Gravity-induced detachment of Devonian basin sediments in northern Svalbard

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The Svalbardian tectonic event affecting the Devonian sediments of northern Spitsbergen formed thrusts and folds with cleavage structure, unconformably overlain by Early Carboniferous sediments. The Devonian basin was an asymmetrical, N–S trending graben, characterized by an easterly dipping basement. The Late Silurian to Early Devonian basin infill is affected mostly by extensional features while the Middle and Late Devonian sediments form thrusts and folds associated with cleavage. Bed-parallel normal movements and normal slip surfaces attest a general detachment and movement of the Devonian sediments from west to east. This general detachment is Late Devonian in age and may have been gravity induced, favoured by the slope of the east-dipping asymmetric graben. The detached sediments moving to the east were compressed against the large eastern border fault while they were extended in the western part of the graben. This event did not interrupt significantly the lithospheric graben evolution, and subsidence proceeded afterwards during the Carboniferous.

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The Devonian basin of northern Spitsbergen is more than 50 km wide and trends approximately N–S (Fig. 1). It is infilled by Late Silurian to Late Devonian fluviatile red-bed sediments (Friend & Moddy-Stuart 1972) composed mostly of sandstones and siltstones. In the central and eastern parts of the basin, the sediments are strongly folded and faulted (Harland 1965, 1969; Harland et al. 1974; Burov & Semevskij 1979). As the deformed rocks are unconformably overlain by Permo-Carboniferous sediments the deformation of the basin infill is attributed to a Late Devonian 'Svalbardian' compressional event (Vogt 1928; Harland et al. 1974; Harland & Wright 1979). It can be correlated with the slightly earlier Ellesmerian event of northern Greenland and Arctic Canada (Christie 1979; Soper & Higgins 1987). New basins were formed during the Carboniferous and a slow subsidence continued throughout Permian and Mesozoic time (Birkenmajer 1981). Svalbard and Greenland were separated during the Palaeocene, following the opening of the Eurasian basin (Harland 1967, 1969; Talwani & Eldholm 1977; Srivastava & Tapscott 1986; Rowley & Lottes 1988).

The Devonian graben

The stratigraphic sequence of the Devonian basin has been described by Gee & Moody-Stuart (1966), Friend & Moody-Stuart (1972), Blieck & Heintz (1979) and Murascov & Mokin (1979). The western border of the Devonian basin is marked by normal faults and tilted blocks (Fig. 2). Breccias interbedded in the Late Silurian to Early Devonian Siktefjellet and Red Bay sandstone and siltstone formations may be associated locally with the faults. These breccias are polymictic, mainly made of clasts from the Late Precambrian to Early Palaeozoic Hecla Hoek complex. The clasts can be several metres in diameter, suggesting the existence of important active fault scarps during the Early Devonian. Sedimentation occurred in an active basin subjected to strong extensional deformation and synsedimentary normal faulting. In Bockfjorden for instance, the western border fault of the graben (F1 on Fig. 3), located between the Hecla

