Gravimetry and petrophysics of the Chad basin area: determining the depth of the basement

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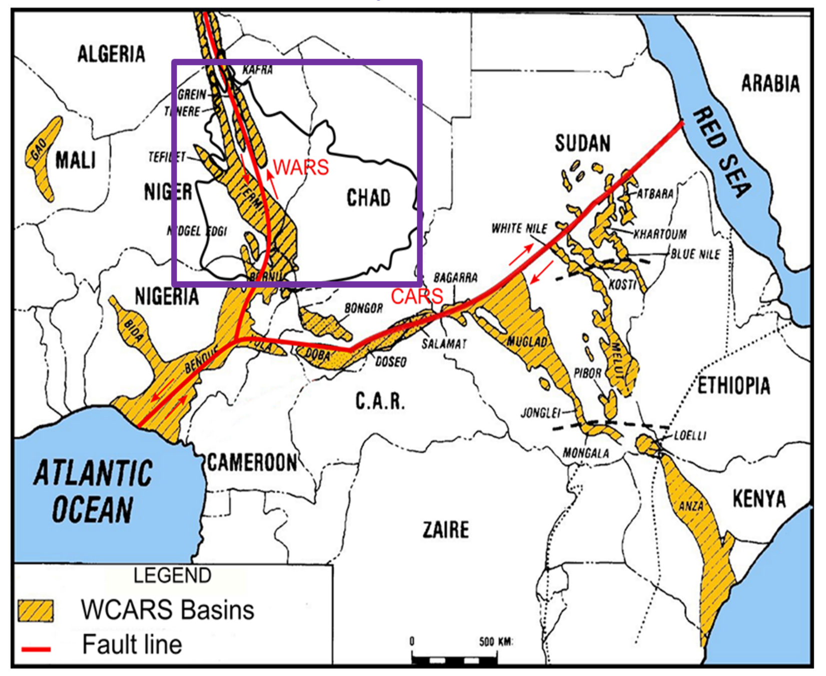
1. STUDY AREA and STATE OF THE ART

The Chad basin (CB) is a huge intracratonic sag-basin (2.5 million km^2) located in the North Central Africa. It covers 8% of the continent surface straddling Algeria, Cameroon, Central African Republic, Republic of Chad, Nigeria and Sudan. Inside the CB, Lake Chad was considered as the fourth largest permanent fresh water reservoir of Africa. It is a fresh water remnant of the Holocene Lake Mega-Chad (age 10.000-5.000 yr) with an extension similar to the Caspian sea (Schuster et al.,2009).

The Chad basin is located over an old intra-continental rift system. It lies in the middle of a vast area also known as "Pan-African mobile zone" and exhibits a platform in a tectonic setting related to rifting. Infact this basin was essentially formed during the extensional tectonic in the Cretaceous period due to the Gondwana breakup, in particular, the West and Central African Rift System (WARS and CARS). The evidences of the CARS are shown by the presence of extensional and transtensional structures along the Bongor and Doba basins in the southern areas. The evidences of the WARS are shown by Kafra, Grein, Tenere, Tefidet, Termit and Bornu pull-apart basins in the western sides (Genik, 1993).

The paleotectonic evolution of WCARS around 126 Ma. In yellow the continental sediment and in red the Chad basin boundaries in an approximated position. The black line means major fault and the arrows means the direction of tectonic movements. The dashed lines represents uncertain rift movements. *Image modified from Genik, 1993.*



