Introduction

During recent regional geology mapping in central Spitsbergen for Norsk Polarinstitutt (Dicksonfjorden map sheet, Dallmann et al. in prep.), I came across some peculiarities within the Middle Carboniferous strata of the area around northern Billefjorden. Some of these observations are controversial to the previously published stratigraphic frame, especially concerning the distinction of the mainly Bashkirian Ebbadalen Formation and the mainly Moscovian Minkinfjellet “Member” (Gee et al. 1953; Cutbill & Challinor 1965; Lauritzen et al. 1989; Johannessen & Steel 1992). Furthermore, some stratigraphical, lithological and geometric observations in the Minkinfjellet strata stimulated some thoughts about the basin-related development of the succession. As time did not permit detailed logging or sampling during this mapping work, I hope that this note will encourage others to consider carrying out a more thorough investigation of this hitherto sparsely described part of the Carboniferous of Svalbard.

Stratigraphic confusion (Table 1)

The term “Minkinfjellet Member” describing the lower part of the Nordenskiöldbreen Formation (Moscovian to Late Carboniferous) was introduced by Cuthill & Challinor (1965). It is meant to comprise a succession of sandstones, limestones, carbonate breccias and local evaporites, stratigraphically situated between the evaporitic Ebbadalen Formation (“Lower Gypisiferous series”, Gee et al. 1953) and the overlying part of the Nordenskiöldbreen Formation (“Cyathophyllum Limestone”, Nordenskiöld 1875). It occurs only to the east of the Billefjorden Fault Zone – has probably been a little farther east than during deposition of the Ebbadalen strata. The thickness attains ca. 350 m in central parts of the basin, and the strata strongly attenuates to the east and south. The base and top are interpreted as low-angle stratigraphical unconformities. The boundary with the overlying Cadellfjellet Member of the Nordenskiöldbreen Formation is locally disrupted by carbonate breccias of suggested earthquake origin. Formation rank is suggested for the sedimentary succession of the Minkinfjellet basin.

Additional information

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A part of the Carboniferous basin stratigraphy, the elastic to carbonaceous Minkinfjellet “Member” of the Nordenskiöldbreen Formation in Central Spitsbergen, is deposited in an asymmetric basin structure (here referred to as the Minkinfjellet Basin), similar to the underlying Ebbadalen Formation. The western boundary – situated within the Billefjorden Fault Zone – has probably been a little farther east than during deposition of the Ebbadalen strata. The thickness attains ca. 350 m in central parts of the basin, and the strata strongly attenuates to the east and south. The base and top are interpreted as low-angle stratigraphical unconformities. The boundary with the overlying Cadellfjellet Member of the Nordenskiöldbreen Formation is locally disrupted by carbonate breccias of suggested earthquake origin. Formation rank is suggested for the sedimentary succession of the Minkinfjellet basin.

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linor do not describe but only mention the latter, a distinction cannot be made.

In the top area of the Pyramiden mountain, the “Pyramiden conglomerates” are overlain by a light-grey sandstone succession of approximately 100 m thickness (Figs. 2, which in return is overlain by limestones of the Nordenskiöldbreen Formation (Cadellfjellet Member). This sandstone succession has by previous authors (e.g. Lauritzen et al. 1989) been considered as part of the Minkinfjellet “Member”.

According to my observations, however, these sandstones tend eastward down, where they form the lower part of the eastern slopes of the mountains Pyramiden, Mumien and Svenbrekågda, and where they are overlain by a thin multicoloured succession. The latter is stratigraphically upward followed by thick evaporites with limestone intercalations lithologically very similar to the gypsiferous Tricolortjellet Member. Except for the presence of the light sandstones, the stratigraphical relations seem thus to be very similar to those at Tricorfjellet (Johannessen & Steel 1992, fig. 8), though they are not so easily observed because of strong faulting and downwarping in the Petuniabukta area related to both Carboniferous and Tertiary tectonism (Harland et al. 1974). Consequently, the light-grey sandstones, both these near the mountain top and those on the slope, are thought to represent a local facies between the interfingering Odellfjellet and Tricorfjellet Members. They are tentatively grouped with the Odellfjellet Member on Fig. 2. I am tending to assume that no Minkinfjellet strata exist at all in the Pyramiden area or west of Petuniabukta.