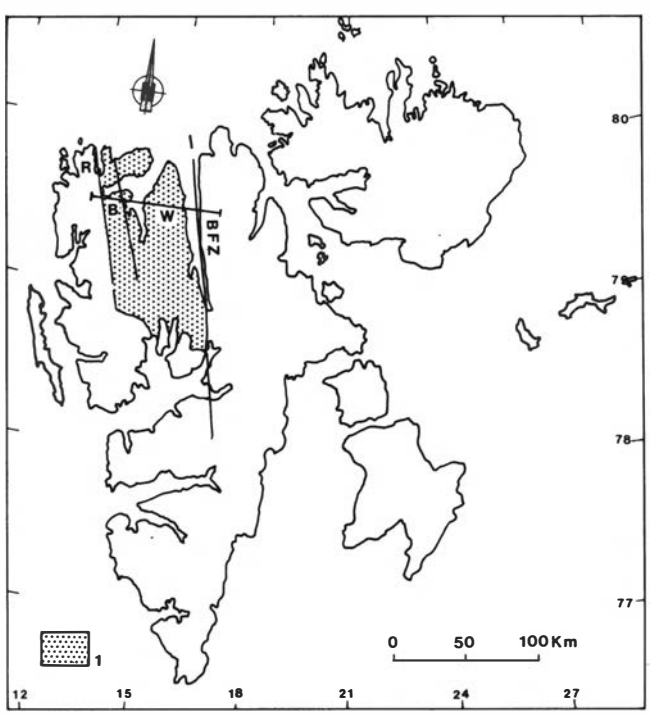


Fig. 1. Location and schematic framework of the Devonian basin of northern Spitsbergen. XY: location of the cross-section of Fig. 2. 1, Devonian basin; BFZ, Billefjorden Fault Zone; B, Bockfjorden; R, Raudfjorden; W, Wijdefjorden.

