

PS Satellite Gravity and Geoid Studies Reveal the Formations Underlying Large-Scale Basin Structures

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Abstract

We compare results from studies of the global large-scale basins. Such large-scale basins are often referred to as cratonic or intracratonic basins. Detailed study of satellite derived gravity anomalies, geoid undulations and the isostatic state of large-scale basin structures shows that these basins show a series of distinctive features: the basins show in general the presence of volcanic material and a thick sedimentary succession, even with large variations in absolute thickness and areal extent. Most striking, however, is that for the majority of the basins we find evidence for high-density material in the lower crust and/or upper mantle. These high-density structures compensate at least partly for the low-density sedimentary infill, while crustal thickness variations and Moho topography cannot be considered solely as mechanisms of compensation of the sedimentary loading. This is in clear contrast to rift-type basins, and formation of large-scale basins is apparently inked to large-scale lithospheric processes. The global comparison allows us also to test mechanism models, which might be valid for less well known basins; e.g., the Congo basin.



Satellite gravity and geoid studies reveal the formations underlying large-scale basin structures

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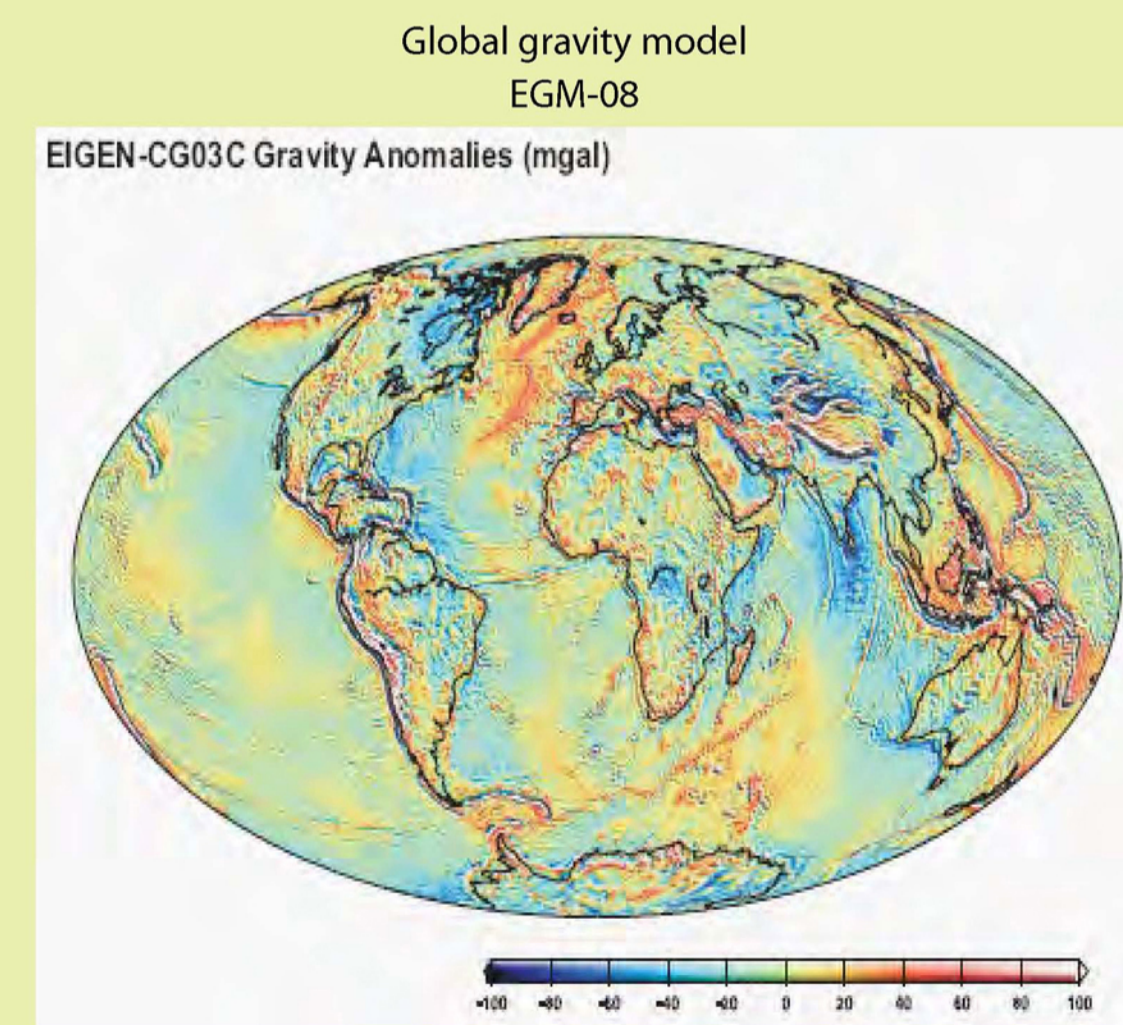
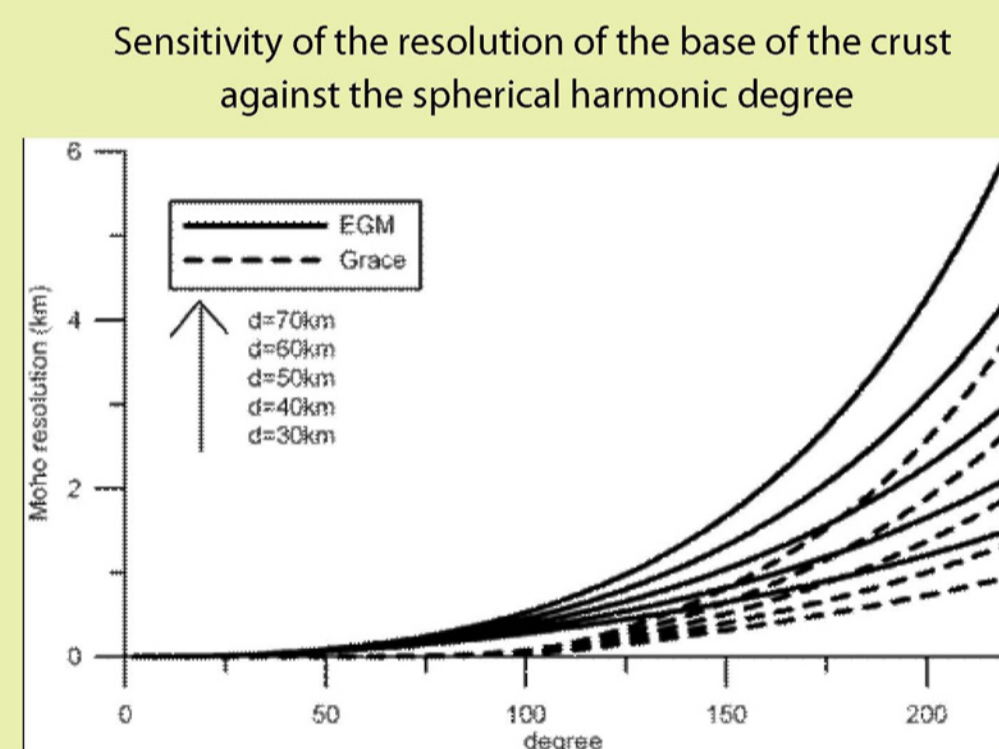
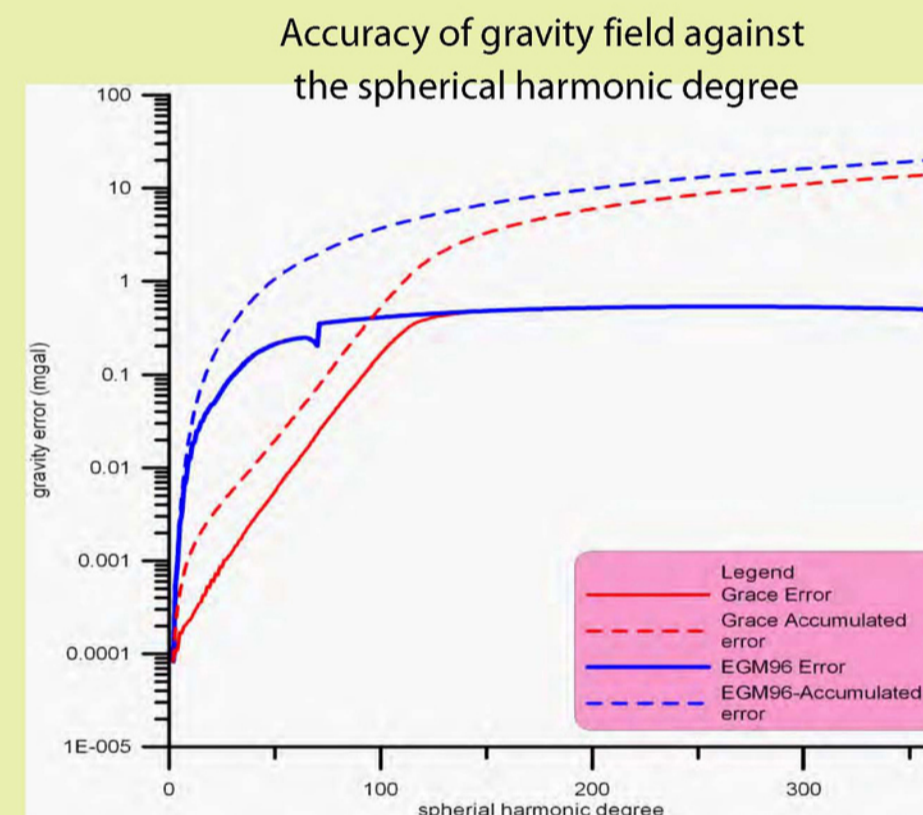
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Introduction

