How did the West Spitsbergen Fold and Thrust Belt change the sedimentation in the Central Tertiary Basin?

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Introduction – Tectonic Framework

The Paleogene rocks of the Central Tertiary Basin (CTB) are interpreted to have been deposited in a foreland basin that developed related to The West Spitsbergen Fold and Thrust Belt (WSFTB). This orogeny was part of the larger scale Eurekan deformation that took place in the Arctic, on Ellesmere Island and North Greenland as well as Svalbard. The major deformation zone is related to opening of the North Atlantic Ocean and the drift of Greenland as a separate plate and can be divided into two main stages *(Figure 1)* (Piepjohn et al., 2016).

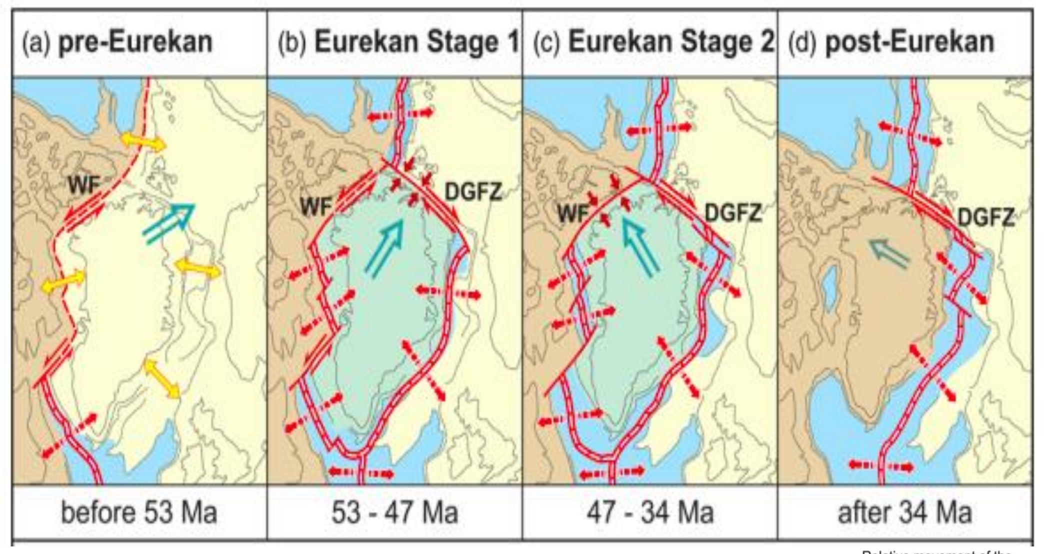


Figure 1: The evolution of the Eurekan deformation. Shows how the opening of the North Atlantic Ocean and Greenland moving as a separate plate caused a two-staged deformation in Svalbard and the Arctic. (Piepjohn et al., 2016).

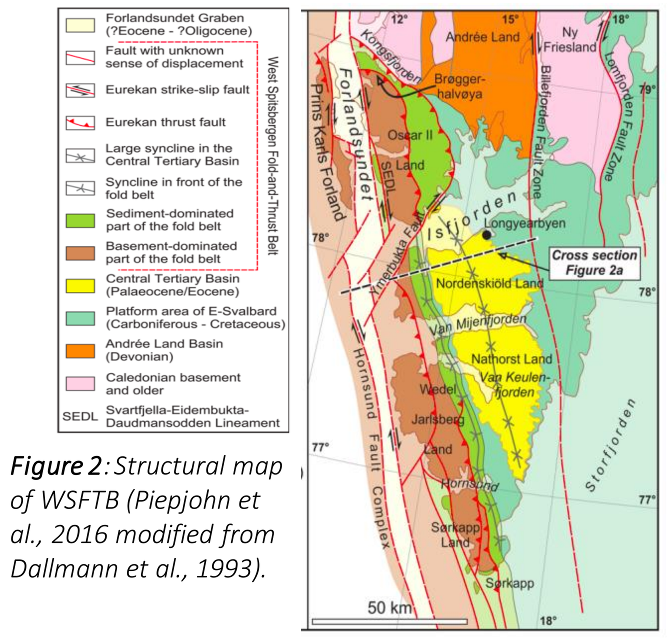


Figure 2: Structural map of WSFTB (Piepjohn et al., 2016 modified from Dallmann et al., 1993).

