

The middle Cambrian *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones in Västergötland, Sweden

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New trilobite discoveries from eight localities in Västergötland, south-central Sweden, demonstrate that the middle Cambrian *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones are present in most Lower Palaeozoic outcrop areas of Västergötland, though as a thin and impersistent conglomeratic limestone, up to approximately 15 cm thick. These zones have not previously been recognised in Västergötland, except for a thin bed of limestone on Hunneberg.

Key words: Trilobites, middle Cambrian, *Ptychagnostus punctuosus* Zone, *Goniagnostus nathorsti* Zone, Västergötland, Sweden.

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The famous dolerite capped table mountains of Västergötland, south-central Sweden (Fig. 1), with almost flat-lying and undisturbed Lower Palaeozoic successions have been investigated for more than two hundred years. Mount Kinnekulle, the Halleberg-Hunneberg and Falbygden-Billingen areas reveal parts of the Scandinavian Alum Shale facies, which reach from Bornholm and Scania (Skåne) in the south, to Lapland and northernmost Norway in the north. The middle Cambrian–lowermost Ordovician (Tremadocian) Alum Shale facies is generally characterised by organic-rich black shales with beds and lenses of limestone, locally with interbedded conglomerates and calcareous sandstones (for general reviews, see e.g. Martinsson 1974; Andersson *et al.* 1985; Buchardt *et al.* 1997; Ahlberg 1998).

In Västergötland, the lower Cambrian sandstone succession below the Alum Shale Formation (*sensu* Buchardt *et al.* 1997) has yielded only a few determinable trilobites (Ahlberg *et al.* 1986). The middle Cambrian Exsulans Limestone of the *Ptychagnostus gibbus* Zone, with a varied trilobite fauna in Scania, Bornholm and Öland, is not represented in Väter-

götland. The Andrarum Limestone of the *Solenopleura*? (or *Erratojincella*) *brachymetopa* Zone, with the greatest number of trilobite genera and species diversity found in the middle Cambrian of the southernmost part of Scandinavia, on Bornholm and in Scania (Westergård 1946, 1953; Berg-Madsen 1985a), is represented only by a poorly developed counterpart on Hunneberg and Kinnekulle (cf. Bruton & Harper 2000, fig. 3). These two fossiliferous limestone units represent shallow-water facies, deposited in well-oxygenated environments (e.g. Conway Morris & Rushton 1988; Nielsen 1996; Rushton & Berg-Madsen 2002). As the Exsulans Limestone is absent, and as the Andrarum Limestone is poorly developed in Västergötland, the middle Cambrian faunal sequence appears less diverse than those of most other Lower Palaeozoic outcrop areas in southern Scandinavia. In Västergötland, it is only in the so called 'Exsculptus-layer' (*sensu* Wallerius 1895) of Falbygden, within the stinkstone lenses of the *Lejopyge laevigata* Zone, that the middle Cambrian reaches a short-ranged climax in faunal diversification.