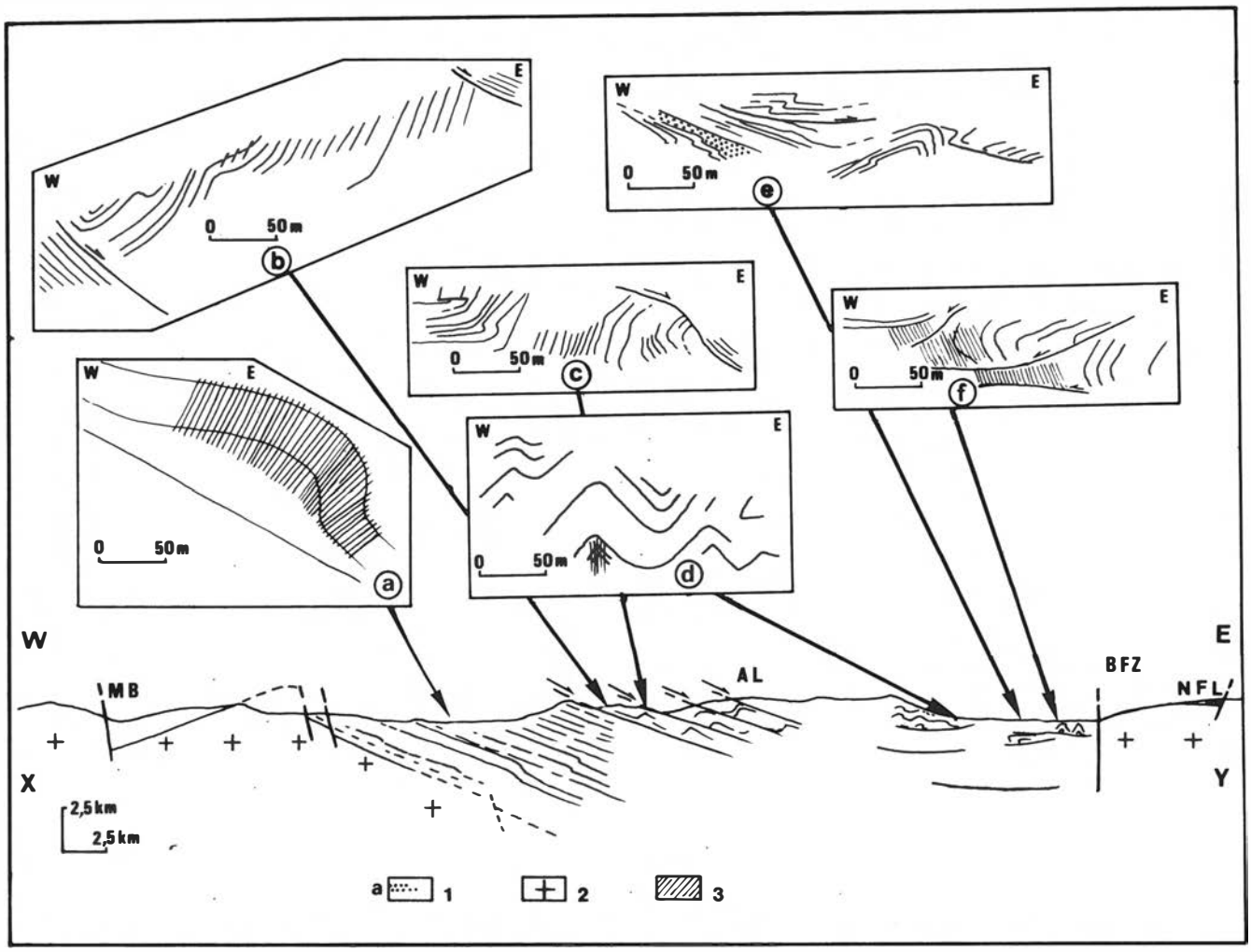


Fig. 2. Cross-section X–Y (see location on Fig. 1) showing some examples of cross-sections of folds and of reverse and normal shears affecting the Devonian sediments (a–f). 1, Devonian sediments including conglomerates (a); 2, Caledonian basement; 3, cleavage. AL, Andréeland; BFZ, Billefjorden Fault Zone; MB, Monacobreen; NFL, Ny Friesland.

Hoek and the Siktefjellet Formation of the Early Devonian, is normal and unconformably covered by the late Siktefjellet layers. Synsedimentary normal faulting is well exposed in outcrops in Raudfjorden (Fig. 4). Near the eastern border fault of the graben, on the shore of Wijdefjorden (Straumtangen), large slumps affecting the Middle Devonian layers (Grey Hoek Formation), unconformably overlain (Fig. 5) by conglomeratic rocks of the same age, indicate that the general slope of the basin floor was dipping to the east. Such observations indicate that the Devonian basin was an asymmetrical graben dipping predominantly to the east and bounded on the east by the Billefjorden Fault Zone (BFZ). In the eastern part of the basin, at least 4.5 km of sediments are preserved (Manby & Lyberis, this volume).

The Svalbardian deformation

In the central and eastern parts of the graben, the sediments were strongly folded and sheared prior to the Early Carboniferous. The folds are symmetrical or overfolded (Fig. 2a–f) and are associated with a well developed and frequent fracture cleavage affecting the soft sediments. The axes and the cleavage trend in all directions, mostly NE–SW to N–S and NNW–SSE (Fig. 6). The faults associated with the folds (Fig. 2b, c, e. f) are well exposed in the southeastern part of the graben (Lamar et al. 1985). Kinematic indicators, such as striations on fault planes and fold vergence, indicate that most of these slip surfaces have a normal sense of displacement while others are reverse faults (Fig. 2b, c, e, f). Normal slip surfaces and also normal bedding-parallel movements are found more frequently in the central part of the graben (Fig. 2). They are associated with the folds and together are assigned to the Svalbardian event.

The intra-rift gravitational detachment model

The resulting composite cross-section of the whole graben (Fig. 2) shows that the Svalbardian deformation

