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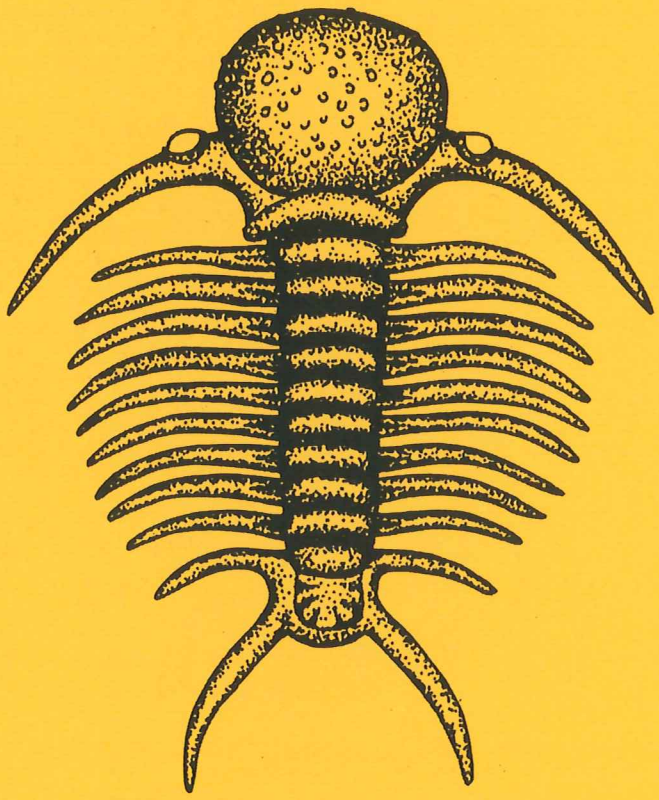

Middle Cambrian trilobites and biostratigraphy of the Almbacken drill core, Scania, Sweden

Niklas Axheimer

Lund 2001 Examensarbete, 20 p Nr 133
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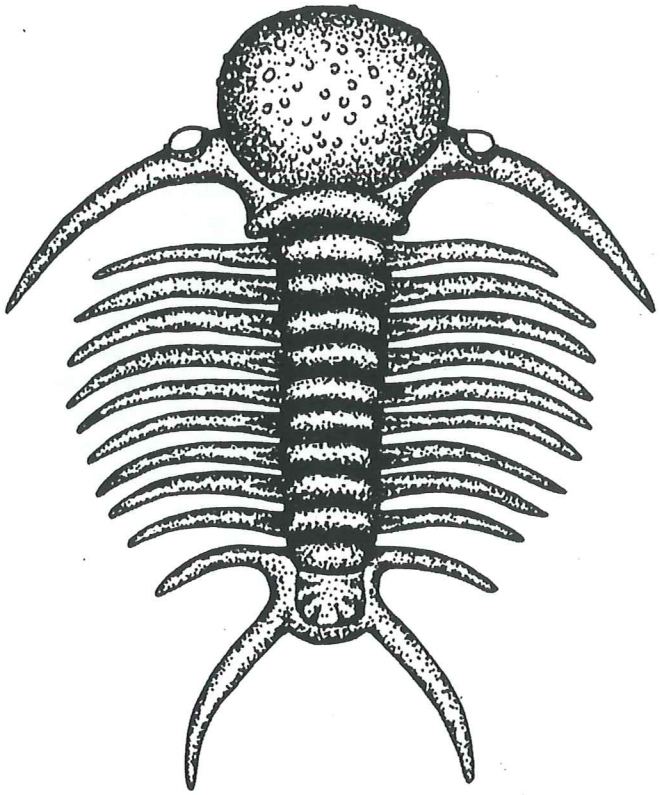

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NIKLAS AXHEIMER

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Abstract: A core drilling at Almbacken in Södra Sandby, Scania, southern Sweden, penetrated a c. 30 m thick succession of Middle Cambrian–upper Lower Cambrian strata. The Middle Cambrian of this core is the most complete one so far documented in Scania. The core contains a stratigraphical sequence from the *Lejopyge laevigata* Zone (upper *Paradoxides forchhammeri* Stage) to the *Holmia kjerulfi*-group Zone (upper Lower Cambrian). The *Acadoparadoxides oelandicus* Stage is probably missing. The Middle Cambrian is c. 28.3 m thick and consists of dark grey to black mudstones and shales (alum shale) with stinkstone and limestone beds. Three major limestone beds can be identified: the "Fragment Limestone", the Exsulans Limestone, and the Andrarum Limestone. The Middle Cambrian is richly fossiliferous and the faunas are dominated by agnostid trilobites. Polymerid trilobites and indeterminate lingulate brachiopods are common at some levels. The succession of trilobite species are used for a biostratigraphical subdivision into seven biozones. The preservation is generally good and 31 trilobite species were identified. The excellent preservation in the stinkstones allowed a description of growth stages in pygidia of *Ptychagnostus punctuosus* (Angelin, 1851). Only the upper part of the Lower Cambrian (Gislöv Formation) was recovered, comprising c. 1.5 m of siltstones and a thin limestone bed at the base of the core.

Keywords: Trilobita, taxonomy, biostratigraphy, ontogeny, alum shale, Middle Cambrian, Lower Cambrian, Almbacken, Scania, Sweden.

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The Cambrian of Scandinavia consists predominantly of siliciclastic deposits which accumulated under generally shallow to moderately deep marine conditions. Outside the Caledonides, these deposits have escaped tectonic deformation and are completely unmetamorphosed. Arenaceous strata laid down in a near-shore shallow marine environment generally dominate Lower Cambrian successions. In Scania (Skåne), southern Sweden, the Lower Cambrian is subdivided into four formations. In ascending order these are the Hardeberga Formation, the Norretorp Formation, the Rispebjerg Sandstone, and the Gislöv Formation (e.g. Bergström & Ahlberg 1981; Bergström & Gee 1985; Ahlberg 1998).

The Lower Cambrian is succeeded by a series of mudstones and shales, which comprise the Middle Cambrian. These Middle Cambrian argillaceous deposits are often very dark due to a high organic content, and form part of the Alum Shale Formation (e.g. Bergström & Ahlberg 1981; Buchardt *et al.* 1997). The Alum Shale Formation consists of dark grey to black mudstones and shales with lenses and beds of dark grey limestone (often referred to as orsten in Swedish). Three major limestone units can be identified in the lower part of the Alum Shale Formation in Scania. These are, from base to top: the "Fragment" Limestone, the Exsulans Limestone, and the Andrarum Limestone (e.g. Hadding 1958; Ahlberg 1998). They are considered to have been deposited during regressive events (Bergström & Gee 1985; Conway Morris & Rushton 1988; Nielsen 1996).

The accumulation of mudstone and shale was a very slow process with a deposition rate of merely 1-10 mm/1000 years in a principally dysoxic environment (Buchardt *et al.* 1997). The dysoxic environment resulted in slow decay of dead organisms, and the preservation in the alum shale is therefore generally good, especially in the stinkstones.

The biostratigraphy of the Middle Cambrian (Paradoxides Series) of Scandinavia is based mainly upon trilobites. The Middle Cambrian is subdivided into three stages (in ascending order): the *Acadoparadoxides oelandicus* Stage, the *Paradoxides paradoxissimus* Stage, and the *Paradoxides forchhammeri* Stage. The *A. oelandicus* Stage has not been recorded with certainty in Scania, whereas the latter stages are generally complete. In other areas of Scandinavia, the *P. paradoxissimus* and *P. forchhammeri* stages are generally incomplete or occasionally even missing. The probable absence of the *A. oelandicus* Stage in Scania seems to coincide with the Hawke Bay regression of North America (Bergström & Ahlberg 1981).

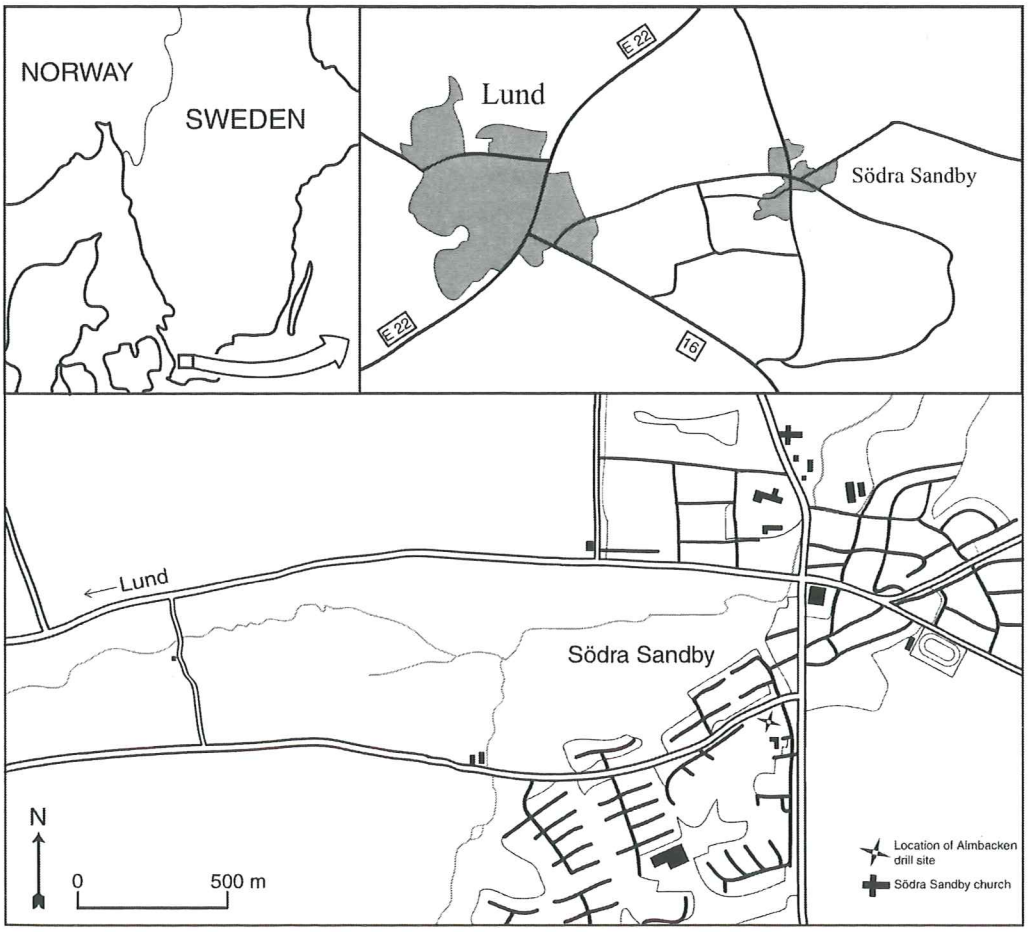


Fig. 1. Map showing the location of the drill site at Almbacken, Södra Sandby, Scania, southern Sweden.

Middle Cambrian sedimentary outcrops are fairly sparse in Scania and confined to only a few localities in the south-eastern parts of the province, the most extensive ones being the old quarries at Andrarum. Thus our knowledge of the thickness, faunal content, and stratigraphy of the Middle Cambrian is to a great extent based on drillings. A series of drillings in Scania were carried out in the 1940's under the supervision of the Swedish paleontologist A. H. Westergård. Much of this work has been an important source of knowledge in understanding the Middle Cambrian of Scania. An additional boring was made in 1949 at Almbacken in Södra Sandby, western Scania. This paper focuses on the succession of trilobites and the biostratigraphy of the Almbacken core.

Location and general remarks

In 1941 and 1942 a series of drillings were made in Scania on commission of the Swedish Geological Survey in order to obtain information on the alum shale in Scania. Drillings were made at Andrarum, Gislövshammar, Åkarpsmölla, and Södra Sandby. Unfortunately the boring at Södra Sandby struck a diabase dyke and only an incomplete succession through the Alum Shale Formation was obtained (Westergård 1944). To complete the Södra Sandby core an additional boring was made in 1949 at Almbacken, in the southern part of Södra Sandby (Fig. 1). The Almbacken estate is situated about 1 km south of Södra Sandby church, and the drilling was probably made slightly north of the Almbacken farm.

The Almbacken drilling was a success and a more or less complete core through the Middle Cambrian was recovered, as well as the uppermost part of the Lower Cambrian. The boring reached a depth of approximately 33 m and penetrated the following sequences: Quaternary (0-2.87 m), Middle Cambrian (2.87-31.20 m), and Lower Cambrian (31.20-32.70 m) (Plate 1). The core diameter is 7.2 cm. The Middle Cambrian succession has a thickness of c. 28.3 m and consists mainly of medium to dark grey shale and laminated mudstone with seven limestone intercalations. For a detailed description of the lithological succession and its faunal content, see Appendix. The core was briefly examined by Per Ahlberg, who also collected fossils from all fossiliferous intervals. These fossils form the basis for this study. The lithologies and the lithologic succession in the Almbacken core were described by Meyerson (1997).

Middle Cambrian biostratigraphy of Scandinavia

The stratigraphic classification of the Middle Cambrian has gone through numerous revisions, especially in the early twentieth century. Before the series of borings took place, the Middle Cambrian stratigraphy of Scania was based solely upon studies of various outcrops, especially those in and around the Andrarum quarries, revealing only partial sections of Cambrian strata (Westergård 1944). These outcrops were used by Swedish palaeontologist Tullberg (1882) when he proposed a biostratigraphy for the Middle Cambrian of Scandinavia. Tullberg divided the Paradoxides Shale (Middle Cambrian) into thirteen zones. His classification was later revised by Grönwall (1902) into no more than four zones during an attempt to correlate the Middle Cambrian in Scania with that of Bornholm using Tullberg's (1882) scheme. Moberg (1910) later revised Grönwall's (1902) four zones into the following three, in ascending order: the *Paradoxides oelandicus* Zone, the *Paradoxides tessini* (=*Paradoxides paradoxissimus*) Zone, and the *Paradoxides forchhammeri* Zone. Finally, Westergård (1944) believed that these three zones were of too great importance to represent zones alone and regarded them as stages instead. These three stages are still in use today. The *P. oelandicus* Stage is known today as the *Acadoparadoxides oelandicus* Stage.

