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Geophysical prospecting in the Krousovitis dam (N. Greece) by seismic and resistivity methods

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Abstract: *The use of two geophysical methods in the investigation of the geological setting in the area of a dam foundation is presented in this study. The seismic method was used in order to map the structure of the upper layers near the riverbed. VES and resistivity tomographs were also carried out. The depth to the basement was estimated by interpreting the VES curves. Interpretation of the topographic images, along with the inferred models from the seismic data, revealed the thickness of the colluvial deposits.*

Key Words: *Seismic, VES, Resistivity Tomography, Dam Foundation.*

INTRODUCTION

The necessity of controlling the water flow in order to cover the agricultural activities is increasing. For that reason, dams are usually built in areas, which are close to the upper and middle part of rivers. The present paper is dealing with such a case in N. Greece. More specifically, geophysical prospecting was applied to clarify the near surface geological setting in the area where a dam is to be constructed on the Krousovitis River. This river flows southwestwards and joins up the Strymon river, one of the biggest rivers in Greece (Fig. 1) (Wessel and Smith, 1995).

The geophysical prospecting methods are commonly used in the sites of foundation of dams. They are aiming to map the subsurface geological formations in order to minimise the suggested boreholes. These informations are used in the initial stage of the whole study in order to re-evaluate the suggested position for the foundation of the dam.

For these reasons three geophysical methods were applied for the particular study, namely, the seismic method, the resistivity tomography and the VES method. The first one is the geophysical method most commonly used in geotechnical works. Thus, refraction seismic along with the resistivity tomography method was used to assess the structure of the near surface layers. The VES method was mainly used to estimate the depth to the top of the basement. It was also used to add information about the layer thicknesses.

The dam of Krousovitis River is to be constructed across a small basin. The geological formations found are sediments of Cenozoic age (Fig. 2). The Neogene sediments cover the biggest part of the small basin. Olistholith (cohesive limestone conglomerates) is found in the southwestern part who forms the basin boundary. Approximately the watercourse of the Krousovitis River terminates the occurrence of the olistholiths to the east part of the basin. The Neogene sediments possibly overly the basement (gneiss or marbles) that is present in the broader area (Staikopoulos and Koukouzas, personal communication). Up-to-date colluvial deposits overlay the Neogene formation. These are accumulations caused by the erection of a small dam, presented in Figure 2. This old dam is inactive since the valley fill reached the upper level of the dam.

