Globosphaeridium cerinum, Polygonium primarium, Skiagia orbiculare, S. ornata, S. compressa, S. ciliosa, Lophosphaeridium dubium, Tasmanites bobrowskae, T. tenellus*, *Dictyotidium priscum*, and *Cymatiosphaera postae*, and it has been referred to the *Heliosphaeridium dissimilare - Skiagia ciliosa* assemblage Zone (Vidal 1981*a*, 1981*b*, 1985; Moczydlowska & Vidal 1986; Moczydlowska 1991; Fig. 10). The Lingulid Sand-

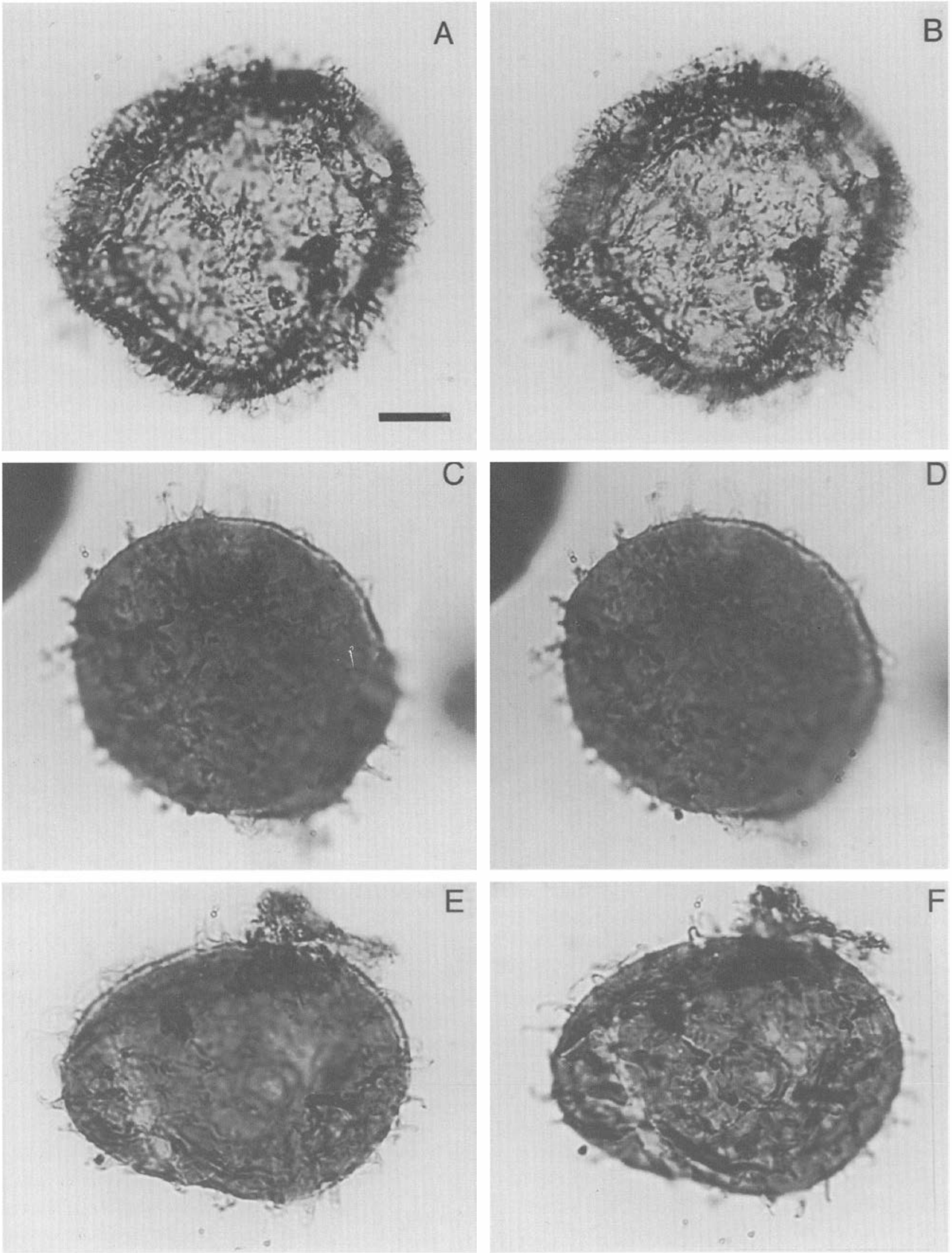


Fig. 9. Lower Cambrian acritarchs from Baltoscandia. A-B. *Comasphaeridium brachyspinosum* from the Hardeberga Formation in the Hardeberga Quarry, Scania. C-F. *Skiagia ciliosa* from the Lingulid Sandstone Member, Västergötland. Scale bar in A is 10 μm for all photomicrographs. Reproduced from *Geologiska Föreningens i Stockholm Förhandlingar 108(3)*, with the permission of the Geological Society of Sweden.

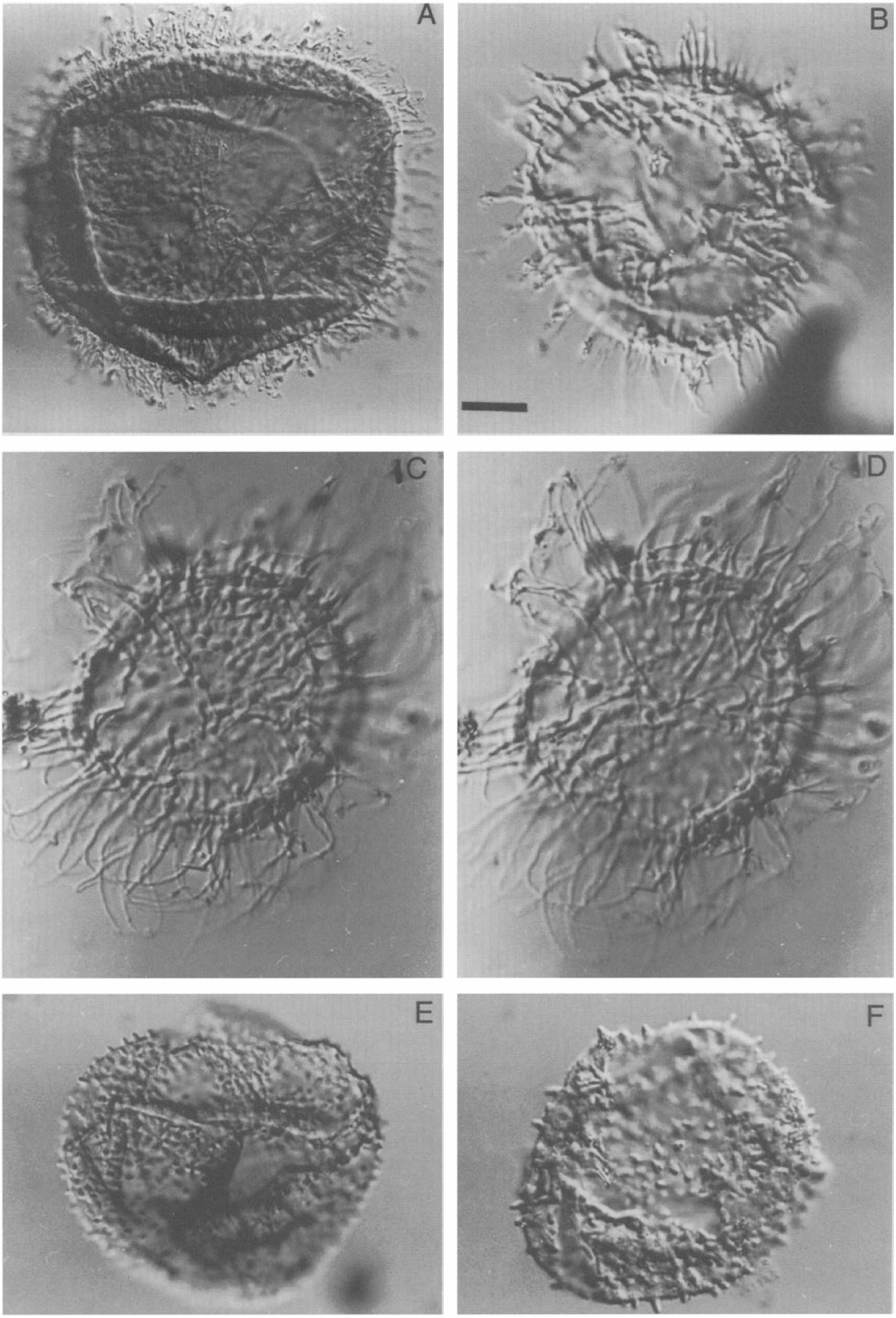


Fig. 10. Lower Cambrian acritarchs from Baltoscandia. A. *Comasphaeridium molliculum*. B. *Globosphaeridium cerinum*. C-D. *Skiagia ornata*. E-F. *Lophosphaeridium dubium*. All specimens from the Mickwitzia Sandstone Member, Lugnåsberget, Västergötland. Scale bar in B is 10 μm for all photomicrographs. Reproduced from *Geologiska Föreningens i Stockholm Förhandlingar 108(3)*, with the permission of the Geological Society of Sweden.

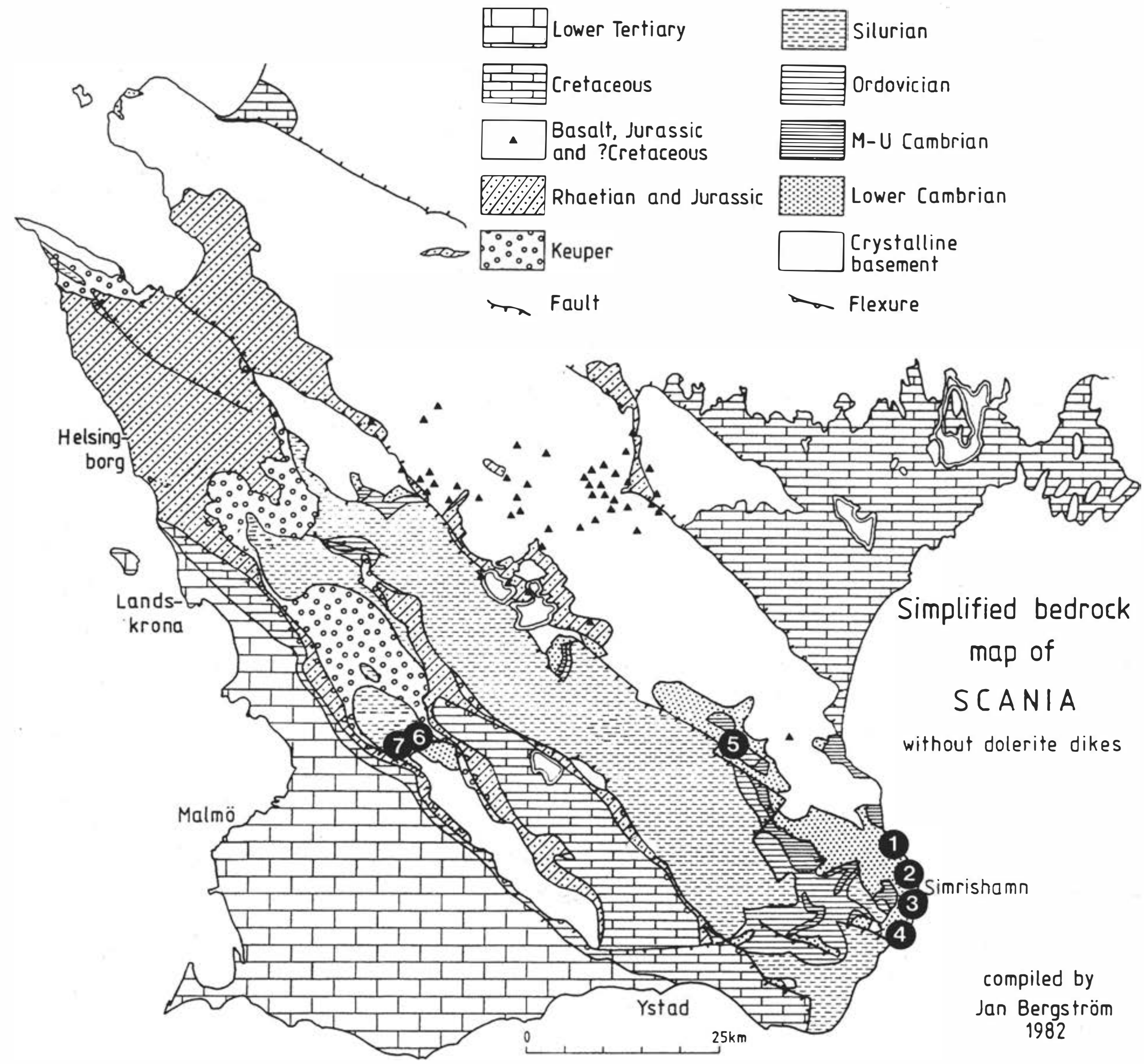


Fig. 11. Simplified bedrock map of Scania with excursion stops. From Bergström *in* Bergström et al (1982, fig. 1).

stone contains additionally *Polygonium varium, Solisphaeridium implicatum, Lophosphaeridium tentativum, Asteridium lanatum, Heliosphaeridium dissimilare, H. obscurum, Pterospermella solida, Leiovalia tenera, and Tasmanites volkovae*, but the entire assemblage suggests the same acritarch zone as the *Mickwitzia* Sandstone (Moczydlowska 1991; Fig. 9).

In Östergötland, the Mickwitzia Sandstone contains a diagnostic assemblage of acritarchs that includes *Comasphaeridium brachyspinosum, C. strigosum, Fimbriaglomerella membranacea, Globosphaeridium cerinum, Polygonium primarium, Tasmanites bobrowskae, T. volkovae, Skiagia orbiculare, S. ornata, S. compressa, S. ciliosa, Pterospermella solida*, *Cymatiosphaera postae, Multiplicisphaeridium xianum, Estiastra minima* , *Heliosphaeridium dissimilare, Asteridium spinosum*, and *Dictyotidium priscum*. This assemblage allows comparison with the *Heliosphaeridium dissimilare - Skiagia ciliosa* Zone (Eklund 1990; Moczydlowska 1991). The Lingulid Sandstone yielded diagnostic species including *Volkovia dentifera, Lophosphaeridium latviense, Pterospermella vitrae*, and *Leiovalia tenera,* indicating the *Volkovia dentifera - Liepaina plana* acritarch Zone of the Lower Cambrian and the basalmost Middle Cambrian (Eklund 1990; Hagenfeldt 1989; Moczydlowska 1991). *Lophosphaeridium latviense* is a species that appears at the base of the Middle Cambrian elsewhere. The above data suggest that the Lingulid Sandstone in Östergötland comprises strata of wider biostratigraphic range than in Västergötland. The transitional contact between deposits containing the acritarch assemblage diagnostic of the *Volkovia dentifera - Liepaina plana* Zone and that of the *Acadoparadoxides oelandicus* Zone within the upper Lingulid Sandstone indicates a continuous passage from Lower to Middle Cambrian (Eklund 1990).

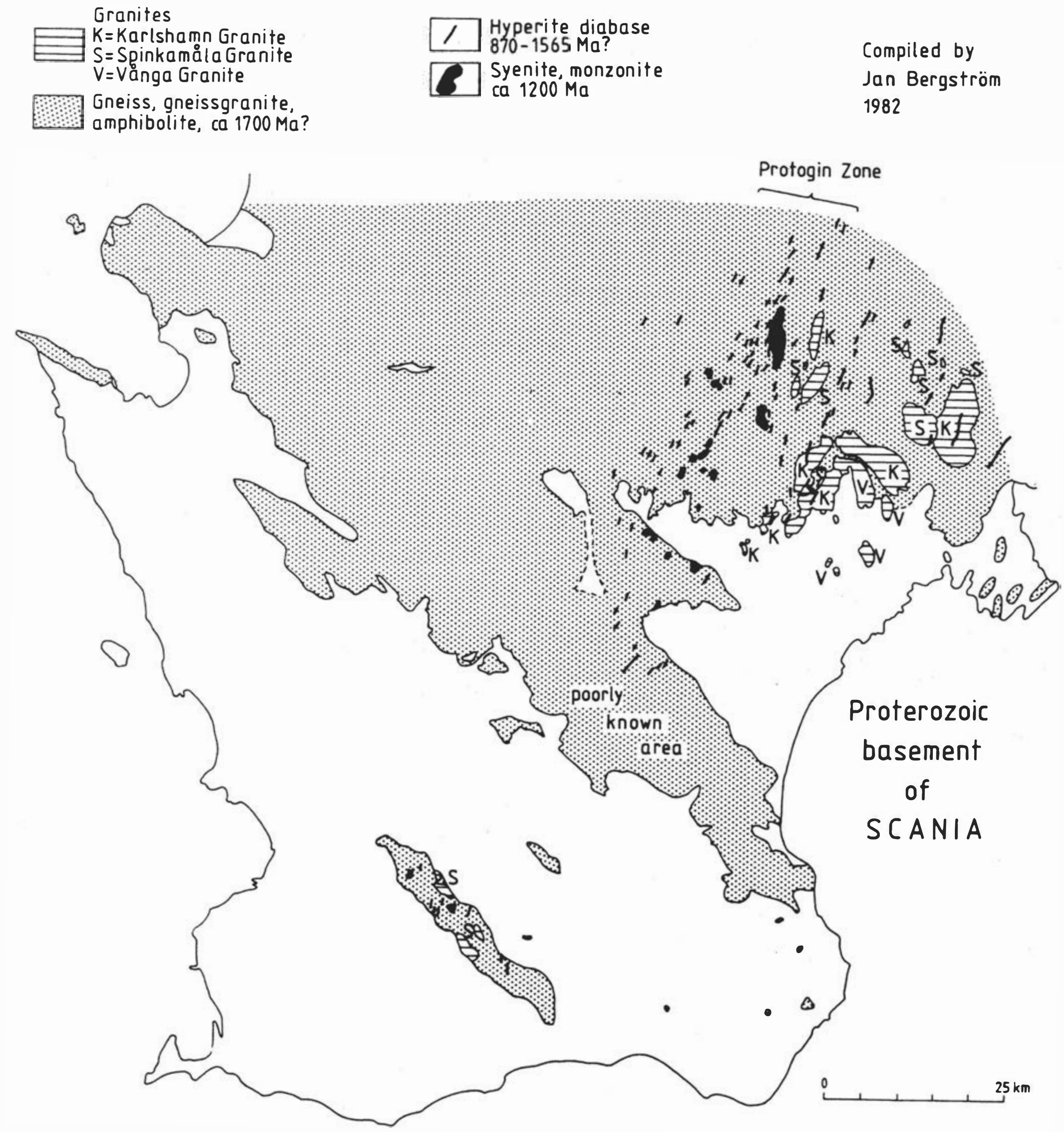


Fig. 12. Basement rocks of Scania. From Bergström *in* Bergström et al. (1982, fig. 2).

