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Geophysical Methods to Improve Productivity of a Marble Quarry

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SUMMARY

Marble is probably the most popular ornamental stone in the world. Technological evolution in the extraction techniques resulted in significant improvements with regard to productivity and quality of the commercial blocks. In order to improve productivity, through the early detection of fractures in the cutting procedure, geophysical methods like GPR, EM and ERT have been tested in “Dionyssos” quarry with its famous worldwide marbles which have been used for Acropolis of Athens construction. GPR method is in its favorable environment to see ahead and identify regions with or without cracks with the suggested processing resulting to sections easily understood by engineers. ERT method can lithologically identify the medium with the only problem the high electrode contact resistance while EM method is fast and cheap giving though less information.

Introduction

Marble is probably the most popular ornamental stone in the world. The Ancient Greeks were among the first civilisations, which noticed the unique properties of this stone and have started exploiting it systematically. The extraction methods used in ancient times are not known. Nevertheless, according to findings and studies concerning the ancient quarries, the procedures did not differ much from those applied a few years ago, before the extensive use of the modern quarrying machinery (Laskaridis, 2004), since the main aim was always the extraction of a block from the solid rock with as little damage as possible (Menegaki and Kazatsanidis, 2009).

Technological evolution in the extraction techniques resulted in significant improvements with regard to productivity and quality of the commercial blocks. The most significant technological development was put into practice when diamond wire cutting started being used in the '70s. Since then, there is a continuous attempt for further evolution based either on current technologies equipped with modern tools and parts (e.g. diamond wire configurations) or on completely new technologies. Despite the generally modern extraction equipment, the recovery percentage of the marble deposits is relatively low due to the rock mass discontinuity spacing. Moreover, the quality of the commercial blocks, thus, their marketable value, depends on the properties of the rock and the formation. The detection of heterogeneities and discontinuities in an early stage of the procedure is a critical factor in achieving better results.

The paper examines the case of the "Dionyssos" marble open cast quarry, which is located at the Penteli Mountain. The company exploits a white to semi-white marble statigrafically overlying the famous "Pentelikon marble" also known as "Bianco di Pendeli" or "Marmo Greco Fino", which has been widely exploited during classic antiquity and the Hellenistic period and has been used in the construction of the Parthenon, the Erechtheion and the Propylaea on the Acropolis of Athens and other ancient Greek cities. Pentelikon marble has been also used in structures all over the world (eg. House of Worship in New Delhi, India, Fig. 1b).

a.  b. 

Figure 1 *a) The 5th century BC Acropolis, Athens, b) House of Worship in New Delhi.*

The "Dionyssos" quarry is in the "Almyropotamos-Attiki" autochthonous unit (Fig.2) which is a big unit of formations occurring at the internal zones area in form of tectonic windows that belongs to the huge platform of Gavrovo-Tripolis zone. It consists of a series of Mesozoic to Middle Eocenic marbles, of great thickness accompanied by metaflysch formations and metamorphic Lower-Middle Triassic and possibly Upper-Paleozoic formations, which constitute its basement (IGME, 2002).

The marble extracted from the "Dionyssos" quarry is white calcitic and belongs to the so-called "lower marble" horizon. The main tectonic characteristic of the quarry area is the existence of an upfold with a south-western to north-eastern orientation as well as the variety of natural fractures that cut into pieces the marble area, resulting in the low recovery rate of high quality marble blocks.

In order to improve productivity, through the early detection of fractures in the cutting procedure, Dionysos Marbles SA has collaborated with the School of Mining Engineering and Metallurgy of National Technical University of Athens.

Geophysical methods like GPR, EM and ERT have been tested and a setup has to be proposed in order a non-geophysicist to use a detecting device for looking ahead of the excavation.