We compare the potential field signatures from studies of global large-scale basins. Such large-scale basins are often referred to as cratonic or intracratonic basins. Detailed study of satellite derived gravity anomalies, geoid undulations and the isostatic state of large-scale basin structures shows that these basins show a series of distinctive features: the basins show in general the presence of volcanic material and a thick sedimentary succession, even with large variations in absolute thickness and areal extent. Most striking, however, is that for the majority of the basins we find evidence for high-density material in the lower crust and/or upper mantle. These high-density structures compensate at least partly for the low-density sedimentary infill, while crustal thickness variations and Moho topography cannot be considered solely as mechanisms of compensation of the sedimentary loading. This is in clear contrast to rift-type basins, and formation of large-scale basins is apparently linked to large-scale lithospheric processes. The global comparison allows us also to test mechanism models, which might be valid for less well known basins; as e.g., the Congo basin.

Satellite data and Earth gravity models

New data acquired by the GRACE and recently launched GOCE satellite gravity mission greatly improved accuracy and spatial resolution of the determination of the global earth gravity field (e.g., Tapley et al., 2004; Förste et al., 2006). Models of the Earth gravity field (e.g., EIGEN-GL04C, EGM08) combine these satellite data with terrestrial data sets and enable global studies of the gravity and geoid field over geologically interesting features. Cratonic or intracratonic basins, or in general the basins termed as "large scale basins," are a perfect example of geological structures that can be studied on a global basis with the GRACE field, as their size is $0.5 \times 10^6 \text{ km}^2$ and greater.



