Publications of the Institute of Geophysics, Polish Academy of Sciences
Geophysical Data Bases, Processing and Instrumentation
vol. 452 (P-4), 2025, pp. 47–52
DOI: 10.25171/InstGeoph_PAS_Publs-2025-005
SVALGEOBASE II: Tectono-thermal evolution of Svalbard, geological workshop, Svalbard 2024

An Alternative Hypothesis for Forming the Eurekan Fold and Thrust Belts of Spitsbergen and North Greenland

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Abstract

The 300 km long, 80 km wide, NNE-NE-directed West Spitsbergen fold and thrust belt and the N-directed Eurekan fold and thrust Belt of North Greenland have much in common with foreland fold and thrust belts. Kinematic reconstructions suggest that before the opening of the Eurasian Basin and the Norwegian–Greenland Sea, Svalbard was linked to North America. The Greenland–Svalbard separation is widely believed to have occurred due to a right-lateral strike-slip along the De Geer Fracture Zone. Many models attribute the formation of both fold belts to dextral transpression along this fracture zone as Svalbard separated from Greenland. In this work, an alternative model explains the origin as the result of Greenland-Svalbard convergence driven by the anticlockwise rotation of Greenland during the opening of the Labrador Sea – Baffin Bay. The characteristics of Svalbard's fold and thrust belt are outlined, and the supporting evidence is critically assessed, ensuring the validity and reliability of our findings.

1. INTRODUCTION

Svalbard, situated on the northwestern margin of the Barents Sea shelf, separated from North Greenland during the opening of the North Atlantic and Arctic Ocean Basins in the Late Palaeocene-Eocene (CHRON 25/24, 59/56 Ma, Talwani and Eldholm 1977; Vogt et al. 1982; Srivastava 1985). From the Oligocene to the Recent Times, the northward propagation of the Knipovich Ridge (Dumais et al. 2021) led to a marked thinning of the broad continental crust along the western margin of Svalbard. This thinning was accompanied by significant subsidence and the deposition of thick Tertiary sediments (Myhre et al. 1992; Eiken and Austegard

1987). The stretching of the continental lithosphere subsequently gave rise to a 3 km uplift of the rift shoulder of Svalbard and explains the present elevation of the WSFTB and the 10-120 eastward tilt of the Central Tertiary Basin (Manby and Lyberis 1996 and references therein).

Svalbard and North Greenland were subjected to significant folding and thrust faulting. In the present-day locations, the NNE-NE-directed West Spitsbergen Fold and Thrust Belt (WSFTB) formed while the north-directed Eurekan Fold and Thrust Belt (EFTB) developed in North Greenland.

The WSFTB is widely accepted as characterised by foreland propagating fold and thrust belt deformation. The structurally higher thrust nappes, which involve the basement, are characterised by listric thrust faults, suggesting a thick-skinned origin. Further east, where the nappes involve the Lower Palaeozoic–Mesozoic sequences and have stair-case geometries, have a thin-skinned origin.

Our research presents two contrasting models for forming and timing the two Cenozoic fold and thrust belts in the North Atlantic-Arctic Ocean Realm. Over several years, we meticulously gathered and analysed field data, including stress tensor determinations, from the entire length of WSFTB and the Kap Washington area of the EFTB of North Greenland, ensuring a comprehensive investigation.

2. THE STRIKE-SLIP MODEL

Most of the authors propose that the Northeast-directed West Spitsbergen Fold and Thrust Belt (WSFTB) and the North-directed Thrust Belt of North Greenland were the products of dextral transpression motion along the De Geer Fault Zone (e.g., Harland 1969; Lowell 1972) in the Late Palaeocene. The separation of the Svalbard–Greenland Blocks was facilitated by an intervening zone of weakness first identified by De Geer (1926) as the De Geer Fracture Zone.

