IMAGING THE UPPER CRUST USING DECOMPENSATIVE ISOSTATIC GRAVITY ANOMALY (CASE-STUDY ON THE ARABIAN SHIELD AND COVER ROCK)

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Summary

The isostatic residual map better images short wavelength structures within the upper crust that are of interest in this study. However, the continued presence of long wavelength anomalies in the isostatic residual map indicates that the region containing the study area is either not in isostatic equilibrium or assumptions used in the determination of the isostatic correction are not entirely valid (e.g. the crust is not responding in an Airy manner with effect elastic thickness Te=0) or there are density variations in the upper mantle. The long wavelength anomalies seen in the isostatic residual map are negative anomaly to the southeast of the Cover Rocks and positive anomaly to the north and northeast of the Cover Rocks. To effectively eliminate the dominating effect of these anomalies, the isostatic residual anomaly map has been further corrected by the Decompensative correction. Decompensative anomalies are considered to be produced in the main by density inhomogeneities in the upper 15-20 km of the crust. The Isostatic correction has eliminated the gravity compensating effect of topography but other long wavelength gravity effects due to features not accounted for in the Airy model remain.

The decompensative correction attempts to remove the anomalies associated with sources deeper than the crust. These gravity effects are isolated by upward continuation. Therefore, the isostatic residual anomaly has been upward continued to 40 km so that the resulting field due to sources at or deeper than 40 km can be estimated. The resultant decompensative anomalies can be assumed to be produced mainly by density inhomogeneities in the upper 15-20 km of the crust. Therefore the resultant decompensative map closely correlates with the major geological structures in the Arabian Shield and Cover Rock.

Introduction

The Arabian Shield extends the length of the eastern coastline of the Red Sea being at its widest in the central part of Arabia. The morphology of Saudi Arabia reveals that the Arabian Shield forms the highest part of Saudi Arabia and is also the most rugged. The areas outside the Shield are generally characterized by rather soft geomorphological features. The sudden drop in elevation and the development of steep cliffs along the eastern coast of the Red Sea is characteristic throughout the exposures of the Precambrian rocks but specifically in the central part. The geomorphic development of Saudi Arabia was greatly influenced by the Red Sea tectonism. During the Late Oligocene and Early Miocene, a thermal uplift influenced the whole of the western part of the Arabian Plate resulting in an easterly dipping of the land surface. The Phanerozoic cover above the Precambrian Shield complex increases towards the east where it reaches over 10 km in the eastern part of Saudi Arabia. The subsurface geology of the Arabian Shield and Cover Rock can be investigated by mapping the variations in Earth’s gravity field caused by lateral density changes in subsurface geology. To investigate the subsurface geological structures of the Arabian Shield and Cover Rock, all existing gravity surveys (Figure 1) were reprocessed and integrated to create Bouguer, isostatic and decompensative maps. All gravity data mentioned above and their accompanying geodetic co-ordinates were converted to a common set of parameters. Latitudes and Longitudes reduced to common geodetic reference system “Ain el Abd 1970”. Gravity formula used is the 1967 Geodetic Reference System Formula (GRS67). The reduction density used for Bouguer anomalies is 2.67 grams per cubic centimeter. Terrain corrections were not applied for the regional gravity surveys.

