Devonian core complex exhumation and Cenozoic decollements as alternatives to the Ellesmerian Orogeny

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Take-home message

Devonian core complex exhumation, and Cenozoic transpression decoupling through decollements in Mississippian coal- and shale-rich sedimentary rocks in Spitsbergen may be realistic alternatives to the Ellesmerian Orogeny.

Introduction

The Ellesmerian Orogeny (Piepjohn et al., 2000) is a short-lived contractional–transpressional event that occurred in the Late Devonian–Mississippian, i.e., after Devonian collapse of the Caledonides and prior to Carboniferous rifting. Thus far, this episode of contraction–transpression was required to explain the presence of undeformed Carboniferous–Permian sedimentary rocks on top of folded Upper Devonian strata in central Spitsbergen. The orogen is poorly constrained in other parts of the Arctic due to the lack/poor exposure of Devonian–Carboniferous sedimentary rocks (Rippington et al., 2010). We present an alternative model involving core complex exhumation through continuous, decreasing, Devonian–Carboniferous extension during the collapse of the Caledonides, and (partial) strain decoupling during Cenozoic transpression in Svalbard.

Results

In Pyramiden, Mississippian coals and coaly shales of the Billefjorden Group overlying folded Devonian strata are intensively deformed, displaying lithological units with steeply dipping and curved bedding surfaces (dashed red in fig. 2). We interpret these as Cenozoic shears and bedding-parallel thrusts arranged in hindward-dipping duplexes, which are separated from one another by unit-parallel decollements localized at lithological boundaries (yellow in fig. 2).

Seismic data in Sassenfjorden–Tempelfjorden (fig. 1) show a package of Z-shaped high-amplitude reflections thickening towards (a) major brittle fault(s) (fig. 3). We interpret these as sheared and overthrusted syn-tectonic coal-rich Mississippian sedimentary deposits of the Billefjorden Group arranged in hindward-dipping duplexes separated by decollement levels analog to those observed onshore in Pyramiden (fig. 2). Partial decoupling of Cenozoic transpression is also suggested by minor thrusts in Pennsylvanian–Cisuralian strata flattening and soling into Mississippian coals (fig. 3).

We also restored an E–W-oriented field cross-section in Adriabukta, in southern Spitsbergen (fig. 1 & 4a), prior to Cenozoic transpression by flattening the unconformity between Devonian–Mississippian strata of the Adriabukta Formation and Pennsylvanian strata of the Hyrnefjellet Formation (fig. 4b). After restoration, we find that reverse kinematic indicators in the field along the Mariekammen Shear Zone (e.g., reverse offset of basement lenses; Bergh et al., 2011) actually indicate down-east normal movement and extension.

