Research Note

Notes on the stratigraphy, extent and tectonic implications of the Minkinfjellet Basin, Middle Carboniferous of central Spitsbergen

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A part of the Carboniferous basin stratigraphy, the clastic 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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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 Cutbill & 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 Gypsiferous 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 (Fig. 1), though approximately coeval strata (Scheteligfjellet Member, ?Tårnkanten Formation) are exposed at some distance to the west.

The Minkinfjellet "Member" was earlier named the "Passage Beds" (Wordie 1919). Gee et al. (1953) tentatively correlated the Passage Beds with a multicoloured sandstone-conglomerate succession at the mountain Pyramiden which they named the "Pyramiden conglomerates" according to the earlier described "Pyramiden conglomerate Formation" (Ljutkevič 1937) or "Pyramiden Formation" (Ustrickij 1967) (Fig. 2). Later stratigraphical work by Gjelberg & Steel (1981), Johannessen (1980) and Johannessen & Steel (1992), however, placed much of the "Pyramiden conglomerates" into the Ebbadalen Formation and explained them as lateral equivalents to the Ebbadalen evaporites, situated in a proximal setting close to the Billefjorden Fault zone (Odellfjellet Member of the Ebbadalen Formation). The stratigraphic relation between the conglomeratic and the evaporatic parts of the Ebbadalen Formation (Tricolorfjellet Member) can be observed farther north at the mountains Tricolorfjellet and Odellfjellet (north of Fig. 1 map area). Still, on the geological map sheet Billefjorden (Lauritzen et al. 1989), these conglomerates are grouped with the Minkinfjellet "Member", unfortunately without discussing the reason.

Another name, "Elsabreen conglomerate beds" was used by Cutbill & Challinor (1965). These beds were defined at the northern side of Pyramiden, but mean probably the same succession as "Pyramiden conglomerates". Since Cutbill & Chal-

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

Gee et al. 1953	Cutbill & Challinor 1965	Johannessen 1980 Johannessen & Steel 1992	proposed here
Cyathophyllum Limestones (Wordiekammen Limestones of Forbes et al. 1958)	Nordenskiöldbreen Formation Tyrrellfjellet Member Cadellfjellet Member	Nordenskiöldbreen Formation Tyrrellfjellet Member Cadellfjellet Member	Nordenskiöldbreen Formation Tyrrellfjellet Member Cadellfjellet Member
Campbellryggen Group Passage beds	Minkinfjellet Member Anservika beds Carronelva beds Pyramiden beds Elsabreen beds	Minkinfjellet Member	Minkinfjellet Formation Fortet Member Anservika Member Carronelva Member
		Ebbadalen Formation	Ebbadalen Formation
Lower Gypsiferous Series	Ebbadalen Formation	Odellfjellet Member Tricolorfjellet Member Ebbaelva Member	Odellfjellet Member Tricolorfjellet Member Elsabreen Member
Culm	Billefjorden Group		

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 (Eo_2 on Fig. 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; Johannessen & Steel 1992) been considered as part of the Minkinfjellet "Member".

According to my observations, however, these sandstones bend eastward down, where they form the lower part of the eastern slopes of the mountains Pyramiden, Mumien and Svenbrehøgda, 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 Tricolorfjellet Member. Except for the presence of the light sandstones, the stratigraphical relations seem thus to be very similar to those at Tricolorfjellet (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 Tricolorfjellet 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.

Basin geometry and geographic extent

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.

Post-sedimentary tectonics and possible earthquake breccias

Still, there is evidence for minor faulting soon after the deposition of the Minkinfjellet succession. In several places at the western side of Wordiekammen and at Fortet, peculiar fissures which are filled with chaotic breccias can be observed (Figs. 6 and 7). The fissures dissect the base of the Cadellfjellet Member