Westergård made many extensive studies of Cambrian stratigraphy and trilobite faunas of Sweden and subdivided the Middle Cambrian into the following nine zones (in ascending order): the *Eccaparadoxides insularis* Zone, the *Paradoxides pinus* Zone, the *Ptychagnostus gibbus* Zone, the *Tomagnostus fissus*/*Ptychagnostus atavus* Zone, the *Hypagnostus parvifrons* Zone, the *Ptychagnostus punctuosus* Zone, the *Ptychagnostus lundgreni*/*Goniagnostus nathorsti* Zone, the *Solenopleura brachymetopa* Zone, and the *Lejopyge laevigata* Zone (Westergård 1946). The *P. pinus* Zone is currently referred to as the *Ptychagnostus praecurrens* Zone (Ahlberg 1989). The reason for giving some zones more than one species name is that in some localities one of the species might be rare or sometimes even absent.

Since Westergård's (1946) work on the Middle Cambrian, various other subdivisions have been suggested, e.g. by Robison (1982, 1984). Based upon the succession of agnostids Robison's (1984) intention was, and still is, to propose a global zonation for the Middle Cambrian. This zonation is primarily based upon species of the family Ptychagnostidae (Robison 1984). The Ptychagnostidae was selected because of its frequent usage by researchers around the world. Robison (1982, 1984) defined the lower boundary of each zone by the first appearance of a single species and the upper boundary by the base of the overlying zone, in contrary to Westergård (1946) who never really explained how the zonal boundaries were to be defined. Robison (1984) and Peng & Robison (2000) created a system with five interval-zones. In ascending order these are the *Ptychagnostus praecurrens* Zone, the *P. gibbus* Zone, the *P. atavus* Zone, the *P. punctuosus* Zone, and the *L. laevigata* Zone (lower and upper). The zonal index fossils were selected because of their wide geographical distribution and abundance. The lower three zones were defined in an earlier publication (Robison 1982).

Robison (1984) excluded Westergård's (1946) *Tomagnostus fissus* and *Hypagnostus parvifrons* zones in his biostratigraphy. Peng & Robison (2000) state that "*T. fissus* is known from shallow- to deep-water lithofacies of high paleolatitudes but from only deep-water lithofacies of low paleolatitudes", and they therefore consider *T. fissus* to be of less stratigraphical significance than *P. ata-*

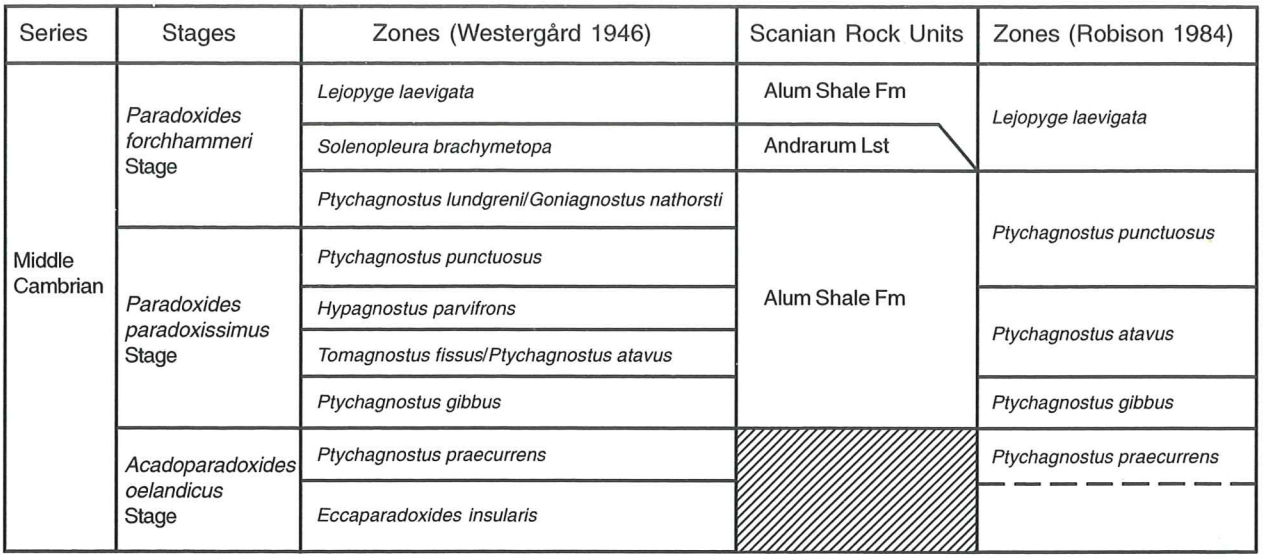


Fig. 2. Middle Cambrian stratigraphy of Scania, southern Sweden, and Middle Cambrian biostratigraphy according to Westergård (1946) and Robison (1984).

vus. Regarding *H. parvifrons*, Peng & Robison (2000) claims that its stratigraphical range is much longer than that of *P. atavus*, and that it should therefore be excluded as an index fossil. The *P. lundgreni/G. nathorsti* Zone is also not present in Robison's (1984) zonation. Many authors have excluded this zone due to the long range of *P. lundgreni* and the fact that *P. lundgreni* can not always be found together with *G. nathorsti* (Berg-Madsen 1985*a*, 1985*b*).

The Middle Cambrian zonation of Westergård (1946) is applied in this paper because Robison's (1982, 1984) zonation is largely based upon North American agnostid faunas. A comparison between the Middle Cambrian zonation of Westergård (1946) and Robison (1984) is shown in Fig. 2.

Stratigraphical remarks

Middle Cambrian. – The Middle Cambrian of the Almbacken core has a thickness of c. 28.3 m and is dominated by dark grey to black mudstone and shale. It is richly fossiliferous, except in the lower c. 6 m, and has a highly diverse fauna containing 31 identified agnostid and polymerid trilobite species. The preservation is generally good, especially in the stinkstones. In addition to shale and stinkstone, the Middle Cambrian contains three major limestone beds, and these are in ascending order: the "Fragment" Limestone (28.25-28.60 m), the Exsulans Limestone (25.08-25.47 m), and the Andrarum Limestone (4.10-5.65 m). These beds are richly fossiliferous, except for the "Fragment" Limestone, which contains only indeterminate brachiopod valves and trilobite fragments. The Andrarum Limestone is well known for its rich faunas (Ahlberg 1998) but has yielded only four species in the Almbacken core.

The first appearance of an index fossil is that of *Ptychagnostus gibbus* at 25.23 m. Accordingly the *Acadoparadoxides oelandicus* Stage is missing, or can at least not be positively identified. The first appearance of *P. gibbus* coincides with the first appearance of *T. fissus*. This implies a difficulty when establishing the lower boundaries of the *T. fissus/P. atavus* Zone and the *P. gibbus* Zone, because application of first appearance data is not possible. Unfortunately Westergård (1946) never explained exactly how he defined these boundaries. He states, however, that the *P. gibbus* Zone includes the Exsulans Limestone layer (Westergård 1946). Therefore, the boundary between the *P. gibbus* Zone and *T. fissus/P. atavus* Zone is placed at the last appearance of *P. gibbus* (25.09 m).

Hypagnostus parvifrons is sparse and cannot be considered to be frequent at any level. *Ptychagnostus atavus* is as most common around the 23 m level and occurs in great numbers at 22.80 m, which is above the first appearance of *H. parvifrons*. The *P. atavus* Zone should therefore extend up to this level, at least. The lower boundary of the *H. parvifrons* Zone is set at 22.40 m, a level where the frequency of *P. atavus* starts to decrease and the last appearance of *T. fissus*, the latter being restricted to the *T. fissus/P. atavus* Zone (Westergård 1946). *H. parvifrons* generally extends from the *T. fissus/P. atavus* Zone and continues up into the lower part of the *Ptychagnostus punctuosus* Zone (Westergård 1944). In the Almbacken core *H. parvifrons* appears in the *T. fissus/P. atavus* Zone but terminates just below the first appearance of *P. punctuosus*.

The occurrence of *Peronopsis fallax depressa*, diagnostic of the *H. parvifrons* Zone, at 15.45 m marks where the lower boundary of the *P. punctuosus* Zone is placed, a level close to where the frequency of *P. punctuosus* starts to increase. This is also a level where *Ptychagnostus* cf. *stenorrhachis* occurs, a species diagnostic of the *P. punctuosus* Zone (Westergård 1946). However, since the identification of *P. stenorrhachis* is uncertain, its stratigraphical significance should be taken with precaution. *Parasolenopleura linnarssoni* generally ranges to the upper boundary of the *H. parvifrons* Zone (Westergård 1953), and this is also the case in the Almbacken core.

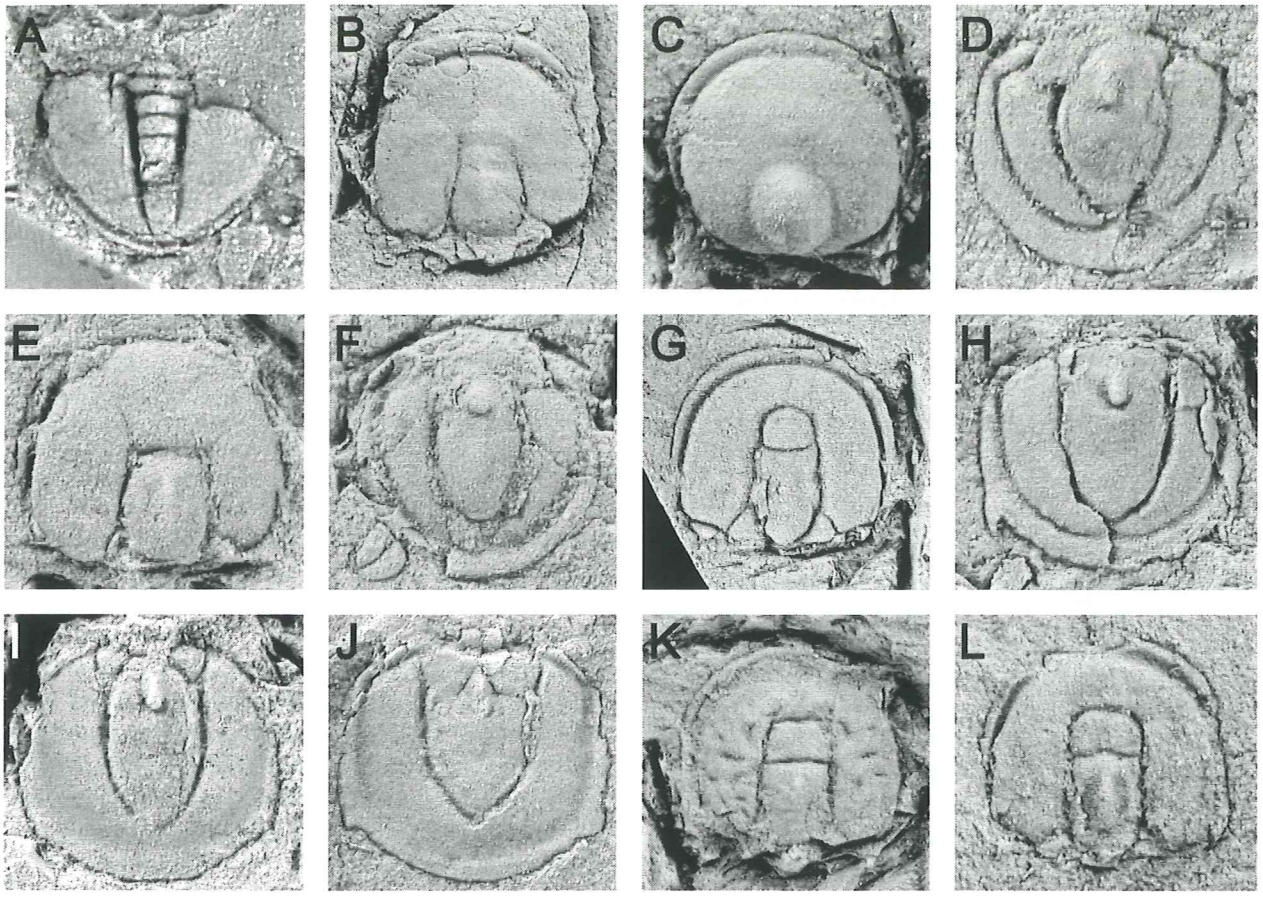


Fig. 3. **A.** *Eodiscus scanicus* (Linnarsson, 1883), incomplete pygidium. *P. gibbus* Zone in the Almbacken core (25.08 m). ×17. **B.** *Cotalagnostus lens claudicans* (Grönwall, 1902), cephalon. *T. fissus/P. atavus* Zone in the Almbacken core (22.80 m). ×7. **C-D.** *Hypagnostus parvifrons* (Linnarsson, 1869). **C,** cephalon. *H. parvifrons* Zone in the Almbacken core (17.72 m). ×9.5. **D,** pygidium. *T. fissus/P. atavus* Zone in the Almbacken core (22.94 m). ×15. **E-F.** *Hypagnostus* cf. *nepos* (Brögger, 1878). *P. lundgreni/G. nathorsti* Zone in the Almbacken core. **E,** cephalon (9.57 m). ×12.5. **F,** incomplete pygidium (9.63 m). ×9.5. **G-H.** *Peronopsis fallax* (Linnarsson, 1869). *T. fissus/P. atavus* Zone in the Almbacken core. **G,** cephalon (24.46 m). ×6. **H,** pygidium (24.70 m). ×8. **I.** *Peronopsis fallax depressa* Westergård, 1946, pygidium. *H. parvifrons* Zone in the Almbacken core (15.45 m). ×9. **J.** *Peronopsis fallax ferox* (Tullberg, 1880), pygidium, latex cast of external mould. *P. punctuosus* Zone in the Almbacken core (11.17 m). ×8. **K-L.** *Diplagnostus planicauda* (Angelin, 1851). *P. punctuosus* Zone in the Almbacken core. **K,** cephalon (10.55 m). ×8. **L,** cephalon (10.63 m). ×8.