SEISMIC DATA

The StrataView of GEOMETRICS was used for

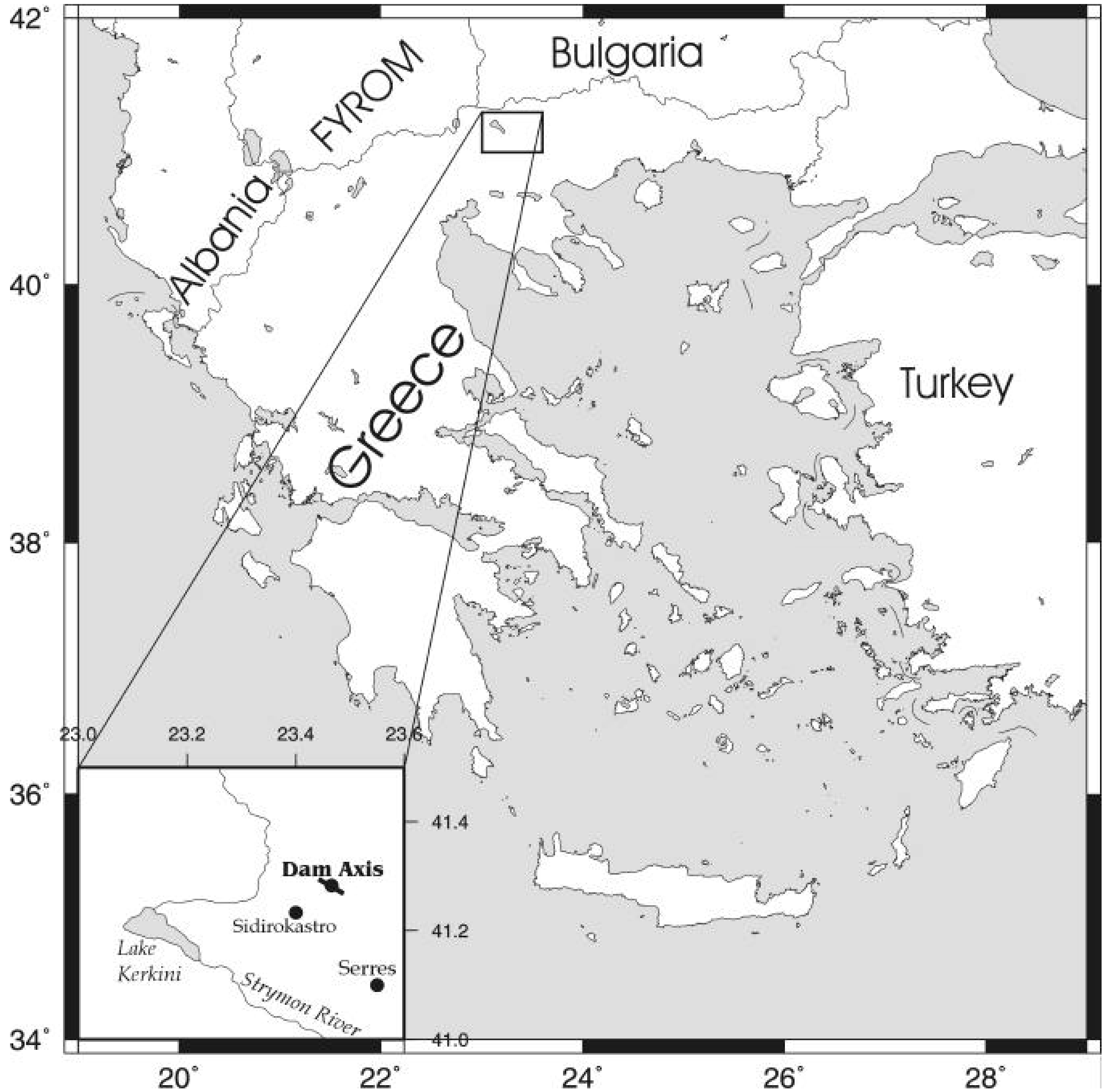

FIG. 1. Map of Greece showing the area of the foundation of the dam in the inlet. The axis of the dam has been also drawn. It is striking in the WNW-ESE direction approximately.

the acquisition of the seismic data. The geological setting of the area implies an increase of the seismic velocity with depth. For that reason the seismic refraction method was used as the most suitable method for the investigation of the near surface structure. A falling weight of 40 kg was used as source of P waves. The weight was let to fall freely from the height of 3 m

A total number of 12 seismic lines were conducted in the area of study (Fig. 3). The starting point of each line is marked with an arrow at the beginning of the line. The geophones spacing was equal to 6 m for lines 10 and 11; 4 m for lines 1, 2 and 4; 3 m for lines 5 and 6; 2 m for lines 3, 7 and 8; and 1 m for line 9. A setup of 24 geophones was used in all seismic lines except in line 9 where 12 geophones were used. Generation of elastic waves was carried out in at least three positions for each line. One position was at the middle of the line and the two others in the off-end mode at a distance from the line of geophones equal to the geophones spacing. The seismic data were processed applying the plus/minus refraction method (Hagedoorn, 1959; Gardner, 1967) and finally, were interpreted using the inversion method of Scott(1973). General information of the method used along with comparative results of the applied inversion method with other methods can be found at Scott and Markiewich(1990). All seismic lines investigated the structure down to the depth of 10 m approximately. The results from all seismic data show a 2-layer model with mean P velocities 250 and 2200 m/sec for the upper and lower layer, respectively. The formations of colluvial deposits and the Neogene sediments were attributed to these layers.

A first attempt for a 3-D model of the boundary between the colluvial deposits and the Neogene sediments of the area is presented in Figure 4. The model presented is implemented from the results of the seismic lines 1, 2, 3, 8 and 9. The exact positions of the seismic lines are presented with black solid