Our understanding of middle Cambrian stratigra-

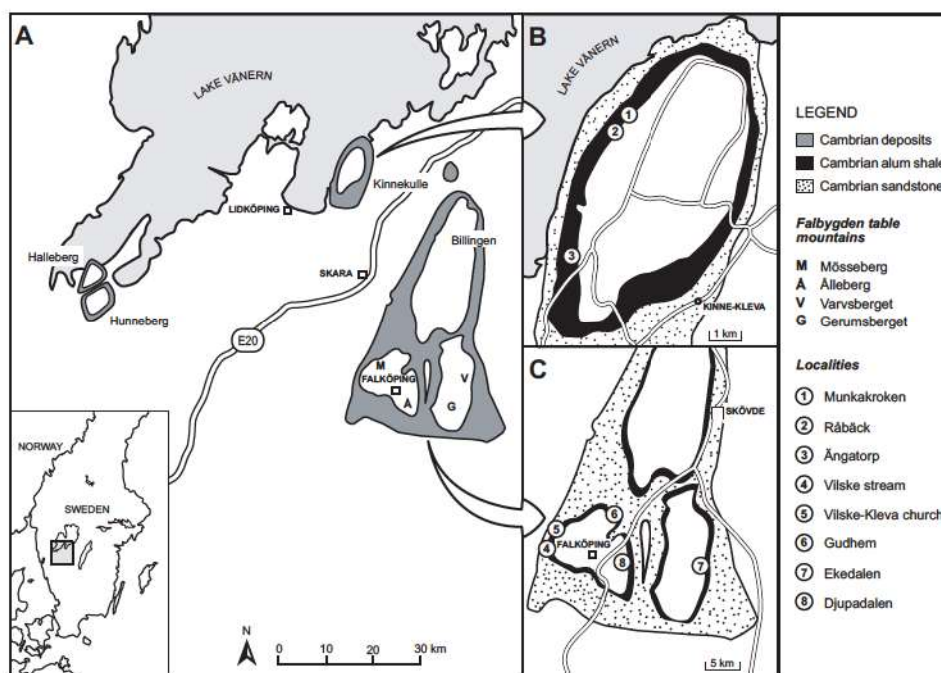


Fig. 1. Sketch-map of Västergötland, south-central Sweden, showing Lower Palaeozoic outcrop areas and localities referred to in the text.

phy and faunas of Västergötland is based mainly on the works of early pioneers such as Linnarsson (1869, 1872, 1877), Wallerius (1894, 1895, 1896, 1930), Holm (1901), and Munthe (1905), along with Westergård (1928, 1931, 1943, 1946, 1948, 1950, 1953). The main area of research has been Kinnekulle and, consequently, the more extensive Cambrian of the much

larger area of Falbygden-Billingen is less well known (Martinsson 1974). The occurrence of the Andrarum Limestone in Västergötland was mentioned long ago by Linnarsson (1872, p. 243) at Gudhem, Lovened (Djupadalen), Hällekis, and Råbäck, and by Holm (1901, p. 28) at Råbäck.

Westergård (1946, p. 19) published a biostratigraph-

SUPERZONES	ZONES	WESTERGÅRD 1946	THIS PAPER
<i>Paradoxides forchhammeri</i>	<i>Lejopyge laevigata</i>	AS	AS
	<i>Solenopleura? brachymetopa</i>	A, E	A, E
	<i>Goniagnostus nathorsti</i>	C	C
<i>Paradoxides paradoxissimus</i>	<i>Ptychagnostus punctuosus</i>	H	H
	<i>Hypagnostus parvifrons</i>	AS	AS
	<i>Tomagnostus fissus - Ptychagnostus atavus</i>		
	<i>Ptychagnostus gibbus</i>		
<i>Acadoparadoxides oelandicus</i>	<i>Ptychagnostus praecurrens</i>		
	<i>Eccaparadoxides insularis</i>		

Fig. 2. Middle Cambrian stratigraphy of Västergötland, south-central Sweden. A = Andrarum Limestone; E = Exporrecta Conglomerate; H = 'Hypagnostus limestone bank'; AS = Alum shale with lenses and beds of limestone; C = Conglomeratic limestone. Vertical lines indicate gaps in the succession. Note that the conglomeratic limestone between the 'Hypagnostus limestone bank' and the Exporrecta Conglomerate is very thin, only up to 15 cm, and that the *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones most likely are incomplete. Biostratigraphy slightly modified after Westergård (1946).

ical zonation and a correlation table that ever since has remained unchanged for the province of Västergötland (Fig. 2). The *Acadoparadoxides oelandicus* Superzone (or 'Stage') is absent in Västergötland. The *Ptychagnostus gibbus*, *Tomagnostus fissus*-*Ptychagnostus atavus*, and *Hypagnostus parvifrons* zones of the *Paradoxides paradoxissimus* Superzone are present on Hunneberg in the west and on Kinnekulle and in the Falbygden-Billingen area in the east. According to Westergård (1943, 1946), the *Ptychagnostus punctuosus* and '*P. lundgreni*-*Goniagnostus nathorsti*' zones are absent in Västergötland, except for a thin bed of dark grey to black, finely crystalline limestone on Hunneberg (cf. Grönwall 1902, p. 316–317). This limestone is overlain by the Andrarum Limestone, which here comprises the *Solenopleura? brachymetopa* Zone (Westergård 1946; Martinsson 1974).