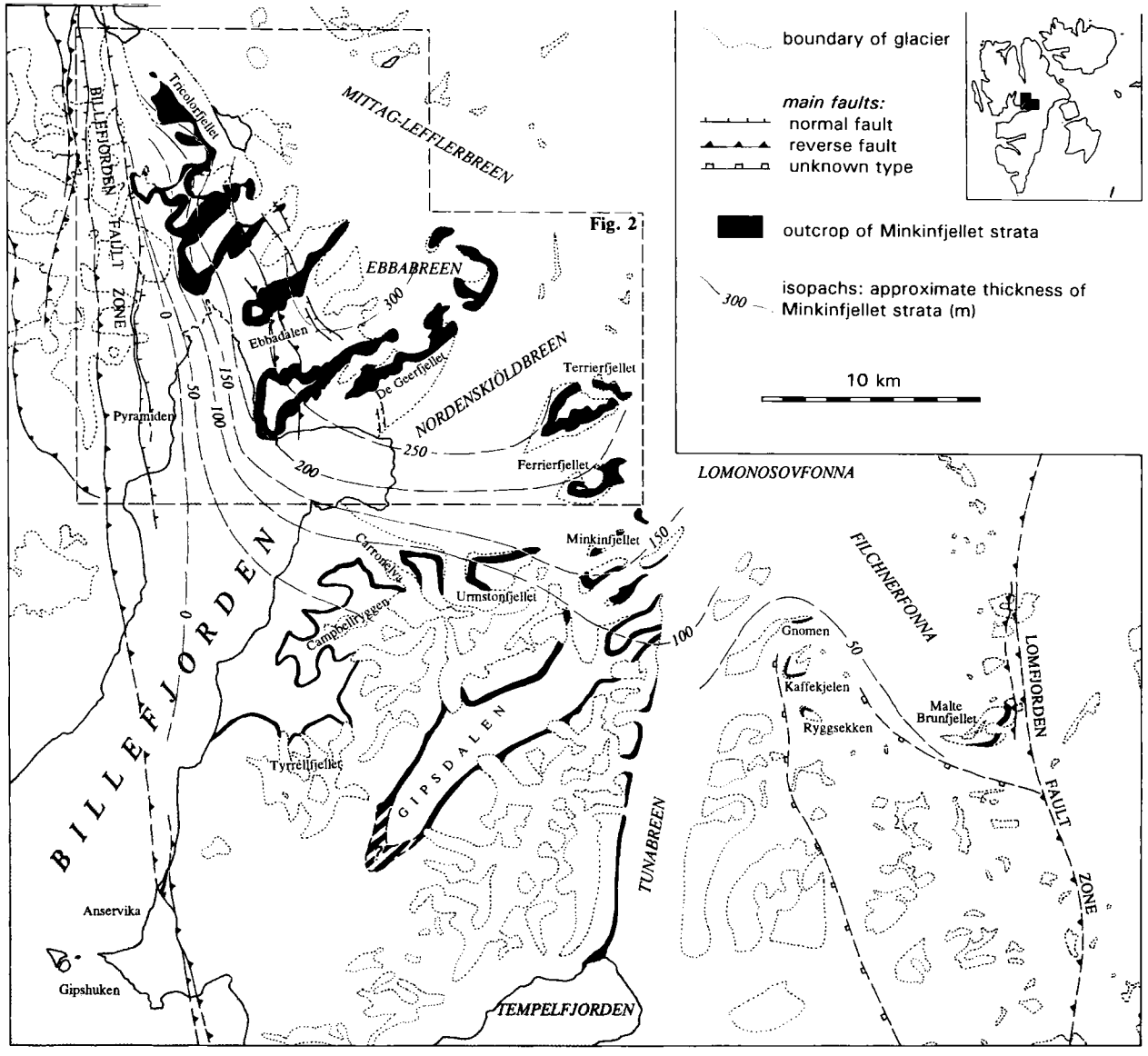

Fig. 1. Map showing the outcrops of the Minkinfjellet strata (from Gee et al. 1953, Lauritzen et al. 1989, Miloslavskij et al. 1992 and Dallmann et al. in prep.). Thicknesses are uncertain south of Minkinfjellet/Carronelva and west of Tunabreen. Isopachs are given for the Minkinfjellet succession within the investigated area. The frame indicates the location of Fig. 2. Insert map: Location of the area.