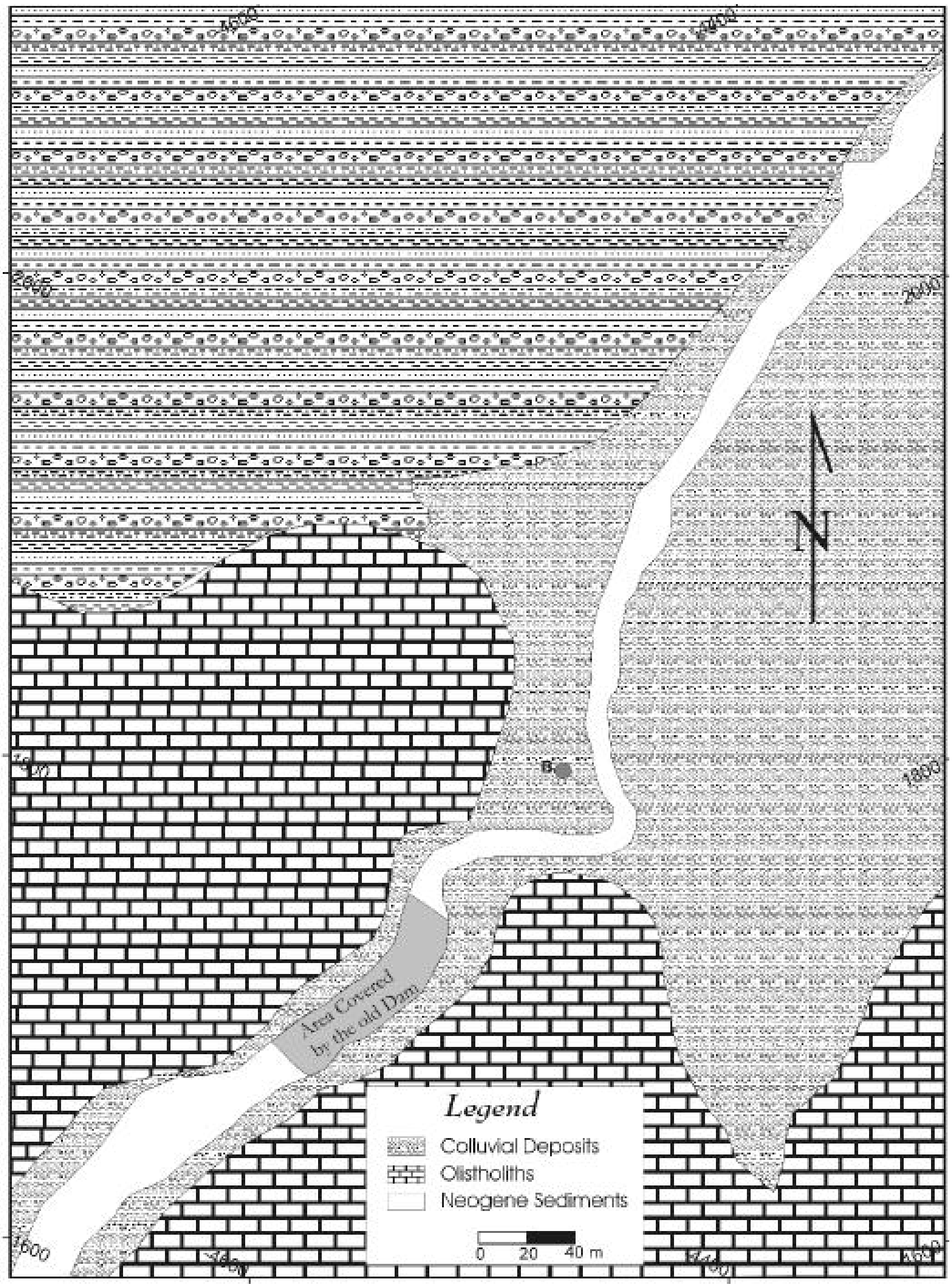

FIG. 2. Simplified geological map of the site where the Krousovitis dam will be built. The grey circle marked with **B** show the position of a borehole in the area.

lines and projections of these, onto the subsurface, with green dashed lines. Faults of a NW-SE direction is easily identified with a downthrow of approximately 2.5 m.

Another attempt for a 3-D model of the geological formations of the area is presented in Figure 5. The upper surface of the Neogene sediments is mapped. The model presented is implemented from the results of the seismic lines 4, 5, 6 and 7. The exact positions of the seismic lines are presented with black solid lines. The green dashed lines represent the 2-D model inferred from the respective line which, lays in the same vertical plane. Faults of WNW-ESE direction are identified. The faults show a downthrow of about 5 m in the western most part and reaches a minimum value of 2 m in the northeastern most part.

RESISTIVITY DATA

The pole-dipole method was used for the resistivity tomography measurements. That method was selected because it has a good resolution in the horizontal direction and a reasonably good resolution in depth (Ward, 1989). Also there is a good signal to noise

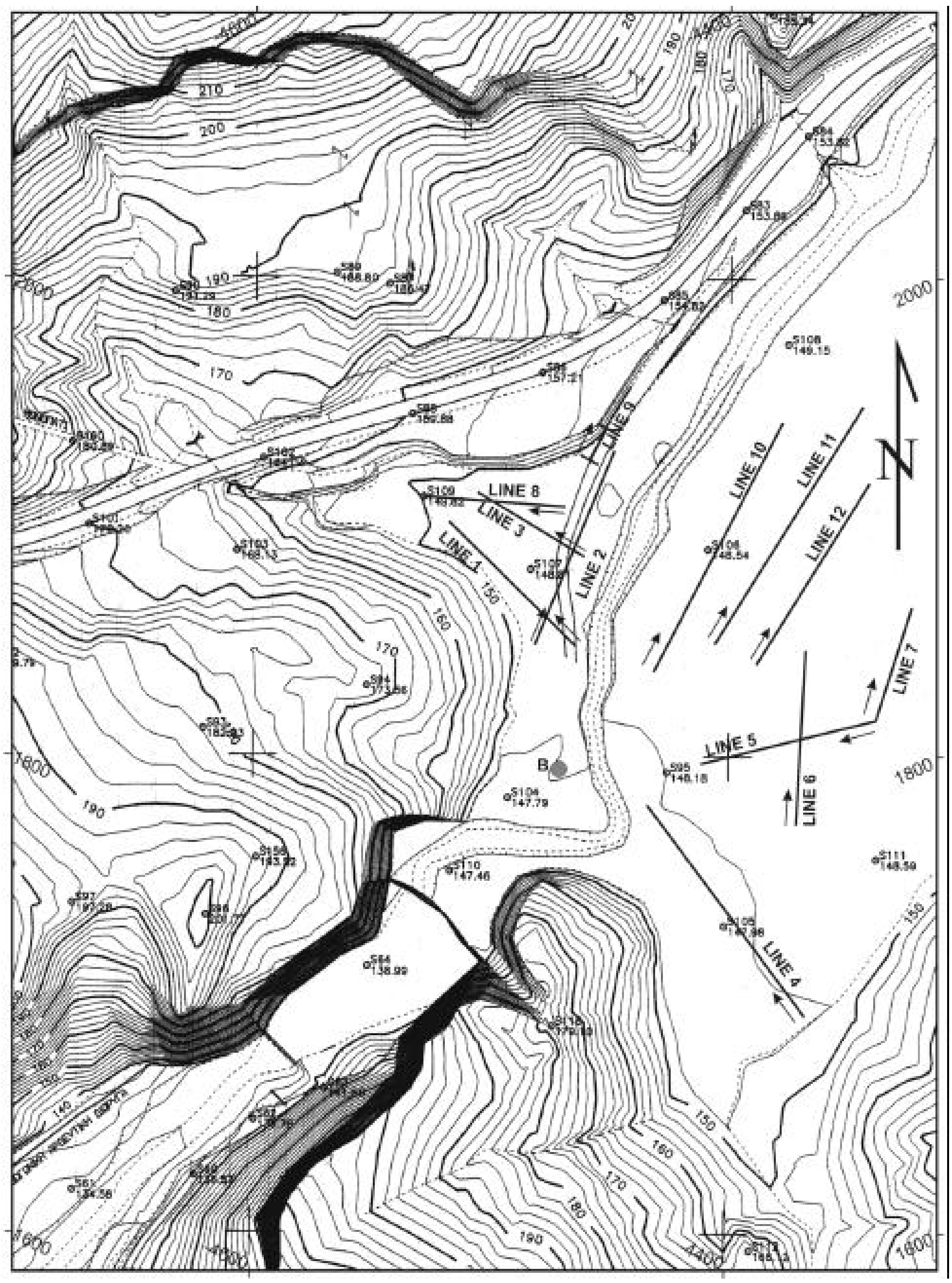

FIG. 3. Topography map of the area of study. The seismic lines are presented with dark lines. The arrow in each line shows the position of the first geophone. The grey circle marked with **B** show the position of a borehole in the area.

