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Krzysztof BIRKENMAJER

Institute of Geological Sciences
Polish Academy of Sciences
Senacka 1–3
31-002 Kraków, POLAND

The Jarlsbergian unconformity (Proterozoic/Cambrian boundary) and the problem of Varangian tillites in South Spitsbergen

ABSTRACT: The Jarlsbergian unconformity at the Late Proterozoic-Early Cambrian boundary, is expressed in the Hecla Hoek Succession of South Spitsbergen as a regional low-angle unconformity, the result of folding and subsequent erosion of the Late Precambrian Jarlsbergian Basin deposits. The unconformity pre-dates the *Bonnia-Olenellus* trilobite zone; the sedimentary hiatus covers the lowest Cambrian *Fallotaspis* and *Nevadella* trilobite zones, and a closer undefined uppermost part of the Late Proterozoic. There are no Varangian (latest Proterozoic) tillites present in south Spitsbergen at the top of the Late Proterozoic metasediment column which is represented by the Gåshamna Formation phyllites and associated rocks.

Key words: Arctic, Spitsbergen, Late Proterozoic, Early Cambrian, unconformity.

Introduction

The Jarlsbergian unconformity, so-named by the present author after Wedel Jarlsberg Land in South Spitsbergen (Birkenmajer 1975) — Figure 1, separates the Late Proterozoic Gåshamna Formation phyllites from the Early Cambrian arenaceous dolostones of the Blåstertoppen Formation. Trilobites determined from the latter formation correspond to the *Bonnia-Olenellus* Zone of Early Cambrian; there is no evidence for the presence of older still *Fallotaspis* and *Nevadella* zones of the earliest Cambrian. The stratigraphic hiatus between the Gåshamna Formation and the Blåstertoppen Formation may thus cover the lowest part of the Cambrian, and an undetermined part of the latest Proterozoic (Birkenmajer and Orłowski 1977; Birkenmajer 1978a) — Fig. 2.

Fragments of phyllites derived from the Gåshamna Formation appear as secondary deposit already in the Lower Cambrian Blåstertoppen Formation (arenaceous dolostones); the latter show only slight metamorphic changes, and

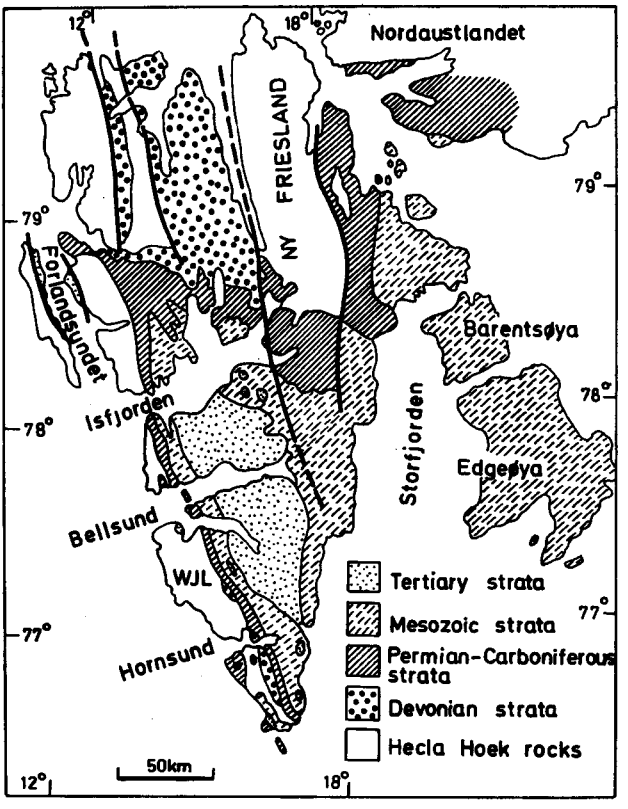

Fig. 1. Geological sketch map of Svalbard (Hecla Hoek rocks — Proterozoic through Ordovician, partly Silurian). Simplified from several sources

often contain well preserved trilobite remains. This was the base for an assumption that phyllitization of the Gåshamna sediments, a result of dynamic metamorphism, had been accomplished already before the Early Cambrian marine transgression (Birkenmajer 1960a, 1975, 1978a, 1981, 1991a; Birkenmajer and Orłowski 1977).