Ptychagnostus lundgreni appears in the uppermost part of the *P. punctuosus* Zone in most localities in Scania (Westergård 1946), but not in the Almbacken core. However, it is generally rare in the core, which may explain its absence in this zone. The lower boundary of the *Ptychagnostus lundgreni/Goniagnostus nathorsti* Zone is here defined by the first appearance of *P. lundgreni* (9.75 m). The low frequency of *G. nathorsti* in the Almbacken core corresponds with Westergård's observations from Andrarum, whereas in other localities this condition might be reversed, hence the usage of two index fossils (Westergård 1946).

There is an uncertainty concerning the boundary between the *Solenopleura brachymetopa* Zone and the *Lejopyge laevigata* Zone, because neither of these zonal fossils are with certainty present in the core. Following Westergård (1953), the *S. brachymetopa* Zone is tentatively set to comprise the Andrarum Limestone (4.10-5.65 m). Very poorly preserved specimens of *Lejopyge* have been found in the lower part of, and just above, the Andrarum Limestone, but no species identification was possible.

The *Acadoparadoxides oelandicus* Stage has not been recorded with certainty from any localities or drill cores in Scania. This is generally explained by an interruption of sedimentation due to a regressive event (Lindström *et al.* 2000).

Lower Cambrian. – The transition beds between the Middle Cambrian and strata herein considered as Lower Cambrian are poorly fossiliferous, containing only indeterminate lingulate brachiopod valves and trilobite fragments. The boundary between the Middle and Lower Cambrian is therefore based upon lithology and is tentatively placed at 31.20 m where a series of dark grey to black mudstones overlies a series of siltstones. This implies a core recovery of c. 1.5 m of Lower Cambrian strata. The siltstones are 1.20 m thick, medium to dark grey in colour, highly calcareous, and pyritiferous. They overlie a thin limestone bed, comprising 0.3 m. The limestone, which is light grey in colour, is rich in small rounded quartz grains. Fossils are present, but observable only as cross sections of polymerid trilobites, making any form of identification impossible without extensive preparation.

The siltstone and limestone sequences seems to represent the *Holmia kjerulfi*-group Zone of the Gislöv Formation although no definite correlation can be made since the available material is sparse (fragmentary sections comprising 1.5 m) and fossil identification virtually impossible.

Systematic palaeontology

Terminology. – The morphological terms applied herein are those defined by Whittington (*in* Kaesler 1997) and Robison (1982, 1988, 1994).

Repository. – Discussed and illustrated specimens are stored at the Department of Geology, University of Lund.

Class Trilobita Walch, 1771

Order Agnostida Salter, 1864

Family Eodiscidae Raymond 1913

Genus *Eodiscus* Hartt *in* Walcott, 1884

Eodiscus scanicus (Linnarsson, 1883)

Fig. 3A

Material. – One nearly complete pygidium.

Remarks. – The species was described by Westergård (1946, pp. 25-26, pl. 1, figs. 6-11) and Babcock (1994, pp. 112-115, fig. 28, 1-5). It is considered to be fairly common in a thin layer just above the Exsulans Limestone at Andrarum in Scania (Westergård 1944). *E. scanicus* occurs at the corresponding level in the Almbacken core (25.08 m).

Occurrence. – Zone of *Ptychagnostus gibbus* in the Almbacken core. Also known from Norway, Great Britain, Canada, and Greenland (Westergård 1946; Babcock 1994).

Genus *Opsidiscus* Westergård, 1950

Opsidiscus bilobatus (Westergård, 1946)

Material. – Three cephala, one being nearly complete.

Remarks. – The species was discussed and illustrated by Westergård (1946, p. 27, pl. 1, figs. 16-22). The Almbacken specimens are poorly preserved in shale. The species is considered to be rare in all localities in Scania and all specimens found have been of inferior preservation. The name *bilobatus* is derived from the bilobate-shaped glabella, a feature that seems to be unique in the family Eodiscidae (Westergård 1946).

Occurrence. – Zone of *Lejopyge laevigata* in the Almbacken core. *O. bilobatus* has also been recorded from Andrarum, Östergötland, and Västergötland (Westergård 1946).

Family Peronopsidae Westergård, 1936

Genus *Cotalagnostus* Whitehouse, 1936

Cotalagnostus lens claudicans (Grönwall, 1902)

Fig. 3B

Material. – One nearly complete cephalon and one poorly preserved pygidium.

Remarks. – *C. lens claudicans* shares many morphological characteristics with *Hypagnostus truncatus* (Brögger, 1878) as well as with many other species of *Hypagnostus*, but can be distinguished by e.g. a less rectangular glabella and a less defined anterior glabellar furrow. According to Westergård (1946), *H. truncatus* is a forerunner of *C. lens claudicans*. The subspecies was described by Westergård (1946, p. 54, pl. 6, figs. 20-27). The cephalon of *C. lens claudicans* can be separated from the nominal subspecies by its less oval shape.

Occurrence. – *T. fissus/P. atavus* Zone in the Almbacken core. In Scania, it is also known from Brantevik and Gislövshammar, where it appears to be fairly rare (Westergård 1946).

Genus *Hypagnostus* Jaekel, 1909

Hypagnostus parvifrons (Linnarsson, 1869)

Fig. 3C-D

Material. – Thirteen cephala and two pygidia.

Remarks. – Brögger (1878) distinguished two varieties of *H. parvifrons*, viz. *nepos* and *mammillata*. The former was regarded as a species by Westergård (1946). *H. parvifrons* is extremely rare in the Middle Cambrian of Australia, but there are a few occurrences in the *Euagnostus opimus* Zone (Öpik 1979). *H. parvifrons* was discussed by e.g. Westergård (1946, p. 45, pl. 4, figs. 27-31), Öpik (1979, pp. 66-67, pl. 6, figs. 7-8), and Peng & Robison (2000, pp. 60-63, fig. 45).

Occurrence. – The species appears in the upper part of the *T. fissus/P. atavus* Zone and ranges through the *H. parvifrons* Zone in the Almbacken core. It is widely distributed in Scandinavia, and has also been recorded from e.g. Great Britain, North America, Greenland, and China (Westergård 1946; Robison 1994; Peng & Robison 2000).

Hypagnostus cf. *nepos* (Brögger, 1878)

Fig. 3E-F

Material. – About thirty cephala and thirty pygidia.

Remarks. – The species was originally described by Brögger (1878, p. 72, pl. 6, fig. 2) and later by Westergård (1946, pp. 47-48, pl. 5, figs. 5-8). The preservation of the Almbacken material is very poor, and the species identification is uncertain. *H. nepos* differs from its ascendant *H. parvifrons* in having a more elongate glabella and a narrower posteroaxis, features only seen in few of the specimens in this study.

Occurrence. – *H.* cf. *nepos* was found in the lower part of the *P. lundgreni/G. nathorsti* Zone in the Almbacken core. According to Westergård (1946) the species probably ranges through the *P. punctuosus* Zone to the lower portion of the *S. brachymetopa* Zone. The species is known from numerous localities in Sweden and Norway (Westergård 1946).

Hypagnostus sp.

Material. – Some twenty cephala and numerous fragmentary shields.

Remarks. – The material seems to represent the genus *Hypagnostus*, but the poor state of preservation makes further classification difficult.

Occurrence. – Occurs sporadically from the *H. parvifrons* Zone to the lower part of the *P. lundgreni/G. nathorsti* Zone in the Almbacken core.

Genus *Peronopsis* Hawle & Corda, 1847

Peronopsis fallax (Linnarsson, 1869)

Fig. 3G-H

Material. – Hundreds of disarticulated specimens.

Remarks. – This is by far the most abundant species in the Almbacken core. The long range of *P. fallax* implies that its use in biostratigraphy is limited (Öpik 1979). The species was revised by Westergård (1946, pp. 37-39) and his classification, which include three subspecies, has been generally accepted. *P. fallax* was described and illustrated by Westergård (1946, p. 37, pl. 2, figs. 18-24) and Öpik (1979, pp. 54-55, pl. 4, figs. 4-7).

Occurrence. – In the Almbacken core the species ranges from the uppermost part of the *P. gibbus* Zone to the lowermost part of the *P. punctuosus* Zone.

Peronopsis fallax depressa Westergård, 1946

Fig. 3I

Material. – Two pygidia.

Remarks. – The pygidium has a low convexity and a slightly ogival-shaped posteroaxis with a transverse sulcus. The preservation in one of the specimens is poor, but it shows one of the pygidial spines, a feature rarely seen in the Almbacken material. The subspecies was described by Westergård (1946, pp. 37-38, pl. 2, figs. 25-26).

Occurrence. – This subspecies occurs at the top of the *H. parvifrons* Zone in the Almbacken core. It is also present, but rare, in other localities in Scania (Westergård 1946).

Peronoposis fallax ferox (Tullberg, 1880)

Fig. 3J

Material. – Two cephala and six pygidia.

Remarks. – This subspecies can be distinguished from *P. fallax fallax* by its shorter pygidial axis, and the lateral lobes being uniform in breadth throughout (Westergård 1946). The Almbacken specimens conforms in all essential features with Westergård's (1946) description, but has a somewhat less blunt termination of the pygidial axis.

Occurrence. – Upper part of the *P. punctuosus* Zone in the Almbacken core. It is widely distributed in Scandinavia, and ranges from the *P. punctuosus* Zone into the lowermost part of the *S. brachymetopa* Zone (Westergård 1946).

Peronopsis pusilla (Tullberg, 1880)

Material. – One pygidium.

Remarks. – The pygidium is incomplete and not well preserved, but shows several morphological features. The pygidial axis is short, faintly ogival in shape and nearly as wide as each of the lateral lobes, which are equal in breadth throughout and separated by a very faint postaxial furrow. The external exoskeletal surface is smooth but can sometimes be faintly granulated (Westergård 1946). The species was thoroughly described by Westergård (1946, pp. 42-43, pl. 4, figs. 12-18).

Occurrence. – *P. punctuosus* Zone of the Almbacken core. The species is known from many localities in Scania, and also from e.g. Bornholm (Denmark), Newfoundland, and Norway (Westergård 1946).

Peronopsis scutalis (Salter *in* Hicks, 1872)

Material. – Four cephala and six pygidia.

Remarks. – The pygidium of *P. scutalis* is similar to that of *C. lens claudicans*, but has a shorter, narrower, and more pointed posteroaxis. The species was described by Westergård (1946, pp. 41-42, pl. 4, figs. 4-11).

Occurrence. – Uppermost part of *T. fissus/P. atavus* Zone in the Almbacken core. It is known to appear just above the Exsulans Limestone and range to the top of the *T. fissus/P. atavus* Zone (Westergård 1946). Outside Scania, *P. scutalis* is recorded from Great Britain and Newfoundland (Westergård 1946).

Peronopsis sp.

Material. – Hundreds of disarticulated specimens.

Remarks. – All shields are either too small or too damaged for species identification.

Occurrence. – Ranges through the major part of the Almbacken core, from the upper *P. gibbus* Zone to the middle *P. lundgreni/G. nathorsti* Zone.

Family Phalacromidae Hawle & Corda, 1847

Genus *Phalacroma* Hawle & Corda, 1847

Phalacroma scanicum (Tullberg, 1880)

Fig. 4B

Material. – Two pygidia, one of which is an external mould.

Remarks. – This species is rare and poorly known (Westergård 1946). A brief description of the species was made by Westergård (1946, p. 93, pl. 14, figs. 15-18), based upon only a few poorly preserved specimens. The pygidium of *P. scanicum* is similar to that of *Phalacroma marginatum* (Brögger, 1878) but has a more oval posteroaxis and a border which is more or less subequal in breadth, occasionally expanding backwards, as seen in the Alm-

