Cambrian to basal Ordovician lithostratigraphy in southern Scandinavia

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The lithostratigraphic subdivision of the Cambrian successions in Scania-Bornholm, Östergötland, Västergötland, Närke, Öland-Gotland, the southern Bothnian Sea and the Mjøsa District is reviewed and revised. The review includes the Tremadocian part of the Alum Shale Formation.

The Cambrian of Scania-Bornholm comprises the Nexø, Hardeberga, Læså, Gislöv and Alum Shale formations. The Nexø Formation of Bornholm is subdivided into the new Gadeby and Langeskanse members, which are *c.* 40 and 50 m thick, respectively. The 1–15 m thick arkosic basal part of the sandstone succession in Scania, previously treated as part of the Hardeberga Sandstone, is allocated to the Nexø Formation. The 'Balka Sandstone' of Bornholm is considered an integrated part of the Hardeberga Formation and the designation Balka Sandstone Formation is abandoned. The Hardeberga Formation, which is 109 m thick on Bornholm and *c.* 105–110 m in Scania, comprises the Hadeborg (new), Lunkaberg (Scania only), Vik, Brantevik and Tobisvik members. The overlying Læså Formation contains the Norretorp and Rispebjerg members; the former is regarded a senior synonym of the Broens Odde member of Bornholm. The Norretorp Member is thicker in Scania than previously estimated (> 25 m, rather likely even > 30 m); on Bornholm it is 103 m thick. The Rispebjerg Member is 1–3.7 m thick.

The Cambrian of the Öland-Gotland area, the southern Bothnian Sea and the districts of south central Sweden comprises the File Haidar, Borgholm and Alum Shale formations. The File Haidar Formation of the Öland-Gotland area, which is up to 127 m thick, includes the Viklau, När Shale and När Sandstone members; the Grötlingbo Member is transferred to the Borgholm Formation. The validity of the Kalmarsund Member is questioned; its lithological characteristics probably reflect diagenesis. The Lingulid and Mickwitzia sandstone members constitute the File Haidar Formation in south central Sweden, where the unit is up to 37 m thick.

New names and to some extent new definitions are introduced for the members of the Borgholm Formation, viz. Kvarntorp Member (new name for the thin glauconitic sandstone overlying the Lingulid Sandstone Member in central Sweden), Mossberga Member (new name for the coarse part of the *Eccaparadoxides oelandicus* Shale *sensu* Hagenfeldt 1994), Bårstad Member (new name for the fine-grained part of the *Eccaparadoxides oelandicus* Shale), Äleklinta Member (new name for the *Paradoxides paradoxissimus* Siltstone) and Tornby Member (new name for the *Paradoxides paradoxissimus* Shale). The Granulata Conglomerate (= Acrothele Conglomerate of previous literature) is formally ranked as a bed at the base of the Äleklinta Member. The informal designation Söderfjärden formation is abandoned. The Borgholm Formation locally exceeds 150 m in the Öland-Gotland area; it is significantly thinner in south central Sweden.

The Cambrian of the Mjøsa District comprises the Vangsås, Ringstrand and Alum Shale formations. Of these, the new Ringstrand Formation encompasses the strata between the Vangsås and Alum Shale formations, previously referred to as the 'Holmia Series'. The Ringstrand Formation includes the Brennsætersag (new), Redalen (new), Tømten (new), Evjevik and Skyberg (new) members. Thickness estimates are rendered difficult due to tectonic overprinting, but the Ringstrand Formation is probably about 50-60 m thick in the Lower Allochthon around Lake Mjøsa.

The Scandinavian Alum Shale Formation, which is up to 100 m thick in Scania and even thicker subsurface of Kattegat, is restricted to encompass only kerogeneous mudstones/shales with subordinate limestones and very rare sandstone beds. It is proposed abandoning the Kläppe Shale and Fjällbränna Formation of the Lower Allochthon of Jämtland and to regard these units as part of the Alum Shale Formation. Several widespread thin units are formally ranked as beds within the Alum Shale Formation, including the Forsemölla Limestone Bed (new name for the 'fragment limestone' at or near the base of the Alum Shale Formation in Scania; this unit is also developed in Östergötland

and Närke), the Exsulans Limestone Bed, the Hyolithes Limestone Bed, the Andrarum Limestone Bed, the Exporrecta Conglomerate Bed, the Kakeled Limestone Bed (new name for the 'Great Orsten Bank' of south central Sweden), the Skåningstorp Sandstone Bed (new name for the thin sandstone intercalation at the base of the Ordovician in Östergötland) and the Incipiens Limestone Bed.

Key words: Cambrian, Tremadocian, lithostratigraphy, Denmark, Sweden, Norway.

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The current lithostratigraphic framework used for the Cambrian of Scandinavia has been developed during more than 100 years of research (for reviews, see Martinsson (1974), Jaeger (1984), Bergström & Gee (1985), Mens *et al.* (1990) and Moczydłowska (1991)). Only a small number of units are defined by boundary stratotypes, but with few exceptions this has not created noteworthy ambiguity. The present paper presents a general review and revision of the Cambrian lithostratigraphic units of Scania-Bornholm, Östergötland-Närke-Västergötland, the southern Bothnian Sea, Öland-Gotland and the Mjøsa District (Fig. 1). Within these districts the Cambrian is 40 to 350 m thick. The revised lithostratigraphy adopted in this paper is shown in Figures 2 and 3.

Renaming well-established units just because they do not meet current standards of definition or naming may cause controversy. Nonetheless, it is proposed to omit the lithologic 'designator' in old names and for instance just refer to the Nexø Formation rather than the Nexø Sandstone Formation because this is shorter, does not cause ambiguity and follows the recommendations of Salvador (1994). Retention of a lithological term is only suggested in the few cases where an omission can lead to misunderstandings (e.g. the När Sandstone and När Shale members of the File Haidar Formation). The lithologic 'designator' is also maintained in old terms based on fossil names (e.g. the Lingulid Sandstone Member of central Sweden), and is proposed for a few new units like the Forsemölla Limestone Bed in order to match the general style for the previously named beds of the Alum Shale Formation.

Non-geographic names like the Alum Shale Formation, Lingulid Sandstone Member or the Exsulans Limestone Bed strictly speaking do not meet the recommendations of Salvador (1994), but these designations are well-established in the literature and are not changed.

Stratigraphic units

Scania-Bornholm

The Cambrian is up to *c.* 250 and 340 m thick in Scania and on Bornholm, respectively, and comprises the Nexø, Hardeberga, Læså, Gislöv and Alum Shale formations. The latter unit is treated separately below. The positions of localities and wells referred to in the text are shown in Figure 4.

Nexø Formation

(Ørsted & Esmarch 1819; Surlyk 1980; emended)

Stratotype. The Borggård core, southern Bornholm, between 310.45–218.3 m is designated as the stratotype section (Fig. 5).

Members. On Bornholm the formation comprises the Gadeby and Langeskanse members. The Nexø Formation of Scania is not subdivided into members.

Lithology. On Bornholm the lower part of the formation is dominated by reddish, poorly sorted, subarkosic sandstone with high clay-matrix content (Gadeby Member), whereas the upper part is more quartzose, better sorted, only partly red-striped and has significantly lower clay-matrix content (Langeskanse Member). The thin Nexø Formation of Scania comprises coarse-grained and conglomeratic arkosic sandstone. Hansen (1936a), Hadding (1929) and Bruun-Petersen (1971) provide petrographic descriptions of the unit; see also the individual members.

Boundaries. The formation rests unconformably on more or less weathered crystalline basement. It is conformably overlain with a sharp boundary by the Hardeberga Formation.

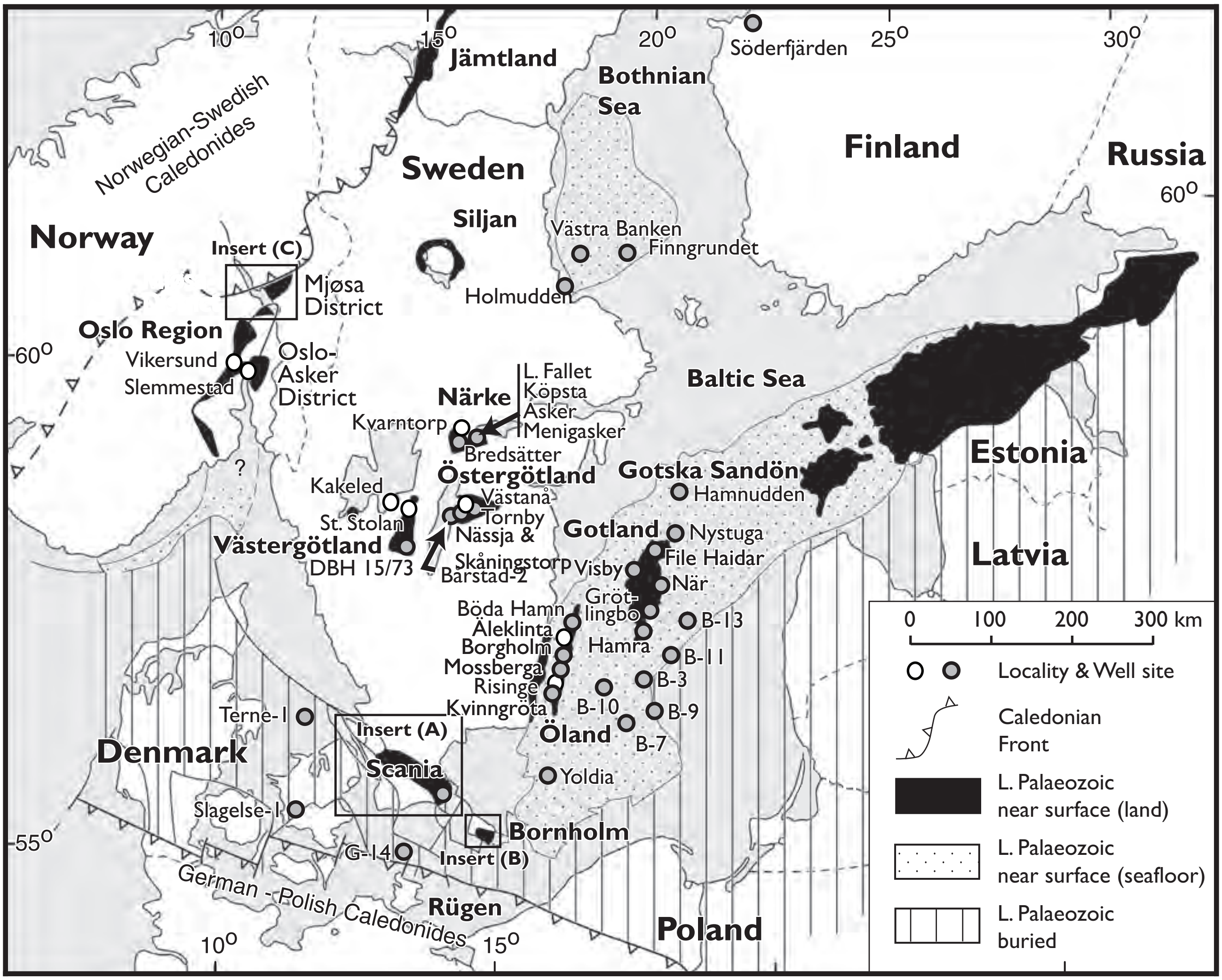


Figure 1. Map showing the position of localities and wells referred to in the text. Inserts indicate position of the detailed maps shown in Figs 4 and 7 (close ups of Scania, Bornholm and the Mjøsa District).

Distribution and thickness. The Nexø Formation is present in Scania and on Bornholm. It is 15 m thick at Skrylle in central western Scania (cf. Molnos 2002), 1–10 m at Lunkaberg in SE Scania (basal arkose *sensu* Lindström & Staude 1971) and *c*. 2 m at Rekekroken in NW Scania (basal arkose *sensu* Hadding 1929, pp. 75–77). In southeastern Bornholm the formation is 92 m in the Borggård well and probably about 100–110 m in the Nexø area, but the latter figure is uncertain.

The Nexø Formation is a lateral equivalent of the up to 186.5 m thick Żarnowiec Formation in northeastern Poland introduced by Lendzion (1970) (for review, see Jaworowski & Sikorska (2003)). The distinction of two formations reflects national rather than lithological differences. The Adlergrund Conglomerate Member, 55.5 m thick, of the offshore G-14 well north of Rügen (Fig. 1) probably also represents the Nexø/Żarnowiec Formation (cf. Feldrappe *et al*. 2005).

Age. The formation is assumed to be of earliest Cambrian age (e.g. Bruun-Petersen 1977; V. Poulsen 1978 and subsequent authors) but with the exception of rare *Planolites* (Bromley 2002, p. 81) no body or trace fossils have been reported. Attempts to use palaeomagnetic data for dating have produced ambiguous results (cf. Lewandowski & Abrahamsen 2003 and references therein).

Remarks. On Bornholm the formation has previously been referred to as the Nexøer Sandsten (Ørsted & Esmarch 1819, p. 21), Nexø/Neksø Sandstone (many authors) and Neksø Sandstone Formation (Surlyk

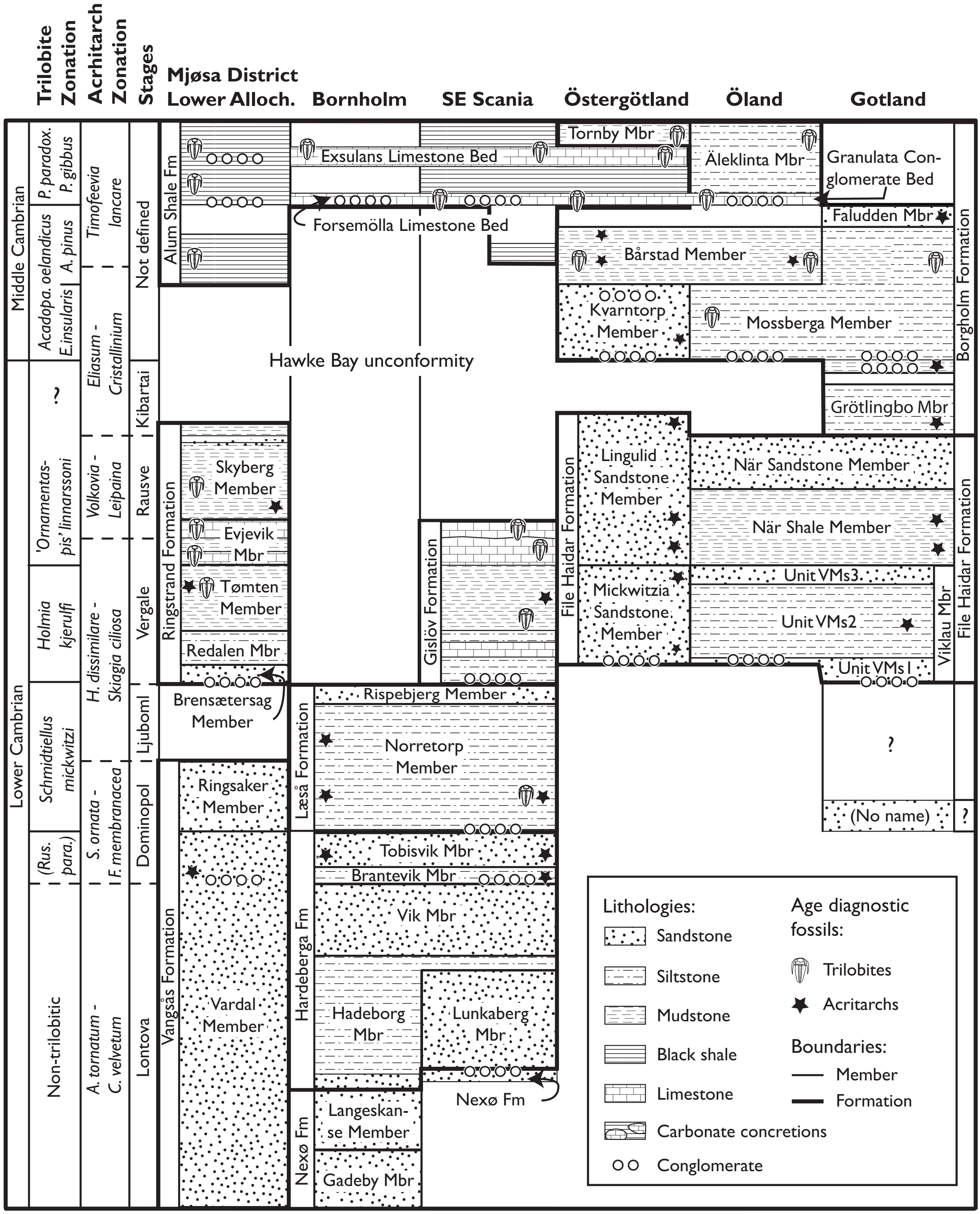


Figure 2. Revised lithostratigraphic scheme for the Lower and lower Middle Cambrian of southern Scandinavia. Correlations and biozones according to Nielsen & Schovsbo (in prep.). The traditional definition of the Lower/Middle Cambrian boundary is adopted in this paper (compare alternative proposal by Moczydłowska 1999). Abbreviations: *Rus. para.* = *Rusophycus parallelum*; for explanation of VMs1-3, see remarks on the Viklau Member.

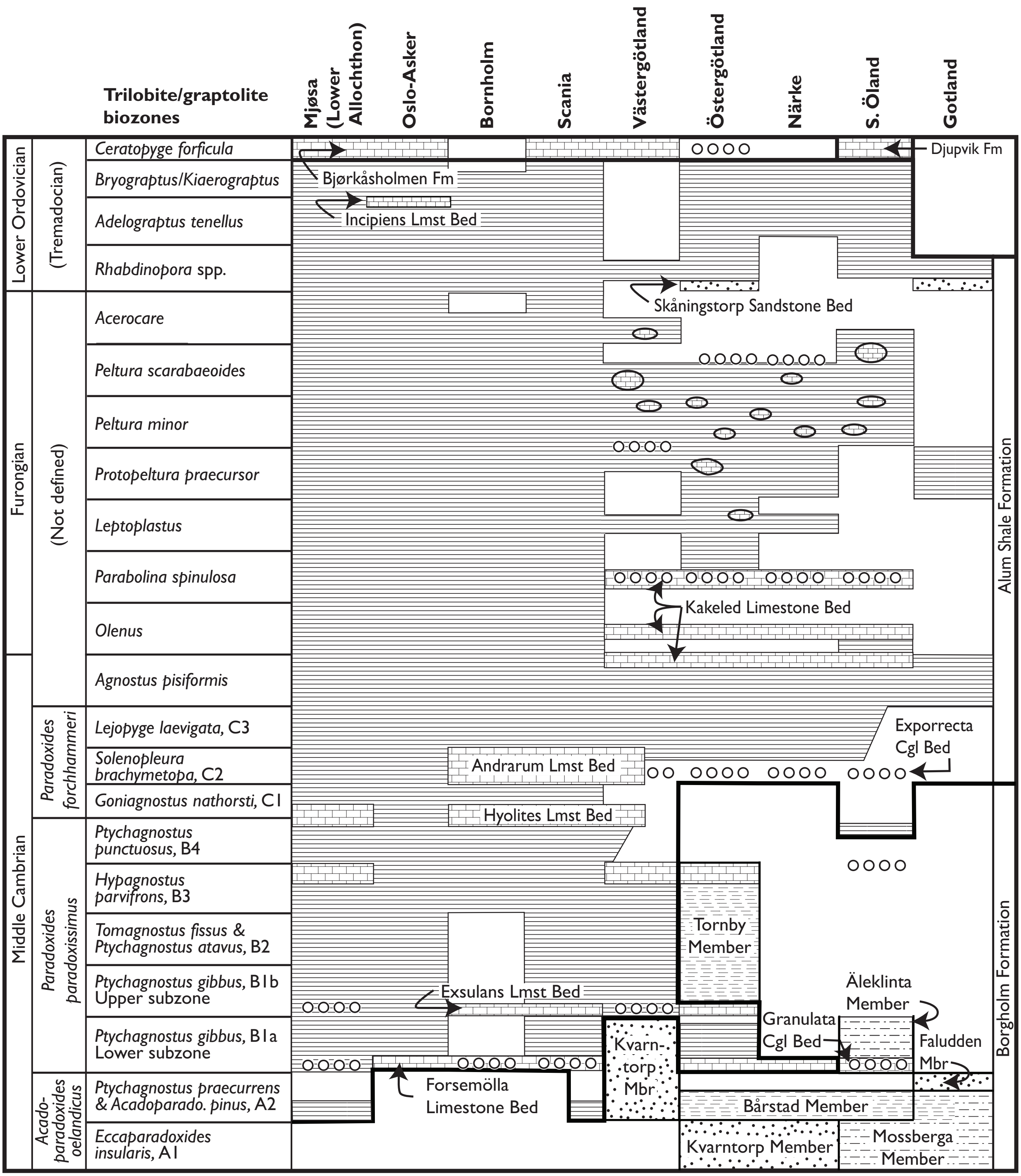


Figure 3. Revised lithostratigraphic scheme for the Middle Cambrian and Furongian of southern Scandinavia. For legend, see Figure 2. Correlations and biozones according to Nielsen & Schovsbo (in prep.). Most of the units are fossiliferous, and particularly trilobites provide a detailed biostratigraphic framework. Presence of biostratigraphic diagnostic fossils in the individual units is therefore not specified. For definition of the Furongian, see Shergold & Cooper (2004).

