Stratigraphy and tectonics of the Precambrian of Svalbard

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Abstract

On the basis of a comparative historical-geological analysis, a general scheme of the stratigraphic division of the Precambrian of Svalbard is proposed. Two complexes of rocks have been recognized, corresponding to two periods of the development of the region in the Precambrian. The metamorphic successions of the lower complex have provisionally been assigned to the Lower-Middle Proterozoic; the mainly sedimentary formations of the upper complex which on the whole are comparable with the Riphean and Vendian of the folded framing of the East European Platform, are considered as Upper Proterozoic. According to set and succession of the upper Proterozoic formations, two types of section are clearly distinguished, characterizing different palaeotectonic zones, separated by a geoanticlinal uplift: the western-orthogeosynclinal and eastern-miogeosynclinal.

The Precambrian-Lower Paleozoic complex of metamorphic and sedimentary rocks, known in the literature as the "Hecla Hoek Formation", forms the Caledonides of Svalbard and is structurally clearly distinguishable from younger formations. The Precambrian-Early Paleozoic formations occur in four extensive but spatially separated areas in the northern part of the archipelago and along its west coast. These areas belong to different structural zones and have been studied by geologists from different countries and scientific schools. This accounts for the great variety of local stratigraphic standards and the occasional absence of reliable criteria for their correlation. Recent studies provide a possible basis for a single stratigraphic standard for the Precambrian of Svalbard.

A characteristic type section is recognized in each of the tectonic regions: Nordaustlandet, north-east (Ny Friesland), north-west, and western coast of Spitsbergen. The correlation of the four sections and their relation to the time-stratigraphic scale accepted in the USSR is shown in Fig. 1.

The comparative historical-geological method was used for the subdivision of the Precambrian of Svalbard because of the limited occurrence of fossils and the absence of reliable isotopic dates. Two contrasting complexes each corresponding to a major period in the Precambrian development of the archipelago have been recognized. The lower complex corresponds to the crystalline