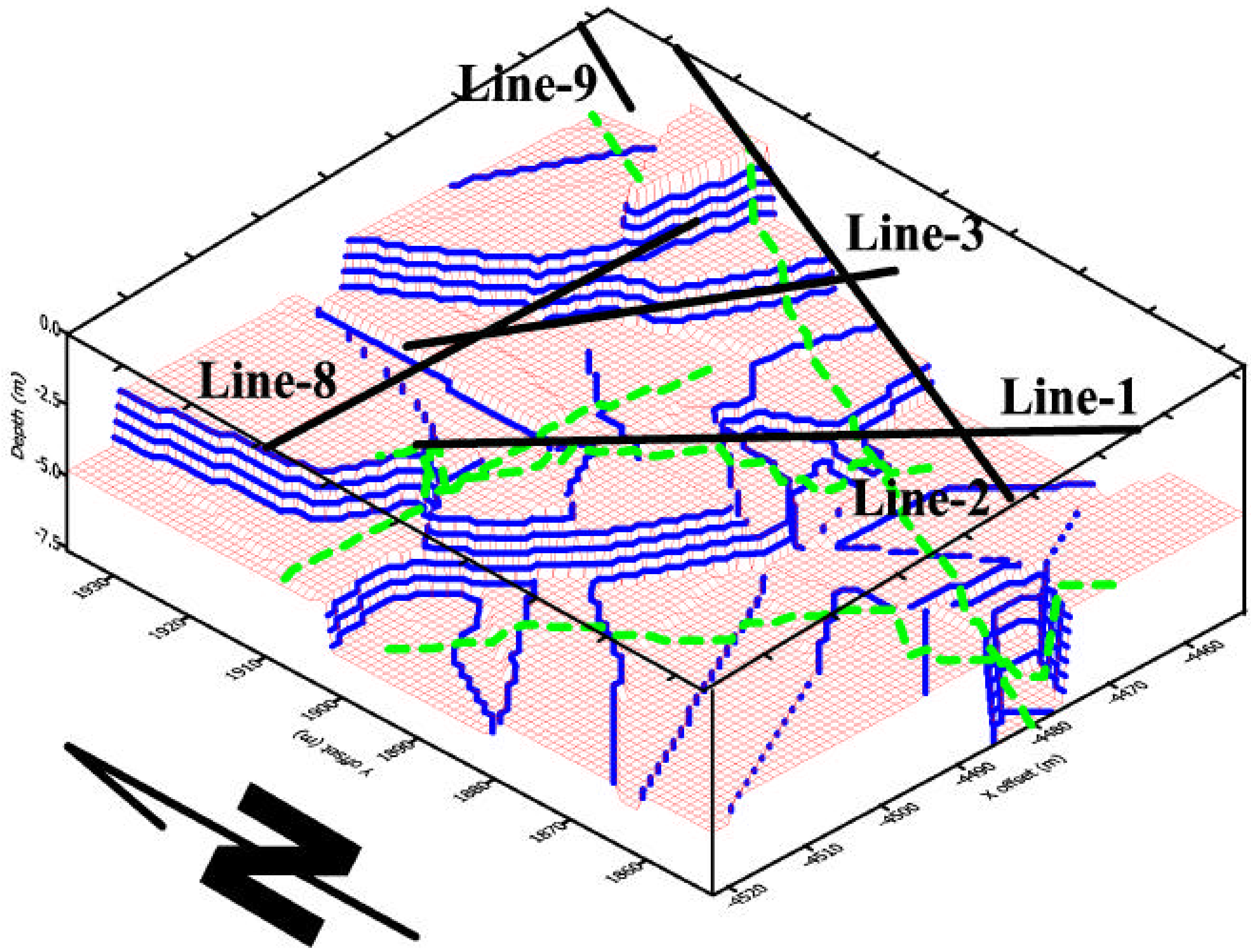

FIG. 4. The proposed 3-D model of the boundary between the colluvial deposits and the Neogene sediments for the area that has been investigated through seismic lines 1,2, 3,8 and 9. The blue colour denotes the possible fault planes inferred by the interpretation of the seismic data. The location of the seismic lines on the ground surface is shown by the black solid which are annotated by the respective names. The dashed green curves represent the interface between the colluvial and Neogene formation obtained by the respective line, i.e. each black seismic line and the corresponding 2-D model shown by a green line, both lay in the same vertical plane.

ratio that is important for the precision of the measurements.

The positions of the lines along which resistivity tomography was performed are shown in Figure 6. The distance between the electrodes was defined to 4 m for TOMO2 and TOMO3 with maximum distance (n) between the potential dipole and the current dipole equal to 18 dipoles (72 m). In TOMO1, the distance between the electrodes was 3 m and *n* was equal to 18 dipoles.

The data were interpreted using an inversion algorithm (Tsourlos *et al*., 1998) The algorithm used is for a two dimensional non-linear inversion and executes an iterative optimisation based on a finite element modelling procedure. The algorithm is fully automated based on Occam's inversion (Constable *et al*., 1987).