These models require that the fold belt formed between the Latest Palaeocene and Oligocene (56–36 Ma) times. The transpressional model's mechanism for forming the WSFTB is intricately linked to the age and strain recorded within the Tertiary rocks. The weak deformation recorded by the Tertiary rocks in the Central Tertiary Basin and the Kongsfjorden area is invoked to support an Eocene timing for the primary fold belt deformation (see discussion by Harland 1995 and Maher et al. 1995). Implicit in this hypothesis is that the entire Tertiary succession must pre-date the onset of the deformation. The uncertainty of the precise age of the terrigenous Tertiary sediments has led to controversy regarding the age and mechanism of formation of the West Spitsbergen Fold Belt. However, it has been noted (e.g., Steel and Worsley 1984) that there is no sedimentary record (intraformational breccias or conglomerates) of any marked tectonic activity during the accumulation of the Tertiary succession, underscoring the pressing need for more evidence. Furthermore, there is some uncertainty in the exact location of the De Geer fault zone. Indeed, reported geophysical evidence suggests that all the major faults are listric extensional structures and show little evidence of lateral displacement (e.g. Austegard et al. 1988).

The NNE-directed WSFTB and North directed Eurekan Fold Belt of North Greenland exhibit the near-normal angular relationship between the fault zones, and the fold and thrust transport directions contrast markedly with those developed in association with well-established incontrovertible strike-slip fault zones such as the San Andreas and the Dead Sea fault zones. To overcome this contradiction in their hypothesis, Harland (1995) and other authors (e.g. Maher et al. 1995) allude to a decoupled transpression model, which requires the presence of an unidentifiable offshore dextral strike-slip fault while the onshore compression direction is orthogonal to the continental margin. The decoupling hypothesis would, however, require that the upper crust of Svalbard behave as a ridged block during the WSFTB formation. The pre-Devonian rocks within the WSFTB are extensively affected by brittle and ductile structures, suggesting that the upper crust did not behave rigidly. Furthermore, the transpressional models invoke a series of complex motions between Greenland and Svalbard in a short period (e.g. Braathen et al. 1995). These models, based on structural evidence only, fail to consider that a 125 km thick lithospheric plate is characterised by a significant moment of inertia and rates of change of direction take place over many (10's) millions of years, not 2 or 3 as implied by the transpressional models (e.g. Braathen and Berg 1995).

It is worth noting that the slow-spreading Nansen Ridge in Eurasia Basin became active ca 56 Ma while on the North Atlantic seafloor-spreading along the Knipovich Ridge, from 20 Ma, propagated northwards to connect the two oceans via the Molloy Transform Zone (Dumais et al. 2021). Thus, the separation of Svalbard from North Greenland was achieved essentially by rotation of the former driven by seafloor spreading rather than by strike-slip along the difficult-to-locate De Geer Fracture Zone.

3. ALTERNATIVE MODEL

The model presented here was arrived at by combining quantitative analyses of plate kinematics, structures including folds, slip vectors on fault planes, and a stress tensor analysis of the entire fold belt. Our study aimed to determine the stress pattern related to the relative motion of Greenland and Svalbard. We measured the orientations of fault planes and slickenside lineations in meso- and mega-structures along the entire WSFTB and Central and Eastern Spitsbergen. Several measurements were taken from each location to minimise the effects of rotations. The chronology of fault motions was established from stratigraphic and field evidence. Folds, cleavages, tension gashes and stylolites were also considered. The data were collected over a seven-year field mapping programme. Additional data was collected while participating in the BGR-funded CASE I & II projects along the WSFTB (1992) and the Eurekan Fold Belt, North Greenland (1994). These observations confirm that the WSFTB and the early stages of the Eurekan Fold Belt deformation of North Greenland resulted from the significant Svalbard–Greenland convergence in the Late Cretaceous-Palaeocene. This convergence, accompanying the initial opening of the Labrador Sea and before the spreading in the North Atlantic and Arctic Ocean basins, is a critical element of the alternative hypothesis (Fig. 1).

