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GRAVIMETRY AND PETROPHYSICS OF THE CHAD BASIN AREA: DETERMINING THE DEPTH OF THE BASEMENT AND IMPLICATION FOR DEFINING A SCIENTIFIC DRILLING SITE (ICDP-CHADRILL PROJECT)

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Introduction. The purpose of this work is to investigate the basement depth under the Chad Lake using the inversion of gravity residual data obtained by the regression analysis between gravity and topography data. It has been carried on with a collaboration between the University of Trieste and the Institut de Physique du Globe de Strasbourg (IPGS) of Strasburg in order to contribute to the decision of the location of a ICDP drilling site. This project consists in a compared analysis between gravity data with other geological/geophysical data and their interpretation in terms of tectonic features composing the Chad Basin.

The Chad basin is one of the largest endorheic basin of the world (2.5 million of km^2) and intracratonic sag-basin located in the north Central Africa, located between 8°-24° N and 6°-24° E, covering 8% of the surface area of the African continent, straddling Algeria, Cameroon, Central African Republic, Republic of Chad, Niger, Nigeria and Sudan. The detailed geology of the area remains still poorly known. Gravity studies in the Chad Basin started in 1959 at the ORSTOM (Office de la Recherche Scientifique and Technique d'Outre-Mer), nowadays known as IRD (Institut de Recherche pour le Développement). Afterwards, several geological and geophysical studies were carried out in the framework of the project "*Contribution géophysique a la connaissance geologique du basin du Lac Tchad*" by P. Louis, 1970. More recently, in

1993, Genik, 1993 gave an overview on petroleum geology of the rift basins located in Niger, Chad, and Central African Republic, based on seismic reflection and well-log data of Exxon (1969-1991).

The main objectives of this work are: 1) estimation of the depth of the basement under the Chad basin through a joint analysis and interpretation of satellite and terrestrial gravity data (BGI) with borehole data and density values of Cameroon-Chadian rock samples taken from the collection of Prof. A. De Min of the University of Trieste. 2) estimation and interpretation of the Bouguer and residual gravity anomalies.

The results obtained will give crucial information (*i.e.* depth of the geologic basement, thickness of sediment infill of the basin) for drilling a scientific core onshore of Lake Chad, in the framework of the International Continental Drilling Project (ICDP). This borehole will bring to scientists an archive of the paleo-climates and paleo-environments of continental Africa over some 10 million years. This area has experienced the variability of the Monsoon since several million years, that in turn has strongly impacted environmental changes (droughts and desert versus hydrographic network reactivation) through time and space, at a period that is crucial for the emergence and evolution of early hominids.

Methods. For this project, we used the following methods:

1- to determine the density values of each rock samples we took several measurements of their weight with a hydrostatic balance and we calculated the average values;

2- to calculate the complete Bouguer anomaly in forward modelling, topography of the study area is divided in more than ten thousand spherical prisms ("*tesseroids*") and the gravity effect produced by each one was calculated;

3- the regression analysis of Bouguer anomaly field map and topography data is a method particularly suitable for geophysical surveys in areas almost uncovered by data like the Chad basin (Braitenberg *et al.*, 2013; Braitenberg, 2015). Indeed, with very few parameters, it is possible to obtain information about the isostatic conditions of the study area. The processing with the regression analysis, observing the relation between topography and the gravity field, consists in a *Spectral Analysis* on topography and gravity data, previously discussed in other works. The processing with the regression analysis is needed for several scopes: 1) to determine the anomalies due to the crustal mass inhomogeneity, 2) to reduce the Bouguer anomaly for the effect of crustal thickness variations; 3) to allow the regression analysis to identify various tectonic features, which produce a different correlation between topography and gravity; 4) to use the residuals of the regression line to invert for the depth of the basement. The results of the regression analysis are displayed in Fig. 1. The black line and the blue points displayed in Fig.1 represent the average regression between topography and gravity, and local deviations (anomalies) from the regression line, respectively. We can further observe that the intercept of the regression line is ~ -25 mGal, indicating a prevalence of negative anomalies inside the Chad basin. The value of the slope is -0.08 mGal/m and is strictly