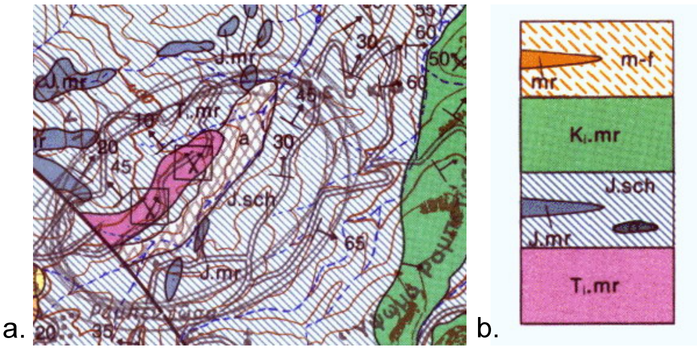

Figure 2 a) *Part of the geological map "Sheet Kifisia" (IGME, 2002),* ***b)*** *the "Almyropotamos-Attiki" autochthonous unit:* ***i.*** *Metaflysch formations (m-f) with marble (mr) intercalations,* ***ii.*** *NE/ern Attiki marbles (Kmr) hosting Fe-mineral ore deposits (Fe),* ***iii.*** *NE/ern Attiki schist formations (J.sch) with intercalations of marble (J.mr) and serpentinite (σ),* ***iv.*** *Penteli marbles (T.mr)*

Figure 3 *Dionyssos-Pentelikon. S.A. quarry (left) with the underground chamber (center and right). Yellow, blue and green lines denote GPR profiles while the red denotes the ERT profile.*

Geophysical survey

Open pit survey

On a terrace of the open pit area, on the wall, GPR profiles (in 1m and 1.7m height, yellow line in Fig. 3 and Fig. 4h) with MALA shielded antennas of 250MHz and 500MHz made to see ahead in 2-4m depth. The GPR method applied on marbles is benefitted since their resistivity is high with the desired targets cracks or cracked medium expected to easily be detected. In a part of the GPR profile an ERT profile is trying to lithologically identify various medium detected with GPR.

The processing of the GPR profiles with antennas of 250MHz and 500MHz with REFLEXW software (Sandmeier, 2012) is: a) subtract mean (dewow), b) correct max. phase, c) move start time, d) energy decay, e) bandpass butterworth, f) background removal, g) spectral whitening and h) fk migration (stolt). Both GPR sections (at 1m height) with the two antennas look identical (Fig 4 a,b) with the one of 250MHz going deep (3m) but showing cracked regions (mesh of reflections) and cracks in a broader area (Fig. 4a) rather than their finer detection in the one of 500MHz (Fig. 4b) with less detection depth (2m). Further processing of the migrated sections with Hilbert transformation and instantaneous amplitude distribution (Fig. 4c,d) gives a GPR picture of the marble detected volume quite better understood to the mining engineers responsible for excavation.

EM measurements (Fig. 4e) at the same line of the GPR profile with conductivity meter GF Instruments (CMD-2 with both coil orientations) show that in the areas of the marble the GPR section is without reflections we have stable EM measurements while cracks or cracked regions increase apparent conductivity and we have undulations in the EM measurements.

The ERT section (Fig. 4f) with dipole-dipole electrode array, in part of the GPR profile, shows very similar picture outlining the high resistivity values undisturbed marble (lack of reflections in the GPR sections) and the cracked regions with decreasing resistivity values. Finally the electrodes used (Fig. 4g) were not the nails with conductive zele at 1m height (very high contact resistance) but electrodes at the bottom corner of the terrace resulting to the high magnitude of resistivity values (not semi-infinite medium). Bentonite electrodes (Tsourlos and Tsokas, 2011) will be tested.