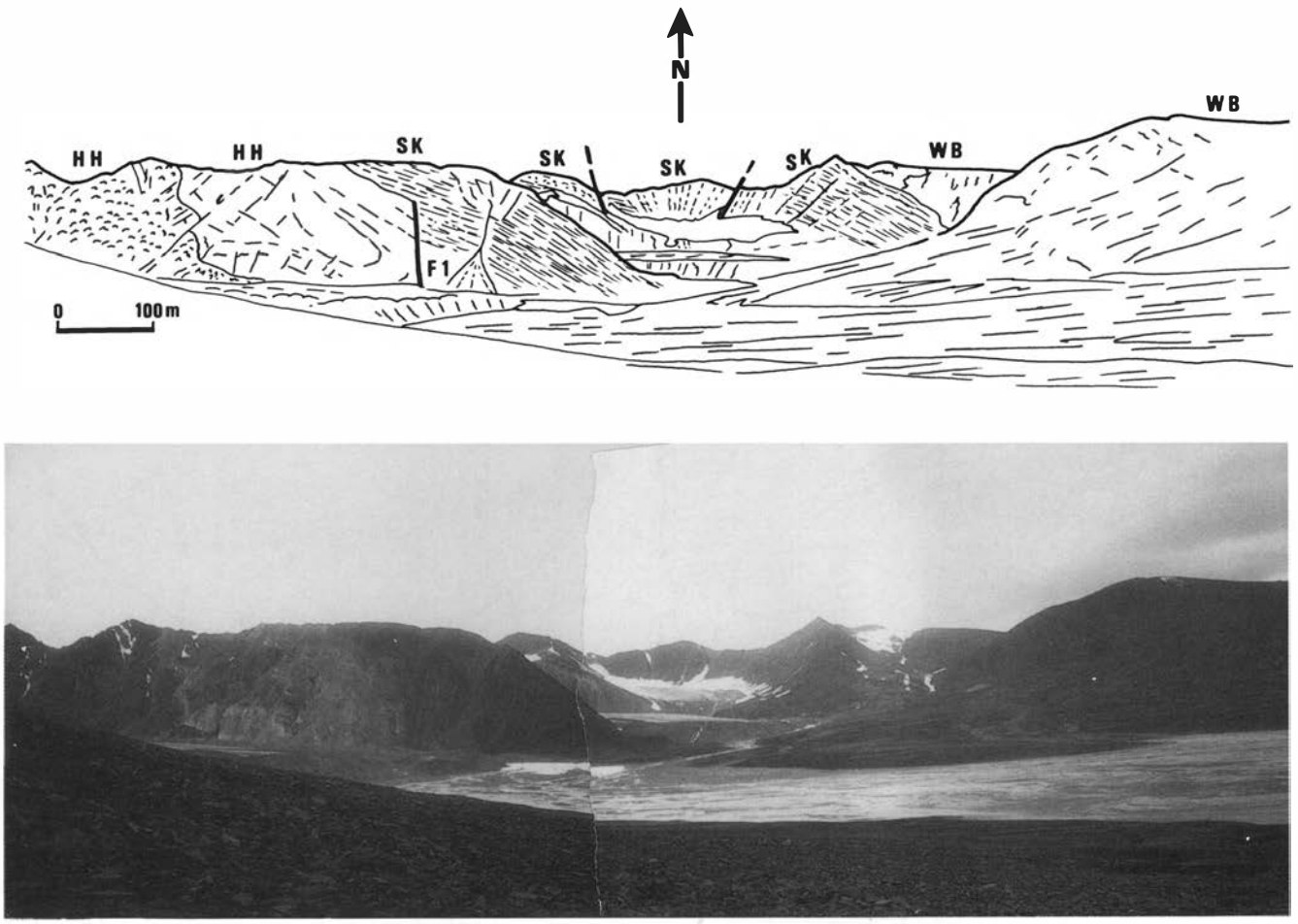


Fig. 3. Panorama of northern Bockfjorden showing the synsedimentary western border fault of the Devonian graben (F1) unconformably overlain by Early Devonian sediments. See location B on Fig. 1. HH, Hecla Hoek basement; SK, Siktefjellet Formation; WB, Wood Bay Formation.