Outline of the geology of Scania

JAN BERGSTRÖM and KARL-AXEL KORNFÄLT

Scania (Swedish: Skåne; German: Schonen) is the southernmost province of Sweden. As a result of the position on the edge of the Fennoscandian Shield, Scania has had a complex geological history. Accordingly, the geological map shows a mosaic of different rocks at the bedrock surface (Fig. 11). The bedrock is dominated by Precambrian gneisses and granites, and Lower Palaeozoic and Mesozoic-Tertiary deposits. The geology is much more complex than can be shown on a small-scale map, and due to the Quaternary cover known only in outline in many areas.

Basement rocks

The usual division of the Precambrian of southern Sweden into the 1.75-0.9 Ga old Southwest Swedish Gneiss Region in the west, and the 1.85-1.65 Ga old Transscandinavian Igneous Belt (TIB) in the east, separated by the large intraplate tectonic zone known as the Protogine Zone (Fig. 12), appears to be valid also for Scania. Along the southern part of the Protogine Zone, c. 1.2 Ga old (Johansson 1990) (quartz) syenites and 0.93 Ga and 1.18 Ga old (Johansson & Jo-

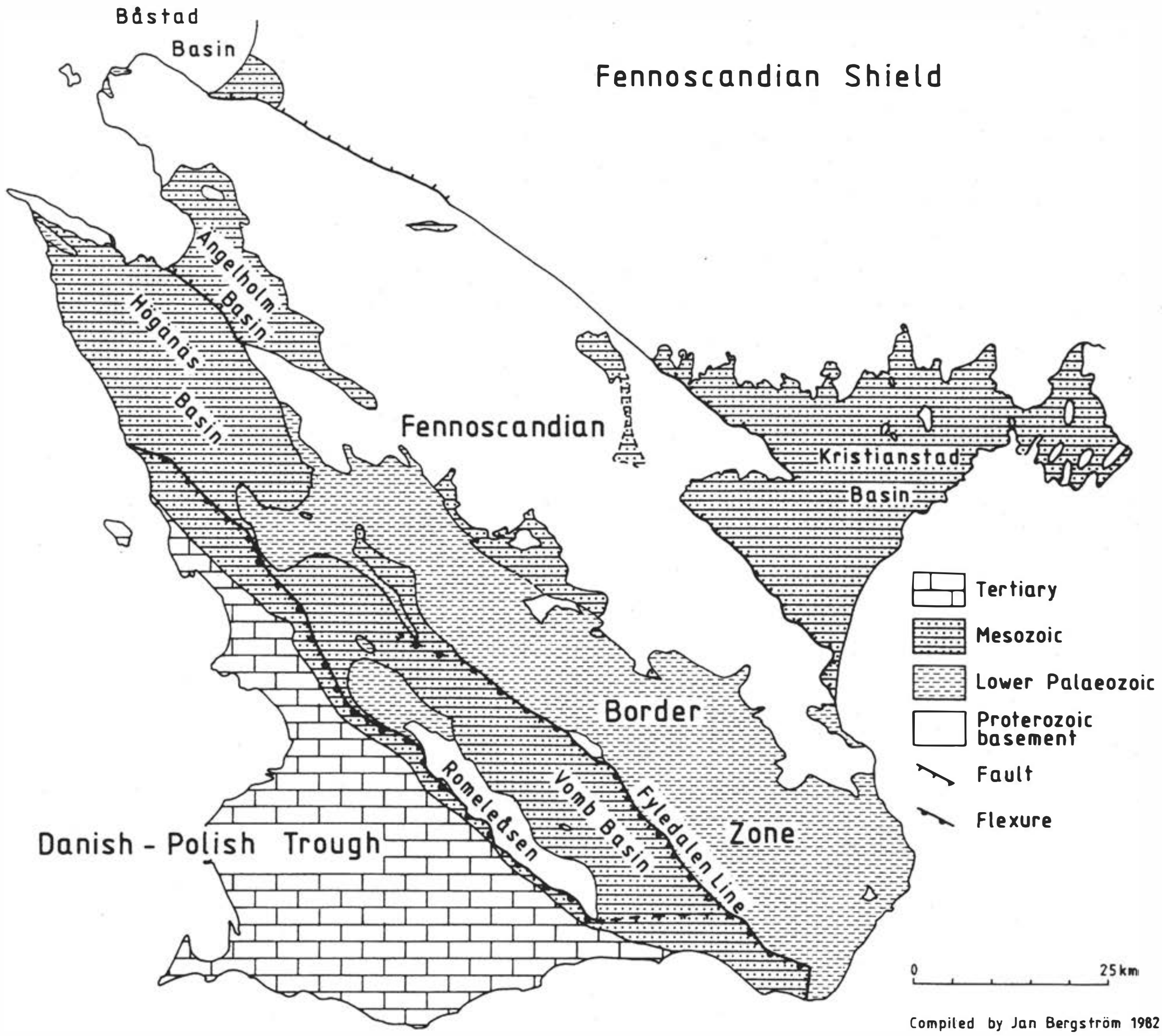


Fig. 13. Large tectonic and stratigraphic units of Scania. From Bergström *in* Bergström et al. (1982, fig. 10).

hansson 1990) so-called hyperite dolerite dikes occur (Wikman & Bergström 1987). The gneisses in the region west of the Protogine Zone have been affected by the 1.1-0.9 Ga old Sveconorwegian Orogeny and is characterised by high-grade, partly granulite metamorphism (Johansson et al. 1991). East of the Protogine Zone there are no signs of such influence on the bedrock in Scania and Blekinge. Southern Scania is transected by the Phanerozoic, NW-SE striking Tornquist Zone. The fault tectonics of this zone were fully developed at the time of the intrusion of numerous Permo-Carboniferous dolerites (305 Ma; Klingspor 1976), the orientation of which was controlled by the NW-ly fracture zones. A final magmatic event is indicated by the presence of basaltic necks, most of which are found in central Scania. Radiometric dating of the basalts has yielded ages of 170 Ma and 110 Ma (Klingspor 1976). The first-mentioned age is more reliable. A basalt tuff has yielded microfossils reliably demonstrating an age around the Early/Middle Jurassic transition (Tralau 1973).

The oldest bedrock unit of southernmost Sweden east of the Protogine Zone is the Västanå supracrustal formation, consisting of acid metavolcanic rocks (mainly rhyolite), metabasites and quartzites. The Västanå formation is situated just east of the Protogine Zone. Parts of the metavolcanic rocks have been strongly foliated into a mica schist-like rock along a NNW-SSE-ly striking tectonic zone, possibly a branch of the Protogine Zone. Towards the east the metavolcanic rocks grade into the so-called coastal gneiss of Blekinge. Recent mapping in eastern Blekinge has shown, however, that the gneiss, at least in eastern Blekinge, also includes rocks that presumably could have originated from deformation of older coarse-grained granitoids, an interpretation already favoured by Asklund (1947). The coastal gneiss has been intruded by coarse-grained, c. 1.77 Ga (Johansson & Larsen 1987; Kornfält 1993*a*) granitoids of mainly granodioritic to adamellitic composition known as Tving granite. That granite is very likely a more basic variety of the Småland granite which belongs to the TIB-granites (Kornfält 1993*a*). The metamorphic grade of eastern Scania and western Blekinge rocks is greenschist to amphibolite facies.

Around 1.45 Ga ago a suite of "anorogenic" granites intruded the gneisses and granitoids in Blekinge and northeastern Scania (Åberg et al. 1985; Åberg & Kornfält 1986). These granites, known as the Karlshamn granite group, include the coarsely porphyritic Karlshamn granite proper, the medium-grained Spinkamåla granite, fine-grained granite and pegmatite (Kornfält 1993*b*).

Cover rocks

The general pattern of geological boundaries, dolerite dikes and tectonic features is strongly dominated by a NW-SE trend (Fig. 11). This is the direction of the Tornquist Zone, a complex major structural feature near the platform border that can be traced from the North Sea across Jutland in Denmark, Scania, and Poland toward the Black Sea. In the north of Scania the surface of the basement plunges gently towards the southwest and south beneath the mainly Upper Cretaceous rocks of the Båstad and Kristianstad Basins (Fig. 13). The northern boundaries of these Cretaceous covers are caused by denudation, and numerous outliers and locally derived erratics indicate the former existence of a more widespread Cretaceous cover (Lidmar-Bergström 1982). The Cretaceous basins are fairly shallow, with a maximum depth in the south, where they terminate against fault-lines. These faults form the northeastern boundary in Scania of the vaguely defined Fennoscandian Border Zone (this term was coined by Sorgenfrei & Buch 1964), which in reality can be recognised as a major inversion axis (Ziegler 1975, fig. 17).

In very generalised terms, the Fennoscandian Border Zone consists of a large block of basement gently tilted to the southwest (Figs. 11, 13). Thus basement rocks are exposed in a belt along the northeastern boundary. To the southwest follow Cambrian to Silurian strata, which in the northwest are overlain by Triassic and Jurassic rocks. Deposits of the latter ages are also found directly on the basement rocks, particularly in the northwest.

The tilted basement block extends to a line from Landskrona over Fyledalen to the southeastern tip of Scania. The southwestern boundary is formed by a section of the important Landskrona-Romeleåsen flexure and fault system and by the Fyledalen flexure and fault line. Southwest of the Fyledalen line is another basement block tilted in the opposite direction, viz. to the northeast (Figs. 11, 13). It is a matter of taste if this block is included in the Fennoscandian Border Zone or not. Its basement core is exposed in the Romeleåsen Horst, while the northeastern belt, the Vomb Basin, has a succession of up to around 1000 m of Upper Triassic to Upper Cretaceous rocks lying directly on the basement. The Vomb Basin proper is terminated in the south by a fault system extending east from the southeastern tip of the Romeleåsen Horst. Southeast of this fault system the continuation of the Vomb Basin is still deeper.

The triangular part of Scania southwest of the Landskrona – Romeleåsen disturbance belongs geologically to the Danish-Polish Trough (Fig. 13). Here, the basement surface lies deeper than anywhere else in Scania. The greatest depth, 2500 m, is found at the southwestern tip. In the southwest the basement is overlain by up to 800 m of Cambro-Silurian strata. Closer to the Landskrona-Romeleåsen disturbance the Palaeozoic is absent. The Mesozoic starts with Lower Triassic rocks in the southwest and with Upper Triassic in the northeast and ends with the uppermost Cretaceous. Much of the thickness (which measures some 1900 m at Höllviken in the southwest; Brotzen 1945, 1950) is caused by the up to 1200 m thick Upper Cretaceous strata. On top lies a comparatively thin sheet of Danian limestone, locally overlain by younger Paleocene and Eocene deposits.

During the Early Palaeozoic Scania formed part of the vast shelf area facing the rising orogen of the Scandinavian and North Sea-Polish Caledonides. Early Palaeozoic marine deposits, ranging in age from Cambrian to Early Silurian, form in Scania a comparatively thin and originally even cover. During the Late Silurian, Scania formed part of the North Sea-Polish Caledonides, and became tilted to the south. This was accompanied by considerable faulting. Upper Silurian deeper water clastics may have been thousands of metres thick (cf. Buchardt & Nielsen 1985). Permo-Carboniferous wrench-faulting resulted in the uplift of basement blocks and the profound truncation of the Lower Palaeozoic series. These are now preserved only in the Central Colonus Shale Trough, in southwesternmost Scania and in the Kattegat.

The Cambrian of Scania

PER AHLBERG and JAN BERGSTRÖM

In Scania, Cambrian rocks outcrop in several scattered areas. The succession is best known from three areas, viz. the Hardeberga area east of Lund, the Röstånga area along the southern flank of the Söderåsen Horst, and southeast Scania (Simrishamn, Brantevik, Vik, Kiviks Esperöd, and Andrarum). There are also a number of other isolated occurrences, for instance at Rekekroken and Torekov in northwest Scania, and southwest of Hörby in central Scania.

The Lower Cambrian of Scania consists predominantly of arenaceous deposits laid down in shallow marine environments. Its thickness in southeast Scania is estimated at around 120 m (Lindström & Staude 1971), and at Hardeberga it is at least 120 m (Regnéll 1960; Bergström et al. 1982, pp. 11-12). The succession is subdivided into four formations (Bergström & Ahlberg 1981). From base to top these are (1) the Hardeberga Sandstone Formation (*sensu* Bergström 1970 and Bergström & Ahlberg 1981), (2) the Norretorp Formation, (3) the Rispebjerg Sandstone, and (4) the Gislöv Formation (Fig. 14). In southeast Scania the Hardeberga Formation has been called the Simrishamn Formation (Shaikh & Skoglund 1974). A southeastward continuation of the Lower Cambrian of Scania is present in the southern part of the island of Bornholm, Denmark, but it is worth noting that there is no equivalent of the Gislöv Formation.

The Hardeberga Formation makes up the greater part of the Lower Cambrian in Scania. It rests unconformably on the Proterozoic crystalline basement, which was eroded extensively prior to the local early Cambrian transgression. The formation is subdivided into four members, the Lunkaberg, Vik, Brantevik, and Tobisvik Members (Bergström & Ahlberg 1981; Hamberg 1990, 1991). These members were originally regarded as discrete formations (Lindström & Staude 1971), but it is appropriate to include all sedimentary rocks below the Norretorp Formation in a single formation (Bergström & Ahlberg 1981).

The Hardeberga Formation comprises a basal, 15-25 m thick, arkosic sandstone unit, overlain by three, 30 to 50 m thick, vertically stacked marine sequences

SERIES	STAGES AND ZONES			SCANIAN ROCK UNITS
Upper Cambrian	no stages	*Acerocare*		Alum Shale Fm
		Peltura		
		Leptoplastus and *Eurycare*		
		Parabolina spinulosa		
		Olenus and *Agnostus (H.) obesus*		
		Agnostus pisiformis		
Middle Cambrian	*Paradoxides forchhammeri* Stage	*Lejopyge laevigata*		
		Solenopleura brachymetopa		Andrarum Lst
		P. lundgreni and *Goniagn. nathorsti*		Alum Shale Fm
	Paradoxides paradoxissimus Stage	*Ptychagnostus punctuosus*		
		Hypagnostus parvifrons		
		Tomagnostus fissus and *Ptychagn. atavus*		
		Ptychagnostus gibbus		
	Eccaparadoxides oelandicus Stage	*Eccaparadoxides oelandicus* f. *pinus*		(hatched)
		Eccaparadoxides insularis		(hatched)
	Hawke Bay hiatus			(hatched)
Lower Cambrian	no stages	*Proampyx linnarssoni* *Holmia kjerulfi* group		Gislöv Fm
				Rispebjerg Ss
		Schmidtiellus mickwitzi; Mobergella		Norretorp Fm
		Platysolenites antiquissimus	"*Rusophycus*"	Hardeberga Ss
			"*Spirosolenites*"	(hatched)
		Sabellidites cambriensis		(hatched)

Fig. 14. Cambrian stratigraphy of Scania. From Bergström *in* Bergström et al. (1982, fig. 3).

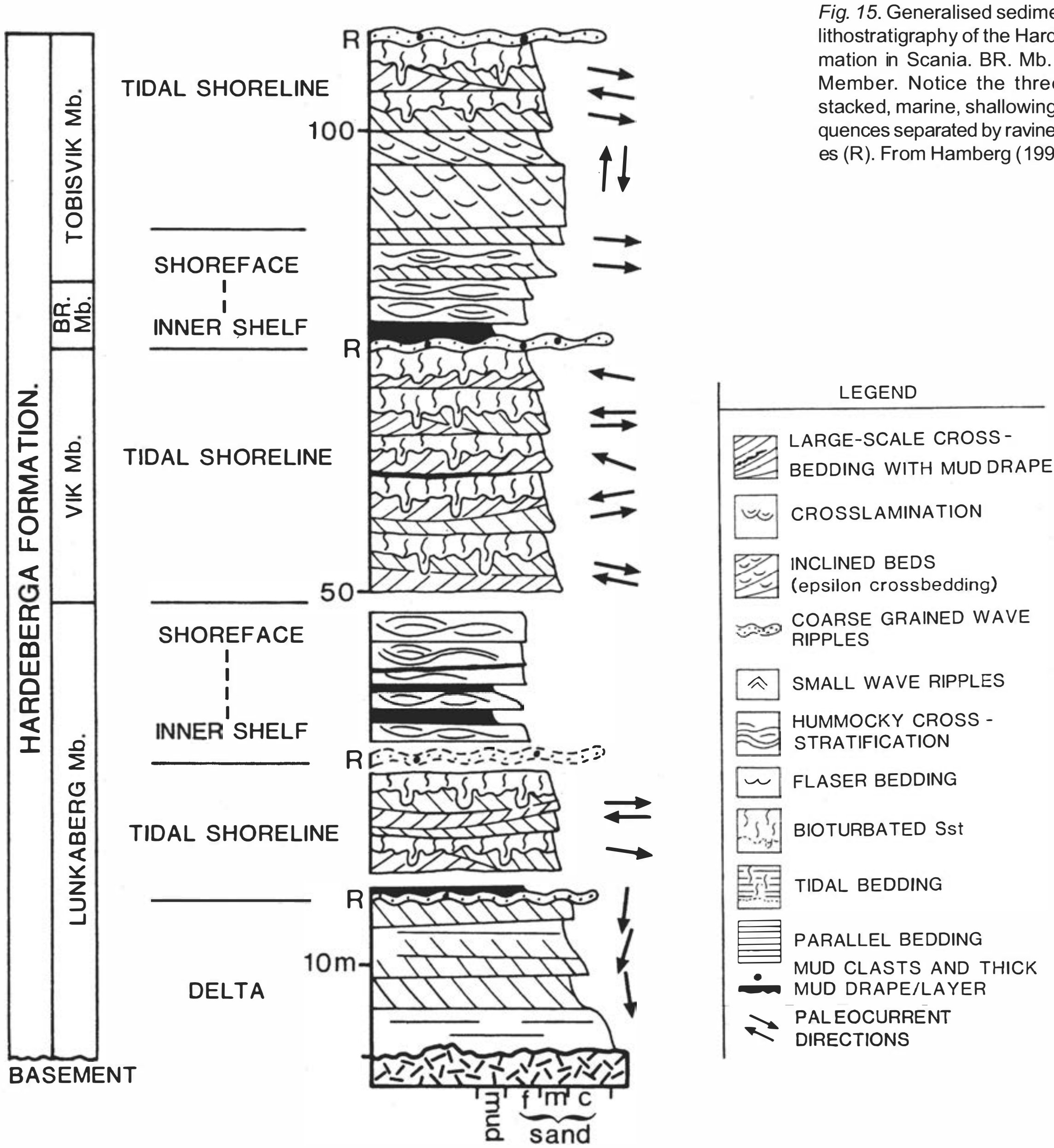


Fig. 15. Generalised sedimentology and lithostratigraphy of the Hardeberga Formation in Scania. BR. Mb. = Brantevik Member. Notice the three, vertically stacked, marine, shallowing-upward sequences separated by ravinement surfaces (R). From Hamberg (1991, fig. 3).