References
(1) Schuster, M., Duringer, P., Ghienne, J.-F., Roquin, C., Sepulchre, P., Moussa, A., Lebatard, A.-E., Mackaye, H. T., Likius, A., Vignaud, P., et al. (2009). "Chad Basin: paleoenvironments of the Sahara since the Late Miocene". Comptes Rendus Geoscience 341.8, pp. 603–611.
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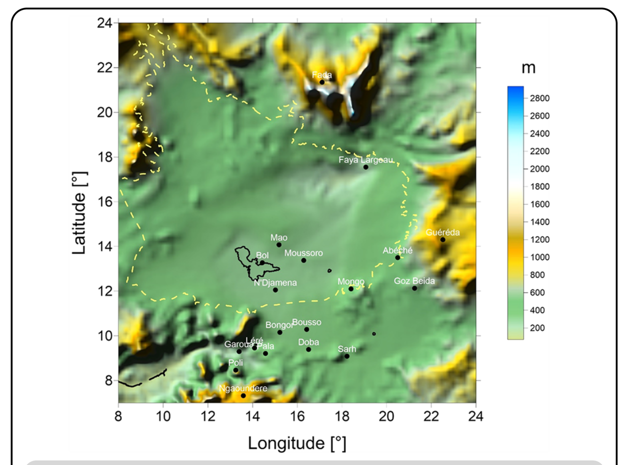
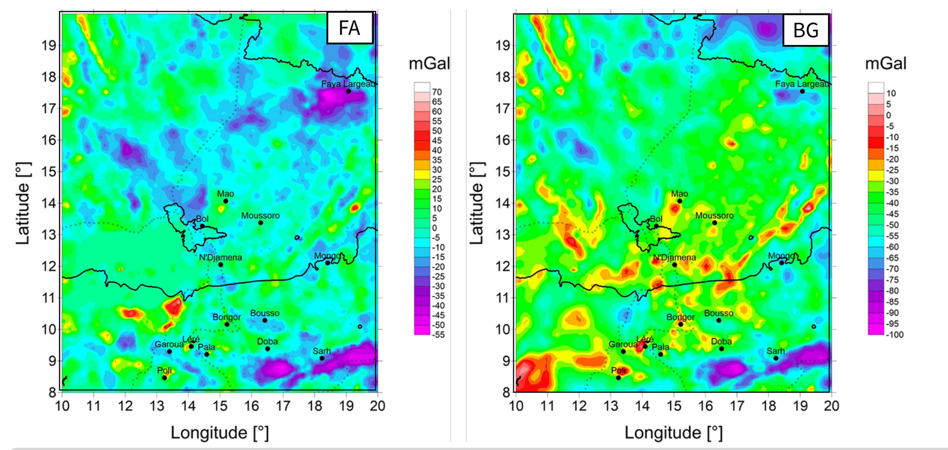
(3) Louis P. (1970). Contribution gèophisique à la connaissance géologique du bassin du lac Tchad. Orstom
(4) Yuanyuan Li, Carla Braitenberg, Yushan Yang (2013). Interpretation of gravity data by the continous wavelet transform: the caseof Chad lineament (North

The geophysical surveys over the Chad basin area started since the 1959 but only in 1970, significant geophysical results were produced thanks to the work of P. Louis titled: "Contribution géophysique a la connaissance geologique du basin du Lac Tchad" by P. Louis (1970), where all the geological and geophysical information on the Chad basin were collected. After, in 1992, G.J Genik gives us an overview on petroleum geology of rift basins in Niger, Chad and Central African Republic based on the exploration work by Exxon (1969-1991) which included 50.000 km of reflection seismic profiles and 53 exploration wells (Genik, 1993). then, Y. Li and C.Braitenberg (2014) conducted sudies on gravity anomaly field obtained by GOCE satellite in the continental areas of West-Central Africa. In this study, a geological information on a continental scale for the large areas was revealed. It has been possible after the isolation of the near surface geological signal from the contributions of thickness variation between crust, lithosphere and the isostatic compensation of surface relief. Regression analysis between gravity and topography shows coefficents that are consistently positive for the free gravity anomaly and negative for the Bouguer gravity anomaly.

