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The Contribution of Urban Gravity Survey to the Subsurface Geological Structure of the Athens Basin (Greece)

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Summary

The gravity method has been applied, with a total of 1.122 gravity measurements for the subsurface investigation of the geotectonic structure beneath the urban and sub-urban areas of Athens basin. The aim was to gather new information for the subsurface geological and tectonic structure of Athens basin and re-assess the seismic hazard risk of the area that may damage its infrastructures. The standard corrections have been applied (drift, tide, latitude, free-air, Bouguer, terrain ones) along with an additional Building Correction that has been calculated based on the urban characteristics. Afterwards, the isolation of the residual anomaly has been accomplished with the contribution of the Fourier filters and the analysis of the power energy spectrum. The processing results provided important data regarding the geological and tectonic structure beneath the Quaternary formations that cover the basin. We managed to verify already proposed concealed fault zones or even discover and propose new ones that may affect the city in the future by generating disastrous earthquakes. In the context of the interpretation, two geophysical-geological profiles have been constructed, along which the geotectonic regime of the subsurface is clarified.

Introduction

Athens basin hosts the metropolis city of Greece, with almost 4 million residents. Taking into consideration the major damage caused by the catastrophic earthquake of 7th September 1999 (5.9R), the need for further and deeper investigation of the geological structure of the subsurface came up. Especially in such urban and fully residentially developed areas, the knowledge on the existence of concealed active faults is absolutely valuable. The damage distribution of an earthquake is usually related to the tectonic structures of the area. Unfortunately, since the areas are covered with artificial surfaces, such as buildings, industrial infrastructures, roads, bridges and generally artificial surfaces, the geological research is quite complicated.

Geological and tectonic setting

The autochthonous metamorphic unit is compiled mainly of dolomites, marbles and shales, where the last two exist as continuous overlaying layers. On the other hand, the "*Ypopelagoniki"* unit consists of Triassic-Jurassic limestones and some base clastic formations from Paleozoic. The *Athens Unit* is comprised of two main parts, the upper one which is basically limestones and the lower one, called "*Athens Schists*" which is basically a geological mélange that consists of sandstones, shales, phyllites, limestones and marls. The "*Alepovouni"*, located tectonically between the autochthonous metamorphic unit and the "*Athens"* unit, consists of limestones (upper part) and additionally schists and phyllites in the base, because of its low metamorphism.

The post-alpine geological formations cover the biggest part of the basin, with the exception of some remaining hills in the center (*Filopappou, Acropolis, Lycabettus, Ardittou, Tourkovounia, Kokkou*), constituted mainly by the *Athens Unit*. More than ten different post-alpine, Quaternary and Neogene, geological formations had been proposed by Papanikolaou D. *et al.,* (2002), but here they are observed simplified in groups that will help the gravity survey, based on Dilalos (2018). Their thickness varies from a few meters to a few hundreds of meters. Because of their existence, it is difficult to understand with no doubt the geotectonic regime of the basin.

The alpine tectonic regime is controlled mainly by low-angle fault zones, known as part of the West Cycladic Detachment System (Grasemann *et al*., 2012; Iglseder *et al*., 2011; Lekkas *et al*., 2011). The *Alepovouni Unit* is delimited by two low-angle fault zones, one with the relative autochthonous underlying Metamorphic Unit dipping to Northwest. The tectonic contact between the *Athens* and *Alepovouni* Units is almost identical with the west margin of *Hymettus* and *Penteli* Mountains. It is considered to be a major tensile detachment zone, where metamorphic formations adjust to unmetamorphic ones, leading to the rise of the metamorphic up to the surface (Xypolias *et al.,* 2003).

Data acquisition and processing

The station grid spacing had been set primarily to 1km and then some stations had been added in between the first ones, in order to clarify the status of some ambiguous areas. The gravity database is comprised of 1.122 gravity stations (Fig. 1). The gravity meter LaCoste & Romberg G-496 was used for the data acquisition. We used Differential Global Positioning System (dGPS) in order to calculate the necessary coordinates of each gravity station and base with high precision. This was compiled by two different, dual-frequency TopCon HiperPro GPS antennas. The static technique had been chosen, because of the long distances and the blear of the buildings. The coordinates were calculated in the Hellenic Geodetic Reference System (EGSA'87).