The misfit between the field data and the computed effect of the inferred resistivity sections was evaluated by means of the difference between these data sets. Small RMS values was evaluated for all resistivity tomography lines. The results after the inversion for TOMO1 are shown in Figure 7. The distribution of the resistivity values of the subsurface is presented for TOMO1. TOMO1 was carried out on the formation of the olistholiths. The high resistivity values in the NW part of the resistivity image reflect to the presence of Olistholiths in the corresponding location. The low resistivity values in the SE part of the section are due to slide rocks. A probable fault has caused this inhomogeneity of the subsurface resistivity distribution. The probable location of the fault is marked with a dashed black line in Figure 7.

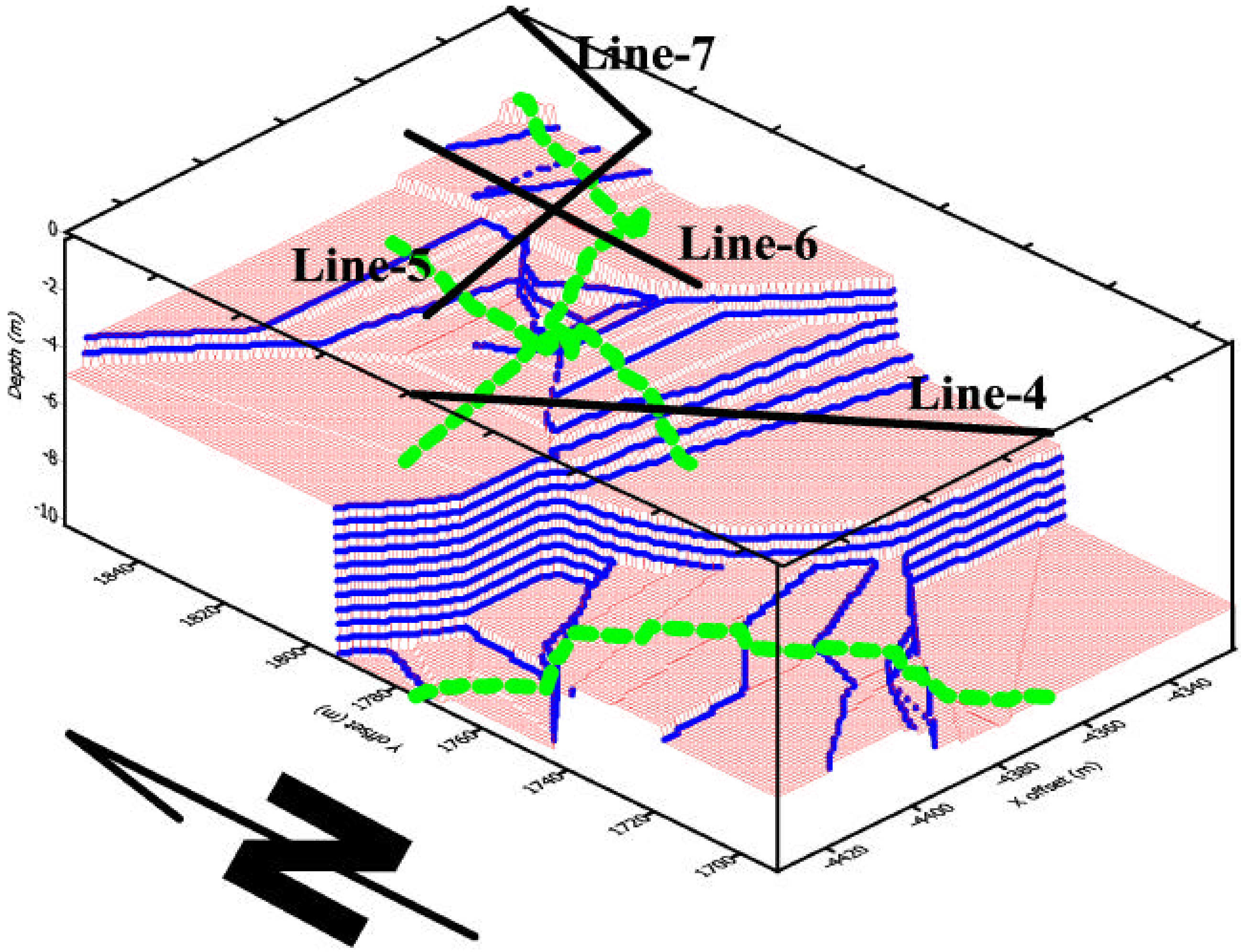

FIG. 5. The proposed 3-D model of the boundary between the colluvial deposits and the Neogene sediments for the area that has been investigated through seismic lines 4, 5, 6 and 7. The annotations are identical to those of Figure 4.

The resistivity tomography line TOMO2 was carried out approximately in the position of the proposed axes of the dam. This line is at the same position with seismic line 4. In Figure 8, the observed apparent resistivity data (A), model data (B) and the error distribution (in percentage of the observed data) during the calculation of the forward modelling (C) are presented. Two resistivity layers were identified after the interpretation of the resistivity tomography data (Fig. 9). In the upper part the formation of colluvial deposits is proposed with a thickness of 10 m. The relatively low resistivity in this formation is due to clay and sand in that formation which is found saturated. In greater depth a formation of high resistivity is present. That corresponds to the formation of the Neogene sediments. This result is in agreement with the stratigraphy from borehole (B) that is situated approximately 40 m NW to the end of TOMO2. The thickness of the colluvial deposits is increasing as we move closest to the bank of the river.