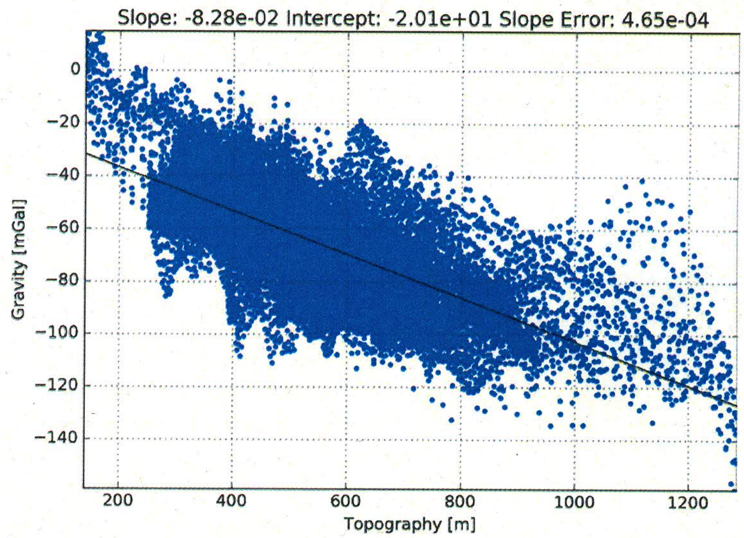

Fig. 1 - The results of regression analysis (regression line) and the correlation between topography and Bouguer gravity anomaly (Eigen-6c4) for Chad basin and surrounding areas.

connected to the density contrast between the crust and mantle;

4- to confirm the stability of the residuals, we derived six cross-sections through the anomalies Bouguer map. In each profile, the complete Bouguer anomaly and the free-air anomaly field show similar trends and the stability of the residuals is confirmed by the perfect overlapping of the residual trends with different filters;

5- we made the inversion of the negative values of the residuals for the depth of the basement discretizing the Chad basin with a series of rectangular prisms of size of ~ 10 km. In the inversion, we used different density contrast between crust and sediments. We chose a range of values of density contrast (200-400 kg/m^3) on the base of the density of the samples measured with the hydrostatic balance. The density contrast is an important constrain since the depth of the basement depends on it. Indeed, a reduction of this contrast, leads to a proportional increase in the basement depth.

Main results. *Topography-gravity regression.* For low topography (< 1000 m) there is an inverse proportion between the Bouguer gravity anomalies and topography (Fig. 1). This is due to isostatic compensation. For higher topography, the correlation is loose. This indicates the increase of crustal density of the Tibesti volcanic Massif area, the only value of the topography >1000 m.

Residual Maps. They have been obtained from the regression analysis using satellite and terrain dataset (Fig. 2). These maps show the gravity signal induced by the crustal density variations occurring between the tectonic features, after the removal of the effect of topography and crustal root. The Residual Map (Fig. 2), shows: 1) a large, generally weak, negative anomaly (< -20 mGal), affecting most of the basin, related to the sedimentary infill. A higher negative anomaly (-30 mGal) with a "U" shape, extending north to the Chad lake is probably related with the Termit rift basin, already identified by seismic reflection profiles (Genik, 1993). 2) We can recognize inside the basin some small positive anomalies (20-30 mGal), probably due to some local basalt dykes. 3) We can observe a negative gravity anomaly (~ -50 mGal) around Sarth, trending NE-SW, corresponding to the Central African Rift (CAR) (Genik, 1992). 4) Along the northwestern edge of the basin there is a pattern of positive anomalies (~ 40 mGal) trending NW-SE, likely corresponding to the volcanic intrusions along the edges of the rifts. 5) An interesting local positive anomaly lineament (~ 50 mGal) discussed by Braitenberg *et al.* (2011) and Li *et al.* (2013) and Liégeois *et al.* (2013) along the southeastern edges of the basin and approximately 1000 m extended.