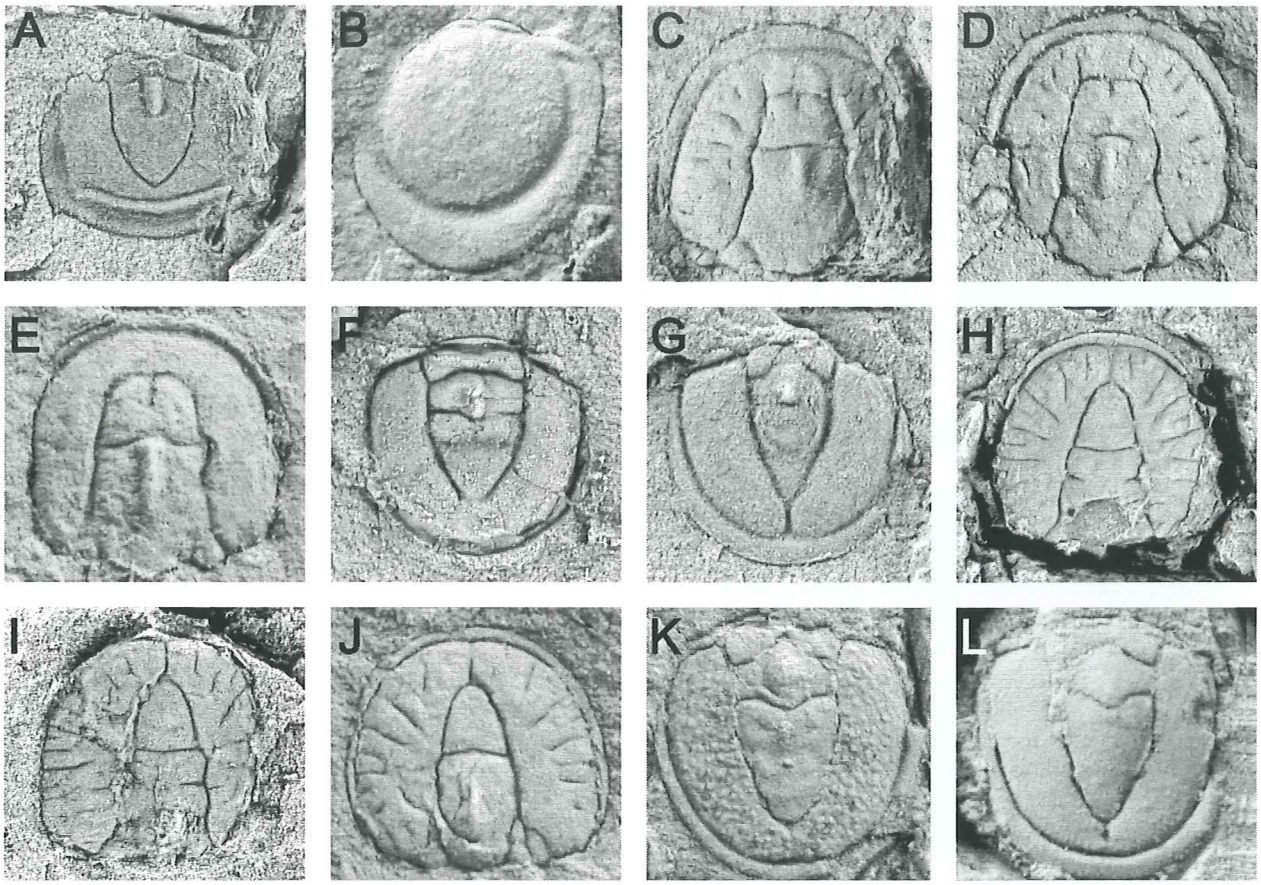


Fig. 4. **A.** *Diplagnostus planicauda* (Angelin, 1851), incomplete pygidium. *P. punctuosus* Zone in the Almbacken core (10.52 m). ×8. **B.** *Phalacroma scanicum* (Tullberg, 1880), pygidium, latex cast of external mould. *P. punctuosus* Zone in the Almbacken core (15.22 m). ×12. **C-F.** *Tomagnostus fissus* (Linnarsson, 1879). *H. parvifrons Zone* in the Almbacken core. **C,** cephalon (22.45 m). ×8.5. **D,** cephalon (22.45 m). ×9. **E,** cephalon (22.50 m). ×9.5. **F,** pygidium (22.45 m). ×8. **G.** *Doryagnostus incertus* (Brögger, 1878), pygidium. *P. punctuosus* Zone in the Almbacken core (13.50 m). ×11. **H-I.** *Goniagnostus nathorsti* (Brögger, 1878). *P. lundgreni/G. nathorsti* Zone in the Almbacken core. **H,** cephalon (9.40 m). ×7.5. **I,** incomplete cephalon (9.40 m). ×7.5. **J-K.** *Ptychagnostus affinis* (Brögger, 1878). *H. parvifrons* Zone in the Almbacken core. **J,** cephalon (17.76 m). ×13. **K,** pygidium (15.60 m). ×9.5. **L.** *Ptychagnostus lundgreni nanus* (Grönwall, 1902), pygidium. *P. lundgreni/G. nathorsti* Zone in the Almbacken core (6.46 m). ×11.

backen core. This posterior expansion of the border is, however, not as pronounced as in *P. marginatum*.

Occurrence. – Lower portion of the *P. punctuosus* Zone in the Almbacken core. It is also known from Andrarum, Brantevik, and Gislövshammar in Scania (Westergård 1946).

Family Diplagnostidae Whitehouse, 1939

Genus *Diplagnostus* Jaekel, 1909

Diplagnostus planicauda (Angelin, 1851)

Fig. 3K-L, 4A

Material. – Approximately 40 cephala and 30 pygidia of various sizes and states of preservation.

Remarks. – The species was described by Westergård (1946, pp. 61-62, pl. 8, figs. 13-24) and most recently by Peng & Robison (2000, p. 49, figs. 5.5, 35). Three subspecies have been described (see Westergård 1946). However, Robison (1988, pp. 33-35) noted that these are based on characters that can vary within populations and that there is no reason to distinguish subspecies. This view is followed herein and *D. planicauda bilobatus* is only regarded as a variety of *D. planicauda*.

Occurrence. – Ranges from the upper part of the *P. punctuosus* Zone into the *P. lundgreni/G. nathorsti* Zone in the Almbacken core. Besides Scania, *D. planicauda* is widely distributed in Scandinavia (Westergård 1946). Outside Scandinavia *D. planicauda* is known from e.g. Australia, China, and Greenland (Robison 1988; Peng & Robison 2000).

Genus *Tomagnostus* Howell, 1935

Tomagnostus fissus (Linnarsson, 1879)

Fig. 4C-F

Material. – Approximately one hundred cephala and pygidia in various states of preservation, generally flattened. No complete specimens or thoracic segments found.

Remarks. – Scandinavian specimens were described thoroughly by Westergård (1946, pp. 58-59, pl. 7, figs. 21-29). It is considered to be rare in the Exsulans Limestone (Westergård 1946), which is in accordance with the number of specimens in the Exsulans Limestone of the Almbacken core. Some specimens found in the Almbacken core show faint radiating grooves on the cheeks. Displayment of grooves on the cheeks is a feature that usu-

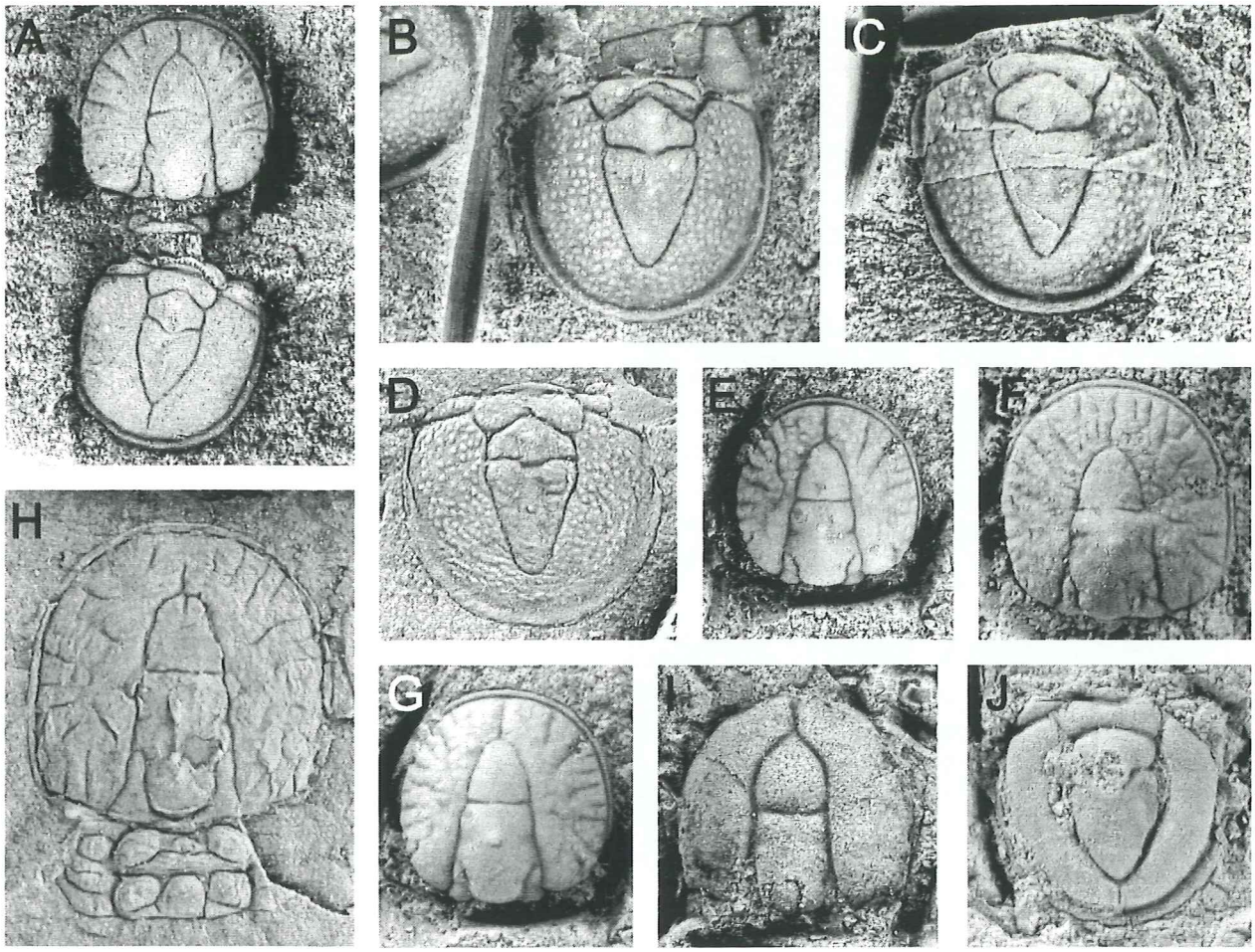


Fig. 5. **A-G.** *Ptychagnostus punctuosus* (Angelin, 1851). *P. punctuosus* Zone in the Almbacken core. **A,** nearly complete specimen (14.80 m). ×9. **B,** pygidium (14.15 m). ×8. **C,** pygidium (11.90 m). ×7. **D,** pygidium (11.17 m). ×7. **E,** cephalon (14.80 m). ×6. **F,** cephalon (14.80 m). ×8.5. **G,** cephalon (14.80 m). ×7. **H.** *Ptychagnostus affinis* (Brögger, 1878), cephalon with attached thoracic segments. *H. parvifrons* Zone in the Almbacken core (17.76 m). ×9.5. **I-J.** *Ptychagnostus gibbus* (Linnarsson, 1869). *P. gibbus* Zone in the Almbacken core. **I,** cephalon (25.10 m). ×6.5. **J,** pygidium (25.23 m). ×7.

ally occurs in the species, but they may sometimes be absent (Westergård 1946). Absence of grooves on the cheeks can be seen in a few specimens in the Almbacken core, but may be a result of poor preservation.

Occurrence. – Appears in the upper part of the *P. gibbus* Zone and continues through the *T. fissus/P. atavus* Zone to the lower boundary of the *H. parvifrons* Zone in the Almbacken core. The species is also known from Great Britain and eastern North America (Westergård 1946).

Family Doryagnostidae Shergold, Laurie & Sun, 1990

Genus *Doryagnostus* Kobayashi, 1939

Doryagnostus incertus (Brögger, 1878)

Fig. 4G

Material. – One nearly complete pygidium.

Remarks. – The species was described by Westergård (1946, pp. 83-84, pl. 12, figs. 20-23) and Öpik (1979, p. 82, pl. 17, fig. 3). The pygidium of *D. incertus* is characterized by a narrow terminal axis with a pointed termination of the posteroaxis and a transverse sulcus. The genus *Doryagnostus* was initially assigned to the family Agnostidae M'Coy, 1849, but was later reassigned, by Kobayashi (1939), to the family Ptychagnostidae. Currently, *D. incertus* is the only species in the Doryagnostidae, a family erected by Shergold, Laurie & Sun (1990).

Occurrence. – Middle part of the *P. punctuosus* Zone in the Almbacken core. According to Peng & Robison (2000) *D. incertus* ranges from the base of the *P. punctuosus* Zone to the *P. lundgreni/G. nathorsti* Zone. *D. incertus* has been recorded from Scandinavia, Australia, and China (Westergård 1946; Öpik 1979; Peng & Robison 2000).

Family Ptychagnostidae Kobayashi, 1939

Genus *Goniagnostus* Howell, 1935

Goniagnostus nathorsti (Brögger, 1878)

Fig. 4H-I

Material. – Four incomplete cephala and one incomplete pygidium.

Remarks. – This is a distinctive and easily identified species. The surface of the genae and the pleural fields are finely granular, but in poorly preserved specimens the surface may appear smooth (Westergård 1946). *G. nath-*

orsti was described by Westergård (1946, p. 81, pl. 12, figs. 12-16) and Öpik (1979, pp. 150-152, pl. 47, fig. 6; pl. 60, figs. 1-5; pl 61, figs. 1, 3-6). It was recently discussed by Peng & Robison (2000), who gave a complete list of synonyms.

Occurrence. – Lower part of the *P. lundgreni/G. nathorsti* Zone in the Almbacken core. *G. nathorsti* is known from several districts in Scandinavia, as well as from Australia, Canada, and China (Westergård 1946; Öpik 1979; Peng & Robison 2000).

Genus *Lejopyge* Hawle & Corda, 1847

Lejopyge sp.

Material. – Six cephala and seven pygidia, none of them complete.

Remarks. – The cephala and pygidia from the Almbacken core are poorly preserved, but show some of the characteristics of *Lejopyge*. Their stratigraphic occurrence suggest that they probably belong to *Lejopyge laevigata*.

Occurrence. – Lower part of the *S. brachymetopa* Zone and the lower part of what is considered to be the *L. laevigata* Zone. In Sweden *Lejopyge* is restricted to the middle and upper part of the *P. forchhammeri* Stage (Westergård 1946).

Genus *Ptychagnostus* Jaekel, 1909

Ptychagnostus affinis (Brögger, 1878)

Fig. 4J-K, 5H

Material. – Approximately 70 cephala and 100 pygidia.

Remarks. – This species is similar to *P. punctuosus* and *P. atavus*, and is considered to be an intermediate form between these two species (Westergård 1946). It seems to be most closely related to *P. atavus*. The pygidium of *P. affinis* is characterized by a weak granulation on the pleural fields, but not on the pygidial axis (Robison 1984). This granulation is, however, not always distinct, especially not in the Almbacken material where most of the specimens are flattened. This makes it sometimes difficult to separate pygidia of *P. affinis* from *P. atavus*, since the latter lacks any form of granulation.

