Reappraisal of the Mid-Jurassic Central North Sea doming based on a compilation of the regional stratigraphy and denuation history.

Abstract: The Mid-Jurassic thermal doming in the North Sea corresponds to a regional regression culminating during the Aalenian. The regression is concomitant to enhanced erosion on Palaeozoic highs. The thermal doming event started around 180Ma, preceding the localized rifting of the Central Graben that started around 160Ma. This Late-Jurassic rift reactivated Permo-Triassic extensive structures. The doming has been presented either as radial with a locus approximatively of the Forties volcanic Province, or as axial, with a rough West-East extension. Along the Central Graben, it is associated with asymmetric distribution of Jurassic Volcanism.
Over the last 20 years, several studies have locally estimated the amount of erosion during the North Sea Basins and surrounding highs. However, a regional evaluation of the results was still lacking. Our study present regional compilations and review of erosion/denudation data. We show that the maximum amount of the Mid-Late Jurassic erosion occurred along the Central Graben and decay away from it. It appears that the amount of removed section is at first order controlled by the distribution of the Palaeozoic highs and tectonic blocks boundaries.
The geometry of the Caledonian suture between Baltica and Avalonia tectonic blocks and its reactivation could have controlled the locus and the asymmetry of the Mid-Jurassic doming. It suggests that increased erosion on topographic highs far from the Central graben, such as the Brabent massif, could be linked to changes boundary conditions during the Mid-Jurassic rather than to large-scale uplift controlled by astenospheric upwelling. This work leads to better understanding of the intra-continental lithosphere, and suggests a new trail to investigate the interaction between astenospheric upwelling

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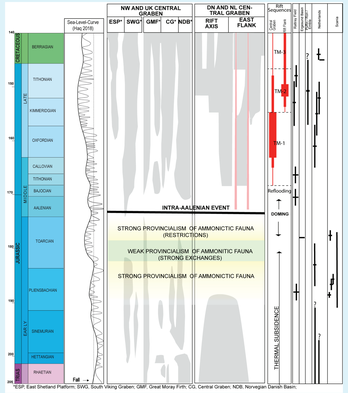
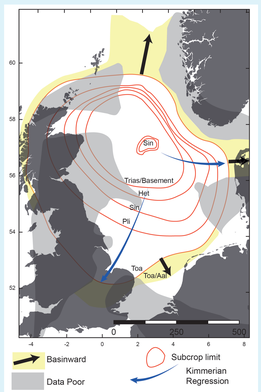
GEOLOGICAL CONTEXT: JURASSIC RIFTING AND UPLIFT



Stratigraphic chart displaying the evolution of the main Jurassic Graben, as well as the rifting events in the Dutch Central Graben in relation with dated volcanic events.

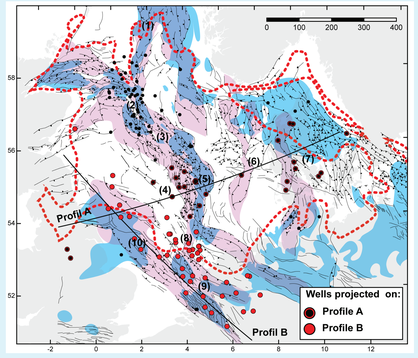


Mesozoic subcrops maps during the Aalenian Even modified from Underhill and Partington (1993). The map shows a doming pattern

THE INTRA-AALENIAN EVENT, a prelude to intracontinental rifting:
Initial rifting phase (280Ma -240Ma) followed by ultra slow Late Triassic-Early Jurassic extension.
Late-Toarcian, restrictions of the exchanges of ammonitic faunas between the Arctic and the Tethysian provinces.
Intra Aalenian hiatus and regional unconformity, reflooding in the grabens during Aalenian-Bajocian times.
Basaltic magmatism pre- and post-dating the Aalenian event.
Mid-Late Jurassic rifting stage (160Ma-140-Ma)

The mid-North Sea mid- to late Jurassic is often associated with plume activity to explaine the doming pattern.

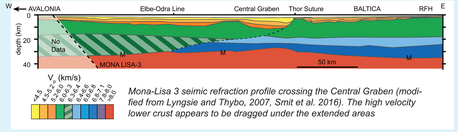
MATERIAL AND METHOD



Maps of the wells used in this study and projected on the A and B profiles (see below). (1) South Viking Graben, (2) Triple Junction, (3) Central Graben, (4) Elbow Spit Hihg, (5) Dutch Central Graben, (6) Horn Graben, (7) Glueckstadt Graben and Danish Basin, (8)Vlieland Basin, (9) West and Central Netherland Basin

DATA USED: 36 publications (reports, papers, thesises).
Amount of estimated erosion/denudation for the Jurassic based on Vitrinite reflectance, Burial Anomaly, AFTA, and seismic stratigraphy.
LIMITS: several phases of erosion (Jurassic and post late-Cretaceous Alpine phases), heat flux models, paleo-water depth models, and salt tectonics.