Due to strong Caledonian folding and thrusting recognizable in the Hornsund area of south Spitsbergen, the contact of the Cambrian and Upper Precambrian rock-complexes is seldom preserved in its original form (Birkenmajer 1960a, b, 1972, 1975, 1978a, b, 1981). This is especially true of the area north of Hornsund between Gnålodden and Nørdstetinden (Sofiekammen mountain range), where all contacts between the Cambrian and Precambrian rocks are tectonized due to Caledonian and partly also Tertiary thrusting (Fig. 3). Still further north, in the upper and middle reaches of austre Torellbreen, there are exposures (at Blåstertoppen, Isløva, Kverven and Rastknausane) where only slight, if any, post-Early Cambrian deformations disturb the Camb-

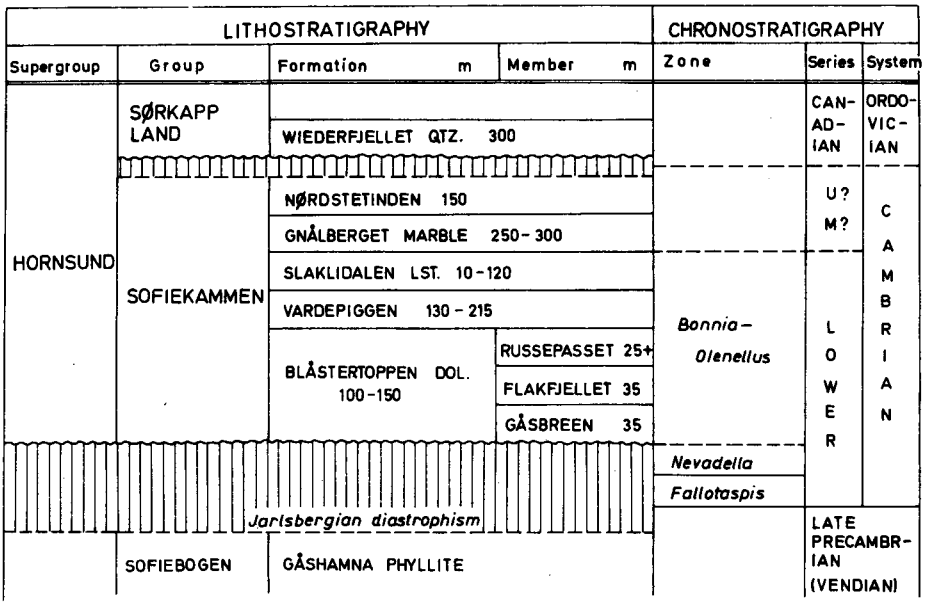

Fig. 2. Stratigraphic position of the Jarlsbergian hiatus in south Spitsbergen (Birkenmajer 1978a)

rian/Precambrian contact (Birkenmajer 1978a). To the south of Hornsund, in Sørkapp Land, the only exposure known to the present author, clearly showing original character of the Cambrian/Precambrian contact, is that at Flakfjellet; the whole sequence of strata is there, nevertheless, tectonically completely overturned (Birkenmajer and Orłowski 1977; Birkenmajer 1978a).

Character of the Proterozoic/Cambrian boundary

Stratigraphic aspects of the Proterozoic/Cambrian boundary in south Spitsbergen may be summarized as follows:

(1) There is a faunal hiatus at the base of the Early Cambrian succession (Sofiekammen Group) comprising the lower Early Cambrian *Fallotaspis* Zone, and the middle Early Cambrian *Nevadella* Zone (Fig. 2).

