Basement map for the NE Atlantic margin and mainland Norway reveals influence of ancient structures on the passive margin system

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Introduction

We present the top basement map for for the passive margin system of the Norwegian shelf and adjacent regions, covering the Northern North Sea, the Viking Graben, the mid-Norwegian margin system and the western Barents Sea. The top basement defines the transition between the sedimentary strata and the underlying basement, and is of major interest for the understanding of basin formation and margin evolution.

Methodology

Basement structures offshore are indirectly investigated through the combination of potential field data, seismic reflection and refraction profiles. The basement configuration is especially visible in the potential fields, and their interpretation helps to image and follow geological structures from surface to depth.

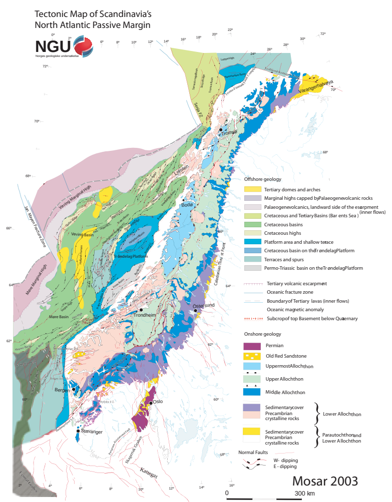
Magnetic depth estimates provide a good starting point for a genuine structural interpretation and have been used effectively on the mid-Norwegian margin, Barents Sea shelf, as well as over the Viking Graben and North Sea (see central panel for details on individual studies).

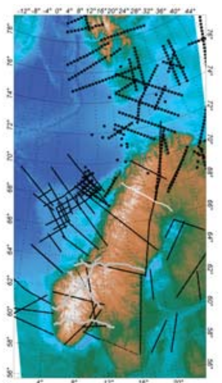
Susceptibilities of the basement can range between 0.005 and 0.035 SI while the susceptibilities of the overlying sediments are only in the order of 0.0003 SI, some one to two orders of magnitude lower. The range of susceptibilities for the basement is depending on composition and varies from 0.005-0.01 for Caledonian basement, 0.01-0.035 for Precambrian basement, to even higher values for mafic intruded basement Therefore, magnetic data are extremely useful to estimate the top basement.

Gravity data are useful to a limited extent in the top basement mapping as, due to sedimentary compaction, in depth >5 km the density contrast between sedimentary rocks and top basement becomes relatively small. Also on seismic data the top crystalline basement is often difficult to recognize. This is a result of a decrease in the contrast in acoustic impedance between sediments and basement at greater depths, as well as a decrease in the signal-to-noise ratio.

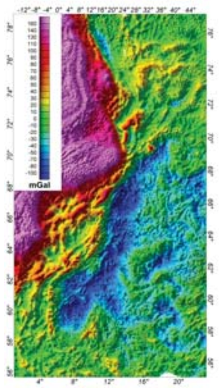
However, 3D modelling decreases the uncertainty as seismic, borehole and petrophysical data are integrated with forward and inverse modelling of the gravity and magnetic fields. Such models provide information on th ecomplete crustal structure and can be used to map the top basement and to distinguish between different basement units.

The amount of constraining data typically used in constructing the 3D models leads to an overall accuracy of the depth horizons within +/- 5% depending on the reliability of the regional seismic data. At the same time, the 3D models provide information about the base of the crust, which allows calculating the total thickness of the crystalline crust.

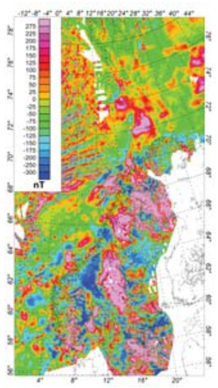




Regional seismic profiles
Gray/white lines indicate recent and ongoing experiments