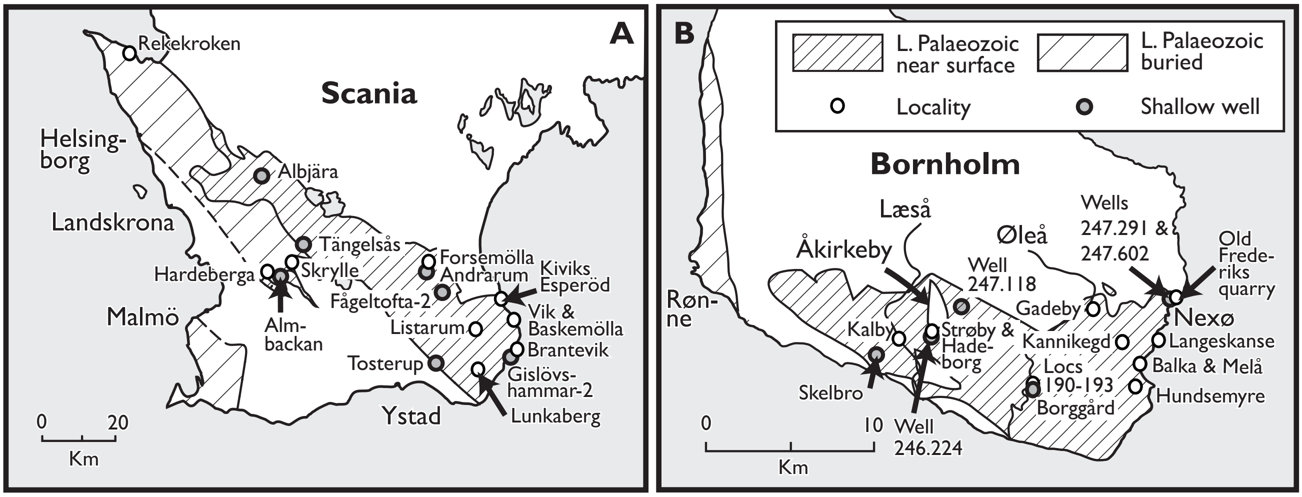


Figure 4. Detailed maps of Scania (A) and Bornholm (B) showing the position of localities and wells referred to in the text. Numbered localities 190–193 on Bornholm according to Hansen (1936a).

1980 and subsequent authors). Regarding spelling, the town of Nexø/Neksø was spelled with 'ks' in the period 1938–1996 (see www.navneforskning.dk); it is suggested reverting to the original spelling with 'x' also in lithostratigraphy.

Originally the Nexø Sandstone included all sandstones below the 'Green shales' (= Læså Formation) of Bornholm (e.g. Johnstrup 1874; Grönwall 1916; Hansen 1936a). Hansen (1938) introduced the designation Balka Quartzite for the upper quartzitic part and subsequently the term Nexø/Neksø Sandstone became restricted to encompass only the lower, reddish to violet subarkosic sandstone quarried at various sites in southern and southeastern Bornholm. The Nexø Formation of Bornholm is here subdivided into the Gadeby and Langeskanse members, following an unpublished proposal by Bruun-Petersen (1971). The two units represent, respectively, the lower, predominantly terrestrial red-coloured 'classical' Nexø Sandstone and a lesser known shallow marine upper part, dominated by partly red-striped quartzites (so-called Gingham sandstone, see Hansen 1936a).

Within recent years the Nexø and Balka sandstones of Bornholm have generally been ranked as two separate formations (e.g. Surlyk 1980; Hamberg 1991). There has, however, been some discussion regarding the separation of these units and whether they should be separated at all (e.g. Bergström & Ahlberg 1981). The previous debate regarding the so-called Åker Formation of southern Bornholm (Gry 1936a, b; Hansen 1936a, b; Larsen 1955) also relates to this issue. The differences in interpretation reflect that the Langeskanse Member includes highly Balka sandstone-like lithologies in combination with the lack of continuous exposures on southern Bornholm, making it difficult to sort out the succession in this intensively faulted area. As an additional complication the colour of the Langeskanse Member is variable because of subsequent hydrothermal remobilisation of iron minerals (notably in the Nexø area) and local bleaching (in the Åkirkeby area). Hence the Langeskanse Member is quite intensively red-striped in the Nexø area and more Balka sandstone-like in the Åkirkeby area.

The rather thin basal arkosic to subarkosic sandstones of Scania, described by Hadding (1929, pp. 69–77) and hitherto included in the Hardeberga Formation (e.g. by Molnos 2002), are here allocated to the Nexø Formation, which is considered a more consistent classification of these red-coloured beds. The colouration is, however, mainly due to a high content of feldspar and is not caused by hematite like on Bornholm.

Gadeby Member

(New)

Derivation of name. The new name alludes to the active quarries at Gadeby, Bornholm, where a section *c.* 10–20 m above the base of the Nexø Formation is excavated. The succession at Gadeby is illustrated and discussed by Clemmensen & Dam (1993) and Pedersen & Surlyk (1999, stop X3).

Stratotype. The Borggård core, southern Bornholm, between 310.45–268.1 m is designated as the stratotype section (Fig. 5).

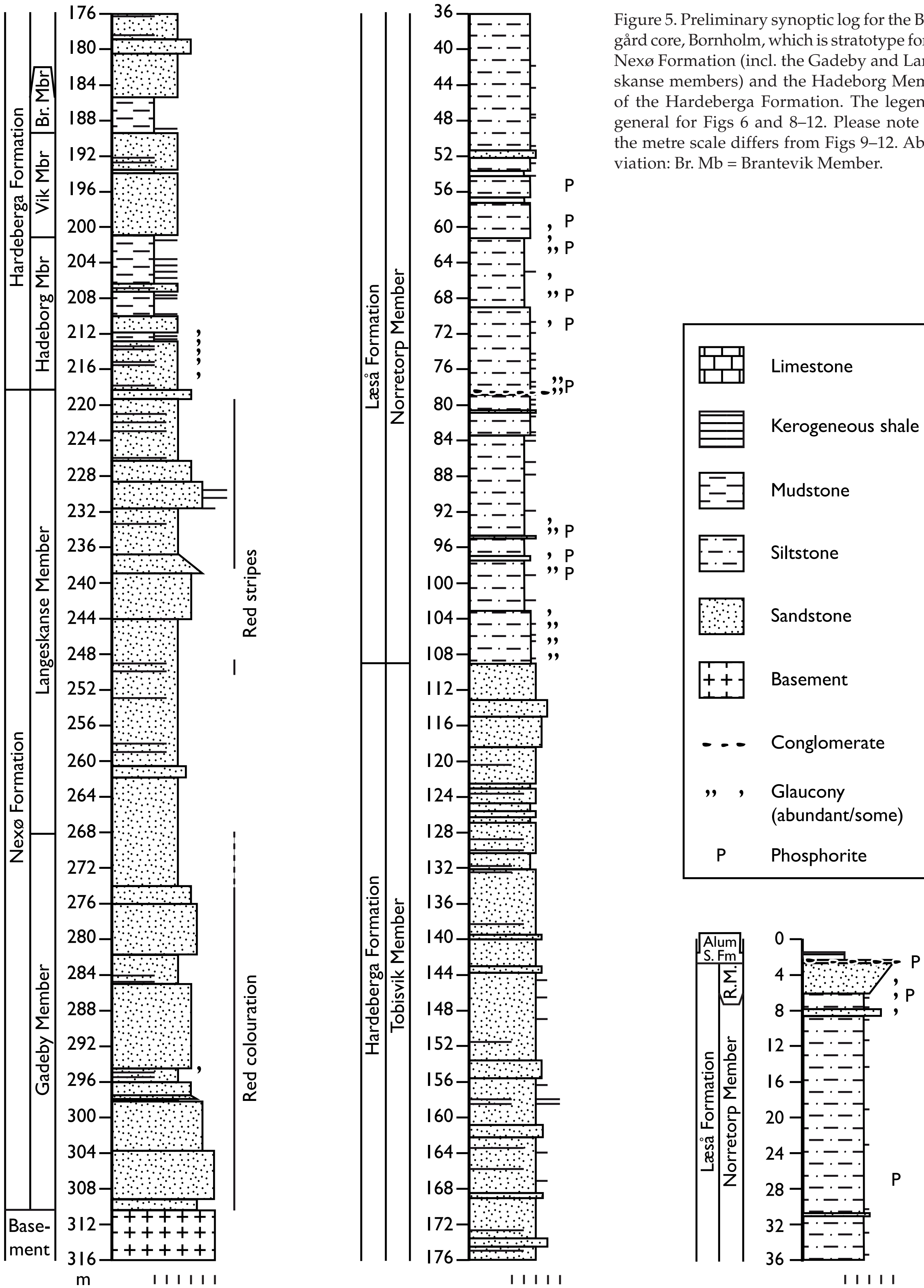


Figure 5. Preliminary synoptic log for the Borggård core, Bornholm, which is stratotype for the Nexø Formation (incl. the Gadeby and Langeskanse members) and the Hadeborg Member of the Hardeberga Formation. The legend is general for Figs 6 and 8–12. Please note that the metre scale differs from Figs 9–12. Abbreviation: Br. Mb = Brantevik Member.

Lithology. The member consists of comparatively poorly sorted sandstone characterised by 12–25% feldspar and a high content of clay matrix (rock types I and II of Hansen 1936a). Unweathered rocks are pinkish, reddish-brown and violet and represent what is nowadays regarded as typical Nexø Sandstone. The red colour is due to hematite in the matrix and as coatings on the sand grains. For descriptions of lithology, see Hansen (1936a), Bruun-Petersen (1971) and Clemmensen & Dam (1993).

Boundaries. The member rests unconformably on the crystalline basement. The typical red Nexø Sandstone is separated by a 12 m transitional succession (*c.* 274–262 m in the Borggård core, Fig. 5) from the overlying Langeskanse Member, showing a gradual upwards decrease in red colouration. In the stratotype core the upper boundary is defined within this transitional section at a level where the colour shifts from subtle pinkish to subtle grey violet, concomitant with the appearance of numerous dark irregular laminae (?clay), which characterize the lower part of the Langeskanse Member and essentially are absent in the Gadeby Member. It is uncertain how consistently this lithological shift can be traced elsewhere on southern Bornholm and the transitional character of the boundary section is emphasized. The pinkish upper part of the Gadeby Member is represented by the upper part of the succession previously quarried in the Old Frederiks Quarry north of Nexø.

Distribution and thickness. The member is developed only on Bornholm. It is about 42 m in the stratotype core and 32–37 m in the Åkirkeby area (cf. Larsen 1955, pl. I). It is possibly slightly thicker in the Nexø area, where two water wells (GEUS nos 247.291 and 247.602) southwest of the Old Frederiks Quarry penetrated 45 m of sandstone. Hence the Gadeby Member may be 45–50 m or maybe even slightly thicker in the Nexø area.

Age. No fossils are known; probably earliest Cambrian.

Remarks. The unit has previously been referred to as the Lower Nexø Sandstone (Stehmann 1934; Gry 1936a) and the Bodilsker member (Bruun-Petersen 1971). See also remarks on the Nexø Formation.

Langeskanse Member

(M. Poulsen *et al*. 2000, emended and formalized)

Stratotype. The Borggård core, southern Bornholm, between 268.1–218.3 m is designated as the stratotype section (Fig. 5).

Lithology. The member is dominated by quartzitic sandstone (including rock types III, IV and VII of Hansen 1936a), generally with a subtle violet tint, and which at some levels are red-striped (the so-called Gingham sandstone, rock type V of Hansen 1936a). In the stratotype core the red striation is largely restricted to the upper 19 m of the unit (Fig. 5). The feldspar content is generally low, but scattered grains are usually visible with the naked eye. Infrequent grains of glaucony (Bruun-Petersen 1971) and conglomeratic quartz-pebble levels are also present in the Langeskanse Member.

The red-striped Gingham-rock has been affected by diagenetic redistribution of iron minerals (Bruun-Petersen 1971), but whether this is the sole origin of the striation is uncertain. The unit is more red-striped in the Nexø-Balka area than in the stratotype core section and the vicinity of Åkirkeby. Within the latter area this may be due to local bleaching (Gry 1936b; Bruun-Petersen 1971).

Boundaries. The lower boundary is transitional and somewhat arbitrarily defined (for description, see Gadeby Member). The Langeskanse Member includes 1.5 m of feldspathic, non-red-striped, medium- to coarse-grained sandstone at the very top, in turn overlain with a conformable but sharp boundary by the Hadeborg Member of the Hardeberga Formation (*q.v.*).

Distribution and thickness. The Langeskanse Member is developed only on Bornholm. It is best exposed along the beach at Langeskanse, eastern Bornholm, (sites nos 221–225 of Hansen 1936a; for a brief review of the exposure see Gry 1936a, pp. 37–38), but can also be seen in the trench at Hadeborg, but where large parts are faulted out (cf. M. Poulsen *et al.* 2000). The member is 50 m in the stratotype core and seems to exceed 38 m in the Åkirkeby area (well 247.118, Larsen 1955). It is probably about 50–60 m in the Nexø-Balka area.

Age. Probably earliest Cambrian, but no fossils have been reported from the member.

Remarks. The Langeskanse member was introduced informally by M. Poulsen *et al.* (2000). It is equivalent to the middle part of the Nexø Sandstone in the sense of Grönwall (1916) and has previously been referred to as the Middle Nexø Sandstone (Stehmann 1934) and the 'Middle littoral series' (Gry 1936a). It includes most of the Åker Formation of Hansen (1936a,b).

By comparison with the Gadeby Member the Langeskanse Member is clearly more quartzitic, the sandstone is better sorted and fine-grained interbeds are typically greenish, not dark red-brown (green interbeds occur, however, in the upper part of the Gadeby Member). The quartzitic Langeskanse Member exhibits a subtle violet tint whereas the comparatively quartz-rich upper part of the Gadeby Member has a faint to pronounced reddish hue. The Langeskanse Member differs from the overlying Hardeberga Formation by being partly red-striped and by containing horizons rich in quartz pebbles, besides having generally higher feldspar content. However, notably in the vicinity of Åkirkeby local bleaching including quartz replacement of feldspar grains (cf. Gry 1936b; Larsen 1955) gives the Langeskanse Member a whitish, superficially highly Hardeberga Sandstone-like appearance and which is well seen in the trench at Hadeborg. In small outcrops it may be difficult or impossible to discern the Langeskanse Member from the Hardeberga Formation.

The Langeskanse Member was ranked as part of the Balka sandstone formation by M. Poulsen *et al.* (2000), but including it as part of the Nexø Formation results in a much more stringently defined boundary between the Nexø and Hardeberga formations. Besides, maintaining a classification of the red-striped 'Gingham sandstone' as part of the Nexø Formation is most practicable for establishing the lithostratigraphy in non-cored water wells.

Hardeberga Formation

(Angelin 1877; Bergström 1970; Hamberg 1990, 1991; emended)

Stratotype. The Hardeberga Quarry, central western Scania (Bergström 1970); only the upper boundary is exposed. The cored 9204 well of Skrylle, penetrating the lower part of the formation, is here designated as a hypostratotype section; for description, see Molnos (2002).

Members. The Hardeberga Formation comprises the Hadeborg, Lunkaberg, Vik, Brantevik and Tobisvik members.

Lithology. The formation is dominated by well-sorted strongly cemented orthoquartzites but also includes mud- and siltstones horizons (notably the Hadeborg and Brantevik members). On Bornholm most of the unit consists of fine- to medium-grained quartzite (rock types VI and VII of Hansen 1936a) that contains very little feldspar and clay matrix (Bruun-Petersen 1971) and coarse-grained beds are almost entirely absent. The sandstone is typically whitish grey to grey, but may locally be darker grey or even completely black; the latter is due to interstitial pyrobitumen (Møller & Friis 1999).

The Hardeberga Formation of Scania broadly contains the same lithologies, but tends to be more strongly bioturbated than on Bornholm; the bioturbated horizons are usually somewhat impure. See Hadding (1929), Hansen (1936a), Lindström & Staude (1971), Shaikh & Skoglund (1974), Hamberg (1991) and Molnos (2002) for description of petrography, lithology and sedimentology.

Boundaries. In Scania the Hardeberga Formation rests conformably on a thin tongue of the Nexø Formation. The fairly sharp boundary is indicated by a shift from arkosic, reddish sandstone to white-grey vaguely pinkish quartzite. On Bornholm the Hardeberga Formation rests conformably on the Langeskanse Member of the Nexø Formation. The sharp boundary is indicated by a shift from feldspar-bearing partly red-striped sandstones to glaucony-bearing quartzite with mudstone laminae and intercalations. The Hardeberga Formation is unconformably overlain by the Læså Formation.

Distribution and thickness. The Hardeberga Formation is a widespread unit recorded from Scania, Bornholm and subsurface of Sjælland and Kattegat, eastern Denmark (Terne-1 (Michelsen & Nielsen 1991); Slagelse-1 (C. Poulsen 1969)). It has also been encountered in deep wells in SW Scania (Norling & Skoglund 1977) and probably corresponds (at least partly) to the *c.* 90 m thick Adlergrund Sandstone Member of the offshore G-14 well north of Rügen (cf. Feldrappe *et al.* 2005).

The formation is approximately 105 m thick in the type area and *c.* 110 m in SE Scania (Lindström & Staude 1971; Falk 1993, minus the succession here allocated to the Nexø Formation). The Hardeberga Formation is 109 m thick in the Borggård well on southern Bornholm (Figs 5, 6).

Age. The Hadeborg Member contains macrofossils suggestive of a late Ediacaran (?) – earliest Cambrian age (see below), whereas acritarchs indicative of the Early Cambrian *Skiagia ornata-Fimbriaglomerella mem-*

branacea Zone have been recovered from the Brantevik and Tobisvik members (Vidal 1981; Moczydłowska 1991). The trace fossils *Syringomorpha nilssoni*, *Psammichnites gigas* and *Rusophycus parallelum* (Lindström & Staude 1971; Bergström 1970) also occur only in the Brantevik and Tobisvik members.

Remarks. The formation has previously been referred to as the Hardeberga Sandstone/Quartzite and Balka Sandstone/Quartzite (many authors). Other previously used designations include Scolithos linearis-sandstone/Diplocraterion sandstone/Syringomorpha sandstone (Hadding 1929, pp. 81, 94, 98), Nexø Sandstone (many authors prior to Hansen 1938), Slagelse quartzite (C. Poulsen 1969), and Simrishamn Formation (Shaikh & Skoglund 1974); see also treatment of individual members below.

In our interpretation the Hardeberga Formation of Scania (Angelin 1877, see below) and the Balka quartzite/sandstone of Bornholm (Hansen 1938) represent the same depositional unit, and the latter designation is therefore abandoned. This simplification was originally proposed by V. Poulsen (1978) and later adopted by Hamberg (1990, 1991) and Mens *et al.* (1990), but it has not been followed by all stratigraphers (e.g. Surlyk 1980; Moczydłowska 1991). Bergström & Ahlberg (1981) also advocated the unification of all basal Lower Cambrian sandstones of Scania-Bornholm into the Hardeberga Sandstone, even including the Nexø Sandstone (see also Bergström 1981), but in which case the latter name has priority.

The designation Hardeberga Sandstone dates back to Angelin (1877), but the name has been used for different rock units over the years (see Bergström 1970 for review of earlier works). Bergström (1970) separated the upper part of the Hardeberga Sandstone *sensu* Angelin as the Norretorp Sandstone (Formation), and this modification has gained widespread acceptance; this unit is here ranked as a member of the Læså Formation (see below). Lindström & Staude (1971) subdivided the Lower Cambrian of SE Scania into the Lunkaberg, Vik, Brantevik, Hardeberga, Norretorp and Rispebjerg sandstone formations. Shaikh & Skoglund (1974) ranked these units as members of a Simrishamn Formation, whereas Bergström & Ahlberg (1981) were sceptical regarding the recognition of the mentioned pre-Norretorp units in other parts of Scania. Hamberg (1991) classified the Lunkaberg, Vik, Brantevik and Hardeberga sandstones of Lindström & Staude (1971) as members of the Hardeberga Formation, and informally introduced the Tobisvik member as a replacement name for the Hardeberga Sandstone *sensu* Lindström & Staude. Hamberg (1991) also extended the usage of the Vik, Brantevik and Tobisvik members to central western Scania, based on sequence stratigraphical correlation.

We here follow Hamberg's approach albeit with slightly modified definitions of the members. The fine-grained Hadeborg and Brantevik members reflect major rises in sea level, and these two drowning horizons form easily identified regional marker levels naturally subdividing the Hardeberga Formation into three sandstone-dominated units, i.e. the Lunkaberg, Vik and Tobisvik members. There are some minor and rather subtle lithological differences between these units, but in many cases it will difficult or impossible to identify which member is present in a specific small exposure of Hardeberga Sandstone.

Hadeborg Member

(M. Poulsen *et al*. 2000, emended and formalized)

Stratotype. The Borggård core, southern Bornholm, between 218.3–201.1 m is designated as the stratotype section (Fig. 5).

Lithology. On Bornholm the upper main part of this member is dominated by dark grey mudstone with thin sandstone interbeds (see Hansen 1936a, fig. 26). The lowermost part is dominated by glauconitic sandstone with thin mudstone interbeds and laminae. In SE Scania the Hadeborg Member consists of dark mudstone with numerous thin sand-beds containing scattered glaucony and phosphorite.

Boundaries. The Hadeborg Member rest conformably but with a sharp boundary on the Langeskanse Member (Nexø Formation) and the Lunkaberg Member (Hardeberga Formation) on Bornholm and in SE Scania, respectively. On Bornholm the lower boundary is defined by the incoming of glauconitic sandstone with mudstone intercalations and in SE Scania by the shift to mudstone lithology. The upper boundary is transitional for 1–2 m in both Scania and on Bornholm (coarsening upward succession of sandstone interspersed by thin mudstone beds; see Lindström & Staude 1971 p. 3; M. Poulsen *et al.* 2000, p. 11). The upper boundary is defined at the level where sandstone becomes dominating in the succession relative to mudstone.