Table 1. Stratigraphic names used in the geological literature related to the discussed succession.

| Gee et al. 1953 | Cuthill & Challinor 1965 | Johannessen 1980 | proposed here |
|----------------|-------------------------|------------------|--------------|
| Cyathophyllum Limestones (Wordiekammen Limestones of Forbes et al. 1958) | Nordenskiöldbreen Formation | Tyrellfjellet Member | Nordenskiöldbreen Formation |
| Campbellryggen Group | Minkinfjellet Member | Anservika beds | Minkinfjellet Member |
| Passage beds | Ebbadalen Formation | Ebbadalen Formation | Ebbadalen Formation |
| Lower Gypsiferous Series | Ebbadalen Formation | Odellfjellet Member | Odellfjellet Member |
| Culm | | Tricolfjellet Member | Tricolfjellet Member |
| | | Ebbadalen Formation | Ebbadalen Formation |
| | | Elsbreen beds | Elsbreen beds |

Post-sedimentary tectonics and possible earthquake breccias

As can be concluded from the above discussion, the fault terminating the Minkinfjellet basin stratigraphy to the west is situated farther east than that of the Ebbadalen basin strata. This would be the case whether or not this fault represented the primary basin margin or a post-Minkinfjellet/pre-Cadellfjellet fault uplift to the west that possibly led to erosion of the Minkinfjellet strata (Figs. 3 and 4).

A peculiar feature of the Minkinfjellet succession, in similarity with the Ebbadalen strata, is the considerable change in thickness (see isopachs in Fig. 1). Close to the fault, at Cheopsfjellet, it is about 50 m, but increases rapidly to ca. 350 m to the east of Petuniabukta. From there, it decreases slowly eastward and southward to thicknesses of a few tens of metres at Filchnerfonna and southern Billefjorden. Its continuation to the north is, unfortunately, not exposed.

The angular unconformity above the Minkinfjellet succession is very slight and shows overstepping characteristics. This and the considerable facies variations within the succession (see below) may exclude the idea that the asymmetric geometry of the basin fill could be due to post-Minkinfjellet downwarping and erosion.

Though the strata to the east of Petuniabukta is cut by both normal and reverse faults, none of these seem to be of Middle to Late Carboniferous age. Reverse faults affect the entire Carboniferous strata (Fig. 5) and are probably of Tertiary age, while most normal faults do not proceed higher than into the Lower Carboniferous and are overlain by the undeformed Ebbadalen succession. Some of these normal faults have probably been reactivated later (Tertiary?), but no deformation structures are unconformably covered by the Cadellfjellet Member of the Nordenskiöldbreen Formation.

The asymmetric basin structure in which the Minkinfjellet succession lies is thus much more pronounced than indicated by earlier authors.
**Fig. 1.** Map showing the outcrops of the Minkinfjellet strata (from Gee et al. 1953, Lauritzen et al. 1989, Miolakovskij et al. 1992 and Dallmann et al. in prep.). Thicknesses are uncertain south of Minkinfjellet/Carronelva and west of Tunabreen. Isopachs are given for the Minkinfjellet succession within the investigated area. The frame indicates the location of Fig. 2. Insert map: Location of the area.
It is thus reasonable to address the Minkinfjellet succession as an individual basin sequence and to raise it from a member to a formation rank. Like the Ebbadalen strata, the Minkinfjellet strata have also been deposited in a fault-bounded basin, have a comparable thickness range and a complex lithological variety that needs a subdivision into members. This succession should be excluded from the platform-like deposits of the Nordenskiöldbreen Formation and be called the Minkinfjellet Formation*, though facies transitions occur in eastern areas, where the Minkinfjellet succession is comparatively thin.

