Gravimetry of the Chad basin area: determining the depth of the basement and implication for defining a scientific drilling site (ICDP-CHADRILL project)

F. Maddaloni*[1], C. Braitenberg[1], A. De Min[1], M. Schuster[2], T. Pivetta[1], F. Morsut[1]
[1] Dept. of Mathematics and Geosciences, University of Trieste, Trieste, Italy
[2] Institute de Physique du Globe de Strasbourg, CNRS UMR 7516, University of Strasbourg, Strasbourg, France

PURPOSE

Estimation of basement depth below the city of Bol

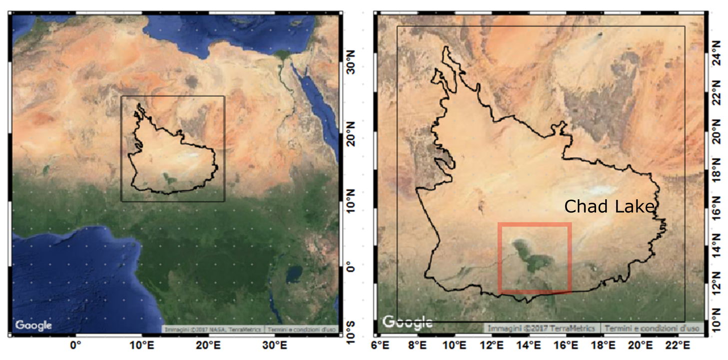
→

APPLICATION

ICDP Drilling site for anthropological and paleo-enviromental research

1. STUDY AREA

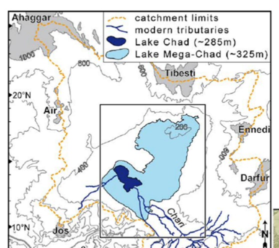
The Chad basin is a huge intracratonic sag-basin (2.5 million km^2) located in the North Central Africa. It covers 8% of the african continent surface straddling Algeria, Cameroon, Central African Republic, Republic of Chad, Nigeria and Sudan. The detailed geology of the area remains still poorly known nowadays.



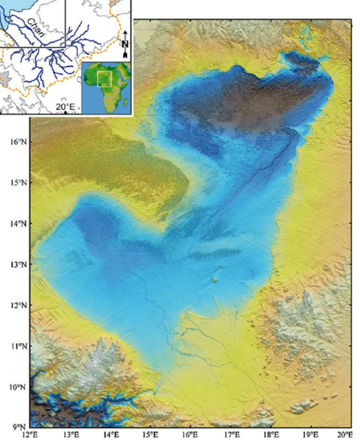
The view of the Chad basin area and its spatial extension. Google Earth

Inside the Chad basin, Lake Chad was considered as the fourth largest permanent fresh water reservoir of Africa. It is a brackish water remnant of the Pleistocene Lake Mega-Chad (10.000-5.000 yr ago) with an extension similar to the Caspian sea. The existence of this huge lacustrial basin is well dimostrated by widespread typical lake deposits occupying the central part of the basin.

(*) 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.



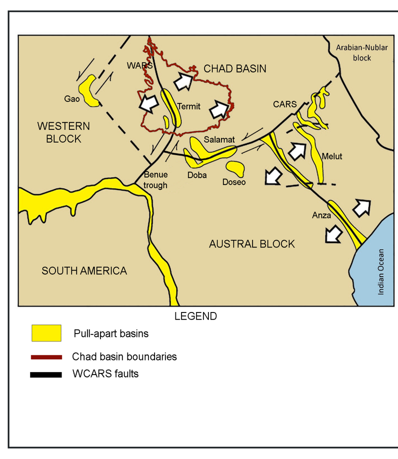
The actual Chad lake (blue) and the Holocene Lake Mega Chad (light blue) during the past few decades. Image processing by C.Roquin, published in Schuster et al., 2009 (*)