There are of course other morphological features, which can be used for classification even though the granulation seems to be the most characteristic one. *P. affinis* sometimes display one to five pairs of faint lateral grooves on the posteroaxis (Westergård 1946). This feature is, however, only evident in adult specimens, and has not been observed in the Almbacken material, despite the presence of relatively well preserved specimens. Because of the difficulties in discrimination between the two species, some specimens have been left under open nomenclature. This is unsatisfactory since the preservation of these specimens is generally good enough to enable further assignment. Furthermore there are intermediate forms between the two, forming a practically continuous evolutionary series (Westergård 1946).

P. affinis was described and illustrated by e.g. Westergård (1946, p. 79, pl. 11, figs. 26-33), Öpik (1979, pp. 91-92, pl. 39, fig. 8; pl. 40, figs. 2-7) and Robison (1984, pp. 16-17, fig. 9).

Occurrence. – *P. affinis* ranges from the lower *H. parvifrons* Zone to the lower middle *P. punctuosus* Zone in the Almbacken core. It is known from numerous localities in Sweden and has also been documented from e.g. China, Greenland, and Norway (Westergård 1946; Öpik 1979; Peng & Robison 2000).

Ptychagnostus atavus (Tullberg, 1880)

Fig. 8C-D

Material. – Nearly 110 cephala and 95 pygidia.

Remarks. – As mentioned above, *P. atavus* is similar to *P. affinis*, but lacks any kind of coarse granulation on the pleural fields. The surface of the genae may vary from smooth to moderately scrobiculate (Peng & Robison 2000). According to Westergård (1946) specimens with smooth genae are known from Sweden. Westergård (1946) regarded *Ptychagnostus intermedius* as a synonym of *P. atavus*. This was discarded by, amongst others, Robison (1982) and Öpik (1979) who considered *P. intermedius* as a separate species.

The species was thoroughly described and discussed by Westergård (1946, pp. 76-77, pl. 11, figs. 8-23), Robison (1984, pp. 18-21, fig. 11) and Öpik (1979, pp. 93-94, pl. 29, fig. 7; pl. 42, figs. 7-8; pl. 43, figs. 1-4).

Occurrence. – The species first appears, often in great numbers, in the *T. fissus/P. atavus* Zone and continues into the upper part of the *H. parvifrons* Zone in the Almbacken core. *P. atavus* is considered to be a common species and is reported from e.g. Australia, China, Denmark, North America, and Norway (Robison 1984).

Ptychagnostus gibbus (Linnarsson, 1869)

Fig. 5I-J, 8A-B

Material. – Thirty cephala, twenty-eight pygidia and one complete specimen.

Remarks. – *P. gibbus* is the index fossil for the lowermost zone in the Almbacken core and can be found within and just above the Exsulans Limestone. Despite the abundance of cephala in the Almbacken core (25.09-25.21 m) no cephalic spines have been observed. The spines, which are characteristic of the species, are generally broken off in specimens preserved in limestone (Westergård 1946). Besides the cephalic spines, *P. gibbus* bears one spine on the posterior thoracic segment and one on the M2 of the pygidium, but in the Almbacken material only the latter spine is visible. Its spinosity separates it from other Scandinavian species of *Ptychagnostus* (Westergård 1946).

P. gibbus was described and discussed by Westergård (1946, pp. 70-71, pl. 9, figs. 17-24) and Robison (1984, pp. 22-24, fig. 13).

Occurrence. – Occurs in what is herein considered to be the uppermost part of the *P. gibbus* Zone. *P. gibbus* has been documented from all continents except Africa and South America, and is considered to be a very common species (Robison 1984).

Ptychagnostus cf. *hybridus* (Brögger, 1878)

Material. – One incomplete cephalon.

Remarks. – This species was briefly described by Westergård (1946, pp. 71-72, pl. 9, figs. 25-26, pl. 10, figs. 1-2) and the cephalon found in the Almbacken core seems to be in accordance with his illustrations. The identification remains uncertain since the cephalon is imperfectly preserved, and because of the uncertainty of whether or not the species occurs in the *P. punctuosus* Zone.

Occurrence. – Lower part of the *P. punctuosus* Zone in the Almbacken material. *Ptychagnostus* cf. *hybridus* is also known from Canada, Great Britain, and Norway (Westergård 1946).

Ptychagnostus cf. *intermedius* (Tullberg, 1880)

Fig. 9A

Material. – One poorly preserved cephalon.

Remarks. – *P. intermedius* commonly shows a pair of crescentic scrobicules on the anterior parts of the cheek (Robison 1984), a feature visible on the specimen found in the Almbacken material. The species was fully described by Robison (1984, pp. 25-28, fig. 15), and briefly by Öpik (1979, p. 95, pl. 41, fig. 8).

Occurrence. – Lowermost part of the *T. fissus/P. atavus* Zone in the Almbacken core. The species is also known from e.g. Australia, China, Norway, and Greenland (Robison 1984). The only documented occurrence in the *T. fissus/P. atavus* Zone proper is from Australia; in all other parts of the world it is known only from the *P. gibbus* Zone (Robison 1984). This information has not been used herein for determination of the *T. fissus/P. atavus* - *P. gibbus* boundary since the species identification is uncertain.

Ptychagnostus lundgreni (Tullberg, 1880)

Fig. 9D

Material. – Eighteen cephala, nine pygidia and one complete specimen.

Remarks. – The generic affiliation of this species has changed during the past decades. Robison (1984, 1994) claimed that *P. lundgreni* was an ancestral species of the genus *Lejopyge*, thought to have been derived from *P. intermedius* by paedomorphism (Robison 1984). Robison (1994) later revised his own classification and assigned *L. lundgreni* to the genus *Pseudophalacroma*. In the same paper Robison (1994) reports that "the origin of *P. lundgreni* within the Ptychagnostidae remains unclear". I therefore follow Westergård (1946), who assigned the species to *Ptychagnostus*. The species was briefly discussed by Westergård (1946, p. 75, pl. 10, figs. 23-25; pl. 11, figs. 1-2) and in detail by Robison (e.g. 1984, pp. 46-49, figs. 27-28).

Occurrence. – Appears at the base of the *P. lundgreni/G. nathorsti* Zone and ranges to the base of the *S. brachymetopa* Zone in the Almbacken core.

Ptychagnostus lundgreni nanus (Grönwall, 1902)

Fig. 4L

Material. – Fifteen cephala and eighteen pygidia.

Remarks. – The most distinctive feature, which differentiates this subspecies from the nominal subspecies is a narrower posteroaxis. Furthermore, the glabella is less convex and the transverse furrows shallower in *P. lundgreni nanus* (Westergård 1946). According to Robison (1984) there is no reason for distinguishing subspecies since the differences are very subtle. In the present material, however, the differences are subtle, but still distinguishable. The subspecies was briefly described by Westergård (1946, pp. 75-76, pl. 11, figs. 3-7).

Occurrence. – *P. lundgreni nanus* ranges from the lower *P. lundgreni/G. nathorsti* Zone to the lower part of the *L. laevigata* Zone in the Almbacken core. According to Westergård (1946) the range of this subspecies is associated with that of *P. lundgreni lundgreni*. The range in the Almbacken core is in accordance with the known stratigraphical range of *P. lundgreni lundgreni* (see Robison 1984).

Ptychagnostus punctuosus (Angelin, 1851)

Fig. 5A-G

Material. – 300 cephala and pygidia, and one nearly complete specimen.

Remarks. – The characteristics of *P. punctuosus* are similar to those of *P. affinis*, but *P. punctuosus* shows a much more elaborate granulation, often visible on the major part of the test, except on the thoracic segments. Contrary to *P. affinis*, *P. punctuosus* also shows granules on the cephalic surface. As in many other species within the genus *Ptychagnostus*, *P. punctuosus* is variable in many respects (Westergård 1946). The species was described by e.g. Westergård (1946, pp. 78-79, pl. 11, figs. 34-35; pl.12, figs. 1-7) and Robison (1984, pp. 33-35, fig. 20).

Ontogeny. – A small number of well-preserved juvenile specimens were found at three different levels: 11.90 m, 14.15 m, and 14.80 m. These specimens certainly belong to *P. punctuosus* since no other species have been found at these levels. Nine juvenile pygidia and four juvenile cephala were found. Features showing morphological changes during the ontogeny have been observed, but many stages of growth are probably missing. No protaspids were found, something that might be explained by the fact that the present study was carried out using a microscope with a magnification capacity of merely x10. Only the pygidia will be discussed since the cephala found display only minor changes during ontogeny. The size of each discussed and illustrated specimen can be seen in Fig. 7.

The youngest specimen found is considered to be of an early meraspid stage (Fig. 6A). The future segmentation of the thorax is visible by a pair of fused thoracic segments on the anterior part of the pygidium. The pygidial axis is short and narrow. The posteroaxis has a

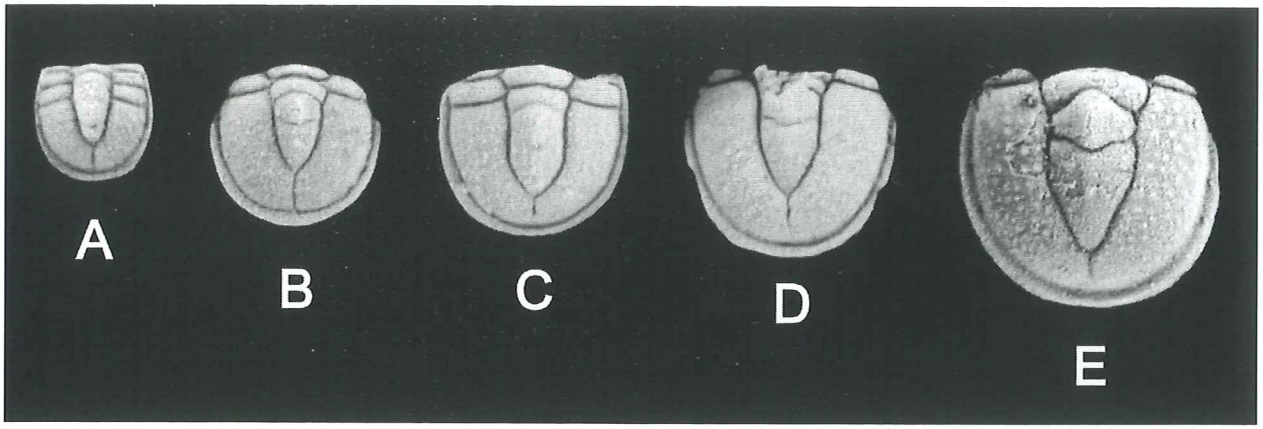


Fig. 6. Growth stages in pygidia of *Ptychagnostus punctuosus* (Angelin, 1851). *P. punctuosus* Zone in the Almbacken core. **A,** pygidium (14.15 m). ×15. **B,** pygidium (11.90 m). ×15. **C,** pygidium (14.15 m). ×15. **D,** pygidium (14.80 m). ×15. **E,** pygidium (11.90 m). ×14.

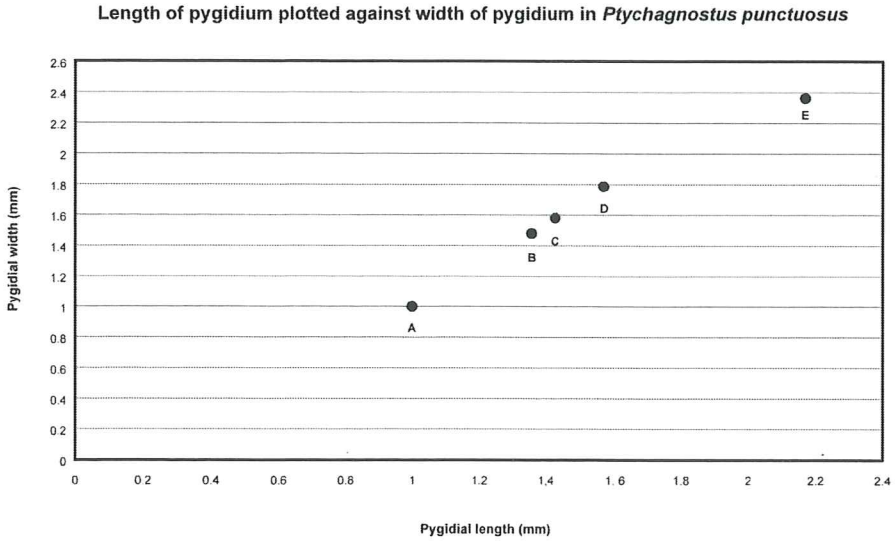
lanceolate form and is acutely pointed. A small posteriorly orientated protuberance is faintly visible. The segmentation of the anteroaxis is not yet visible at this stage. The pleural fields are smooth and tapers slightly posteriorly. The postaxial median furrow is clearly visible.

Still in a meraspid stage, Fig. 6B displays several morphological changes. Besides the obvious increase in size, the first of the two thoracic segments has been released from the pygidium into the thorax. The posteroaxis is still lanceolate in shape. Faint lateral axial furrows are now visible. A very small axial node is visible on the anterior part of the future M2 of the pygidial axis. The posteriorly orientated protuberance still exists and is now considered to be a secondary median node, a feature that will be effaced in later stages. The termination of the posteroaxis is more acutely pointed than in the previous stage. The postaxial median furrow is well defined. There are still no signs of granulation on the test. The pygidial rim is somewhat wider compared to the previous stage.

The posterior thoracic segment is still attached to the pygidium in Fig. 6C. The major changes are an increase in size and in the morphology of the pygidial axis. The thoracic segment in the specimen is very well defined by its deep lateral furrows and will probably be released into the thorax during the next moulting. The posteroaxis displays a more ogival shape and the F1 and F2 of the pygidial axis are clearly visible. The axial node on the M2 is not as distinct in this specimen but the secondary median node is. The absence of the axial node is probably due to poor preservation. The pleural fields display a very faint granulation, barely visible, and the postaxial median furrow is not as pronounced as in the former specimens. The presence of a postaxial median furrow is a typical juvenile feature in *P. punctuosus* and it becomes completely effaced at a later stage (Westergård 1946). There is no sign of a depression of the posteroaxis.