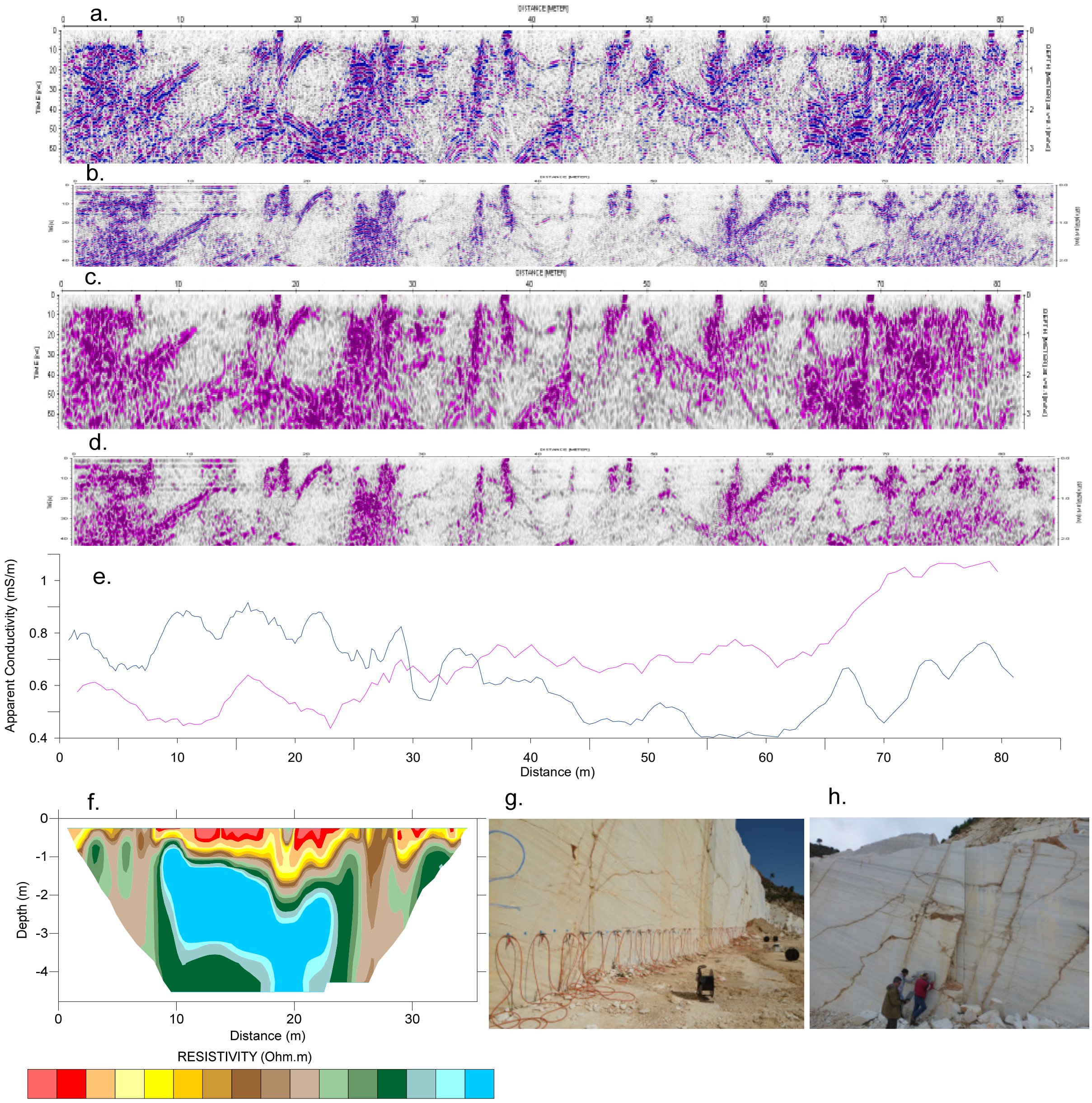

Figure 4 *At the wall of a terrace in the open pit, processed GPR sections until migration for 250MHz (a) and 500MHz (b) antennas and after Hilbert transform (c) and (d) respectively, EM measurements (e) in the same line as GPR profile show the change of apparent conductivity with distance (red line VCP, blue line HCP), ERT section (f) in part of the survey line, photo with ERT electrode setup (g), photo of the GPR measurements with 250MHz antenna.*

<u>Underground chamber survey</u>

Two areas at the entrance of the underground chamber and at the head wall of excavation (Fig. 3) were detected by GPR method. Following the previously referred processing procedure and including and Hilbert transform in order to be presented to the engineers we conclude in the 3D presentation of GPR profiles shown in Fig 5. Same conclusions with the similarity of the GPR sections for both antennas, finer detection with 500MHz especially for the cracks, deeper detection with 250MHz.