Distribution and thickness. The Hadeborg Member is

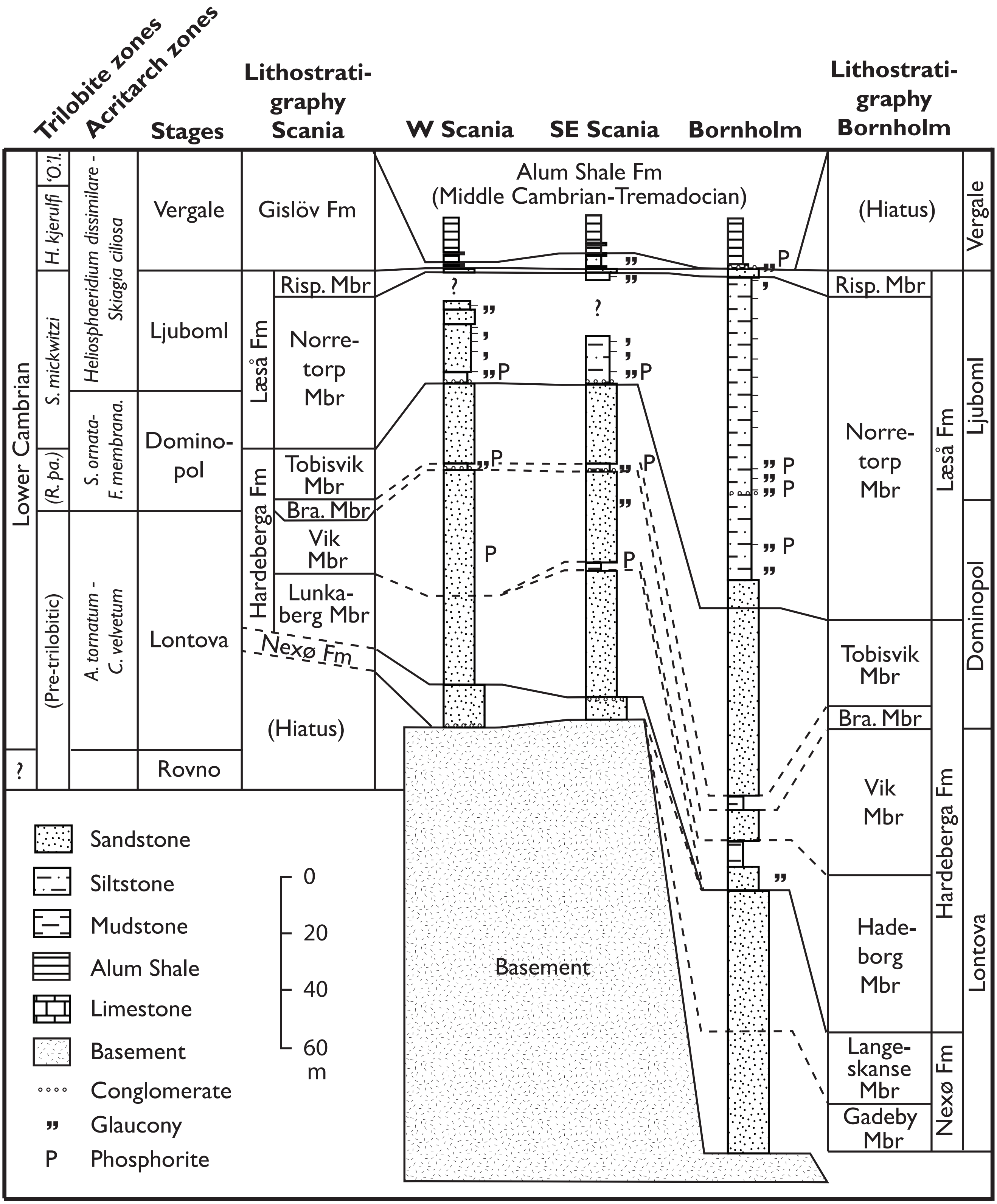


Figure 6. Synoptic logs of the Lower Cambrian of Bornholm-Scania showing thickness variations (based on Lindström & Staude (1971), Hamberg (1991), Falk (1993) and new data, notably from the Borggård core). Correlations according to Nielsen & Schovsbo (in prep.). Abbreviations: *R. pa. = Rusophycus parallelum; 'O'.l = 'Ornamentaspis' linnarssoni*; Bra. Mbr = Brantevik Member; Risp. Mbr = Rispebjerg Member.

developed in Bornholm and SE Scania, where it is 17 m and 3 m thick, respectively (new data; Lindström & Staude 1971). The supposedly coeval succession in central western Scania is assigned to the Lunkaberg Member (see remarks). The 8 m thick argillaceous sandstone unit g, described from the Lunkaberg Quarry by Lindström & Staude (1971, p. 3), may be considered a transitional facies between the Lunkaberg and Hadeborg members (in particular the lower part of unit g), but the sand-dominated transitional succession is retained within the Lunkaberg Member.

Age. On Bornholm parts of the Hadeborg Member contain very common *Sabellidites cambriensis*, previously referred to as annelids resembling *Byronia* by C. Poulsen (1967) and as algae by Bromley (2002, fig. 5). *S. cambriensis* is primarily known from the Ediacaran(?)-basal Cambrian Rovno and Lontova stages of the East Baltic area (Mens *et al.* 1990, p. 8).

Only stratigraphically undiagnostic acritarchs were recorded from the 'Lunkaberg sandstone' (presumably the mudstone here assigned to the Hadeborg Member) by Vidal (1981, p. 184). The Hadeborg Member of Bornholm has so far failed to produce acritarchs (Moczydłowska personal communication 2004).

Remarks. The Hadeborg Member was introduced informally by M. Poulsen *et al.* (2000), based on the exposure in the trench at Hadeborg, Strøby, southern Bornholm, which currently is the only exposure of this unit (see Bromley 2002, fig. 4). The member corresponds to 4.2–*c.* 12.5 m in the section shown by M. Poulsen *et al.* (2000, p. 11). The unit is significantly thicker in the stratotype core and the lower glauconitic part of the member is faulted out at Hadeborg. This inference is corroborated by data from water well GEUS no. 246.224 located 300 m south of the Hadeborg trench, where the Hadeborg Member is about 15 m thick. The mudstone-rich member was observed by Jespersen (1865) at Kannikegård, Melå and Hundsemyre, but none of these exposures exist any longer.

We regard the lower main part of the so-called 'Lunkaberg Wechselfolge' in SE Scania (see Lindström & Staude 1971) as a thin tongue of the Hadeborg Member; the base is located approximately 44 m above the local base of the Hardeberga Formation as defined here. The strongly bioturbated horizon mentioned by Falk (1993) at *c.* 27–31 m above the base of the Hardeberga Formation (as defined here) in drill-core 9204 from Skrylle is probably a sandy equivalent of the Hadeborg Member of SE Scania, but for lithological reasons this succession is here assigned to the Lunkaberg Member. This core-section was destroyed for analytical purposes and is no longer available for study. The preserved parts of the core adjacent to this horizon are dark-coloured and clay-rich.

Lunkaberg Member

(Lindström & Staude 1971; Hamberg 1991; emended)

Stratotype. The abandoned and partly water-filled quarry at Lunkaberg, SE Scania (Lindström & Staude 1971).

Lithology. The Lunkaberg Member is dominated by medium-grained slightly feldspathic, partly argillaceous quartzite, which typically displays a more or less pronounced pinkish colour when fresh (Lindström & Staude 1971; Falk 1993). Bioturbation is sparse. For a brief description of the succession, see Lindström & Staude (1971).

Boundaries. The member overlies the Nexø Formation with a sharp boundary, characterized by a rapid decline in feldspar content accompanied by a shift to grey colour, albeit a faint pinkish tint still prevails. In SE Scania the Lunkaberg Member, as redefined here, is overlain with a sharp boundary by a thin tongue of the mudstone-dominated Hadeborg Member (see remarks). In central Scania the uppermost part of the Lunkaberg Member is a dark grey to blackish, impure sandstone, some 4 m thick, which is overlain by grey sandstone assigned to the Vik Member. However, the upper boundary of the Lunkaberg Member is here less obvious to pinpoint than in SE Scania.

Distribution and thickness. The Lunkaberg Member is developed only in Scania and is envisaged representing a nearshore deposit corresponding in age to the Hadeborg Member of Bornholm. The member is 31 m thick below the Skrylle Quarry in central Scania (Falk 1993, Molnos 2002 minus the succession here allocated to the Nexø Formation) and about 44 m at Lunkaberg in SE Scania (see Lindström & Staude 1971).

Age. Most likely Early Cambrian, but no fossils are known.

Remarks. The unit was originally established as the Lunkaberg Sandstone Formation (Lindström & Staude 1971) but we here follow Hamberg (1991) ranking it as a member of the Hardeberga Formation.

Originally the Lunkaberg Sandstone included the mudstone dominated 'Lunkaberg-Wechselfolge' *sensu* Lindström & Staude (1971), but which here is considered a tongue of the Hadeborg Member. The sandstone exposed above the Hadeborg Member at Lunkaberg was also originally included in the Lunkaberg sandstone, but this succession is here allocated to the Vik Member.

Vik Member

(Lindström & Staude 1971; Hamberg 1991; emended)

Stratotype. The coastal exposures near Vik, SE Scania, were designated as the stratotype section by Lindström & Staude (1971), but here the base of the member is not exposed. We designate the Lunkaberg Quarry, where the redefined lower boundary is exposed, as a hypostratotype section.

Lithology. The Vik Member is dominated by fine- to medium-grained quartzite. Within SE Scania the member is characterized by couplets of whitish rather pure quartzite and greenish somewhat argillaceous sandstone, which is strongly bioturbated (see Hamberg 1991, fig. 10). The intense bioturbation – which is well seen in the type section near Vik – was the main distinguishing criterion of the Vik Sandstone emphasized by Lindström & Staude (1971). However, the lower part of the member in SE Scania as well as its counterpart on Bornholm is little bioturbated.

Boundaries. The lower boundary is redefined here (see remarks). Within Bornholm and SE Scania the Vik Member conformably overlies the Hadeborg Member. The boundary is transitional for 1–2 m, forming a coarsening upward unit containing fewer and fewer mudstone interbeds. The lower boundary of the Vik Member is defined at the level where sandstone dominates relative to mudstone. In central Scania the lower boundary of the Vik Member is known only from the fully cored 9204 borehole in the Skrylle Quarry, described by Falk (1993) and Molnos (2002). It here overlies a dark coloured 4 m thick argillaceous sand unit (27–31 m above the base of the Hardeberga Formation as defined here), forming the top of the Lunkaberg Member.

The Vik Member is unconformally overlain by the Brantevik Member in Scania and with a sharp boundary on Bornholm

Distribution and thickness. The Vik Member, as redefined here, is some 44 m thick in central Scania (data from Falk 1993) and more than 34 m thick in SE Scania (Lindström & Staude 1971; Hamberg 1988). The member is 12 m thick in the Borggård core on southern Bornholm (Fig. 5).

Age. Most likely Early Cambrian, but no fossils are known.

Remarks. The member has previously been referred to as the Vik Sandstone Formation (Lindström & Staude 1971) and Strøby member (M. Poulsen *et al.* 2000).

The boundary conditions between the Lunkaberg and Vik sandstones were not discussed when Lindström & Staude (1971) defined these units. By analogy with the boundary defined between the Brantevik and Tobisvik members we suggest redefining the regressive Vik Member to include the entire succession from the easily identified maximum flooding horizon represented by the Hadeborg Member of Bornholm and SE Scania and its equivalent level within Central Scania. The redefined Vik Member includes the uppermost part of the Lunkaberg sandstone *sensu* Lindström & Staude (1971).

Brantevik Member

(Lindström & Staude 1971; Hamberg 1991; emended)

Stratotype. The exposure between the two harbours at Brantevik on the east coast of Scania, described by Hadding (1932, fig. 26, loc. 6), was designated as stratotype section for the Brantevik Glauconite Sandstone Formation by Lindström & Staude (1971). However, this locality has within recent years been covered by the construction of a small recreational area.

The Skrylle Quarry (Fig. 4A), where both the lower and upper boundaries of the Brantevik Member are well-exposed in the northern walls, is here designated as a neostratotype section.

Lithology. Within Scania the member consists of thin-bedded, dark-coloured, locally strongly glauconitic silt- and sandstone interbedded with thin mudstone. For description, see Hadding (1929, pp. 100–102) and Hamberg (1991). On Bornholm the member is represented by a predominantly greenish mudstone with sporadic very thin sandstone interbeds.

Boundaries. The Brantevik Member is sandwiched by the quartzite-dominated Vik and Tobisvik members. In Scania the lower boundary is a well-defined unconformity associated with a phosphoritic conglomerate also containing sandstone clasts. Hadding (1929, p. 100) reported sandstone boulders up to 0.3 m in diameter. On Bornholm the lower boundary is conformable and gradual for 0.4 m, exhibiting an upward decrease in sandstone content. We suggest defining the boundary where mudstone becomes dominating relative to sandstone. In Scania the upper boundary of the member is less distinct; it is here placed where the mudstone intercalations essentially disappear and the lithology changes to quartzite (see remarks). On Bornholm the upper boundary is sharp and marked by an abrupt shift from mudstone to sandstone although the lower part of the overlying Tobisvik Member still contains a few thin mudstone beds.

Distribution and thickness. The member is a thin (2–3 m) easily identified marker level known from several exposures in southeast and central western Scania (Hadding 1929, p. 98; Lindström & Staude 1971). It is located 28–30 m below top of the Hardeberga Formation in central western Scania and more than 25 m below top of the formation in SE Scania (Hamberg 1991). On Bornholm (Borggård core, Fig. 5) the member is represented by a 4 m thick succession 76.5–80.5 m below top of the Hardeberga Formation. The horizon is currently available for study only in the Borggård core, but it is readily recognized in water wells due to a distinctive gamma-log response (cf. Klitten & Larsen 1998).

Age. Early Cambrian, *Skiagia ornata - Fimbriaglomerella membranacea* acritarch Zone (Vidal 1981; Moczydłowska 1991).

Remarks. The Brantevik Member has previously been referred to as the "Greywacke zone"/Lower glauconite zone (Hadding 1929, p. 98), Brantevik Glauconite Sandstone Formation (Lindström & Staude 1971), Brantevik Sandstone (Shaikh & Skoglund 1974) and Brantevik unit (Molnos 2002). It was ranked as a member of the Hardeberga Formation by Hamberg (1991).

Hamberg (1991) and Falk (1993) defined the upper boundary of the Brantevik Member at a thin mudstone occurring 2–2.5 m above the top of the member as defined here. The upper part of the Brantevik Member in their terminology consists of amalgamated hummocky-cross-stratified sandstone which we for lithological reasons assign to the Tobisvik Member.

Tobisvik Member

(Hamberg 1991; formalized)

Stratotype. There are no suitable exposures in the Tobisvik area that may serve as basal stratotype section, and we instead designate the excellent and complete exposure of the member in the Skrylle Quarry, central Scania, as the stratotype section.

Lithology. Within Scania the middle main part of the member consist of very pure, well-cemented comparatively coarse quartz-sandstone (Hamberg 1988, 1991; Falk 1993). On Bornholm the thick unit is dominated by fine-grained quartzite. In both Bornholm and Scania the upper 5–6 m of the unit are thoroughly bioturbated and comparatively impure (Hamberg 1991; Falk 1993, new data) thus reminding of the Scanian Vik Member.

Boundaries. Within Scania the lower boundary is gradual within a zone of 2–3 m. We suggest defining it where the silt-mudstone intercalations essentially disappear and sandstone becomes dominating. On Bornholm the boundary is sharp and marked by an abrupt shift from mudstone to sandstone.

Distribution and thickness. The Tobisvik Member is developed in Scania and Bornholm. It is more than 25 m thick in SE Scania and ranges between 28 to 30 m in central Scania (Lindström & Staude 1971, Hamberg 1991, Falk 1993). On Bornholm it reaches 77 m in the Borggård core (Fig. 5).

Age. Early Cambrian, *Skiagia ornata – Fimbriaglomerella membranacea* acritarch Zone (Vidal 1981; Moczydłowska 1991).

Remarks. The member has previously been referred to as the Syringomorpha sandstone (Hadding 1929) and Hardeberga Sandstone Formation (Lindström & Staude 1971). The name Tobisvik member was introduced by Hamberg (1991), but the unit has never been formally defined.

Læså Formation

(Surlyk 1980, emended and formalized)

Stratotype. The Hardeberga Quarry, Scania (see Norretorp Member). The Borggård core, southern Bornholm, between 109–2.6 m is designated as a hypostratotype section (Fig. 5).

Members. The Læså Formation, as redefined here, comprises the Norretorp and Rispebjerg members.

Lithology. On Bornholm greyish-greenish siltstone, variably glauconitic and with phosphorite nodules at several levels, is the predominant lithology in the lower main part of the formation. Sandstone interbeds are common and some horizons, in particular in the upper part of the unit, are quite sandy due to intense bioturbation, which has mixed the sand interbeds with the finer-grained 'host' sediment. The member is dominated by fine-grained sandstone and siltstone in central western and SE Scania, respectively. The thin, medium- to coarse-grained Rispebjerg Member constitutes the uppermost part of the formation. For petrographic descriptions, see Hadding (1932), Hansen (1936a) and de Marino (1980a).

Boundaries. The Læså Formation unconformably and with a sharp contact overlies the Hardeberga Formation. A thin basal phosphoritic conglomerate is present in Scania. A basal conglomerate was also mentioned by C. Poulsen (1967) from Bornholm, but in the Borggård core no such conglomerate is developed. Here the sharp boundary is indicated by the incoming of frequent glaucony and a decrease in grain size. The lower boundary is currently exposed only in central western Scania, where the basal conglomerate is overlain by a *c.* 1 m thick siltstone. The formation is unconformably and with a sharp boundary overlain by the Gislöv Formation (Scania) or the Alum Shale Formation (Bornholm).

Distribution and thickness. The formation is present on Bornholm, where it measures 106.5 m in the Borggård core, and in Scania, where it at least is up to 26 m thick (for references, see the individual members). The formation is less than 8 m thick in the Slagelse-1 well on Sjælland (cf. C. Poulsen 1969). The Læså Formation has also been reported from the offshore well G-14 NE of Rügen, where it is assumed to measure some 170 m (Feldrappe *et al.* 2005), but we strongly suspect that the lower main part of that succession in fact matches the Hardeberga Formation.

Age. Early Cambrian. The formation represents the *Schmidtiellus mickwitzi* trilobite Zone and straddles the *Skiagia ornata-Fimbriaglomerella membranacea* and *Heliosphaeridium dissimilare-Skiagia ciliosa* acritarch zones (Moberg 1892, 1899; Bergström 1973; Vidal 1981; Ahlberg 1984; Moczydłowska & Vidal 1992).

Remarks. The Norretorp sandstone and Læså formations were explicitly introduced informally and without designation of stratotypes by Bergström (1970) and Surlyk (1980), but subsequent authors have mostly treated them as formal lithostratigraphic units. The strata here assigned to the Læså Formation were referred to as the Norretorp Formation by Vejbæk *et al.* (1994), but we suggest ranking the 'Norretorp Sandstone' as a member of the Læså Formation. The Norretorp silt/sandstone of Scania and the somewhat thicker 'Green shales' of Bornholm – informally named the Broens Odde member by Surlyk (1980) – is here combined into one member since they broadly speaking exhibit the same lithologies and undoubtedly represent the same depositional unit. Hence the Norretorp Member is considered a senior synonym of the Broens Odde member. The proposed lithostratigraphy also streamlines the classification of the overlying Rispebjerg Sandstone, ranked as a member of the Læså Formation on Bornholm (Surlyk 1980) and as a separate formation in Scania (Lindström & Staude 1971; Bergström & Ahlberg 1981).

Norretorp Member

(Bergström 1970; Mens *et al.* 1990; emended)

Stratotype. The Hardeberga Quarry, Scania, was listed as stratotype for the Norretorp Formation by Mens *et al.* (1990). Here the lower boundary of the unit is well exposed and the section also serves as the basal stratotype for the Læså Formation.

Lithology. The member is dominated by siltstone, often somewhat sandy, in SE Scania and on Bornholm and by fine-grained sandstone in central western Scania. Glaucony and phosphorite nodules are common at some levels. Thin sandbeds are abundant in the unit on Bornholm, in particular in the upper half. Due to intense bioturbation the sandbeds are more or less mixed with the more fine-grained 'host' sediment. Thicker sand units occur in the upper part of the member in central western Scania. For descriptions of lithology, see Troedsson (1917), Hadding (1929, 1932), Hansen (1936a), Shaikh & Skoglund (1974), Clausen & Vilhjálmsson (1986) and Falk (1993).

Boundaries. The member rests unconformably and with a sharp boundary on the Hardeberga Formation. There is a thin phosphoritic conglomerate at the base in Scania (Hamberg 1991; Molnos 2002). A basal conglomerate has also been reported from Bornholm (Hansen 1936a, loc. 74; C. Poulsen 1967), but was not found in the drilling at Borggård (Fig. 5).

However, here the boundary is still sharp, being marked by the abrupt incoming of glaucony and finer-grained lithology. The Norretorp Member is overlain by the Rispebjerg Member, usually with a sharp, well-defined boundary.

Distribution and thickness. The unit is more than 16.5 m thick in SE Scania (Shaikh & Skoglund 1974) and exceeds 25.6 m in central western Scania (Falk 1993). No Norretorp Member is present at the drill-sites Albjära-1 (Lauridsen 2000) and Tängelsås-1 (Erlström *et al*. 2001), where the Alum Shale Formation rests directly on the Hardeberga Formation (at the latter site this may, however, be a tectonic complication). The Norretorp Member is often quoted as being 3–5 m thick in SE Scania, but only the topmost part is exposed in the beach sections south of Brantevik, and there is no constraint on the small thickness originally estimated by Hadding (1929, p. 98) and reiterated e.g. by Lindström & Staude (1971), Mens *et al.* (1990) and Ahlberg (1998). The Norretorp Member is 103 m in the Borggård well on southern Bornholm (Fig. 5).

Age. In Scania rare trilobites are indicative of the *Schmidtiellus mickwitzi* Zone (Moberg 1892, 1899; Bergström 1973; Ahlberg 1984). The various small shelly fossils reported from Bornholm by C. Poulsen (1967) are not age-diagnostic. In both Scania and on Bornholm the lower part of the member has yielded acritarchs diagnostic of the *Skiagia ornata-Fimbriaglomerella membranacea* Zone (Vidal 1981; Moczydłowska & Vidal 1992). On Bornholm the upper half of the unit represents the *Heliosphaeridium dissimilare-Skiagia ciliosa* acritarch Zone (Moczydłowska & Vidal 1992); the corresponding level has not been dated by acritarchs in Scania.

Remarks. The Norretorp Member was originally included as the upper part of the Hardeberga Sandstone in Scania (Angelin 1877). Subsequently it has been referred to as Olenellus-sandstone (Törnebohm & Hennig 1904), greywacke (e.g. Moberg 1910), Norretorp Sandstone (Bergström 1970), Norretorp Glauconite Sandstone Formation (Lindström & Staude 1971) and Norretorp Siltstone (Shaikh & Skoglund 1974). On Bornholm the unit has previously been referred to as Green Shales (introduced by Forchhammer 1835) or 'Green shales'. This long-lasting but somewhat misguiding designation was abandoned after introduction of the informal Broens Odde member (Surlyk 1980). However, this unit is a local counterpart of the Norretorp sand/siltstone of Scania and we propose combining these similar units into just one member.

