Can We Recognize Extensional Tectonic Geomorphology from the Late Paleozoic? A Study of Three Half-Grabens Onshore the Northeast Atlantic Margin

Linda Cecilia Haaland[1,1], Per Terje Osmundsen[1,1], Tim Redfield[2,2], Katia Svendby[2,2], and Kim Senger[3,3]

[1]NTNU
[2]NGU
[3]UNIS

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Abstract

In this study we investigate how landscapes are inherited from continental rifting on long timescales. Areas that are currently undergoing extension typically have topographical features and drainage patterns that are easy to recognize. How these topographical rift features evolve on long timescales, however, is poorly understood. Recent work from onshore parts of the northeast Atlantic margin suggests that some present-day landforms are inherited from late Paleozoic, Mesozoic and Early Cenozoic rifting and opening of the North Atlantic Ocean. These relict landscapes are difficult to recognize, as the topography is reworked by post-rift Cenozoic uplift and erosion, as well as repeated Quaternary glaciations. For that reason, interpretations of these landscapes vary considerably. However, some of these relict rift features are demonstrably preserved in half-grabens, as sedimentary basins with well-established ages. Our research studies the topography around three half-grabens in Norway and on Svalbard, and aims to quantify landscape inheritance from rifting and margin formation. To do so, we use structural and geomorphological field observations, and remote sensing such as digital elevation model analyses and seismic images. We classify landscapes in detail, systematically reviewing present-day landscape distributions in order to distinguish extensional tectonic landforms from other geomorphological features. Preliminary results find that certain present-day landforms along the northeast Atlantic Ocean are relics from rifting from as far back as the late Paleozoic. This is expressed by, among other things, major topographic contrasts between footwall and hanging wall in all three half-grabens. This means higher topographical elevations and deeper incision in the footwalls compared to the hanging walls. Additionally, the three study areas have very different landscapes, suggesting that their individual post-rift landscape evolutions were very different from each other. These differences seem to be influenced by the degree of glacial incision, the degree of erosional exploitation of pre-rift structures, and possible Late-Cretaceous or younger reactivation of basin-bounding normal faults.

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Can We Recognize Extensional Tectonic Geomorphology from the Late Paleozoic?

A Study of Tribe Hall Graben Onshore the Northeast Atlantic Margin

Hadera L. Gebrezgabher[1], Haakon I. Fossen[1], Kristian A. Kolhaugen[1]

[1]UiBergen, [2]

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ABOUT OUR RESEARCH

This research investigates how **rift-inherited geometries** from Permian-Triassic **extension** and rifting in the Late Paleozoic influence subsequent tectonic deformation.

We study topography, in and around the Hall graben basin, onshore the north western continental margin of Norway.

Our study area is ideal to explore **what inherited geometries from rifting** strong **control** contemporary topography.

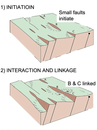
Or does **rift-inherited features influence the present-day geomorphology** during **passive continental margins?**

Interested in seeing more background? Keep on reading.

The formation and evolution of passive continental margins remains a fundamental topic in Earth science. Extensional tectonic structures inherited from the phase of continental rifting may, in turn, control the topography and structure of the continental margin for millions of years after rifting ceased.

Although the influence of inherited structures on the topography of passive continental margins has been recognized in the offshore, the extent to which these structures control onshore topography remains poorly constrained. This study aims to bridge this gap by examining the Hall Graben onshore Norway, to assess the influence of Permian-Triassic extensional structures on the topography of a formerly rifted passive continental margin.

Recent studies have shown that the Scandinavian Mountains underwent significant uplift during Cenozoic time, which has been attributed to various mechanisms, including mantle processes, glacial isostatic adjustment, and remote stressing such as ridge push. However, these models primarily focus on broad regional uplift and do not adequately address the observed topographic variations within the range. Consequently, the role of inherited structures in shaping the topography of this region remains a critical question that warrants further investigation.



Using the conceptual model of extensional fault zone evolution by Jackson and Rotevatn (2013) with 3D seismic data to understand the subsurface geometry of rift systems from offshore, especially:

1. Initial fault nucleation and growth
2. Fault linkage and interaction
3. Through-going fault zone development and how it influences sediment dispersal in basin margin settings, and ultimately how it influences topography

This method has the potential to:

Help us understand how and at what rate rifting-related faults will contribute to the geomorphic landscape of Fennoscandia.

METHODS AND STUDY AREAS

Methods

- Fieldwork to collect structural data, lithostratigraphy and geomorphology
- Remote sensing - digital elevation datasets (topography) to delineate lineaments, and lineament analysis to study their orientations and distributions
- Use the collected data to develop a conceptual model of rifting

Study areas

Three half-graben basins onshore the northeast Atlantic margin

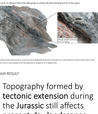
The Billefjorden Trough, on Spitsbergen, is an exhumed Permian rift, with the Billefjorden Fault Complex bounding the western margin. Additionally, there is a stratigraphy record preserved covering both the hanging wall and footwall.

