The Gravity Potential Derivatives as a Means to Classify the Barents Sea Basin in the Context of Cratonic Basins

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Summary

Detailed study of the gravity field and the isostatic state of the Barents Sea Region shows that the Eastern Barents Sea basins are not typical rift basins. They exhibit distinctive features such as large wavelengths, high lithospheric mantle density, thick sequences of sediments, a flat Moho and high elastic thickness. These attributes are normally associated with cratonic or intracratonic basins. To understand the geological history of the Eastern Barents Sea basins, we make a comparison with other well studied cratonic basins: the West Siberian basin, the Michigan basin in North America, the Solimões, Amazon, Parnaìba and Paranà basins in South America, the Tarim basin in Central Asia and the Congo basin in Africa. For these basins, the structure, subsidence history and temperature evolution is relatively well known. Our analysis includes the characterization in terms of gravity, geoid undulations, isostatic state, age and igneous activity.

An important constraint in sedimentary basin evolution is the presence of the volcanism and the relative age of the volcanic strata with respect to the sedimentary package. In all the considered basins, except the Congo basin, volcanic masses are present at some time-stage and at some depth at the basin. Each of the basins exhibits some deviation from the classic isostatic equilibrium model that predicts the crustal thickness (thinning in this case) from the topographic and sedimentary load. Instead of crustal thinning, high density masses in the crust and mantle appear to be a typical feature. The basins may be divided into two groups, one in which the given basin correlates with the geoid, the second in which the geoid is independent. This discrimination points towards different density characteristics in the integrated crustal column.

Introduction

The Eastern and Western Barents Sea basins have been found to have very different characteristics. The most obvious is the wavelength of the basement: in the west exist a series of deep and narrow basins with a strong regional directionality, whereas the Eastern Barents Sea basins have a large elliptical shape (length 1400 km, width 550 km). Inversion of the gravity field and isostatic considerations led Ebbing et al. (2006, 2007) to conclude the underlying mantle was responsible for the different morphology. The Eastern basin is underlain by high density lower crust and high density upper mantle, a feature absent in the Western Barents Sea. It is therefore interesting to compare the Eastern Barents Sea basin to other large-scale basins, in order to understand whether the properties found in the Eastern Barents Sea are typical and necessary for its formation history. Of particular interest is that the Eastern Barents Sea apparently lacked faulting during its formation.

As the underlying mantle densities seem to exert important controls on the formation of the basins, the study of the gravity field, the potential and the gradient tensor, and the isostatic state is an essential means by which to classify them. We present a selection of representative basins that have been taken for comparison. These are the West Siberian basin, the Tarim basin, the Congo basin (Cuvette Centrale, Zaire), the Michigan and Illinois basins, and the Parana', Parnaiba and Amazon basins of Brazil. Bibliographic research on large scale basins indicates that these are associated with cratons either at the borders of the basins, or underlying the basins. However, due to the typical large thickness of the sediments (4 to 20 km) in some cases it is ambiguous whether the basin is underlain by a craton, or not. The study of the large scale basins is of general interest, as some have been found to be very productive (e.g. West Siberian, Tarim, Amazon basin) in contrast to others (e.g. Paraná).

Features common to each of the basins are a long history of subsidence (greater than 250 Ma), volcanic events at some stage during basin evolution, and their large dimension (> 0.4 10^{6} km^{2}). Here we have classified the basins in term of the gravity potential field and its derivatives with the aim of drawing conclusions on the density distribution at depth and its relation to the formation.

Methodology

Given the size and remote locations of the basins, the use of satellite derived fields is necessary. Thus we employ spherical coordinates in the analysis and for the calculations of the gravity potential field. We generally use the potential fields in the expansion in spherical harmonics. Only for the North-American basins do we use point-terrestrial data (source for latter: BGI).

We consider the geoid undulations reduced from the longest wavelength variations. We have systematically subtracted the geoid field up to degree and order 10 in the spherical harmonic expansion in order to obtain a field representative of crust and upper mantle structures. This reduction corresponds to subtracting the components of the field with wavelength greater than 2000 km at mid-latitudes. The terrain-corrected geoid is the analogue to the Bouguer gravity field, and has been reduced from the effect of topographic masses by direct calculation of prisms deduced from the digital terrain model (Forsberg, 1984). We reduce the gravity anomaly derived from the spherical harmonic expansion for the topographic masses using a height level chosen to be higher than the regional topography, obtaining the Bouguer anomaly (Shin et al., 2007***).***

The Bouguer anomaly represents mainly crustal sources and constitutes a blueprint for crustal thickness variations in younger tectonic areas. In the case of cratonic areas the base of the crust shows little variation, and the Bouguer anomaly features mainly the density variations in the crust or upper mantle. The isostatic gravity anomaly, here equivalent to the Airy isostatic anomaly, can be used to identify additional loads. A positive isostatic gravity anomaly indicates under-compensation, a negative isostatic anomaly corresponds to over-compensation, and an isostatic anomaly of zero indicates isostatic equilibrium. The isostatic calculations are made considering both surface and subsurface loads, the latter being constituted by the sediments and the volcanic high density material.

In Figure 1 the Bouguer gravity field for the Barents Sea is shown. It is seen to have little variation; nonetheless the Eastern Barents Sea basin is up to 20 km deep. The lack of the negative signal is due to the presence of high density material in lower crust and mantle. The crustal thickness has little variation, remaining rather flat at a value of over 40 km. The thick sedimentary basin is not isostatically balanced by crustal thinning.