Rispebjerg Member

(Grönwall 1899; Surlyk 1980)

Stratotype. The name refers to a site near Øleå, Bornholm, but the locality at Kalby, Læså (Hansen 1936a, loc. 86), is more instructive than the small exposures along the Øleå (Hansen 1936a, locs 190–193). The Kalby section, where the entire member is exposed or can easily be dug out, is here designated as the stratotype.

Lithology. The member consists of medium- to coarse-grained quartz sandstone (cf. Pedersen 1989, fig. 2); the lower part is glauconitic on Bornholm. Petrographic descriptions are published by Hadding (1932, pp. 58–59), Hansen (1936a) and de Marino (1980a). The top of the unit is impregnated with phosphorite; this zone is locally up to 0.3–0.4 m thick on Bornholm and 0.05–0.1 m in Scania. Lower levels are also impregnated with phosphorite on Bornholm (Hansen 1945; de Marino 1980a).

Boundaries. The lower boundary is a sharp change from the strongly bioturbated glauconitic siltstones of the Norretorp Member to the quartz sandstones of the Rispebjerg Member. There is a phosphorite conglomerate at the base in Scania and locally also on Bornholm (see Pedersen 1989); no such conglomerate is described from the stratotype section. The Rispebjerg Member is unconformably overlain by the Gislöv Formation in Scania and by the Exsulans Limestone Bed of the Alum Shale Formation on Bornholm.

Distribution and thickness. The Rispebjerg Member is present in Scania and Bornholm, where it is about 1 m and 3.5–3.7 m thick, respectively (Grönwall 1902a; Hadding 1929; Pedersen 1989; Mens *et al.* 1990). The maximum thickness of 3.7 m was recorded in the Skelbro-1 drill-core (Pedersen 1989, fig. 2). The Rispebjerg Member is also reported from the G-14 well north of Rügen, where it is *c.* 1 m thick (Piske & Neumann 1993).

Age. No age-diagnostic fossils have been found in the Rispebjerg Member.

Remarks. The Rispebjerg Sandstone was ranked as a member of the Læså Formation by Surlyk (1980), whereas it in Scania has been treated as a separate formation (Lindström & Staude 1971 and subsequent authors, see also Mens *et al.* 1990). The unit has previously been referred to as Tiger sandstone (Deecke 1897), Fosforitsandsten (upper phosphorite impregnated part on Bornholm, Grönwall 1899), Rispebjærg/Rispebjerg sandstone (many authors) and Leopard sandstone (e.g. Hansen 1937).

Gislöv Formation

(Bergström & Ahlberg 1981)

Stratotype. Shore exposure 1 km SW of Brantevik, SE Scania (Bergström & Ahlberg 1981).

Lithology. The lower part of the Gislöv Formation comprises mudstone and strongly glauconitic siltstone, whereas the upper part consists of partly conglomeratic bioclastic limestone (de Marino 1980b, Bergström & Ahlberg 1981). In the Slagelse-1 core the unit consists of coarse siltstone with phosphoritic nodules and minor glaucony (C. Poulsen 1969).

Boundaries. The formation rest unconformably on the Rispebjerg Member of the Læså Formation, and the lower boundary is sharp and readily identified, although the Gislöv Formation usually contains sand in the basal *c.* 0.1 m. The formation is upwards unconformably overlain by the Alum Shale Formation. However, where the formation is capped by the Forsemölla Limestone Bed, the upper boundary appears just as an ordinary discontinuity surface.

Distribution and thickness. The Gislöv Formation is mainly known from Scania (Bergström & Ahlberg 1981), where it is 0.7–5.7 m thick. The stated maximum thickness was encountered in the Tosterup-1 core (Meyerson personal communication 2004); the formation is 5.25 m in the Fågeltofta-2 core although the upper part here is faulted out (new data). The formation is possibly up to 10 m in uncored wells in eastern Scania (Mens *et al.* 1990), whereas it is absent in the Albjära core and the Tängelsås well (Lauridsen 2000; Erlström *et al*. 2001). The amalgamated Forsemölla and Exsulans limestone beds at the base of the Alum Shale Formation on Bornholm contains reworked fossils (C. Poulsen 1942; V. Poulsen 1965, 1966a) suggesting that layers equivalent to the Gislöv Formation originally were deposited also in the Bornholm area. It is likely that the phosphorite-bearing carbonaceous mudstone 1625.8–1626.5 m in the G-14 drilling offshore Rügen represents the Gislöv Formation. The Gislöv Formation also appears present in the Slagelse-1 well on Sjælland, where it is minimum 14 m and maximum 22 m thick (cf. C. Poulsen 1969, Bergström & Ahlberg 1981). Vejbæk *et al.* (1994) also listed it from the offshore Terne-1 well of Kattegat.

Age. The trilobite fauna of the Gislöv Formation is indicative of the *Holmia kjerulfi* and *'Ornamentaspis' linnarssoni* zones (Bergström & Ahlberg 1981; Ahlberg & Bergström 1993). The few acritarchs reported from the unit are indicative of the *Heliosphaeridium dissimilare-Skiagia ciliosa* or the *Volkovia dentifera-Liepaina plana* zones (Moczydłowska 1998).

Remarks. Parts of the Gislöv Formation have previously been referred to as the Paradoxides Wahlenbergii strata/Paradoxides Kjerulfi strata (see Linnarsson 1883), greywacke/greywacke zone (e.g. Westergård 1942) and phosphorite limestone (e.g. Troedsson 1917).

Mjøsa District

Cambrian strata are present in the Autochthon, Parautochthon and Lower Allochthon of the Mjøsa District (Figs 1, 7). The label Parautochthon is here used for the allochthon east of Brumundal, previously regarded as part of the Autochthon by Skjeseth (1963). The sedimentary facies of the Lower Cambrian, in particular of the Ringstrand Formation, in our opinion indicate that the thrust-slices of this area are less far travelled than the successions of the Lower Allochthon further west. The positions of localities referred to in the text are shown in Figure 7.

The Cambrian of the Autochthon comprises the Ringstrand and Alum Shale formations. The succes-

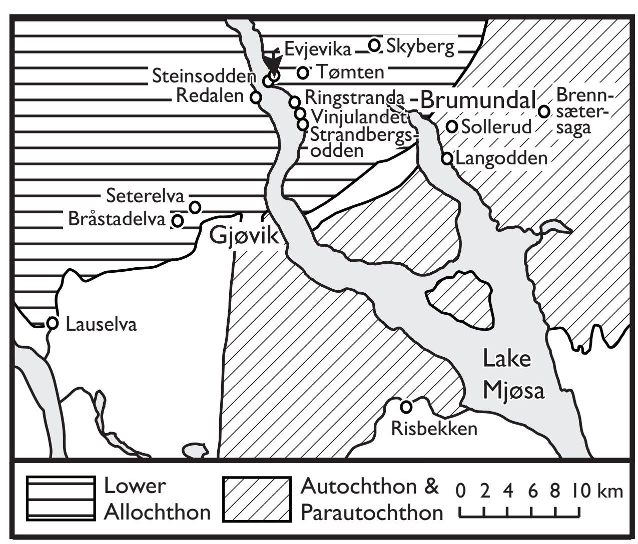


Figure 7. Detailed map of the southern part of the Mjøsa District (Fig. 1, insert C) showing the position of localities referred to in the text. Regarding distinction of the Parautochthon, see text.

sion is probably around 50 m thick, but thickness estimates are speculative because the Alum Shale Formation is strongly tectonized. Thickness estimates for the Cambrian of the Parautochthon and Lower Allochthon are also highly tentative, partly because the position of the Precambrian/Cambrian boundary is uncertain, and partly because of the tectonic overprinting, which in particular has distorted the mudstones. Within the Lower Allochthon the basal terrestrial part may total *c.* 100 m and the overlying marine Cambrian may reach a thickness of *c.* 200 m. The terrestrial Cambrian probably includes parts of or the entire 'Middle Vardal Sandstone' *sensu* Dreyer (1988), whereas the marine succession comprises the upper part of the Vangsås, the Ringstrand and the Alum Shale formations. The Alum Shale Formation is treated separately below.

Vangsås Formation: Vardal and Ringsaker members

(Bjørlykke *et al.* 1967)

Remarks. The Vangsås Formation is the uppermost unit in the >2000 m thick Hedmark Group of the Mjøsa District. No stratotype has been designated. The formation comprises the Vardal and Ringsaker members (the latter including the Mjøsa Quartzsandstone Formation of Skjeseth 1963), which are maintained for the time being, but eventually the Vardal Member may possibly be split into three members (lower, middle and upper Vardal Sandstone *sensu* Dreyer 1988). The acritarch *Fimbriaglomerella minuta* was reported from the upper marine part of the Vardal Member by Vidal & Nystuen (1990, p. 189). This species is characteristic of the *Skiagia ornata-Fimbriaglomerella membranacea* and *Heliosphaeridium dissimilare-Skiagia ciliosa* zones (Moczydłowska 1991), i.e. not the basal Cambrian by comparison with the East Baltic area.

Because of their superficial similarity, the Ringsaker Member and the Hardeberga Formation have generally been considered equivalent deposits (e.g. Mens *et al.* 1990), but we assume that the former is younger (Fig. 2). So far the Ringsaker Member has not yielded stratigraphically diagnostic acritarchs or macrofossils.

Ringstrand Formation

(New)

Derivation of name. The name alludes to Ringstranda on the eastern shore of Lake Mjøsa, where the lower part of the new formation is exposed in a couple of thrust-slices (Vogt 1924, fig. 13; see also Skjeseth 1963, pl. 1). The exposures at Vinjulandet, Ringstranda, Steinsodden and Evjevika along the eastern shore of Mjøsa south of Moelv are described by Brøgger (1882a), Kiær (1917), Vogt (1924), Strand (1929) and Skjeseth (1963).

Stratotype. The Lower Allochthon section at Steinsodden, Mjøsa District (Skjeseth 1963, fig. 16) is designated as the basal stratotype (see Redalen Member).

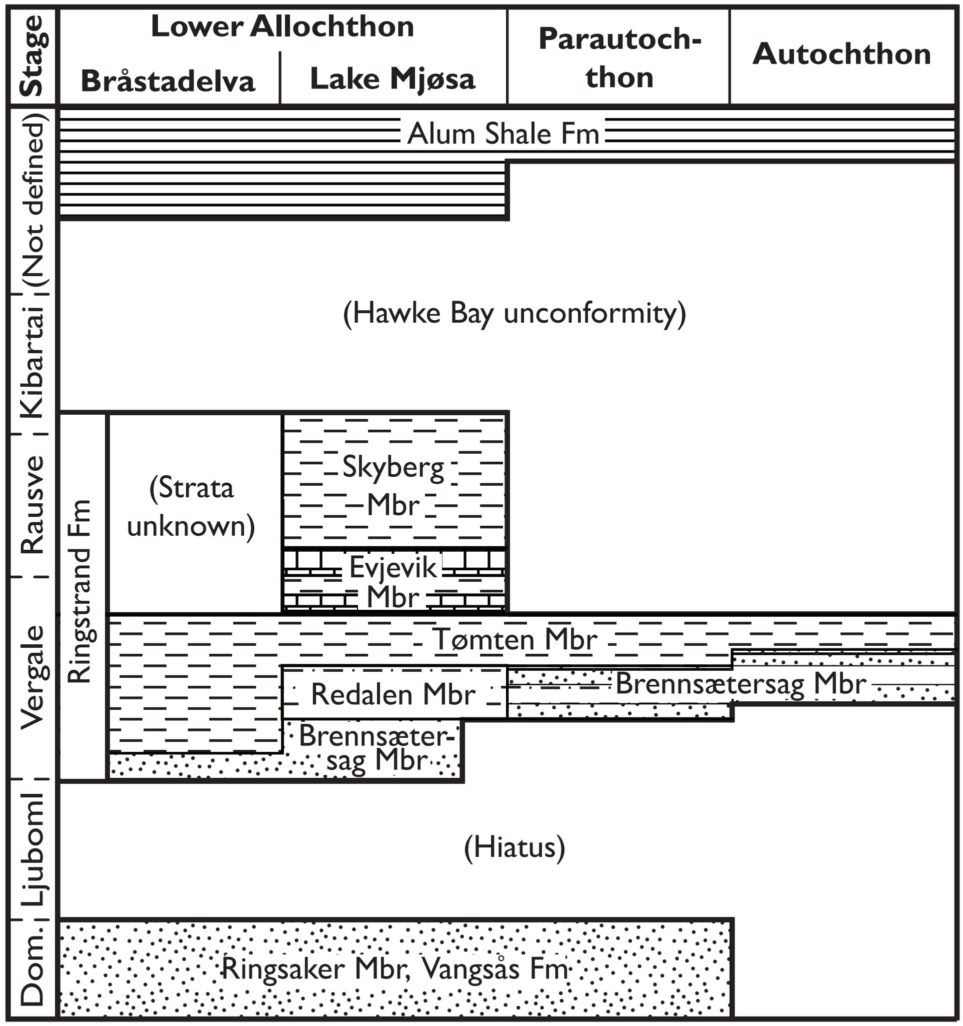
Members. The Ringstrand Formation comprises the Brennsætersag, Redalen, Tømten, Evjevik and Skyberg members (Fig. 8).

Lithology. The formation is dominated by mudstone but sand- and siltstones also occur, particularly in the lower part. Two thin limestone intercalations are present near the top of the formation. For lithological description, see in particular Vogt (1924) and Skjeseth (1963).

Boundaries. In the Autochthon the Ringstrand Formation rests unconformably on weathered crystalline basement and a basal conglomerate is always developed. In the Parautochthon and Lower Allochthon the formation rests unconformably on the Vangsås Formation. The lower boundary is also here associated with a conglomerate and is readily identified by the shift from the monotonous quartzitic Ringsaker Member to the finer-grained and more heterogeneous Ringstrand Formation. The formation is upwards bounded by the Hawke Bay unconformity and is everywhere unconformably overlain by the Alum Shale Formation.

Distribution and thickness. The Ringstrand Formation is developed in the Autochthon, Parautochthon and Lower Allochthon of the Mjøsa District. It is 2 m thick in the Autochthon at Risbekken (Høyberget, new measurement, see also Strand 1929) and 14 m in the Parautochthon at Brennsætersaga (Høyberget, new measurement, see also Vidal & Nystuen 1991). The formation is presumably about 50-60 m in the Lower Allochthon around Lake Mjøsa, but due to tectonic disturbance it is impossible to state an exact thickness, and it may theoretically even be up to about 80–100 m.

Figure 8. Correlation of the Ringstrand Formation within the Mjøsa District according to Nielsen & Schovsbo (in prep.). Lithological signatures as in Figure 5. Abbreviation: Dom. = Dominopol.



Age. Late Early Cambrian. The formation represents the upper main part of the *Heliosphaeridium dissimilare-Skiagia ciliosa* acritarch Zone and possibly ranges into the *Volkovia dentifera-Liepaina plana* Zone (see treatment of the individual members for references). It straddles the *Holmia kjerulfi* and *'Ornamentaspis' linnarssoni* trilobite zones (see entries on the Tømten and Evjevik members).

Remarks. Several thin lithostratigraphic units, referred to as formations of the Holmia Series in older literature (Skjeseth 1963 and subsequent authors), are present between the Vangsås and the Alum Shale formations. They are here combined into one formation for which the name Ringstrand Formation is proposed. This unit is more comparable in scope with the under- and overlying formations, although still thinner. The various units described by Skjeseth (1963), some of which were renamed by Vidal & Nystuen (1991), are in a modified or recombined form ranked as members of the Ringstrand Formation (see separate sections below). The thin Lower Cambrian autochthonous deposits present in the Mjøsa District (Strand 1929, Skjeseth 1963, Bjørlykke 1979) are also assigned to the Ringstrand Formation.

Redalen Member

(New)

Derivation of name. The beach section at Steinsodden is designated as the stratotype, but the names Stein and Steinsholmen are pre-occupied by Ordovician lithostratigraphic units (see Rasmussen & Bruton 1994), hence the name Redalen Member is proposed in order to avoid misunderstandings. The new name alludes to the nearby exposure on the western shore of Lake Mjøsa just north of Redalen (see Vogt 1924).

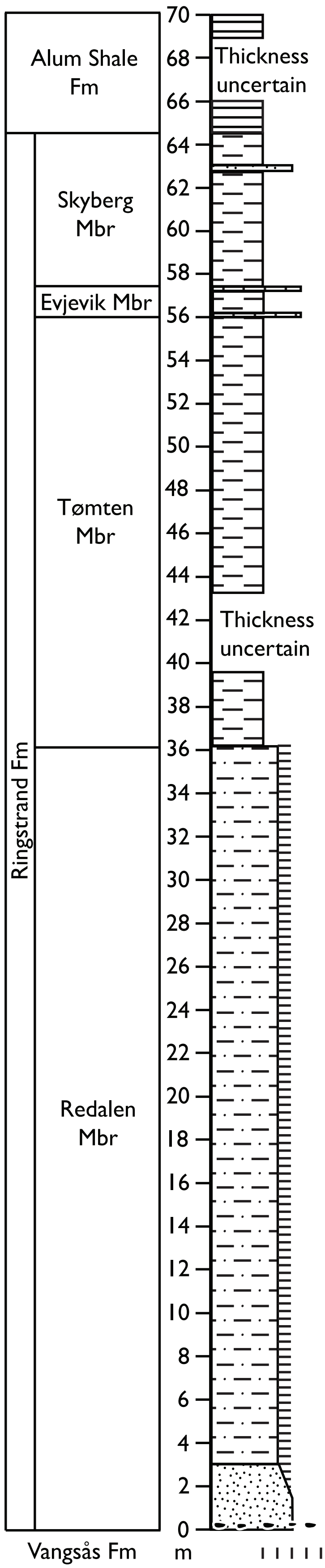


Figure 9. Composite section of the Lower Cambrian in the Lower Allochthon, eastern part of the Mjøsa District (new data mainly). The Redalen Member was measured at Steinsodden (stratotype for this member and basal stratotype for the Ringstrand Formation). The Evjevik and Skyberg members were measured at Skyberg (hypostratotype and stratotype for these members). For legend, see Figure 5.

Stratotype. The Lower Allochthon section at Steinsodden (Vogt 1924; Skjeseth 1963, fig. 16) is designated as the stratotype. The strata are overturned but otherwise little affected by tectonism and here both the lower and upper boundaries of the new member are exposed. The lower part of the log shown in Figure 9 is based on this exposure, which is most instructive, when the water level is low in Lake Mjøsa.

Lithology. The heterolithic unit consists of thin-bedded silt- and mudstones with numerous sandstone beds (all beds and interbeds are generally 1–2 cm thick, but a few sandstone beds are up to 5–15 cm). At Steinsodden the sandstone beds are somewhat thicker in the basal *c.* 5 m forming a fining-upward succession. In the uppermost 5–6 m of the member there is a slightly higher frequency of sandstone beds, 2–5 cm thick, but this coarsening upward trend is subtle. Trace fossils are very common. For description of lithology, see Vogt (1924).

Boundaries. The new member rests unconformably on the Vangsås Formation at Steinsodden and Redalen and conformably on the Brennsætersag Member at Strandbergsodden. The Redalen Member is in turn conformably overlain by the Tømten Member. Although there is no sedimentary break, the upper boundary can be identified within a metre as the lithologic shift is quite rapid; there are no sandy interbeds in the Tømten Member of the Lower Allochthon.

Distribution and thickness. The member is restricted to the eastern part of the Lower Allochthon around Lake Mjøsa, where it is exposed at Ringstranda, Strandbergsodden, Skyberg (in the yard at the farmhouse), Steinsodden and north of Redalen. The new member is *c.* 36 m thick in the relatively undisturbed exposure at Steinsodden, which is the only site where the thickness can be measured (new measurement; Vogt (1924) estimated a thickness of *c.* 40 m). The Redalen Member is absent in the Autochthon and Parautochthon as well as in the higher thrust slices of the Lower Allochthon (e.g. Bråstad River section). Here the Tømten Member rests directly on a thin Brennsætersag Member (cf. Vogt 1924), and the lower part of the Tømten Member is probably coeval with the Redalen Member (Fig. 8).

Age. No fossils are known from the Redalen Member.

Remarks. This characteristic unit is inferred representing a lateral equivalent of the Brennsætersag Member of the Autochthon and the Parautochthon (Fig. 8). The occasional absence of the Brennsætersag

Member in the Lower Allochthon indicates that the unconformity separating the Vangsås and Ringstrand formations locally is slightly more extensive.

Brennsætersag Member

(New)

Derivation of name. The name refers to the stratotype locality.

*Stratotype.*The Parautochthon river section at Brennsætersaga (Fig. 10) is designated as the stratotype. Here the new member is 4 m thick and rests unconformably on the Ringsaker Member of the Vangsås Formation. It is overlain by the Tømten Member of the Ringstrand Formation.

Lithology. The lower part of the member is dominated by siltstone with thin interbeds of sandstone whereas the upper part consists of medium- to coarse-grained quartz sandstone (the 'Bråstad sandstone' of previous literature).

Boundaries. In the Lower Allochthon and Parautochthon the Brennsætersag Member rests unconformably on the Vangsås Formation and there is a thin basal conglomerate, locally with boulders up to 0.3 m in diameter of Ringsaker Quartzite (Skjeseth 1963, p. 47). Small-scale channels have been observed in the top of the Ringsaker Member at Sollerud (new data). In the Autochthon the Brennsætersag Member rests on weathered crystalline basement, also with a conglomerate at the base. The boundary towards the overlying mud- and siltstones of the Tømten and Redalen members is sharp.