(2) The first trilobite zone recognized some 36–40 m above the base of the oldest Lower Cambrian lithostratigraphic unit, the Blåstertoppen Formation, is the *Bonnia-Olenellus* Zone (Birkenmajer and Orłowski 1977; Birkenmajer 1978a). The lowest part (0–36 m above the base) of arenaceous dolostones of this formation is barren of fossils. Thus we cannot as yet solve the problem whether this part of the formation already represents the *Bonnia-Olenellus* Zone, or the missing *Fallotaspis* and *Nevadella* zones. Taking into account that the next, thick fossiliferous unit, the Vardepiggen Formation, also belongs to the *Bon-*

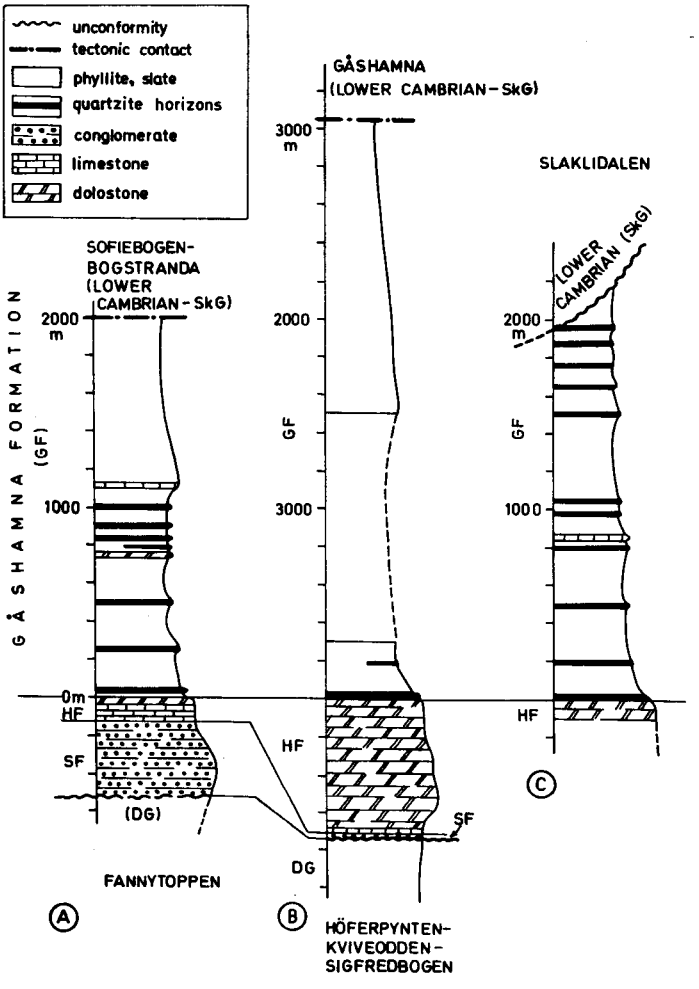

Fig. 3. Lithostratigraphic columns of the Upper Precambrian Sofiebogen Group at Hornsund showing its relation to the Cambrian. DG — Deilegga Group; SF — Slyngfjellet Formation; HF — Höferpynten Formation; GF — Gåshamna Formation; SkG — Sofiekammen Group

nia-Olenellus Zone, a faunal hiatus at the base of the sequence, comprising two oldest trilobite zones, has been accepted (Birkenmajer 1978a);

(3) The hiatus at the Proterozoic/Cambrian boundary may extend further down into the latest Proterozoic, as the Varangian tillites, corresponding to the glacial period at the close of the Late Proterozoic (Vendian), are totally missing from the Hornsund area, most probably as a result of deep erosion following the Jarlsbergian diastrophism (*e.g.*, Birkenmajer 1981, 1990a, 1991a). Contrary to Harland (1979, 1985), Hambrey *et. al.* (1981), Hambrey and Waddams (1981) and Hambrey (1983), the present author sees no evidence for glacial origin of the Slyngfjellet Conglomerate Formation (Birkenmajer 1990a). The conglomerate

certainly represents the stratigraphic base (Fig. 3), and not the top (as erroneously assumed by Harland 1979), of the Upper Proterozoic Sofiebogen Group.

Principal exposures of the Proterozoic/Cambrian boundary

Principal exposures of the Proterozoic/Cambrian boundary in the area north and south of Hornsund, south Spitsbergen, will be briefly summarized below, mainly after published sources.