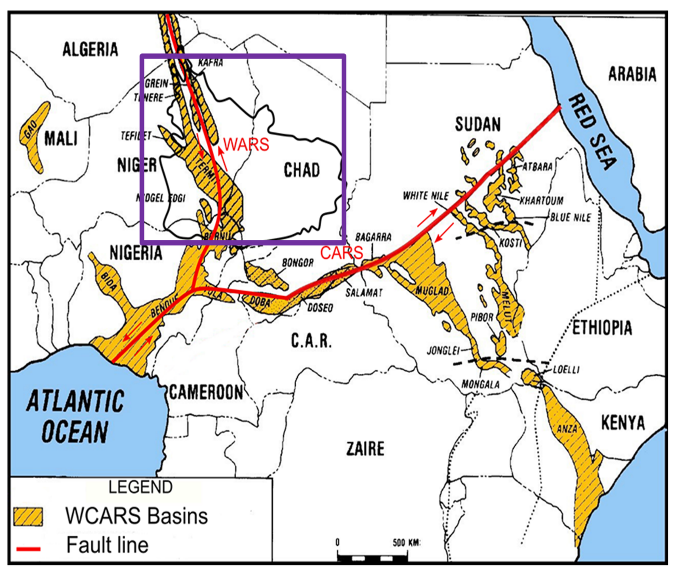
The shaded relief image of the Chad basin derived from the SRTM3 DEM emphasizes the extension of Lake Mega Chad (bluish:lacustrine area, yellowish: terrestrial area). Image processing by C.Roquin, published in Schuster et al., 2009 (*)

2. GEODYNAMICS

The Chad basin is located over an old intra-continental rift system composed of several peripheral uplifts. It lies in the middle of a vast area also known as "Pan-African mobile zone" and exhibits a platform in tectonic settings related to rifting. Infacts 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.



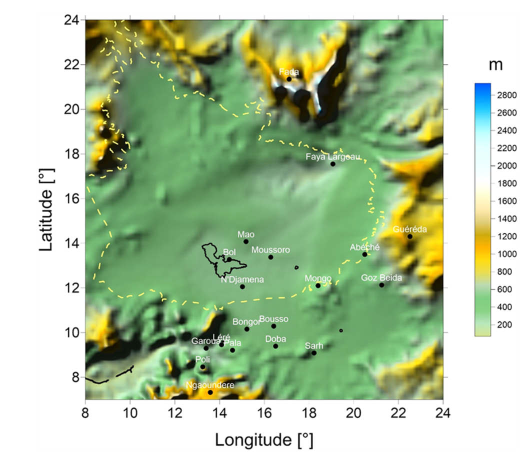
The paleotectonic evolution of WCARS around 126 Ma. In yellow the continental sediment and in red the Chad basin boundaries in an approximated position. The black line means major fault and the arrows means the direction of tectonic movements. The dashed lines represents uncertain rift movements. Image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



The WCARS extension and its location. It is divided in WARS and CARS. The dotted lines indicate the general trace of East African Rifting, the solid red line represents the major fault. The dashed line means a probable fault. Image modified from Wycisk et al.,1990 and Genik, 1993 (**).

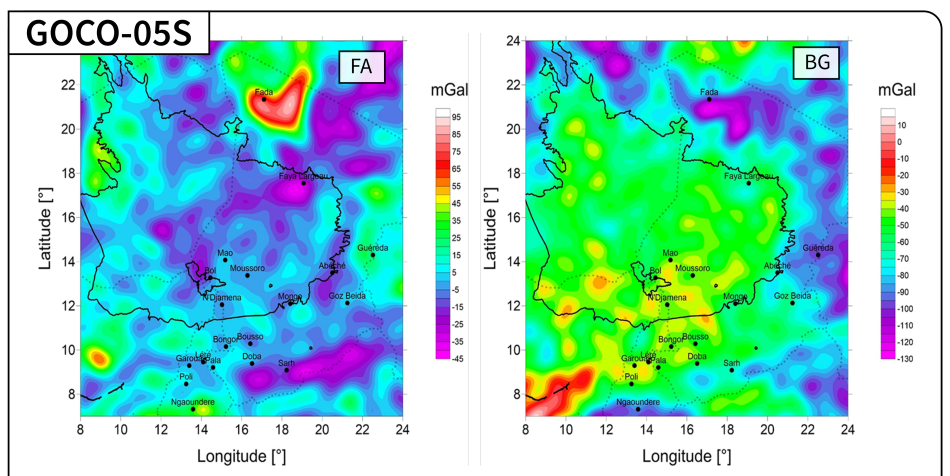
(**) Genik, G. (1993). "Petroleum geology of Cretaceous-Tertiary rift basins in Niger, Chad, and Central African Republic". AAPG Bulletin 77.8, pp. 1405–1434.