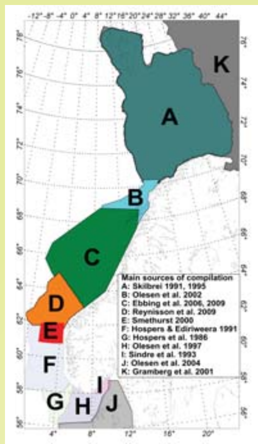
Bouguer anomaly



Magnetic anomaly

(see Poster Olesen et al. for more details and data sources)

Data sources for compilation



	Area	Source	Compilation type	Accuracy
A	Western Barents Sea	Skilbrei 1991, 1995	Magnetic depth	10-15%
B	Lofoten-Vesterålen	Olesen et al. 2002	3D Model	5-15 %
C	Vøring-Lofoten	Ebbing et al. 2006, 2009	3D Model	5-10 %
D	Møre	Reynisson et al. 2009	3D Model	5-10%
E	Viking Graben	Smethurst 2000	Magnetic depth	10-15 %
F	Northeastern North Sea	Hospers & Ediriweera 1991	Magnetic depth	15%
G	North Sea	Hospers et al. 1986	Magnetic depth	15%
H	Norwegian-Danish basin	Olesen et al. 1997	Magnetic depth, 2D modelling	10%
I	Skagerrak	Sindre et al. 1993	Magnetic depth	15%
J	Skagerrak/Kattegat	Olesen et al. 2004	Magnetic depth	>15%
K	Barents Sea	Gramberg et al. 2001	??	??

The table and figure above present the different compilations, which have been integrated into the new top basement map. Basically, two types of interpretation methods can be distinguished: 1) Magnetic depth estimates and 2) 3D Modelling.

1) Magnetic depth: these studies use different methods (e.g. Euler Deconvolution, Peter's slope method) to estimate the top of the magnetic basement. Selected seismic profiles, well data and gravity modelling along 2D profiles often constrain the interpretation. The resulting maps are interpolated (often handcontoured) between the magnetic depth estimates. Comparison of magnetic depth estimates and seismic, borehole, and petrophysical data yield errors that generally vary between 5 and 15%.

2) 3D Modelling utilizes stratigraphic horizons from 2D and 3D seismic surveys and compilations for the sedimentary succession, academic and, if available, industrial seismic profiles, well data and petrophysical information. Geometry, density and magnetic parameters of the model are evaluated against the observed gravity and magnetic anomalies. The errors of these compilations are in general less than for the magnetic depth estimates, and vary between 5 and 10 %.

Skilbrei & Olesen (2005) studied the accuracy and the geological meaning of the 'magnetic basement' on the mid-Norwegian margin. They found generally good agreement between estimates made from magnetic anomalies and the depth to the Precambrian basement. In some areas may exist non-magnetic Devonian basins, and low-magnetic Caledonian nappes can overly the Precambrian basement. In the latter case, the true crystalline basement would lie above the 'magnetic basement'.

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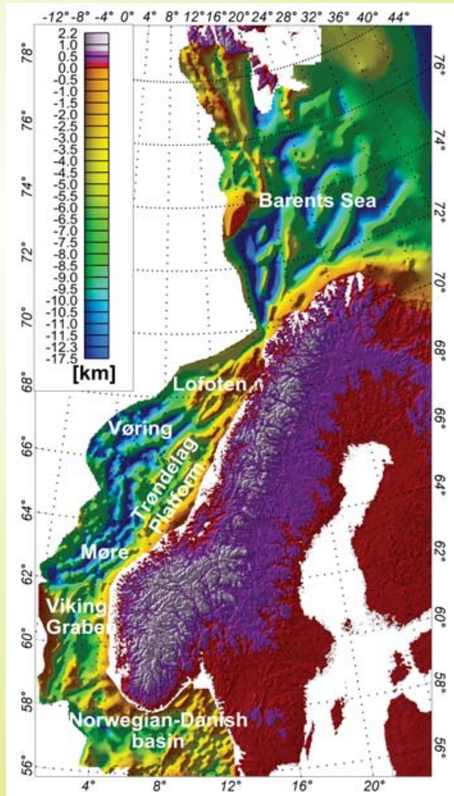
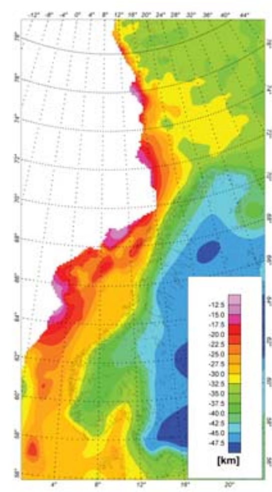
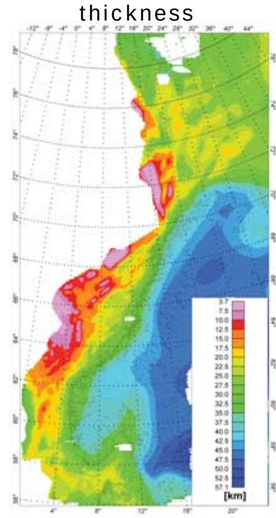
Top Basement Map of the NE Atlantic