Westergård (1946, p. 16) found a few specimens of *Ptychagnostus punctuosus*, possibly reworked, associated with forms distinctive of the *Paradoxides forchhammeri* Superzone at Djupadalen in the Falbygden area (see also Wallerius 1895). He did not, however, consider that these findings were positive enough to warrant the presence of the *P. punctuosus* and '*P. lundgreni*-*Goniagnostus nathorsti*' zones over the major part of Västergötland. The Exporrecta Conglomerate, part of which is a lateral equivalent of the Andrarum Limestone, has not yielded any elements from the two missing zones (Westergård 1946, p. 16).

Remarks on the middle Cambrian biostratigraphy of Scandinavia

Westergård (1946) established a high-resolution biostratigraphy for the middle Cambrian of Scandinavia based on agnostoids (Fig. 2). Although the Cambrian of Scandinavia has come to be recognised as a reference standard, Westergård neither described the zones in detail, nor defined the zonal boundaries. Berg-Madsen (1985b) questioned the validity of Westergård's (1946) *Ptychagnostus lundgreni*-*Goniagnostus nathorsti* Zone and suggested that it should be included in the *Ptychagnostus punctuosus* Zone (cf. Robison 1984). *Ptychagnostus lundgreni* is obviously a long-ranging species that appears in the *P. punctuosus* Zone and ranges upwards into the *Solenopleura? brachymetopa* Zone (Westergård 1946; Robison 1984; Berg-Madsen 1985b). It has therefore been excluded as a zonal index fossil by, among others, Henningsmoen (1956). *Goniagnostus nathorsti*, however, consistently appears well above the first appearance of *P. punctuosus* (e.g. Peng & Robison 2000; Axheimer &

Ahlberg 2003), and the presence of a *G. nathorsti* Zone above the *P. punctuosus* Zone seems justified. The base of the zones can be defined by the lowest stratigraphical occurrence of the eponymous species (Peng & Robison 2000).

Since Westergård's (1946) monographic study, agnostoid trilobites have been used in biostratigraphy and correlations at an accelerating rate. There is now sufficient data available for a global agnostoid zonation of middle Cambrian and lower upper Cambrian open-shelf successions, the base of each zone defined by the first appearance of a selected, geographically widespread species, and the top by the base of the succeeding zone (Robison 1982, 1984; Peng & Robison 2000). Recent studies on the middle Cambrian of Scania, southern Sweden, particularly based on the agnostoid succession in the Almbacken drill core (Axheimer & Ahlberg 2003) and other drill cores from Scania, show that the global agnostoid zonation proposed by Peng & Robison (2000) can be applied tentatively also to Scandinavian strata. With slight modifications, the middle Cambrian zonation of Westergård (1946) is, however, applied herein pending further investigations.

The localities in Falbygden and on Kinnekulle

Glacial erratics presumably originating from Västergötland occur en masse at the Palsgård (or As Hoved) Cliff near Juelsminde, Jylland (Jutland), Denmark (cf. Geyer *et al.* 2004 and map therein). These contain middle Cambrian material with mixed faunas from the *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones. This occurrence prompted a search for the original source, and in the spring of 2001 several outcrops of middle Cambrian strata across Kinnekulle, Falbygden, and Billingen were revisited, areas where the direct contact between the 'Hypagnostus limestone bank' (*Hypagnostus parvifrons* Zone) and the Exporrecta Conglomerate had previously been observed.

The localities are (Fig. 1): 1. Munkakroken, 1500 m northeast of Råbäck, Kinnekulle, where the 'Hypagnostus limestone bank' and the Exporrecta Conglomerate crop out in a small stream. 2. A drainage canal just southwest of Råbäck, Kinnekulle, where the same succession is visible over a distance of 1–2 m close to the railway tracks. This locality was described in detail by Holm (1901, p. 28). 3. Ångatorp near Västerplana, Kinnekulle. Boulders containing middle Cambrian faunas are accessible in the stream bed and on a field nearby. 4. An unnamed stream near