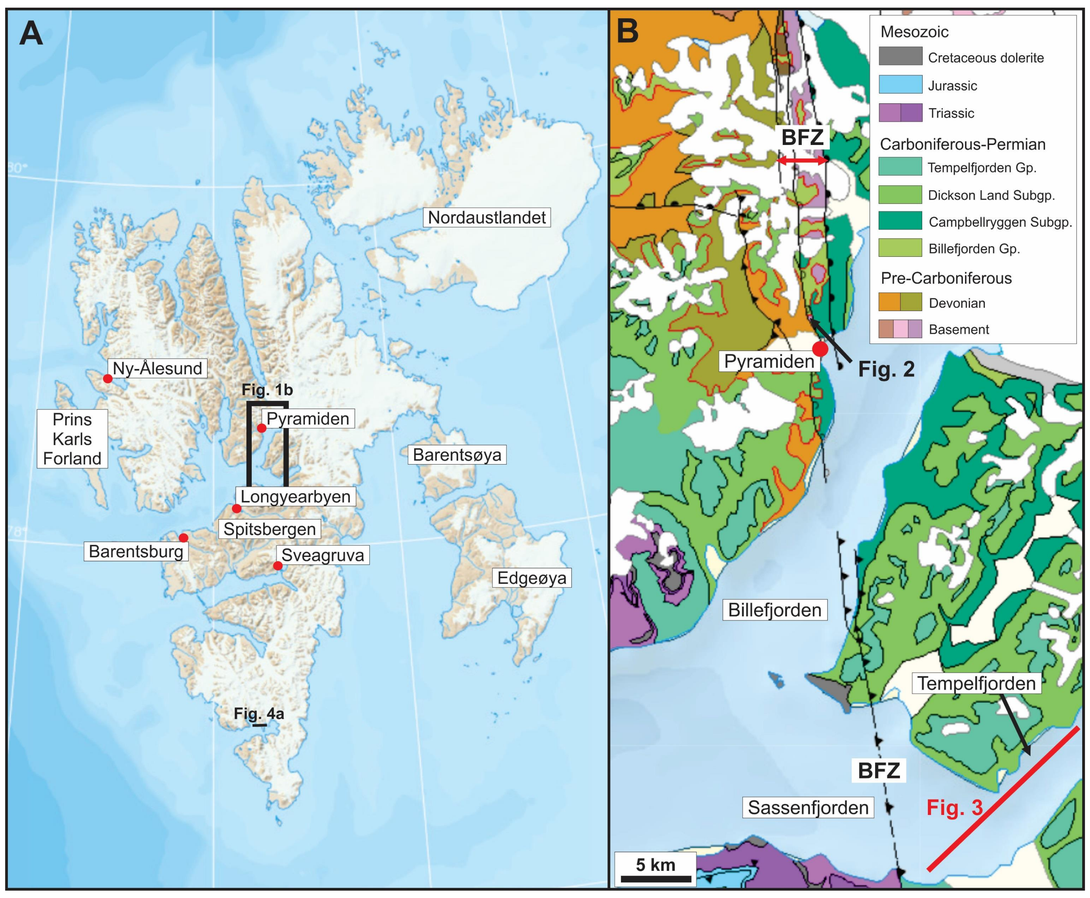

Figure 1: (a) Location map of the study area in Svalbard. Modified from toposvalbard.npolar.no. (b) Geological map of the Billefjorden–Sassenfjorden–Tempelfjorden area in central Spitsbergen showing previous interpretation of the Billefjorden Fault Zone (BFZ) across the fjords. Modified from svalbardkartet.npolar.no.

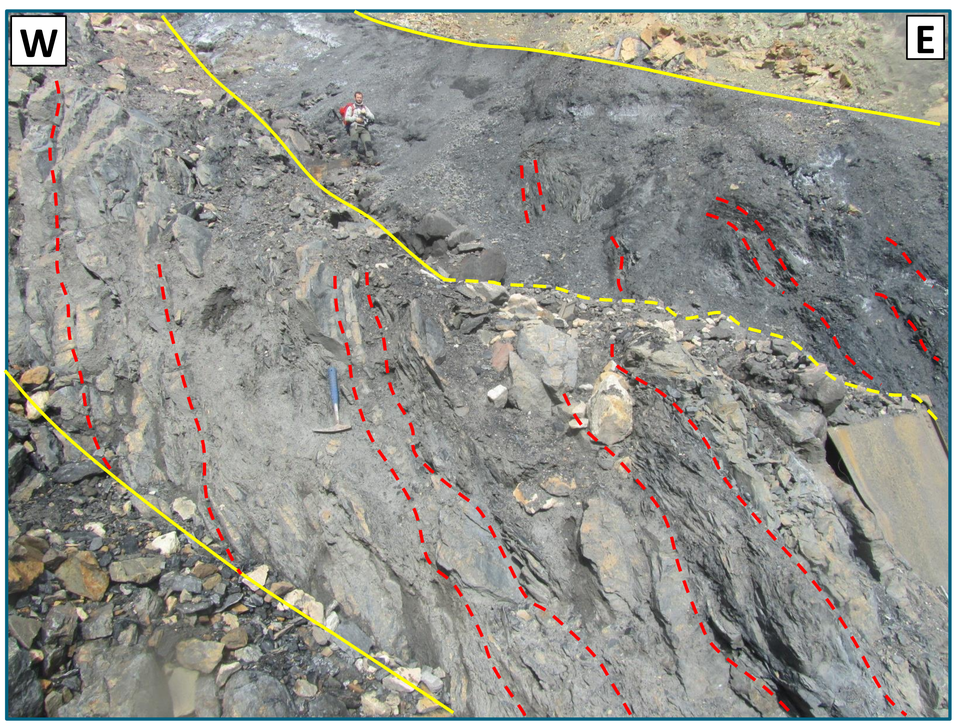

Figure 2: Field photograph of sheared Mississippian coals and coaly shales of the Billefjorden Group in Pyramiden forming hindward-dipping duplexes (red) separated by bedding-parallel decollement levels (yellow).