Moho depth



Crystalline crustal thickness



The Moho depth is defined after Kinck et al. (1993) with modifications on the continental margin after Christiansson et al. (2000), Mjelde et al. (2005), Osmundsen and Ebbing (2008), Tsikalas et al. (2008), Olesen et al. (2002) and the recent Barents Sea compilation by Ritzmann et al. (2007).

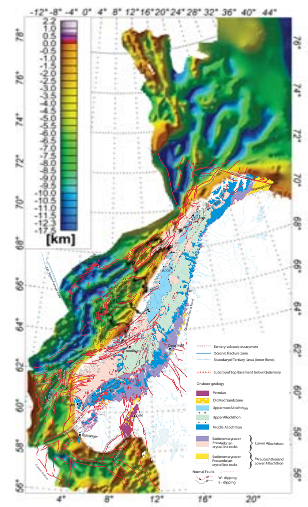
The crustal thickness map is defined as the difference between the top basement and the base of the crust. Our definition of the crustal thickness regards the entire crust as crystalline basement. Both low-magnetic Devonian basins and lower crustal body have been observed on the margin, which strictly are not part of the crystalline basement

In the Barents Sea the crustal thickness is typically larger than 20 km with local exceptions (e.g. Nordkapp basin). The same is true for the area south of the Hardangerfjord Shear Zone. On the mid-Norwegian margin, with the exception of the Trøndelag Platform, the crustal thickness is less than 20 km, and for most areas even less than 12.5 km. This enormous thinning of the crust reflects the multiple rift episodes of the margin, and indicates a direct link between the location of the margin segments and the opening history of the North Atlantic.

In the areas with extreme thinned crust on the Vøring and Møre margin, a high-velocity, high-density body at the base of the crust has been mapped. The thickness of this lower crustal body has been mapped to be more than 6 km, which would imply that that almost no crystalline crust exists below parts of the Vøring and Møre basins (see Poster by Reynisson et al. for further discussion).

Comparison to onshore geology

The main structural domains of the passive margin are separated by several major normal fault systems. These fault systems and related structural highs and half graben features are also reflected in the top basement map. The figure to the right shows the extension of the normal faults on the margin and their correlation with top basement structures. The entire margin segmentation is controlled by offshore extension of these low-angle faults and shear zones.



Of particular interest is the recognition of the structurally denuded basement culminations onshore Norway, and their bounding detachments. These major detachments formed during orogen-parallel extension, i.e. at a high angle to the orogenic front (Mosar 2003, Braathen 2000). Extrapolating the onshore structures to the offshore realm, it can be deduced that NE-SW trending (i.e. orogen-parallel) late Caledonian gravity collapse affected the entire mid-Norwegian margin.

Another important implication of our study is the thermal state of the margin. As shown in recent studies the thermal regime of the margin and onshore is largely controlled by the crustal configuration and the distribution of different basement domains and the geometry of the top basement. The top basement and crustal thickness map allows to estimate the influence of the deep crustal structure on the heat-flux into the sedimentary basins. Basement highs often are associated with pathways for fluid circulation, which can lead to an anomalous high heat flow.

Acknowledgements

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