Cuttill & Challinor (1965) subdivided their Minkinfjellet “Member” into the Carronelva, Elsabreen, Anservika and Pyramiden beds. As argued above, the Pyramiden beds (not defined by the authors, but probably identical with the “Pyramiden conglomerate” of Gee et al. 1953) perform the laterally interfingering westward continuation of the Ebbadalen Formation (Gjelberg & Steel 1981; Johannessen 1980; Johannessen & Steel 1992). The Elseabreen beds are similarly defined, though in a place a little farther north. The only explanation I can offer after having mapped the area is that these two successions are identical. The Carronelva and Anservika beds, both defined in places east of Billefjorden, have distinct characteristics and should be raised to member rank. For another distinct lithology that occurs in western parts of the Minkinfjellet basin, I would like to propose the name “Fortet Member”.

Carronelva Member (Figs. 5, 8 and 9). – The Carronelva Member forms the lower part of the Minkinfjellet succession in central and northern parts of the basin. It underlies the breccias of the Fortet Member near Petuniabukta and the carbonate rocks of the Anservika Member. In eastern areas it may consist of only a few metres of red beds or multicoloured clastic rocks (shales, sandstones and conglomerates), either below Anservika limestones (Malte Brunfjellet) or as the only representative of the Minkinfjellet basin succession (Gnomun). At Ebbabreen and Ragnardreen the Carronelva Member also starts with coarse clastic rocks at the base (polymict sedimentary breccias with a carbonate matrix). These basal beds pinch out westward where they are replaced by greenish to yellowish medium-grained sandstones (western half of Skjønsen, Løvehovden and Wörteckamen). The overlying succession consists of yellowish sandstones, locally with a distinct sulphurous smell. Shales, marls, limestones and sandy limestones with gypsum vugs are intercalated in the upper part, where a complex interfingeri ng of lithologies between the Anservika and Carronelva Members occurs. Gypsum layers occur in the type locality at Carronelva, south of Nordenskiöldbreen (Cuttill & Challinor 1965). The thickness at the type locality is 61 m, while it attains more than 100 m in Ebbadalen and Ragnardalen.

Anservika Member (Figs. 5, 8 and 9). – The Anservika Member consists of dolomites, limestones and fine-grained limestone conglomerates and occurs mainly in eastern and southern areas, but also in the upper levels of the central and northern basin areas between Adolfbukta and Terrieffjellet. In places, it comprises most of the basin succession, e.g. Anservika, Minkinfjellet, Terrieffjellet, Flemingfjellet, Malte Brunfjellet, though thin clastic beds of the Carronelva Member may lie below it. The carbonate rocks are interlayered with marls or marly limestones which often give the succession a distinctly stratified appearance. They are more massive and rich in flint concretions or flintstone intercalations in the west at Petuniabukta. A few gypsum layers are intercalated in their lower

Stratigraphic subdivision/ nomenclature and facies distribution

The base of the Minkinfjellet succession is an apparently parallel stratigraphic unconformity: it is defined by a straight, lithologically distinct bed boundary throughout the outcrop area, while both the Minkinfjellet and the underlying Ebbadalen successions, respectively, are characterized by lateral facies changes with interfingeri ng of their lithological facies (members). Most member boundaries are, at a regional scale, diachronous zig-zag planes arranged obliquely to the formation boundaries (i.e. bases of Ebbadalen, Minkinfjellet and Cadellfjellet successions).

* The formal stratigraphic nomenclature of Svalbard is recently being elaborated by the Committee on the Stratigraphy of Svalbard (SKS). The revision proposed here has been formally submitted to the committee for consideration.
cross section (Fig. 3)
boundary of glacier
main faults:
- normal fault (local final strain)
- reverse fault (local final strain)
strata younger than Minkinfjellet Formation
Minkinfjellet "Formation" (proposed rank):
Fortet Member
Anservika Member
Carronelva Member
Ebbadalen Formation:
- Tricolorfjellet Member
- Odelfjellet Member
- Ebbaelva Member
strata older than Ebbadalen Formation

