Preparation Study Based on Borehole Data for Delphi-Distomon Mining Area to Better Design Geophysical Works

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Summary

Europe is in need of fresh aluminum for its vast variety of developments and Greece has the potential to deliver. Delphi Distomon S.A is one of the largest bauxite producers in Greece and is interested to explore new deposits in new unexploited areas. Logistics, accessibility, environmental issues and high cost are key obstacles in the application of a high-definition 3D active seismic survey. Hence, an alternative integrated method of exploration will be carried out based on gravity, magnetotelluric and passive seismic methods. As a preliminary step for an optimized acquisition scheme, a dynamical approach is followed that utilizes a lithology model created by available drilling data, its transformation to a density one, the forward modelling and the comparison of the synthetic data with a previous gravity study in the area. The preliminary results of the analysis gave the chance to identify the vulnerabilities of the lithology and the equivalent geophysical model. As it was observed, they should be enriched during the survey with additional geological information and in situ observations. The emerged models can contribute remarkable to the stage of the processing of the different geophysical methods as well as the final stage of the integrated interpretation.

Introduction

Europe is in need of fresh aluminum (and alumina: aluminum oxide) for its vast variety of developments and Greece has the potential to deliver. The exploitation of bauxite ore found in the Greek territory bears an important mining tradition going back to early 1930's. It is a major asset of the Greek mining industry and for years bauxite was the most important Greek mineral commodity, in terms of value of production and export sale values, being a consistent pillar of the national economy of Greece. Delphi Distomon S.A., a subsidiary of Aluminum of Greece, is one of the largest bauxite producers in Greece and in Europe (650,000 tons annually) and is interested to explore new deposits in new unexploited areas.

The area to be investigated, Gerolekas, sits within the overlap of the geological structure of Parnassus–Giona zone situated between Giona and Parnassus mountains (Figure 1a). Currently, there is no information below the depth of 400m on the continuation of the bauxite deposits and knowing this will be of a great help in future planning and sustaining mining activities in the site. An area about 25km^2 will be investigated. Any new discoveries in the area will help to sustain Al market of Delphi Distomon.

Logistics, accessibility, environmental issues and high cost are key obstacles in providing high-definition geophysical results using a full 3D active seismic survey in Gerolekas. Hence, an alternative integrated method of exploration will be carried out based on gravity, magnetotelluric and passive seismic, in areas where such information is difficult or even impossible to acquire, accepting a cost of low resolution due to sparse sampling. The integration of geophysical methods and geological-geotechnical information will provide a Unified Geophysical-Geological Model that can assist into the delineation of the interface between flysch and upper limestone.

As a preliminary step for an optimized acquisition scheme, a specific procedure is followed, by a) the creation of a lithological model using available drilling data, b) its transformation to an equivalent geophysical model (a density one at this point) c) application of forward modelling with different grid sizes and interstation distances d) comparison between synthetic and pre-existing gravity data, measured in the survey area.

This is a bidirectional procedure which provides additional useful information about the validity of the derived lithological model, the effectiveness of the acquisition grid and an indicator for a correct selection of density values for the corresponding lithological units. The preliminary results of the aforementioned approach are presented in this study

Geological setting and description of the study area

The Greek bauxite deposits are mainly hosted within carbonate rocks and are part of the wider Mediterranean karstic bauxite belt. They are mainly found within the Parnassus – Ghiona geotechnical zone, in the mountainous areas of Parnassus, Helikon and Ghiona. Bauxite horizons are deposited in the underlying irregularly shaped karstic limestone formation, having a pocket-like, lenticular form, which usually is interrupted by faults at depths varying from 70 to 400m in the wider target area (Figure 1c). The materials that are explored and exploited are: (i) upper cretaceous limestone as hanging wall of bauxite, (ii) mid cretaceous limestone as the footwall of bauxite, and (iii) bauxite diasporic (monohydrated) for metallurgical purposes.

The deposits are considered to be allochthonous (Aronis, 1955) as a product of the laterisation of ophiolithes found in eastern Greece, which were transported and deposited into karstic cavities of the underlying limestone in the Parnassus region. This took place during different geological periods and thus three separate bauxite horizons have been formed (Benardos and Katopodis, 2011), "b1" (lower) horizon between the calcareous Middle and Upper Jurassic units, "b2" (intermediate) between the Upper Jurassic - Kimmeridian and Tithonian limestone formations and "b3" (upper) bauxite deposits found between Cenonmanian and Turonian - Senonian units (Middle and Upper Cretaceous). From the three bauxite horizons, only the two upper ones (b2, b3) present significant value in terms of mineable reserves. The upper horizon (b3) is the most important one and contains bauxite of diasporic type, while the bauxite of the intermediate horizon is characterized as boehematic.