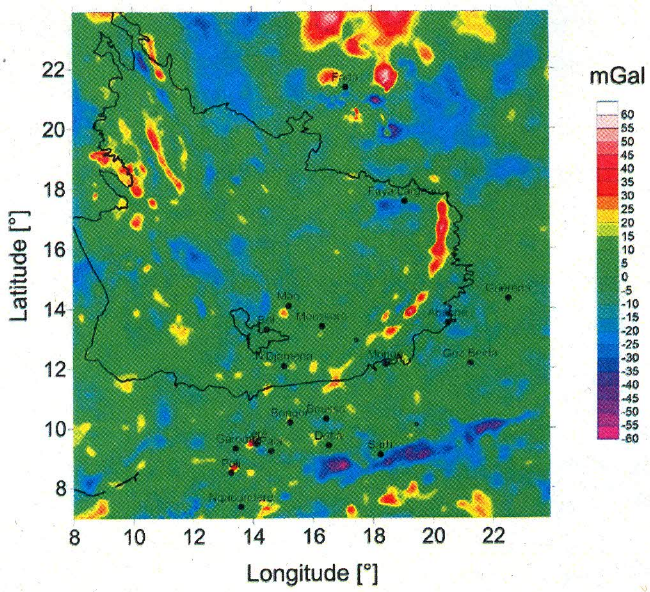

Fig. 2 - Gravity Residual Map from satellite data (Eigen-6c4) after the regression analysis.

Depth of the basement under the Lake Chad. It has been obtained from the inversion of the residuals (Fig. 3). The depth of the basement under Lake Chad shows a sharp variation from north to south. In the northern part of Lake Chad, the basement is between 4 and 6 km deep, and reaches the depth of ~12 km in the Termit Rifting Basin. This value is consistent with that estimated in the previous study of Genik (1993). In contrast, in the southern part of the Lake Chad, the basement shallows to 2-3 km. The depth of the basement under the city of Bol ranges between 2 and 4 km. The largest depth of the basement (~ 15 km) is observed 100 km west of the Chad Lake, cannot be connected with a specific tectonic feature, because of the poor

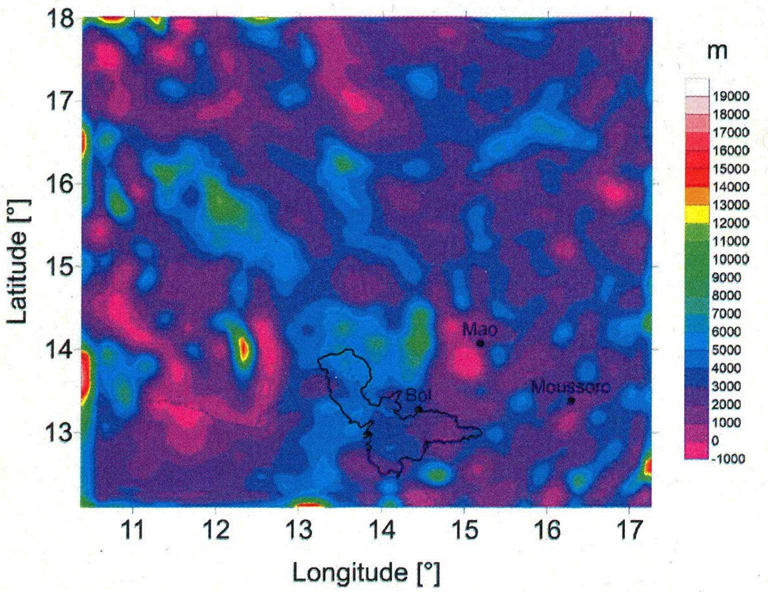

Fig. 3 - Basement map of the Chad lake area from gravity inversion. 200 kg/m^3 is the density contrast between rock basement and sediments.

knowledge of the geology of the area. Unfortunately, we do not have further geological/geophysical constraints to confirm the value found. In the other parts of the study area (e.g., under the city of Mao and Moussoro) the depth of the basement is quite shallow (1-2 km).