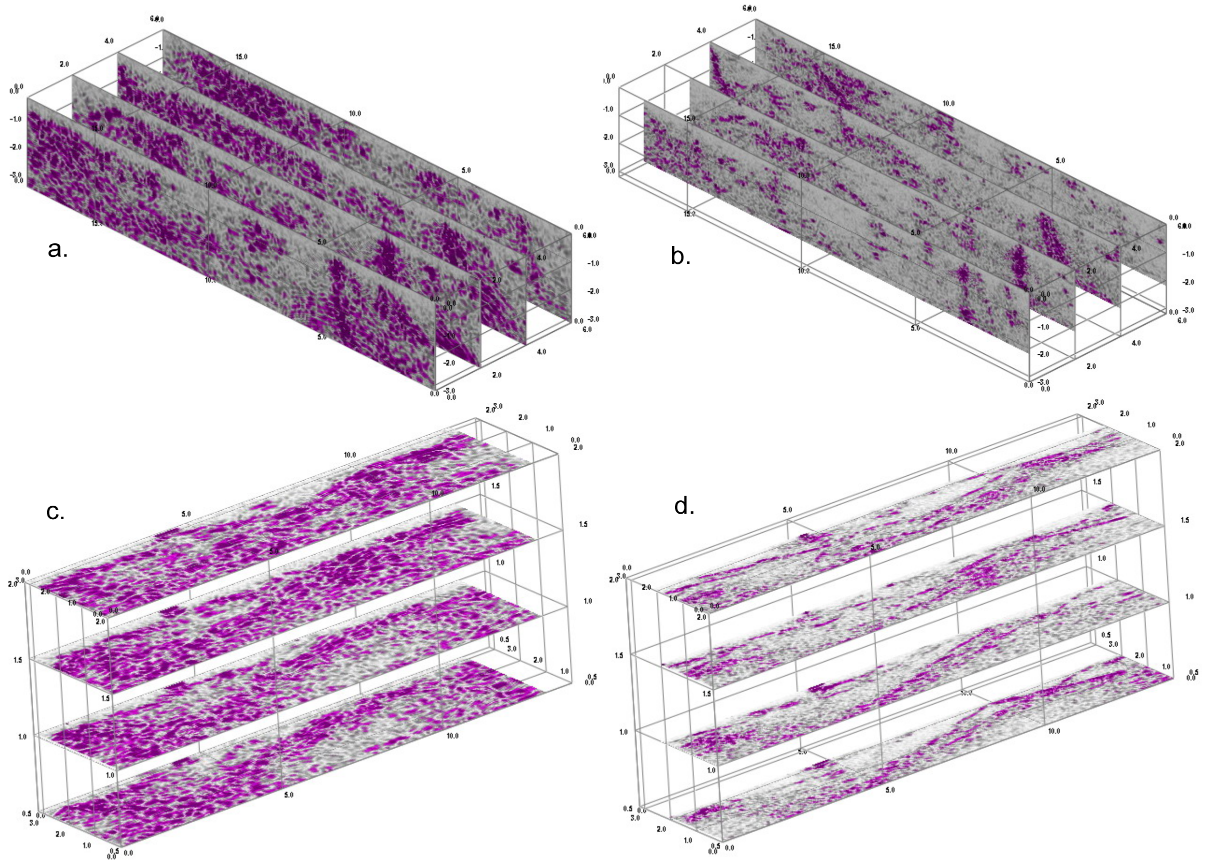

Figure 5 *3D presentation of GPR sections down at the entrance of the underground chamber (a) with 250MHz (a) and 500MHz (b) antennas and at one of its walls (c) and (d) respectively.*

Conclusions

GPR method is in its favourable environment to by applied in a marble quarry to see ahead and identify regions with or without cracks with the suggested processing resulting to sections easily understood by engineers. The 250MHz antenna has the desired detection depth (3-4m) and the 500MHz antenna gives sections of better quality. ERT method can lithologically identify the medium ahead of the excavation with the only problem the high electrode contact resistance. EM measurements is a cheap and fast method of identification of the space ahead with less information.

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References

Laskaridis, K. [2004] *Greek marble through the ages: an overview of geology and the today stone sector, in Dimension stone*. Taylor & Francis Group: London, edited by Přikryl, 67-72.

Menegaki, M. and Kazatsanidis, L. [2009] Comparing alternative cutting technologies in marble quarries. Proceed*ings of the 18th International Symposium on Mine Planning and Equipment Selection (MPES 2009)*, Banff, Alberta, Canada, 531-538.

Sandmeier, K.J [2012] *REFLEXW – software for the processing of seismic, acoustic or electromagnetic reflection, refraction and transmission data*. http://www.sandmeier-geo.de/.

Tsourlos, P.I. and Tsokas, G.N. [2011]. Non-destructive Electrical Resistivity Tomography Survey at the South Walls of the Acropolis of Athens. *Archaeological Prospection*, **18**, 173-186.