Svalbard experienced first an event of compression and thin-skinned deformation (stage 1), where the WSFTB developed. Later the movement changed to transform, basement involved, dextral strike-slip (stage 2).

The fold belt can be divided into north and south of Isfjorden. The Paleogene rocks are mostly preserved south of Isfjorden in the CTB (*Figure 2*). Underneath these rocks detachments continue from the fold belt (*Figure 3*) (Piepjohn et al., 2016).

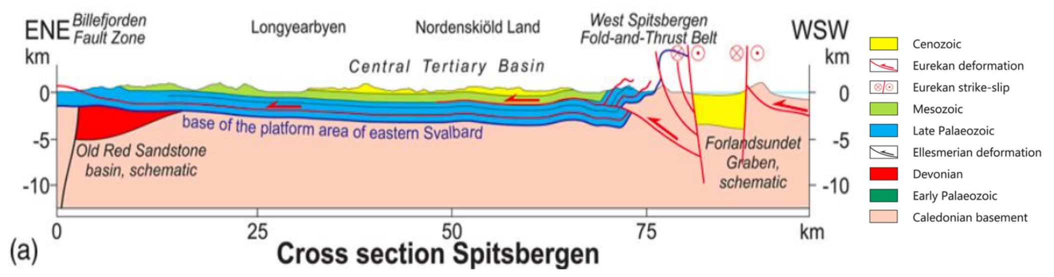
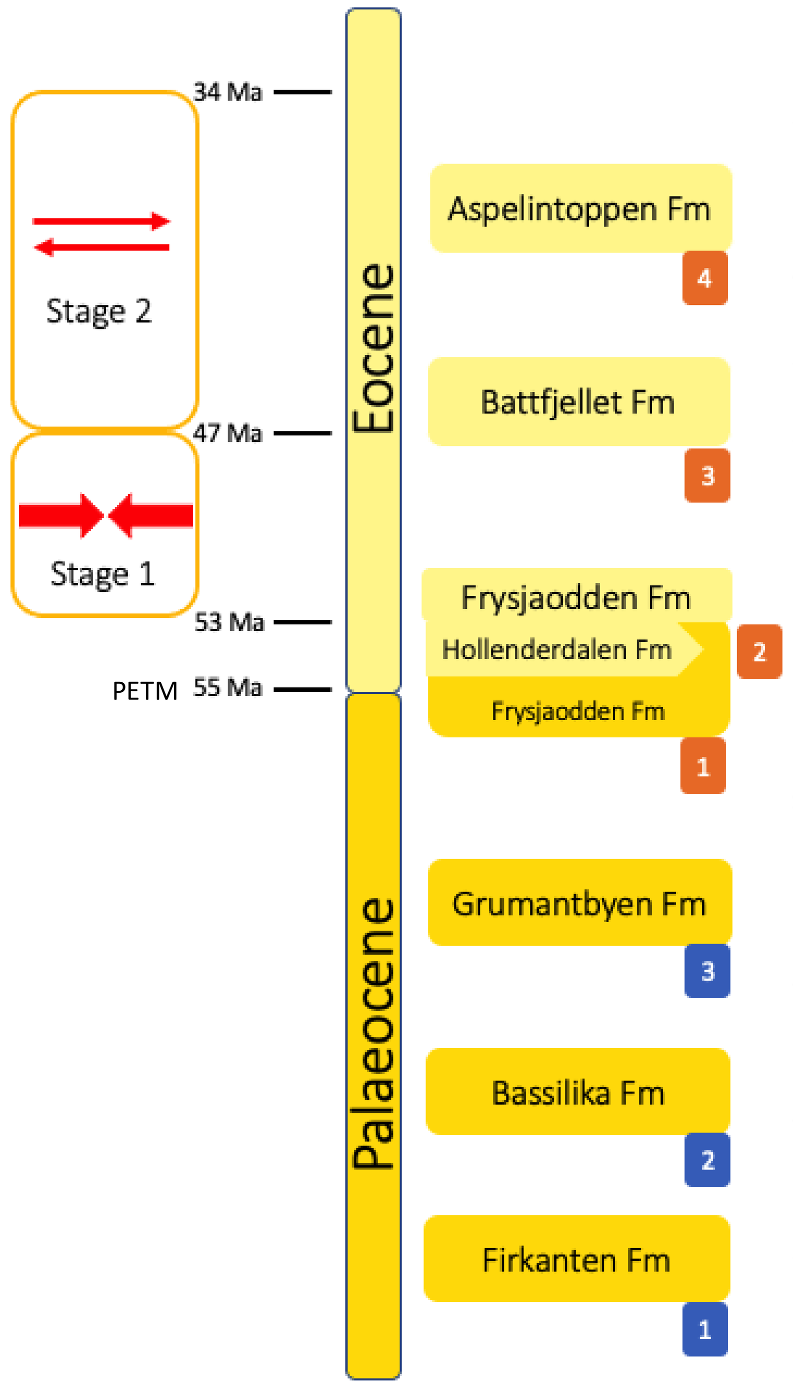