2. GRAVITY INPUT

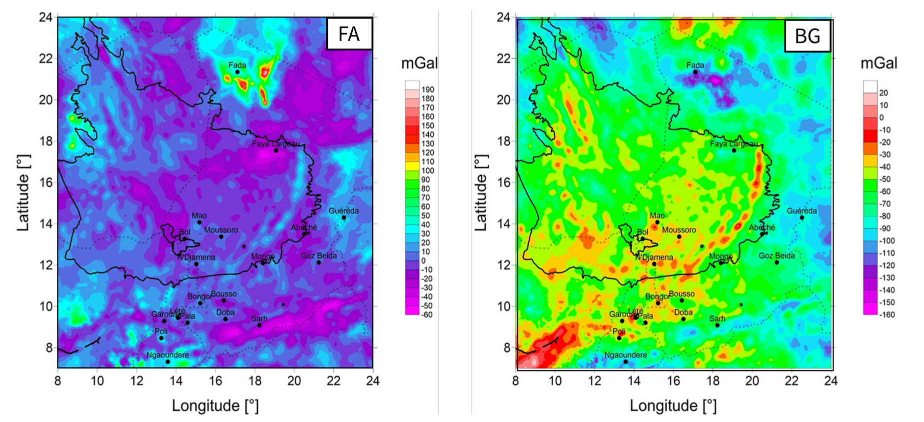


Topography. The Etopo1 model (2008). Gridstep: 0.1°, Max Degree: 2250. The map shows how the Chad basin is a flat zone, especially in the central regions.



The **terrestrial gravity data** used come from the **BGI.**
The free-air anomaly (left image) and **the Bouguer anomaly (right image)** maps confirm the evidences of positive and negative gravity anomalies seen in GOCE's data

Eigen-6c4

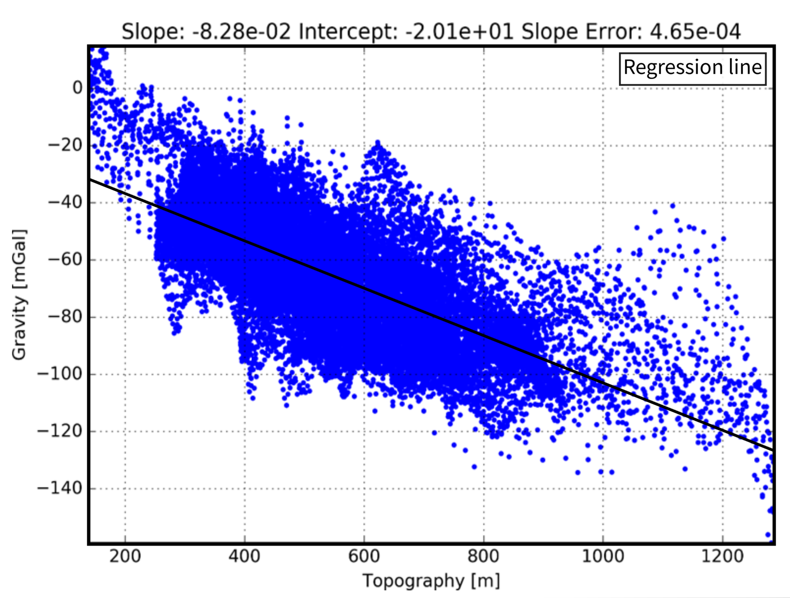


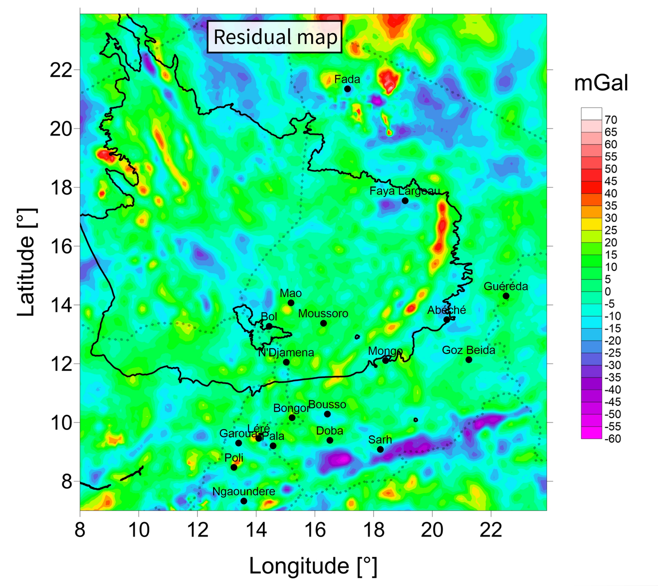
Global gravity models. Eigen-6c4 is the latest release of the Eigen-6c-series, containing the complete data of the GOCE mission and combined with of LAGEOS, GRACE and DTM data. The gridstep is 0.1° and the maximum degree is 2190. **The free-air anomaly field (left image)** changes from -60 mGal to 190 mGal. **The Bouguer anomaly (right image)** values change from -160 mGal to 20 mGal. The central region of the basin is essentially negative, with values around -60 mGal.