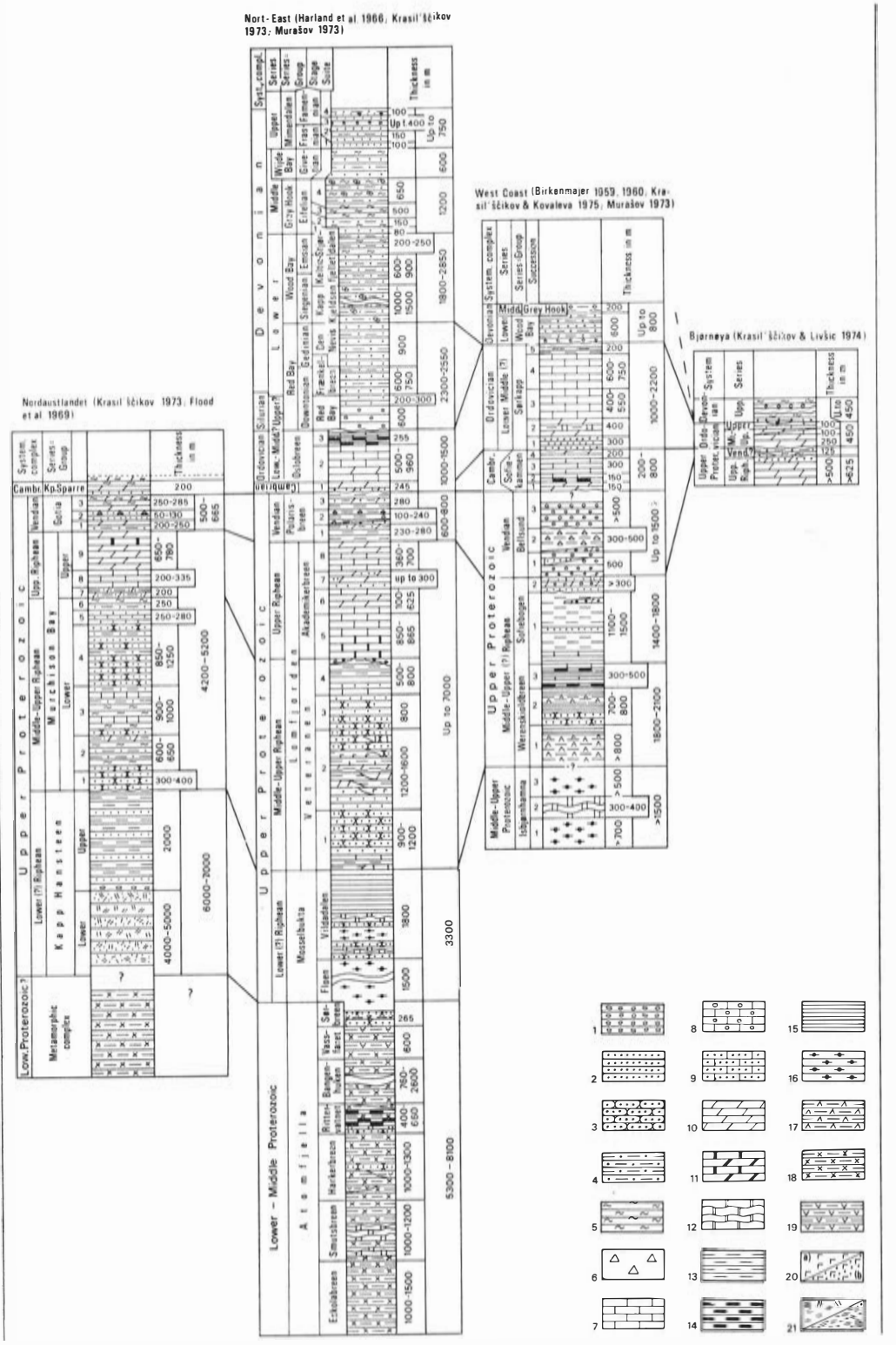
Nordaustlandet (Krasil'ščikov 1973; Flood et al. 1969)
Nort-East (Harland et al. 1966; Krasil'ščikov 1973; Murašov 1973)
West Coast (Birkenmajer 1959, 1960; Krasil'ščikov & Kovaleva 1975; Murašov 1973)
Bjørneya (Krasil'ščikov & Livšic 1974)
Upper Proterozoic
Lower – Middle Proterozoic
Devonian
Thickness in m

Fig. 1.

basement of the Caledonian geosynclinal belt of Europe and Greenland and is tentatively assigned to the Lower-Middle (?) Proterozoic (older than 1650 m.y.). The upper complex, composed mainly of sedimentary rocks, approximately correlates with the Riphean and Vendian of the miogeosynclinal flank of the East-European platform and is regarded as Upper Proterozoic (1650–570 m.y.).

The Lower-Middle (?) Proterozoic includes the relatively strong metamorphosed rocks of Spitsbergen (the Atomfjella Group and its granitized equivalents in the north-west) as well as gneiss-granites of eastern Nordaustlandet. The latter seem to be the result of ultrametamorphism of the oldest rocks of Svalbard. The base of the Lower-Middle (?) Proterozoic section is not known; the upper boundary usually coincides with the base of a thick phyllite sequence assigned to the Upper Proterozoic. In the type localities (Nordaustlandet, Ny Friesland) this boundary sharply separates two contrasting rock-units and is usually marked by an abrupt decrease in metamorphic grade. It is considered to be a structural unconformity modified and obscured by later tectonism.

Among the Lower-Middle (?) Proterozoic rocks, mica and garnet-mica plagiogneisses predominate. Carbonate rocks (marble and calciphyre) and quartzites are subordinate and are used to subdivide the rocks into formations. The north-west area is characterized by highly aluminous schists. Most of these rocks are undoubtedly metasediments, but there is no direct evidence for their age of deposition. A notable feature is the abundance of migmatites and granitized rocks as well as various amphibolite bodies derived, in the opinion of the majority of investigators (Harland 1959; Birkenmajer 1959), from the metamorphism of basic sills, lavas, and tuffs. The thickness of the complex is greater than 5000 m.