The specimen in Fig. 6D is damaged on the anterior part of the pygidial axis. The posterior thoracic segment is now released, which implies that the specimen is in an early holaspid stage. Besides this, few morphological changes have been made. The secondary median node is still visible and so is the postaxial median furrow, although it is very faint. There is no granulation of the test, probably because of poor preservation. A faint depression of the posteroaxis is visible from a lateral view. There is a slight increase in size compared to the previously described specimen.

Fig. 7. Diagram showing pygidial size of *Ptychagnostus punctuosus*. A-E denote specimens illustrated in Fig. 6 A-E.



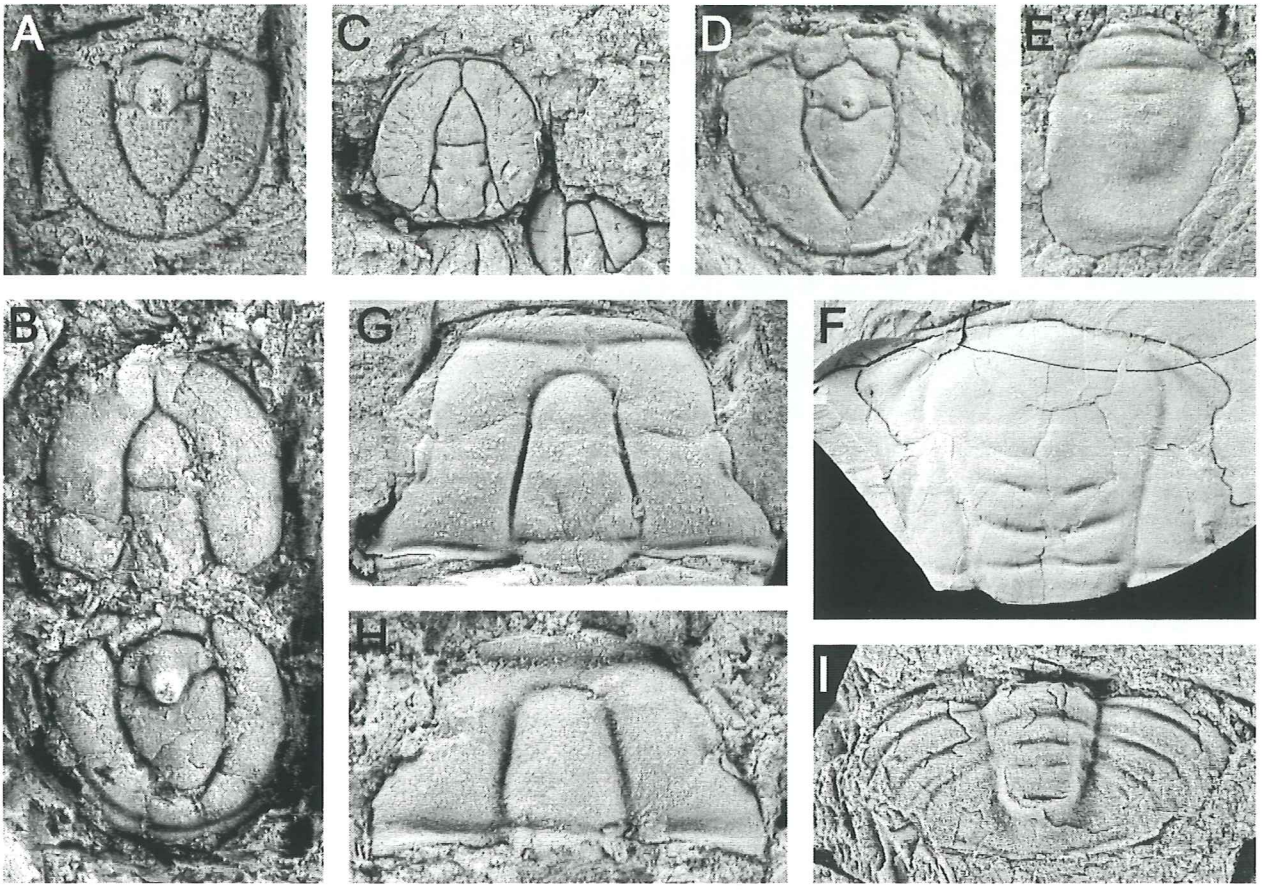


Fig. 8. **A-B.** *Ptychagnostus gibbus* (Linnarsson, 1869). *P. gibbus* Zone in the Almbacken core. **A,** pygidium (25.10 m). ×8. **B,** nearly complete specimen (25.09 m). ×7. **C-D.** *Ptychagnostus atavus* (Tullberg, 1880). *T. fissus/P. atavus* Zone in the Almbacken core. **C,** two cephala (23.29 m). ×4.5. **D,** pygidium (23.27 m). ×10. **E-F.** *Paradoxides paradoxissimus* (Wahlenberg, 1818). **E,** incomplete pygidium, latex cast of external mould. *T. fissus/P.atavus* Zone in the Almbacken core (24.90 m). ×6.5. **F,** cranidium. *H. parvifrons* Zone in the Almbacken core (17.72 m). ×1.5. **G.** *Parasolenopleura* cf. *scanica* (Westergård, 1953), cranidium. *T. fissus/P. atavus* Zone in the Almbacken core (24.00 m). ×3.5. **H.** *Parasolenopleura aculeata* (Angelin, 1851), cranidium. *P. gibbus* Zone in the Almbacken core (25.21 m). ×9.5. **I.** *Parasolenopleura linnarssoni* (Brögger, 1878), pygidium. *T. fissus/P. atavus* Zone in the Almbacken core (24.98 m). ×6.

In Fig. 6E many changes have taken place and there are probably a number of instars between it and the pygidia illustrated in Fig. 6D. The pygidial axis is now very well developed and all the transverse axial divisions (M1 and M2) as well as the lateral furrows (F1 and F2) are clearly visible. The ogival shape of the posteroaxis is distinct, although the termination of the posteroaxis is still quite acute. The secondary median node as well as the postaxial median furrow are no longer as evident as earlier. Granulation on the pleural fields is now abundant. There are, however, no signs of any granulation on the pygidial axis. With further moulting a few minor additional changes of the test would take place, i.e. a more defined depression of the posteroaxis and additional granulation, but from now on the most radical change will be an increase in size until adulthood is reached (Hunt 1967).

Occurrence. – *P. punctuosus* range from the upper part of the *H. parvifrons* Zone to the upper part of the *P. punctuosus* Zone in the Almbacken core. Its occurrence overlaps that of *P. affinis*. According to Robison (1984) the two taxa are normally not associated, but have been documented together in a few areas.

Ptychagnostus cf. *stenorrhachis* (Grönwall, 1902)

Material. – One nearly complete pygidium.

Remarks. – This species is considered to be rare and the description by Westergård (1946, p. 72) is based upon only a few cephala and pygidia. The pygidium found in the Almbacken core is poorly preserved, but still shows many of the characters of *P. stenorrhachis*, such as a narrow pygidial axis. Because of its close alliance to *P. hybridus* it is uncertain if this determination is correct. The species was described by Westergård (1946, p. 72, pl. 10, figs. 3-4).

Occurrence. – At the boundary between the *H. parvifrons* Zone and the *P. punctuosus* Zone in the Almbacken core. The species has also been found at Gislövshammar and Södra Sandby in Scania, and on Bornholm, Denmark (Westergård 1946).

Ptychagnostus sp.

Material. – Seven cephala and five pygidia.

Remarks. – The material is left in open nomenclature due to poor preservation, but most specimens seem to represent either *P. affinis* or *P. atavus*.

Occurrence. – In the Almbacken core, these indeterminable ptychagnostids are known from the *T. fissus/P. atavus* Zone up into the *S. brachymetopa* Zone.

Order Asaphida Salter, 1864

Family Anomocaridae Poulsen, 1927

Genus *Anomocarina* Lermontova, 1940

Anomocarina excavata (Angelin, 1851)

Material. – One incomplete cranidium.

Remarks. – Only part of the glabella and the right cheek are preserved in the Almbacken material. The right posterior glabellar furrow is distinct, as described by Westergård (1950). The long palpebral lobe and the distinct facial suture support the species identification. The species was described by Westergård (1950, pp. 17-19, pl. 3. figs. 12-19).

Occurrence. – *Solenopleura brachymetopa* Zone in the Almbacken core. The species have been recorded from numerous localities in Scandinavia, as well as from Siberia (Westergård 1950).

Order Ptychopariida Swinnerton, 1915

Family Solenopleuridae Angelin, 1854

Genus *Parasolenopleura* Westergård, 1953

Parasolenopleura aculeata (Angelin, 1851)

Fig. 8H

Material. – Four cranidia.

Remarks. – *P. aculeata* was thoroughly described and discussed by Westergård (1953, pp. 23-25, pl. 5. figs. 6-10, pl. 6. figs. 1-4). The Almbacken material is generally very well preserved and the cranidia are nearly complete. Many species of the genus *Parasolenopleura* are very similar and difficult to separate. The external exoskeletal surface is finely granular in most species, a feature visible only under a microscope (Westergård 1953).

Occurrence. – Uppermost part of the *P. gibbus* Zone in the Almbacken core. The species is generally common and appears to be restricted to this zone (Westergård 1953). *P. aculeata* is well known from many areas in Sweden and has also been recorded from Norway (Westergård, 1953).

Parasolenopleura linnarssoni (Brögger, 1878)

Fig. 8I, 9F

Material. – Six incomplete cranidia and one pygidium.

Remarks. – The species was described in detail by Westergård (1953, pp. 26-28, pl. 6, figs. 9-12). According to Westergård (1953) *P. linnarssoni* occurs in two varieties, one with an occipital node and one with an occipital spine. None of these features are preserved in the Almbacken material, but in all other respects it conforms with Westergård's (1953) description of *P. linnarssoni*.

Occurrence. – The species ranges from the lower part of the *T. fissus/P. atavus* Zone to the uppermost part of the *H. parvifrons* Zone in the Almbacken core. It is known from numerous localities in Sweden, and has also been recorded from Bornholm, Norway, and Poland (Westergård 1953).

Parasolenopleura cf. *scanica* (Westergård, 1953)

Fig. 8G

Material. – One complete cranidium.

Remarks. – *P. scanica* was discussed and described by Westergård (1953, pp. 25-26, pl. 6, figs. 5-8). Westergård (1953) states that the test is smooth to the naked eye but reveals granulation under the microscope. The cranidium from the Almbacken core clearly shows granulation, easily visible without a microscope, and this is one of the reasons for the uncertain identification. *P. scanica* resembles *Solenopleura parva*, but has a less convex cranidium (Westergård 1953). Convexity is a feature rarely seen in the Almbacken core because compaction of the shale has resulted in flattened specimens.

Occurrence. – Middle part of the *T. fissus/P. atavus* Zone in the Almbacken core. In Scania the species is known from Andrarum and Brantevik (Westergård 1953).

Parasolenopleura sp.

Material. – One cranidium and one pygidium.

Remarks. – The material is fragmentary and must be treated as indeterminate at species level.

Occurrence. – Upper part of the *T. fissus/P. atavus* Zone to the middle-upper part of the *H. parvifrons* Zone in the Almbacken core.

Genus *Solenopleura* Angelin, 1854

Solenopleura parva Linnarsson, 1879

Fig. 9B-C

Material. – Two cranidia and one small incomplete pygidium.

Remarks. – The species was thoroughly described by Westergård (1953, pp. 12-13, pl. 2, figs. 11-13), who also noted that it is closely related to *S. munsteri*. The cranidia of these two species are very similar and can easily be misidentified. The test is finely granular, not visible to the naked eye.

Occurrence. – All specimens found are from the same level (25.35 m) in the Exsulans Limestone (*P. gibbus* Zone). The species is generally common in the Exsulans Limestone and has been recorded from many Swedish localities (Westergård 1953).

Solenopleura cf. *munsteri* Strand, 1929

Fig. 9E

Material. – One nearly complete cranidium.