3. INPUT



Topography. The Etopo1 model (2008) map shows how the Chad basin a flat zone is, especially in the central regions. The values changes from 300 m a.s.l, inside the basin meanwhile higher values change on average from 1000 m to 2600 m a.s.l around it. The evidence of a spot on the northern side of the topography map with values around 3000 m on m.s.l and a depression around zero in the south-western area, are observable.

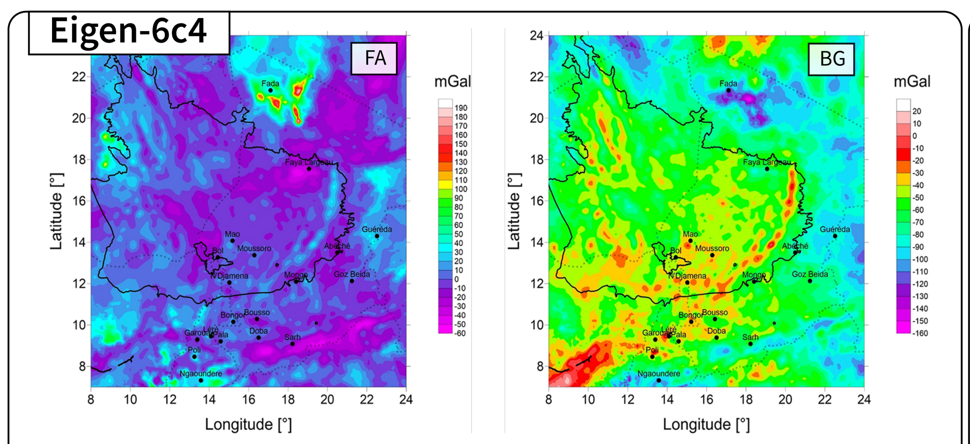
GOCO-05S



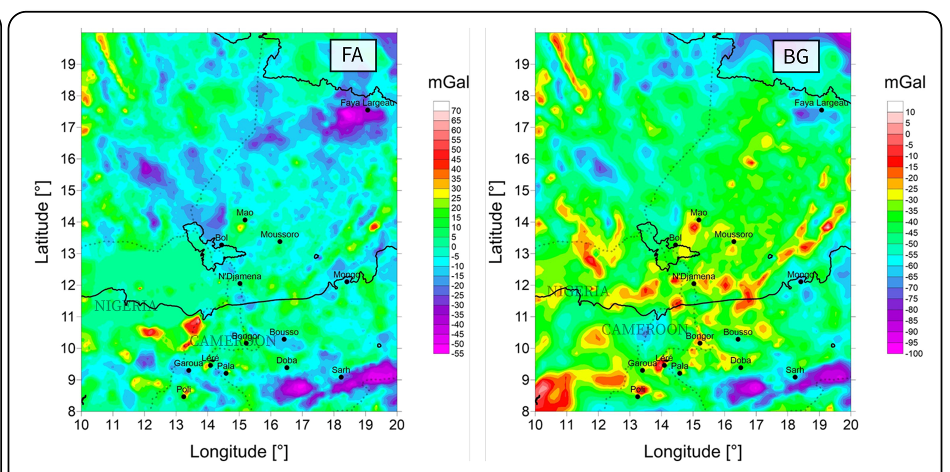
Gravity. GOCO-05S model is a high-accuracy and high-resolution global gravity field model of satellite gravity mission GOCE, GRACE, Kinematic orbits (8 satellites), and SLR (6 satellites). **The free-air anomaly (left image)** change from -45 mGal as min. to 95 mGal as max., a positive spot is concentrated in the northen part of the Chad basin borders. **The Bouguer anomaly (right image)** change from -130 mGal as min. to 10 mGal as max., the positive spot is concentrated in the SW part of the map. The central regions of the basin are negative with values around -50 mGal until -75 mGal. Free Air and Bouguer maps shows some evidences of existing structures, in particular, positive areas shows in the free-air map correspond to a very negative value in the Bouguer anomaly map (Tibesti zone).