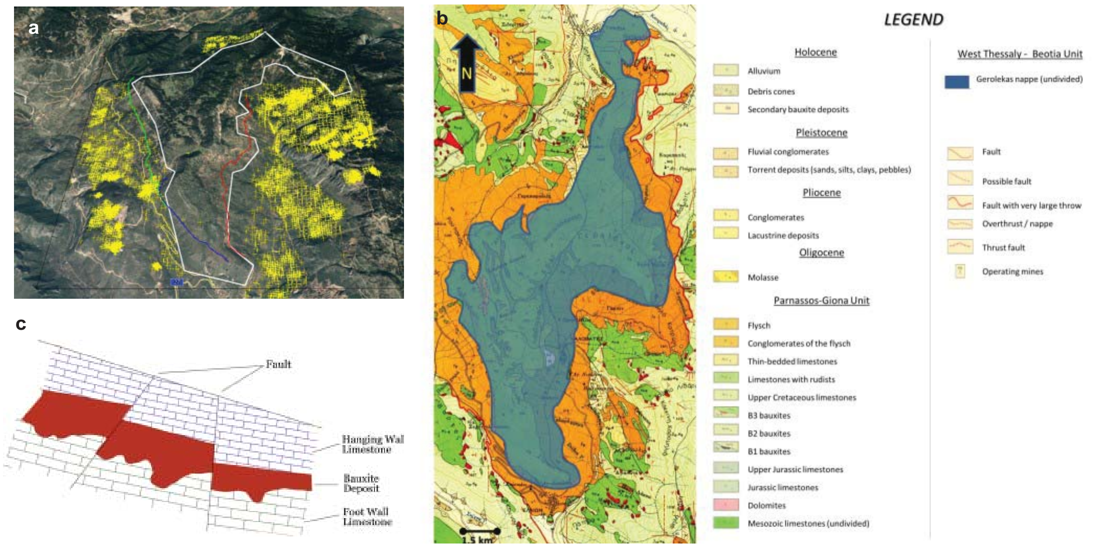

Figure 1 *a) The survey area on Google Earth map, showing the position of the boreholes (yellow crosses) and the 3 gravity profiles(red, blue, green lines) in respect with the limits of the over-thrust zone (white line) b) Geological Map of the survey area c) a simplified sketch of the bauxite deposits among the two limestone formations (Hanging and footwall limestone).*

Gerolekas nappe consists of various Jurassic-Cretaceous carbonate series that were merged in a single unit during the Late Jurassic – Early Cretaceous due to the widespread deposition of an early flysch. The kinematic behavior of Gerolekas nappe is being controlled by the activity of four tensile neotectonic faults (Figure 1b) that force it to sink relatively to the surrounding flysch of Parnassus-Giona unit.

Construction of lithological model

A catalogue of 4050 boreholes containing their exact position, elevation, total depth, as well as the lithological unit that was drilled at each depth, was provided by Delphi Distomon S.A. All the data, after the exclusion of a few spurious ones, were transformed to a proper form for further analysis, using Rockworks software (Rockware, 2014).The lithology units (Table 1) were kept same as characterized by the company's geologists, except from minor changes made in a few boreholes, based on the existing geological map. The spatial distribution of the strip logs of each borehole are presented on figure 2a. Using a grid cell 200x200x50 meters (x,y,z step) a 3d lithology model was created, assigning lithology types to solid model nodes, regarding their distance from a borehole. "Outlying" nodes, positioned beyond a cutoff distance (the distance between a well and its closest neighboring well), were assigned a zero, thus making them invisible in the output model. The 3d lithological model and selected cross sections in the survey area are presented in Figure 2b,c in respect with a geological sketch, provided by the company, that crosses Gerolekas nappe (Figure 2d).

As it can be shown, the similarity is obvious. By the constructed lithological cross section, is suggested that the thickness of the overlying flysch is approximately 900 m, which agrees with the one of the proposed geological scenarios in the area. Nevertheless, as the model in this area is the result of the interpolation of lithological units by quite long distant boreholes, the uncertainty is significant. The proposed integrated geophysical survey is a cost effective way to minimize the uncertainty, specifying the thickness of the overlying flysch and confirming the different geological scenarios in the area.

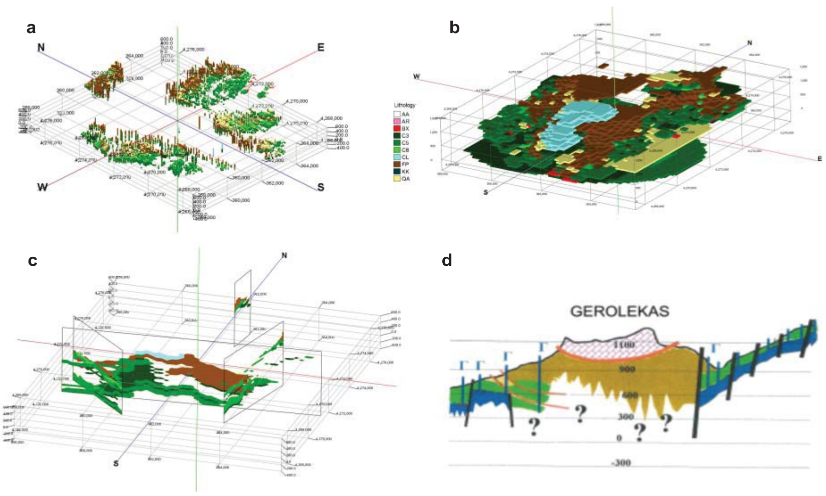

Figure 2 *3-D representation of a) strip logs of available boreholes b) the derived lithology model c) selected cross sections d) geological sketch map crossing the survey area .*