(1) Isløva nunatak, austre Torellbreen (Wedel Jarlsberg Land). The basal part of the Blåstertoppen Formation is represented by massive arenaceous dolostone with pseudo-ooids, probably recrystallized dolostone clasts (Birkenmajer 1960a, 1978a). There is no transition to the underlying Gåshamna Formation phyllites which contain intercalations of quartzite and dolostone (Birkenmajer 1960a, pp. 14–17). The Gåshamna Formation is folded together with the Blåstertoppen Formation, the dolostone fills synclines formed during the Caledonian orogeny (Birkenmajer 1978a, Fig. 6). No basal conglomerate occurs at the contact of the Blåstertoppen Formation with the Gåshamna Formation.

(2) Blåstertoppen nunatak, upper reaches of austre Torellbreen (Wedel Jarlsberg Land). The Blåstertoppen Formation fills the core of a narrow syncline recumbent to the east (Birkenmajer 1978a, Fig. 4), similarly as at Isløva. At the base of massive arenaceous dolostone (Blåstertoppen Formation), there appears a discontinuous coarse-grained sandstone passing to fine-grained quartz-conglomerate band with well-rounded quartz grains/pebbles supported by dolostone matrix. This basal arenite (basal conglomerate) is considered to be the first Lower Cambrian marine deposit laid down upon eroded Upper Proterozoic basement; its contact with the Gåshamna Formation (phyllites with quartzite intercalations) is sharp.

(3) Kverven nunatak, middle part of austre Torellbreen (Wedel Jarlsberg Land). Another syncline of the Blåstertoppen Formation, also recumbent to the east, is exposed at Kverven (Birkenmajer 1978a, Fig. 7). The dolostone is here slightly arenaceous, with intercalations of dolostone-flake sedimentary breccias and oolitic interbeds, but without basal arenite. Lamination in the dolostone appears here and there, and there are some thin black shale intercalations. The Gåshamna Formation consists of phyllites with quartzite horizons; its contact with the Blåstertopen Formation is sharp.

(4) Rastknausane, eastern slope, lower part of austre Torellbreen (Wedel Jarlsberg Land). The exposure near the top of the nunatak (visited during helicopter reconnaissance of the 1990 Norwegian Polar Institute's expedition together with Dr Y. Ohta) shows sharp, west-dipping (at about 45 degrees) contact of the Blåstertoppen Formation with the Gåshamna Formation. The

Blåstertoppen Formation consists of grey, yellowish-weathered laminated arenaceous dolostone with intercalations of intraformational dolostone-pellet conglomerate, with thin interbeds of oolitic dolostone, and with layers of dolomitic sandstone 2–50 cm thick. The Gåshamna Formation is here represented by black phyllites with thin quartzite intercalations.

(5) Sofiekammen range (Wedel Jarlsberg Land). The contact of the Cambrian Sofiekammen Group with the Gåshamna Formation along the whole western slope of the Sofiekammen mountain range is tectonic due to Caledonian thrusting modified by Tertiary thrusting (Birkenmajer 1960b, 1972, 1978a, 1990b, *in press*). Clasts of the Gåshamna phyllites occur there in breccia intercalations within the Lower Cambrian Vardepiggen Formation (in trilobite-bearing Olenellusbreen Member — Birkenmajer 1978a), indicating reworking of the Upper Proterozoic basement during the Early Cambrian times. The Blåstertoppen Formation is here represented by dolomitic sandstone, dolostone, and dolomitic limestone.

(6) Midifjellet (Sørkapp Land). The contact of the Blåstertoppen Formation with the Gåshamna Formation is here tectonic (Birkenmajer 1978a, pp. 22–25, Figs 12, 13) due to Caledonian thrusting, only slightly modified by younger deformations (*see* Birkenmajer, 1990b). The Blåstertoppen Formation is here represented by often arenaceous dolostone and dolomitic limestone in the lower part, and by quartzite, dolomitic quartzite and sandstone in the upper part. The Gåshamna Formation, at the contact with the Cambrian, is represented mainly by phyllites.