The topography and gravity data used are: (1) spherical harmonic models from ICGEM (International Centre International Centre for Global Earth Models) http://icgem.gfz-potsdam.de/ICGEM/; (2) scattered data points of gravity takenfrom BGI (Bureau Gravimétric International) http://bgi.omp.obs-mip.fr/.ICGEM and BGI are two of five services coordinated by the International GravityField Service (IGFS) of the International Association of Geodesy (IAG). These data were useful for observing the topography variations but also to calculatethe values of simple and complete Bouguer anomaly field.

Eigen-6c4

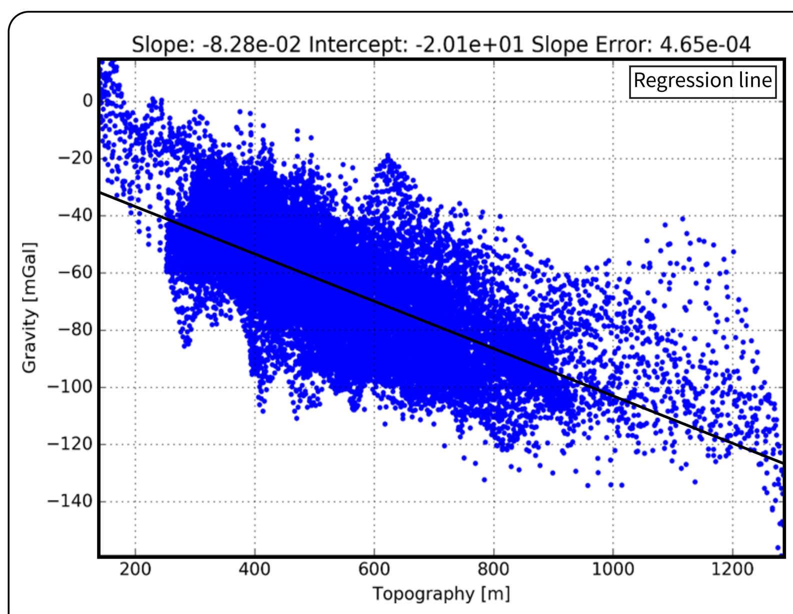


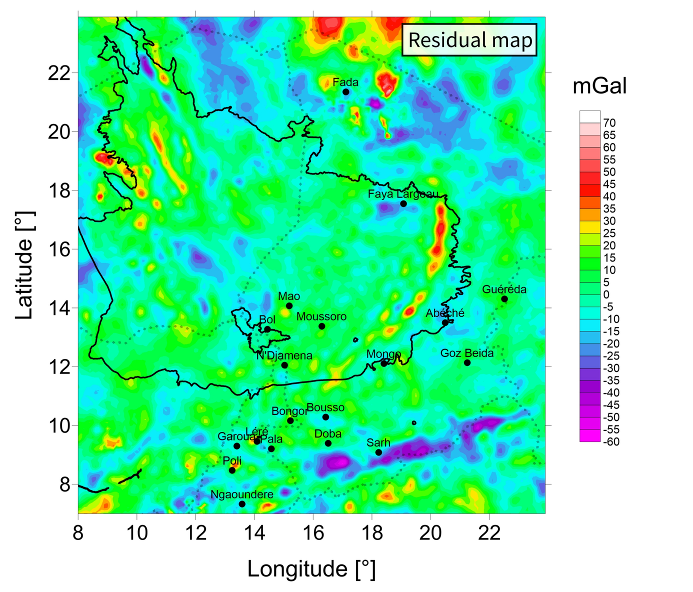
Gravity. Eigen-6c4 is the latest release of the Eigen-6c-Series, containing the complete data of the GOCE Mission and combination of LAGEOS, GRACE, GOCE and DTM ground data. **The free-air anomaly field (left image)** change from -60 mGal as minimum to 190 mGal as max. Despite the area is mostly positive with lower values around 10 mGal, some spots show negative values around -40 mGal (violet areas), especially among the Chad lake. **The Bouguer anomaly (right image)** values change from -160 mGal as minimum to 20 mGal as maximum. The positive spot is concentrated in the southwestern part of the map. The central region of the basin are