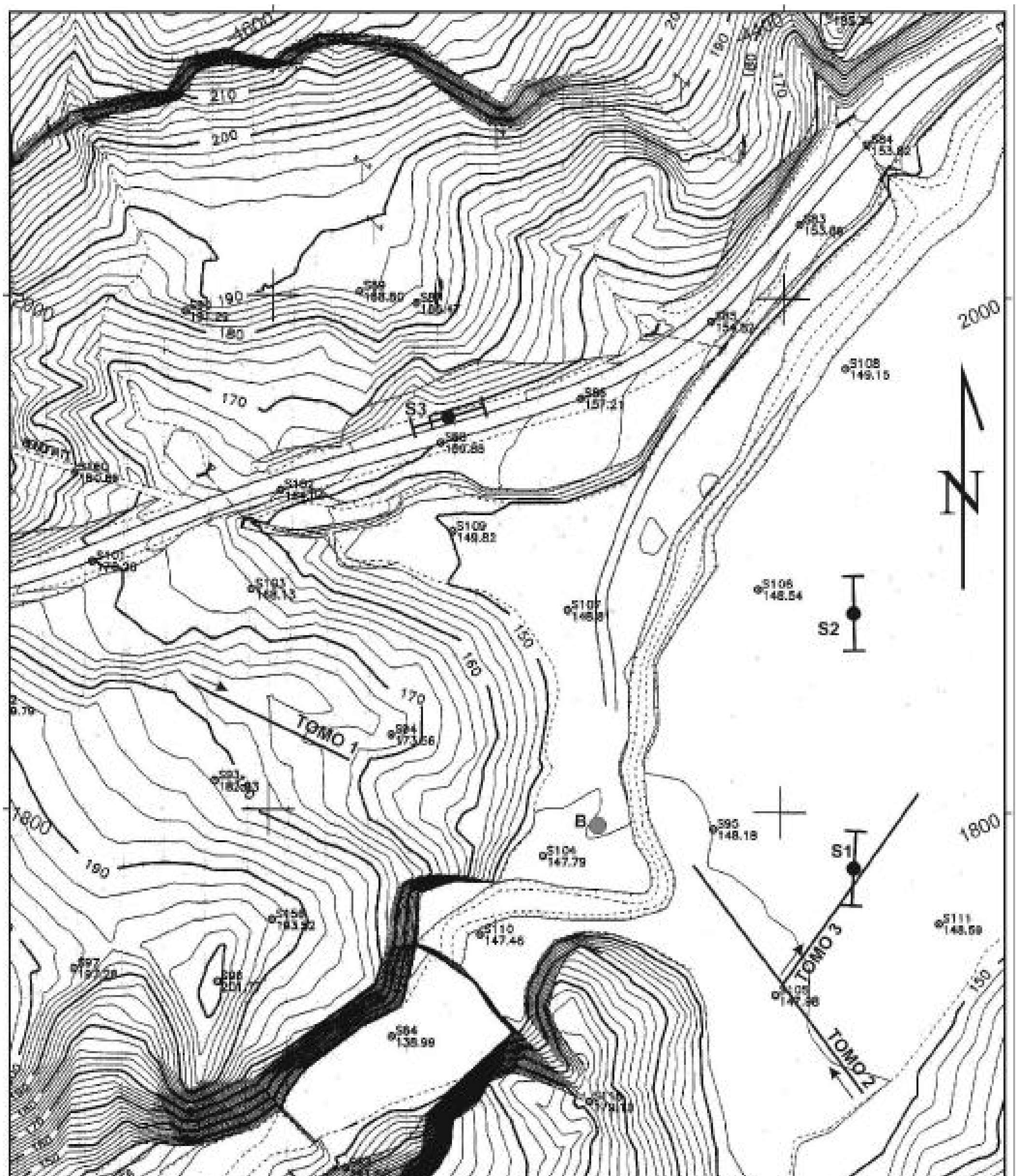

FIG. 6. Layout of the lines along which resistivity tomographs were carried out. These lines are presented as black solid lines. The arrow in each line shows the starting point. The dark circles marked with S and a number show the positions of the VES's. The grey circle marked with **B** show the position of a borehole in the area.

Table 1. Thickness of the geological formations as they inferred from the VES Data.

	S1	S2	S3
Colluvial Deposits	8 m	10.6 m	2.5 m
Neogene Sediments	68 m	92.4 m	108.5 m

Resistivity tomography line TOMO3 starts approximately at the middle point of TOMO2 and extents to the NNE (Fig. 6). The model proposed after the inversion (Fig. 10) is almost the same in the upper part with that obtained for TOMO2. This is expected since these two lines are very close. A depth of 10 m is suggested for the colluvial deposits in the upper part. The formation of the Neogene sediments is suggested for the structure in higher depth. The high resistivity values, till the depth of 20 m, corresponds to the upper formation of the Neogene sediments. The low resistivity image for depths greater than 20 meters is possibly due to another formation of the Neogene sediments that is saturated.

In order to reveal the structure below the Neogene sediments three VES were carried out at the locations marked as S1, S2 and S3 in Figure 6. The Sclumberger array was selected for this purpose. The thickness of the Neogene sediments and the depth to the upper part of the basement has been revealed (Table 1) by the inferred 1-D models. The depth to the basement was found equal to 76 m, 103 m, and 111 m for S1, S2 and S3, respectively. This information implies that the upper part of the basement is dipping to the NNE with a possible fault striking ESE-WNW between S2 and S1. This result is in agreement with the observed topographic relief in the western part of Figure 6.