Conclusions. In this project, we estimated for the first time the depth of the basement under the Chad basin in a more detailed way, focusing our attention on the city of Bol where in the framework of the project ICDP, it is planned to drill a borehole for paleo-environmental and anthropological research. For this purpose, we made a joint analysis and interpretation of a spherical harmonic gravity model (GOCE) and terrestrial gravity data (BGI) with well-logs data and density values of Cameroon-Chadian rock samples taken from the collection of the University of Trieste.

We found a large negative anomaly (-30 mGal) under the Chad basin connected to the presence of low density sediments. Furthermore, there are several positive anomalies around the edges of the basin and a pattern of negative anomalies outside of it. Both types of trends are linked to the presence of rifts and extensional structures.

We could observe a sharp variation of the depth of the basement moving from the northern (4-6 km) to southern part (2-3 km) of the Chad lake. The deepening of the basement is connected to the Termit rift basin and the values are consistent with previous seismic surveys. The depth of the 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 we used a minimum value of the density contrast (200 kg/m^3) among the range defined (200-400 kg/m^3), it is possible to assume that the maximum expected depth of the basement is about 4 km. Furthermore, we suggest an integrative geophysical survey, such as a seismic reflection campaign to get more detailed information about the structure of the basement (faults, highs and lows) as well as on the variability of its depth and the thickness of the sediment cover.

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DEEP SEISMIC PROSPECTING: IMAGES FROM CENTRAL SICILY

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Introduction. The seismic transect SIRIPRO, long about 100 km, was acquired in 2007 starting from Termini Imerese, in the north, to Gela at southern coast, crossing Maghrebian belt and Caltanissetta through the slope of Hyblean and Pelagian platform facing southern Sicily. It allowed exploring structures of Central Sicily illuminating the foreland crust and the large-scale Neogene overthrust of the Maghrebian Chain. An exhaustive analysis of the profile let us depict important targets: a) Caltanissetta crustal scale syncline developed between foreland and hinterland of the Maghrebian Chain with the accumulation of allochthonous terrains; b) nature of the foreland crust and its northwards thinning; c) collisional mechanism up to recent uplifts and northwest-southeast compressions even though with slow movements; d) development of the frontal shape of the fold&thrust belt constrained by the inhomogeneity of the foreland plate; e) southward pushes of Tyrrhenian deep crust and mantle.

Newly processed data (after Accaino *et al.*, 2011) improved signal/noise ratio extracting information previously hidden by approximate static corrections and source generated noise. To relocate shots and receivers at a given datum plane, usual assumption of a vertical near-surface ray-path, when static corrections are applied, looks inadequate for acquisitions wit long offsets and significant laterally varying velocities, obstacles that did not favour penetration and energy focusing. The choice of a group spacing of 50 m and shots intervals of 250 m, obligatory detecting reflected energy from deeper interfaces, ignored potential complex near-surface structures while crossing a fold&thrust belt. The coverage took advantage of the large number (240) of active channels, but the near surface information remained poor or absent. To increase energy penetration, signal recovery and more reliable migration process more shots/km should have been adopted.

To remove missteps from rapid variations of the near surface velocity, complex methods, such as Wave Equation Datuming (WED), should be used. Likewise, we applied WED to remove source generated noise, increase resolution and signal/noise ratio, which is a correct and appropriate procedure to improve deep crustal reflections (i.e., Barison *et al.*, 2011; Giustiniani *et al.*, 2015).

New processing of SIRIPRO seismic profile. Considering the length of the seismic profile (about 100 km), we divided it into two parts, labelled PN (northern part) and PS (southern part) from here on, to easily manage a huge amount of data during processing, especially for WED application. We also limited listening time to first 12 s to reduce computation times. In fact, WED demands heavy computations requiring long-lasting times. Anyway, a limitation to 12 s allowed us to have an image of a whole crust on section PS, whereas the structures of the deep crust and its involvement in the chain building was our main interest on PN section. We utilized parallel computing facilities at CINECA (www.cineca.it) centre.