Figure 3: Simplified cross-section through Spitsbergen south of Isfjorden (Piepjohn et al., 2016 modified from Dallmann et al., 1993)

Timeline of the Central Tertiary Basin

The timeline shows the stratigraphic evolution of the CTB as well as the tectonic stages in the area. The basin consist of the Van Mijenfjorden Group which can be divided into a lower succession of Palaeocene age and an upper succession of Eocene age (Grundvåg et al., 2014). The successions of Paleocene age (Figure 4) had a mainly easterly sedimentary source area, while the Eocene sediments (Figure 5) were derived from the western fold and thrust belt (Dypvik et al., 2011):



Lithology & depositional environment:

Marginal marine to continental (Grundvåg et al., 2014) consisting of flood plain and delta plain deposits, grey/green sandstone and grey/brown siltstone (Dypvik et al., 2011).

Silt and sandstone in multiple coarsening upward units representing wave dominated, deltaic & tide-influenced shorelines (Dypvik et al., 2011).

Frys. Fm: Offshore and prodelta slope (Grundvåg et al., 2014) dominated shale deposition.
Holl. Fm: Delta outbuilding and delta/offshore facies. (Dietmar Müller and Spielhagen, 1990)

Regrasive mega-sequence (Grundvåg et al., 2014)

Highly bioturbated sandstone, deposited as a submarine shelf (Dypvik et al., 2011).

Coarsening upward succession (Dallmann et al., 1999). Shelf mud, clay and siltstone.

Delta-plain interfingered with shoreface sediments deposited in a transgressive phase, coal bearing (Dypvik et al., 2011).

Transgressive basin filling (Dypvik et al., 2011)

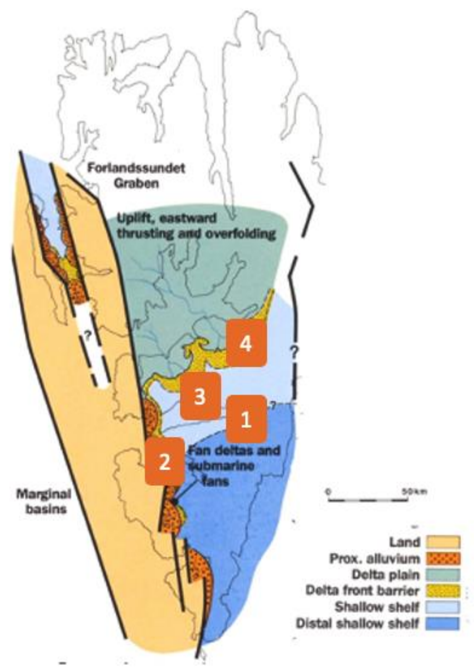


Figure 5: Visualizing the environment of the deposition in Eocene. Modified from J. Steel and Worsley (1984). The formations are considered as a regressive mega-sequence that was sources form the orogenic wedge to the west (Grundvåg et al., 2014).