The Upper Proterozoic consists mainly of sedimentary rocks resting in deeply metamorphosed Lower-Middle Proterozoic rocks and overlain fossiliferous Cambrian deposits. Both lithologic and biostratigraphic criteria were used to subdivide the Upper Proterozoic into Lower Riphean (?), Middle-Upper Riphean, and Vendian complexes (Fig. 1).

The Lower Riphean (?) complex consists of distinctive shaly sequences (Kapp Hansteen and Mossel Groups and their possible equivalents on the western coast). These non-fossiliferous deposits are tentatively[1] assigned to the Lower Riphean. In some sections there are transitional beds between the shales and the overlying carbonate and terrigenous deposits. Microphytollites in these

[1] Considering that the Lower Riphean was tentatively assigned to the Upper Proterozoic (Salop 1973) the age in stratigraphic columns that follow is shown as Middle Proterozoic, lower Upper Proterozoic inclusive.

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Fig. 1. *Correlation chart of the Precambrian and Lower Paleozoic (including Devonian) for Svalbard. 1. conglomerates; 2. sandstones; 3. quartzites; 4. siltstones; 5. mudstones; 6. boulders in tillite-like rocks; 7. limestones; 8. biogenic limestones; 9. clastic limestones; 10. dolomites; 11. bituminous carbonate rocks; 12. marbles and calciphyres; 13. shales; 14. "black shales"; 15. chlorite and sericite shales; 16. micaceous and garnet-micaceous schists (phyllites); 17. actinolite schists; 18. gneisses and plagiogneisses; 19. amphibolites; 20. basic lavas and tuffs; 21. acid and intermediate lavas and tuffs.*

beds suggest a Middle Riphean age (RAABEN and ZABRODIN 1969; KRASIL'ŠČIKOV 1970). Argillaceous deposits containing occasional terrigenous and carbonate material are predominant in the Lower Riphean (?) deposits. In Nordaustlandet argillaceous deposits pass laterally into effusive and pyroclastic rocks within the Kapp Hansteen Group. Early Riphean volcanic deposits are unknown from other regions of the archipelago. A maximum thickness of more than 5000 m for the Lower Riphean was measured in Nordaustlandet (FLOOD et al. 1969; KRASIL'ŠČIKOV 1973). In Ny Friesland and the western coast of Spitsbergen it decreases to 3300 and 1500 m, respectively (HARLAND 1960).

The Middle-Upper Proterozoic complex is most complete in Ny Friesland (the Lomfjorden Supergroup) and western Nordaustlandet (the Murchison Bay Supergroup). Both sections are characterized by a transgressive sequence from quartz sandstones through silty-argillaceous and argillaceous-carbonate deposits to limestones and dolomites. Despite a general similarity, the total thickness of the complex varies from 4000–5000 m in Nordaustlandet (FLOOD et al. 1969; KRASIL'ŠČIKOV 1973) to 6000–7000 m in Ny Friesland (HARLAND et al. 1966). The complex is divided into two parts: lower, mainly terrigenous deposits (3700 to 4500 m), and upper carbonates (1300 to 2500 m). The boundary is drawn at the top of a variegated siltstone-mudstone sequence. The carbonates yield stromatolites and microphytollites of Upper Riphean age (KRASIL'ŠČIKOV, GOLOVANOV, and MILSTEIN 1965; RAABEN and ZABRODIN 1969). The lower part is Middle and lower Upper Riphean in age (RAABEN and ZABRODIN 1969; KRASIL'ŠČIKOV 1970).