In Figure 2. the Bouguer field for the Solimões-Amazon basin is shown. The Solimões- Amazon basin extends over a length of 2500 km and width of 500 km, over an area of more than 1.1 10^{6} km^{2}, with the sediments reaching the thickness of up to 5000 m (Milani and Thomaz Filho, 2000). The Bouguer anomaly map shows a chain of gravity highs of +40 mGal to +90 mGal that transects the basin roughly coincident with the maximum thickness of sedimentary rocks. The gravity highs are flanked by gravity lows of -40 ± 20 mGal. The relatively high values of the Bouguer field in correspondence to the basin point towards crustal thinning or densification of crust or upper mantle. Because sediments contribute to lower the Bouguer gravity signal, if no low is observed, there must be either Moho shallowing or else crustal densification to balance the negative signal produced by the sediments. As the crustal thickness has been estimated to be more than 42 km, the high density lower crust or upper mantle can be concluded.

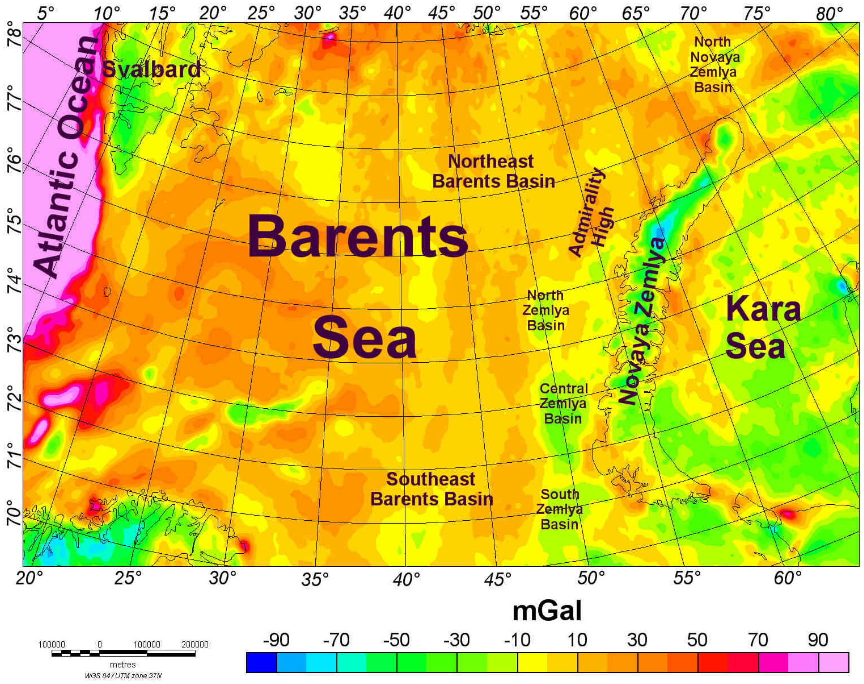

Figure 1. Bouguer anomaly map of the Barents Sea Region. The complete Bouguer reduction was calculated with a reference density of 2670 kg/m^3 for onshore and offshore regions. The ice cover on Novaya Zemlya has been removed applying a density of 921 kg/m^3 (Ebbing et al. 2006).

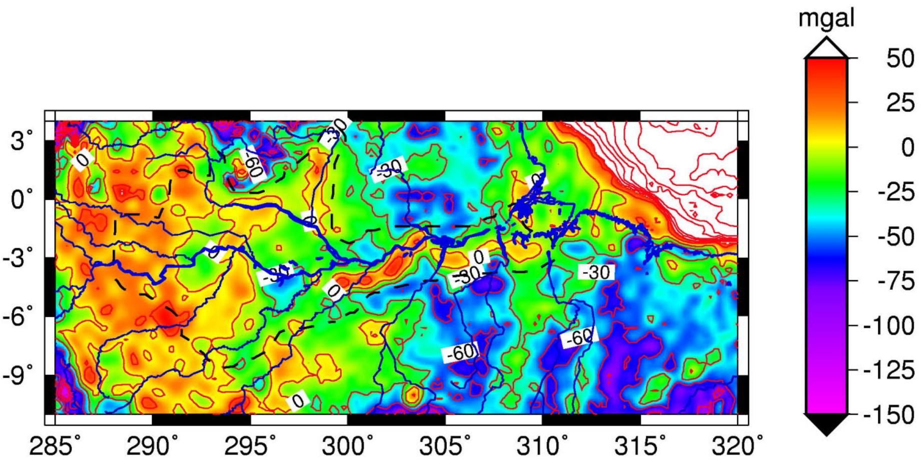

Figure 2. Bouguer anomaly (mGal) for the Solimões and Amazon basins. Data: EIGEN-GL04C (Förste et al., 2006). Coastline and major rivers in blue. Basin outline stippled..

Conclusions

The deviation from the classic isostatic equilibrium model that predicts the crustal thickness from the topographic and sedimentary load is a typical feature of the large-scale basins. Detailed models have been formulated for the Paranà, Michigan, Amazon and Congo basins, arriving at the common conclusion that inferred dense material in the lower crust or upper mantle contributes to the isostatic equilibrium, the crustal thickness remaining rather flat and with greater thickness (greater than 40 km) than the normal reference crust (35 km). High density masses in the crust and mantle are therefore a typical feature. The study of the gravity and geoid fields is thus an essential tool in understanding the structure of this type of basins.

Typical gravity anomaly values for the basins are between -30 and -50 mGal. A subset of basins of our grouping (Amazon, West Siberian Basin, Michigan and Illinois) presents a linear gravity high, which can reach +50 mGal. The attributed explanation to this signal is an extinct rift beneath the basins. The geoid undulations show greater variability, and in several cases are in good correlation with the basins. Among those studied, definite and pronounced residual geoid lows are found for the West Siberian, Amazon, Parana', Tarim and Congo basins. In the Parnaiba, Michigan and Illinois basins cases, the residual geoid reveals a variation at larger scale, but exhibits no evident correlation with the basin.

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