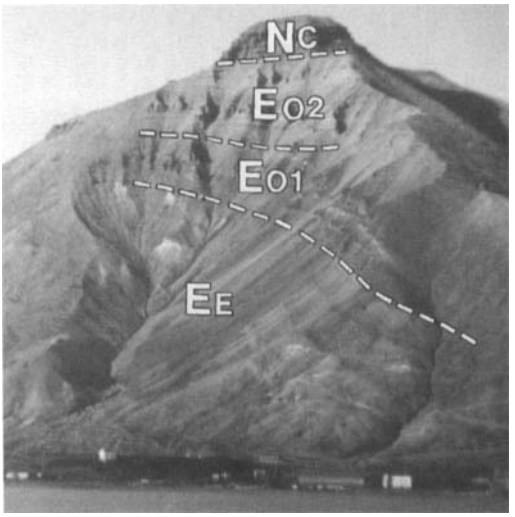

Fig. 2. The mountain Pyramiden with indicated stratigraphic units (E = Ebbadalen Formation; EE = Ebbaelva Member; EO = Odellfjellet Member; O_1 = red part; o_2 = light part; NC = Cadellfjellet Member of Nordenskiöldbreen Formation). Despite earlier published work, there is probably no Minkinfjellet strata in this area.

and are uncomformably overlain by a limestone ca. 20–30 m higher up. The strata below has locally suffered minor displacements. In one place, the uppermost dissected limestones are broken up and a section has been rotated (Fig. 6). The breccias consist of adjacent carbonate lithologies, i.e both of the upper Minkinfjellet and the lower Cadellfjellet carbonate rocks. They are completely consolidated (Fig. 7). The most reasonable explanation for these features I can suggest are earthquakes with related fissure formation and minor offsets along the latter.

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 interfingering 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).

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.

Cutbill & 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 Elsabreen 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 (Gnomen). At Ebbabreen and Ragnarbreen 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 Sfinksen, Løvehovden and Wordiekammen). 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 interfingering of lithologies between the Anservika and Carronelva Members occurs. Gypsum layers occur in the type locality at Carronelva, south of Nordenskiöldbreen (Cutbill & Challinor 1965). The thickness at the type locality is 41 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 Terrierfjellet. In places, it comprises most of the basin succession, e.g. Anservika, Minkinfjellet, Terrierfjellet, 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

* 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.