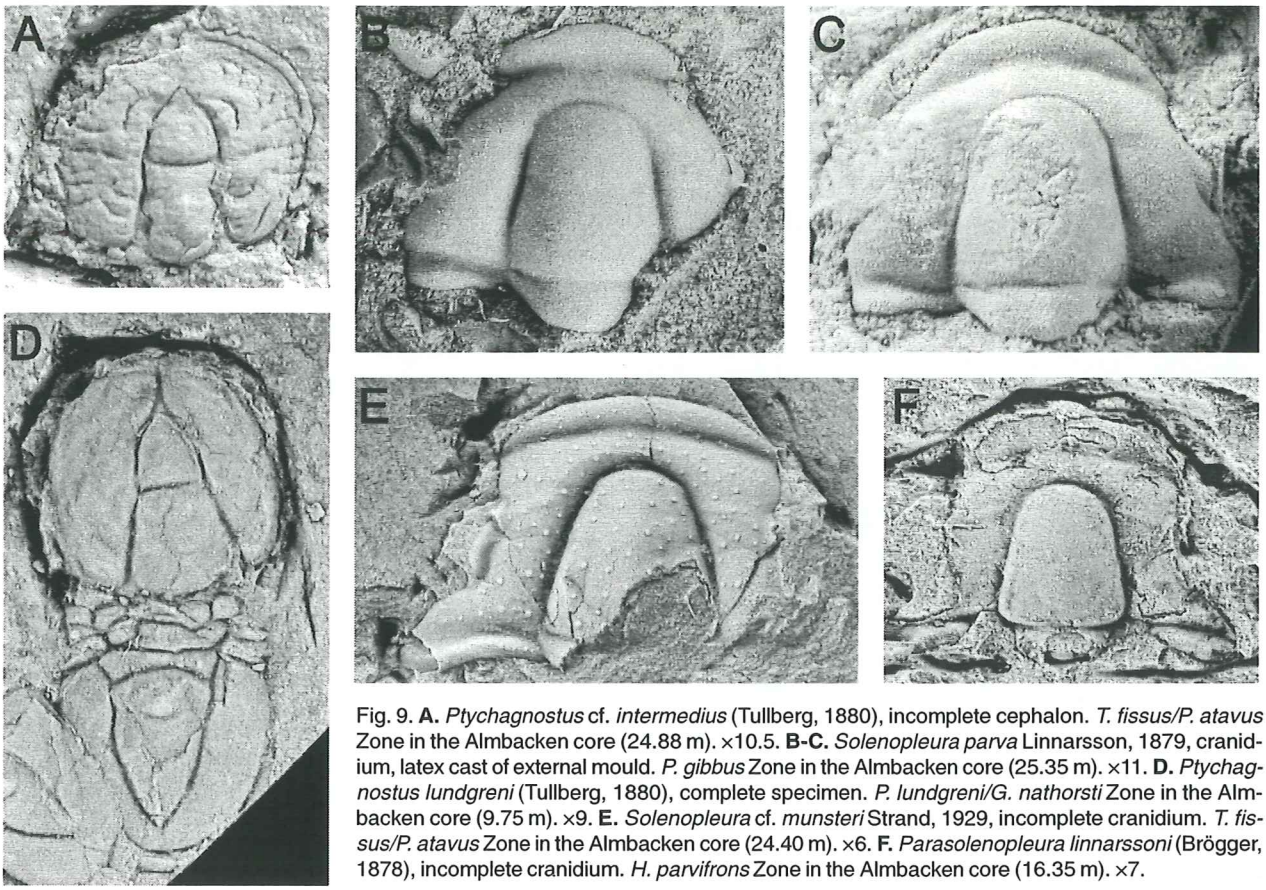


Fig. 9. **A.** *Ptychagnostus* cf. *intermedius* (Tullberg, 1880), incomplete cephalon. *T. fissus/P. atavus* Zone in the Almbacken core (24.88 m). ×10.5. **B-C.** *Solenopleura parva* Linnarsson, 1879, cranidium, latex cast of external mould. *P. gibbus* Zone in the Almbacken core (25.35 m). ×11. **D.** *Ptychagnostus lundgreni* (Tullberg, 1880), complete specimen. *P. lundgreni/G. nathorsti* Zone in the Almbacken core (9.75 m). ×9. **E.** *Solenopleura* cf. *munsteri* Strand, 1929, incomplete cranidium. *T. fissus/P. atavus* Zone in the Almbacken core (24.40 m). ×6. **F.** *Parasolenopleura linnarssoni* (Brögger, 1878), incomplete cranidium. *H. parvifrons* Zone in the Almbacken core (16.35 m). ×7.

Remarks. – According to Westergård (1953), there are no significant differences between cranidia of *S. parva* and *S. munsteri*, except that *S. munsteri* attains a size twice as large as *S. parva*. The cranidium found in the Almbacken core is comparatively twice as large and seem to represent *S. munsteri*. However, it has a slightly narrower glabella than Westergård's (1953) description of *S. munsteri*.

Occurrence. – *T. fissus/P. atavus* Zone in the Almbacken core. Also known from various other localities in Sweden, as well as in Norway (Westergård 1953). According to Westergård, *S. munsteri* is restricted to the *P. gibbus* Zone. The specimen found in the Almbacken core is from a level above the Exsulans Limestone (*P. gibbus* Zone).

Solenopleura sp.

Material. – Six cranidia and two librigena.

Remarks. – Most of the cranidia are small and represent larval stages. No further identification is possible. Species of *Solenopleura* share many similarities with those of *Parasolenopleura* (Poulsen 1954), and it is possible that some of the specimens belong to *Parasolenopleura*.

Occurrence. – Ranges from the top of the *P. gibbus* Zone to the lowermost *P. punctuosus* Zone in the Almbacken core.

Order Redlichiida Richter, 1932

Family Paradoxididae Hawle & Corda, 1847

Genus *Paradoxides* Brongniart, 1822

Paradoxides paradoxissimus (Wahlenberg, 1818)

Fig. 8E-F

Material. – One nearly complete cranidium and one pygidium.

Remarks. – The type specimen of *P. paradoxissimus* was illustrated by Westergård (1953, pl. 8. fig. 2). *P. paradoxissimus* is a distinctive and sometimes fairly common species in the *P. paradoxissimus* Stage of Scandinavia.

Occurrence. – In the Almbacken core *P. paradoxissimus* occurs in the lower part of the *T. fissus/P. atavus* Zone and in the middle-upper part of the *H. parvifrons* Zone. Outside Scandinavia, *P. paradoxissimus* is known from Bornholm (Denmark), Great Britain, and Norway (Westergård 1953).

Paradoxides sp.

Material. – Several fragments, mainly thoracic tergites.

Remarks. – The fragments are generally too incomplete or too poorly preserved for species identification.

Occurrence. – *P. gibbus* Zone up into the *P. punctuosus* Zone in the Almbacken core.

Order uncertain

Family Burlingiidae Walcott, 1908

Genus *Burlingia* Walcott, 1908

Burlingia sp.

Material. – One incomplete cephalon and a fragmentary pygidium.

Remarks. – The material is very poorly preserved, but the morphology of the cephalon with its lack of border and presence of pits on the glabella resembles that of *Burlingia*.

Occurrence. – *Ptychagnostus punctuosus* Zone in the Almbacken core.

Conclusions

The core drilling at Almbacken in Södra Sandby penetrated a c. 30 m thick succession of Middle Cambrian–upper Lower Cambrian strata. The Middle Cambrian of this core is one of the stratigraphically most complete ones so far available from Scania. The core contains a stratigraphical sequence from the middle *Lejopyge laevigata* Zone (upper *Paradoxides forchhammeri* Stage) to the *Holmia kjerulfi*-group Zone (upper Lower Cambrian). There is no faunal evidence for the presence of the *Acadoparadoxides oelandicus* Stage. Only the uppermost part of the Lower Cambrian (Gislöv Formation) was recovered, comprising c. 1.5 m of unfossiliferous siltstones and a thin limestone bed with indeterminable trilobite fragments at the base of the core.

The Middle Cambrian is c. 28.3 m thick and consists of dark grey to black mudstones and shales (alum shale) with stinkstones and limestone beds. Three major limestone beds can be identified, in ascending order: the "Fragment Limestone" (35 cm), the Exsulans Limestone (40 cm), and the Andrarum Limestone (155 cm). The Middle Cambrian is richly fossiliferous, except in the lower six metres, and the faunas are dominated by agnostid trilobites. Polymerid trilobites and indeterminate lingulate brachiopods are abundant at some levels. The succession of trilobite species are used for a biostratigraphical subdivision into seven biozones. The preservation is generally good and 31 trilobite species were identified. The excellent preservation in the stinkstones allowed a description of growth stages in pygidia of *Ptychagnostus punctuosus*.

Except for the *Lejopyge laevigata* Zone and the *Tomagnostus fissus/Ptychagnostus atavus* Zone, all of the zones in the Almbacken core reach a greater thickness compared to the borings that were made in 1941 and 1942 in, e.g., Andrarum and Gislövshammar. The total thickness of the Middle Cambrian in the Almbacken core is 28.3 m. In the Andrarum and Gislövhammar cores, the thickness of the Middle Cambrian is 19.9 m and 18.6 m, respectively (Westergård 1944). Thus the thickness of the Middle Cambrian of Scania seems to increase westwards (cf. Buchardt et al. 1997, fig. 7).

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Appendix

Lithological succession and faunal content

Alum shale (2.87-4.10 m)

Dark grey to black, laminated mudstone and shale with thin calcite lamina and pyrite grains.

Agnostid fragments: 3.20 m; poorly preserved.

Opsidiscus bilobatus Westergård, 1946: 2.93-3.17 m; three poorly preserved cephala.

Lejopyge sp.: 3.95 m; one poorly preserved pygidium.

Lingulate brachiopods: 3.50, 3.60, 3.95 m.

Ptychagnostus lundgreni nanus (Grönwall, 1902): 3.95 m.

Limestone (4.10-5.65 m)

Andrarum Limestone. The colour ranges from light grey to almost black. It is commonly dense, hard and crystalline, but sometimes tends to have thin argillaceous intercalations (for instance at 5.50 m). Calcite-filled fissures as well as pyrite concretions occur. The fossils are dominated by lingulate brachiopods and trilobite fragments.

Agnostid fragments: 4.44 m; poor preservation.

Anomocarina excavata (Angelin, 1851): 4.77 m.

Fragments of polymerid trilobites: 5.50 m.

Lejopyge sp.: 5.45-5.50 m; very poor preservation.

Lingulate brachiopods: 4.66, 4.77, 4.92, 5.24, 5.50 m.

Ptychagnostus lundgreni nanus (Grönwall, 1902): 4.66 m.

Ptychagnostus sp.: 4.92 m.

Alum shale (5.65-11.80 m)

Dark grey to black, laminated mudstone and shale. Thin laminae and concretions of pyrite and small fissures of calcite occur throughout this interval.

Agnostid fragments: 8.00, 8.06 m.

Burlingia sp.: 10.55 m.

Diplagnostus planicauda (Angelin, 1851): 7.48, 7.63-7.92, 8.06, 8.99, 10.52-10.55, 10.63-10.65, 10.82 m; numerous disarticulated specimens at 10.52 m and 10.63 m.

Fragments of paradoxidid trilobites: 10.63 m.

Goniagnostus nathorsti (Brögger, 1878): 9.40 m - 9.57 m.
Hypagnostus cf. *nepos* (Brögger, 1878): 9.57 m - 9.63 m; numerous disarticulated specimens at 9.61 m and 9.59 m.
Lingulate brachiopods: 6.46, 8.47 m.
Peronopsis fallax ferox (Tullberg, 1880): 10.60, 11.17, 11.30,11.54 m.
Peronopsis sp.: 8.32, 9.54 m.
Ptychagnostus lundgreni (Tullberg, 1880): 5.76, 6.71-7.18, 7.50, 7.84-7.90, 8.06, 8.47, 8.99, 9.75 m; one complete specimen at 9.75 m.
Ptychagnostus lundgreni nanus (Grönwall, 1902): 6.46, 7.92, 8.44 m; numerous disarticulated specimens at 6.46 m.
Ptychagnostus punctuosus (Angelin, 1851): 10.55-10.90, 11.15-11.30, 11.54 m; one complete specimen at 11.22 m, numerous disarticulated specimens at 11.15 and 10.78 m.
Ptychagnostus sp.: 8.75 m.

Limestone (stinkstone or orsten) (11.80-12.00 m)
Crystalline, hard and black limestone with many scattered pyrite grains. The fossil preservation is very good. The only fossil observed is that of the index fossil *P. punctuosus*.
Ptychagnostus punctuosus (Angelin, 1851): 11.90,12.00 m; very well preserved.

Alum shale (12.00-14.10 m)
Dark grey to black, laminated mudstone and shale with occasional small calcite-filled fissures.
Doryagnostus incertus (Brögger, 1878): 13.50 m.
Lingulate brachiopods: 12.80 m.
Fragments of paradoxidid trilobites: 12.98 m.
Peronopsis pusilla (Tullberg, 1880): 12.80 m; one poorly preserved pygidium.
Peronopsis sp.: 12.60 m.
Ptychagnostus affinis (Brögger, 1878): 12.95 m.
Ptychagnostus punctuosus (Angelin, 1851): 12.95-13.05, 13.15, 13.50-13.57, 13.74, 13.94-14.03 m; crowded with disarticulated specimens at 13.98 m.
Ptychagnostus sp.: 12.60 m.

Limestone (stinkstone or orsten) (14.10-14.20 m)
Black in colour with minor calcite precipitations and calcite-filled fissures. Very well preserved disarticulated trilobites including adult as well as juvenile specimens of the index fossil *P. punctuosus*.
Ptychagnostus punctuosus (Angelin, 1851): 14.15-14.20 m.

Alum shale (14.20-21.20 m)
Dark grey to black laminated mudstone and shale. One thin bed of dark grey limestone (stinkstone) at 14.80 m contains very well preserved specimens of *P. punctuosus*.
Fragments of paradoxidid trilobites: 14.22, 15.88 m.
Fragments of polymerid trilobites: 17.02, 17.60 m.
Hypagnostus parvifrons (Linnarsson, 1869): 16.09, 16.11, 17.60, 17.72-17.75, 17.90-18.07 m.
Hypagnostus sp.: 15.90-16.05, 17.55 m.
Lingulate brachiopods: 17.02 m.
Paradoxides paradoxissimus (Wahlenberg, 1818): 17.72 m; one nearly complete cranidium.
Parasolenopleura linnarssoni (Brögger, 1878): 16.09, 16.11, 16.35 m; numerous fragments at 16.35 m.
Parasolenopleura sp.: 17.90 m.
Peronopsis fallax (Linnarsson, 1869): 15.22,15.51-15.54, 15.75-16.10, 16.24-16.35 m; crowded with disarticulated specimens at 15.75 and 15.54 m.
Peronopsis fallax depressa Westergård, 1946: 15.45 m.
Peronopsis sp.: 15.75, 16.11, 17.20-17.72 m.
Phalacroma scanicum (Tullberg, 1880): 15.22 m.
Ptychagnostus affinis (Brögger, 1878): 15.51, 15.60-15.75, 17.57, 17.72-18.30, 19.50-20.75 m; one cephalon complete with thoracic segments at 20.75 m, numerous specimens at 15.75 m.
Ptychagnostus cf. *affinis* (Brögger, 1878): 18.07 m.
Ptychagnostus atavus (Tullberg, 1880): 16.09, 16.43-17.00, 17.30 m.
Ptychagnostus cf. *hybridus* (Brögger, 1878): 14.26 m.
Ptychagnostus punctuosus (Angelin, 1851): 14.20-14.26, 14.48, 14.70, 14.80-14.90, 15.05-15.10, 15.28-15.39, 15.75, 15.90 m; numerous specimens at 15.75, 14.90 m and 14.85 m, one nearly complete specimen and several very well preserved specimens at 14.80 m.
Ptychagnostus cf. *stenorrhachis* (Grönwall, 1902): 15.45 m.
Ptychagnostus sp.: 18.70 m.
Solenopleura sp.: 15.22 m.