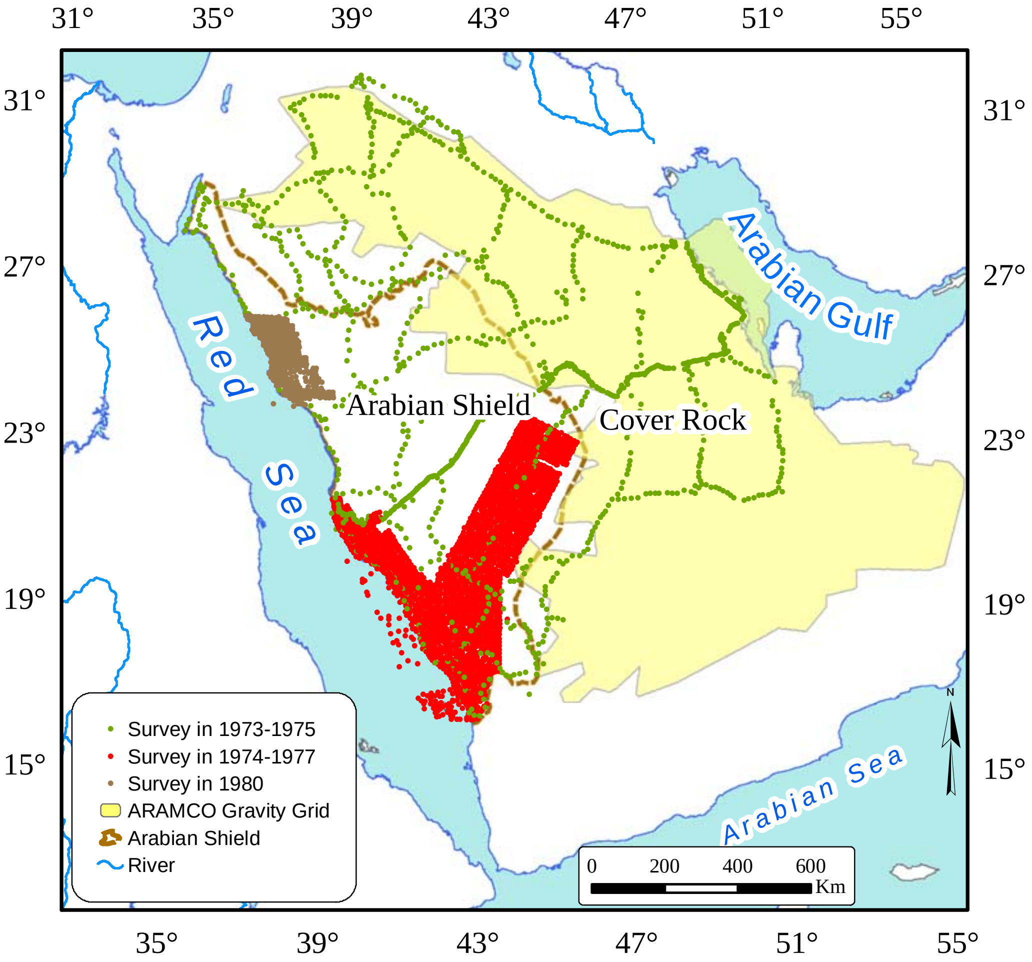


Figure 1 Available gravity surveys in Arabian Shield and Cover Rocks.

Isostatic Residual Anomaly

The Bouguer anomaly map images anomalies that result from the whole crustal section including variations in the Moho and lateral densities in the upper mantle. The long wavelength gradients could result from variations in Moho thickness and tend to obscure the upper crustal structures that are related to the study area. These long wavelength Bouguer anomalies can be estimated in the form of the Isostatic correction and removed from the Bouguer anomalies (Watts, 2001).

Isostatic Residual Anomaly = Bouguer Anomaly-Isostatic Correction

The Isostatic correction accounts for assumed variations in the depth of the Moho. For much of Saudi Arabia, one can assume a simple system of isostatic equilibrium is operating. This assumption implies a simple relation between topographic relief and the Moho depth.

The Airy-Heiskanen model of isostacy has been used in this study to derive the Isostatic correction. The Airy-Heiskanen model assumes a fixed density for the crust and varying depth of the Moho to compensate for the mass of the topography. The gravitational attraction of the Moho was determined from the 30 arc-seconds topography data, Calculation of the isostatic correction field was performed using the grid based Fast Fourier Transform using 2.67 g/cm^{-3} and 3.3 g/cm^{-3} densities for the crust and mantle respectively. A mean thickness of 40 km was used, which is the mean thickness of the crust in Saudi Arabia (Al-Amri, 1999; Badri, 1991).

The isostatic residual map better images short wavelength structures within the upper crust that are of interest in this study. However, the continued presence of long wavelength anomalies in the isostatic residual map (Figure 2a) indicates that the region containing the study area is either not in isostatic equilibrium or assumptions used in the determination of the isostatic correction are not entirely valid (e.g. the crust is not responding in an Airy manner with effect elastic thickness Te=0) or there are density variations in the upper mantle. The long wavelength anomalies seen in the isostatic residual map (Figure 2a) are negative anomaly to the southeast of the Cover Rocks and positive anomaly to the north and northeast of the Cover Rocks. To effectively eliminate the dominating effect of these anomalies, the isostatic residual anomaly map has been further corrected by the Decompensative correction.