(Hamberg 1991; Fig. 15). The basal unit consists of a fluvio-deltaic sequence, truncated by a marine erosion surface (a ravinement surface). The three marine sequences are separated by ravinements and were deposited as a result of a northerly directed regional transgression over the southern part of the Baltic Shield (Hamberg 1991). Each sequence contains three major facies associations that document the progradation of a mixed tide- and wave-influenced barrier island shoreline. The facies sequence, with a vertical development from inner shelf deposits to backbarrier tidal channels, represents progradation of a barrier island shoreline through longshore drift and accumulation of sand in the shallow shoreface and offshore zones (Hamberg 1991).

Excluding trace fossils the Hardeberga Formation is poorly fossiliferous, but has yielded hyoliths and a possible impression of a trilobite (Ahlberg et al. 1986). Trace fossils are locally extremely abundant and include, e.g., *Diplocraterion parallelum*, *Skolithos linearis*, *Syringomorpha nilssoni*, *Psammichnites gigas*, *Planolites* sp., and *Didymaulichnus* sp. (e.g. Hadding 1929; Hamberg 1991). In addition, Bergström (1970) described a trilobite type trace fossil, *Rusophycus parallelum*, from the upper part of the formation in the Hardeberga Quarry, east of Lund. Acritarchs recovered from the Hardeberga Formation are indicative of the *Skiagia ornata - Fimbriaglomerella membranacea* Zone (Vidal 1981*a*, 1981*b*; Moczydlowska 1991, p. 37).

The Norretorp Formation was established by Bergström (1970) for the greenish-grey strata succeeding the Hardeberga Formation. The formation consists of slightly calcareous and generally hummocky cross-

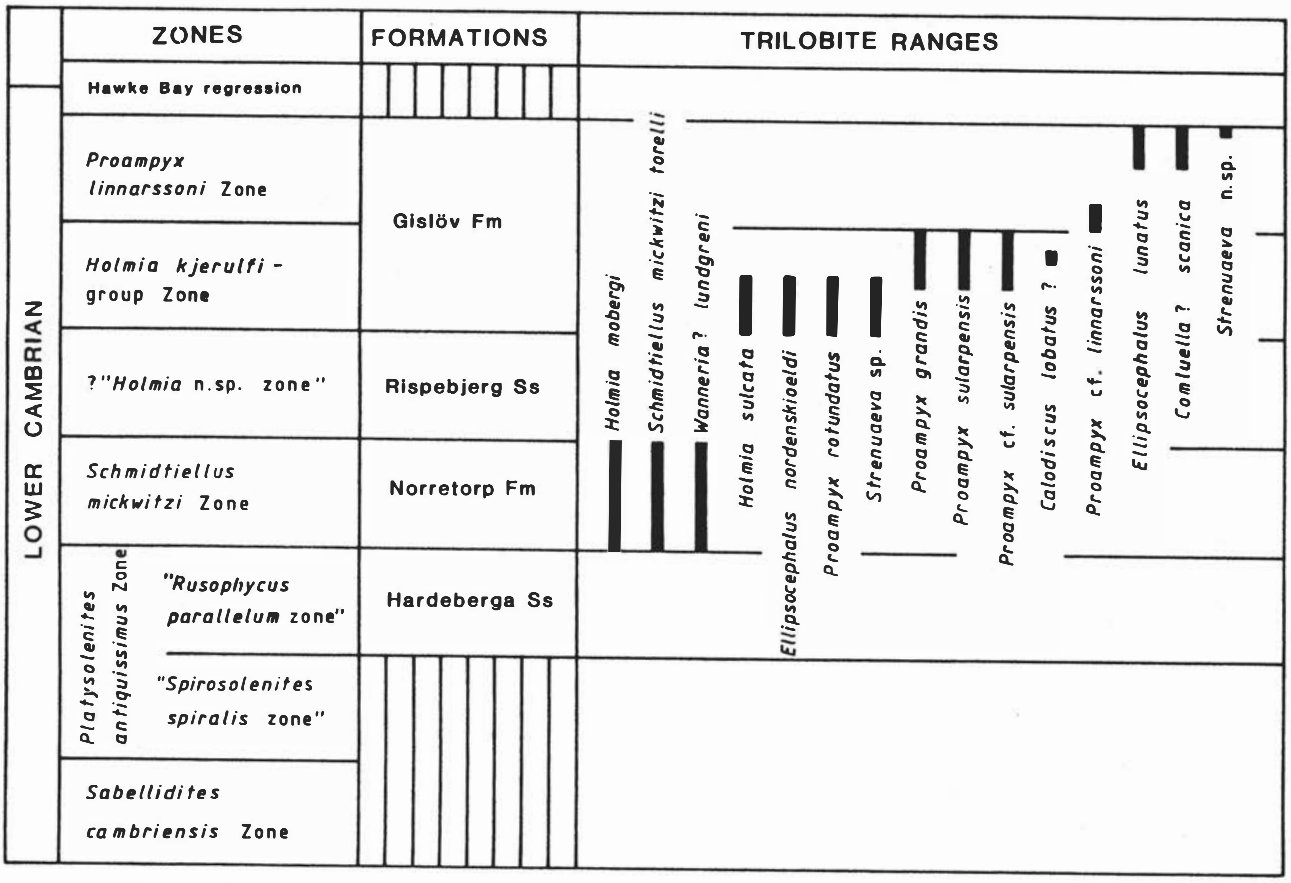


Fig. 16. Ranges of trilobites in the Lower Cambrian of Scania. From Ahlberg (1984*c*).

stratified siltstones and sandstones with abundant glauconite and phosphorite, and it seems to be a thin equivalent of the ”Green Shales” (Broens Odde Member) of Bornholm. Its thickness amounts to around 15 m in the Hardeberga Quarry (Bergström 1970; Lindström & Staude 1971) and 4 m in southeast Scania (Lindström & Staude 1971). It has yielded olenellid trilobites indicative of the *Schmidtiellus mickwitzi* Zone (Fig. 16). These were described by Moberg (1892, 1899) and Bergström (1973), and include *Schmidtiellus mickwitzi torelli* (Moberg, 1892), *Holmia mobergi* Bergström, 1973, and *Kjerulfia*? *lundgreni* (Moberg, 1892). In addition to trilobites, the Norretorp Formation has yielded obolellid brachiopods, hyoliths, *Volborthella tenuis* (a single specimen from Listarum in southeast Scania), and various trace fossils, including ”*Scolithus*” *errans* and trilobite type traces. Acritarch assemblages recovered from the Norretorp Formation indicate the *Skiagia ornata - Fimbriaglomerella membranacea* Zone (Vidal 1981*a*, 1981*b*; Moczydlowska 1991, p. 37).

The Rispebjerg Sandstone is a thin, homogeneous sequence of calcareous and generally coarse-grained sandstones with abundant phosphorite. Apart from a few indeterminate fossil fragments, the only fossils found in Scania are generally large horizontal burrows near the top of the formation.

The Rispebjerg Sandstone is overlain disconformably by the Gislöv Formation (Bergström & Ahlberg 1981). This is a thin (average thickness only about 1 m) but lithologically variable unit, and it reflects a major transition from earlier, dominantly arenaceous sedimentation to later, dominantly argillaceous or carbonate sedimentation. The top of the formation coincides with a regional unconformity and with the Lower-Middle Cambrian boundary in Scania (Bergström & Ahlberg 1981). The Gislöv Formation has yielded fairly rich and varied faunal assemblages including trilobites, brachiopods, hyoliths, helcionellids, a lapworthellid (Bengtson 1977, p. 752, 1980, p. 55), a hyolithelminthid, conodont? elements, and rare bradoriid arthropods. In addition, de Marino (1980*a*, p. 19) has identified echinoderm fragments. The vertical ranges of the faunal elements are described by Bergström & Ahlberg (1981).

Trilobites are biostratigraphically important fossils in the Gislöv Formation, and their systematics and distribution were described by Bergström (1973), Ahlberg & Bergström (1978), Bergström & Ahlberg (1981), and Ahlberg & Bergström (1993). Silty beds and limestones in the lower part of the formation have yielded *Holmia sulcata* Bergström, 1973, *Calodiscus lobatus* (Hall, 1847) (now known from more than a hundred specimens), and a number of ellipsocephalid trilobites (Fig. 16). These trilobites are indicative of the *Holmia kjerulfi*-group Zone. Younger assemblages with ellipsocephalid trilobites from limestones in the middle and upper part of the formation suggest a correlation with the *Proampyx* (or *Ornamentaspis*) *linnarssoni* Zone.

The Middle and Upper Cambrian, and the basal Tremadocian of Scania forms a fairly monotonous sequence of finely laminated alum shale with kerogenous limestone (stinkstone) forming lenses and bands and a few levels of more pure limestone. The sequence is remarkably complete, although the *Acadoparadoxides oelandicus* Stage appears to be missing, at least in southeast Scania. There is a wealth of information from scattered exposures, drift material, and borings (e.g. Moberg 1911; Westergård 1922, 1944; 1946; Bergström & Ahlberg 1981). The thickness is around 20 m for the Middle Cambrian, 40-55 m for the Upper Cambrian, and 9-17 m for the Tremadocian Dictyonema Shale (Westergård 1944; Regnéll 1960). The most accessible and complete sections are to be found in the old alum shale workings at Andrarum in southeast Scania. The Andrarum Limestone of the *Solenopleura brachymetopa* Zone is famous for having yielded many of the Cambrian trilobites described by Angelin (1851, 1854).

Excursion localities in Scania

Stop 1. Vik

Anders Ahlberg

Object: Back-barrier tidal deposits in the Lower Cambrian, and a remarkable case of postdepositional deformation.

South of the harbour of the picturesque village of Vik, about 7 km north of Simrishamn, a 300 m long low-relief shore section of Lower Cambrian strata faces the Baltic Sea. The deposits are indurated by quartz cement, and they are consequently resistant to coastal erosion. The exposed strata belong to the Vik Member of the Hardeberga Formation.

The section is predominantly composed of 20-30 cm thick interbeds of two lithologies. A) Mineralogically mature arenites (quartz arenites) typically show trough crossbedding formed by migration of 3D-dunes. In this lithology, foreset migration directions make up a bipolar pattern, and stacked bedsets show herringbone structures. B) The second lithology comprises bioturbated muddy sandstones (at places quartz wackes). Here, trace fossils are dominated by *Diplocraterion* and occasional *Monocraterion* and *Skolithos* burrows, i.e., a typical example of the shorebound *Skolithos* ichnofacies.

The interbedded lithologies (A and B) have been attributed to the dendritic drainage channels of back-barrier lagoons. The crossbedded sandstones were formed in active tidal channels, whereas mud deposition and intensive bioturbation occurred in abandoned enclosed channels (Hamberg 1994). The stacked interbedding of the two lithologies may simply be attributed to longshore lateral facies migration. However, Hamberg (1991) claimed that the density and development of the ichnofauna in each strongly bioturbated bed would require a duration on the scale of a season. Strong bioturbation in abandoned channels has been assigned to calm summer conditions, whereas the cross-bedded sandstone has been formed in active channels during high energy winter conditions (Hamberg 1991, 1994).

At Vik, c. 10 m wide ring-shaped structures disrupt the otherwise fairly horizontally preserved strata (Lindström 1967). The most impressive structure is locally called "the vicars bathtub", and indeed "the tub" gets filled with brackish water during high stand of the Baltic Sea. Early ideas of these funnel structures include the possibility of extraterrestrial impacts, but in more recent times soft sediment eruptions (liquefaction) of the muddy sandstone beds have been favoured (Hamberg 1994). This idea is supported by the association between the structures and sandstone dikes in the section (Hamberg 1994). However, Katzung & Obst (1998, p. 170) claim that sudden opening of fissures and cracks in the basement created a vacuum which led to an implosively sucking down of the overlying water saturated sediments. This process might also be a possible reason for the development of the funnel structures.

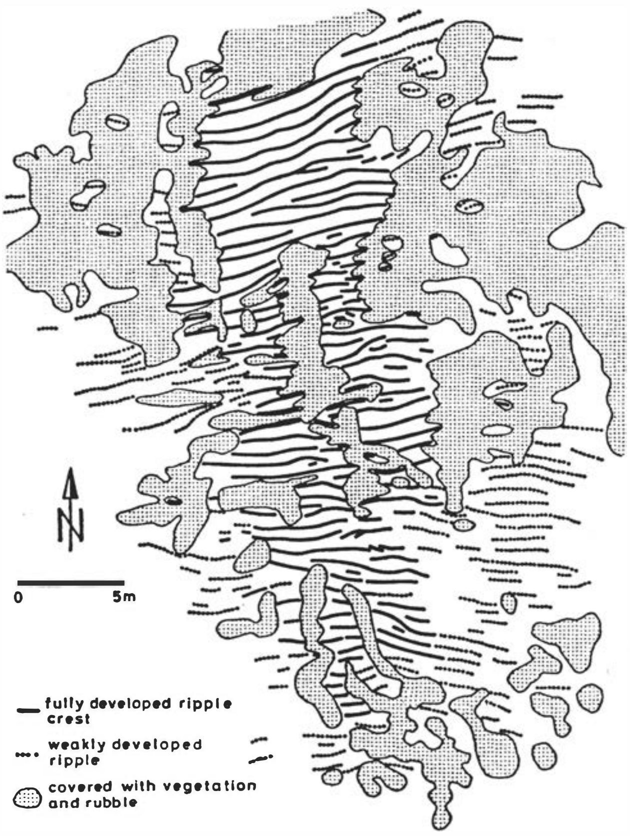


Fig. 17. Field of wave-ripples southwest of the Tobisborg quarry. From Lindström (1972, fig. 2).

Stop 2. Tobisborg

Anders Ahlberg

Object: Fields with wave-ripples in Lower Cambrian sandstones (Tobisvik Member).

At Tobisborg, north of Simrishamn, well sorted Lower Cambrian sandstones are exposed. These sandstones belong to the Tobisvik Member of the Hardeberga Formation. Local quarrying of stratiform building material (quartzitic sandstone) has exposed a surface with large undulating ripples. The wave length of the ripples is around 60 cm and their height is typically around 10 cm. Ripple Symmetry Index and the tendency to bifurcate clearly indicate oscillation as the forming sedimentary process, and the orientation of these ripples indicates an E-W orientation of the coast line (Lindström 1972). A particularly extensive field with wave-ripples is present southwest of the quarry (Lindström 1972, fig. 2, pl. 2, fig. 8; Fig. 17). In the Hardeberga Formation fields of large wave-ripples have been interpreted as lower shoreface deposits, formed during waning storms (Hamberg 1991; cf. Troedsson 1927).

Stop 3. Simrislund

Jan Bergström

Object: Lower Cambrian and Bronze-age rock carvings.

The Lower Cambrian sandstones are comparatively resistant to denudation and form long stretches of the shoreline in the Simrishamn-Brantevik area in southeastern Scania. The upper part of the succession is exposed in a abandoned quarry and on the shore just south of the village of Simrislund, where rock carvings are also to be seen. The quarry exposes the uppermost quartz-arenitic member (the Tobisvik Member) of the Hardeberga Formation. At the entrance of the quarry there is a small conical depression of the kind described from Vik (stop 1; Lindström 1967).

The boundary between the Hardeberga Formation and the overlying Norretorp Formation is exposed on the shore. The Norretorp Formation is only a few metres thick at this locality. It is greener than the same formation at Hardeberga (where it is around 15 m thick) and therefore is more reminiscent of the probably corresponding ”green siltstones” (Broens Odde Member; 80-100 m thick) of Bornholm. The colour is highly influenced by the variable content of glauconite and phosphate. The locality has yielded a brachiopod species, the trilobite *Schmidtiellus mickwitzi torelli* (see Bergström 1973), and trilobite type trace fossils. Overlying strata belonging to the top of the Lower Cambrian (Rispebjerg Sandstone and Gislöv Formation) follow in the water. Sections through this interval were described from localities further to the south along the coast (de Marino 1980*a*; Bergström & Ahlberg 1981; see stop 4 herein).

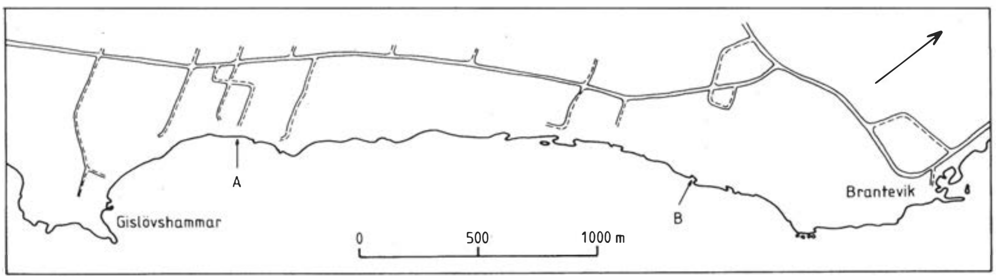


Fig. 18. Locations of sections through the Gislöv Formation in the Brantevik-Gislövshammar area, southeastern Scania. ”A” marks the position of a section 600 m N of Gislövshammar and ”B” marks the position of the sections 1 km SW of Brantevik (Figs. 19-20). From Bergström & Ahlberg (1981, fig. 4).