Distribution and thickness. The member is most typically developed in the Parautochthon of the Mjøsa District, where it is 1.5–4 m thick (Sollerud and Brennsætersaga sections, respectively). It is suggested attributing the lower sandy part of the Ringstrand Formation in the Autochthon to the Brennsætersag Member as well. In the Lauselva section this unit is 1.25 m thick and includes a conglomerate in the middle (a log is shown by Ebbestad *et al.* 2003, fig. 3). A very thin Brennsætersag Member is present in the higher trust slices of the Lower Allochthon, e.g. in the Bråstad River, where it is only 0.6 m thick (see Vogt 1924). Skjeseth (1963) reported a slightly greater thickness, but minor faulting has repeated the basal part of the succession. Here it is directly overlain by the Tømten Member. At Strandbergsodden (also Lower Allochthon) the Brennsætersag Member is *c.* 2.5 m thick and is overlain by the Redalen Member (see Vogt 1924). Both of these successions display a coarsening-upward trend, but no 'Bråstad sandstone' unit (*sensu* Vidal & Nystuen 1991) is developed. Elsewhere in the Lower Allochthon, e.g. north of Redalen and at Steinsodden, no Brennsætersag Member is developed.

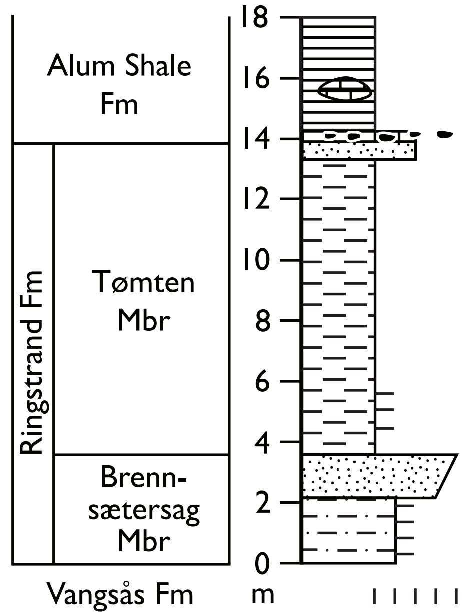


Figure 10. The Lower and basal Middle Cambrian at Brennsætersaga (Parautochthon), which is stratotype for the Brennsætersag and Tømten members. Simplified from Høyberget (unpublished 2004). For legend, see Figure 5.

Age. The Brennsætersag Member of the Parautochthon contains acritarchs of the *Heliosphaeridium dissimilare-Skiagia ciliosa* Zone (Vidal & Nystuen 1991). *Holmia* cf. *mobergi* has been reported from the unit at Brennsætersaga (Skjeseth 1963; Bergström 1980, 1981), but the single trilobite specimen most likely derives from the sandstone bed in the top of the Tømten Member in this section (M. Høyberget personal communication 2004). The Brennsætersag Member of the Lower Allochthon is inferred to be older than the Brennsætersag Member of the Parautochthon and Autochthon (Fig. 8).

Remarks. The member has previously been referred to as 'Basalavdeling med *Discinella holsti*' (Vogt 1924), Brennsæter Limestone, 1α_1 (Skjeseth 1963), Brennsæter shale (Vidal & Nystuen 1991) and Bråstad sandstone (1α_2) (Skjeseth 1963; Vidal & Nystuen 1991). The so-called Brennsæter shale and Bråstad sandstone of the Parautochthon cannot be correlated to sections within the Autochthon and Lower Allochthon in a consistent way and we suggest combination of them into just one coarsening-upward member.

Tømten Member

(New)

Derivation of name. The name refers to the classical locality at Tømten, described by Kiær (1917).

Stratotype. The protected locality at Tømten is now completely overgrown and cannot serve as stratotype; besides, only the upper part of the unit was originally exposed. Instead the Parautochthon Brennsætersaga section is designated as the stratotype. Here both the lower and upper boundaries of the *c.* 10 m thick Tømten Member are exposed (Fig. 10); logs of this section are published by Skjeseth (1963, p. 38), Moczydłowska & Vidal (1986, fig. 2) and Vidal & Nystuen (1991, fig. 2).

Lithology. The Tømten Member includes the informal Bråstad shale of Vidal & Nystuen (1991), which is dominated by arenaceous mudstone, and the greenish-grey mudstones, previously referred to as the Holmia shale. For description of lithology, see Kiær (1917), Vogt (1924), Skjeseth (1963) and Vidal & Nystuen (1991).

Boundaries. In the Brennsætersaga and Sollerud sections of the Parautochthon the Tømten Member overlies the Brennsætersag Member. The boundary is sharp and Skjeseth (1963) described a thin phosphorite-conglomerate from this level. No such conglomerate is currently visible at Brennsætersaga. The upper boundary of the Tømten Member is the Hawke Bay unconformity, which is located inside the so-called Oelandicus conglomerate of Skjeseth (1963) and Vidal & Nystuen (1991). The lower part of this 0.5–0.7 m thick bed is a calcareous sandstone (Høyberget personal communication 2005), which is truncated by the unconformity, in turn overlain by a phosphorite conglomerate (Fig. 10). In the Lauselva section (Autochthon) the Tømten Member is conformably resting on the Brennsætersag Member and the lower boundary is indicated by the shift from sandstone to siltstone. The Tømten Member is unconformably overlain by Middle Cambrian also in the Autochthon as seen in the Risbekken section (cf. Skjeseth 1963). In the Lower Allochthon the Tømten Member rests conformably on the Brennsætersag Member (only Bråstad River section) or the Redalen Member (sections around Lake Mjøsa). The boundary is indicated by a decrease in grain size from sand and silt to mud without thin sandstone interbeds.

Distribution and thickness. The Tømten Member is present in the Autochthon, Parautochthon and Lower Allochthon of the Mjøsa District. It is only *c.* 9 m thick in the Parautochthon at Brennsætersaga (Høyberget, personal communication 2005) and its upper more fine-grained part ('Holmia shale') is not present. Whether this is a lateral facies difference from the Lower Allochthon or due to truncation by the Hawke Bay unconformity is unknown. Because of tectonic disturbance the thickness of the Tømten Member in the Lower Allochthon is uncertain, but maximum thickness may be around 40–50 m (cf. Bjørlykke 1979, p. 22). The preserved part of the unit is 0.8 m in the autochthonous Lauselva section (cf. Ebbestad *et al.* 2003); it is at least 10 m at Dokkaelva in the Torpa area a little further west (Bjørlykke 1979, p. 22).

Age. The Tømten Member contains acritarchs of the *Heliosphaeridium dissimilare-Skiagia ciliosa* Zone (Vidal & Nystuen 1991) and trilobites diagnostic of the *Holmia kjerulfi* Zone (Kiær 1917; Vogt 1924; Ahlberg 1984; Ahlberg *et al.* 1986). *Holmia inusitata* occurs in the Autochthon at Lauselva (Ebbestad *et al.* 2003). We regard the *H. inusitata* Zone as a local biozone within the *H. kjerulfi* Chronozone; inferred age relations are outlined in Figure 8.

Remarks. The member includes the informal Bråstad shale of Vidal & Nystuen (1991) (= 1αβ of Skjeseth 1963) and the overlying Holmia shale (1αβ) (Kiær 1917; Skjeseth 1963). The latter name is deeply entrenched in the literature, but the 'Bråstad' and 'Holmia' shales have mainly been distinguished because of a different faunal content. We therefore suggest uniting these two units into just one fining-upward member.

Evjevik Member

(Skjeseth 1963)

Stratotype. Evjevika was designated as stratotype for the 1bβ zone by Skjeseth (1963). However, the Evjevik Member is poorly exposed at this site and visible only during extremely low water level in Lake Mjøsa. The easily accessible nearby exposure at Skyberg is significantly more instructive and is designated as a hypostratotype section. A simplified log of this section was shown by Vidal & Nystuen (1991, fig. 5); the upper part of the log shown in Figure 9 is based on the Skyberg exposure.

Lithology. The member consists of two bioclastic limestone beds (each typically 0.20–0.25 m thick), usually separated by 0.5–1 m of mudstone.

Boundaries. The lower and upper boundaries of the Evjevik Member are well-defined and readily identified, being located at the base and the top of the limestone beds encasing this unit. The surrounding units consist of mudstones.

Distribution and thickness. The member is known only from the Lower Allochthon of the Mjøsa District, where it usually is around 1–1.5 m, rarely up to 2 m thick (Skjeseth 1963; Høyberget, personal communication 2005). The equivalent level is not preserved in the Parautochthon or the Autochthon (Hawke Bay unconformity).

Age. The limestone beds of the Evjevik Member contain trilobites characteristic of the *'Ornamentaspis' linnarssoni* Zone (Kiær 1917; Nikolaisen 1986; Ahlberg 1984). No age-diagnostic acritarchs have been reported from the unit so far.

Remarks. The member has previously been referred to as Strenuella limestone (Kiær 1917) and Evjevik limestone/1bβ (Skjeseth 1963). It is a border line case whether this unit should be ranked as a member or as two individual marker limestone beds, but for historical reasons a distinction as member is suggested.

Skyberg Member

(New)

Derivation of name. The new name refers to the stratotype locality.

Stratotype. The road cut near the farm Skyberg, Mjøsa District (Lower Allochthon) is designated as the stratotype section. Here both the lower and upper boundaries of the new member are exposed or can easily be excavated. A simplified log is shown by Vidal & Nystuen (1991, fig. 5); a re-measured section is included in the composite log shown in Figure 9.

Lithology. The member consists of greenish-grey rather homogenous mudstone with sporadic small phosphorite nodules. There is a discontinuous sandstone bed, up to 0.25 m thick, *c.* 1.4–1.6 m below top of the unit.
Boundaries. The Skyberg Member rests on the Evjevik Member with a sharp boundary. Upwards, it is unconformably overlain by the Alum Shale Formation.

Distribution and thickness. The new member is so far known only from the stratotype locality within the Lower Allochthon, where it is *c.* 7 m thick. The equivalent level is not preserved in the Parautochthon and Autochthon (Hawke Bay unconformity).

Age. The Skyberg Member contains sparse trilobites, which seemingly are indicative of the *'Ornamentaspis' linnarssoni* Zone, but as yet no systematic study has been made of the fauna. Acritarchs, most of which are biostratigraphically undiagnostic, have been reported from the lower part of the unit (Vidal & Nystuen 1991). The presence of *Baltisphaeridium [= Lophosphaeridium] dubium* indicates that the level is older than the *Eliasum-Cristallinium* acritarch assemblage zone (cf. Hagenfeldt 1989a; Eklund 1990).

Öland-Gotland, south central Sweden and the southern Bothnian Sea

The Cambrian of these districts is divided into the File Haidar, Borgholm and Alum Shale formations. The Cambrian is 40–50 m thick in the Bothnian Sea, 50–60 m in south central Sweden and up to 235 m onshore and 267 m offshore in the Öland-Gotland area. The Alum Shale Formation is treated separately below. The positions of localities and wells referred to in the text are shown in Figure 1.

File Haidar Formation

(Bergström & Gee 1985, emended)

Stratotype. The File Haidar core, southern Gotland, section between 500–412 m (see remarks), described by Thorslund & Westergård (1938) and designated by Bergström & Gee (1985).

Members. The File Haidar Formation comprises the Viklau, När Shale and När Sandstone members in the Öland-Gotland area; the När Shale Member is also present in the southern Bothnian Sea. In south central Sweden the formation consists of the Lingulid Sandstone and Mickwitzia Sandstone members.

Lithology. The formation is dominated by fine- to medium-grained quartz-sandstone with subordinate silt- and mudstones, which, however, locally may reach considerable thickness. For description of lithology, see Thorslund & Westergård (1938), Hessland (1955), Hagenfeldt (1989a, 1994), Eklund (1990) and Jensen (1997).

Boundaries. The formation rests unconformably on crystalline basement or Proterozoic sediments. It is in most areas overlain by the Borgholm Formation and locally by the Alum Shale Formation. In the Gotland area and below northern Öland the formation is conformably overlain by the Grötlingbo Member of the Borgholm Formation, and the boundary is transitional (see entry on the Grötlingbo Member below). In the southern Bothnian Sea a thin File Haidar Formation is unconformably overlain by an atypical sandy Grötlingbo Member. In south central Sweden and most parts of Öland the File Haidar Formation is bounded upwards by the Hawke Bay unconformity. In Östergötland-Närke and the Falbygden-Billingen-Kinnekulle districts of Västergötland this unconformity is overlain by the Kvarntorp Member (Borgholm Formation), which contains a basal phosphorite conglomerate or Fe-ooid bed. At Hunneberg in Västergötland the unconformity is overlain by a sandy conglomerate forming the basal part of the Alum Shale Formation. Below southern and central Öland the unconformity is overlain by the Mossberga Member of the Borgholm Formation.

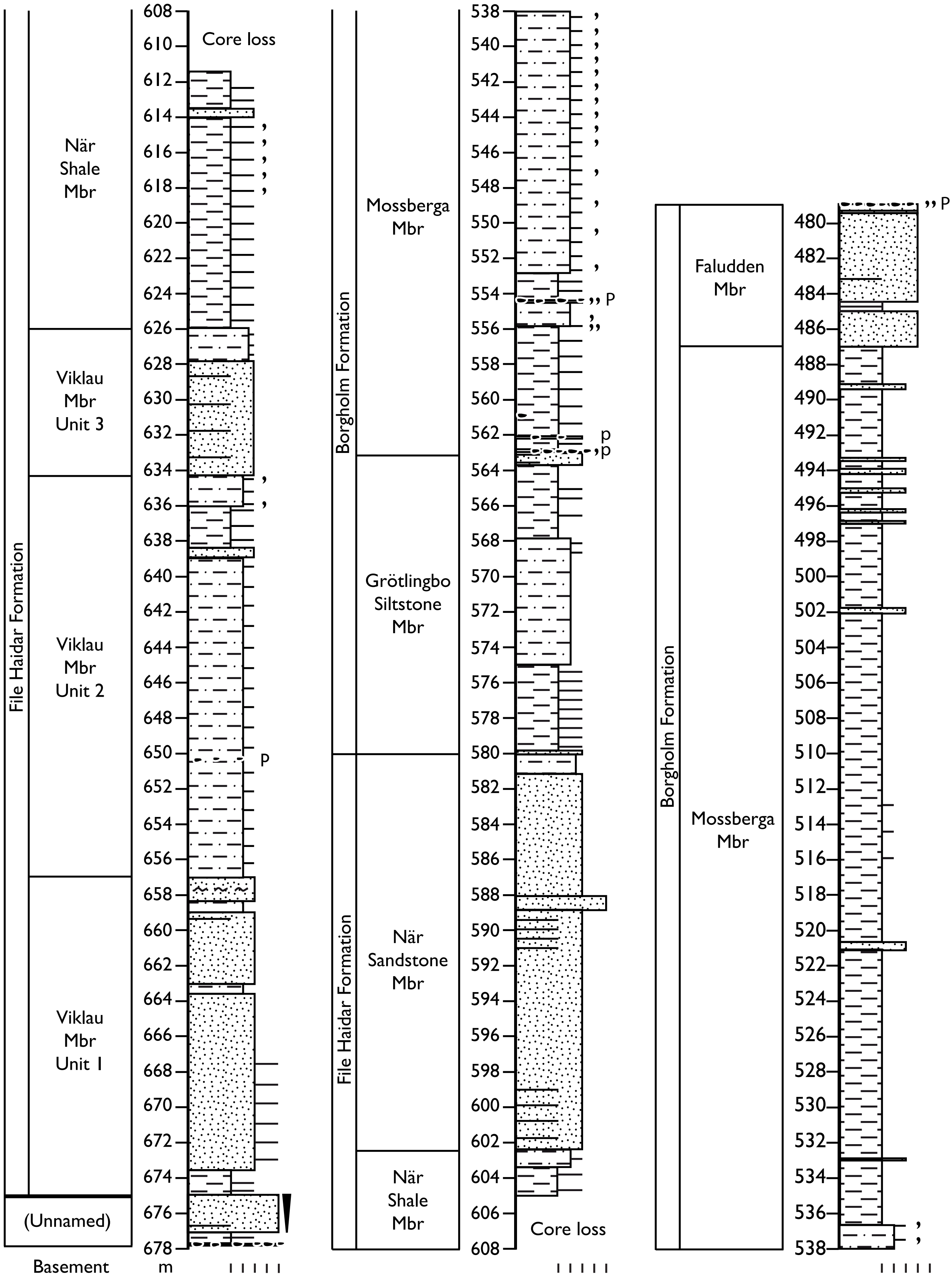
Distribution and thickness. The File Haidar Formation is present in the Öland-Gotland area, the southern Bothnian Sea and Västergötland, Östergötland and Närke. As redefined here the formation is 88 m thick in the File Haidar stratotype core, and reaches 100–107 m in various other wells on Gotland (see Hagenfeldt 1994, p. 107). On Öland the formation is mostly 72–112 m (Hagenfeldt 1994); it is anomalously thin in the Mossberga core (Westergård 1936) and absent in the offshore B-10 well (OPAB unpublished completion report). Maximum thickness recorded is 127 m in the offshore B-3 well located 45 km south of Gotland (OPAB unpublished completion report). The formation is between 21–37 m in the different districts of central Sweden (Martinsson 1974; Hagenfeldt 1994; new data), even locally down to 14–17 m in NW Närke (Karis & Magnusson 1973; Hagenfeldt 1994). The File Haidar Formation is 2.5–3.5 m in the southern Bothnian Sea and maybe more than 11.6 m in a drilling at Holmudden NE of Gävle (see remarks).

Age. Late Early Cambrian. Trilobites are very rare in the File Haidar Formation (Ahlberg 1984; Ahlberg *et al.* 1986) and have little biostratigraphic significance. Acritarch data are available from the Grötlingbo-1, Hamnudden and Finngrundet cores of Gotland, Gotska Sandön and the southern Bothnian Sea (Hagenfeldt 1989a,b). Acritarchs have been also been studied in detail in the Bårstad-2 core of Östergötland (Eklund 1990). The File Haidar Formation spans the *Heliosphaeridium dissimilare-Skiagia ciliosa*, *Volkovia dentifera-Liepaina plana* and, locally, the lower part of the *Eliasum-Cristallinium* assemblage zone. The boundary between the File Haidar and Borgholm formations is diachronous, becoming younger in a western direction (Fig. 2).

Remarks. It is unclear how much of the stratotype core section that was originally intended to define the File Haidar Formation since the stated thickness (157 m; Bergström & Gee 1985, p. 252) includes a 32 m thick Middle Cambrian succession. Thorslund & Westergård (1938) originally identified the Mid Cambrian age of this section – assuming the Lower/Middle Cambrian boundary to be located at 374.1 m or 373.6 m in the core – and since no mentioning of including the Middle Cambrian in the File Haidar Formation was made by Bergström & Gee (1985), the stated thickness was in all probability a typographic error, but which has been reiterated by several subsequent authors (e.g. Mens *et al.* 1990; Moczydłowska 1991; Hagenfeldt 1994).

Based on the Grötlingbo-1 core Hagenfeldt & Bjerkéus (1991) proposed an informal four-fold subdivision of the File Haidar Formation, comprising the Viklau sandstone, När shale, När sandstone and Grötlingbo siltstone. The Viklau sandstone and the Grötlingbo siltstone were subsequently ranked as formal members and described in greater detail by Hagenfeldt (1994), whereas the När shale and När sandstone were classified as subunits of a När Member. It is here suggested to revert to the initial classification and distinguish four members in the Öland-Gotland area (the Viklau, När Shale, När Sandstone and Grötlingbo members, Fig. 2), as this is considered a more consistent classification, but of which the Grötlingbo Member is allocated to the Borgholm Formation (see below). In the File Haidar stratotype core the upper boundary of the File Haidar Formation is therefore drawn at *c.* 412 m.

Facing page:
Figure 11. Lithostratigraphy of the Grötlingbo-1 core simplified from Szabo (1968). This core is stratotype for the Viklau, När Shale, and När Sandstone of the File Haidar Formation and the Grötlingbo and Faludden members of the Borgholm Formation. For legend, see Figure 5.


File Haidar Formation
När Shale Mbr
Viklau Mbr Unit 3
Viklau Mbr Unit 2
Viklau Mbr Unit 1
(Unnamed)
Basement
m
Core loss
P
Borgholm Formation
Mossberga Mbr
Grötlingbo Siltstone Mbr
File Haidar Formation
När Sandstone Mbr
När Shale Mbr
Core loss
P
p
p
Borgholm Formation
Faludden Mbr
Mossberga Mbr
P

The lithostratigraphic classification of the pre-Tremadocian succession in the Finngrundet and Västra Banken cores of the southern Bothnian Sea is problematic (for description, see Thorslund & Axberg 1979). Hagenfeldt (1989a,b, 1994) assigned the strata in question to the Söderfjärden Formation, but this unit has never been formally introduced and the potential stratotype is a strongly disturbed succession in an impact crater (see e.g. Lauren *et al*. 1978). We therefore suggest avoiding the designation Söderfjärden formation. The succession overlying the crystalline basement in the Finngrundet core and up to level 98.34 m is suggested representing the När Shale Member whereas the section 98.34–72.50 m is inferred to represent a comparatively coarse-grained Grötlingbo Member equivalent. The Västra Banken succession is even more atypical, as the horizons corresponding to the När Shale (144.38–141.9 m) and Grötlingbo (141.9–123.52 m) members are rather sandy. Westergård (1939) reported 11.6 m of blue-green clay from the bottom of a drilling made at Holmudden and which may represent a more typical När Shale Member, but alternatively the undated section represents the Borgholm Formation.

The Kalmarsund sandstone, known only from the east coast of the Swedish mainland (for review, see Martinsson 1974), was also ranked as a member of the File Haidar Formation by Bergström & Gee (1985). The strong cementation of parts of the Kalmarsund sandstone and possibly also its red striation are suspected, however, to reflect local diagenetic conditions (cf. remarks on the red colouration of the Kalmarsund sandstone by Martinsson 1974, discussion by Tuuling *et al*. 1997, p. 52 and description of the Langeskanse Member above). In our interpretation the Kalmarsund sandstone represents the Viklau, När Shale and När Sandstone members, and should not be ranked as a separate member. The well-known fossiliferous glauconitic level with *Mobergella* (see e.g. Åhman & Martinsson 1965) likely represents the När Shale Member (compare succession of the Böda Hamn core, Hessland 1955).

Viklau Member

(Hagenfeldt & Bjerkéus 1991; Hagenfeldt 1994)

Stratotype. The Grötlingbo-1 core, southern Gotland, section between 675.5–626 m (Fig. 11), described by Hagenfeldt (1989a, pp. 162–166) and designated by Hagenfeldt (1994). For comments on the lower boundary, see remarks.