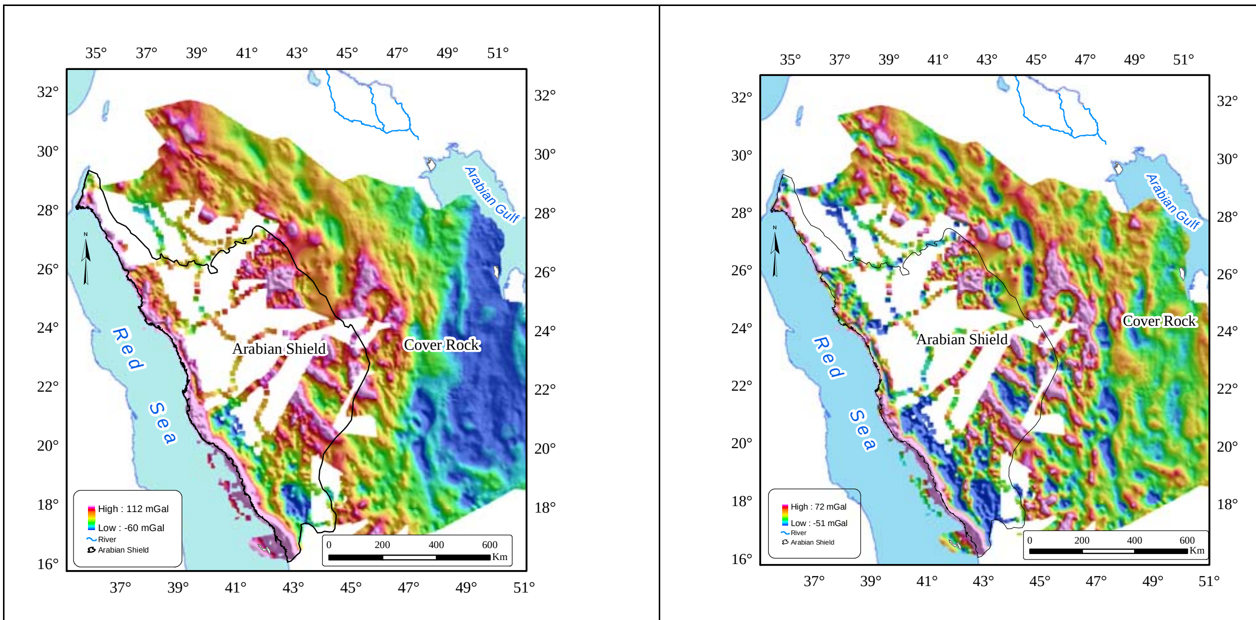
Decompensative Isostatic Residual Anomaly

Decompensative anomalies are considered to be produced in the main by density inhomogeneities in the upper 15-20 km of the crust (Cordell et al., 1991). The Isostatic correction has eliminated the gravity compensating effect of topography but other long wavelength gravity effects due to features not accounted for in the Airy model remain.
Lockwood (2004) has discussed the concept of bottom loading of Forsyth (1985) and suggests that variations in the depth to the base of the crust could be caused by processes originating in the mantle and that some of the topography of the crust could be in part the response of a load applied at the base of the crust.

The decompensative correction attempts to remove the anomalies associated with sources deeper than the crust. These gravity effects are isolated by upward continuation. Therefore, the isostatic residual anomaly has been upward continued to 40 km so that the resulting field due to sources at or deeper than 40 km can be estimated. The decompensative gravity anomaly field Figure 2b was determined by subtracting the upward continued field from the isostatic residual anomalies.

Lockwood (2004) argued that the results of separation filtering process by upward continuation of the potential field should be interpreted qualitatively rather than quantitatively due to the fact that it is impossible to guarantee that the upward continued field contains only signals from the deeper sources (i.e. broad upper crustal anomalies will be seen in the 40 km upward continued field).

The resultant decompensative anomalies (Figure 2b) can be assumed to be produced mainly by density inhomogeneities in the upper 15-20 km of the crust. Thus Figure 2b should closely correlate with the major geological structures in the study area.



(a) (b)

Figure 2a isostatic gravity anomalies, (b) Decompensative gravity anomalies map showing more geological structures from the upper crust.

Conclusions

The isostatic residual anomaly attempts to isolate the gravitational effects of the geology contained within the upper crust. It is often calculated using a simple ‘Airy’ model of isostasy that assumes a zero crustal strength, constant density crust and mantle and a simple relationship between topographic height and Moho depth. Although the corrections for the variations in Moho depth work well when the other assumptions are valid, it often fails, although is it not necessarily obvious where. The decompensative anomaly is the difference between the isostatic residual anomaly and its upward continued field at 40 km. The decompensative anomaly thus images all anomalies with wavelengths less than about 70 km while the upward continued field identifies the spatial set of anomalies greater than 70 km where the isostatic assumptions **may be invalid.** Please note the words **may be invalid** since it is possible to have upper crustal geological features that generate wavelengths in excess of 70 km. These anomaly types can thus help in the analysis of the spatial changes seen in the surface geology.

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