Dukagården, 700 m southwest of the church of Vilske-Kleva, western Mösseberg, herein called Vilske stream. Middle and upper Cambrian strata are exposed along the stream. 5. A stone and waste pile close to Vilske-Kleva church, western Mösseberg. The pile contains numerous boulders bearing a middle Cambrian fauna. 6. The old alum shale quarry at Gudhem, northern Mösseberg. Middle Cambrian shales and limestones are exposed on the west side of the small stream running through the quarry. 7. An unnamed stream near Ekedalen at Varvsberget. Middle Cambrian deposits are exposed along the stream running through the old alum shale quarry Ödegården (cf. Westergård 1922, p. 67–68, 1946, p. 103). 8. Djupadalen, 5 km east of Falköping, described in detail by Wallerius (1895), and more briefly by Grönwall (1902, p. 314–315), Westergård (1922, p. 70, 1946, p. 16, 103), and Thorslund & Jaanusson (1960).

In addition to the localities mentioned above numerous dry stream beds were followed during the summer of 2001, especially on both the western and eastern sides of Kinnekulle, though without finding the contact between the 'Hypagnostus limestone bank' and the Exporrecta Conglomerate.

Evidence for the *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones in Västergötland

In most places in Västergötland the Exporrecta Conglomerate rests directly on a continuous bed of dark grey limestone, the 'Hypagnostus limestone bank'. For example, at the waterfall near Stora Stolan on northern Billingen, the direct contact between the 'Hypagnostus limestone bank' and the Exporrecta Conglomerate can be followed over more than 5 m laterally. At seven of the localities (Munkakroken, Råbäck, Ängatorp, Vilske stream, Vilske-Kleva church, Gudhem, and Ekedalen), however, a thin layer of a conglomeratic limestone with a thickness of up to 15 cm, hitherto unrecognised, is present between the 'Hypagnostus limestone bank' and the Exporrecta Conglomerate (Fig. 2). It is richly fossiliferous in its upper part. The conglomeratic limestone, noted already by Wallerius (1895) at Djupadalen, is clearly distinguished from the overlying Exporrecta Conglomerate of the *Solenopleura? brachymetopa* Zone by its characteristic fossil content. Trilobites, hyoliths, and brachiopods of the *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones occur mixed together. Selected trilobites from these two zones are shown in Fig. 3 (for a complete list of trilobites, see Table 1).

At Mösseberg (Vilske stream, Vilske-Kleva church, and Gudhem) the conglomeratic limestone containing the faunas of the *Ptychagnostus punctuosus* and the *Goniagnostus nathorsti* zones is generally one to a few cm thick, and forms the uppermost part of the 'Hypagnostus limestone bank'. At Vilske stream and Vilske-Kleva church it is hard, unweathered and overlain by the Exporrecta Conglomerate. At Gudhem it is weathered to a red-brown mud from which only a few resistant fossiliferous fragments could be retrieved. Here it is overlain by a grey limestone with *Oligomys exporrecta* (Linnarsson, 1876), followed by the Exporrecta Conglomerate proper, above which is the greenish, impure limestone mentioned by Westergård (1948, p. 9) from several localities.

At Ekedalen in the eastern part of Falbygden, and at Råbäck on Kinnekulle, the conglomeratic limestone is brecciated and up to 15 cm thick. It is overlain by the Exporrecta Conglomerate and/or a greenish limestone, which at Råbäck has yielded *Oligomys exporrecta*, *Dorypyge aenigma* (Linnarsson, 1869), *Dolichometopus svecicus* Angelin, 1854, and *Solenopleura? brachymetopa* (Angelin, 1851). Holm (1901, pp. 24, 25, 28) included the agnostoid-bearing conglomeratic limestone in his Exporrecta Conglomerate and did not recognise it as a separate unit.

At Munkakroken faunal elements of the *Ptychagnostus punctuosus* Zone have been found in the Exporrecta Conglomerate as previously defined by Holm (1901).