Lithology. In most areas the lower and upper parts of the member are dominated by quartz sandstone, whereas the middle part comprises bioturbated siltstone (so-called 'crow rock') or laminated darkish green shale. The basal part of the member is somewhat arkosic and contains conglomerates. For lithological descriptions, see Hessland (1955) and Hagenfeldt (1989a, 1994).

Boundaries. The member rests unconformably on the crystalline basement with a conglomerate at the base. It is in turn overlain by the När Shale Member. The upper boundary is associated with a conglomerate in wells on NW Gotland (see Hagenfeldt 1994, fig. 5), but this boundary is generally conformable and may be transitional for a couple of metres. It is then defined where sandstone interbeds become uncommon and mudstone/siltstone dominate.

Distribution and thickness. The Viklau Member is present in the Öland-Gotland area, including the west coast of Sweden (basal part of the 'Kalmarsund sandstone'). It is 5–57 m thick below Gotland and generally 40–74 m below Öland (Hagenfeldt 1994). It is locally absent below Öland (the Mossberga core, Westergård 1936) and offshore east of Öland (the B-10 well, OPAB unpublished completion report). The Viklau Member is 56 m in the offshore B-3 well south of Gotland (OPAB unpublished completion report).

Age. Late Early Cambrian. The member contains acritarchs characteristic of the *Heliosphaeridium dissimilare-Skiagia ciliosa* Zone (Hagenfeldt 1989a).

Remarks. By anlogy with the När Shale/Sandstone members it could be considered ranking the three subunits of the Viklau Sandstone (VSs1–s3), discerned by Hagenfeldt (1994), as individual members, but there seems to be a rather pronounced lateral facies variation (cf. Hagenfeldt 1994, fig. 5), making such fine-scaled lithostratigraphic subdivision ambiguous and difficult to employ in practise. It is suggested referring to these informal subunits as VMs1 to VMs3 (= Viklau Member subunit 1 etc.).

It is strongly suspected that a tongue of Dominopol age sediments (i.e. the *Skiagia ornata-Fimbriaglomerella membranacea* acritarch Zone) is present in the offshore wells BO-12, BO-13 and BO-21 east of Gotland and it is likely that the section 680–675.5 m of the Grötlingbo-1 core represents a westernmost extension of this package (Figs 2, 11). We therefore propose redefining the Viklau Member to start at level 675.5 m.

När Shale Member

(Hagenfeldt & Bjerkéus 1991; formalized)

Stratotype. The Grötlingbo-1 core, southern Gotland, between 626.0–602.5 m is here designated as the stratotype section. For desription, see Hagenfeldt (1989a, pp. 162–166); a simplified log is shown in Figure 11.

Lithology. In the stratotype section, which represents a distal inner shelf depositional environment, this unit is dominated by greenish, greenish grey to somewhat reddish siltstone/shale, partly laminated, partly bioturbated and with rare thin sandstone beds. In more inboard sections, for instance the File Haidar core (see Thorslund & Westergård 1938), the sand content is higher, but the member is still overall more fine-grained than the units below and above. For lithological descriptions, see Hessland (1955) and Hagenfeldt (1989a, 1994).

Boundaries. The unit rests on the Viklau Member with a sharp boundary or the boundary may be transitional over a few metres (e.g. in the stratotype section). In the latter case the boundary is drawn when silt- or mudstones become predominant relative to sandstone. The När Shale Member is conformably overlain by the När Sandstone Member, but usually the boundary is well-defined.

Distribution and thickness. The När Shale Member is present in the Öland-Gotland area, including the west coast of Sweden (part of the 'Kalmarsund sandstone') and it forms the basal part of the Cambrian succession in the southern Bothnian Sea. The member is 13–30 m thick in the Öland-Gotland area (Hagenfeldt 1994) and *c.* 4 m in the Finngrundet core, southern Bothnian Sea (section between 102.01–98.39 m according to the depth scale of Thorslund & Axberg 1979; 100.7–104.5 m according to the scale of Hagenfeldt 1989a). It is locally absent below Öland (the Mossberga core, Westergård 1936) and offshore east of Öland (the B-10 well, OPAB unpublished completion report). The När Shale is 36 and 39 m thick in the offshore wells B-9 and B-3, respectively (OPAB unpublished completion reports).

Age. Late Early Cambrian. The När Shale Member contains acritarchs characteristic of the *Heliosphaeridium dissimilare-Skiagia ciliosa* and the *Volkovia dentifera-Liepaina plana* zones (Hagenfeldt 1989a).

Remarks. The När shale was introduced informally by Hagenfeldt & Bjerkéus (1991) and subsequently included as part of the När Member by Hagenfeldt (1994). We suggest reverting to the original classification.

The core section of the Västra Banken well equivalent to the När Shale Member of the Finngrundet well (located some 35 km further east in the southern Bothnian Sea) is comparatively sandy (cf. Thorslund & Axberg 1979) and we are reluctant assigning it to the När Shale Member. The > 11.6 m of blue-green clay recorded in the drilling at Holmudden NE of Gävle may represent the När Shale Member (cf. Westergård 1939, p. 45), but could also correspond to the Bårstad Member of the Borgholm Formation.

När Sandstone Member

(Hagenfeldt & Bjerkéus 1991; formalized)

Stratotype. The Grötlingbo-1 core, southern Gotland, between 602.5–579.8 m is here designated as the stratotype section. For description, see Hagenfeldt (1989a, pp. 162–166); a simplified log is shown in Figure 11.

Lithology. The member is dominated by fine- to medium-grained sandstone with occasional interbeds of mud- and siltstone. For lithological description, see Thorslund & Westergård (1938), Hessland (1955) and Hagenfeldt (1989a, 1994).

Boundaries. The member is resting conformably on the När Shale Member, but the boundary is in most cases sharp and readily identifiable (cf. Hagenfeldt 1989a, figs 9, 10, 12). It is conformably overlain by the Grötlingbo Member and the boundary may be transitional for a few metres.

Distribution and thickness The När Sandstone Member is present only in the Öland-Gotland area, but it roughly corresponds to the Lingulid Sandstone Member of central Sweden. The När Sandstone Member is 7–32 m thick in onshore wells on Öland and Gotland (Hagenfeldt 1994) and up to 52 m thick in offshore wells east and south of Gotland (B-9; OPAB unpublished completion report). It is locally absent in the Mossberga core (Westergård 1936) and the B-10 well offshore east of Öland (OPAB unpublished completion report).

Age. No age-diagnostic fossils have been reported from the När Sandstone Member. It is underlain by the När Shale Member, containing acritarchs of the *Volkovia dentifera-Liepaina plana* Zone, and overlain by the Grötlingbo Member (Borgholm Formation), containing acritarchs of the *Eliasum-Cristallinium* assemblage zone (Hagenfeldt 1989a,b).

Remarks. The När sandstone was introduced informally by Hagenfeldt & Bjerkéus (1991) and subsequently included as part of the När Member by Hagenfeldt (1994). We suggest reverting to the original classification.

Mickwitzia Sandstone Member

(Holm 1901; Bergström & Gee 1985)

Stratotype. The Bårstad-2 core, Östergötland, between 74.50–63.80 m is here designated as the stratotype section. For description, see Eklund (1990); a simplified log of this core is shown in Figure 12A. Regarding choice of stratotype and upper boundary, see remarks on the Lingulid Sandstone Member.

Lithology. The member is dominated by thin-bedded silt- and sandstone with thin interbeds of clay. Parts of the unit are red and green coloured. In Östergötland-Närke the member contains *c.* 2 m of medium-grained sandstone in the basal part. Overall the member exhibits a rather uniform development throughout the districts of central Sweden. For detailed descriptions of the succession, see Eklund (1990) and Jensen (1997).

Boundaries. The member rests unconformably on the crystalline basement, usually with a conglomerate at the base. It is unconformably overlain by the Lingulid Sandstone Member.

Distribution and thickness. The Mickwitzia Sandstone Member, which is 8–10 m thick, is present in Västergötland, Östergötland and Närke (Westergård 1940; Karis & Magnusson 1973; Eklund 1990; Jensen 1997).

Age. Late Early Cambrian. The rich acritarch content is indicative of the *Heliosphaeridium dissimilare-Skiagia ciliosa* Zone (Eklund 1990), see also review in Moczydłowska (1991).

Remarks. For an exhaustive review of previous work, see Jensen (1997). Before Holm (1901) introduced the name Mickwitzia sandstone the strongly bioturbated unit was referred to as the Eophyton sandstone (Wallin 1868).

Lingulid Sandstone Member

(Holm 1901; Bergström & Gee 1985)

Stratotype. The Bårstad-2 core, Östergötland, between 63.80–49.38 m is here designated as the stratotype section. For description, see Eklund (1990); a simplified log of this core is shown in Figure 12A. Regarding choice of stratotype, see remarks.

Lithology. The member displays an overall coarsening upward trend. In Västergötland it is dominated by light grey, moderately to poorly cemented fine-grained quartz sandstone (Martinsson 1974). The unit is more heterolithic in Östergötland and Närke and contains interbeds of silt- and mudstones (Karis & Magnusson 1973; Eklund 1990). Here only the upper part is dominated by fine-grained quartz sandstone.

Boundaries. The unit overlies the Mickwitzia Sandstone Member. We suggest defining the lower boundary of the Lingulid Sandstone Member at an unconformity, representing a regional sequence boundary (see remarks); it is often associated with a thin conglomerate. In Västergötland this unconformity divides the heterolithic Mickwitzia Sandstone Member from the generally sandy Lingulid Sandstone Member, but in Östergötland-Närke the lower part of the Lingulid Sandstone Member resembles the underlying Mickwitzia Sandstone Member (cf. Eklund 1990). Here it is necessary to identify the unconformity in order to distinguish the members. The Lingulid Sandstone is upwards unconformably overlain by the strongly glauconitic Kvarntorp Member of the Borgholm Formation. The sharp boundary is associated with a phosphoritic conglomerate or, locally, a Fe-ooid bed.

Distribution and thickness The member is developed in Central Sweden (Västergötland, Östergötland and Närke). It is 22.5 m thick in the Mossen core of Kinnekulle, Västergötland (Hagenfeldt 1994, modified), and 28.6 m in the DBH 15/73 core of southern Billingen (new data). It is up to 15.5 m in Östergötland (Nässja core, Wikman *et al.* 1980) and probably only about 10–11 m in Närke (cf. Westergård 1940; Karis & Magnusson 1973; Martinsson 1974), maybe even down to 8.5 m in the Lilla Fallet core (cf. Karis & Magnusson 1973).

Age. Late Early Cambrian. A few trilobites have been found in the unit (Ahlberg *et al.* 1986), but in our opinion they are not age-diagnostic. Acritarchs from the lower part of the member are indicative of the *Heliosphaeridium dissimilare-Skiagia ciliosa* and the

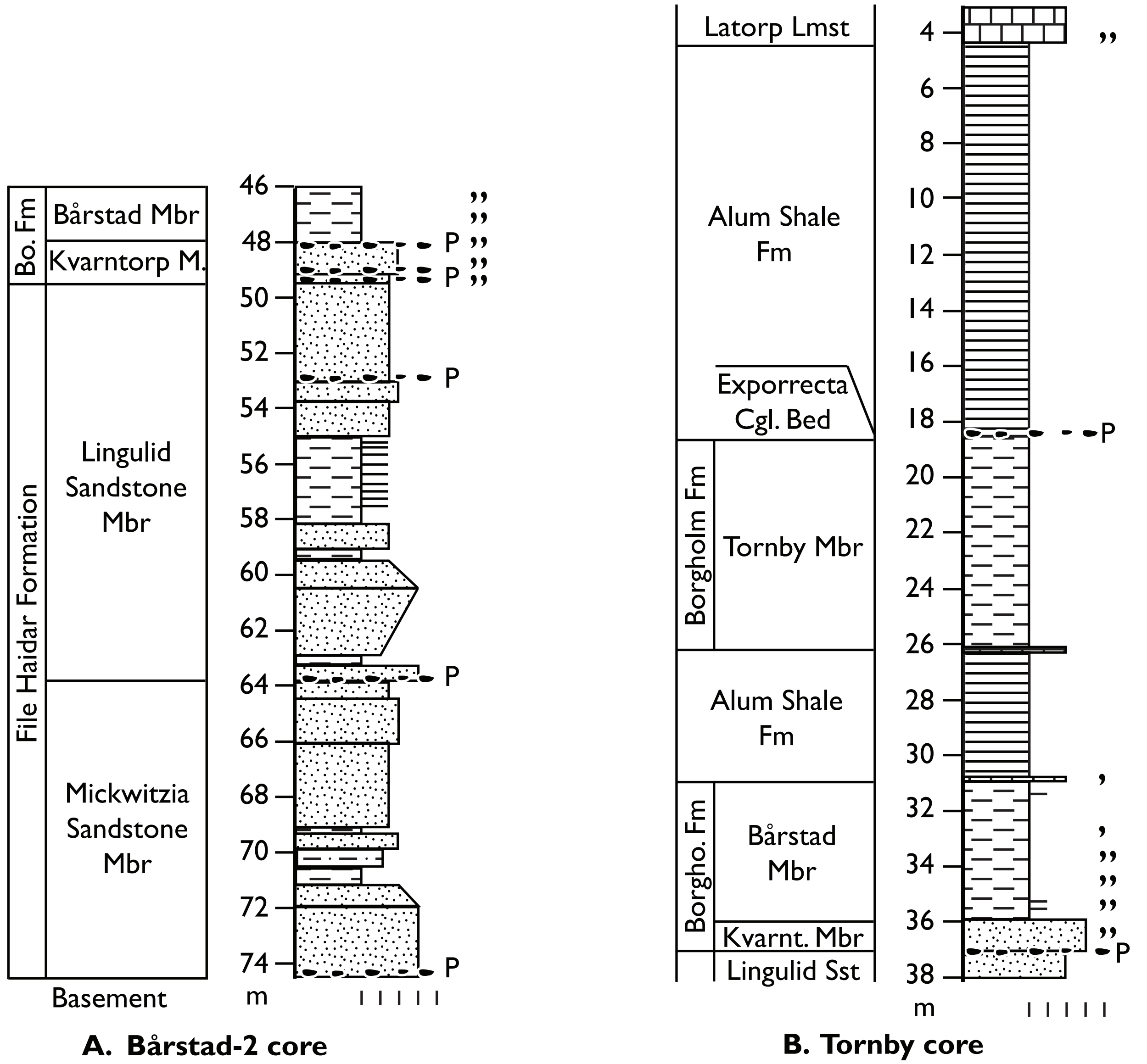


Figure 12. The Cambrian of Östergötland. A. Simplified log of the lower part of the Bårstad-2 core, based on Eklund (1990). The core is stratotype for the Mickwitzia and Lingulid sandstone members of the File Haidar Formation. The remaining Cambrian section of this core is shown by Wikman *et al.* (1980). B. Simplified log of the Tornby core above the File Haidar Formation, based on Westergård (1940). This core is stratotype for the Bårstad and Tornby members of the Borgholm Formation. There is no Skåningstorp Sandstone Bed developed in this core. For legend, see Figure 5. Abbreviations: Bo. Fm and Borgho. Fm = Borgholm Formation; Kvarnt Mbr. = Kvarntorp Member.

Volkovia dentifera-Liepaina plana zones (Eklund 1990). The very top of the Lingulid sandstone of Östergötland represents the *Eliasum-Cristallinium* assemblage zone (Eklund 1990).

Remarks. The member has previously been referred to as the Fucoid sandstone (Wallin 1868). A precise boundary between the Mickwitzia and Lingulid sandstones has never been defined (e.g. Eklund 1990; Jensen 1997); see the latter author for discussion of previous interpretations. A regionally identifiable unconformity, representing a gap in deposition, is located at 63.8 m in the Bårstad-2 core, where it is overlain by a thin conglomerate (see Eklund 1990), and at level 10.6 m in the Mossen core of Västergötland (see Jensen 1997, fig. 3). This unconformity in our opinion represents a logical and well-defined boundary, which essentially does not alter the established concepts of the two units and it is often associated with a conglomerate. For historical reasons it might have been preferable to designate a stratotype in Västergötland, but currently no section is investigated to the same degree of detail as the Bårstad-2 core of Östergötland.

Borgholm Formation

(Hagenfeldt 1994, emended)

Stratotype. The Borgholm core, Öland, section between 41.4–2.5 m, described by Westergård (1929) and designated by Hagenfeldt (1994) (see remarks).

Members. The Borgholm Formation comprises the Grötlingbo, Mossberga, Bårstad, Faludden and Äleklinta members in the Öland-Gotland area, and the Kvarntorp, Mossberga, Bårstad and Tornby members within south central Sweden (Fig. 3). The Grötlingbo Member can also be discerned in the Finngrundet core, southern Bothnian Sea, whereas the subdivision of the upper part of the Borgholm Formation in this core is uncertain.

Lithology. The formation consists predominantly of silt- and mudstones with thin interbeds of sandstone (see description of the individual members).

Boundaries. Below Gotland, the northern parts of Öland and in the southern Bothnian Sea the formation rests conformably on the File Haidar Formation and the lower boundary is transitional. It is defined when silt/mudstone (Grötlingbo Member) becomes predominant relative to sandstone. Below remaining Öland and in central Sweden the formation rests unconformably on the File Haidar Formation from which it is separated by the Hawke Bay unconformity. Upwards the Borgholm Fm is capped by the Alum Shale Formation, generally unconformably, but interfingering is seen in Östergötland (see remarks on the Alum Shale Formation).

Distribution and thickness. The formation is developed in the Öland-Gotland area, the southern Bothnian Sea and Östergötland-Närke and a thin tongue also extends into Västergötland. The major part and possibly all of the succession preserved in the impact crater at Söderfjärden on the west coast of Finland represents the Borgholm Formation.

The largest known thicknesses of the Borgholm Formation have been encountered in offshore exploration wells south and east of Gotland (147–152.2 m in the B-13, B-11, B-9 and B-7 wells; OPAB unpublished completion reports). Onshore, the formation is up to 127 m below southern Gotland (Hamra-1) and thins northwards to 70 m at File Haidar (cf. Hagenfeldt 1994). On Öland the largest thickness has been encountered in the Kvinnsgröta well (114 m) and from there the formation thins to only 49 m in the Böda Hamn core of northern Öland (Hessland 1955; Hagenfeldt 1994) and to 48 m in the offshore Yoldia-1 well, located *c.* 70 km south of Öland (OPAB unpublished completion report). Elsewhere the formation is *c.* 37 m in the Finngrundet core (cf. Thorslund & Axberg 1979; the lower boundary of the Grötlingbo Member is located at 98.34 m) and *c.* 18 m in the Tornby core of Östergötland (Westergård 1940), where it is subdivided into a lower and upper part by *c.* 4 m of Alum Shale representing the lower *P. gibbus* Zone (Fig. 12B). The equivalent succession is 27 m in the Nässja core (also Östergötland); here the intercalation of Alum Shale is 7 m thick (cf. Wikman *et al.* 1980). In Närke the Borgholm Formation is up to 13.5 m thick (Menigasker and Asker cores; Karis & Magnusson 1973).

Age. Trilobites are common in the upper main part of the Borgholm Formation. It ranges in age from the latest Early Cambrian (trilobite zone not defined) through the Mid Cambrian *Acadoparadoxides oelandicus* Superzone and into the middle part of the *Paradoxides paradoxissimus* Superzone. In terms of acritarch zonation it spans the *Eliasum-Cristallinium* assemblage zone plus an as yet unnamed zone containing *Timofeevia lancare.* For details, see treatment of the individual members below.

Remarks. The uppermost Lower Cambrian to Middle Cambrian succession of Scandinavia is divided into the Borgholm and Alum Shale formations (Hagenfeldt 1994; Gee 1972). The former includes the units previously referred to as the *Oelandicus* beds, Tessini sandstone and *Paradoxides* siltstone (many authors) and the upper main part of the Söderfjärden Formation *sensu* Hagenfeldt (1989a,b, 1994) as well as Hagenfeldt´s *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* shale members. Regarding distinction between the Borgholm and Alum Shale formations, see remarks on the Alum Shale Formation below.

Hagenfeldt (1994) recognized three members in the Borgholm Formation of the Baltic area, viz. the *Eccaparadoxides oelandicus* Shale, the Faludden Sandstone and the *Paradoxides paradoxissimus* Siltstone, and two members in south central Sweden, the *Eccaparadoxides oelandicus* Shale and the *Paradoxides paradoxissimus* Shale. It is suggested maintaining the Faludden Member whereas new names are introduced for the other units (see below). It is furthermore suggested ranking the Grötlingbo Member as a basal member of the Borgholm Formation.

According to Hagenfeldt (1994, p. 83) the Borgholm Formation was "named after the town of Borgholm, with reference to the Borgholm drill-core". Here the Mossberga Member rests directly on the Lower Cambrian När Sandstone Member (File Haidar Formation).

Grötlingbo Member

(Hagenfeldt & Bjerkéus 1991; Hagenfeldt 1994; reallocated)

Stratotype. The Grötlingbo-1 core, southern Gotland, section between 579.8–562.4 m, described by Hagenfeldt (1989a, pp. 162–166) and designated by Hagenfeldt (1994). A simplified log of this core is shown in Fig. 11.

Lithology. The member consists of alternating layers of siltstone and mudstone with occasional interbeds of sand. For description of lithology, see Hagenfeldt (1989a, 1994).

Boundaries. The member rests conformably on the När Sandstone Member. The boundary is fairly sharp, but may be gradual within a few metres. The member is upwards truncated by the Hawke Bay unconformity and overlain by the Mossberga Member. For remarks on the upper boundary, see treatment of the Mossberga Member below. In the southern Bothnian Sea the Grötlingbo Member rests unconformably on the När Shale Member.

Distribution and thickness. The member is developed in the Öland-Gotland area and the southern Bothnian Sea, but here the unit is comparatively sandy. The Grötlingbo Member is the uppermost Cambrian unit preserved in the Hamnudden core of Gotska Sandön.