Discussion

In southern Spitsbergen, we propose that normal movement along the Mariekammen Shear Zone, part of the tilting of Devonian–Mississippian strata, and the angular unconformities between Devonian–Mississippian–Pennsylvanian strata (fig. 4) might be the products of the exhumation of a N–S-trending core complex in Devonian times. This is supported by the presence of a major Devonian core complex in northwestern (Braathen et al., 2018) and central Spitsbergen (Koehl et al., in prep.). We further argue that rheological contrasts between coaly shales–coals of the Billefjorden Group and Devonian–Mississippian–Pennsylvanian clastic sedimentary deposits facilitated (partial) decoupling during Cenozoic transpression through the development of decollement levels within relatively soft shale- and coal-rich Mississippian strata (fig. 2 & 3). Thus, decollements within Mississippian shales and coals potentially explain differential deformation between folded Devonian strata and relatively undeformed overlying Pennsylvanian deposits in central Spitsbergen through continuous decreasing Devonian–Carboniferous extension, without requiring any major change of tectonic regime in the Devonian–Mississippian.

Conclusion

(1) After restoration, normal sense of shear along the Mariekammen Shear Zone and angular unconformities between Devonian–Carboniferous strata in southern Spitsbergen might be the results of core complex exhumation and extension.

(2) Decollements in coal- and shale-rich Mississippian sedimentary rocks of the Billefjorden Group may have (partly) decoupled Cenozoic transpression, accommodating most of the deformation while overlying Mississippian–Cisuralian strata remained relatively undeformed.

(3) Ellesmerian contraction–transpression is not required to explain the presence of undeformed Mississippian–Cisuralian sedimentary rocks over folded Devonian strata.

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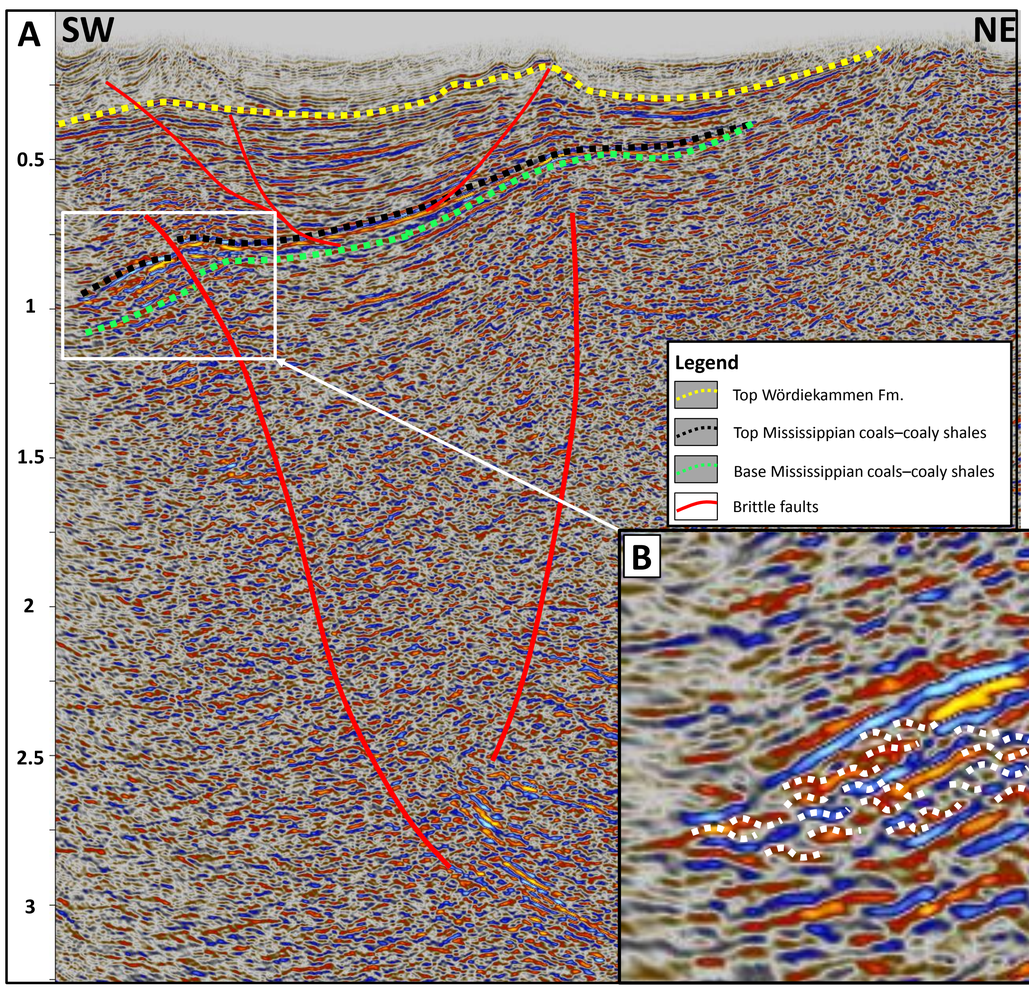