The *Oasis Montaj* software was used for the data reduction. The assumed constant density for the Bouguer correction was set up to 2.67gr/cm^3. Therefore, the Simple Bouguer Anomaly has been calculated (Dilalos and Alexopoulos, 2017; Dilalos, 2018). An inner radius equal to 1.500 meters had been set, along with an outer radius distance equal to 21 kilometers. Normally, with the aim of calculating the Complete Bouguer Anomaly only the Terrain corrections need to be added to the Simple Bouguer Anomaly. However, in this urban geophysical survey, we have calculated and added the necessary Building Corrections (Dilalos, 2018; Dilalos *et al.,* 2018), caused by the gravitational attraction of the buildings and infrastructures of the city.

In the context of this paper, we chose to proceed to the regional-residual separation with Fourier analysis and Filtering, since we consider it as the most reliable and up-to-date technique, especially for such a complicated geological structure. The processing was carried out with the contribution of Oasis Montaj software and the *MAGMAP* extension. The separation of the regional and residual gravity fields was based on the information provided by the corresponding Power Spectrum Analysis of the Complete Bouguer data. The application of the Gaussian filter has been chosen as the most appropriate for this case, applied successfully in several other cases. We produced a residual map with a cutoff wavelength of 500m and standard deviation equal to 0.25 cycles/km mainly for the shallow structures. Beyond that, a second residual map of the basement, with standard deviation equal to 0.02 cycles/km, was produced, including the anomaly sources and information from deeper structures of the bedrock.