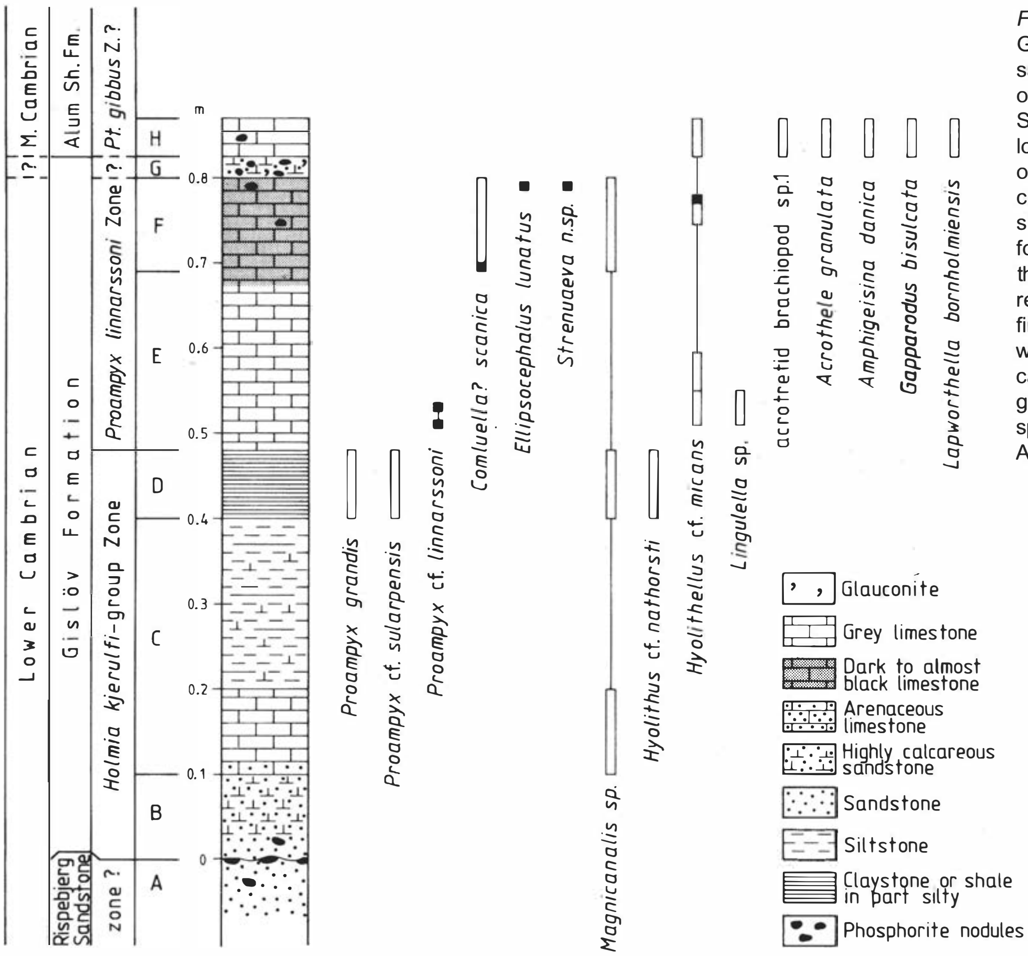


Fig. 19. Section through the Gislöv Formation and the basal Middle Cambrian 1 km SW of Brantevik, southeastern Scania, showing general lithologic succession, occurrence of fossils, and stratigraphic classification of the succession. This is the type section for the Gislöv Formation. For the fossils, a filled square represents an exactly localised find of at least one specimen, while an open symbol indicates the approximate stratigraphic position of at least one specimen. From Bergström & Ahlberg (1981, fig. 5).

At the entrance of the above-mentioned quarry there is a severely circumscribed surface with bronze-age rock carvings. The sandstone yields nice polished surfaces and seems to have been much appreciated for rock-carving purposes. There are several known examples in the Simrishamn area. The carvings are supposed to have a symbolic character. Common objects in such carvings are men, axes, ships, sun-wheels, and small pits.

Stop 4. Brantevik

Per Ahlberg

Object: Lower Cambrian and the Lower-Middle Cambrian transition.

The Lower Cambrian Tobisvik Member (upper Hardeberga Formation) is well exposed at Brantevik, southeastern Scania. In the southern harbour of Brantevik it contains excellently preserved trails of *Psammichnites gigas* (Torell, 1868). These ribbonlike trails are 2 to 5 cm wide. They were formed by burrowing inside the sediment, and show a narrow longitudinal median ridge and closely spaced, fine transverse ridges. South of the harbour, the Tobisvik Member is exposed along the shore for about 600 m. It is cut by a fault in the south. The basal strata consist of fine-grained partly bioturbated sandstones with hummocky cross-stratification, superimposed by coarse-grained sandstones with large-scale 2D-dunes and oscillation ripples (see Hadding 1929, figs. 28 and 40, and Lindström & Staude 1971, pl. 1, fig. 3). The Tobisvik Member sediments at Brantevik were probably deposited in the lower shoreface, under the influence of storms (Hamberg 1991). The Norretorp Formation and the Rispebjerg Sandstone are well exposed south of the fault mentioned above. The Norretorp Formation consists of greenish-grey, generally bioturbated siltstones with glauconite and phosphorite. It has yielded three species of olenellid trilobites (*Holmia mobergi*, *Schmidtiellus mickwitzi torelli* and *Kjerulfia*? *lundgreni*; Bergström 1973). The Rispebjerg Sandstone has a thickness of about 1 m and consists of medium- to coarse-grained quartz-arenites. Its upper surface is easily recognisable and larded with phosphorite nodules (see Hadding 1929, fig. 13 and Lindström & Staude 1971, pl. 1, fig. 6). The strata south of Brantevik dip gently towards the southeast.

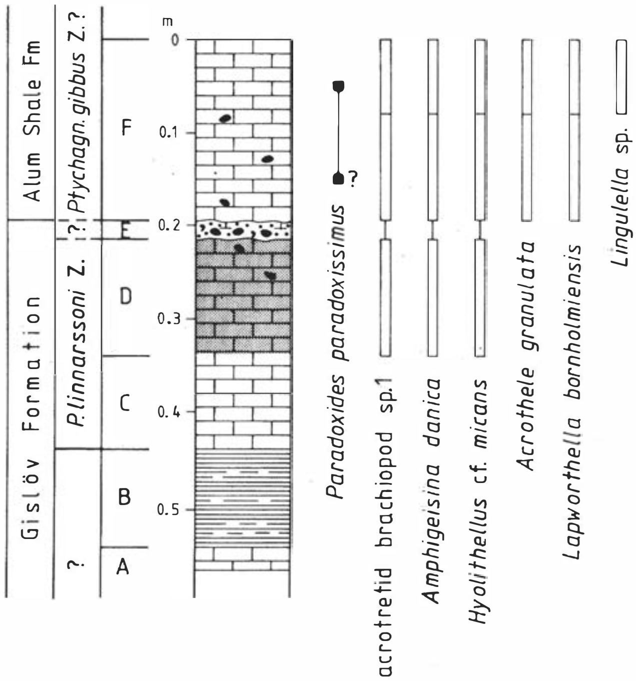


Fig. 20. Lithologic succession and stratigraphic distribution of identified fossils in a section 1 km SW of Brantevik. The section is situated about 30 m S of the section shown in Fig. 19. For legend see Fig. 19. From Bergström & Ahlberg (1981, fig. 6).

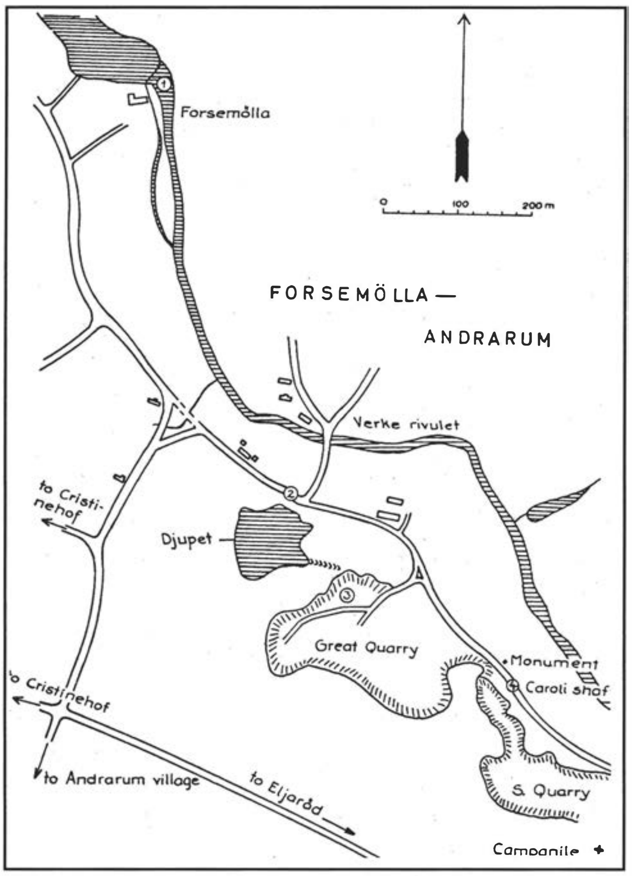


Fig. 21. Sketch-map of the Forsemölla-Andrarum area, south-eastern Scania. From Regnéll (1960, fig. 7).

On the shore about 1 km southwest of Brantevik there is a complete section through the Gislöv Formation, accessible however only in case of low water level (Fig. 18). The section is described in detail by Bergström & Ahlberg (1981, pp. 197-200). The Gislöv Formation is here about 0.8 m thick and consists of calcareous quartz-arenites (basal 0.1 m), silty shales or laminated siltstones, and light to dark grey, generally silty and clayey limestones (Fig. 19). It rests disconformably on the Rispebjerg Sandstone. The lower part of the formation belongs to the *Holmia kjerulfi*-group Zone, and the upper part to the *Proampyx* (or *Ornamentaspis*) *linnarssoni* Zone. Superimposed on the Gislöv Formation is a medium to dark grey phosphatic biocalcarenite ("fragment limestone"), assigned to the *Ptychagnostus gibbus* Zone.

About 30 m south of the section described above there is a 0.55 m thick section through the upper Gislöv Formation and the basal Middle Cambrian (locality 13 of Hadding 1932, fig. 26 and Regnéll 1960, fig. 6). The contact with the Rispebjerg Sandstone is not exposed. The uppermost part of the Gislöv Formation consists of a dark grey, phosphatic calcilutite, overlain by a 2-3 cm thick calcareous and phosphatic glauconite-arenite, considered to be the top of the local Lower Cambrian (de Marino 1980, p. 18, fig. 3; Bergström & Ahlberg 1981, p. 200; Fig. 20). The glauconitic arenite is succeeded by two massive beds of a medium to dark grey phosphatic biocalcarenite ("fragment limestone"; Hadding 1958, p. 71, fig. 7), with a total thickness of about 0.2 m. The stage index fossil *Paradoxides paradoxissimus* (Wahlenberg, 1818) was found in the "fragment limestone" by Jan Bergström in 1977, and the limestone is assigned to the *Ptychagnostus gibbus* Zone. Dissolution of the limestone in acetic acid has yielded various phosphatic microfossils, e.g. *Lapworthella bornholmiensis* (Poulsen, 1942), *Amphigeisina danica* (Poulsen, 1966), and acrotretid brachiopods (Bergström & Ahlberg 1981; cf. Bengtson 1976).

Stop 5. Andrarum

Euan N. K. Clarkson, Cecilia M. Taylor and Per Ahlberg

Object: Upper Cambrian strata.

The most accessible and complete sections within the Upper Cambrian in Sweden are to be found in the old alum shale workings at Andrarum. Here there is a largely continuous, gently dipping, and undeformed succession of Middle to Upper Cambrian and Tremadocian alum shales, some 80-90 m thick. Of this succession 20 m belongs to the Middle Cambrian, 49 m to the Upper Cambrian, and more than 8 m to the overlying Dictyonema Shale (Westergård 1944). Tremadocian strata are not exposed. The Cambrian succession is best exposed in the old quarries, exploited between 1637 and 1912 (Stoltz 1932; Andersson 1974). These quarries were described in detail by Tullberg (1880), Moberg (1911) and Westergård (1922), all of whom provide maps of the quarries. The exposures available today seem to be much as they were 70 years ago. The three main quarries lie in a NW-SE chain parallel with the Verkaån rivulet (Fig. 21); they form a protected site lying within the Verkaån Nature Reserve. The old workings are about 1 km long and, since the dip of the beds towards the SE is never more than a few degrees, an almost complete succession of Middle and Upper Cambrian strata has formerly been available within the quarries, as shown, for example, by Moberg (1911). Much of the succession is now overgrown by trees, especially in the south quarry (Caroli Schakt) near the ruined boiler house (Pannhuset). The most recently worked faces in the central quarry (Stora Brottet; the Great Quarry), however, expose an excellent succession of shale and stinkstone in the *Agnostus pisiformis* and *Agnostus* (*Homagnostus*) *obesus*/*Olenus* Zones, and some of the higher zones are sporadically exposed elsewhere in the old workings. The only excavations made this century in the higher part of the succession (Persson 1904) revealed that the *Leptoplastus* Zone lies close to the surface. Lower Cambrian strata are exposed at Forsemölla, north of Andrarum (Bergström & Ahlberg 1981, pp. 203-204, fig. 9). The sequence of strata in the Forsemölla-Andrarum area was first studied by Nathorst (1869).

In the north-central part of Stora Brottet (the Great Quarry), trilobites are generally confined to the limestone concretions and the intervening shales are unfossiliferous. In other areas of the same quarry, however, there are some parts of the succession where well-preserved though flattened trilobites are present, and in great numbers, in the shales. In particular, the northernmost end of the quarry, in which the *Agnostus* (*Homagnostus*) *obesus*/*Olenus* Zone is well exposed, yields abundant flattened trilobites, as well as three-dimensional specimens in the limestones. Westergård (1922, profile 1, fig. 4; Fig. 22) documented one such section here, some 20 m east of the tunnel (Pysslingahålet) connecting the main quarry to the old workings at Djupet (the Deep), which is now a lake. *Olenus* and *Agnostus obesus* are very common in this part of the quarry, but their abundances fluctuate dramatically (Clarkson et al. 1998). The rare *Glyptagnostus* and the bradoriid arthropod *Cyclotron* are confined to par-

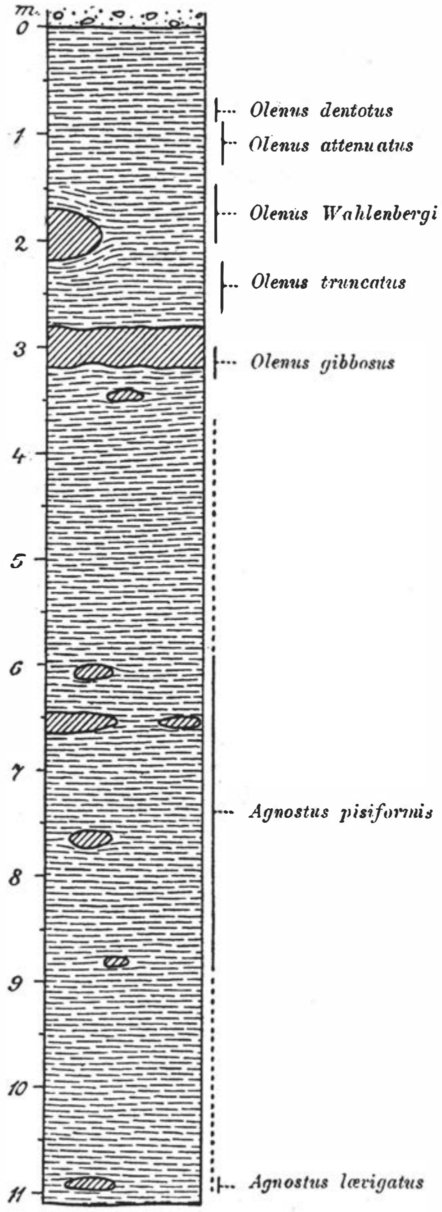


Fig. 22. Distribution of trilobites in the north-eastern part of Stora Brottet (the Great Quarry), Andrarum. From Westergård (1922, fig. 4).

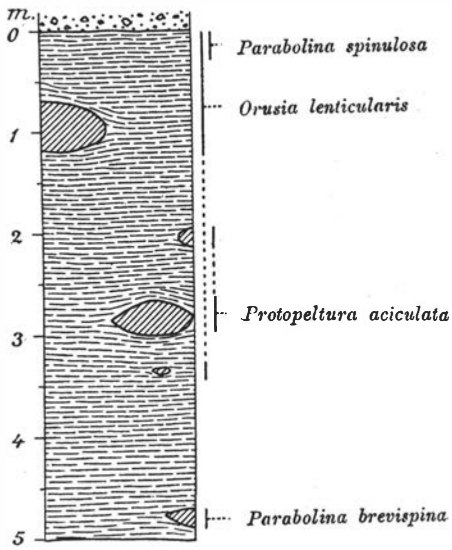


Fig. 23. Distribution of fossils in the north-western end of the south quarry (Caroli Schakt), Andrarum. From Westergård (1922, fig. 7).

ticular levels within the *Agnostus* (*Homagnostus*) *obesus*/*Olenus* Zone.

The order of succession of *Olenus* species at Andrarum is well known from the work of Westergård (1922, 1944, 1947) and Kaufmann (1933). In ascending sequence we have, in a 2.5 m section, *O. gibbosus, O. transversus, O. truncatus, O. wahlenbergi, O. attenuatus* and *O. dentatus*. The ranges of the last two species slightly overlap. All these species are closely related and formed the basis of Kaufmann´s (1933) classic microevolutionary studies. Kaufmann collected band by band through the section in the north-central part of Stora Brottet, and he established that certain morphological features, especially those of the pygidium, changed during the time interval. He concluded that these six species formed four independent lineages at the species level. These conclusions on iterative evolution, however, were considered by Hoffman & Reif (1994) to be equivocal. Above the level of the short-ranging *O. dentatus* there is a gap of 5.5 m (Westergård 1922, p. 19, fig. 5) up to the last representative of the genus, *O. scanicus,* is encountered. The latter species occurs with the bradoriid arthropod *Cyclotron angelini. O. scanicus* is rare, and was not found in the drill-cores made in 1941-42 at Andrarum or elsewhere in Scania (Westergård 1944).

In the north-western end of the south quarry (Caroli Schakt) there is a section through the *Parabolina spinulosa* Zone (Westergård 1922, p. 20, fig. 7; Fig. 23). The lower part of the section yields *P. brevispina* followed by *P. aciculata* and an abundance of the brachiopod *Orusia lenticularis*. The uppermost part of the section contains *P. spinulosa* and *O. lenticularis.*

Stop 6. Södra Sandby

Per Ahlberg

Object: Upper Cambrian strata (the *Acerocare* Zone).

The Fågelsångsdalen valley and its surroundings is a classical area for studies on Cambrian-Silurian stratigraphy and faunas (e.g. Moberg 1911; Ahlberg 1992). In the eastern extremity of the valley, at Södra Sandby, there is an exposure of Upper Cambrian strata. It was described in detail by Moberg & Möller (1898). The section is situated along the north bank of the Sularpsbäcken rivulet (locality F5 of Moberg 1911, p. 72; locality 5 of Westergård 1922, fig. 8) and comprises about two m of alum shales with limestone lenses. The lower part of the section contains *Acerocare ecorne* (abundant) and *Parabolina acanthura*, indicative of the *Acerocare ecorne* Subzone of the *Acerocare* Zone. The middle and upper part of the section is poorly fossiliferous, but has yielded a few indeterminate fragments of trilobites.