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Fig. 3. Trilobites from the *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones of Västergötland, south-central Sweden. Scale bar 1 mm. All illustrated specimens are deposited in the type collection of the Department of Geology, Lund University, Sweden (depository acronym LO). A–C. *Ptychagnostus punctuosus* (Angelin, 1851), Vilske stream, Falbygden. A. Cephalon, LO 9547t. B. Pygidium, LO 9548t. C. Pygidium, LO 9549t. D–E. *Doryagnostus incertus* (Brögger, 1878). D. Cephalon, Vilske stream, LO 9550t. E. Pygidium, Vilske-Kleva church, LO 9551t. F–H. *Lejopyge elegans* (Tullberg, 1880), Vilske stream, Falbygden. F. Cephalon, LO 9552t. G. Pygidium, LO 9553t. H. Pygidium, LO 9554t. I. *Parasolenopleura? peregrina* (Wallerius, 1930), nearly complete cranidium, Vilske stream, Falbygden, LO 9555t. J–M. *Ptychagnostus lundgreni* (Tullberg, 1880). J. Cephalon, Vilske stream, Falbygden, LO 9556t. K. Two cephalons (LO 9557t; LO 9558t) and two pygidia (LO 9559t; LO 9560t), Vilske stream. L. Pygidium, Vilske stream, Falbygden, LO 9561t. M. Pygidium, Ekedalen, Falbygden, LO 9562t. N–S. *Goniagnostus nathorsti* (Brögger, 1878). N. Cephalon, Vilske stream, Falbygden, LO 9563t. O. Cephalon, Gudhem, Falbygden, LO 9564t. P. Cephalon, Råbäck, Kinnekulle, LO 9565t. Q. Pygidium, Vilske stream, Falbygden, LO 9566t. R. Pygidium, Vilske stream, Falbygden, LO 9567t. S. Pygidium, Råbäck, Kinnekulle, LO 9568t.



Table 1. List of trilobites from the *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones of Kinnekulle and the Falbygden area in Västergötland, south-central Sweden.

<i>Conocephalina ornata</i> (Brögger, 1878)
<i>Doryagnostus incertus</i> (Brögger, 1878)
<i>Goniagnostus nathorsti</i> (Brögger, 1878)
<i>Groenwallia?</i> sp.
<i>Lejopyge elegans</i> (Tullberg, 1880)
<i>Onymagnostus hybridus</i> (Brögger, 1878)
<i>Paradoxides</i> sp.
<i>Parasolenopleura? peregrina</i> (Wallerius, 1930)
<i>Parasolenopleura</i> sp.
<i>Peratagnostus cicer</i> (Tullberg, 1880)
<i>Peronopsis fallax ferox</i> (Tullberg, 1880)
<i>Ptychagnostus lundgreni</i> (Tullberg, 1880)
<i>Ptychagnostus punctuosus</i> (Angelin, 1851)
<i>Tomagnostella exsculpta</i> (Angelin, 1851)

Conclusions

Glacial erratics from Palsgård Cliff near Juelsminde, Denmark, are identical in appearance and faunal content with the beds that outcrop at Vilske and Ekedalen in the Falbygden area, Västergötland. The Danish erratics also include blocks of Exporrecta Conglomerate and typical Andrarum Limestone. The Andrarum Limestone boulders found at Palsgård Cliff differ, however, from the Andrarum Limestone at Hunneberg in being light grey in colour rather than bluish black. The following fauna was obtained from the Andrarum Limestone erratics: *Agnostus pater* Westergård, 1930, *Diplagnostus planicauda* forma *vestgothicus* (Wallerius, 1895), *Megagnostus glandiformis* (Angelin, 1851), *Solenopleura? brachymetopa* (Angelin, 1851), *Proampyx difformis* (Angelin, 1851), *Acontheus acutangulus* Angelin, 1851, *Dolichometopus svecicus* Angelin, 1854, and *Groenwallia microphthalma* (Angelin, 1851). *Dolichometopus svecicus* is also known from an erratic block of Exporrecta Conglomerate at Melbjerg Cliff, Hvalpsund, in the southern Limfjord area, Denmark (Rushton & Weidner 2002; for location see Geyer *et al.* 2004, fig. 1).

The trilobites collected from the eight localities in Västergötland mentioned above show that the *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones are actually present in most parts of Västergötland, though as a thin and impersistent conglomeratic limestone.

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