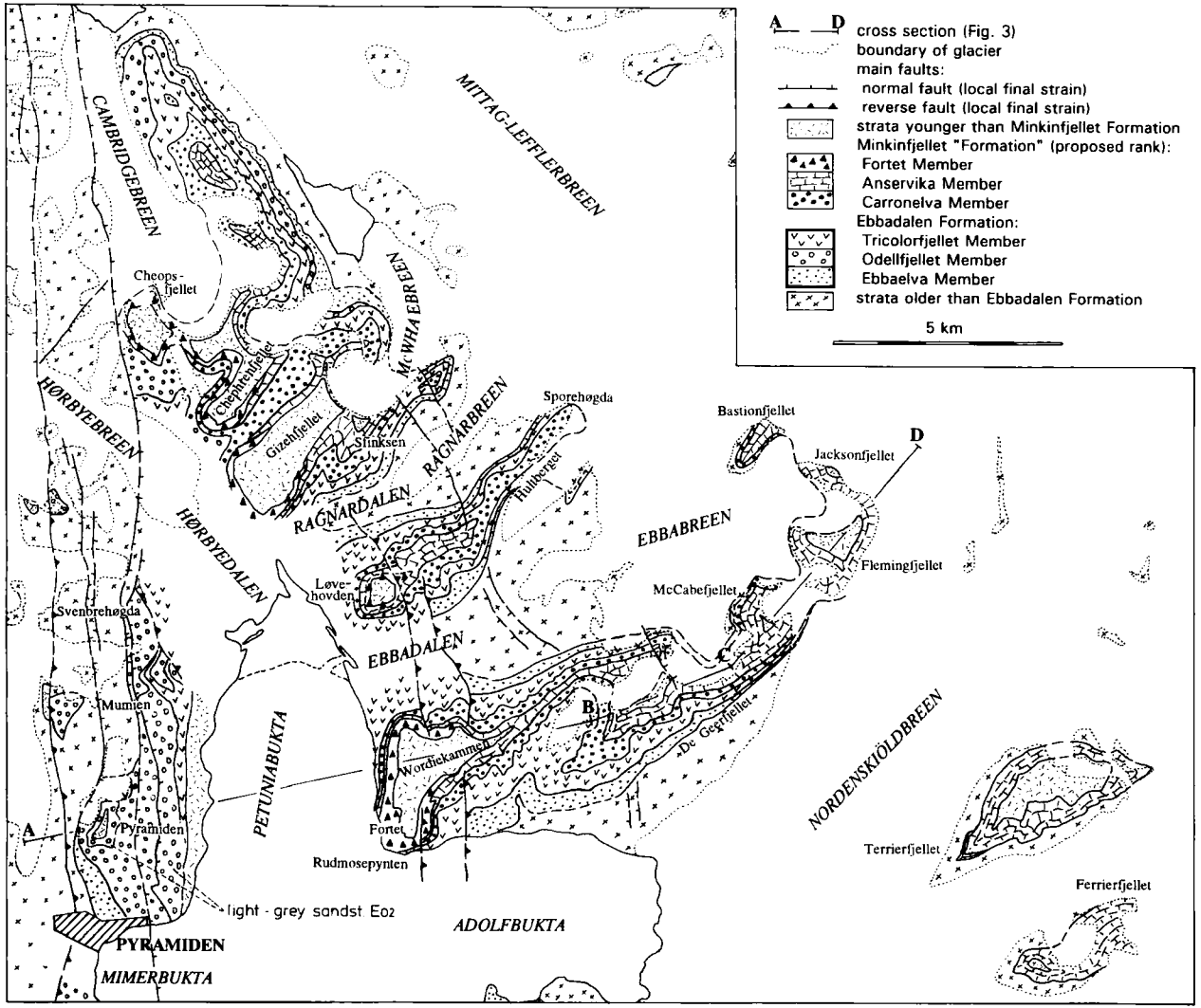

Fig. 3. Member subdivision of the Ebbadalen and Minkinfjellet successions within the investigated area.

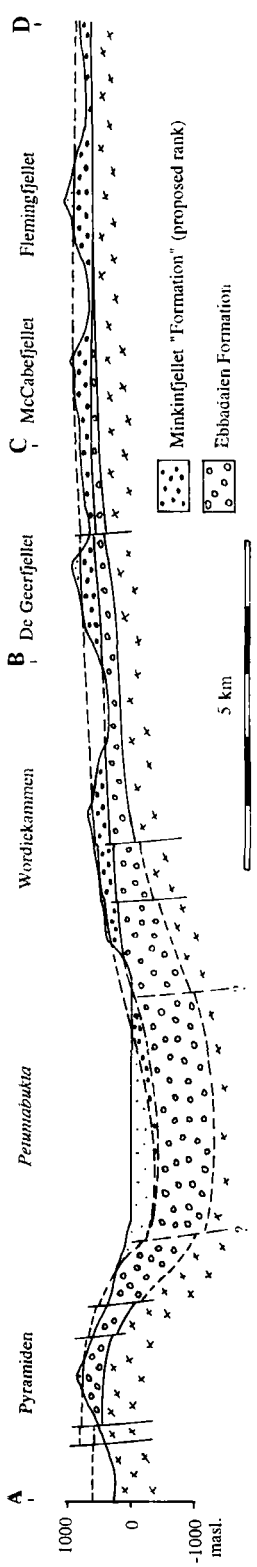

Fig. 4. Cross section through the Ebbadalen and Minkinfjellet strata in the Petuniabukta area. Approximate depth of the base of the Ebbadalen Formation estimated after stratigraphical drill data (B. Klimov, pers. comm. 1993).

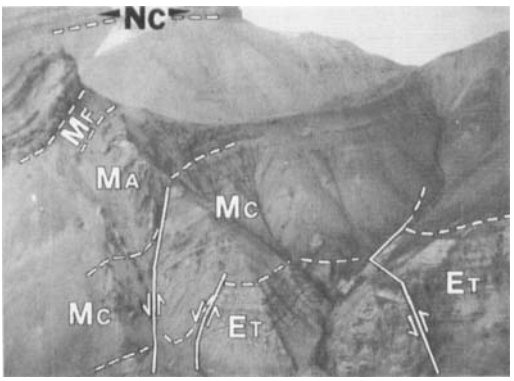

Fig. 5. Fault set of probably Tertiary age at the northern side of Ebbadalen that turns over into a flexure fold within the Minkinfjellet succession. ET = Tricolorfjellet Member of Ebbadalen Formation; MC = Carronelva Member; MA = Anservika Member; MF = Fortet Member; NC = Cadellfjellet Member of Nordenskiöldbreen 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 Løvehovden) or