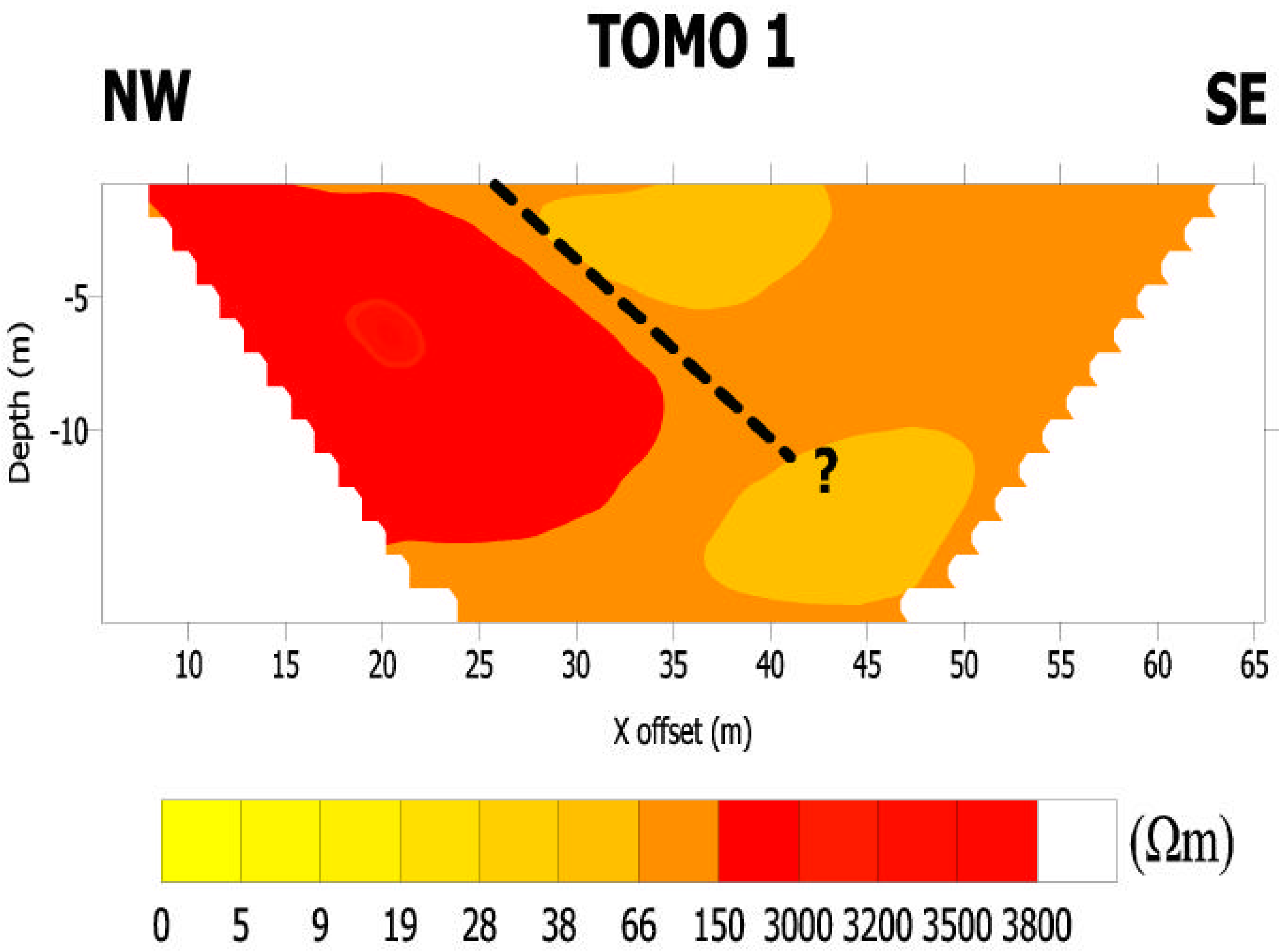

FIG. 7. Proposed subsurface resistivity image for the tomography line TOMO1. The dark dashed line in TOMO1 shows the position of a possible fault.