On the West coast of Spitsbergen the Upper Proterozoic section has a completely different structure accounting for the tentative nature of earlier stratigraphic correlations (BIRKENMAJER 1960; HARLAND 1961; WINSNES 1965; KRASIL'ŠČIKOV 1973). A new preliminary scheme for the subdivision of the Upper Proterozoic for the west coast, based on tectonics (KRASIL'ŠČIKOV and KOVALEVA 1979), shows that three groups separated by unconformities of uncertain extent can be recognized. The upper Bellsund Group, carbonate-clastic, is correlated with "tillite-like" formations of the eastern regions of the archipelago, which are of Vendian age. The middle and lower groups, flysch-like Sofiebogen Group and carbonates and sedimentary-volcanics of Werenskioldbreen Group are tentatively assigned to the Middle-Upper Riphean.

The lower sedimentary-volcanic Werenskioldbreen Group, up to 2000 m thick, is subdivided into several formations. Basic volcanics at the base are overlain by a complex sequence of greenschists, possibly metamorphosed tuffs followed by a typical "black shale formation" consisting of homogeneous black limestones, silicified dolomites and shales rich in organic matter.

The middle flysch-like carbonate Sofiebogen Group is up to 1800 m thick and includes the Gåshamna and Höferpynten Formations (MAJOR and WINSNES 1955; BIRKENMAJER 1959, 1960). Assuming the beds in the Hornsund type locality to be the right way up (cf. BIRKENMAJER), the authors assume a break before the deposition of the upper Höferpynten Formation marked by a quartz gritstone horizon. A uniform microphytollite assemblage of Middle Riphean aspect (RAABEN and ZABRODIN 1969; MILSTEIN in press), presumably

reworked, has been found in the clastic dolomites of the Höferpynten Formation and in similar clastic-carbonate rocks of the Bellsund Group.

The Vendian complex includes the Sveanor Group of Nordaustlandet and the Polarisbreen Group of Ny Friesland as well as the carbonate-clastic Bellsund Group of the west coast of Spitsbergen. The Vendian age is suggested by its position directly below fossiliferous Cambrian rocks and is supported by the occurrence of microphytollites typical of the Vendian of the Urals and Siberia (KRASIL'ŠČIKOV et al. 1965; RAABEN and ZABRODIN 1969). The Vendian of eastern Svalbard includes fine-grained terrigenous rocks and characteristic horizons up to 50–150 m thick of coarse-clastic material in the middle part of the section (Sveanor and Wilsonbreen Formations). The total thickness of the Vendian is 500 to 700 m.

The upper carbonate-clastic Bellsund Group, up to 1500 m thick, includes the various conglomerate sequences of the west coast. Geologic-petrographic studies show no major differences between these sequences. Stratigraphic relationships between the Bellsund Group and previously defined stratigraphic units are not always clear. The Bellsund series consists of quartzite (rarely polymict) conglomerates of the Slyngfjellet type overlain by carbonate-clastic rocks and shales with varying amounts of boulders followed by a sequence of largely dolomitic conglomerates of the Kapp Lyell type often resting on eroded beds of the lower part of the succession.

Upper Proterozoic deposits are also known from southern Bjørnøya, where they are subdivided into two formations: the dolomitic Russehamna Formation and the sandstone-siltstone Sørhamna Formation (HOLTEDAHL 1920; KRASIL'ŠČIKOV and LIVŠIC 1974). The Russehamna Formation contains microphytollite assemblages common in the top of the Upper Riphean and transitional between the Upper Riphean and the Vendian (RAABEN and ZABRODIN 1969; KRASIL'ŠČIKOV and MILSTEIN, in press). The Upper Proterozoic age given to the overlying non-fossiliferous Sørhamna Formation is quite tentative as there is a proven stratigraphic unconformity at its base. A Vendian age is suggested by the similar structural framework, the presence of underlying Upper Riphean dolomites and the lithological similarity of the formation to terrigenous Vendian rocks in other areas of the Barents Sea region.