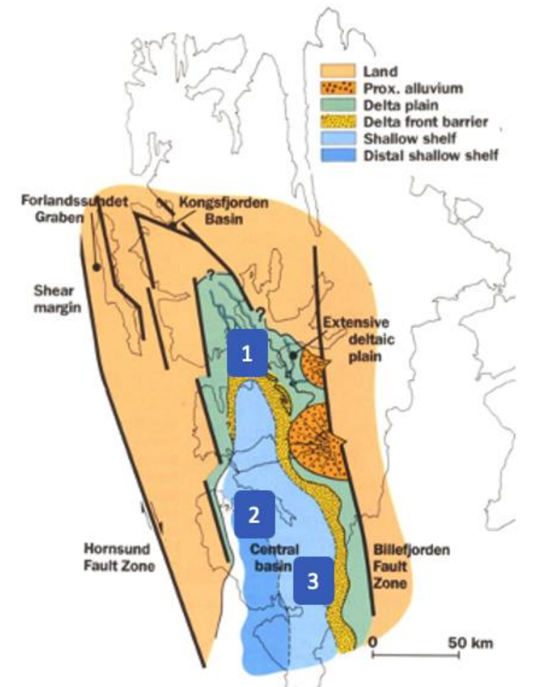


Figure 4: Visualizing the environment of the deposition in early Palaeocene. Modified from J. Steel and Worsley (1984). The early formations are considered as a transgressive basin filling with sediments mainly sources in the east – northeast (Dypvik et al., 2011).

Seismic Interpretation

Isfjorden

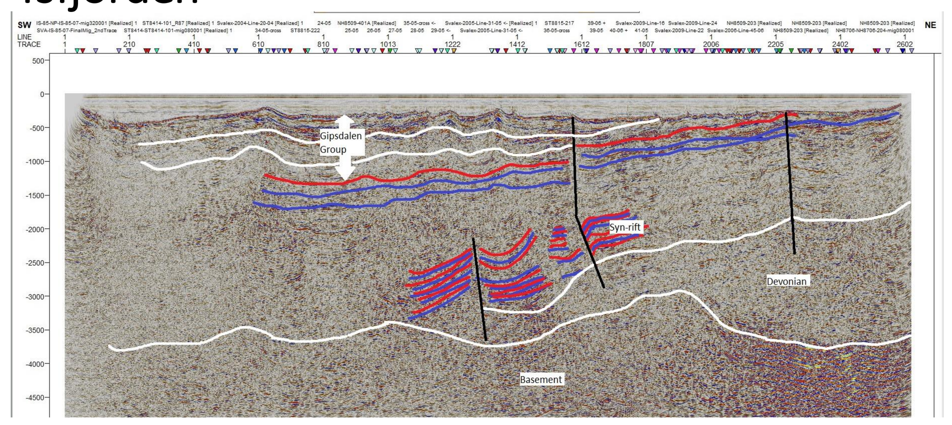


Figure 6. Seismic imaging across Isfjorden. Data shows a strong anomaly that is interpreted as the metamorphic basement. Visible also is the Devonian basement in the East, as well as syn-rifting and faulting. The Gipsdalen group is visible in the West.

Reindalen

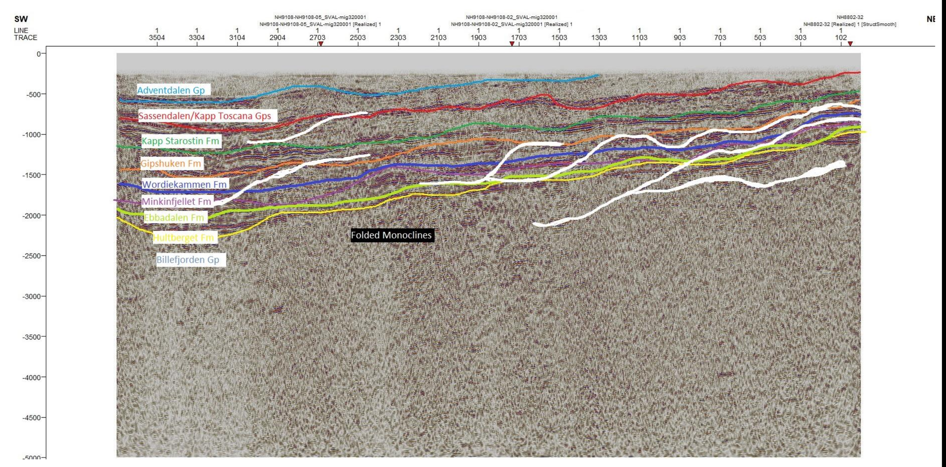


Figure 7. Seismic imaging across Reindalen. Glacial icecaps result in shadows causing blank spots at the top of the profile and masking underlying reflectors. The Billefjorden Fault Zone appears to create a compression structure with folded monoclines overlying the basement.