DISCUSSION

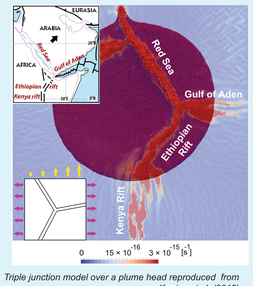


Mona-Lisa 3 seimic refraction profile crossing the Central Graben (modified from Lyngsie and Thybo, 2007, Smit et al. 2016). The high velocity lower crust appears to be dragged under the extended areas

- Strong lower crust anisotropy suggests localisation of mesozoic events along Paleozoic terranes boundaries.
- The amount of erosion is very poorly constraint.
- Timing of vertical motion ? Low-Mid-Jurassic regional uplift and more localized during Upper-Jurassic and Rift propagation.

- Flexural wavelength 200-250 Km suggests either:
- Extension-induced rift shoulder uplift rather than doming and low extension rates and/or strong faulted lithosphere (e.g. Olive et al. 2016, 2018) and low amount of extension.
- Reappraisal of rifting under far-field stresses compatible with the extension to the South (180-160Ma).

The mantle plume hypothesis and multi-directional extension



Triple junction model over a plume head reproduced from Koptev et al. (2018)

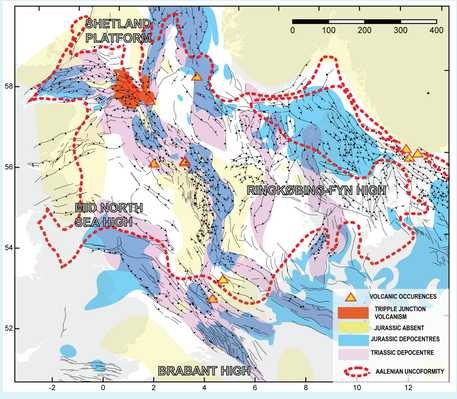
Multi-directional extension over a plume head produces rift initiation and continental lithopshere break-up.

There are strong similarities between the Afar and the North Sea Rift tripple junctions.
Yet, the North Sea Rift system failed.

Consequently, how and why the North Sea Rift system starts to propagate and finally failed remains poorly understood.

A future numerical modelling study will hopefully shed new light on the North Sea Rift System.

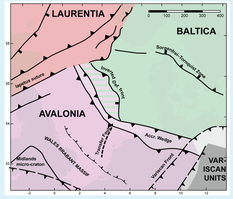
STRUCTURAL ELEMENTS, DEPOCENTRES AND VOLCANISM



Synthetic structural map of the North Sea from litterature compilation. The map shows the distribution of the Triassic and Jurassic depocenters in the triple-arm rift associated to Jurassic volcanism (Rattray volcanic Province, orange). Late-Jurassic volcanism is located on the south shoulder of the Central Graben. Orange area, Pentland Fm and volcanics from Quirie et al. (2018).
Aalenian unconformity redrawn from Japsen et al. (2007),Mesozoic data modified from Maystrenko et al. (2013a, 2013b, 2017), and Doornenbal, J.C. and Stevenson, A.G. (editors):SPBA, (2010). Structural elements based on a compilation from several authors.

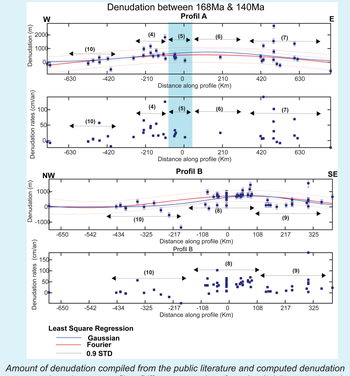
Synthetic map of the Mesozoic depocenters
Triple junction (continent-continent-continent) volcanism on the Caledonian suture.
Rattray volcanic province, formerly described as a basaltic volcanic province.

Jurassic is thin (<100m) or absent on the Central Graben shoulders.
Structural control on the extent of the Aalenian unconformity.



Map of the tectonic domains in the North Sea Area. The tripple junction Laurentia - Avalonia - Baltica is the result of the closure of the Iapetus Ocean around 480-440Ma.

MID-UPPER JURASSIC REGIONAL UPLIFT AND EROSION



Amount of denudation compiled from the public literature and computed denudation rates projected on two profiles. Different scenarios of erosion (minimum and maximum) exists for the several published burial histories. Major erosive phases in the North Sea are Mid-Jurassic and Upper-Cretaceous and Cenonozoic (Alpine phases).

Vertical motions in the North Sea
Erosion of Upper Triassic and Lower Jurassic unconsolidated sediments.
Maximum amount of erosion on the rift shoulder (<1400 m).
Progressive decay away from the shoulder.
Erosion favoured on the rift shoulders, max width <80 km
Flexural wavelength 220km.
In the South Central Graben:
Sharp variation of erosion suggests more localised deformations linked to oblique accomodation

Uplift by underplating ?

Assuming an elastic model (e.g. Watts, 2001), and instantaneous uplift. Underplated thickness U:

if Te = 5 Km --> U < 2.5 Km
if Te = 30km -->U < 14 Km

With E = 30e9, u = 0.5 , a density of 2.9 for underplated material, and a flexural wavelength of 220km.

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