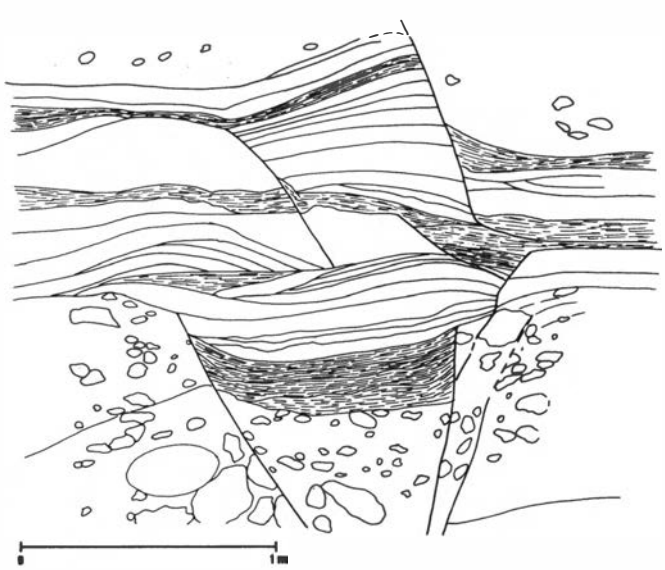
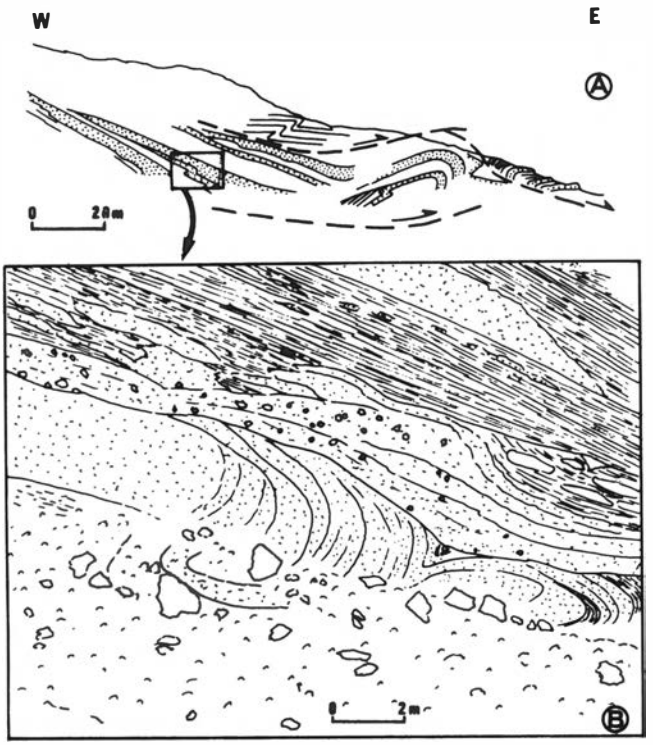


Fig. 4. Synsedimentary normal faulting in the Early Devonian Siktefjellet Formation of Raudfjorden. See location R on Fig. 1.

was expressed by combined extension and detatchment in the west, and compression in the east. This pattern suggests a large general detatchment of the sedimentary infill of the Devonian basin owing to gravity along the east-dipping slope of the asymmetrical graben. The detached sediments slid bed by bed to the east, forming extensional detachments in the central part while they were compressed against the BFZ in the east. For easily deformable sediments, such as siltstones interbedded with sandstones, gravity may induce detachment and movement along shallow slopes dipping only a few degrees. During the evolution of an asymmetrical graben (Chorowicz et al. 1987), the main subsidence is located near the major bordering fault, here the eastern fault. The shoulders are progressively uplifted by thermal effects due to the thinning of the lithosphere. Consequently, the general slope of the basement and of the earlier sediments filling the graben, dipping in our case to the east, increases and may reach



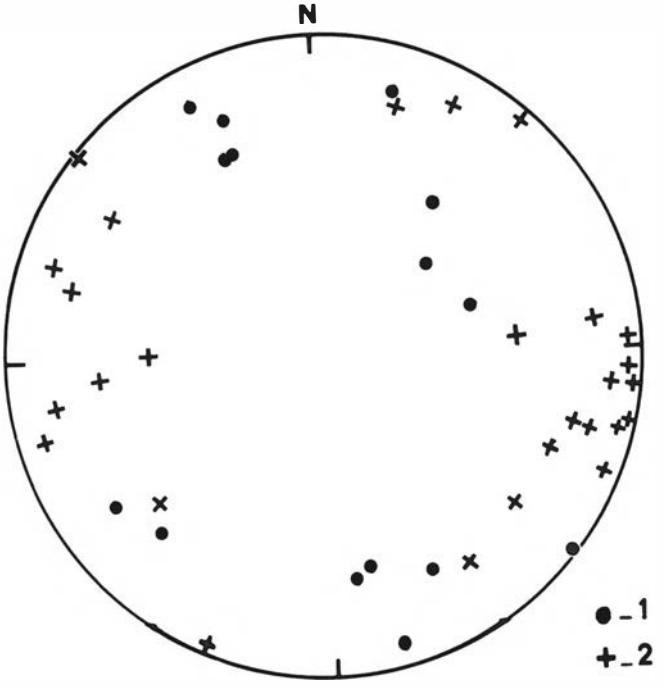


Fig. 6. Schmidt diagram (lower hemisphere) of fold axes (●) and poles to cleavage planes (+) affecting the Devonian rocks of northern Spitsbergen.