In the small stream about 50 m southeast of the locality described above there was previously a section through the *Peltura costata* Subzone of the *Acerocare* Zone (locality F6 of Moberg 1911). It is now inaccessible, but yielded *Acerocarina granulata* and *Parabolina heres heres.*

Stop 7. Hardeberga Quarry

Jan Bergström and Per Ahlberg

Object: Lower Cambrian strata and Permo-Carboniferous dolerite.

Hardeberga is situated a few kilometres east of Lund, in a position where the Proterozoic basement of the Romeleåsen Horst dips towards the northwest beneath Lower Palaeozoic rocks (Fig. 24). Hardeberga Quarry exploits the upper part of the Lower Cambrian sandstone succession and Permo-Carboniferous dolerite dikes, the latter cutting the sedimentary strata. The quarry is operated by AB Sydsten.

The lowest formation exposed is the Hardeberga Formation (Fig. 25). The thickness is unknown, but a drilling made by AB Sydsten in the northernmost part of the quarry penetrated 94 m of the Hardeberga Formation without reaching the underlying basement. The drilling started just under the top of the formation, apparently only some 2 m from the top according to information from Mr Bror Arvidsson, former engineer at AB Sydsten. The entire thickness is probably between 100 and 150 m.

The bulk of the Hardeberga Formation consists of a pure whitish quartz arenite (up to 98% silica) with fairly little variation throughout the drill core (Bror Arvidsson, pers. comm.). The sand is obviously the result of the winnowing of weathered basement rocks and deposition in shallow near-shore environments (cf. Hadding 1929). Wave ripples, mud cracks and clay galls are occasionally found. The sedimentology and the depositional environments were studied by Hamberg (1991), who recognised five major facies associations: an inner shelf to shoreface facies association, a tidal inlet facies association, an upper shoreface facies association, a barrier tidal creek facies association, and a backbarrier tidal channel facies association (Fig. 26). Locally there is impregnation or fissure fillings of fluorite, and there are rare veins of galena. This mineralization was presumably caused by the Permo-Carboniferous magmatic event.

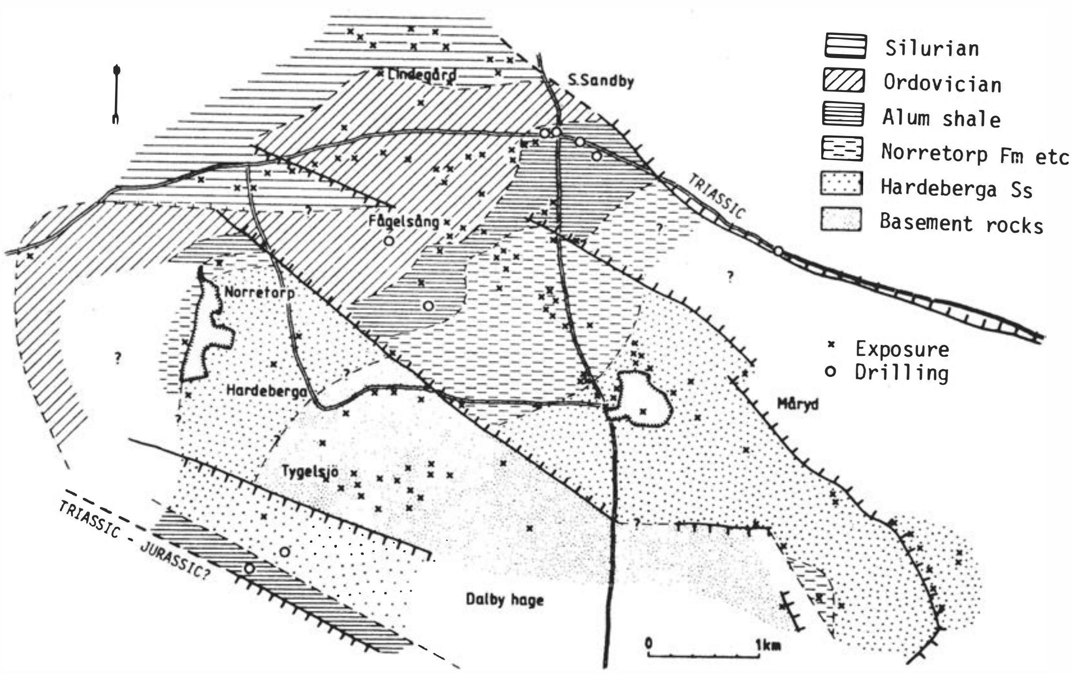


Fig. 24. Geological sketch map of the northwest end of the Romeleåsen Horst east of Lund. The Hardeberga Quarry is indicated at Hardeberga. From Bergström *in* Bergström et al. (1982, fig. 31).

The fauna is poor, consisting of trace fossils such as *Diplocraterion parallelum*, *Skolithos linearis*, *Syringomorpha nilssoni*, *Planolites* sp., and the trilobite type trace fossil *Rusophycus parallelum* (Hadding 1929; Westergård 1931*b*; Bergström 1970; Hamberg 1991). Shale partings in the quarry have yielded acritarchs (Vidal 1981*b*, p. 185). The assemblage indicates the *Skiagia ornata - Fimbriaglomerella membranacea* Zone (Moczydlowska 1991, p. 37).

The succession in and outside the quarry is penetrated by Permo-Carboniferous dolerite dikes trending roughly NW-SE (Troedsson 1917; Hjelmqvist 1940; Regnéll 1960, fig. 8). As seen in the sections there is only minor vertical displacement between the two walls of each dike. A larger fault or system of faults of W-E direction must be present in the small valley north of the quarry, as Silurian strata are found in and north of the valley.

The upper half of the northwestern wall of the Hardeberga quarry is notably darker in colour than the surroundings. This is the Norretorp Formation (Bergström 1979). It is dominated by inner shelf to shoreface deposits and separated from the Hardeberga Formation by an erosion surface (a ravinement; Hamberg 1991, figs. 4 and 8c). Due to the faulting the thickness of the Norretorp Formation is not known exactly but is estimated at 15 m. It consists largely of sandstones and siltstones with carbonate, glauconite, phosphorite and pyrite. It also contains titanium and uranium. This formation contains the first trilobite

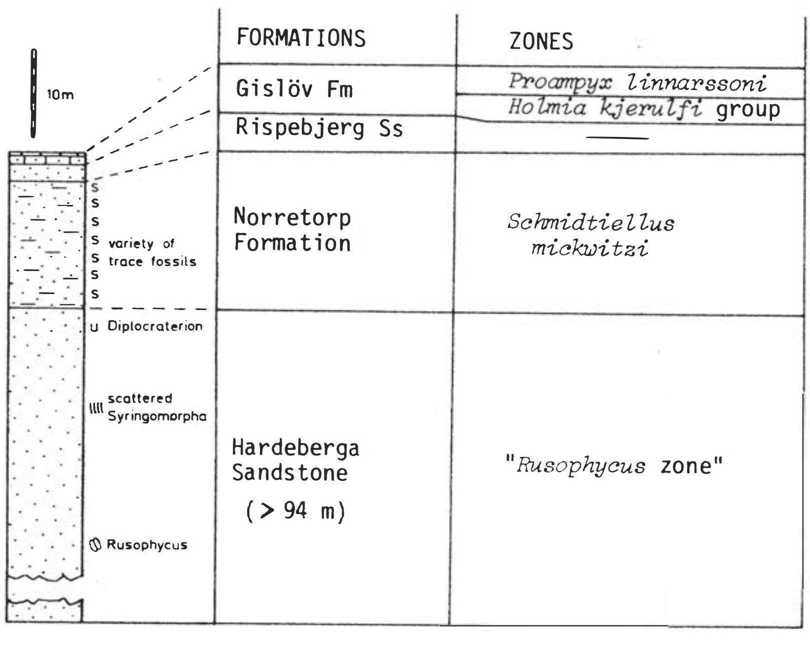


Fig. 25. Lower Cambrian succession of the Hardeberga area. Vertical scale only approximate. From Bergström *in* Bergström et al. (1982, fig. 32).

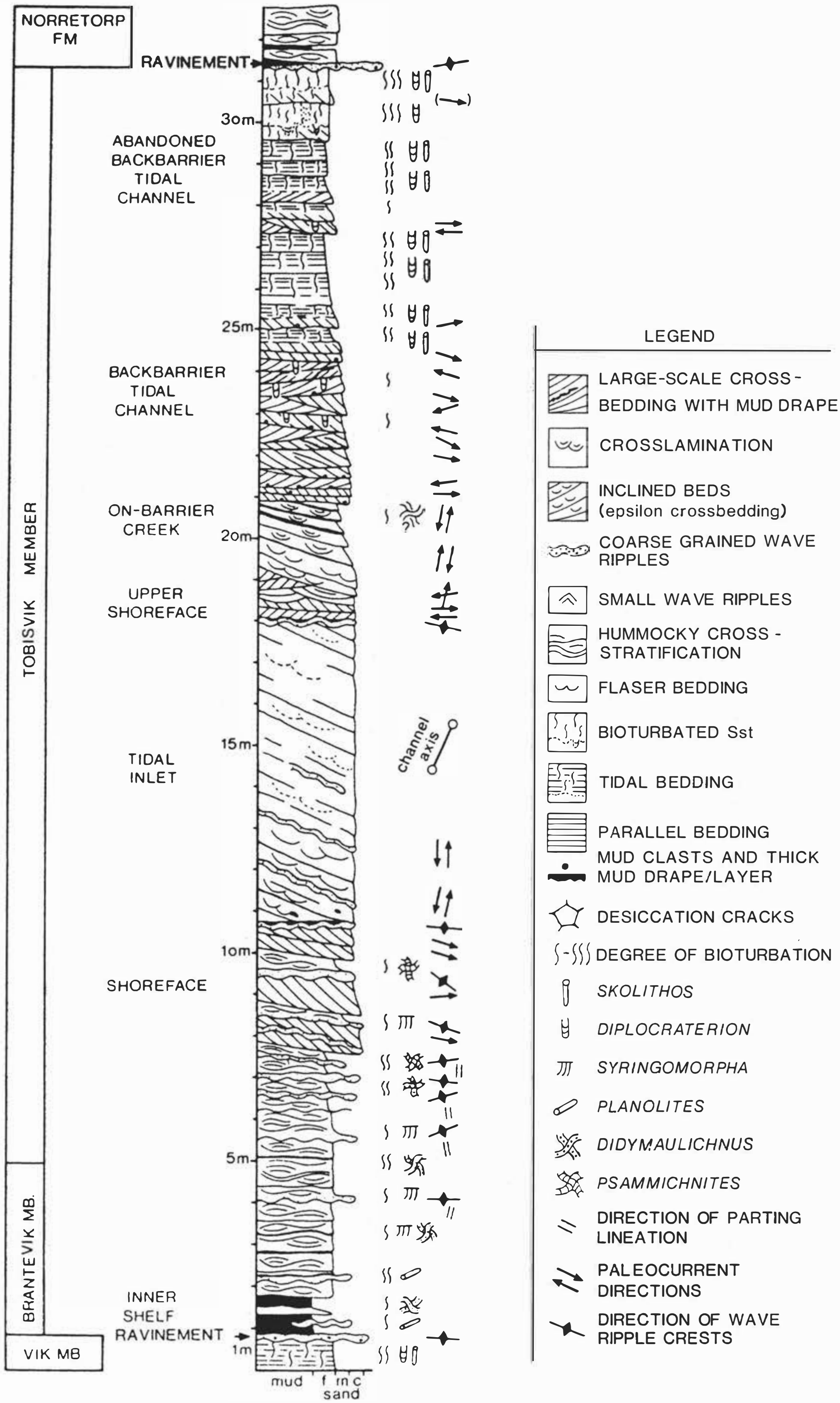


Fig. 26. Section through the upper Hardeberga Formation in the Hardeberga area. The section represents a prograded barrier island shoreline preserved between two ravinement surfaces. Notice the consistent east-west orientation of the coarse grained wave ripple crestlines. From Hamberg (1991, fig. 4).

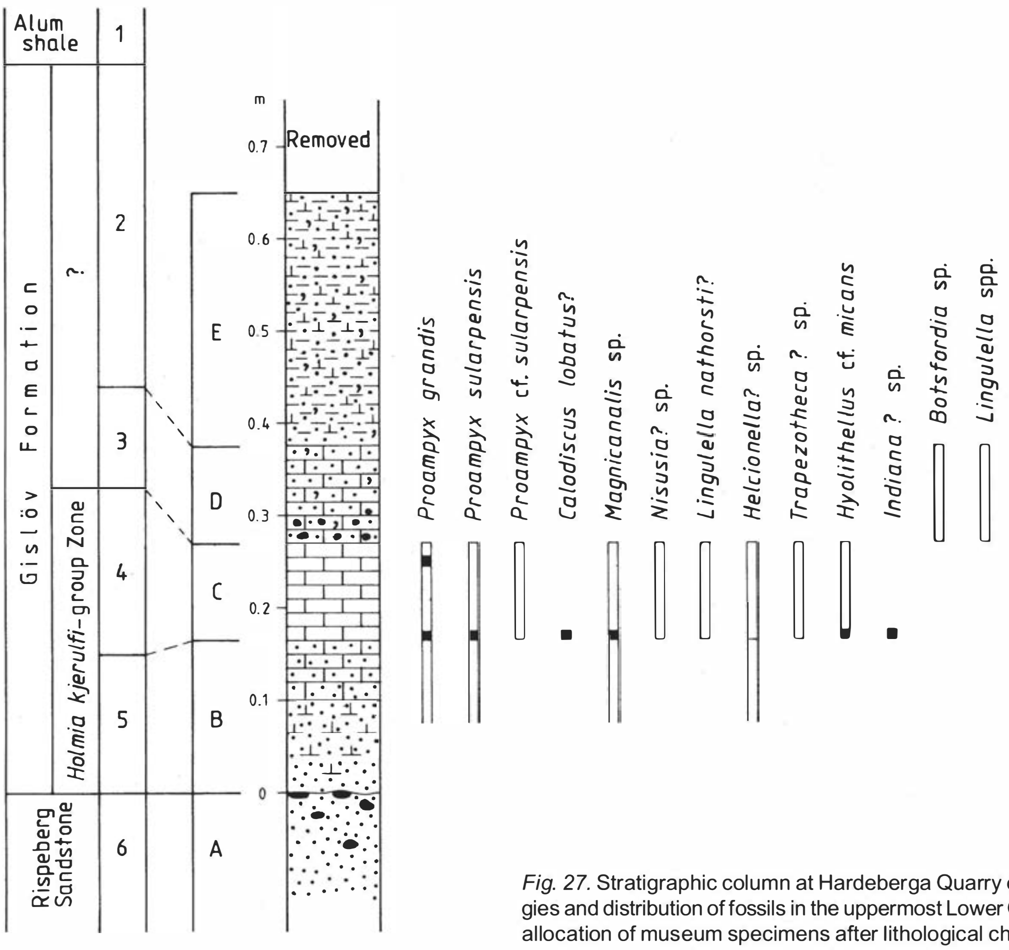


Fig. 27. Stratigraphic column at Hardeberga Quarry east of Lund, showing lithologies and distribution of fossils in the uppermost Lower Cambrian. Open bar indicates allocation of museum specimens after lithological characteristics, filled bar represents detailed sampling. Figures 1-6 indicate divisions of Troedsson (1917, section II). The differences in measurements are due to swift lateral changes in thickness. Middle Cambrian alum shale no longer exposed. For legend see Fig. 19. From Bergström & Ahlberg (1981, fig. 10).

fauna, indicative of the *Schmidtiellus mickwitzi* Zone (Bergström 1973, 1981).

In the walls of the old railway entrance to the quarry there are exposures of the two uppermost formations of the Lower Cambrian (Troedsson 1917; Hadding 1929, p. 83; 1958, pp. 61-64; Hansen 1937, pp. 157-159, 179; Bergström & Ahlberg 1981, pp. 204-205). The Rispebjerg Sandstone varies much in composition but tends to be a matrix-supported sandstone with fairly large and well rounded quartz grains. The matrix is phosphatic, and if conclusions based on this formation on Bornholm are applied (de Marino 1980*b*), the calcium phosphate should have been formed by diagenetic transformation of calcium carbonate. The sandstone contains occasional pyrite lumps. Fossil fragments can be seen in the matrix but no determinable specimens have been found.

The Rispebjerg Sandstone is overlain by the Gislöv Formation, which is a condensed suite comprising at least two trilobite zones despite its inconsiderable thickness, only about 0.8 m at Hardeberga (Fig. 27). The contact with the overlying Middle Cambrian alum shale succession was visible until some 25 years ago, but is now destroyed. The formation contains calcium carbonate throughout. The lowest part has picked up grains of sand from the underlying Rispebjerg Sandstone. Higher in the section there is a variable influx of sand, silt, glauconite and phosphorite. The fauna of the *Holmia kjerulfi*-group Zone contains i.a. trilobites (including a possible *Calodiscus lobatus*) and brachiopods. A few brachiopods may represent the overlying *Proampyx linnarssoni* Zone. The fauna is described by Ahlberg & Bergström (1978) and Bergström & Ahlberg (1981). Acritarchs recovered from the *Holmia kjerulfi*-group Zone may indicate the *Heliosphaeridium dissimilare - Skiagia ciliosa* Zone (Vidal 1981*b*, p. 185; Moczydlowska 1991, p. 38).