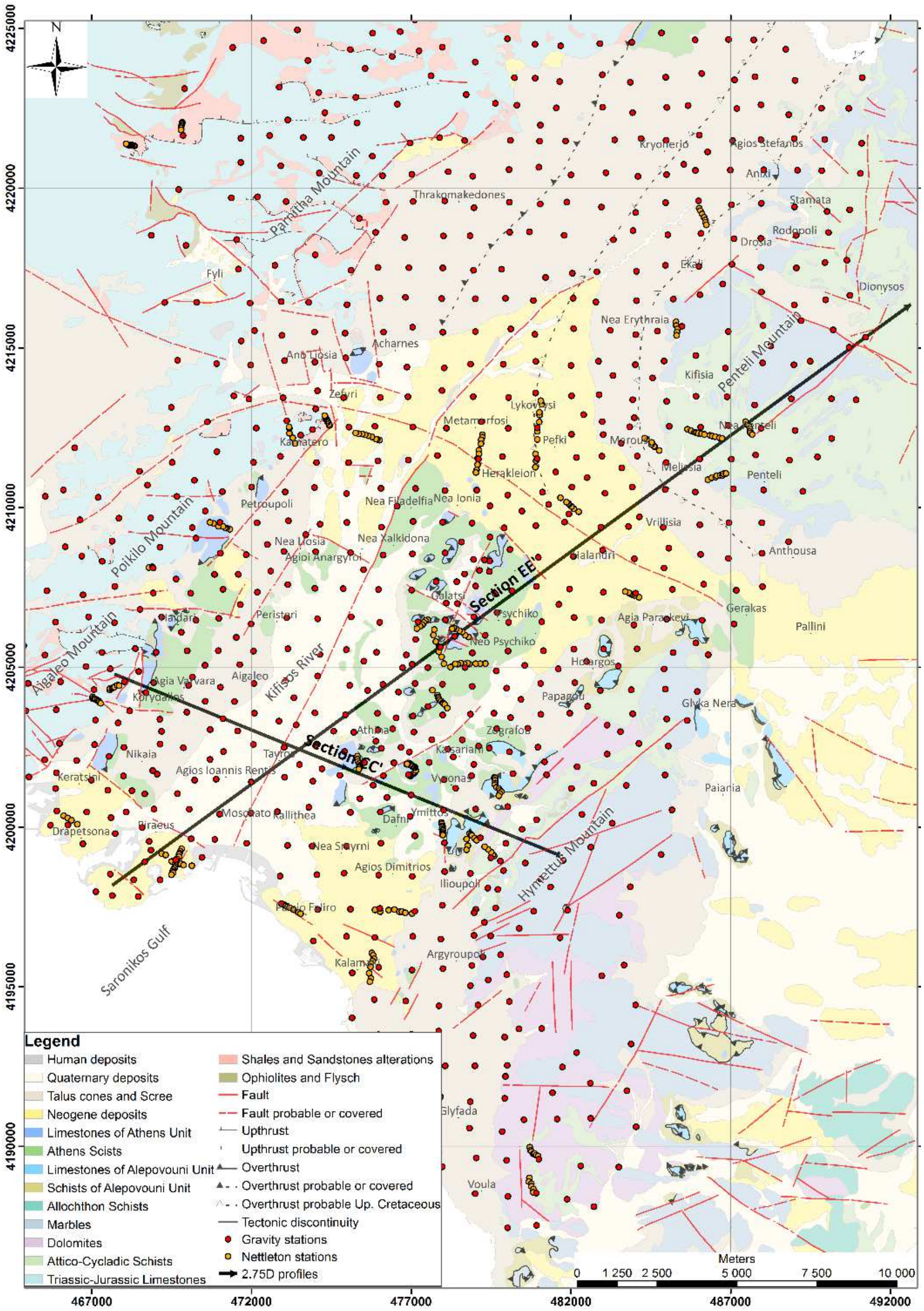

Figure 1. Geological and tectonic map along with the locations of the gravity stations and gravity bases. The locations of the interpretative geological models are also illustrated.

Geological-gravity modelling

Two model (2) sections have been constructed (Fig. 2) in order to contribute to the adumbration of the tectonic framework of the Athens basin subsurface. The density values assigned to each block/prism are based on the values proposed by Dilalos (2018).