Lithological Units	Code
Alluvium -quaternary (qa)	*QA*
Flysch (fp)	*FP*
Maastrichtian limestone (c8)	*C8*
Upper Cretaceous limestone –hanging wall (c5-7)	*C5*
Clay (ar)	*AR*
Bauxite (bx)	*BX*
Mid Cretaceous limestone- foot wall (c3-4)	*C3*
Void	*KK*
Undefined	*AA*
Tectonic cap- Beotia unit	*CL*

Table 1 *The various lithological units that exist in the borehole database.*

Synthetic Gravity Data

After filling the gaps in the lithology model using an interpolation technique (closest point), a density value was assigned to each lithology unit (2.55 gr/cm^3 for flysch, 2.716 gr/cm^3 for cretaceous limestones and 2.655 gr/cm^3 for tectonic cap), based on previous studies, leading to the 3d density model of the survey area (Figure 3b). Afterwards, the Bouguer anomaly for various interstation distances (250m, 500m, 1000m) was calculated using Grablox software (Pirttijärvi, 2008). The best compromise between the number of measurements and the quality of the calculated gravity anomaly seems to be at a 500 m interstation distance. The calculated Bouguer anomaly in respect with borehole position and the limits of Gerolekas‘ nappe is presented in Figure 3d. Three lines are also depicted (blue, red, green), which correspond to the approximate position of three gravity profiles that have been measured in a previous geophysical study in the survey area. According to the previous study report, the gravity anomalies represent the complete Bouguer anomalies (mgal), without still knowing the base elevation used for the corrections. In addition, the x- axis corresponds to shot points (gravity stations) rather than real distance, complicating even more the direct comparison between the synthetic data (600m base elevation complete Bouguer anomaly), with the three measured gravity profiles in the area.

Nevertheless, taking the above aforementioned issues into consideration, it is concluded that: a) even though, differences exist between measured and calculated values (Figure 3a&c), the trend of the anomalies are similar, reinforced the validity of the lithology model. b) The relative maximum variation of the anomalies has a significant difference especially in profile 3 (in area with the lowest borehole coverage), indicating the need of adjusting density values related to each lithology units or/and reforming lithology model, utilizing additional information from available geology maps or in situ observations.

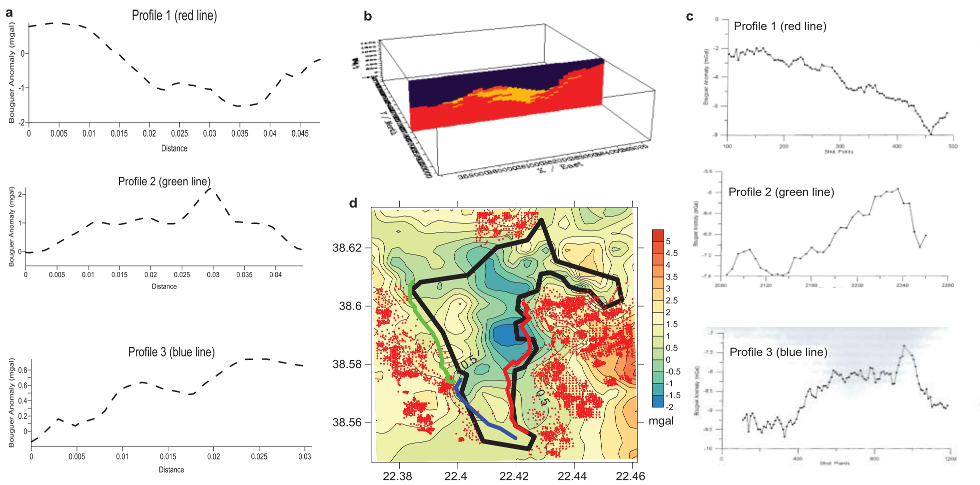

***Figure 3** a) Synthetic data of the three profiles (red, green, blue line) b) the density model used for the forward modelling c) the measured gravity data (Bouguer anomaly) of the three profiles (red, green, blue line) d) the calculated Bouguer anomaly using the derived density model by the boreholes analysis with an interstation distance 500 m .*

Conclusion

By following a dynamic approach, it was possible on one hand to select the optimum interstation distance for the gravity survey and on the other hand to confirm the validity of the constructed density model. Furthermore, this bidirectional procedure that utilise the lithology model, its transformation to a density one, the forward modelling and the comparison of the synthetic data with a previous gravity study in the area, gave the chance to identify the vulnerabilities of the lithology and the equivalent geophysical model. As it was observed, it should be enriched during the survey with additional geological information and in situ observations. The lithology model could also be transformed to a seismic velocity or resistivity one, using existing empirical functions or even by the application of in situ measurements at the surface or inside the mining galleries. The emerged models can contribute remarkable to the stage of the processing of the different geophysical methods as well as the final stage of the integrated interpretation.

Acknowledgments

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