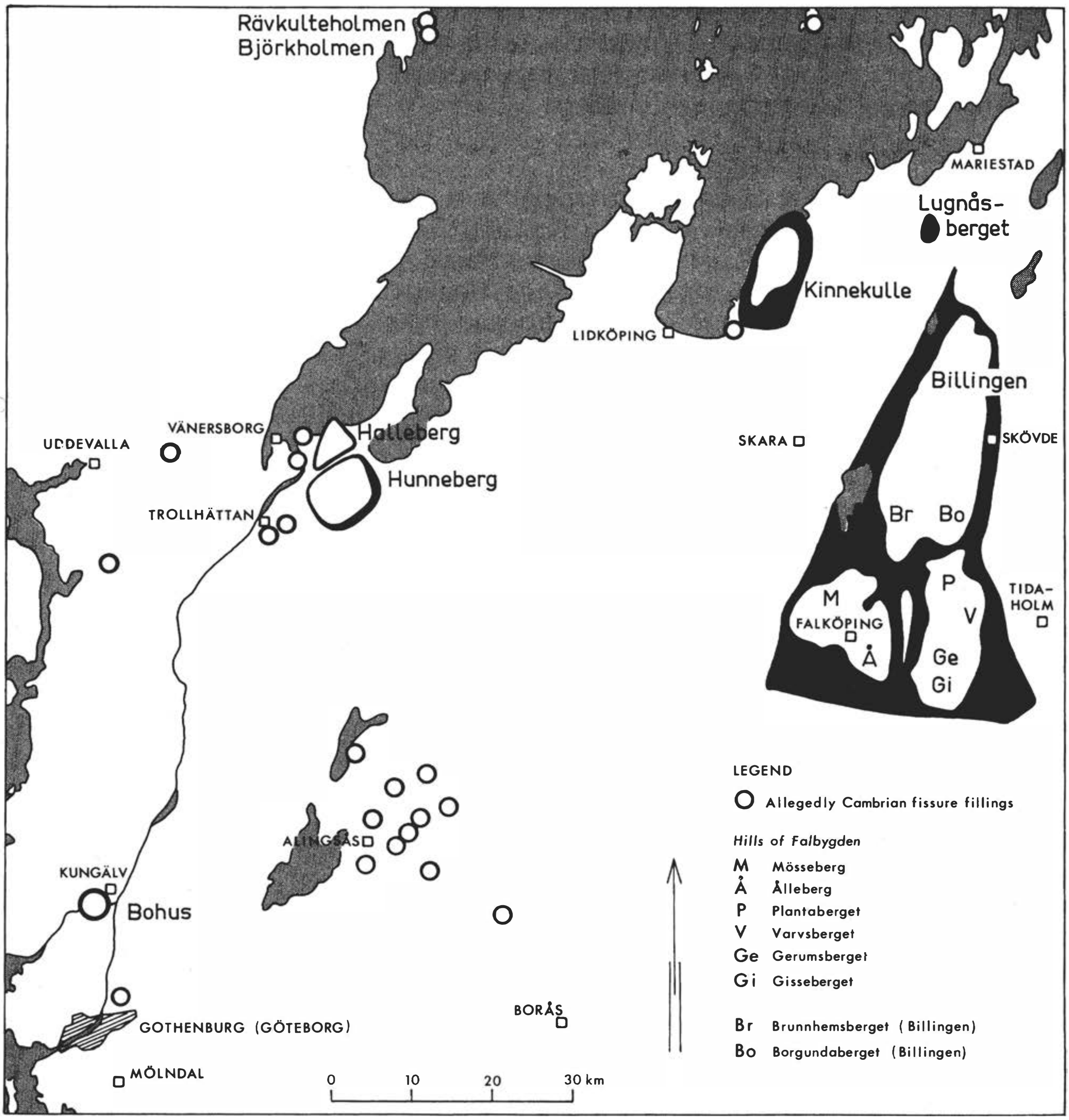


Fig. 28. Map showing distribution of Cambrian deposits in Västergötland, Dalsland, and Bohuslän. From Martinsson (1974, fig. 9).

The Cambrian of Västergötland

SÖREN JENSEN and PER AHLBERG

The Lower Palaeozoic of Västergötland, south-central Sweden, occurs as erosional outliers resting on a Precambrian crystalline basement. These outliers constitute the geologically famous hills or mountains of Västergötland, and they have a long history of palaeontological and stratigraphical research, extending back to the eighteenth century; already before 1750, the succession was correctly described by Carl Linnaeus and Pehr Kalm in their travel accounts. It is customary to group the mountains into three main districts (Fig. 28): (1) Billingen-Falbygden, which comprises the Billingen hill in the north and Falbygden with its numerous small-

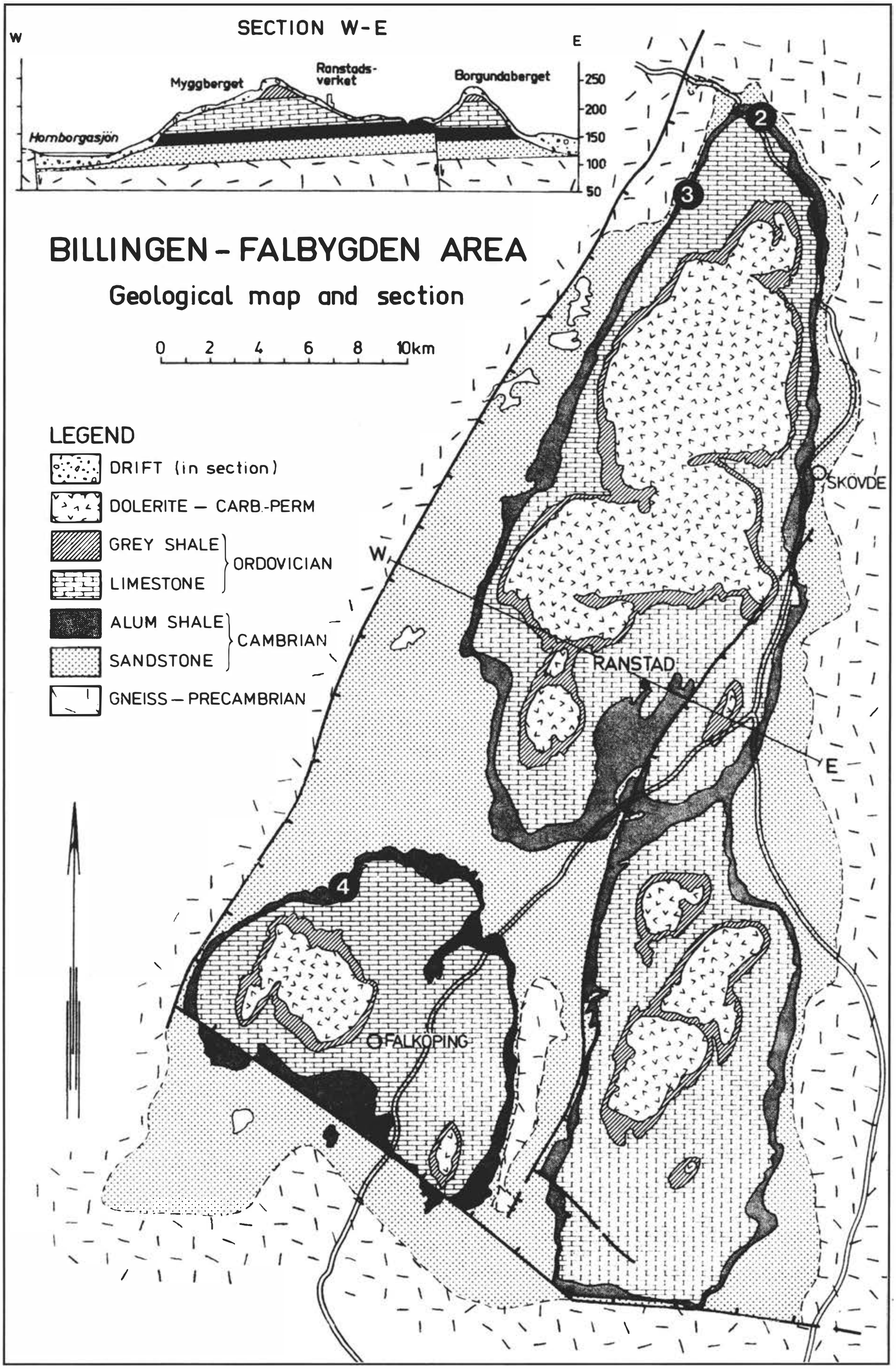


Fig. 29. Bedrock geology of the Billingen-Falbygden outlier, Västergötland, with excursion stops. Lugnås (stop 1) is situated north of Billingen (see Fig. 28). From Andersson et al. (1985, fig. 5).

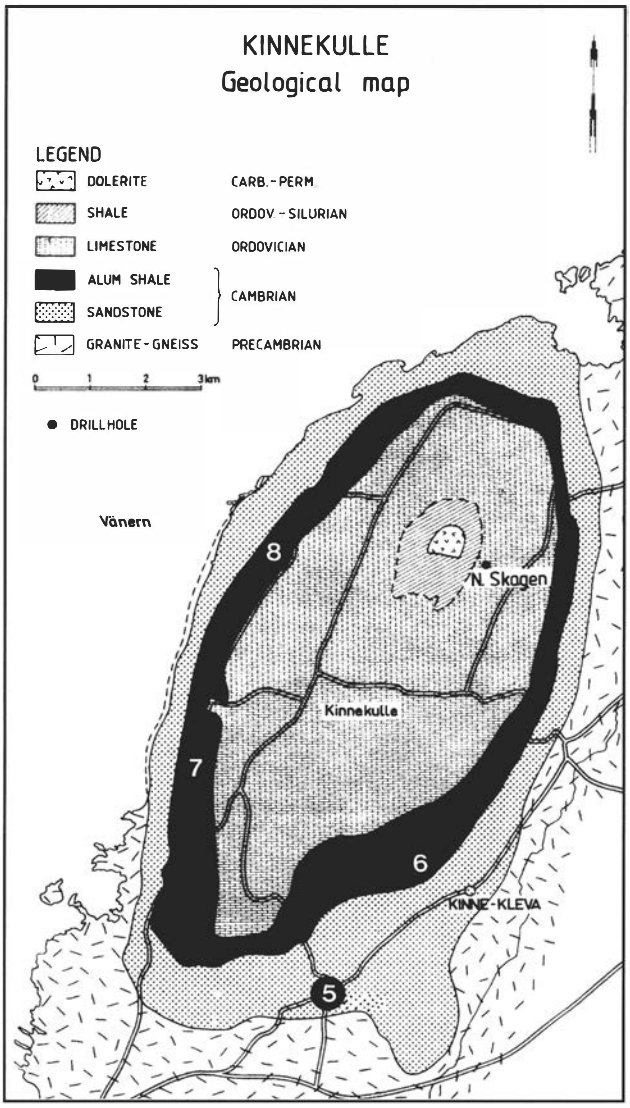


Fig. 30. Bedrock geology of the Kinnekulle outlier, Västergötland, with excursion stops. From Andersson et al. (1985, fig. 10).

er hills in the south (Fig. 29), (2) Kinnekulle at Lake Vänern northwest of Billingen-Falbygden (Fig. 30), and (3) Halleberg and Hunneberg at the southwestern end of Lake Vänern.

The hills are capped by a thick sheet of Permo-Carboniferous dolerite, originally intruded as sills at different levels in the sedimentary sequence. The capping of the dolerite, and occasionally down-faulting, accounts for the preservation of the Lower Palaeozoic deposits. Lugnåsberget north of Billingen is an outlier without a dolerite cap. There top of the succession is within the Upper Cambrian *Parabolina spinulosa* Zone. Outside the main outliers, Cambrian strata are also preserved as fissure fillings in the Precambrian basement (Fig. 28). The sedimentary strata are flat-lying or nearly so and most complete on Kinnekulle and in the Billingen-Falbygden district. In these districts the Lower Palaeozoic reaches up into the lower Silurian (Llandovery). The total thickness of the sedimentary sequence is about 215 m on Kinnekulle and some 150-160 m in the Billingen-Falbygden district. In the Halleberg-Hunneberg outlier the dolerite intrusion cuts gently upwards from the north (Halleberg), where it rests on Cambrian strata, to the south (Hunneberg), where it rests on Lower Ordovician shales and limestones.

The Lower Cambrian of Västergötland consists of a thin succession of essentially flat-lying siliciclastic sediments divided into a lower Mickwitzia Sandstone Member (about 10 m) and an upper Lingulid Sandstone Member (about 25 m) (Holm 1901; Westergård 1931*a*, 1943). These form western extensions of the File Haidar Formation (Bergström & Gee 1985; Hagenfeldt 1994). The Mickwitzia Sandstone is mostly thin-bedded with an alternation of siltstone and sandstone with clayey layers, while the Lingulid Sandstone is a more homogeneous and fine-grained sandstone (Hadding 1929). The former is typically hard, rich in mica flakes, and often has haematitic staining, while the latter is cleaner and poorly cemented, with a higher porosity. The boundary between the two units is usually set close to the first appearance of thicker-bedded sandstones. The Mickwitzia Sandstone is poorly exposed, essentially restricted to abandoned quarries and mines at Lugnås and scattered exposures on the west side of Kinnekulle. By contrast, the Lingulid Sandstone forms prominent yellow-white cliffs in all the areas in Västergötland with Cambrian rocks. The most precise biostratigraphic control comes from acritarchs (Moczydlowska & Vidal 1986), which indicate that both the Mickwitzia and Lingulid Sandstones in Västergötland correspond to the *Heliosphaeridium dissimilare - Skiagia ciliosa* acritarch Zone (Moczydlowska 1991; Fig. 31).

The basal part of the Mickwitzia Sandstone consists of a polymict conglomerate. It rests on a denuded Precambrian gneiss basement of low relief. The development of the conglomerate varies; it may rest directly on the basement, be separated from it by sandstone, or be absent. Locally there are mega-ripples. Especially at Lugnås, the conglomerate contains large pebbles of quartz, including some which have been interpreted as wind-faceted (Nathorst 1886). The only body fossil reported from the conglomerate is *Torellella laevigata*. Trace fossils in the sandier parts of the basal beds include *Monocraterion* and *Diplocraterion*. Horizontal and flatly U-shaped spreite burrows are numerous on the base of the upper sandy part, including poorly preserved *Rhizocorallium*. Also, in the lower beds, there are arthropod trace fossils. The basal conglomerate has long been interpreted as a transgressive lag deposit over the denuded basement. This is followed by 2-3 m of thin-bedded typically micaceous sand-

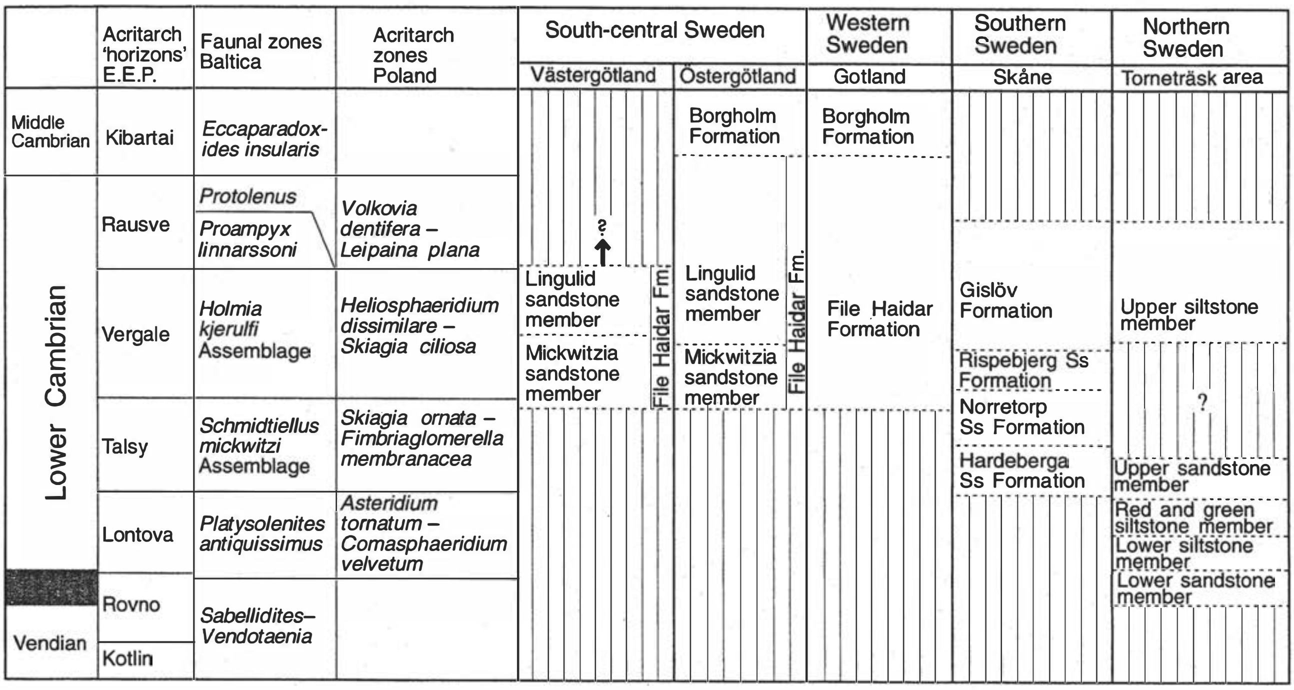


Fig. 31. Tentative correlation of the File Haidar Formation with sections in Scania and the Torneträsk area, northern Sweden, largely based on Moczydlowska (1991). From Jensen (1997, fig. 19).

and siltstones with thin clayey layers. Sand- and siltstone beds are mostly less than 7 cm thick with sharp bases, and with horizontal or near-horizontal lamination, at the top turning into wave-ripple lamination. Tops of beds mostly with ripples of interference type, though straight-crested ripples also occur. This interval is rich in well-preserved trace fossils, including *Cruziana rusoformis*, *Cruziana tenella*, *Diplocraterion parallelum*, *Gyrolithes polonicus*, *Palaeophycus imbricatus*, *Olenichnus* isp, *Rosselia socialis*, *Rusophycus dispar*, *Rusophycus jenningsi*, *Trichophycus* isp. and *Zoophycos* (*Rhizocorallium*) isp. (Torell 1870; Linnarsson 1871; Jensen 1997). Physical sedimentary structures include *Aristophycus*-like forms, flute casts, load casts, obstacle marks, pot- and gutter casts, spill-over ripples, incomplete shrinkage cracks, kinneyian marks and tool marks, including 'Eophyton'. Body fossils consist of the brachiopod *Mickwitzia monilifera*, the agmatan *Volborthella tenuis* and the shelly fossils *Mobergella* sp, and *Torellella laevigata*. From this interval is also known the problematic forms *Spatangopsis* and *Protolyellia* together with a range of other problematica. Traditionally interpreted as remnants of scyphozoans (Nathorst 1910), these have been recently re-interpreted as members of an extinct group of cnidarians forming stabilising sand-skeletons by phagozytizing sand grains (Seilacher & Goldring 1996). Other interpretations invoking a partially or totally inorganic origin has also been advanced (Jensen 1997). The sedimentology and ichnology of this interval suggests deposition in a subtidal storm-influenced setting.

This is followed by an interval (about 4 m) with coarser sediments, typically medium-grained quartz sandstone, with beds 5-10 cm thick, some up to 30 cm, with commonly diffuse bed boundaries due to a high degree of bioturbation. Haematitic staining around quartz grains is common, and pyrite also occurs. At several levels there are flat muddy intraclasts, up to several centimetres in length. Trace fossils include generally poorly preserved but locally abundant *Rhizocorallium jenense*, *Halopoa imbricata* and, more rarely, *Rusophycus dispar* and *Syringomorpha nilssoni* (Jensen 1997). Among the body fossils, only fragmentary specimens of *Mickwitzia* are found in connection with phosphatized mud clasts about 7 m above the basement. At Hällekis there are beds about 6 m above the basement with abundant *Rhizocorallium jenense* attractively developed at the shore of lake Vänern, at about normal water-level. This interval reflects shallowing, possibly entering or approaching a sand flat affected by storm and possibly by tidal currents.