In non-cored exploration wells it is difficult to distinguish the Grötlingbo Member from the overlying Middle Cambrian siltstones making it difficult to obtain precise thickness data. This may be part of the explanation for the extraordinary spread in thicknesses (3–45 m) indicated by Hagenfeldt (1994) in the Gotland area. Broadly speaking the greatest thicknesses are encountered below central and northern Gotland with a maximum thickness (45 m) reported from the Nystuga well of NE Gotland. In our interpretation the Grötlingbo Member is 24 m in the Hamnudden core (Gotska Sandön) and 7 m thick in the Böda Hamn core (northern Öland). The Grötlingbo and Mossberga members cannot be differentiated in the non-cored Kvinnsgröta well on southern Öland or the offshore Yoldia well south of Öland and we are uncertain whether the Grötlingbo Member is present in the south Öland area.

Age. The uppermost part of the Cambrian preserved in the Hamnudden well of Gotska Sandön (core section 183–159 m) is here assigned the Grötlingbo Member; this level represents the *Eliasum-Cristallinium* acritarch assemblage zone (Hagenfeldt 1989a,b). It should be noted that Hagenfeldt (1989a, fig. 3) reported an olenellid? from this siltstone. The Grötlingbo Member of the Finngrundet core represents the same acritarch zone (cf. Hagenfeldt 1989b). Only a few acritarch samples from the Grötlingbo Member of the stratotype section (Grötlingbo-1 core) was investigated by Hagenfeldt (1989a,b), and his correlation with acritarch assemblage 1–2? (= *Heliosphaeridium dissimilare-Skiagia ciliosa* or the *Volkovia dentifera-Liepaina plana* zone) is questioned.

Remarks. The Grötlingbo siltstone was introduced informally by Hagenfeldt & Bjerkéus (1991) and subsequently ranked as a member of the File Haidar Formation by Hagenfeldt (1994). It is here transferred to the Borgholm Formation because the lithology is similar to the overlying Middle Cambrian siltstones (see also remarks by Hagenfeldt 1994, p. 80 regarding oil industry reports). The Grötlingbo Member includes much of the Söderfjärden Formation *sensu* Hagenfeldt (1989a,b, 1994).

The Hawke Bay unconformity (located at 390.15 m in the File Haidar core and at 562.9 m in the Grötlingbo-1 core) was defined as the divider between the File Haidar and Borgholm formations by Hagenfeldt (1994) in the File Haidar core. In non-cored wells this boundary cannot be identified, however, and an assignment of the Grötlingbo Member to the Borgholm Formation is thus more practicable. Hence the File Haidar and Borgholm formations become largely dominated by sandstones and siltstones, respectively. It may be noted that the Grötlingbo Member of the File Haidar core (succession *c.* 412–395 m, for description see Thorslund & Westergård 1938) is more coarse-grained than typical for the unit and may be considered as a transitional facies between the nearshore sand-belt (i.e., 'File Haidar Formation lithology') and the more offshore silt- and mudstones (i.e., 'Borgholm Formation lithology').

Mossberga Member

(New)

Derivation of name. The new name refers to the stratotype core.

Stratotype. The Mossberga core, Öland, between 46.0–10.8 m is designated as the stratotype section. The core is described by Westergård (1936).

Lithology. The predominant lithology of the member is siltstone with intercalations of thin sandstone beds (see Westergård 1929, 1936; Hagenfeldt 1994). The lower main part of the unit is rather dark coloured in all drill-cores from Öland due to a moderately high content of organic material (see Westergård 1936; Hessland 1955). Below Gotland the unit exhibits a coarsening upwards trend and the upper part contains common sandstone interbeds (Hagenfeldt 1989a, 1994).

Boundaries. On Öland and Gotland the Hawke Bay unconformity constitutes the lower boundary of the member. In the stratotype section the underlying Lower Cambrian succession is unusually thin and conglomeratic. The Mossberga Member is conformably overlain by the Bårstad Member in the Öland area. The latter unit is distinguished by being more fine-grained, and usually the boundary is readily identified (see description of the Bårstad Member for details). Below most of Gotland the Mossberga Member is conformably overlain by the Faludden Member and although there are common sandstone intercalations in the upper part of the Mossberga Member, the boundary is mostly well-defined.

Distribution and thickness. The new member is developed in the Öland-Gotland area and maybe also in the southern Bothnian Sea (Finngrundet and Västra Banken cores), but here identification of members within the Borgholm Formation is uncertain.

The member is up to 76 m thick below Gotland (Hamra-1) and up to 26 m on southern Öland (Kvinnsgröta-1) according to Hagenfeldt (1994, partly measured from his fig. 8). However, we are uncertain whether these figures include parts of the Grötlingbo Member. The member is 75 m in the Grötlingbo-1 core (southern Gotland), 43 m in the File Haidar core (northern Gotland) and 24 m in the Böda Hamn core (northern Öland). The unit is not differentiated in the non-cored explorations wells on- and offshore Gotland.

Age. The lower part of the Mossberga Member is non-trilobitic, whereas the upper part contains a diverse fauna indicative of the *Eccaparadoxides insularis* Zone of the *A. oelandicus* Superzone (Westergård 1929, 1936; Wærn 1952). The acritarch data provided by Hagenfeldt (1989a,b) and Eklund (1990) are suggestive of the *Eliasum-Cristallinium* assemblage zone. The upper half of the Mossberga Member of Gotland corresponds in age to the Bårstad Member of Öland (Fig. 2; see remarks on the Bårstad Member).

Remarks. In older literature the Mossberga Member is referred to as the *Oelandicus* beds/shales and in the Öland area the member corresponds to the lower, relatively coarse-grained part of the *Eccaparadoxides oelandicus* Shale *sensu* Hagenfeldt (1994).

It is possible that the uppermost Lower Cambrian overlying the Hawke Bay unconformity in the Gotland area (= 561.9–555.8 m in Grötlingbo-1 core and 390.15–377.5 m in File Haidar core; see Hagenfeldt 1989a; Thorslund & Westergård 1938) should be recognized as an individual member as this succession seems to be more fine-grained than the typical Mossberga Member. Alternatively it could be contemplated including this horizon in the Grötlingbo Member and this solution would be most straightforward to use in non-cored well-sections. The Hawke Bay unconformity signals, however, a fairly major hiatus, as indicated by the presence of an extraformational conglomerate (cf. Hagenfeldt 1989a), and for this reason we are reluctant letting the Grötlingbo Member straddle this unconformity. For further remarks on the Mossberga Member, see treatment of the Bårstad Member below.

Kvarntorp Member

(New)

Derivation of name. The new name alludes to the stratotype locality.

Stratotype. The abandoned Kvarntorp Quarry in Närke is designated as the stratotype section. A brief description with log is provided by Hagenfeldt (1989a, pp. 173–175).

Lithology. The member predominantly consists of strongly glauconitic sandstone. It contains three conglomerate levels in the Bårstad-2 core (Eklund 1990). For description of lithology, see Westergård (1940, 1941) and Eklund (1990). According to Wikman *et al.* (1982) the Kvarntorp Member is locally somewhat argillaceous.

Boundaries. The new member unconformably overlies the Lingulid Sandstone Member of the File Haidar Formation. The lower boundary (the Hawke Bay unconformity) is associated with a conglomerate and, locally, iron ooids (Westergård 1940; Eklund 1990). Within Östergötland-Närke the Kvarntorp Member is conformably overlain by the Bårstad Member, but the shift to glauconitic shales is usually quite sharp. In Västergötland the Kvarntorp Member is conformably overlain by the Alum Shale Formation, and also this boundary is in most cases sharp.

Distribution and thickness. The Kvarntorp Member is developed in Östergötland, Närke and Västergötland. It is 1.4–5.5 m thick in Östergötland (cf. Wikman *et al.* 1982; Eklund 1990) and 0.5–3.7 m in Närke, locally thinner (Karis & Magnusson 1973). In Västergötland the unit is up to 2 m thick (DBH 15/73 core, southern Billingen; unpublished), but is generally 1 m or thinner (cf. Westergård 1943). It is absent at Hunneberg.

Age. Westergård (1940, p. 7) reported various brachiopods (e.g. *Acrothele granulata*) suggestive of a Mid Cambrian age of at least the middle and upper part of the Kvarntorp Member in Östergötland. The acritarchs reported by Eklund (1990) are indicative of the *Eliasum-Cristallinium* assemblage zone. We suspect that the member is younger in Västergötland than in Närke-Östergötland (Fig. 3).

Remarks. The unit has previously been referred to as Glauconite sandstone (Westergård 1940; Karis &Magnusson 1973; Eklund 1990). Eklund (1990) assigned the Glauconitic sandstone to the File Haidar Formation, but being separated from the Lingulid Sandstone Member by the Hawke Bay unconformity we find it more natural to group it with the Borgholm Formation.

Bårstad Member

(New)

Derivation of name. The member is named after the Bårstad-2 core, Östergötland, where the succession 29.5–32.9 m (above sea level) described by Persson *et al.* (1985) represents the new unit.

Stratotype. The Bårstad Member is incompletely developed in the Bårstad-2 core (cf. Persson *et al.* 1985), and instead the Tornby core between 35.92–30.45 m is designated as the stratotype section. This core, which contains the thickest development of the Bårstad Member known from Östergötland, is described by Westergård (1940); a simplified log is shown in Figure 12B.

Lithology. The lower part of the Bårstad Member is typically developed as highly glauconitic mudstone in the Östergötland area, whereas the upper part is a dark grey mudstone with a greenish tint; for descriptions of lithology, see Westergård (1940) and Persson *et al.* (1985). The member is dominated by greenish-grey mudstone/fine siltstone in the Öland area (cf. Westergård 1929; Hessland 1955).

Boundaries. In Östergötland-Närke the Bårstad Member overlies the Kvarntorp Member, generally with a sharp boundary. Locally, as in the Nässja core, the lower boundary is more gradual, but it is here placed where the sand content decreases markedly (in the Nässja core at level –21.5 m, see Wikman *et al.* 1982, fig. 33). In the discussed districts the new member is bounded upwards by the Forsemölla Limestone Bed of the Alum Shale Formation.

In the Öland area the Bårstad Member rests on the Mossberga Member and here the lower boundary is less conspicuous than in central Sweden. By comparison with the Mossberga Member, the Bårstad Member is finer-grained and was described as greenish grey shale by Westergård (1936). The topmost part of the underlying Mossberga Member usually contains a thin sandstone, which for instance is *c.* 0.2 m thick in the Mossberga core of Öland (Westergård 1936). This sandstone bed eases identification of the member boundary immediately above. Besides, the upper third of the Mossberga Member below this more coarse-grained top part is typically the most fine-grained part of the Mossberga Member in the Öland area, and this log motif may also guide the identification of the member boundary above.

Distribution and thickness. The Bårstad Member is developed in Östergötland-Närke, Öland and possibly also in the southern Bothnian Sea, but identification of members in the Bornholm Formation is uncertain within this area. Regarding southern Gotland, see remarks. The new member is up to 17.5 m on Öland (Kvinnsgröta-1) (inferred from Hagenfeldt 1994, fig. 8), 5.5 m in the Tornby core of Östergötland and 9 m in the Bredsätter core of Närke (cf. Westergård 1940). The member seems to be about 10 m or more in the Finngrundet core (the upper boundary is uncertain; it may be up to 11 m thick) and is represented by the succession from 72.5 to about 61.27 m (see Thorslund & Axberg 1979).

Age. Trilobites are locally common in the Bårstad Member. It appears that the *Eccaparadoxides insularis* Zone ranges into the very basal part of the Bårstad Member in the Böda Hamn core (see Wærn 1952; Hessland 1955), but otherwise this member largely represents the *Ptychagnostus praecurrens-Acadoparadoxides pinus* Zone (Westergård 1936, 1940; Hessland 1955). The lowermost part is still within the *Eliasum-Cristallinium* acritarch assemblage zone (Eklund 1990) whereas the upper main part represents an as yet unnamed acritarchs zone containing *Timofeevia lancare* (cf. Hagenfeldt 1989b).

Remarks. The new member corresponds to the fine-grained upper part of the *Eccaparadoxides oelandicus* Shale *sensu* Hagenfeldt (1994). It is referred to as Oelandicus shale in older literature.

The fine-grained middle part of the Mossberga Member below southern Gotland may be regarded as a tongue of the Bårstad Member (e.g. 536.65–*c*. 502 m in the Grötlingbo core, Fig. 11), but it is considered most practicable to assign the entire succession between the Grötlingbo and Faludden members of Gotland to the Mossberga Member.

Faludden Member

(Hagenfeldt & Bjerkéus 1991; Hagenfeldt 1994)

Stratotype. The Grötlingbo-1 core, southern Gotland, between 486–478 m, designated by Hagenfeldt (1994). A simplified log of this core is shown in Figure 11.

Lithology. Predominantly calcareous sandstone with minor intercalations of mudstone (Hagenfeldt 1994); published descriptions are available only from the File Haidar core (Thorslund & Westergård 1938).

Boundaries. The member conformably, but generally with a sharp boundary, overlies the Mossberga Member. It is in turn unconformably overlain by Furongian/Tremadocian strata (Hagenfeldt 1994).

Distribution and thickness. The member is known only from the Gotland area (Hagenfeldt 1994) including offshore wells east and south of this island (OPAB unpublished completion reports). It attains a maximum thickness of 48 m in the offshore B-9 well *c.* 80 km due south of Gotland and from there thins towards the northwest to 5 m in the File Haidar core (Thorslund & Westergård 1938); it is absent below northernmost Gotland (Hagenfeldt 1994).

Age. Thorslund & Westergård (1938, p. 19) reported fragments of *Ellipsocephalus*, believed to represent *E. polytomus*, from 2 m below top of the sandstone in the File Haidar core and inferred a correlation with the *Acadoparadoxides oelandicus* Superzone. *E. polytomus* and *A. oelandicus* occur in the very top of the Mossberga Member in the Visby and När cores (Hedström 1923, Ahlberg 1989), supporting a likely position of the overlying Faludden Member within the *Ptychagnostus praecurrens-Acadoparadoxides pinus* Zone. The Faludden Member contains an impoverished acritarch assemblage (Hagenfeldt & Bjerkéus 1991), but the presence of *Tasmanites convolutus* is suggestive of the unnamed zone containing *Timofeevia lancare*.

Remarks. The Faludden sandstone was introduced informally by Hagenfeldt & Bjerkéus (1991) and subsequently ranked as a member of the Borgholm Formation by Hagenfeldt (1994).

Äleklinta Member

(New)

Derivation of name. The new name refers to the Äleklinta cliff section on northern Öland, which is the most extensive exposure of the member (see Martinsson 1965).

Stratotype. As for the Granulata Conglomerate Bed (see below). The cliff section at Äleklinta, where the upper boundary of the member is exposed (see Martinsson 1965), is designated as a hypostratotype.

Lithology. The member is dominated by siltstone, but with numerous thin sandstone beds at some levels. Mudstone also occurs, but details of the heterogeneous member are poorly known; for a brief account see Martinsson (1965).

Boundaries. The Äleklinta Member unconformably overlies the Bårstad Member and it is in turn unconformably overlain by the Alum Shale Formation. By comparison with the coeval Tornby Member of central Sweden the Äleklinta Member contains more silt- and sandstone beds.

Distribution and thickness. The member is present with certainty only in the Öland area, but possibly the upper part of the Cambrian interval in the Finngrundet core of the southern Bothnian Sea should also be assigned to the Äleklinta Member.

The unit is up to 70 m thick on southern Öland (Kvinnsgröta-1, inferred from Hagenfeldt 1994, fig. 8) and possibly 75 m in the offshore Yoldia-1 well south of Öland (OPAB unpublished completion report, reinterpreted). Further north the Äleklinta Member thins to *c.* 60 m at Segerstad (Martinsson, 1974), 18–26 m in the vicinity of Borgholm (Martinsson 1965) and it is only about 1 m thick in the Böda Hamn core (cf. Hessland 1955).

Age. In southern Öland the Granulata Conglomerate Bed at the base of the Äleklinta Member contains trilobites also known from the Exsulans Limestone of Scania-Bornholm (Wiman 1906), but the bed is nevertheless suggested to represent the basal part of the *P. gibbus* Zone. The Äleklinta Member itself contains a low-diverse trilobite fauna (summarized by Martinsson 1965) characteristic of the *Paradoxides paradoxissimus* Superzone. A thin conglomerate in the top of the unit on southern Öland has yielded a few species characteristic of the *Hypagnostus parvifrons* Zone (Westergård 1946) and the Äleklinta Member has therefore been suggested to straddle the *Ptychagnostus gibbus* to *H. parvifrons* zones, but no detailed zonation is possible (Westergård 1946; Martinsson 1965, 1974). However, the unit is suspected to represent mainly the lower part of the *P. gibbus* Zone.

Remarks. The Äleklinta Member is a replacement name for the *Paradoxissimus* Siltstone of the Öland area, introduced by Martinsson (1965). This unit was subsequently called the *Paradoxides paradoxissimus* Siltstone by Hagenfeldt (1994); in older literature it is referred to as the *Tessini* Sandstone (for review, see Martinsson 1965, 1974).

Granulata Conglomerate Bed

(Andersson 1896, emended)

Stratotype. The shore section southwest of Risinge (*c.* 2 km south of Risingehamn), about 7 km south of Mörbylånga, southern Öland, is designated as the stratotype. This section, which has previously been referred to e.g. by Wiman (1902, 1906), is also considered the basal stratotype for the Äleklinta Member, although very little of this unit is exposed.

Lithology. The matrix of the conglomerate is a 'fragment limestone' rich in sand. The glaucony-impregnated pebbles consists of green-grey impure limestone and shale similar to the subjacent rocks (for description, see Andersson 1896, pp. 165–167; Hadding 1927, pp. 72–77; Westergård 1936).

Boundaries. The distinctive bed rests unconformably on the Mossberga Member of the Borgholm Formation. It forms the basal part of the Äleklinta Member, but is readily distinguished from the upper main part of this unit.

Distribution and thickness. The thin conglomerate, which rarely is more than 0.1–0.15 m thick, is known only from Öland (Hadding 1927; Westergård 1936; Martinsson 1965), but represents a conglomeratic Forsemölla Limestone. Including an upper limy part (see remarks) the thickness may reach 0.2–0.25 m.

Age. The conglomerate rests on the trilobitic Mossberga Member, representing the *Ptychagnostus praecurrens-Acadoparadoxides pinus* Zone of the *A. oelandicus* Superzone and it is overlain by the trilobitic Äleklinta Member, which represents the *Ptychagnostus gibbus* Zone of the *Paradoxides paradoxissimus* Superzone. In southern Öland several trilobites have been reported from the upper limestone part of the Granulata Conglomerate (see remarks) showing that this horizon must also belong to the *P. gibbus* Zone (cf. Wiman 1906). The Granulata Conglomerate Bed is inferred representing the basalmost part of the *P. gibbus* Zone.

Remarks. The Granulata Conglomerate forms a characteristic bed at the base of the Äleklinta Member. It has previously been referred to as the Ölandicus-Tessini conglomerate (Andersson 1892), Acrothele granulata-Conglomerate (Andersson 1896), Acrothele Granulata Conglomerate (Hadding 1927) and lately as the Acrothele Conglomerate (Martinsson 1974 and most subsequent authors). However, we suggest adopting the designation Granulata Conglomerate, used by Martinsson (1965) and occasionally by Hadding (1927, e.g. p. 75). This streamlines the naming style with other units like the Exsulans Limestone and the Exporrecta Conglomerate, and increases nomenclatoric stability since the species name is less likely to change than the generic name. The latter concern reflects the circumstance that *A. granulata* is the type species of the subgenus *Redlichella* Walcott, which was given generic status by Rowell (1965), and the name *Redlichella granulata* Conglomerate has actually been used by Rudolph (1994). Regarding the current status of *Redlichella,* see Bruton & Harper (2000).

In the stratotype section the Granulata Conglomerate *s.str.* is overlain by a 0.11 m thick limestone layer, which has been confused with the Exsulans Limestone Bed of Scania-Bornholm (Wiman 1902, 1906; Westergård 1946; Martinsson 1974), but must be an equivalent of the Forsemölla Limestone Bed. For simplicity the limestone is classified as the upper part of the Granulata Conglomerate Bed.

Tornby Member

(New)

Derivation of name. The new name alludes to the stratotype core section.

Stratotype. The Tornby core, Östergötland, between 26.1–18.65 m is designated as the stratotype section. This core is described by Westergård (1940); a simplified log is shown in Figure 12B.

Lithology. The Tornby Member is a dark grey to greenish mudstone unit with a low organic carbon content. For description of lithology, see Westergård (1940, 1944b).

Boundaries. In Östergötland the member conformably overlies the Exsulans Limestone Bed with a sharp boundary. In Närke, where the member is older, it overlies the Bårstad Member. No distinct boundary was described by Westergård (e.g. 1940) or Karis & Magnusson (1973), but a cryptic unconformity is inferred. The Tornby Member is in both districts unconformably overlain the Alum Shale Formation, often with a basal Exporrecta Conglomerate Bed.

Distribution and thickness. The Tornby Member is developed only in Östergötland and Närke of south central Sweden. The member is 7.2–13 m thick in the former district (Wikman *et al.* 1980) and mostly thin (0.9–2.5 m) or absent in the latter (Westergård 1940, 1941, 1944b), but may theoretically be up to 6 m in the Köpsta core (cf. Karis & Magnusson 1973).

Age. The new member contains a low-diverse trilobite fauna. In Östergötland it straddles the upper *Ptychagnostus gibbus*, *T. fissus-P. atavus* and *Hypagnostus parvifrons* zones (Westergård 1940). The thin horizon preserved locally in Närke represents the lower part of the *P. gibbus* Zone (compare Westergård 1940, 1941).

Remarks. The Tornby Member is a replacement name for the *Paradoxides paradoxissimus* Shale of Hagenfeldt (1994). He did not specify a type section.

Alum Shale Formation

(Gee 1972; Bergström & Gee 1985)

Stratotype. The intensively investigated Gislövshammar-2 core from SE Scania was designated as stratotype section for the Alum Shale Formation by Buchardt *et al.* (1997). The Alum Shale Formation is represented by the core section 23–102 m.

Lithology. The formation consists of kerogeneous (up to 25% TOC), black, more or less fissile shales with beds and lenses of limestone/stinkstones. The content of limestone is relatively high in central Sweden, where the formation is thin, and relatively low in the thicker sections of Scania-Oslo and the Caledonian Mountain Chain further north. For more detailed descriptions, see Martinsson (1974), Thickpenny (1984), Andersson *et al.* (1985) and Buchardt *et al.* (1997).