Earth gravity models

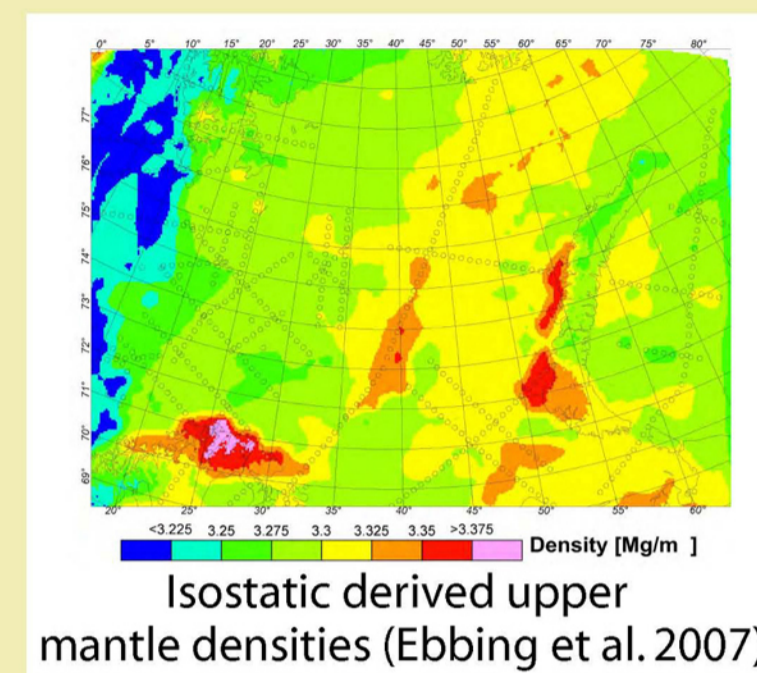
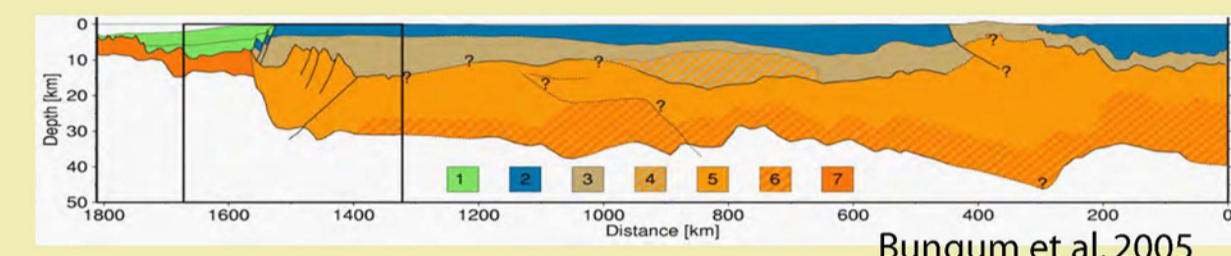
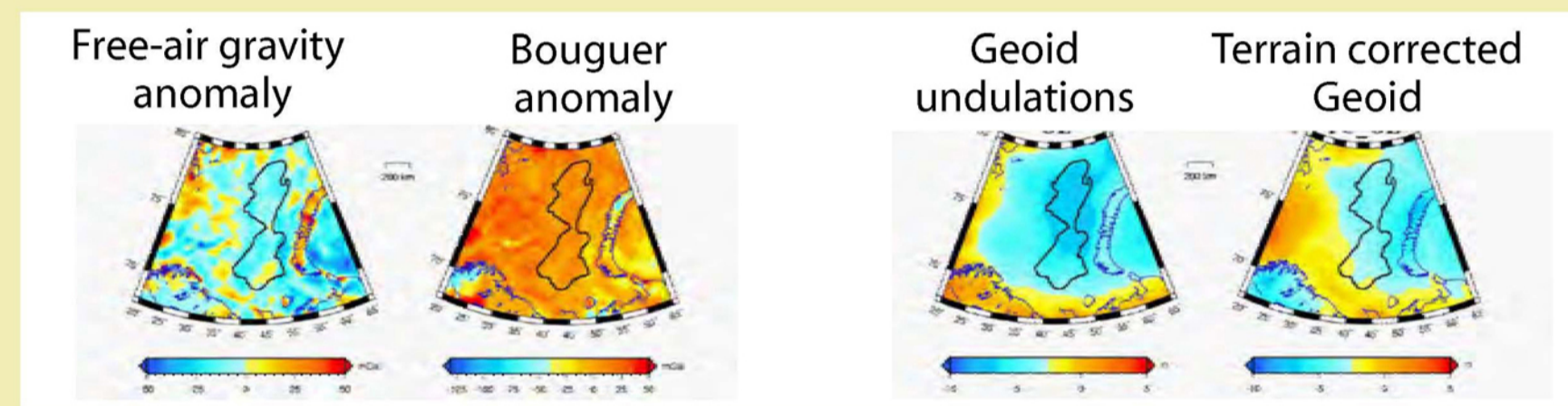
EIGEN-GL04C
GFZ-Potsdam (Förste et al., 2006)
Up to degree and order 120: satellite only
Up to degree and order 360: integration with terrestrial data

EGM-08
NGA, Geodesy and Geophysics Basic and Applied Research (Pavlis et al. 2008)
Complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159.