Input data:
- spherical harmonic models: ICGEM (International Centre International Centre for Global Earth Models).
- scattered data points: BGI (Bureau Gravimétric International).

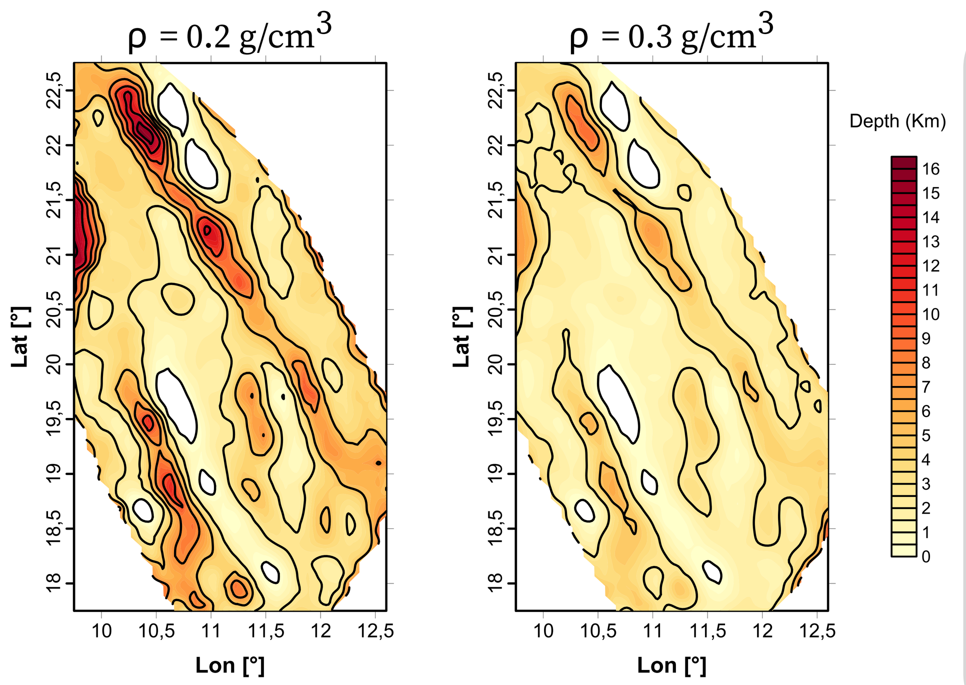
In a first analysis, the gravity anomaly field maps show lower and higher values that are connected to geological features identified by the references and the seismic reflection surveys

3. PROCESSING





Topography-Gravity Regression analysis. This method is based on the linear relation between Bouguer gravity field and the topography used to separate the gravity isostatic effect from superficial heterogeneities (**left image**). For low topography (< 1000 m) there is an inverse proportion between the Bouguer gravity anomalies and the topography due to the isostatic compensation. For higher topography, the correlation is loose. We consider that the highest topography is in the mountains, as the Tibesti, which indicates that the topographic elevations have higher density. The blue dots represent the residual gravity values. The main result of the regression analysis is the production of residual map (**right image**) where the gravity signal induced by the crustal density variations producted by the tectonic features after the removal of the effect of topography and isostatic crustal thickening. In the northwestern edge of the basin there is a pattern of positive anomalies (40 mGal) trending NW-SE.