Boundaries. The lower boundary is in most districts a well-defined unconformity (Lower Allochthon and Autochthon of the Norwegian-Swedish mountain chain, Närke, southern Bothnian Sea, Scania-Bornholm and Öland-Gotland; for summary, see Martinsson 1974). In detail, the unconformity is locally inconspicuous in Scania, when positioned at the base of the Forsemölla Limestone Bed. Upwards, the Alum Shale Formation is capped by the Bjørkåsholmen Formation (= Ceratopyge limestone of older literature) or a corresponding unconformity, or, locally, by the Djupvik Formation (Stouge 2004). In Västergötland the Alum Shale is locally overlying the Kvarntorp Member with a gradual transition, but the boundary is sharp in most places. For comments on the transitional boundary conditions in Östergötland, see remarks.

Distribution and thickness. The Alum Shale Formation is a widespread, characteristic unit, present in essentially all districts of Scandinavia, where Lower Palaeozoic rocks are preserved. The Siljan District is a notable exception, but the local absence of Alum Shale in this area is ascribed to erosion during the Late Tremadocian Ceratopyge Regressive Event (see Nielsen 2004). A Lower Ordovician tongue of Alum Shale extends into Estonia-western Russia.

The formation is about 160 m thick in the Danish offshore Terne-1 well (inferred from the gamma log) and 98 m in the Albjära-1 core of NW Scania (Lauridsen 2000). Across south central Sweden the formation is much thinner, typically about 20 m (Westergård 1922), and broadly speaking it thins eastwards (the lateral distribution is shown by Buchardt *et al.*

1997, fig. 7). Due to tectonic disturbance it is generally not possible to obtain reliable thickness estimates from the Autochthon along the Caledonian mountain belt, but it has been estimated at 80–90 m in the Oslo District (Andersson *et al.* 1985), whereas it seems to be rather thin in Jämtland, varying between 6 to maximum 50 m (Karis & Strömberg 1998).

Age. Mid Cambrian-Early Ordovician (Tremadocian). The base of the Alum Shale Formation is diachronous, becoming younger in an eastwards direction (Fig. 3). The Alum Shale Formation is often richly trilobitic and a sophisticated zonation has been outlined for the Middle Cambrian and Furongian by Westergård (1922, 1946) and Henningsmoen (1957). The stratigraphy of individual areas are dealt with by Westergård (1922, 1940, 1941, 1942, 1943, 1944a,b, 1947a,b, 1953), Brøgger (1882a,b), Skjeseth (1963), Grönwall (1902b), C. Poulsen (1923), V. Poulsen (1966b), Berg-Madsen (1985a,b) and Axheimer & Ahlberg (2003); this list is not exhaustive. The Ordovician part is treated e.g. by Westergård (1909, 1940, 1944a,b), C. Poulsen (1922), von Jansson (1979), Hede (1951), Bulman (1954), Tjernvik (1958) and Spjeldnæs (1986).

Remarks. For reviews of the Alum Shale, see Martinsson (1974), Andersson *et al.* (1985) and Buchardt *et al.* (1997). Parts of fhe Alum Shale Formation have previously been referred to as the Paradoxides shale (many authors), Olenid shale (many authors), Dictyograptus shale (e.g. Westergård 1909), Dictyonema shale (many authors), and Ceratopyge shale (Norway only, see Owen *et al.* 1990, p. 7). The Kläppe Shale and Fjällbränna Formation of the Lower Allochthon of Jämtland (Gee *et al.* 1974; Karis & Strömberg 1998) are local names for the Alum Shale Formation, which we propose abandoning. The Djupvik Formation of northern Öland (van Wamel 1974) in its original sense is also a synonym of the Alum Shale Formation, but Stouge (2004) redefined it to include only the strongly glauconitic 'Ceratopyge shale' of Öland. The Alum Shale Formation is called Türisalu Formation in Estonia (for review, see Mens & Pirrus 1997), Koporye Formation in the St. Petersburg region (see Popov *et al*. 1989) and Słowinski Formation as well as Piaśnica Formation in NE Poland (for review, see Mens *et al.* 1990). The distinction of these units reflects political rather than geological boundaries.

Typical Alum Shale is dark brown to black due to a high organic carbon content and we suggest restricting the term Alum Shale Formation to fine-grained, blackish mudstones/mudshales (with subordinate limestones) and refer the light-coloured and often more coarse-grained Middle Cambrian lithologies to the Borgholm Formation. Adopting such a simple nomenclature is not a panacea to all classification problems, however, and a rigid classification of the successions in Östergötland is difficult since the two formations interdigitate. Here the shift to deposition of Alum Shale took place during the latest *Acadoparadoxides oelandicus* Superzone to basal *Paradoxides paradoxissimus* Superzone and due to continuous sedimentation the distinction between the Alum Shale and Borgholm formations is problematic. The classification problem may be exemplified by the Tornby core described by Westergård (1940), where the section 35.92–30.45 m represents the new Bårstad Member (Fig. 12B). However, it includes in its uppermost part Alum Shale-like lithologies although they are rather lean in organic matter. The overlying horizon 30.35–26.92 m is dominated by dark mudstone (here classified as a tongue of the Alum Shale Formation) but with intercalations of grey mudstone with a greenish tint and the section obviously represents a transitional facies between the Alum Shale and the Borgholm formations. The upper part of the Bårstad Member is even more Alum Shale-like in the Nässja core (cf. Wikman *et al.* 1982). For data on the lateral variations of the Middle Cambrian Borgholm and Alum Shale formations of Östergötland, see Westergård (1940, 1943) and Wikman *et al.* (1980, 1982).

Another problem is the lithostratigraphic classification of the dark-coloured lower part of the *A. oelandicus* Superzone on Öland (see Westergård 1936 and Hessland 1955 for description). Since this horizon is relatively coarse-grained we suggest its inclusion in the Borgholm Formation despite the dark colour. The colouring is a local feature in the Mossberga Member restricted to the Öland area.

The *A. oelandicus* Superzone of the Mjøsa District and the Lower Allochthon of Jämtland is generally referred to the Alum Shale Formation, but the organic content is rather low and parts of the succession consist of grey to dark grey rather than typically blackish Alum Shale. However, for simplicity it is suggested to continue including these deposits in the Alum Shale Formation. For a review of lateral facies variation across Scandinavia, see Thickpenny (1984).

In Scania the dark shale locally underlying the Forsemölla Limestone Bed has been referred to as 'ritskiffer' ('drawing shale', e.g. Bergström & Ahlberg 1981). We include this thin horizon within the Alum Shale Formation. It is inferred representing the *A. oelandicus* Superzone, because of its stratigraphical position below the Forsemölla Limestone Bed, but currently there are no biostratigraphic constrains on this correlation.

The Alum Shale Formation is not subdivided into members but it contains several characteristic marker beds (mostly 0.1–1 m thick), some of which are local whereas others are more widespread. Most of them are important in sequence stratigraphical context. They include the Exsulans and Andrarum limestones, the 'fragment limestone' at or near the base Alum Shale Formation, the Hyolithes Limestone, the Exporrecta Conglomerate, the 'Great Orsten Bank', a previously unnamed sandstone intercalation at the base of the Ordovician in Östergötland and the Tremadocian Platypeltoides incipiens Limestone of the Oslo-Asker District. The Exsulans and Andrarum limestones have previously been ranked as members of the Alum Shale Formation, e.g. by Buchardt *et al.* (1997), or even as separate formations (Berg-Madsen 1985c; Pedersen & Surlyk 1999, p. 73). However, a formal classification as beds within the Alum Shale Formation is considered more appropriate.

There is a regionally widespread limestone layer in the top of the *Hypagnostus parvifrons* Zone in south central Sweden (e.g. Hagenfeldt 1994, p. 90), and limestone is apparently present at the same stratigraphic level in the Lower Allochthon of the Mjøsa District. For the moment a formal name is not introduced but this fairly widespread horizon ('Hypagnostus limestone bank' of Weidner *et al.* 2004) may eventually deserve a name of its own.

The Exsulans (= Coronatus limestone/Coronatus exsulans limestone of older literature; Borregård Member of Berg-Madsen 1981) and Andrarum Limestone beds of Scania-Bornholm are well-known units that will not be discussed any further; the names were introduced, respectively, by Tullberg (1880) and Nathorst (1869). Kiviks Esperöd (Regnéll 1960, p. 12) and Andrarum of eastern Scania (Mens *et al.* 1990, pp. 18–19) have been listed as type sections, but statotypes have never been formally proposed. The so-called 'Kalby Clay' of Bornholm (V. Poulsen 1963) (= Kalby Member of Berg-Madsen 1981) is a weathered equivalent of the Exsulans Limestone. The Exsulans Limestone reported from southern Öland (e.g. Wiman 1906) must be a time-equivalent of the Forsemölla Limestone (see Nielsen & Schovsbo in prep.) and it is here included as part of the Granulata Conglomerate Bed.

Forsemölla Limestone Bed

(New)

Derivation of name. The new name alludes to the stratotype locality.

Stratotype. The river section at Forsemölla near Andrarum in SE Scania is designated as the stratotype. A log of the succession is shown by Bergström & Ahlberg (1981, fig. 9); the Forsemölla Limestone Bed corresponds to their unit E.

Lithology. The Forsemölla Limestone Bed consists of a bioclastic 'fragment' limestone; for description of lithology, see Hadding (1958) and de Marino (1980b). There are gravel-size sand and phosphorite nodules in the basal part of the Forsemölla Limestone Bed in SE Scania (de Marino 1980b, Bergström & Ahlberg 1981, unit G of their fig. 5). The bed is somewhat sandy in Östergötland-Närke (cf. Westergård 1940).

Boundaries. The Forsemölla Limestone Bed has everywhere a sharp and well-defined upper boundary, being overlain by Alum Shale. Where the bed is also underlain by Alum Shale (at Forsemölla and in the Almbacken core of Scania (Bergström & Ahlberg 1981; Meyerson 1997)) the lower boundary is likewise well-defined. The same is the case in Östergötland-Närke, where the bed is underlain by the Bårstad Member of the Borgholm Formation. Elsewhere in Scania (e.g. at Brantevik) the Forsemölla Limestone Bed rests unconformably on limestone beds of the Gislöv Formation, and although the lower boundary is sharp, it just appears as an ordinary bedding surface. However, it represents the Hawke Bay unconformity (cf. Bergström & Ahlberg 1981).

Distribution and thickness. The bed, which is 0.1–0.6 m thick (Westergård 1940; Bergström & Ahlberg 1981), is developed in Scania, Östergötland and probably also Närke, Bornholm and the Oslo-Asker District (see remarks). The Granulata Conglomerate of Öland is a local development of the Forsemölla Limestone.

Age. Basal *Ptychagnostus gibbus* Zone. The bed consists of fossil fragments, but most are not identifiable. However, in both Scania and Östergötland the Forsemölla Limestone Bed contains *Paradoxides paradoxissimus* (Westergård 1940; Bergström & Ahlberg 1981). It is overlain by shales representing the *P. gibbus* Zone. At Slemmestad, Oslo-Asker District, the limestone bed contains *P. gibbus*, *Solenopleura parva* and *S. munsteri* (Spjeldnæs 1955).

Remarks. In Scania the lowermost part of the Alum Shale Formation contains a characteristic, widespread limestone bed (0.1–0.2 m thick), commonly referred to as 'fragment limestone' (e.g. Bergström & Ahlberg 1981). However, 'fragment limestone' is a lithology also seen at other stratigraphical levels (e.g. Hadding 1958; de Marino 1980b) and by analogy with the Exsulans and Andrarum Limestone beds it is suggested formally naming this unit the Forsemölla Limestone Bed. It is also recognisable in Östergötland as a 0.1–0.6 m thick bed separating the *Acadoparadoxides oelandicus* and *Paradoxides paradoxissimus* superzones (e.g. Wikman *et al*. 1980), but it is here more sandy than in Scania (see Westergård 1940). The limestone bed overlying the *A. oelandicus* Superzone in Närke (see Westergård 1941) probably also represents the Forsemölla Limestone Bed. The so-called Exsulans Limestone of southern Öland (e.g. Wiman 1906; Westergård 1946), which also is rather sandy (Westergård 1946, p. 14), is positioned at the base of the *Ptychagnostus gibbus* Zone. It is here considered as part of the Granulata Conglomerate Bed but the conditions in southern Öland obviously represents a transition from the Granulata Conglomerate to the Forsemölla Limestone. On Bornholm the lowermost darker, conglomeratic part of the Exsulans Limestone *sensu* Hansen (1945) and Berg-Madsen (1981) is strongly suspected to represent the Forsemölla Limestone Bed. The *c.* 0.5 m thick limestone locally representing the *P. gibbus* Zone in the Oslo-Asker area (Spjeldnæs 1955) is likely representing the Forsemölla Limestone Bed as well.

Hyolithes Limestone Bed

(Linnarsson 1883)

Stratotype. Andrarum (SE Scania) was listed as the type locality by Mens *et al.* (1990, pp. 18–19).

Lithology. The bed is conglomeratic and dominated by coarse-grained orsten with numerous larger and smaller fragments of trilobites, brachiopods and hyoliths. On Bornholm it contains phosphorite nodules (Grönwall 1902b). For description of lithology, see Hansen (1945, pp. 14–15), Hadding (1958, pp. 77–78) and Berg-Madsen (1985a).

Boundaries. The bed rests on Alum Shale and the lower boundary is sharp, except where 'half' stinkstone concretions grow downwards from the bed, which is often seen on Bornholm. Upwards the Hyolithes Limestone is usually separated from the Andrarum Limestone Bed by a veneer of Alum Shale, only a few centimetres thick on Bornholm (see e.g. Berg-Madsen 1985a, figs 6–7) and about 0.3 m in SE Scania (Regnéll 1960, p. 12).

Distribution and thickness. The Hyolithes Limestone Bed is present in Scania-Bornholm and parts of Västergötland (e.g. Regnéll 1960, Berg-Madsen 1985a, Weidner *et al.* 2004). It is also suspected present in the Lower Allochthon of the Mjøsa District, but this needs verification. The bed is 0.2 m thick on Bornholm (Grönwall 1902b; Hansen 1945) and 0.15 m in Scania and Västergötland (Regnéll 1960, Weidner *et al.* 2004). It is absent at Baskemölla, eastern Scania (Grönwall 1902a).

Age. The precise age of the Hyolithes Limestone Bed is uncertain; it represents either zone C1 or C2 of the *P. forchhammeri* Superzone or both and may even overlap with the B4 zone of the *Paradoxides paradoxissimus* Superzone (see Westergård 1946; Berg-Madsen 1985a,b; Weidner *et al.* 2004). The confused age may theoretically reflect reworking of fossils.

Remarks. The Hyolithes Limestone Bed has often been treated as the lower part of the Andrarum Limestone (e.g. Westergård 1946). For review of earlier work, see Berg-Madsen (1985a). A distinction of the Hyolithes Limestone Bed is useful for sequence stratigraphical purposes and we suggest ranking it as a formal bed within the Alum Shale Formation (see also Berg-Madsen 1985a,b,c; Mens *et al.* 1990, pp. 18–19).

Kakeled Limestone Bed

(New)

Derivation of name. The new name alludes to the stratotype locality.

Stratotype. The small quarry at Kakeled, Kinnekulle, Västergötland, is designated as the stratotype section. For description of this site, see Terfelt (2003); the Kakeled Bed corresponds to the limestone 0.4–1.6 m in his fig. 3.

Lithology. The bed consists of amalgamated layers and lenses of dark grey to black limestone (orsten) conglomeratic at some levels, interspersed by thin lenses of Alum Shale. For a general description of lithology, see Westergård (1922) and Dworatzek (1987).

Boundaries. Both the lower and upper boundaries of this unit are sharp as it is intercalated in ordinary Alum Shale, but locally concretionary growth obscures the lower boundary. We suggest limiting the designation Kakeled Limestone Bed to the coherent limestone bed itself.

Distribution and thickness. The bed, which is typically around 1 m thick, rarely up to 2 m (Westergård 1922), is developed in Västergötland, Östergötland and Närke. A Kakeled Limestone-like bed is also developed elsewhere in Sweden, for instance on central Öland (Westergård 1922), but there is a general tendency that it splits up into two or three separate limestone beds.

Age. The Kakeled Limestone Bed generally spans the *Olenus*, *Parabolina*, *Leptoplastus* and the *Protopeltura praecursor* zones, but locally the base includes the top part of the *Agnostus pisiformis* Zone (Westergård 1922).

Remarks. The Kakeled Limestone Bed is a widespread, easily identified amalgamated limestone bed, previously referred to as the 'Great Orsten Bank' (e.g. Westergård 1922).

Exporrecta Conglomerate Bed

(Wiman 1893)

Stratotype. The waterfall near St. Stolan, Billingen, Västergötland, is designated as the stratotype section. At this locality the Exporrecta Conglomerate is resting on a limestone bed forming the top of the *Hypagnostus parvifrons* Zone (see Westergård 1922, pp. 61–62).

Lithology. The matrix of the conglomerate is limy (often a stinkstone), occasionally with some sand and glaucony. The well-rounded clasts consist of phosphorite and reworked local substrate. For description, see e.g. Hadding (1927, pp. 78–79).

Boundaries. The conglomerate is in most cases resting unconformably on limestone (orsten) representing the *H. parvifrons* Zone. It is conformably overlain by ordinary Alum Shale.

Distribution and thickness. The bed is typically only a few centimetres thick but may locally be up to 0.10–0.15 m. It is developed in Västergötland, Östergötland, Närke, southern Öland, Jämtland and probably also Västerbotten (Westergård 1922, 1946; Martinsson 1974). It is locally absent in Närke (Westergård 1946).

Age. The thin bed is generally regarded coeval with the Andrarum Limestone Bed (e.g. Westergård 1946); it is named after the common brachiopod *Oligomys/Billingsella exporrecta*. Weidner *et al.* (2004) reported e.g. *Solenopleura brachymetopa* from the conglomerate in Västergötland. Locally (southern Öland, Jämtland) the conglomerate contains *Agnostus pisiformis*, suggestive of later reworking (Westergård 1946).

Skåningstorp Sandstone Bed

(New)

Derivation of name. The new name alludes to the stratotype core section.

Stratotype. The Skåningstorp core between 20.8–19.5 m is designated as the stratotype section; for description, see Westergård (1940).

Lithology. The bed consists of dark grey, bituminous sandstone, mostly fine-grained with sporadic coarse grains and small phosphorite nodules near the base. It is locally intercalated with thin beds of Alum Shale. For description of lithology, see Westergård (1909, 1940).

Boundaries. The sandstone rests unconformably and with a sharp boundary on Furongian Alum Shale. Upwards, it is conformably overlain by Alum Shale. Where the sandstone interdigitate with Alum Shale it is suggested to define the upper boundary on top of the uppermost sandbed.

Distribution and thickness. The bed is known only from Östergötland. Maximum thickness is 2 m (Västanå), but it is usually 1.2–1.3 m or even thinner; locally it is absent (Westergård 1940; Wikman *et al.* 1980).

Age. Early Tremadocian. '*Dictyograptus*' [= *Rhabdinopora*] has been reported from the sandstone e.g. by Westergård (1909).

Remarks. The thin sandstone at the base of the Ordovician Alum Shale of Östergötland has previously been referred to as 'Obolus' sandstone (e.g. Westergård 1909; Puura & Holmer 1993).

The relations between the 0.45 m thick sandstone in the basal Ordovician section in the Finngrundet core (Alum Shale with thin sandstone beds, for description, see Thorslund & Axberg 1979) and the Skåningstorp Sandstone Bed are uncertain. This uncertainty regarding lithostratigraphic classification also concerns the cross-bedded Tremadocian sandstone mentioned by Andersson *et al.* (1985) from below Gotland. Broadly speaking, the Tremadocian sandstones of the Alum Shale of Sweden may be regarded as thin extensions of the Kallavere Formation of Estonia (for review, see Mens & Pirrus 1997).

The 10 m thick quartzite reported from the Furongian Alum Shale of the Lower Allochthon of Jämtland (Asklund & Thorslund 1935, p. 17) may eventually be ranked as a separate member.

Incipiens Limestone Bed

(Brøgger 1882b; Henningsmoen 1973; emended)

Stratotype. The Rortunet road-section, Slemmestad, Oslo-Asker District, is designated as the stratotype. Here the top of the Incipiens Limestone Bed is positioned *c.* 6 m below the base of the Bjørkåsholmen Formation.

Lithology. The unit consists of two more or less planar beds of blackish to dark grey limestone interspersed by Alum Shale.

Boundaries. The bi-partite unit has sharp lower and upper boundaries and is readily identified in the Alum Shale succession. There is a thin pyrite bed on top of the upper limestone bed.

Distribution and thickness. This marker bed is developed in the Oslo-Asker District and at Vikersund in the Modum District, Oslo Region (Henningsmoen 1973; Owen *et al*. 1990). The lower and upper limestone beds are 0.15–0.40 m and 0.12–0.20 m thick, respectively, and they are separated by 0.06–0.20 m of Alum Shale.

Age. The lower limestone bed is sparsely trilobitic (see review by Owen *et al*. 1990, p. 7); the fauna indicates a late Tremadocian age.

Remarks. As stated by Owen *et al.* (1990, p. 7) the Incipiens Limestone is a useful unit and we suggest ranking it as a formal bed for easy reference. It has previously been referred to as limestone with *Symphysurus incipiens* (3α) (Brøgger 1882b), the *incipiens* beds (Henningsmoen 1973), Platypeltoides incipiens Limestone and Platypeltoides Limestone (Owen *et al.* 1990). In order to stabilize nomenclature we suggest using the name Incipiens Limestone rather than Platypeltoides Limestone, as the species name is less likely to change due to taxonomic revision (*P. incipiens* has previously been attributed to *Symphysurus*). The fossils occur only in the lower bed, but the characteristic double-bed constitutes an easily identified marker level and we suggest including also the upper planar limestone in the formally defined Incipiens Limestone Bed.

The so-called Brachiopod bed(s) of Scania (Hede 1951; Tjernvik 1958) are probably roughly coeval with the Incipiens Limestone Bed. However, despite being called a bed this is a palaeontologically based designation and the abundant brachiopods are not rock-forming. Hence this horizon should not be formally separated as a lithostratigraphic unit.

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