The upper part of the Mickwitzia Ss has a wide range in bed thicknesses and grain sizes and also is the most difficult to compare between sections. Several levels have thin-bedded sand- and siltstone beds, occasionally of lenticular/flaser bedding-type. These beds have yielded abundant trace fossils, including *Rusophycus dispar*, *Cruziana rusoformis*, *Teichichnus* s.l., and *Cruziana tenella.* Near the top there are also conglomeratic beds. Filled shrinkage cracks are developed in greater numbers and with more nearly polygonal shape than anywhere else in the Mickwitzia Ss but it is not clear that these represent subaerial exposure.

The transition from the Mickwitzia to the Lingulid Sandstone is marked by the appearance of thick-bedded sandstones. These are cross-bedded with truncating sets of laminae, up to 20 cm or more in thickness, with abrupt, laterally discontinuous divisions into thinner beds with clayey partings. *Skolithos* is abundant while *Diplocraterion* is less common. About 11 m above basement, the sediment turns to more consistently fine-grained sandstone which continues throughout the Lingulid Sandstone. This interval probably represents shore face deposition. Erosion is seen from incorporated mud-clasts. The Lingulid Sandstone consists largely of fine-grained quartz sandstone, more poorly cemented, and thicker bedded than the Mickwitzia Sandstone (Hadding 1929). Pyrite is common and in the basal beds may form centimetre-sized lumps. Bedding is in the range of a few up to 200 cm, with some of the thickest beds near the top. Thin seams of clayey material separate the beds. At the top of the Lingulid Sandstone there is a 10-20 cm thick conglomerate with phosphatic sandstone clasts (Westergård 1931*a*, 1943). Few sedimentary structures are seen. Overall the degree of bioturbation is higher than in the Mickwitzia Sandstone. The trace fossils include poorly preserved *Rusophycus* observed in the basal layers at Hjälmsäter as well as in beds near the top of the Lingulid Sandstone at Blomberg on the southern part of Kinnekulle. Also found are *Diplocraterion* and the vertical spreite burrow *Alectorurus*? *circinatus* (Westergård 1931*b*; Jensen & Bergström 1995). In addition there are a number of undescribed trace fossils. Body fossils include the arthropod *Paleomerus hamiltoni* (Størmer 1956) and fragmentary finds of trilobites including *Holmia grandis*? (Ahlberg et al. 1986). Phosphatic brachiopods also have been found, including *Glyptias favosa* (Westergård 1931*a*). The Lingulid Sandstone has been interpreted as formed in deeper water than the Mickwitzia Sandstone, the lower content of clay taken to indicate more intense wave action. Martinsson (1974), however, suggested that the differences could depend on formation at a later stage in the sandstone basin.

The Middle and Upper Cambrian consist predominantly of black alum shales with beds or lenses of stinkstone (orsten). Locally there are conglomerates and calcareous sandstones. The Middle Cambrian comprises the *Paradoxides paradoxissimus* and *P. forchhammeri* Stages (the *Acadoparadoxides oelandicus* Stage is missing). Its thickness generally varies between 6 and 11 m. In most areas, the basal beds of the *P. paradoxissimus* Stage consists of a conglomerate or calcareous sandstone with *Acrothele granulata*, overlain by greenish grey shale (Westergård 1946). Another prominent conglomerate (or conglomeratic limestone with pebbles of phosphoritic sandstone and stinkstone), containing the brachiopod *Billingsella exporrecta*, is present in the *P. forchhammeri* Stage. The *Ptychagnostus punctuosus* Zone is missing on Kinnekulle and Billingen (Westergård 1931*a*, p. 43). The beds with *Hypagnostus parvifrons* generally tend to form a continuous bed of dark grey limestone (0.5-1 m thick). The *Lejopyge laevigata* Zone is up to 4 m thick and consists of alum shale with scattered stinkstone lenses.

The Upper Cambrian of Västergötland is well exposed in a great number of old quarries. It attains a thickness of about 15 m and consists almost exclusively of alum shale with lenses or beds of dark grey limestone (stinkstone or orsten). The succession generally contains several minor and a few major hiata. On Kinnekulle it extends upwards into the lowermost part of the *Acerocare* Zone (Westergård 1922, 1947). A stinkstone bed of considerable lateral persistence (the "Great Stinkstone Bed") occurs in the *Agnostus* (*Homagnostus*) *obesus*/*Olenus* Zone, locally extending down into the *Agnostus pisiformis* and up into the *Parabolina spinulosa* Zones (Westergård 1922). This limestone bed is generally about 1 m thick. The Upper Cambrian stinkstones of Västergötland are of particular interest because they have yielded a variety of small, phosphatized arthropods ("orsten" arthropods), mainly crustaceans and crustacean-like forms (e.g. Müller & Walossek 1985, 1987, 1988; Walossek 1993). The exceptional three-dimensional preservation of their bodies, appendages and setation permits a study of the morphology of these animals, down to details less than one micrometre in size. Conodonts from the Upper Cambrian of Västergötland were described by Müller & Hinz (1991).

Excursion localities in Västergötland

Stop 1. Lugnås

Sören Jensen

Object: Lower Cambrian Mickwitzia Sandstone in a millstone mine.

Production of millstones in the Lugnås area started in the 12th Century, was at its most intensive in the19th Century, and finally stopped in about 1920. The millstones were cut from kaolinized gneiss directly underlying the Mickwitzia Sandstone. In order to reach this gneiss the sedimentary cover had to be removed in quarries or, more often, in mines, some of which are said to have reached 500 m in length. One of these mines has been restored as a cultural memorial, 'Minnesfjället' (for location, see Jensen 1997, fig. 2A). Besides its great cultural interest this mine provides a unique opportunity to be engulfed in Lower Cambrian sediments. The basal conglomerate of the Mickwitzia Sandstone contains wind faceted quartz pebbles and conspicuous dark sideritic clasts. Its contact with the gneiss can be examined in several holes where millstones have been extracted. The walls of the mine consist of heterolithic bedding of thin sandstone beds and clay partings. Some of these clay layers are decimetre-thick and become plastic in the presence of water. The ceiling consists of a few thicker sandstone beds. At the base of these are ripples, flute marks, gutter cats, and various types of trace fossils, including *Cruziana*, *Rusophycus* and *Teichichnus*. In this mine just over 2.5. m of the Mickwitzia Sandstone is exposed but higher levels can be examined in neighbouring quarries.

Stop 2. Stora Stolan

Per Ahlberg

Object: Lower Cambrian-Lower Ordovician strata.

At Stora Stolan on the northern slope of Billingen, the upper part of the Lingulid Sandstone is exposed in an abandoned quarry. The succession consists of light grey, fine-grained and thick-bedded quartz arenites. Excluding trace fossils, it is poorly fossiliferous, but has yielded *Glyptias favosa* and a fragmentary cephalon of *Holmia grandis* Kiær, 1917? (see Ahlberg et al. 1986, p. 50). The top of the Lingulid Sandstone consists of a 10-20 cm thick conglomerate with phosphoritic sandstone pebbles (Westergård 1931*a*, p. 39).

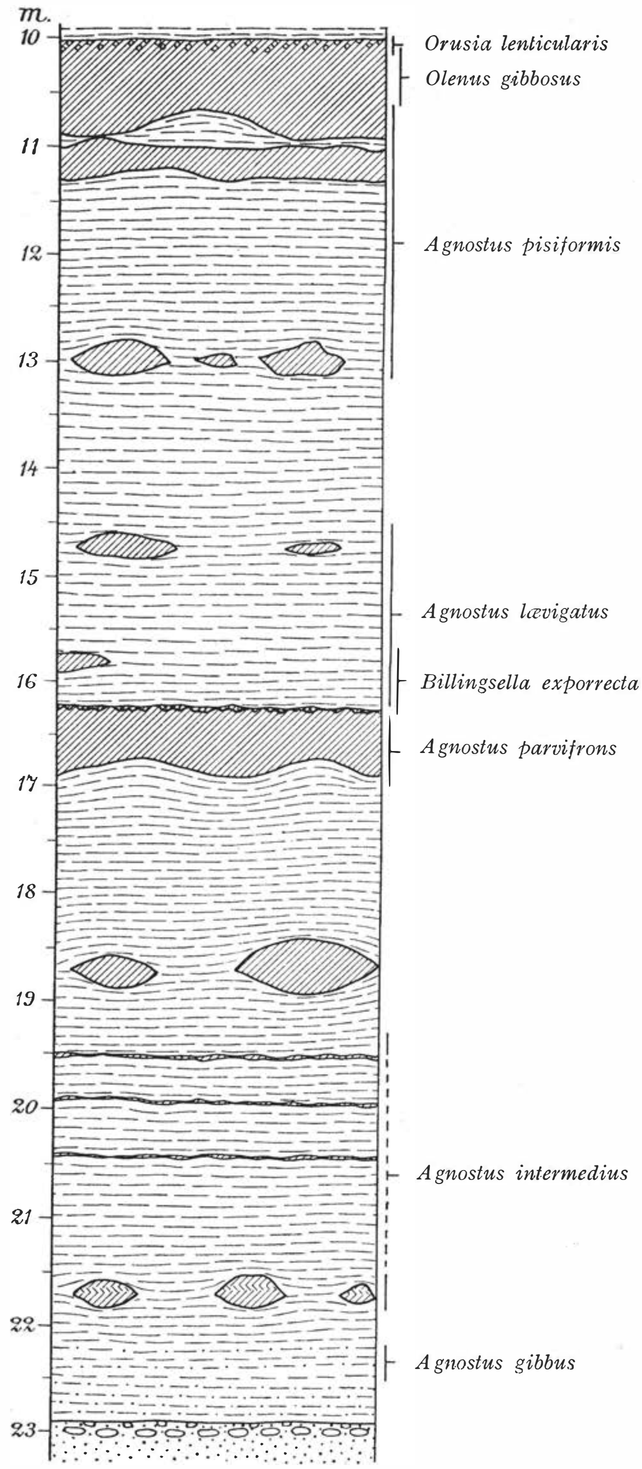


Fig. 32. Section through Middle and Upper Cambrian strata in the small stream at Stora Stolan, Billingen. From Westergård (1931*a*, fig. 14).

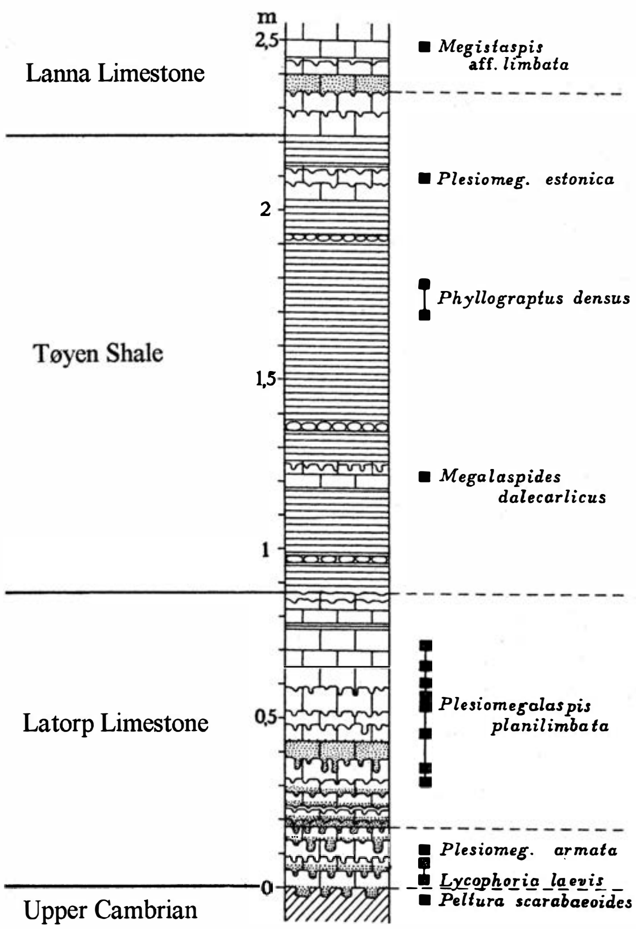


Fig. 33. Section through Upper Cambrian and Lower Ordovician strata in a quarry at Stora Stolan, Billingen. From Tjernvik (1956, fig. 7).

Middle and Upper Cambrian strata are exposed in the small stream at the old mill (Fig. 32). The succession is best exposed at the waterfall. Here, the lowermost part of the succession consists of a continuous bed of stinkstone with *Hypagnostus parvifrons*. It is overlain by a thin conglomeratic stinkstone containing *Billingsella exporrecta*. The middle and upper part of the section comprises the *Lejopyge laevigata* (2.5-3.0 m), the *Agnostus pisiformis* (about 3 m), and the *Agnostus* (*Homagnostus*) *obesus*/*Olenus* Zones. The last-mentioned zone consists of a coherent layer of stinkstone (the ”Great Stinkstone Bed”).

Upper Cambrian and Lower Ordovician strata are exposed in a quarry higher up in the slope. The top of the Cambrian is within the *Peltura scarabaeoides* Zone. This zone is 4-5 m thick at Stora Stolan (Westergård 1931*a*, p. 49, fig. 16). The lower part of the *P. scarabaeoides* Zone is especially rich in small lenses of an argillaceous coal (in Swedish ”kolm”) which have uranium concentrations of 2000-5000 ppm (Andersson et al. 1985, p. 13). The kolm lenses have been quarried at Stora Stolan. Lower Tremadocian strata are missing, and the Cambrian is overlain by a thin (about 0.9 m) limestone succession (Latorp Limestone) of the Hunneberg Substage, followed by 1.35 m of Tøyen Shale of the Billingen Substage (Tjernvik 1956, pp. 126-127, fig. 7; Fig. 33). The top of the section consists of at least 4 m of grey or reddish limestones (Lanna Limestone; Volkhov Stage).

Stop 3. Karlsfors

Per Ahlberg

Object: Lower Cambrian to Lower Ordovician strata.

At Karlsfors there is an almost complete section from the Lower Cambrian Lingulid Sandstone to the Lower Ordovician Lanna Limestone (Volkhov Stage). The main part of the section is exposed in a brook ravine cut into the slope of northwestern Billingen. Much of the succession is covered with scree and vegetation, but large parts of the Cambrian succession, especially the Upper Cambrian, are well exposed.

The Middle Cambrian has a thickness of about 10 m. The *Hypagnostus parvifrons* Zone consists of a continuous bed of stinkstone. It is overlain by a thin (about 0.1 m) section of dark grey shale with brachiopods in abundance (Westergård 1931*a*, pp. 44, 46). This shale is a lateral equivalent of the ”Exporrecta conglomerate”, and it forms the base of the *P. forchhammeri* Stage. Otherwise, the Middle Cambrian consists essentially of alum shale with scattered stinkstone

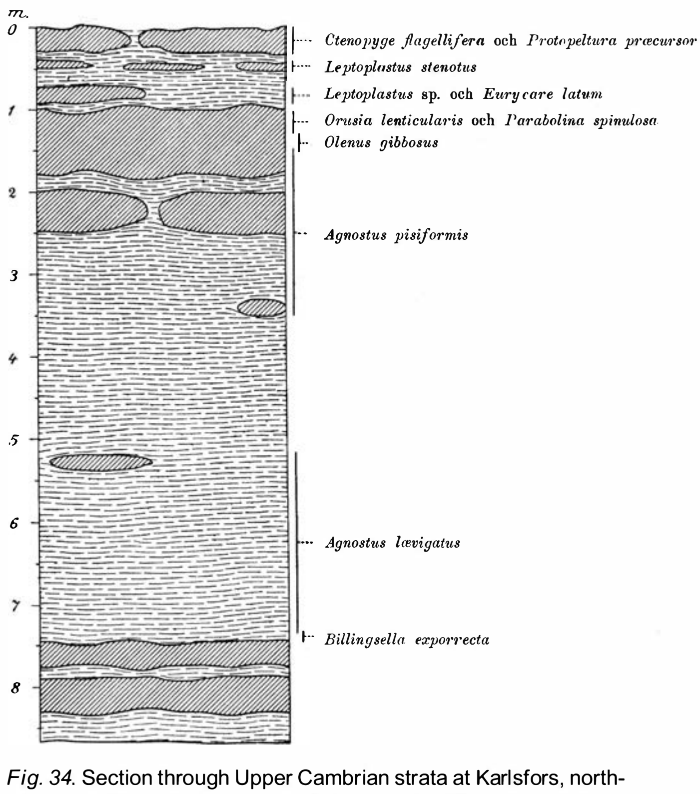


Fig. 34. Section through Upper Cambrian strata at Karlsfors, northwestern Billingen. From Westergård (1922, fig. 29).

lenses. The *Lejopyge laevigata* Zone is 2.5-3.0 m thick. It was briefly described by Wallerius (1895) and Westergård (1922, p. 64). Karlsfors is the type locality for *Lejopyge laevigata perrugata* Westergård, 1946 (a junior synonym of *L. laevigata armata* = *L. armata*). The holotype of that taxon is from the lower part of the *L. laevigata* Zone.

The Upper Cambrian is well exposed at two waterfalls. A section at the lower waterfall was described in detail by Westergård (1922, pp. 63-64, fig. 29; Fig. 34). This section extends from the *Agnostus pisiformis* Zone into the *Protopeltura praecursor* Zone. The "Great Stinkstone Bed" is 0.8 m thick and, as usual, extremely rich in trilobites. It is overlain by the *Leptoplastus* and *Protopeltura praecursor* Zones.

Stop 4. Gudhem

Per Ahlberg and John Ahlgren

Object: Middle and Upper Cambrian strata.

The *Lejopyge laevigata* and *Agnostus pisiformis* Zones are exposed in an old quarry at Gudhem, about 1.2 km west of Gudhem Church in the Falbygden area. The *L. laevigata* Zone is about 4 m thick and consists of alum shale with scattered stinkstone lenses (Wallerius 1895; Fig. 35). The zonal index is common, particularly in the stinkstone lenses, and ranges throughout the zone. It is generally associated with a bradoriid arthropod, *Eremos primordialis* (Linnarsson, 1869). The upper part of the *Lejopyge laevigata* Zone (formerly the "Exsculptus Beds" or *Agnostus exsculptus* Subzone; Wallerius 1895, 1930) contains a diverse and characteristic fauna with, e.g., *Hypagnostus sulcifer, Diplagnostus planicauda vestgothicus*, "*Peronopsis" insignis, Proceratopyge conifrons*, *Toxotis pusilla*, and *Acrocephalites stenometopus*. The uppermost part of the section belongs to the *Agnostus pisiformis* Zone. The Exporrecta conglomerate is exposed at the base of the section. At the northwestern entrance to the quarry there are exposures of the *Hypagnostus parvifrons* Zone.