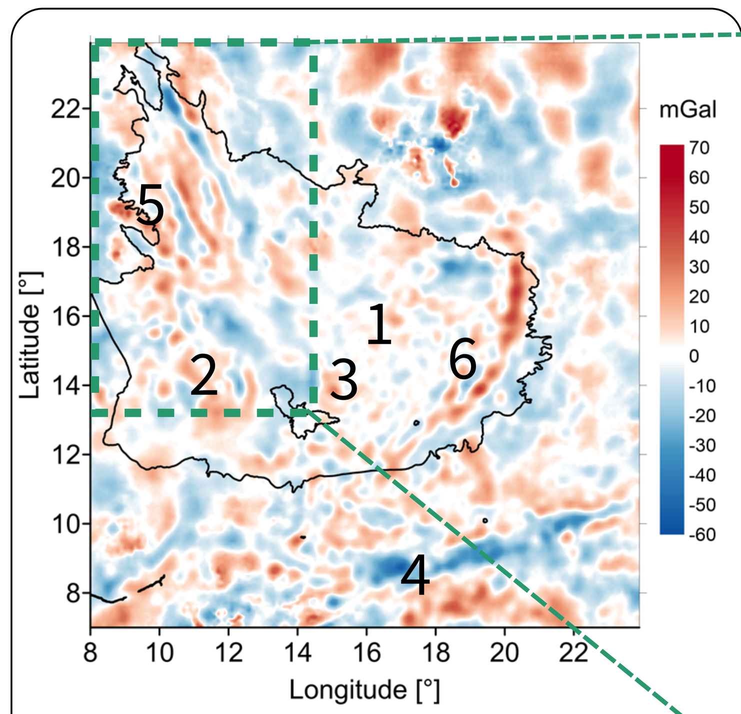


Inversion modelling on gravity residual values in order to estimate the basement depth under the WCARS basins. For the inversion models different range values of density contrasts were used, which were also considered as the most important geological constraint applied in this study case. The information about the lithologies come from: (1) la carte géologique de la République de Tchad, 1:500.000 (1964, BRGM); (2) well logs/ borehole (Genik, 1993). The crystalline basement lithologies are essentially: Gneiss (2.6-2.9 g/cm^3), Pegmatites (2.6 g/cm^3), Hornfels (2.6-2.8 g/cm^3), Granites (2.65 g/cm^3), Quartzite (2,54 g/ cm3), Micashists (2.8-2.9 g/cm^3) and Phillites (2.4 g/cm^3). The sedimentary facies are mainly clastics: Marine/Continental sandstones (2.5-2.7 g/cm^3), shales (2.2-2.3 g/cm^3) with some volcanites intrusions. In the figures two maps of the inversion models using density contrasts at 0.2 g/cm^3 (**left image**) and 0.3 g/cm^3(**right image**) have been presented. As you can see, decreasing the density contrast value, the depth range increases and vice versa. The high depth values are located in depocentres that reach about 14 km for a contrast of 0.2 g/cm^3 and about 9 km for 0.3 g/cm^3. The inversion models clearly show features with a NW-SE trend in which the highest depth values are concentrated.

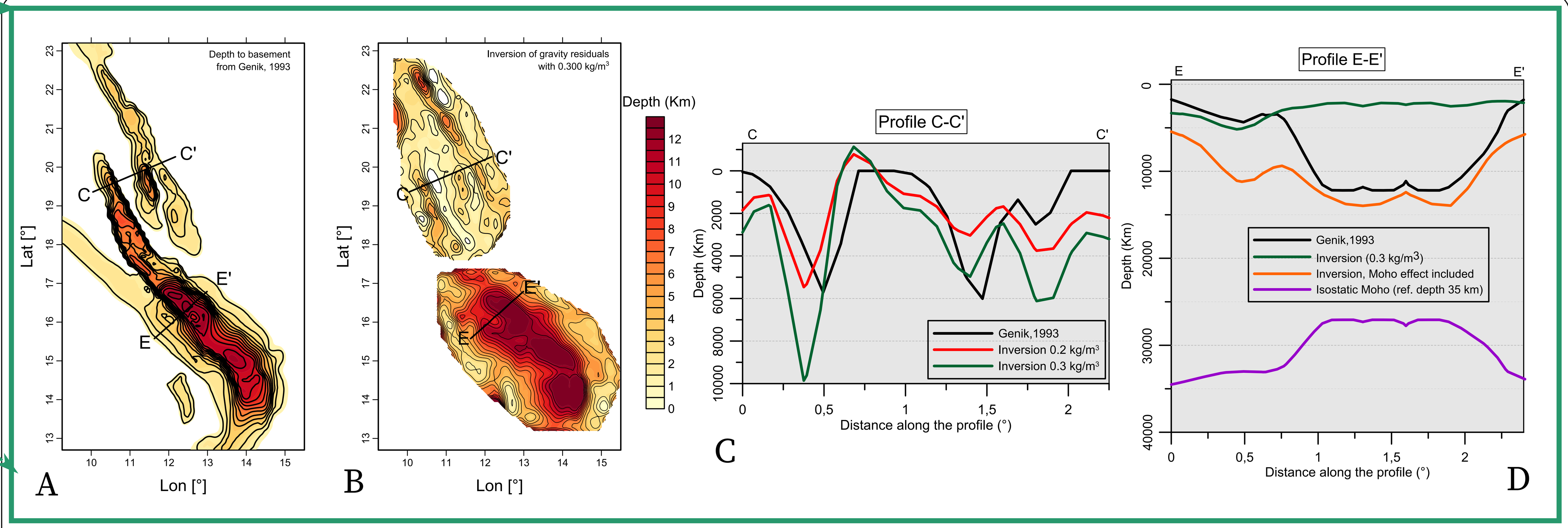
The Chad basin area and the WCARS complex basin-crust structures from gravimetry