Barents Sea

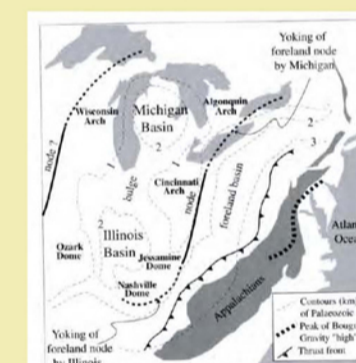
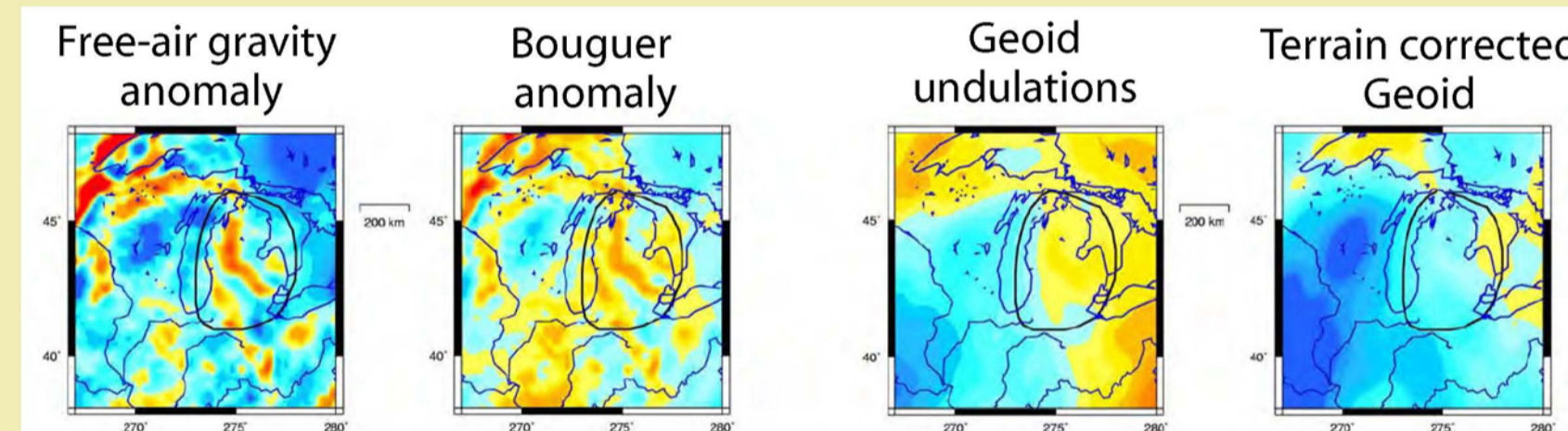
The Eastern Barents Sea basins have a characteristic basin thickness of up to 20 km, and an areal extent of $0.4 \times 10^6 \text{ km}^2$, including the Northern and Southern Eastern Barents Sea basins. In some studies the Eastern Barents Sea is regarded as a single mega-scale basin. However, the gravity anomaly shows no pronounced anomaly related to basins, while the geoid indicates mass deficit in deep crust or mantle. The crustal section shows that the crust is thickening below the areas with largest basin thickness. Isostatic tests point to additional mass in the upper mantle below the Eastern Barents Sea basin (Ebbing et al. 2007).

For more details see also Poster: Insights into Basin Formation and Lithospheric Structure of the Barents Sea.