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

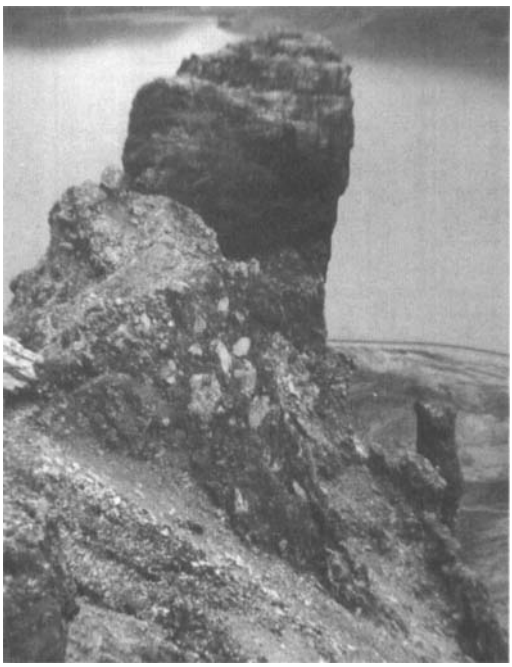

Fig. 7. Suggested earthquake breccias at Fortet. Stratigraphic position as in Fig. 6. The intraformational breccias cut vertically through the strata.

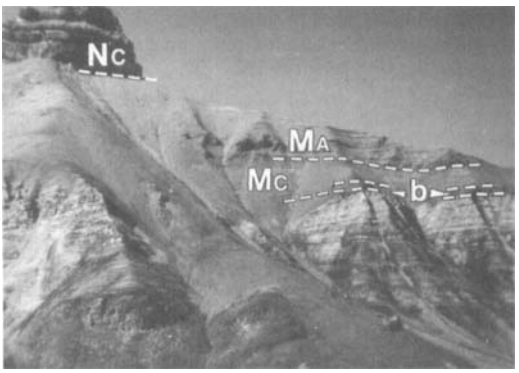

Fig. 8. Minkinfjellet strata on the northern side of Ragnarbreen: A basal sedimentary breccia (b) is overlain by a sandstone-dominated succession grading upward into sandstone-limestone alternations (Mc = Carrondelva Member) and overlying limestones with a few eastward attenuating gypsum beds in its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

replaces them (Cheopsfjellet, western Wordiekammen). The breccias are intraformational and contain unsorted carbonate clasts seldom exceeding diametres 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 pinacles, 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

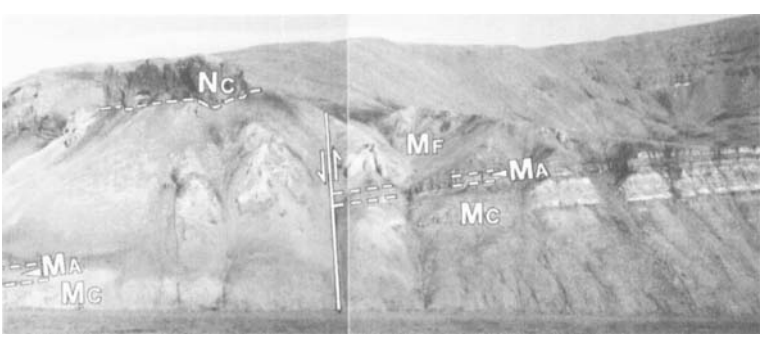

Fig. 9. Fortet, southwestern Wordikammen. 10–12 m of dark Anservika limestone (MA) between thick successions of the underlying Carrondelva Member (Mc), predominantly sandstone and shales) and the overlying Fortet Member (MF, limestone breccias). Nc = Cadellfjellet Member of Nordenskiöldbreen Formation.

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 from the Minkinfjellet Basin are known. Further investigations such as stratigraphical logging, facies analyses and paleontological age determinations are needed in order to understand the development of the basin.

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