What complementary information can we obtain from an isostatic gravity analysis?

4. OUTPUT (RESULTS)



Tectonic features of the Chad basin, observed from residual values of gravity field. (1) A large, weak, negative anomaly (< -20 mGal) related to the sedimentary infill. It affects the most of the basin. (2) A higher negative anomaly (- 30 mGal) with a "U" shape extending north to the Chad lake. (3) Positive anomalies (20-30mGal), due to local basalt dykes. (4) A negative gravity anomaly (-50 mGal) trending NE-SW, corresponding to the CARS. (5) A pattern of positive anomalies (40 mGal) along the NE edge of the basin trending NW-SE, due to volcanic intrusions in alternance to negative anomalies (WARS). (6) A local positive anomaly lineament (50 mGal) along the southeastern edge of the basin probably connected with lower crust (Li et al.,2013) .



The depth of the rock basement below the West African Rift System. The contour map (**image A**) shows the sedimentary thicknesses deduced from seismic reflection previous surveys (Genik, 1993). The map of the depths estimated through the inversion modelling of residual gravity values (**image B**) was included with a density contrast of 0.3 g/cm^3 that produced comparable results to the seismic data. The survey was conducted along two profiles previously beaten by Genik (1993), one located in the northernmost portion of the WARS (**CC'**) and one located further south (**EE'**). A preliminary phase of the study showed a different behavior of the gravity along the two investigated profiles. The results obtained along the profile CC' are comparable with the Genik curve and what emerges is that to obtain more satisfactory results, it will be sufficient to vary the density contrast values in a more local way (**image C**); while along the profile EE' there is a clear and substantial misfit between the two curves (black and green curves, image D) obtained by inversion modelling on gravity residuals and seismic reflaction data (**image D**). **How to solve this ENIGMA?** The McKenzie's theory (1978) considers a mantle upwelling of the asthenosphere as a consequence of the lithospheric stretching along the extensional areas. It can produce an isostatic compensation. For this fact, the gravimetric anomaly relative to an isotatic Moho (for stratched areas on continental crust) 35 km deep (purple curve, image D) appears to be specular to the Genik (1993) black curve, has been calculated. This observation led to the hypothesis that the influence of the Moho at a locally inferior depth could nullify the gravimetric effect relative to the more superficial geological structures (thickness of sediments). The results plotted on image D shows that including the contribution of the isotatic Moho to the inverted values, a curve comparable with seismic reflection data has been obtained.

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Acknowledgements:
work by author FM is being supported by a grant under the European Social Fund, through resources of Region Friuli Venezia Giulia in the form of a PhD fellowship at the University of Trieste. POR 2014-2020, HEaD UNITS.
The contents expressed herein are those of the authors and do not necessarily reflect the views of the funding entities.