It is important to note that numerical modelling (England and Jackson 1989) demonstrates that the width of the deformed zone across the boundary of two continental blocks is directly influenced by their relative motion. Convergence results in a wide deformation zone relative to length, while strike-slip leads to a narrow zone relative to the length. For instance, the 1000 km long dextral E Anatolian Fault only produced a 100 km fold and thrust belt with E-W folds and thrusts cut by NE-SW sinistral strike-slip. Most strike-slip fold belts are characterised by shear zones, rotated folds, and intersecting cleavages that develop as the folds rotate during the progressive strike-slip movement. While no such features are present in the WSFTB, it exhibits, instead, many characteristics found in well-known foreland-propagating fold and thrust belts, such as those in the Canadian Rockies, the Southern Appalachians, and the Moine Thrust Belt of Scotland.

Details of the main structural features of the WSFTB and the Eurekan Fold belt of the North Greenland fold and thrust belt are presented by Manby and Lyberis (1996), Lyberis and Manby (1999); Manby and Lyberis (2000) along with the stress tensor analyses from the entire length of both domains.

Srivastava and Tapscott (1986) present a model showing the successive positions of Svalbard and Northeastern North America for fixed Greenland before the opening of the Labrador Sea through CHRON 25, CHRON 13 times and the Present Day. This reconstruction shows the joint seafloor spreading along the Nansen and Knipovich Ridges. The De Geer Fracture Zone represents a zone of weakness, allowing the Greenland Svalbard separation. As the two ridges