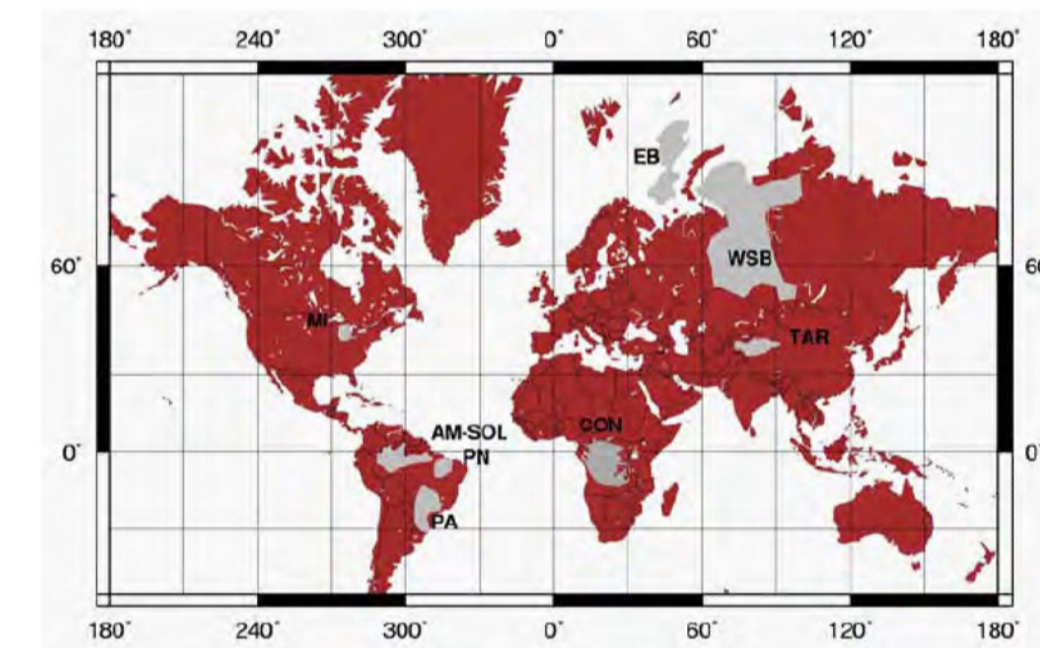
Michigan Basin

The Michigan basin is often regarded as a prototype large-scale basin and has been relatively well studied (e.g., Watts, 2001). The sediments range in age from Middle Ordovician (462 Ma) to Jurassic (136 Ma) with a diameter of about 700 km and a depth of up to 4 km. The basin is supposed to be underlain by a volcanic sequence of 8-km thickness, filling a rift basin about 70 km wide. Gravity anomalies indicate old rift structure below the basin: Late subsidence effect of thermal cooling?



Watts 2001

Selected large-scale basins



Selection of large scale basins: West Siberian basin (WSB), East Barents Sea basins (EB), Tarim basin (TAR), Congo basin (CON), Michigan basin (MI), Solimões-Amazons basin (AM-SOL), Parnaíba basin (PN), Paraná basin (PA).

Table below gives areal extent and maximum thickness, showing large variations in the basin dimensions.

Basin	Aerial extension [10 ⁶ km ²]	Maximum sediment thickness [km]
Eastern Barents Sea Basins	0.4	20
Michigan	0.3	4
Parnaíba Prov.	0.6	3.5
Paraná Basin	1.2	7
Amazon Basin and Solimões Basin	1.1	5
Congo Basin	1.8	9
Tarim Basin	0.8	15
West Siberian Basin	3.2	8