Watch out for bulls!

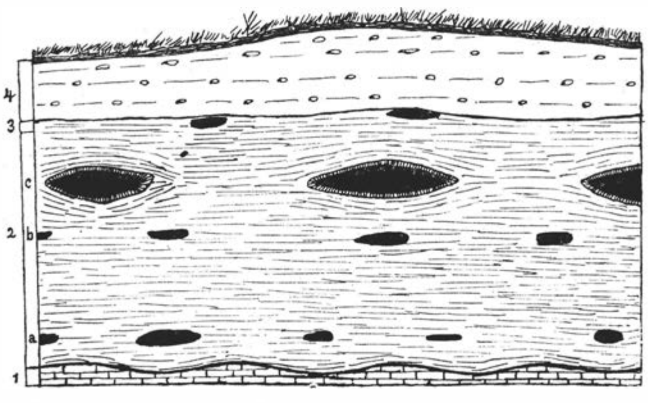


Fig. 35. Section through Middle and Upper Cambrian strata in an old quarry at Gudhem in the Falbygden area, Västergötland. 1, continuous bed of stinkstone; 2, *Lejopyge laevigata* Zone; 3, *Agnostus pisiformis* Zone; 4, Quaternary deposits; a-c, horizons with stinkstone lenses. Approx. 1:130. From Wallerius (1895, fig. 2).

Stop 5. Husaby

Per Ahlberg

Object: Cultural stop (a medieval church and the ruin of the bishop´s castle).

Many important historical events have occurred at Husaby, south of Kinnekulle. History relates that Sweden´s first Christian king, Olof Skötkonung, was baptised here around 1008 AD by an English missionary, St. Sigfrid. The old medieval church is remarkable in having three spires. The steeple and the two stair-towers were built during the 11th Century. The remaining part of the church is mainly from the following century. The bishop´s throne is from the 13th Century. St. Sigfrid´s spring lies just northeast of the church. This is where Olof Skötkonung was baptised.

The bishop´s castle was built during the 15th Century, but it was destroyed during the reformation in the following century. The ruins were restored during the 1960s. Topotypical material of the trace fossil *Alectorurus*? *circinatus* (Brongniart, 1828) is abundant in many building-stones in the walls of the ruin of the castle (Jensen & Bergström 1995). These trace fossils consist of large, vertically oriented protrusive spreite burrows. Judging from the nature of the rock, the material probably originates from the upper part of the Lingulid Sandstone.

Stop 6. Brattefors

Maurits Lindström, Anita Löfgren and Rüdiger Teves

Object: Collapse structures cut through Upper Cambrian alum shale.

Thorslund (*in* Westergård 1943) described seven vertical plugs of sediment that cut through Upper Cambrian black shale at the Brattefors quarry at the foot of Kinnekulle (Fig. 36). He explained them as vents formed by gas expulsion in connection with the emplacement of Late Palaeozoic basalt magma. The ex-

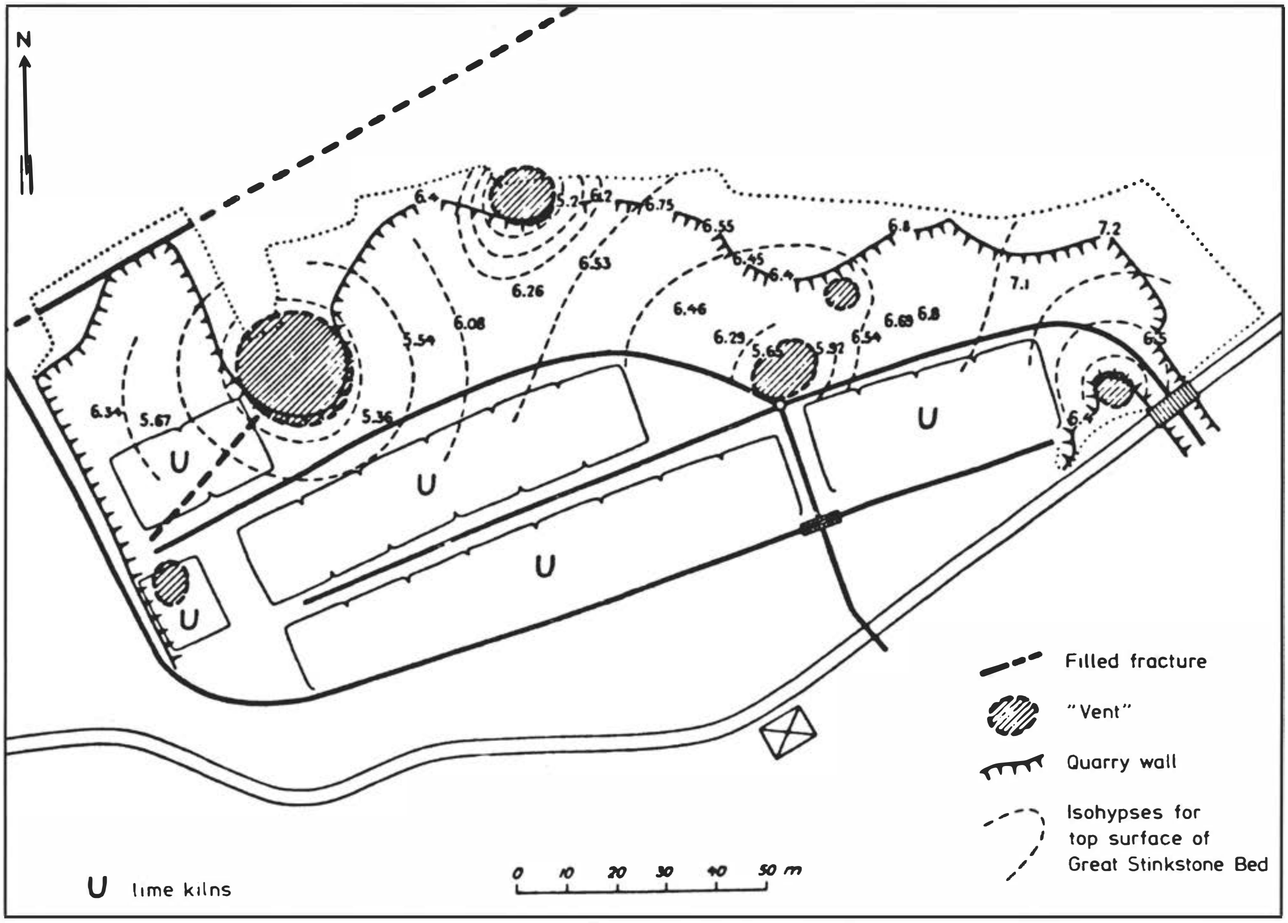


Fig. 36. Thorslund´s (*in* Westergård 1943) sketch of the plugs at Brattefors. The legend is translated from the Swedish and slightly modified in its content.

istence of undisturbed Tremadocian beds in the plugs made this interpretation questionable.

Only two of the plugs originally reported by Thorslund were spared by later quarrying operations. They were subjected to core drilling (6 cm diameter) and to detailed recording and sampling of the exposed sections. Three cores were drilled, two of which penetrated the larger of the two structures. Drillcore Br I was spudded at 60º inclination. Drillcore Br II was spudded vertically and was intended to reveal the inner structure of the plug from top to bottom (Fig. 37).

The horizontally exposed section of the major, north-westernmost plug is oval, with the long axis (WNW) about 11 m and the short axis about 7 m. The central portion consists of relatively undisturbed subhorizontal beds. This portion will be referred to as the "inner plug". It is surrounded by a zone of steeply inclined beds that will be called the "envelope". The envelope is sharply delimited from the "outer marginal zone" in which the bedding exhibits varying but mostly moderate amounts of deformation. The outer marginal zone is continuous with the non-deformed bedding of the wider surroundings. The amount of subsidence of the inner plug is indicated by levels at which the base of the Ordovician and the base of the alum shale normally occur in the area surrounding the structure. The normal level of the Cambrian-Ordovician boundary would be positioned about 6 m above the top of Br II, and the normal level of the base of the alum shale is about 13 m below the top of that drillcore.

The envelope is separated from the inner plug and the outer marginal zone by well-defined fractures along which movements have taken place. Its thickness commonly is 1-2 m. It consists of steeply inclined beds that are lithostratigraphically related to adjacent portions of the inner plug and the outer marginal zone. Exposed portions of the envelope bear strong evidence of shearing movement at the inner and outer boundaries.

The greatest difference between the inner plug and surrounding stratigraphy is a Tremadocian succession that is 12 m thick in the plug but is thin (less than 2 m) or absent outside of it.

Middle Cambrian was not encountered within the plug, but stinkstone presumably representing the Middle Cambrian occurred in the envelope at 23.25-24.10 m of core Br II. The Upper Cambrian includes the Subzones of *Parabolina lobata* and *Peltura scarabaeoides*. The uppermost 4.25 m correspond in thick-

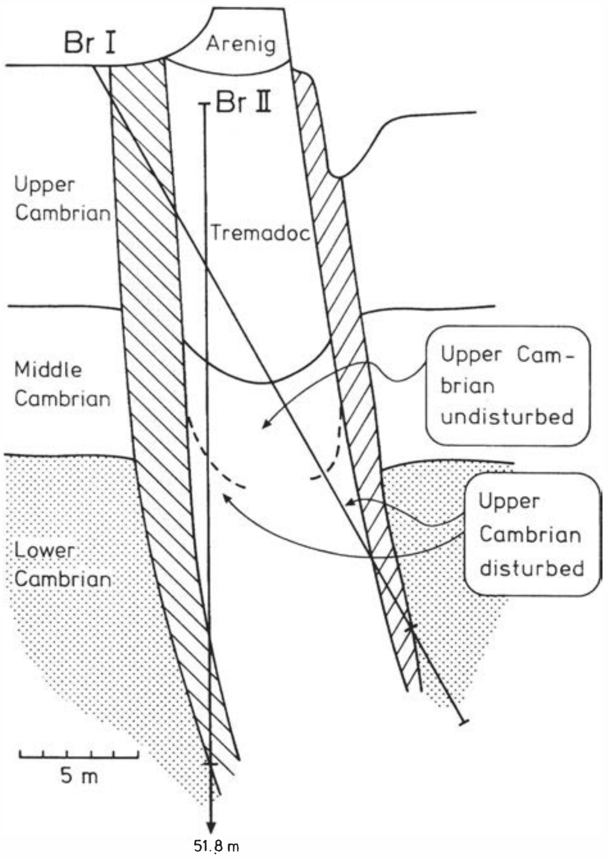


Fig. 37. Vertical section through the major northwestern plug in the plane of Br I from the south. Diagonal ruling = envelope. Br II is projected on the plane of the section. The section is based on the assumption that the cores retained their original orientations. This could be wrong. Therefore it is not out of the question that the plug is more nearly vertical. From Teves & Lindström (1988, fig. 2).

ness and lithology to equivalent beds in the surrounding area. Below this portion Br II penetrated 7.75 m of strongly disturbed alum shale with exceptionally little limestone. The dominant lithology of the Ordovician portion of the inner plug is brownish grey shale with laminae and beds of greensand and, in the upper (Arenigian) part, beds and nodules of light grey limestone. The lowermost greensand bed occurs at the Cambrian-Ordovician boundary.

Structures relevant to the interpretation of the Brattefors plugs have been observed in Lower Cambrian sandstones in different parts of southern Sweden. In Scania, southernmost Sweden, Lindström (1967) mapped collapse structures in which the bedding of the sandstones was bent downwards so as to assume a conical shape ("funnel grabens"; see stop 1 in Scania). The diameter of these structures can be from about 5 m to over 150 m. In the province of Närke, about 100 km from Brattefors, Karis & Magnusson (1972) and Bengtson (1976) found structures that are due to subrosion of the uppermost part of the Lower Cambrian sandstone that corresponds to the Lingulid Sandstone in Västergötland. This subrosion is younger than early Middle Cambrian and probably older than Arenig. As we consider that the late Middle Cambrian to earliest Tremadocian phase of alum shale sedimentation bears evidence of too consistently hypoxic and physically undisturbed sea-bed conditions to allow for any episodes of strong movements of groundwater, we assume that the subrosion was altogether younger than the alum shale.

We agree with Karis & Magnusson´s (1972) suggestion that the structures encountered in Scania and those described from Närke are of closely similar origin and that they could be of identical age. This event can now be dated as mid-Tremadocian. The *Brattefors Event* - as we choose to call it - appears to coincide with the end of alum shale sedimentation and the beginning of Early to Middle Ordovician sedimentation on a generally oxic sea-bed, with a moderately to richly diversified fauna.

The sequence through upper *Paltodus deltifer* Zone strata at Brattefors appears to be more complete than elsewhere in Sweden, probably because the Brattefors beds have been protected from erosion within the collapse structures. Thus, it is possible to distinguish a lower complex with, for instance, *Cordylodus angulatus* and "*Oneotodus*" *variabilis*, a middle complex where *Cordylodus* is lacking but "*O*" *variabilis* is still present, and an upper complex where "O" *variabilis* has also disappeared. "*Oneotodus*" *variabilis* has now also been recognised in North America, and detailed studies of its element design reveal its affinity with the Laurentian taxon *Variabiloconus bassleri*.

Stop 7. Kakeled

Per Ahlberg and John Ahlgren

Object: Upper Cambrian strata.

Up to 7.5 m of Upper Cambrian strata are exposed in an old quarry at Kakeled, southwestern Kinnekulle. The section consists of alum shales with lenses and beds of stinkstone. The upper c. 2.40 m of the *Agnostus pisiformis* Zone is exposed. It consists of alum shale with large stinkstone lenses in the lower part and a continuous bed of stinkstone, forming part of the "Great Stinkstone Bed", in the upper part. In addition to *A. pisiformis* in abundance, the stinkstones have yielded rare specimens of *Schmalenseeia amphionura*. The *A. pisiformis* Zone is overlain by stinkstone beds representing the *Agnostus* (*Homagnostus*) *obesus*/*Olenus* Zone (about 40 cm). The middle part of the exposed succession represents the *Peltura minor* Zone (about 1.0-1.2 m), and the upper part the *P. scarabaeoides*

Zone (3.0-3.5 m). The *Parabolina spinulosa, Leptoplastus*, and *Protopeltura praecursor* Zones are very thin or missing. The "Great Stinkstone Bed" is occasionally conglomeratic and comprises at least the entire *A. obesus/Olenus* Zone and the uppermost part of the *A. pisiformis* Zone.

Stop 8. Trolmen

Per Ahlberg

Object: Upper Cambrian and Lower Ordovician strata.

Upper Cambrian strata are well exposed in an old quarry at Trolmen, western Kinnekulle. The lowermost part of the section (the *Agnostus pisiformis* Zone) consists of alum shale with scattered stinkstone nodules, containing *A. pisiformis* in abundance and rare specimens of *Peratagnostus falanensis* (see Ahlberg & Ahlgren 1996, p. 138, fig. 5G), *Proceratopyge nathorsti*, and *Acrocephalites stenometopus agnostorum*. It is overlain by a nearly 2 m thick stinkstone bed (the "Great Stinkstone Bed"), which is conglomeratic in its upper part. The lower part of this prominent stinkstone bed belongs to the *Agnostus pisiformis* Zone, whereas the middle and upper part belongs to the *Agnostus* (*Homagnostus*) *obesus/Olenus* Zone. The top of the stinkstone bed has yielded trilobites indicative of the *Parabolina spinulosa*, *Leptoplastus*, and *Protopeltura praecursor* Zones (Fig. 38). It is overlain by 7 m of alum shale and stinkstone beds with trilobites indicative of the *Peltura minor* and *P. scarabaeoides* Zones. The alum shale succession ranges upwards into the *Parabolina heres* Subzone (*Peltura transiens* Subzone of Henningsmoen 1957*a*). On top of the Upper Cambrian there is about 1 m of Tremadocian strata (Ceratopyge Limestone; Westergård 1943). A trilobite with North American affinities, *Taenicephalus*? *peregrinus*, was described by Henningsmoen (1957*b*) from the *A. obesus/Olenus* Zone.

Trolmen is the type locality for two of the Upper Cambrian conodonts described by Müller & Hinz (1991), *Nogamiconus falcifer* and *Westergaardodina concamerata*.

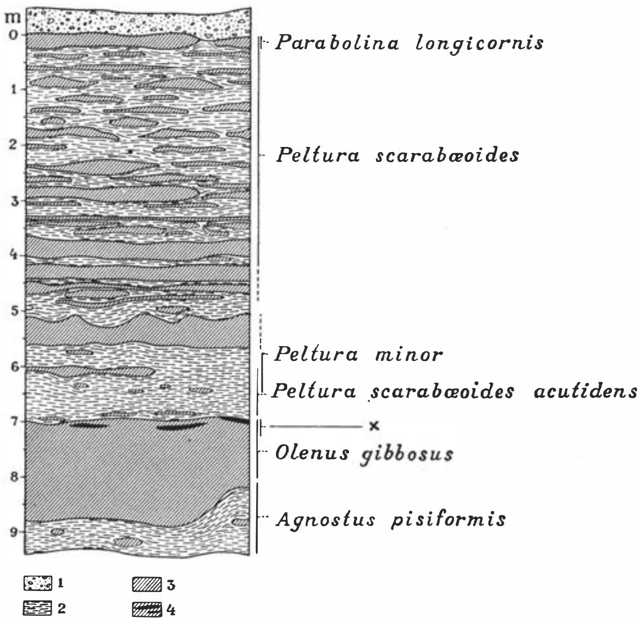


Fig. 38. Section through Upper Cambrian strata in a quarry at Råbäck (adjacent to the quarry at Trolmen), western Kinnekulle, and occurrences of selected trilobites. X indicates the occurrence of *Ctenopyge flagellifera*, *Protopeltura praecursor*, *Leptoplastus ovatus*, *Eurycare latum*, *Parabolina spinulosa*, and *Orusia lenticularis*. Note that *P. longicornis* Westergård, 1922 is a junior synonym of *P. lobata* (Brøgger, 1882). Legend: 1, Quaternary deposits; 2, alum shale; 3, stinkstone (orsten); 4, stinkstone conglomerate. From Westergård (1922, fig. 21) and Thorslund & Jaanusson (1960, fig. 6).

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