Fig. 5. Within thrusted and folded (a) sandstones of the Middle Devonian Grey Hoek Formation, slump-like folds are unconformably covered by flat-laying sandstones and conglomerates. The slump-like folds verge to the east and the sandstones and conglomerates prograde to the east, an interpretation consistent with a synsedimentary (Devonian) east-dipping slope of the basin bottom.

a critical value at a certain time, here in the Late Devonian (Fig. 7).

We may assume that the general detachment and movement to the east would thicken the infill of the basin (Fig. 7). The graben formation being a lithospheric process related to thinning of the lithosphere and associated thermal effects uplifting the shoulders, it would continue despite the relatively superficial detachment and gravity movements and consequently the unconformable Carboniferous basin was located more or less at the same place but it affected a wider area and was characterized by several narrow grabens (Fig. 7c). Basin subsidence evolution continued slowly through Permian and Mesozoic times. Subsequently, Palaeocene E–W directed compression formed conjugate NW–SE sinistral and SW–NE dextral strike-slip faults in the area, which was followed in the Neogene by extensional faulting.

Conclusion

Tectonics of the Devonian basin of northern Svalbard is still poorly known. Several interpretations have been proposed: large, late Devonian strike-slip transpressional movements (Harland et al. 1974); intra-continental transform fault zone (Lamar et al. 1985); Ellesmerian orogeny (Manby & Lyberis this volume). The gravity-induced detachment hypothesis is new and is compatible both with the extensional structures observed in the western part of the basin and the compressional features of the central and eastern parts.

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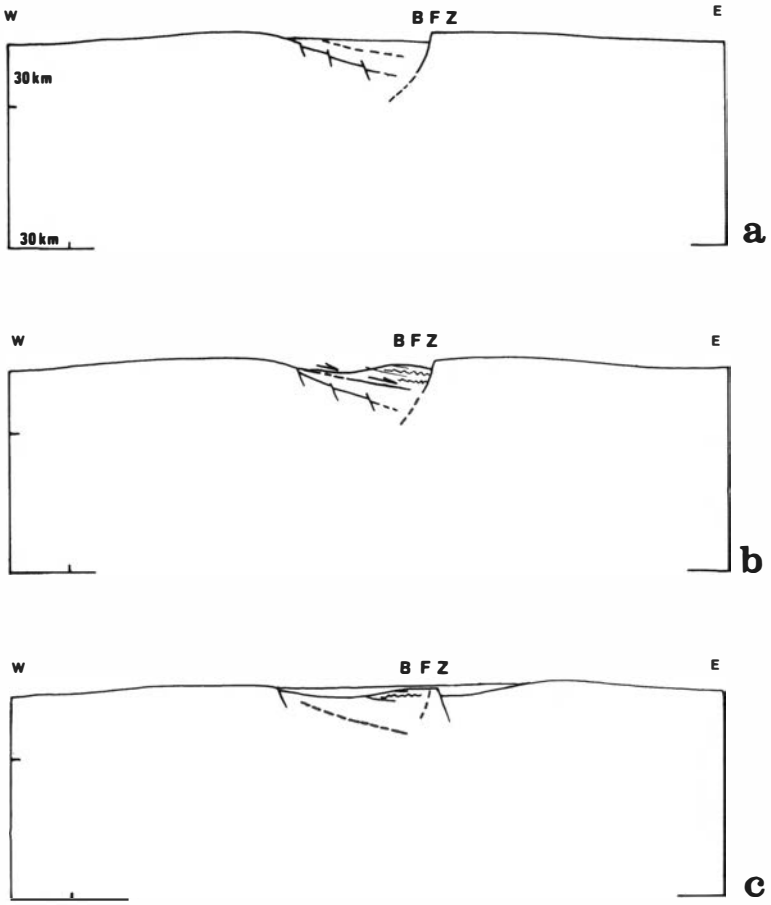

Fig. 7. Schematic geodynamic evolution of the northern Spitsbergen Devonian graben. (a) Devonian times. (b) Generalized detachment and gravity movement event of Late Devonian age. (c) Continuation of graben evolution during the Carboniferous. BFZ, Billefjorden Fault Zone.

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