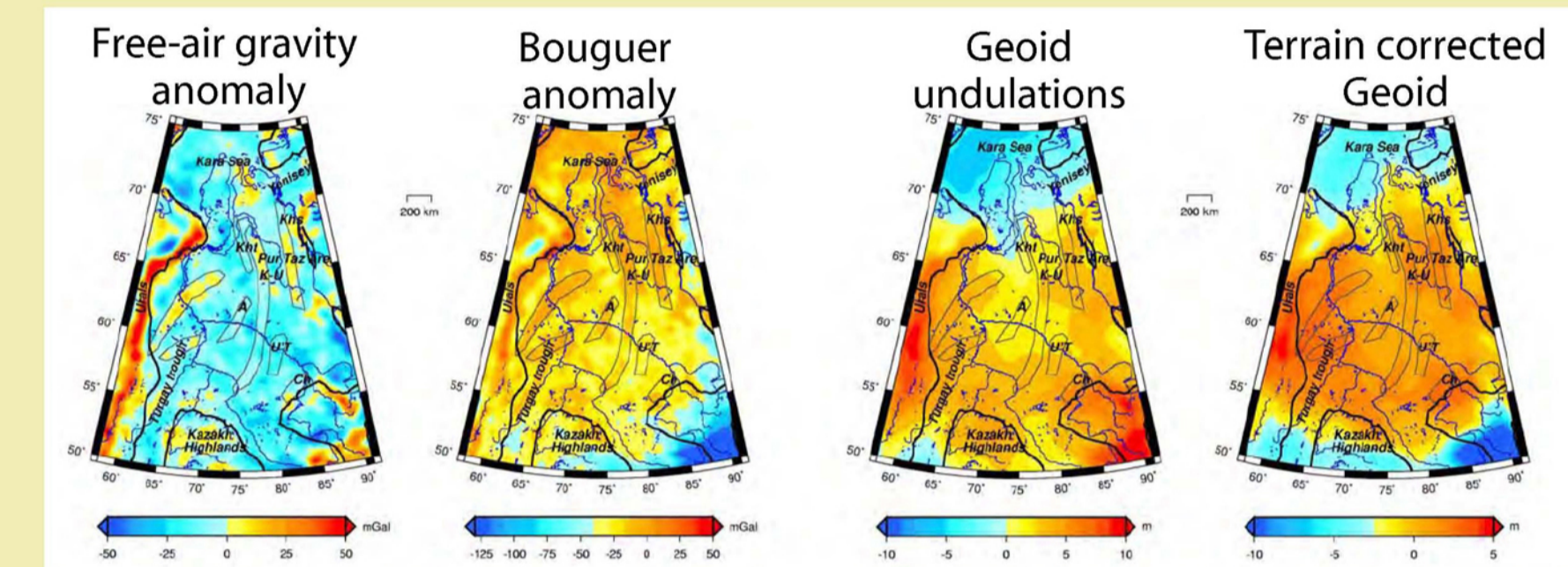
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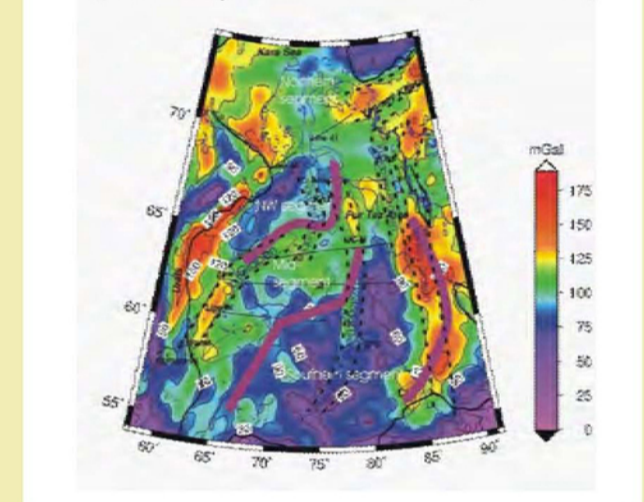
The West Siberian Basin

The West Siberian Basin is one of the largest intracratonic basins of the world with an areal extent of approximately $3.2 \times 10^6 \text{ km}^2$. Crustal thickness varies between 36 and 42 km, with a thickness of 40 km in the central part, flanked by lower values (38 km), but no correlation to the thickness of the sedimentary deposits, which has a maximum of 8 km. Gravity anomalies give indication of extinct rift structures below the basin, while the geoid does not show a distinctive pattern. Using available information about sedimentary thickness, an isostatic anomaly can be calculated, on which the extinct rifts are even more visible.