5 km

Fig. 3. Member subdivision of the Ebbadalen and Minkinfjellet successions within the investigated area.
Fig. 5. Fault set of probably Tertiary age at the northern side of Ebbadalen that turns over into a flexure fold within the Minkinfjellet succession. Et = Tricolorfjellet Member of Ebbadalen Formation; Mc = Carronelva Member; Ma = Anservika Member; Mf = Fortet Member; Nc = Cadellfjellet Member of Nordenskiöldbreen Formation.

part at Petuniabukta, which rapidly pinch out to the east. Foraminifer faunas have been described by Sosipatrova (1967), while brachiopods, corals, bryozoans and molluscs have been reported by others (Gee et al. 1953; Gramberg et al. 1990; Dallmann & Mørk 1991). In addition, I observed limestone beds with abundant crinoids on Tricolorfjellet. The name-giving section at Anservika is 33 m thick (Cutbill & Challinor 1965), while it attains 250 to 300 m on both sides of Nordenskiöldbreen (Terrierfjellet, Flemingfjellet). 

Fortet Member (Figs. 5 and 9). - The abundant appearance of massive carbonate breccias and conglomerates in the upper parts of the Minkinfjellet succession at Petuniabukta suggests defining these beds as a separate member. The Fortet Member overlies the Anservika carbonates (western Lavehovden) or

Fig. 6. Suggested earthquake breccias at western Wodickkammen within the basal limestones of the Cadellfjellet Member (Nordenskiöldbreen Formation). Chaotic intrasessional breccias fill in fissures along syn-sedimentary faults. Overlying beds are undeformed.
Middle Carboniferous of Central Spitsbergen

**Fig. 8.** Minkinfjellet strata on the northern side of Ragnarbreen: A basal sedimentary breccia (b) is overlain by a sandstone-dominated succession grading upward into sandstone-limestone alternations (Mc = Carronclva Member) and overlying limestones with a few eastward attenuating gypsum beds in its lower part (MA = Anservika Member). Nc = Cadellfjellet Member of Nordenskiöldbreen Formation.

replaces them (Cheopsfjellet, western Wordieammen). The breccias are intraformational and contain unsorted carbonate clasts seldom exceeding diameters of 10 cm. They may locally represent in-situ brecciated bedrock, but consist of distinctly transported clasts in other places. Both grain-supported and matrix-supported varieties occur, with a micritic carbonate matrix. The rocks show different degrees of cementation, so that well-cemented parts tend to form cliffs and pinnacles, while the surrounding material is removed by erosion. The exposures on the southern side of Fortet, near Rudmosepynten, are well suited as a type section for the Fortet Member. In this place, the thickness is ca. 240 m, which is about the maximum observed thickness.

**Concluding remarks**

The Middle Carboniferous Minkinfjellet “Member” lies in an asymmetric basin structure with distinctly westward increasing clastic influx. The succession attenuates towards the south and east, where carbonate lithologies dominate (the northern continuation is not exposed).

A rock succession exposed west of Billefjorden, situated within the Billefjorden Fault Zone, has previously been assigned to the Minkinfjellet “Member” though it most probably forms

**Fig. 9.** Fortet, southwestern Wordieammen. 10-12 m of dark Anservika limestone (MA) between thick successions of the underlying Carronclva Member (Mc), predominantly sandstone and shales) and the overlying Fortet Member (MF, limestone breccias). Nc = Cadellfjellet Member of Nordenskiöldbreen Formation.
part of the underlying Ebbadalen Formation. Minkinfjellet strata do not occur west of Billefjorden. Both the base and the top of the Minkinfjellet basin strata are stratigraphic unconformities.

The subdivision of the Minkinfjellet strata is proposed to be extended. The Minkinfjellet succession, formerly defined as a member of the Nordenskiöldbreen Formation, is proposed to be raised to formation rank due to its individual basin character, similar to the underlying Ebbadalen Formation. Few details such as stratigraphical logging, facies analyses and palaeontological age determinations are needed in order to understand the development of the basin.

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