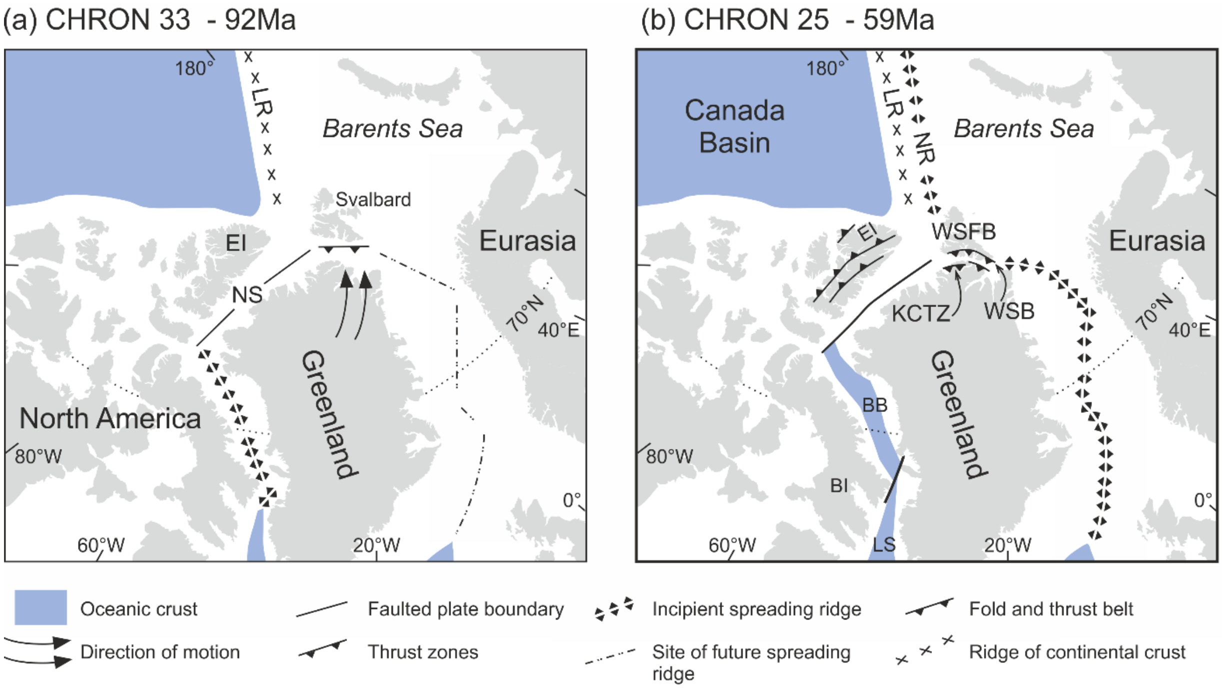

Fig. 1: (a) Greenland and Svalbard Relative positions at CHRON 33 (92 Ma). After Roest and Srivastava (1989), the kinematic model assumes that Svalbard was linked via Lomonosov Ridge to North America; (b) Greenland and Svalbard Relative positions at CHRON 25 (25 Ma). Abbreviations: BB – Baffin Bay, BI – Baffin Island, EI – Ellesmere Island, LS – Labrador Sea, LR – Lomonosov Ridge, NR – Nansen Ridge, NS – Nares Strait, KCTZ – Kap Cannon Thrust Zone, WSFB – West Spitsbergen Fold Belt, WSB – Wandel Sea Basin.

spread, Svalbard rotated globally from the initial De Geer weakness, implying that the De Geer Zone did not become a transform influencing the WSFTB deformation.

These Finite-Difference slip vectors for the CHRON 24–21 and CHRON 21–13 intervals, which give the relative motion of Svalbard concerning Greenland, are oriented N134 and N104, respectively. Such directions would provide a significant extensional component along the N160-oriented Greenland–Svalbard boundary, i.e., no offshore strike-slip fault. The transpressional models, which imply considerable compression across the Greenland–Svalbard boundary, are not supported by the above kinematics for CHRON 25/24–13 (59–36 Ma).

The present-day structure of Svalbard and the offshore region incorporates several N-S to NNW-SSE faults, some of which may be inherited from the Caledonian orogeny. As noted above, seismic reflection profiling of the western offshore region has identified several listric extension faults that cut through relatively undeformed post-WSFTB sediments. These include the Hornsund Fault and the Forlandsundet Graben. The geophysical profiling does not support the view that the two are strike-slip in origin or are linked to form a left-stepping pull-apart basin, as suggested in some transpression models.

4. SUMMARY

Most investigators agree that the West Spitsbergen, North Greenland Fold, and Thrust belts exhibit the same characteristics as other well-known Foreland propagating fold and thrust belts. In both regions, the fold axial traces and thrust front parallel the continental margin, and the principal stress axial trend is orthogonal to the continental margin and thrust fronts.

All well-established on-shore strike-slip regimes are characterised by fold axial traces arrayed at an acute angle to the main strike-slip faults. Such arrangements have yet to be recognised in Svalbard-Greenland.

Fold and thrust belts formed in well-established strike-slip regimes are characterised by rotated folds and intersecting transverse cleavages. Such features have yet to be recognised in Greenland and Svalbard.

The strike-slip model explains the deformation as the result of a decoupling or partitioning of the dextral strike-slip motion, which cannot be located along an ill-defined offshore fault zone(s). At the same time, orthogonal compression was applied across both continental margins as Svalbard separated from North Greenland.

The lack of certainty on the age of the Tertiary sediments on Svalbard, the weak nature of their deformational structures, and the proposal that these features can be attributed to the main Fold and Thrust Belt weaken the strike-slip model.

The model favoured here uses field and geophysical data, including kinematic reconstructions of the timing and causes of the Fold and Thrust belts' deformation.

Before the North Atlantic – Arctic Ocean Basins opened, the Svalbard–Barents Shelf was located North of Greenland. Kinematic reconstructions for the Cretaceous-Palaeocene time show that the opening of the Labrador Sea generated an anticlockwise rotation of Greenland towards the Svalbard–Barents Shelf block, initiating the deformation of the two.

The beginning of Svalbard's separation from North Greenland along the De Geer Fracture Zone coincided with the opening of the Eurasian Basin (ca. 59 Ma). There are conflicting opinions on the location of the De Geer Fracture off the west coast of Svalbard. Geophysical seismic reflection profiling indicates that most offshore faults are predominantly extensional, not strike-slip.

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Received 19 February 2025
Accepted 25 February 2025