Limestone (21.20-21.40 m)
Dark grey, crystalline stinkstone (or orsten), unfossiliferous.

Alum shale (21.40-25.08 m)
Dark grey to black mudstone and shale, finely laminated with a diverse fossil fauna.
Agnostid fragments: 21.44 m.
Cotalagnostus lens claudicans (Grönwall, 1902): 22.80, 23.75 m.
Fragments of paradoxidid trilobites: 22.81, 23.02-23.05, 24.60, 24.65, 24.77 m.
Fragments of polymerid trilobites: 22.87, 24.88-25.10 m; numerous fragments at 25.09-25.08 m.
Hypagnostus parvifrons (Linnarsson, 1869): 22.20, 22.81-22.85, 22.90, 22.94 m.
Hypagnostus sp.: 21.90 m.
Lingulate brachiopods: 22.81, 24.27, 24.88-24.90, 25.08 m.
Paradoxides paradoxissimus (Wahlenberg, 1818): 24.90 m; one complete pygidium.
Parasolenopleura linnarssoni (Brögger, 1878): 22.92, 24.98 m.
Parasolenopleura cf. *scanica* Westergård, 1953: 24.00 m; one complete cranidium.

Parasolenopleura sp.: 23.29, 24.98 m.
Peronopsis fallax (Linnarsson, 1869): 22.81, 22.94-23.05, 23.30, 23.75, 24.06-24.15, 24.46, 24.60-24.70, 24.77-24.90, 25.08 m.
Peronopsis scutalis (Salter *in* Hicks, 1872): 22.80, 22.92 m.
Peronopsis sp.: 22.87-22.90, 22.97, 23.08, 24.27, 24.88, 24.95-24.98, 25.08 m.
Ptychagnostus affinis (Brögger, 1878): 21.48 m - 21.50 m.
Ptychagnostus atavus (Tullberg, 1880): 22.45-22.50, 22.76-22.95, 23.27-23.29, 23.48-23.58 m; crowded with specimens at 23.48, 23.27-23.29 and 22.80 m.
Ptychagnostus gibbus (Linnarsson, 1869): 25.09-25.10 m.
Ptychagnostus cf. *intermedius* (Tullberg, 1880): 24.88 m.
Ptychagnostus sp.: 23.29 m.
Solenopleura cf. *munsteri* (Strand, 1929): 24.40 m.
Solenopleura sp.: 22.90, 24.77, 24.90, 25.10 m.
Tomagnostus fissus (Linnarsson, 1879): 22.43-22.60, 22.80-23.02, 24.42, 24.60, 24.72, 24.88-24.90, 24.99 m.

Limestone (25.08-25.47 m)
Exsulans Limestone. Medium to dark grey argillaceous limestone with thin mudstone intercalations. Numerous fissures filled with crystalline calcite are present. The upper parts are darker in colour and less crystalline in composition compared to the lower parts. It is richly fossiliferous throughout. The trilobites are generally disarticulated.

Eodiscus scanicus (Linnarsson, 1883): 25.08 m; one pygidium.
Fragments of paradoxidid trilobites: 25.35 m.
Fragments of polymerid trilobites: 25.08-25.47; very rich in fragments throughout this interval.
Lingulate brachiopods: 25.08-25.10, 25.19, 25.35 m.
Parasolenopleura aculeata (Angelin, 1851): 25.08, 25.21-25.23 m.
Ptychagnostus gibbus (Linnarsson, 1869): 25.09-25.10, 25.21-25.23, m; one nearly complete specimen at 25.09 m.
Solenopleura parva (Linnarsson, 1879): 25.35 m.
Tomagnostus fissus (Linnarsson, 1879): 25.21-25.23 m; only one poorly preserved cephalon.

Alum shale (25.47-28.25 m)
Medium to dark grey mudstone and shale with numerous small pyrite concretions. Only lingulate brachiopods have been recorded.

Lingulate brachiopods: 25.85, 26.05, 26.36, 27.55, 28.16 m; high abundance at 28.16 m.

Limestone (28.25-28.60 m)
"Fragment" Limestone. Grey, hard limestone consisting exclusively of trilobite fragments, which are sometimes pyritized.

Fragments of polymerid trilobites: 28.25-28.60 m.

Alum shale (28.60-28.90 m)
Dark grey and laminated shale, richly fossiliferous.

Lingulate brachiopods: 28.89-28.90 m; abundant.

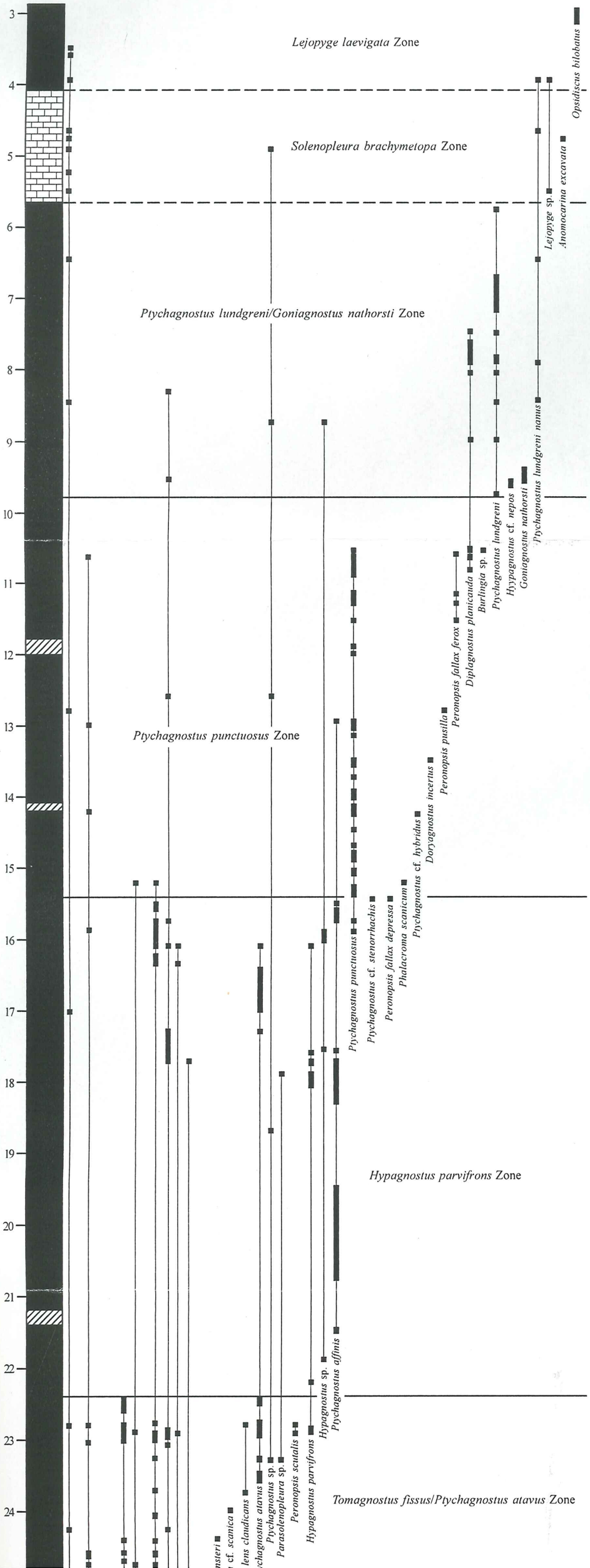
Mudstone (28.90-31.20 m)
Dark grey to almost black and strongly bioturbated mudstone with siltstone intercalations. The succession is rich in pyrite. Generally the pyrite occurs as very small grains but occasionally somewhat larger nodules are present.

Lingulate brachiopods: 28.90-28.96, 29.12, 29.40, 29.55, 29.68, 30.10-30.15, 30.40, 30.74-30.75, 31.15 m.
Bradoriid arthropod: 29.40 m; one nearly complete specimen.

Siltstone (31.20-32.40 m)
Medium to dark grey calcareous siltstone with small, scattered pyrite nodules.

Limestone (32.40-32.70 m)
Massive, light grey arenaceous limestone with subrounded to rounded quartz grains, approximately up to 0.5 mm in diameter. Larger nodules of pyrite are common, as well as numerous cross-sections of polymerid trilobite fragments. The lithology indicates that this is the lower part of the Gislöv Formation, probably unit B of Bergström & Ahlberg (1981, p. 204, fig. 10).

Fragments of polymerid trilobites: 32.40-32.70 m.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Lejopyge laevigata Zone
Solenopleura brachymetopa Zone
Ptychagnostus lundgreni/Goniagnostus nathorsti Zone
Ptychagnostus punctuosus Zone
Hypagnostus parvifrons Zone
Tomagnostus fissus/Ptychagnostus atavus Zone
Opsidiscus bilobatus
Lejopyge sp.
Anomocarina excavata
Ptychagnostus lundgreni namus
Goniagnostus nathorsti
Hyypagnostus cf. nepos
Ptychagnostus lundgreni
Burlingia sp.
Diplagnostus planicauda
Peronopsis fallax ferox
Peronopsis pusilla
Ptychagnostus punctuosus
Ptychagnostus cf. stenorrhachis
Peronopsis fallax depressa
Phalacroma scanicum
Ptychagnostus cf. hybridus
Hypagnostus sp.
Ptychagnostus affinis
Peronopsis scutalis
Parasolenopleura sp.
Ptychagnostus atavus
Peronopsis lens claudicans
Peronopsis cf. scanica
Peronopsis insteri

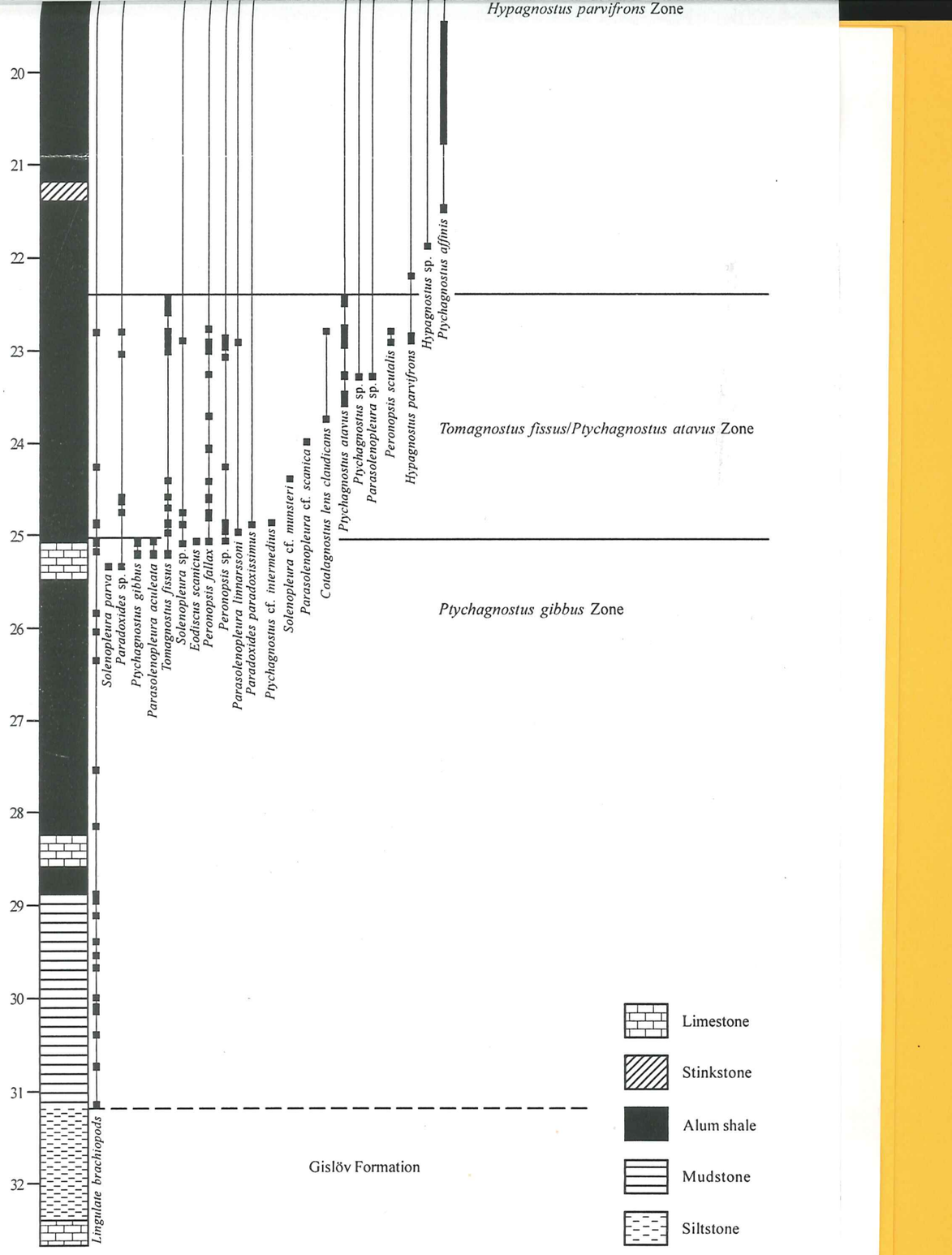

Plate 1. General lithologic succession, stratigraphy, and ranges of fossils in the Almbacken core. Scale is in metres.

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