Three tectonic complexes are recognized within the Caledonides of Spitsbergen: the pre-Upper Proterozoic crystalline basement, the major geosynclinal complex (Upper Proterozoic — Middle Ordovician), and the orogenic molasse complex (Lower-Upper Devonian). The intensive processes of the Caledonian metamorphism and rheomorphism gave rise to a new (Caledonian) infrastructure which obscured the contact between the crystalline basement and the major geosynclinal complex. The western and eastern zones of the Caledonian major geosynclinal complex are separated by a central graben filled by orogenic Devonian deposits.

Tectonic zonality was most distinct in Upper Proterozoic time (the Baikalian Stage). The eastern zone was an extensive depression (Hinlopen) formed at the site of the early-Riphean trough. The depression was asymmetrical as shown by sections in Nordaustlandet and Ny Friesland which, despite similar

lithology, differ greatly in thickness and internal structure of individual stratigraphic units. All the changes take place in a narrow zone related to Hinlopenstretet implying that during the Riphean, sedimentation was controlled by the Hinlopen fault. Both types of section consist of three units, each corresponding to a stage in the development of the basin. The lower terrigenous unit (transgressive) reflects the increasing downwarp of the basin floor. Intense downwarping, a higher gradient and a larger amplitude of oscillatory movements characterized the western margin of the depression. This is indicated by lateral changes in the lower terrigenous unit and the increase in thickness from 2600 m in Nordaustlandet to 4250 m in Ny Friesland.

The carbonate sediments of the second unit accumulated under stable conditions of long-term slow downwarping. The thickness also increases from east to west, from 1200 to 2700 m. Despite a high mobility of the western part of the basin inherited from the preceding stage, there is evidence that the regression (intraformational dolomite breccia beds) occurred almost contemporaneously across the entire Hinlopen depression. The change in regime resulted from tectonism at the close of the Riphean and was accompanied by shallow magmatism of trapp-type accounting for the slightly altered basalt and dolerite pebbles of the Vendian tillite-like rocks (KULLING 1934; KRASIL'ŠČIKOV 1967).

The upper regressive terrigenous unit corresponds to general emergence and filling of the Hinlopen depression. It consists of Vendian deposits (Gotia and Polarisbreen Groups) differing in lithology from the under- and overlying Upper Riphean and Cambrian carbonate sequences. The middle part of the upper terrigenous unit, mainly silty-argillaceous, contains an unsorted bed with scattered boulders and pebbles ("Tillite Formation" after KULLING 1934). The bed thickness and the amount and size of boulder-pebble clasts decrease northeastward. A predominance of well-rounded clasts of local carbonate rocks indicates the relatively short distance of transport from the source area, which presumably was in the south-eastern part of the archipelago. The clast composition suggests that the depth of erosion in the source area was unlikely to have been more than 500 m.

Reconstruction of the tectonic environment of the Baikalian Stage on the West coast of Spitsbergen (western zone) is complicated by the absence of reliable stratigraphic markers, and by extensive faulting and thrusting both of Caledonian and Tertiary age. In comparison with sections in the Hinlopen depression, sections in the west are considerably thinner (up to 6000 m). They are generally terrigenous, containing several conglomeratic horizons and characteristic volcanic sediments with basic intrusions.

The structure of the western zone is considered in more detail elsewhere (see KRASIL'ŠČIKOV and KOVALEVA in this volume). New data suggests the brief existence of a volcanic-orthogeosynclinal trough in the western part of the archipelago at the beginning of the Baikalian Stage. At the close of the Baikalian a compensatory trough developed in place of the volcanic trough as a result of adjacent geoanticlinal uplifts. It was filled first by flysch-like and then by molasse-like carbonate-clastic deposits.

The stage of common inversion of geosynclinal troughs in Svalbard coincides approximately with the major phase of the Caledonian folding in North Europe (440–370 m.y.). The fault monoclinal structures of the Riphean of Bjørnøya, striking north-west ("Baikalian") and overlain by subhorizontal Ordovician deposits, were most probably formed at the margin of an ancient land mass and do not belong to the Caledonian of Spitsbergen.

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