(7) Flakfjellet (Sørkapp Land). This is the best exposure of the contact of the Cambrian and Proterozoic strata in the Hornsund area, known to the present author. It has been described in detail by Birkenmajer and Orłowski (1977; *see also* Birkenmajer 1978a, Figs 8, 9). Though involved in Caledonian folding and thrusting (*see* Birkenmajer, 1990b), the contact of the Blåstertoppen Formation with the Gåshamna Formation — in tectonically overtuned position — shows an angular unconformity between the two formations to be of the order of 30 degrees. The Blåstertoppen Formation starts here with its lowest member (Gåsbreen Member) represented by arenaceous dolostone (30 m thick), followed by thin dolostone (3.5 m) and limestone (2 m); fossiliferous strata of the succeeding Flakfjellt Member (middle part of the Blåstertoppen Formation), which yielded trilobites of the *Bonnia-Olenellus* Zone, are the next in the succession. No basal conglomerate occurs at the contact of the Blåstertoppen and Gåshamna formations.

(8) Slaklidalen-Wiederfjellet (Sørkapp Land). The contacts of the Gåshamna Formation with the Cambrian strata are usually tectonic due to Caledonian folding (*see* Birkenmajer 1978a, 1990b). The Blåstertoppen Formation is here missing, and fossiliferous Slakli Formation (late Lower Cambrian — *see* Major and Winsnes 1955; Birkenmajer 1978a) contacts with well exposed and thick Gåshamna Formation (phyllites with quartzite horizons (Fig. 3).

(9) At Breskilknausen, a nunatak between Olsokbreen and Bjelopolskibreen (southern part of Sørkapp Land), visited by the present author during the 1990 Norwegian Polar Institute's Expedition in the company of Drs W. Dallmann and Y. Ohta, occur well exposed carbonates of the Upper Proterozoic Höferpynten Formation (Sofiebogen Group): yellow and grey cherty limestones and dolostones, and grey laminated limestones with a 1-m-thick black shale intercalation. They are unconformably covered by thin arenaceous dolostone, grey if fresh, yellow-weathered, resembling the Lower Cambrian Blåstertoppen Formation (Birkenmajer *in press*). If confirmed by further investigations, this exposure would represent the only site in south Spitsbergen where Lower Cambrian sea transgressed directly upon the middle formation of the Sofiebogen Group, instead of the upper one, i.e. the Gåshamna Formation. Taking into account that the Gåshamna phyllites are about 2000 m thick at Gåshamna (Fig. 3), strong erosion of Upper Proterozoic metasediments, which had completely removed the phyllite complex, must have taken place there prior to the Blåstertoppen Formation.

Summary of the Proterozoic/Cambrian boundary features

There are several characteristic features recognized at the contact of the Cambrian and Proterozoic strata, as well as in the rocks immediately above and below it, which throw light on the character of the landscape inundated by the Cambrian sea, and on the role of the Jarlsbergian diastrophism, and associated erosion:

(1) The lack of transition between contrasting Upper Proterozoic and Lower Cambrian lithologies, associated with different degree of metamorphic changes (phyllitic grade for the Gåshamna Formation; anchimetamorphic grade for carbonates and shales of the Sofiekammen Group), strongly supports the existence of a stratigraphic break between the two units;

(2) Angular unconformity between the Gåshamna and the Blåstertoppen formations is seldom observable in the field because of Caledonian (Late Ordovician to ?Silurian) folding and thrusting; locally it may amount to as much as 30 degrees (Flakfjellet). It seems that different subunits of the Gåshamna Formation come into contact with the base of the Blåstertoppen Formation (Birkenmajer, 1991a): this would suggest a large-scale regional unconformity due to folding and subsequent erosion, pre-dating the marine Cambrian transgression. Taking into accout preliminary observations at Breskilknausen (see above), the hiatus at the base of the Cambrian would quickly grow southward up to a complete disappearance of the Gåshamna phyllite complex already near the southern tip of Spitsbergen;