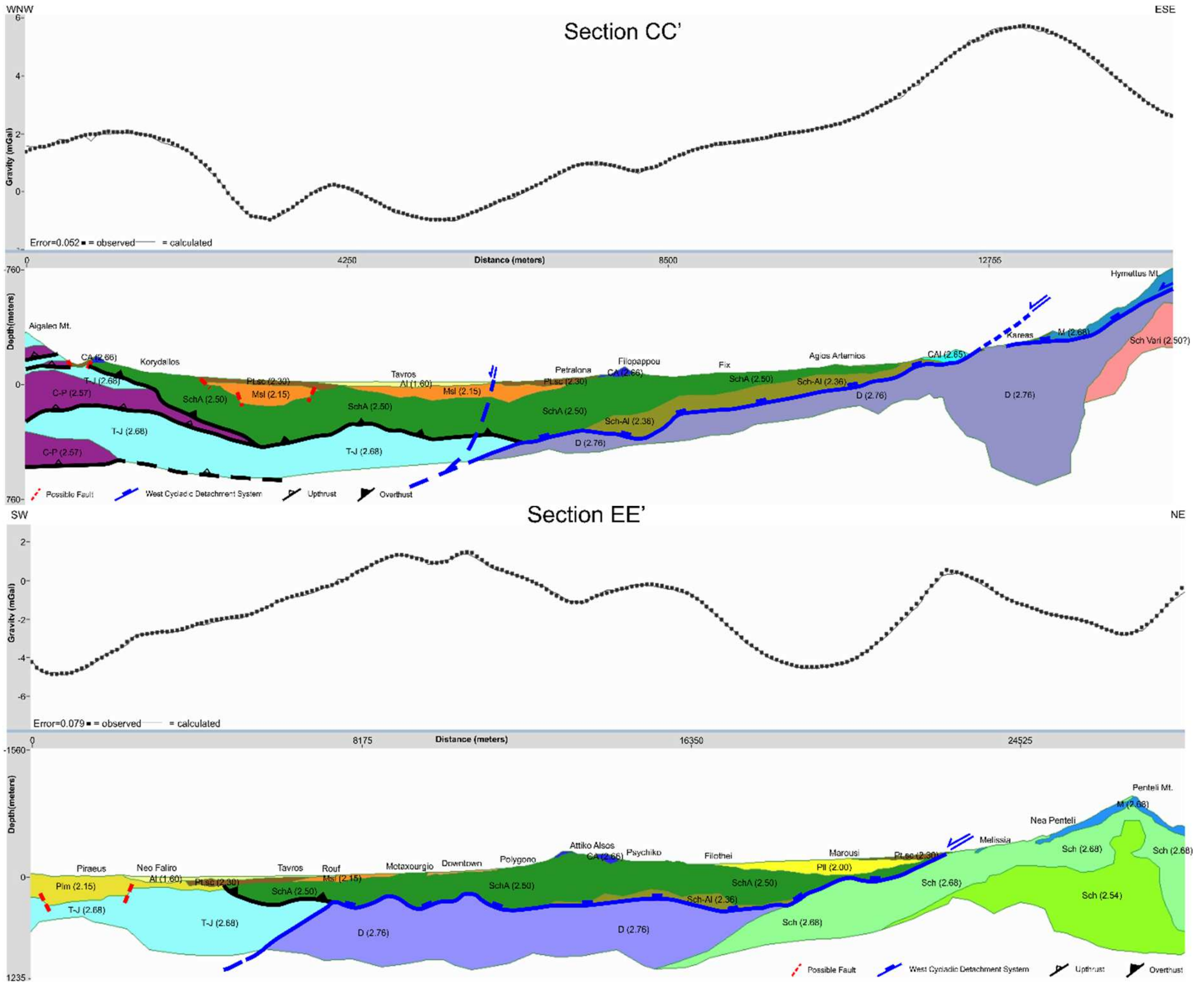

Figure 2. Interpretative geological 2.75-D profiles (scale 1:2). The observed (squares) and calculated (line) residual anomaly are illustrated. The geological formations are:
T-J: Triassic-Jurassic Limestones (Ypopelagoniki Unit), C-P: Shales and Sandstones alterations (Ypopelagoniki Unit), M: Marbles (Metamorphic Unit), Sch: Schists (Metamorphic Unit), D: Dolomites (Metamorphic Unit), Sch-Vari: Varis Schists (Metamorphic Unit), SchA: Athens Schists (Athens Unit); CA: Limestones (Athens Unit), Sch-Al: Schists (Alepovouni Unit), CAl: Limestones (Alepovouni Unit), Msl: Upper Miocene Terrestrial and Lacustrine deposits (Neogene Formations), Pt.sc: Pleistocene Talus and Screes, Al: Alluvium deposits (Loose Quaternary deposits).

In these sections, the Neogene deposits (*Msl*) are observed with thickness, up to 250 meters producing the low values in the residual gravity field (down to -1 mGal). A few **neotectonic fault zones** have been revealed, mostly beneath the Neogene deposits and their underlying formation of Athens Schists, among the areas of *Korydallos, Piraeus*,*Neo Faliro* and *Tavros*. The Athens Schists (*SchA*) and the Schists of Alepovouni Unit (*Sch-Al*) cover a great part of the subsurface, underlying the Neogene deposits, reaching a maximum thickness up to 600 and 200 meters correspondingly. Furthermore, the Dolomites (*D*) of the *Metamorphic Unit* seem to dominate at the lower area below the basin (from depths of 350 meters) and the *Hymettus Mountain*, with thickness that reaches 950 meters. Below *Hymettus Mountain*, it seems that the Schists (*Sch*) are dominating in Section EE' against the Marbles (*M*), with their thicknesses reaching 1,750 and 100 meters correspondingly. On the contrary, in Section CC' the Schists (*Sch*) have been restrained to a thin layer of a few meters.

Discussion & Conclusions

There are some common major fault zones that have been delineated along both sections (Fig.2). The **West Cycladic Detachment System** seems to have been identified, along which the underlying metamorphosed *Metamorphic Unit* is moving upwards relatively to the overlying tectonic units of *Ypopelagoniki, Athens* and *Alepovouni*. The Athens Schists (*SchA*) or the schists of *Alepovouni Unit* (*Sch-Al*) are mostly located overlying. On the other hand, the lithologies of the *Metamorphic Unit*, such as dolomites (*D*), schists (*Sch*) or even marbles (*M*) are underlying. Furthermore, at the first part of the sections three or four **upthrusts** between the Triassic-Jurassic limestones (*T-J*) and the Shales and Sandstones alterations (*C-P*) seem to have been identified, with different thickness. Beyond that, along both sections we can also observe the existence of a **thrust fault** where the Athens Schists (*SchA*) of the *Athens Unit* overlay tectonically the *Ypopelagoniki Unit.*

The results of the 2.75D interpretative profiles and the 3D density models are quite impressive and revealed important subsurface structures that provide new geotectonic data of Athens basin subsurface for depths more than 2,500 meters. Several fault zones already mapped are verified by these models (Dilalos, 2018) and more information about their characteristics might be gained (e.g. throw, depth and dip). But the most significant contribution is that they also validate the existence of several fault zones mapped as possible (blind faults), based on other criteria.

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