Van Mijenfjorden

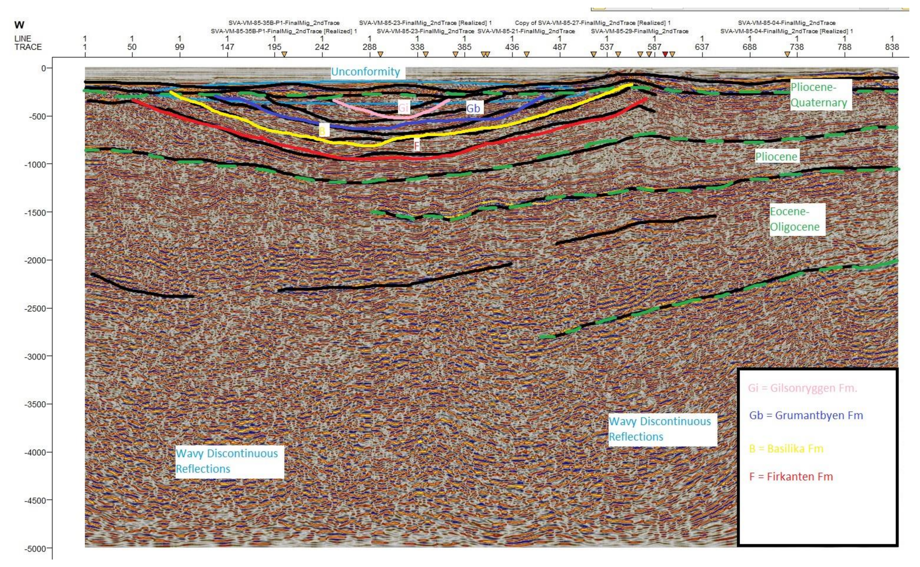


Figure 8. Seismic imaging across Van Mijenfjorden. Visible unconformity between overlying quaternary sediments and Van Mijenfjorden group (Gilsonryggen Fm., Grumantbyen Fm., Basilika Fm., and Firkanten Fm. Divisions between Quaternary-Pliocene, Pliocene, Eocene-Oligocene strata are present.

Science-Dough Model

The different formations in the Van Mijenfjorden Group has been reconstructed (Figure 9) using data from the Geoscientific Atlas of Svalbard (Dallmann (ed.), 2015). The model represents how the thicknesses of the formations change latterly in response to sediment supply from either east to north-east or west. A change from east to west can be recognized between Grumantbyen Fm and Frysjaodden Fm.

The sediment supply of the Paleocene age was mainly from the east to north-east. After the compression event (Stage 1) (Piepjohn et al., 2016) the sediment supply changed direction and came from the west (Dypvik et al., 2011).