essentially negative with values around -60 mGal, there are spots with positive values around 0 mGal (red areas). The gravity anomaly field realized by Free-air and Bouguer maps shows some particular evidences of some body structures existing but in a more detailed way than Goco05s. In particular, it is observable how positive Free-air values corresponds to negative Bouguer ones.



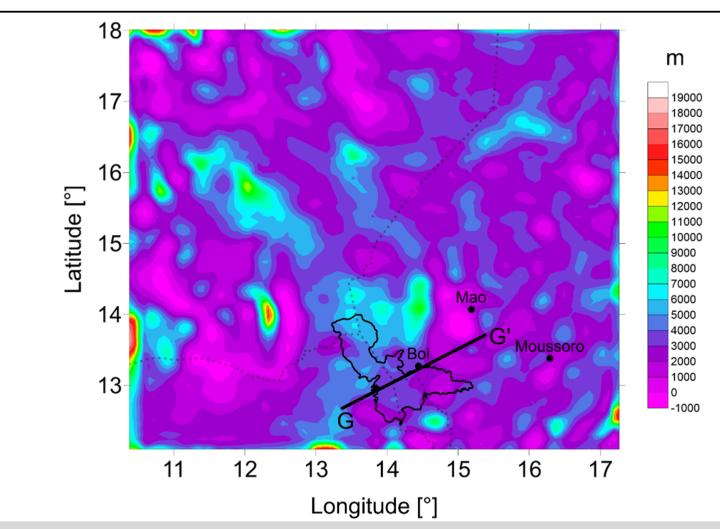
Gravity. The terrestrial data used come from BGI agency. **The free-air anomaly field (left image)** change from -55 mGal as min. to 70 mGal as max. The positive spots (red) are concentrated between the Cameroon and Nigeria. The anomalies on central region confirming the existence of tectonic structure at north of Lake Chad. **The Bouguer anomaly (right image)** field change from -100 mGal as minimum to 10 mGal as maximum. The positive spots are concentrated in the south-western part of the map. The central regions of the basin are negative with values around -40 mGal, in some parts of the basin there are spots with values around -75 mGal (light blue areas). The gravity field realized by Free-air and Bouguer anomaly maps confirm some particular evidences of some density structure maybe connected to tectonic structures.

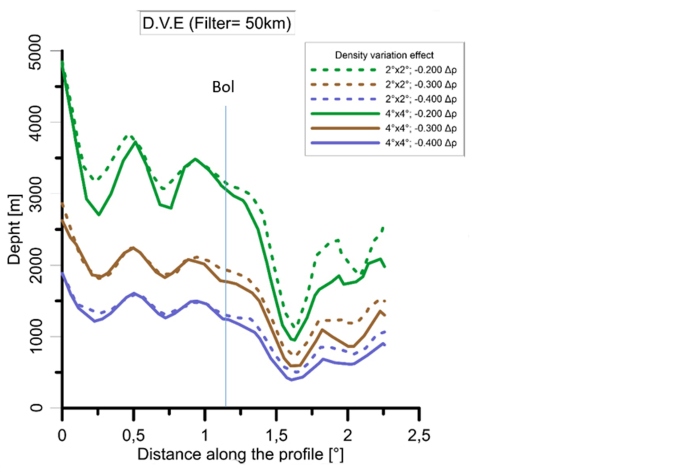
4. PROCESSING (METHODS)