Figure 3: (a) Interpreted seismic section in Sasssenfjorden–Tempelfjorden showing high-amplitude reflections in the hanging wall of the Billefjorden Fault Zone, possibly representing thickened early-rift coal-rich sedimentary strata of the Billefjorden Group. Vertical axis to the left in seconds two-way time; (b) Zoom in thickened Mississippian deposits showing Z-shaped reflections interpreted as potential shears and thrusts (dotted white lines).

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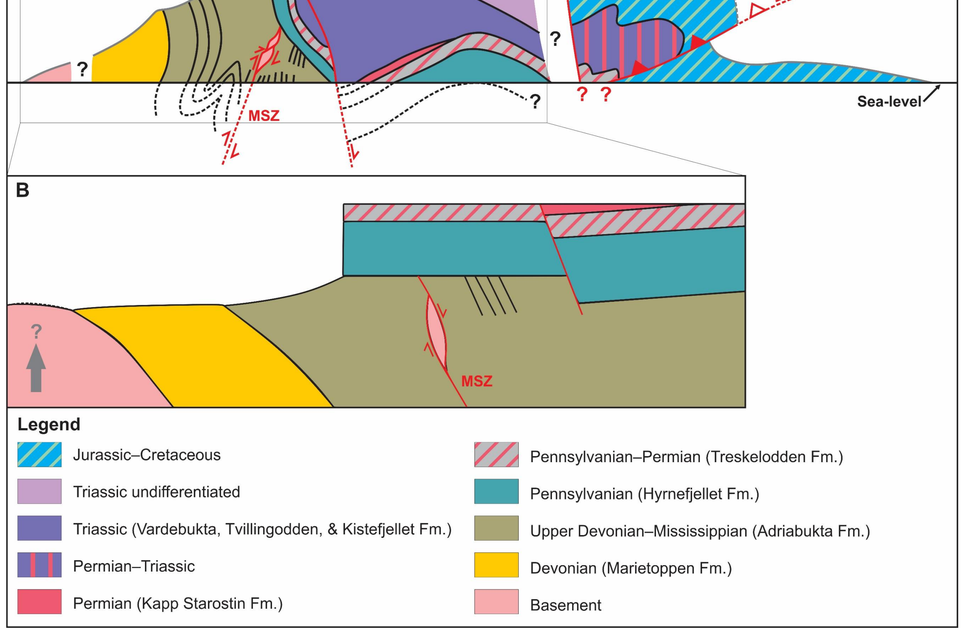

Figure 4: Redrawn (a) and restored (b) Adriabukta section in southern Spitsbergen. Modified after Bergh et al. (2011). Abbreviations as follows: EHF = Eastern Hornsund Fault; MSZ = Mariekammen Shear Zone.