The two half-graben systems exhumed from on-shore Norway are interesting since, the Hall Graben is a Mesozoic half-graben, with the footwall uplifted and exhumed, and the Sortlandsundet half-graben, the hanging wall is preserved, and the footwall is not exposed.

In the Hall Graben the stratigraphy is preserved, but, the depth to basement is not known. In the Sortlandsundet graben, the footwall is being uplifted, and the stratigraphy, thins and pinches out towards the footwall.

Both the Hall Graben and the Sortland half-graben are bounded by a NNE-SSW trending fault system.

As the two larger graben (Sortland Tectonic do not have a stratigraphy record preserved in the footwall, we can use the Billefjorden Trough as a reference for what we can expect in the other two graben. It is also a unique opportunity to see how a half-graben evolves.



Simplified cross-sections of the Beitostølfjorden half-graben in Trøndelag and the Sortlandsundet half-graben in Vesterålen. Both are half-graben systems with a NNE-SSW trending bounding fault. The Beitostølfjorden half-graben is a Permian half-graben, with the footwall exhumed and the hanging wall preserved. The Sortlandsundet half-graben is a Mesozoic half-graben, with the footwall not exposed.

Timing rift focuses on-land

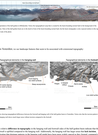
Although we know the timing rifting, we don't know exactly where it was active in western Scandinavia. Geologists have been trying to find out for years.

Recent studies have shown that the Permian-Triassic rift is likely the main rifting event in the region.

Image of a Permian-Triassic dolerite dyke, cutting through the Precambrian basement rocks of the Hardangervidda plateau, Norway. Photo taken by Haakon Fossen in February 2024.

MAIN RESULT

Topography formed by **tectonic extension** during the Jurassic still affects **present-day landscapes.**



OUR FINDINGS

SO FAR, **we have found that some topographical features along parts** contemporary **topography are influenced by inherited structural trends.**

For example:

- **Certain topographical elements like fault scarps may be directly inherited from the rift-related faults** and have been preserved during subsequent erosional processes and tectonic uplift.
- **Lineaments observed in the topography may correspond to rift-related structures** and have been reactivated, or **reoriented, by compressional tectonic topography** from later tectonic events.
- **Rift-related structures** can exert a long-term influence on the landscape, **affecting drainage patterns, sediment** and **groundwater** flow, and **tectonic activity.**

Scroll for more details

Topography in the three study areas is important

A Topographic **ridge** is prominent at all three areas, and as thought to be directly inherited from the basin-bounding faults.

Image of a Jurassic rift-related footwall in Sortlandsundet, Vesterålen. The footwall forms a ridge that is parallel to the fault zone.

Image of a Permian rift-related footwall in Beitostølfjorden, Trøndelag. The footwall forms a ridge that is parallel to the fault zone.

Image of a Permian rift-related footwall in Billefjorden, Svalbard. The footwall forms a ridge that is parallel to the fault zone.

In the **Vesterålen**, we can distinguish between three zones of increasing rift-related topography.

Image of a Jurassic rift-related footwall in Sortlandsundet, Vesterålen. The footwall forms a ridge that is parallel to the fault zone. The topography increases towards the footwall and hangingwall.

The zone **adjacent to hangingwall**, the hanging wall topography is at its lowest and the gradient from hangingwall to footwall is gentle. The zone **adjacent to the footwall**, the topography increases towards the footwall. The zone **in the footwall**, the topography increases towards the footwall, but, the gradient is steeper than the zone adjacent to the footwall. Finally, the topography increases from hangingwall towards footwall, but, the gradient is steeper than the zone adjacent to the footwall.

We can see that the footwall zones reveal more detailed topographic and tectonic trends. The hangingwall, in the hanging wall, seems to be a relatively flat surface, with minor topographic variations.

Hypothesis for the topographic profile of the Sortlandsundet half-graben, based on the observed topography. The hangingwall relatively gentle topography, consisting of rolling hills with the occasional steeper slope. The footwall has higher, more rugged topography.

Image of a Jurassic rift-related footwall in Sortlandsundet, Vesterålen. The footwall forms a ridge that is parallel to the fault zone. The topography increases towards the footwall.

Image of a Permian rift-related footwall in Billefjorden, Svalbard. The footwall forms a ridge that is parallel to the fault zone. The topography increases towards the footwall.

Image of a Permian rift-related footwall in Beitostølfjorden, Trøndelag

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