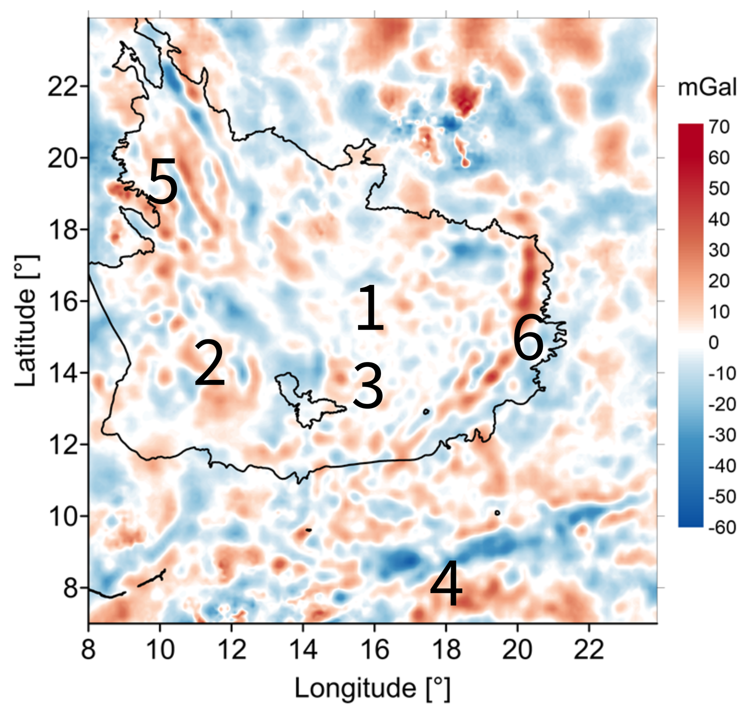
Topography-Gravity Regression analysis. This method is based on the **linear relation** between Bouguer gravity field and the topography $BG \approx 2\pi G(r-d)(\rho m-\rho c) = 2\pi G\rho cTopo$ used to separate the gravity isostatic effect from superficial heterogeneities **(left image)**. For low topography (< 1000 m) there is an inverse proportion between the Bouguer gravity anomalies and the topography. This is due to the isostatic compensation. For higher topography, the correlation is loose with more positive gravity values than expected. If we consider that the highest topography is in the mountains, as the Tibesti, which indicates that the topographic elevations have higher density. 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, corresponding to the volcanic intrusions along the rifts.