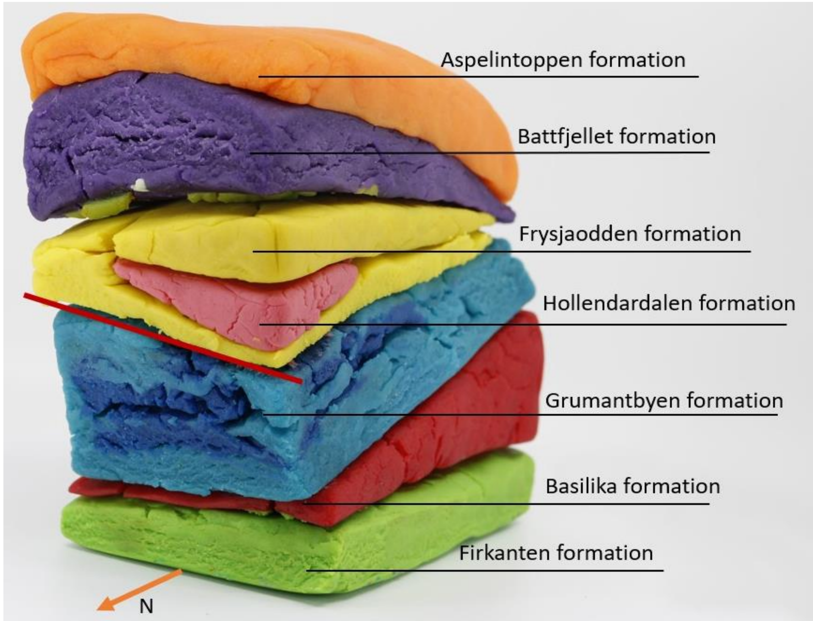
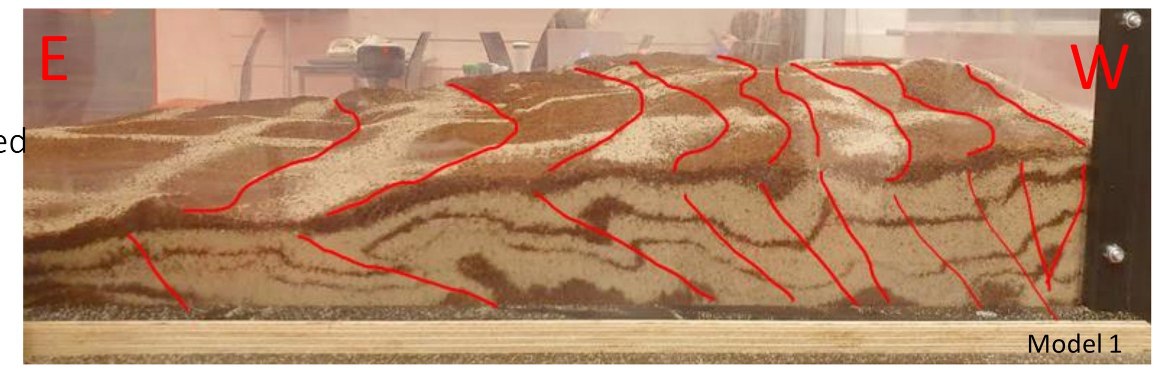


Figure 9: A science-dough model visualizing the thickness of the formations relative to each other and the change in sediment supply direction. The red line represent the approximate Paleocene/Eocene boundary. Note that only the lower part of Aspelintoppen Fm is represented in the model. The 3D model is available at: https://skfb.ly/o6zXT

Sandbox Model

For understanding the mechanisms and development of WSFTB we made an analogue model, a compressional regime in a sandbox. The aim was to visualize the fold belt and foreland basin across Spitsbergen, south of Isfjorden. Time laps videos from Model 2 are available at: https://youtu.be/kMW-9P3mOeE https://youtu.be/WQqrYOv7KU8

Model 1:
A thicker model with simple, continues compression. Thrust faults and folds occurred (marked in red), starting in the west and gradually forming towards the east. Compression forms a "staircase"-architecture with erosion from higher to lower ground.



Model 2:
A thinner model with added sedimentation as the fold belt grows. Pink marker layer shows top pre-deformation. Similar structures as in previous model evolved and syn-sedimentation was also affected by these.

Paleoclimate

During the Paleogene, the climate drastically changed multiple times. The peak temperature of this period occurred during the Paleocene-Eocene thermal maximum (PETM). Generally during the Paleogene, the temperature was warmer than today (Dypvik, et al., 2011). Indicators of a warmer climate can be found throughout the Van Mijenfjorden Group e.g. the coal bearing Firkanten Fm and the abundance of plant fossils found in Aspelintoppen Fm (*Figure 10).* During the Eocene, the Arctic climate went from a subtropical to a much cooler climate, with possible seasonal ice caps and glaciations which could be caused by the topography form the Eurekan belt (Vamvakas et al., 2019).

Figure 10: Fossilised leaf from the Aspelintoppen formation. Indicates a warmer climate on Svalbard, that could support forests. 3D model can be found at: https://skfb.ly/o6zXY

Concluding Remarks

- The WSFTB developed as part of the Eurekan deformation in the Arctic
- Paleocene rocks are deposited pre-Eurekan deformation and has sediment supply mainly from the East and Northeast
- Frysjaodden Fm. marks a change in sediment supply direction, this is correlated to the first stage of Eurekan deformation
- Seismic imaging reveals compressional deformation of sediments older than Paleogene age and underneath the CTB as a result of the WSFTB
- Analogue model of WSFTB shows that deformation also affects syn-deformation deposits

References