(3) Changes of colouration in the Gåshamna phyllites, from predominantly greenish, to reddish, brown and purple near the contact with the Blåstertoppen

Formation (*e.g.*, at Blåstertoppen and Kverven — Birkenmajer 1978a), may indicate deep weathering of the Gåshamna rocks already prior to the Cambrian marine transgression;

(4) The Cambrian starts with largely unfossiliferous arenaceous, often oolitic, dolostones, passing upward and laterally into dolomitic arenites (sandstone, quartzite), with sedimentary features (*see* Birkenmajer 1978a) indicating shallow marine environment. The sea encroached upon a peneplanated low-profile land which supplied only well-rounded quartz grains, sometimes also small quartz pebbles (discontinuous and thin quartz conglomerate). There is no typical basal transgressive conglomerate which would suggest greater denivellations of the terrain and existence of morphological scarps;

(5) Abundant carbonate precipitation at the onset of the Cambrian transgression might indicate temperate to warm climatic conditions during Early Cambrian times in south Spitsbergen;

(6) Appearance of black shales, at first as scarce and thin intercalations in the Blåstertoppen dolostones, then as a main deposit of the succeeding trilobite-bearing Vardepiggen Formation, might indicate gradual deepening of the basin. Intercalations of sedimentary breccias with clasts of the Gåshamna phyllites in euxinic Vardepiggen shales, may be an evidence of slight positive movements along the sea border at that time.

Jarlsbergian distrophism and peneplain

The above features (1–6) are consistent with an assumption of a long time gap at the Proterozoic/Cambrian boundary in south Spitsbergen. During that time, erosion had levelled the land that emerged as a result of the Jarlsbergian diastrophism, and a peneplain had been formed. Extension of this peneplain over Svalbard is unknown in detail. However, similar development of the basal Cambrian strata over the Ny Friesland, Hinlopenstretet and Nordaustlandet regions of Svalbard, in form of arenites and dolostones, comparable with those of the Hornsund area (Birkenmajer 1978a, pp. 39–43, Tab. 3), indicates that peneplanation at the boundary of Proterozoic and Cambrian played an important part along the whole western margin of the Barents craton (Barentsia).

Varangian tillite problem in south Spitsbergen

The lack of the Varangian tillites at the top of Proterozoic sequence at Hornsund, in strong contrast to other localities in Svalbard (*e.g.*, Bellsund, Ny Friesland, Nordaustlandet) is here explained as an effect of deep erosion and planation of land in south Spitsbergen at the Proterozoic/Cambrian boundary.

Deposits of the Varangian glaciation, if any, superimposed upon the Gåshamna phyllites, would in such case be completely removed from the south Spitsbergen land area.

The Jarlsbergian unconformity might post-date the Varangian tillites. To prove that, Cambrian strata need to be found in direct sedimentary contact with the tillites at Bellsund. There is no geological record to this effect thus far from that area (*see* Hjelle 1969; Hjelle *et al.* 1979; Kowallis and Craddock 1984; Bjornerud *et al.*, *in press*).

Harland (1979, 1985) considered both the Slyngfjellet conglomerate (Sofiebogen Group) and much older Vimsodden tilloids (Eimfjellet Group) to represent glacial tillites formed during the same glacial epoch — the Late Proterozoic Varangian glaciation. None of these metaconglomerates in the Hornsund area, in the present author's opinion, qualify as tillites; moreover, the stratigraphic order accepted by Harland in the Precambrian of Hornsund is wrong (Birkenmajer 1990, 1991a, b).

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Streszczenie

Niezgodność jarlsbergiańska na granicy młodszego proterozoiku i kambru w południowym Spitsbergenie jest regionalną niezgodnością, która powstała jako efekt fałdowań, wypiętrzenia i erozji proterozoicznego kompleksu skalnego przed transgresją dolnego kambru (fig. 1–3). W obszarze Hornsundu brak jest późnoproterozoicznych tillitów odnoszonych na pozostałych obszarach Svalbardu do zlodowacenia Varangian; może to być wynikiem wspomnianej erozji na granicy proterozoiku i kambru.