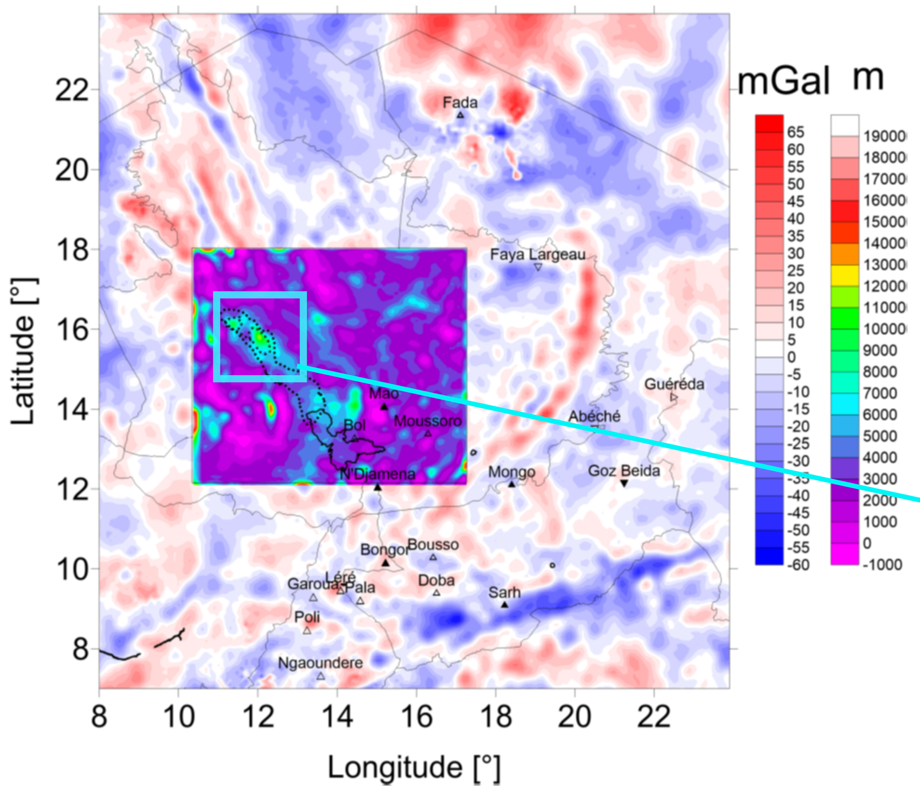


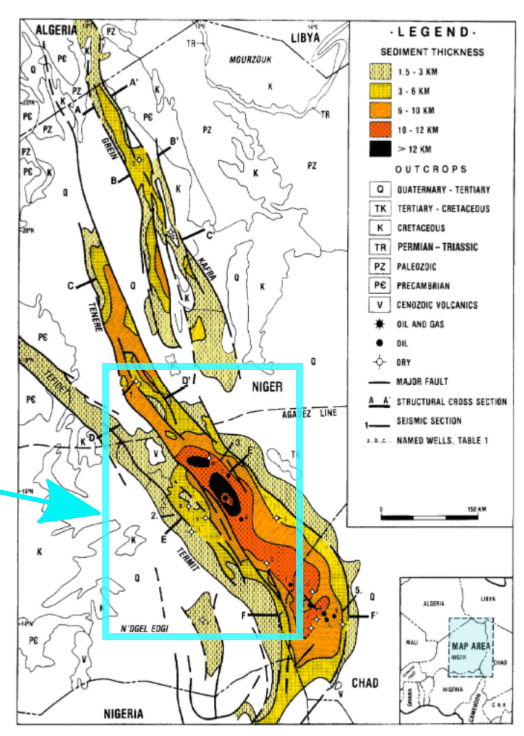
Inversion modelling for definign the basement depth under the Lake Chad. It is obtained from the inversion on residual map values. We assumed constant parameters such as the density gradient (0.005 $g/km*cm^3$) and the observation height (4.000 m) meanwhile the contrast density between rocks and sediments was considered a variable. **The best inversion map producted (image left),** according to works in seismical exploration surveys, has characterized by 0.2 g/cm^3 in density contrast. To test the validity of the inversion, the basement depth along a SW-NE **oriented profile**, passing through Bol has been studied **(image right)**.