Below potential field and names of rift structures (Pavlov, 1995): KU: Koltogory-Urengoi; Khs: Khudosei; Kht: Khudottei; A: Agan; U'T: Ust'

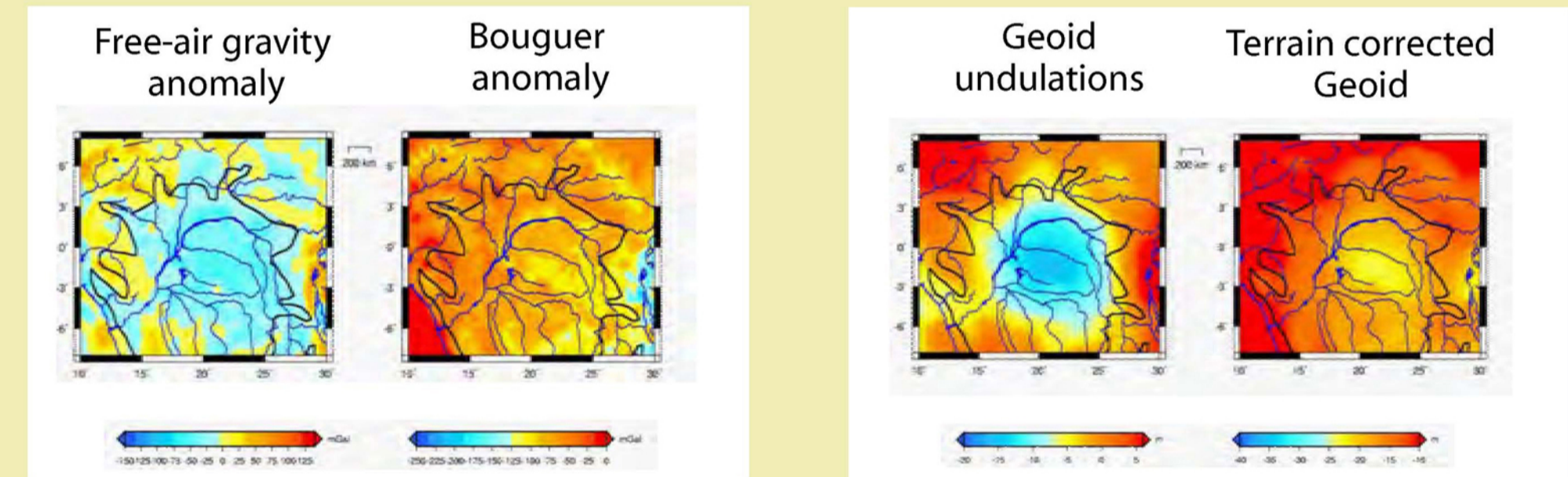


Isostatic gravity anomaly and proposed rift structures (violet; after Pavlov, 1995)



Congo Basin

The Congo basin, also termed Zaire or Cuvette Zaire, is nearly circular in shape with a diameter of about 1500 km and an area of about $1.8 \times 10^6 \text{ km}^2$. The basin itself is filled with up to 9 km of intra-Cambrian to recent sediments. Pronounced geoid low below the basin indicates mass deficit in the mantle (deep lithosphere or below). Dynamic mantle processes are often considered as the cause of the subsidence.



Conclusions

Satellite gravity and geoid are ideal to study large-scale basins:
- Gravity anomalies can reveal extinct rift zones
- Geoid reveals deep lithospheric component

At least two classes of intracratonic basins can be found:

A) e.g., Michigan basin, West Siberian basin
Gravity anomaly reflects extinct rift
Geoid is non-conclusive

B) e.g., E Barents Sea basins, Parnaíba basin, Congo basin
Gravity anomalies do not reflect rift zones
Geoid gives evidence for large-scale lithospheric component

A third class contains the basins not fitting to these characteristics: Paraná basin, Tarim basin

=> A common, global mechanism for the evolution of intracratonic basins is unlikely