5. OUTPUT (RESULTS)

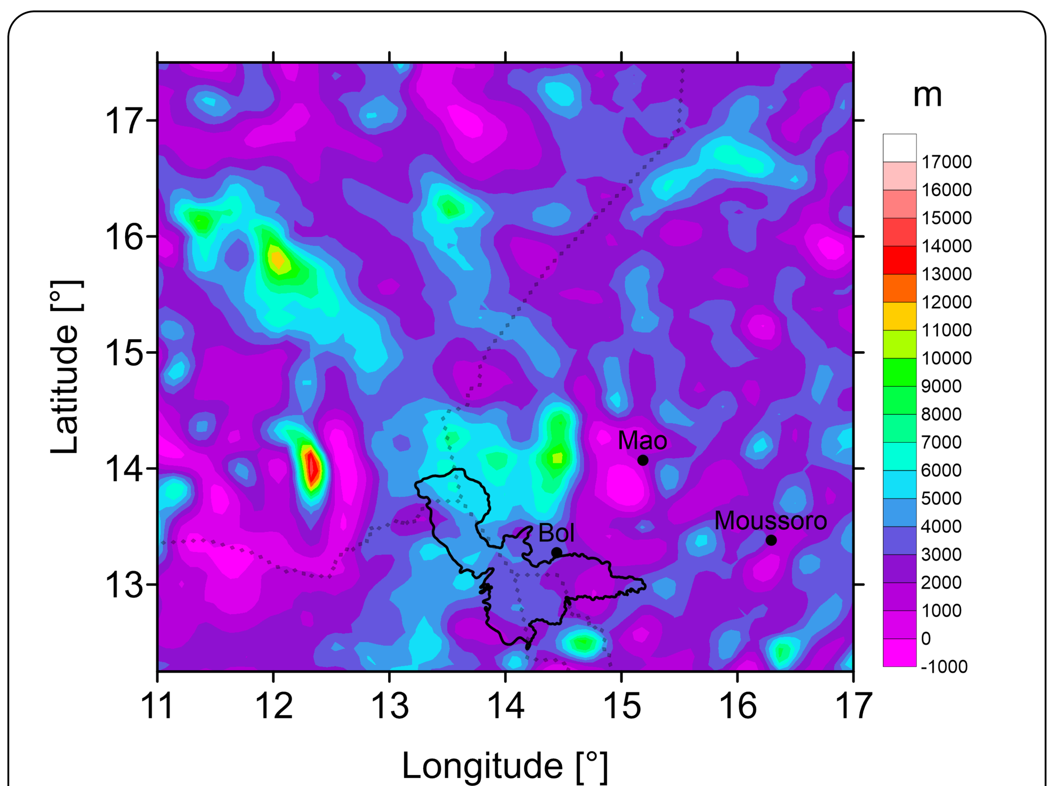


Tectonic features of the Chad basin, observed from residual values of gravity field. **(1)** A large, weak, negative anomaly (< -20 mGal) related to the **sedimentary infill.** It affects the most of the basin. **(2)** A higher negative anomaly (- 30 mGal) with a "U" shape extending north to the Chad lake. **(3)** Positive anomalies (20-30 mGal), 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 northwestern edge of the basin trening NW -SE, due to **volcanic intrusions** in alternace to negative anomalies (WARS). **(6)** A local positive anomaly lineament (50 mGal) along the southeastern edges of the basin probably connected with lower crust.





The depth of the rock basement under the Lake Chad area. To perform a comparison with the **seismic information** from Genik's work (1993) **(right image)**, we had chosen parameter values that produced more realistic and comparable results with seismic reflection surveys conducted along the West African Rift System (WARS). Around the Lake it has been possible to observe a **deepening variation** of the basement depth moving from the southern part (2-3 km) to the northern part (4-6 km) of the Chad lake. Overlapping the inversion map on the residual map, it has been possible to assume that the **deepening of basement along the western areas (12 km) is connected to the Termit rift basin and the West African Rift Subsystem (WARS) extensional structures (left image).**



The ICDP-CHADRILL project site. The depth of basement under the city of Bol is between 3 and 4 km, but unfortunately, there are no other geological/geophysical constraints to confirm these values. For the drilling purpose, since in the inversion I used a minimum value of the density contrast (200 kg/m3) among the range defined (200 kg/m3) among the range defined (200-400 kg/m3), it is possible to assume that the maximum expected depth of the basement is about **4 km**. Furthermore, I suggest an integrative geophysical survey, such as a seismic reflection campaign to get more detailed information, before asking the drilling permission.

UNIVERSITÀ DEGLI STUDI DI TRIESTE

dipartimento di matematica e geoscienze

***contact**: francesca.maddaloni@phd.units.it
Tectonophysics & Geodynamics Research Group
Dept. of Mathematics and Geosciences, Univ. of Trieste
via Edoardo Weiss, 1 34128 Trieste (Italy)

FSE FRIULI VENEZIA GIULIA

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.