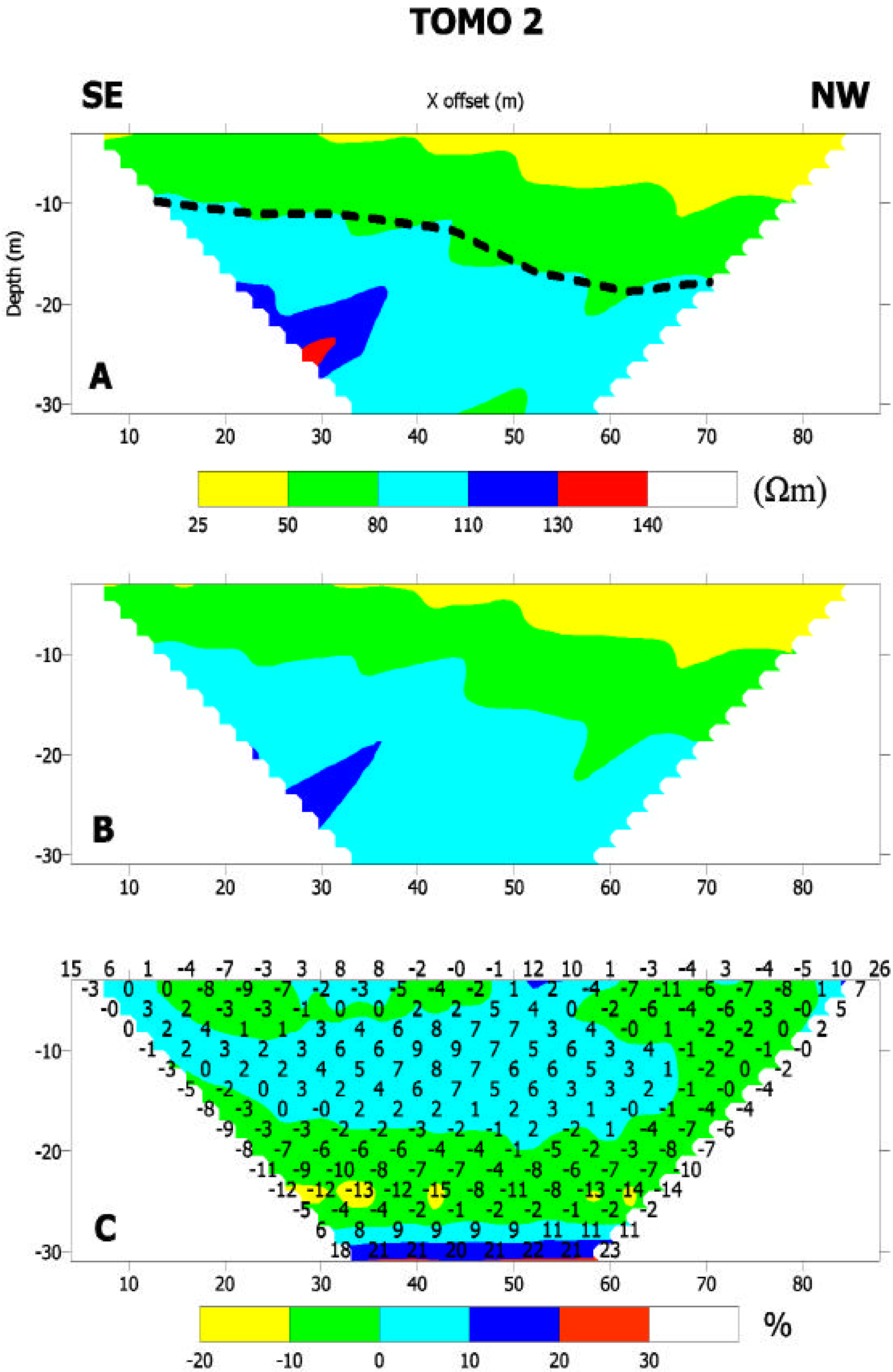

FIG. 8. Observed resistivity data (A), model data (B) and the error distribution (in percentage of the observed data) during the calculation of the forward modelling (C) for TOMO2.

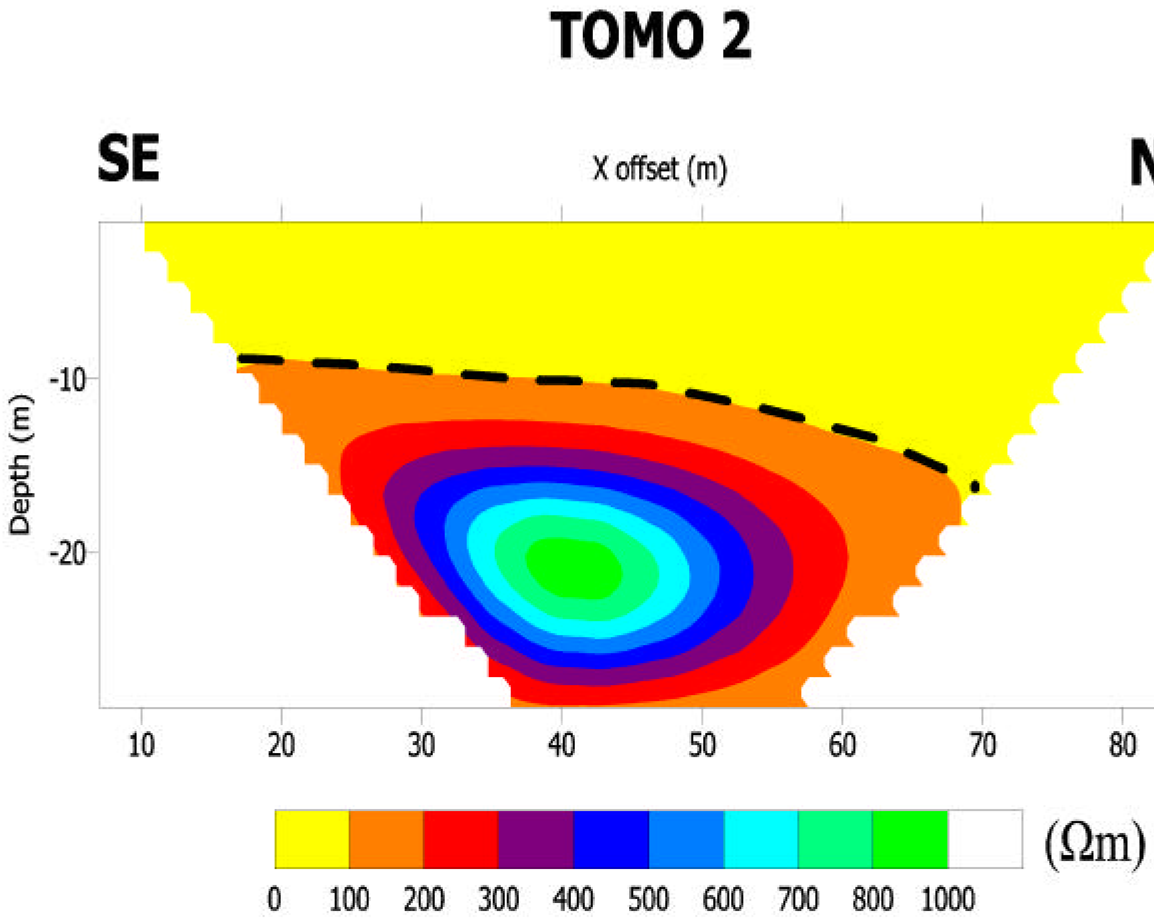

FIG. 9. Proposed subsurface resistivity image for the tomography line TOMO2

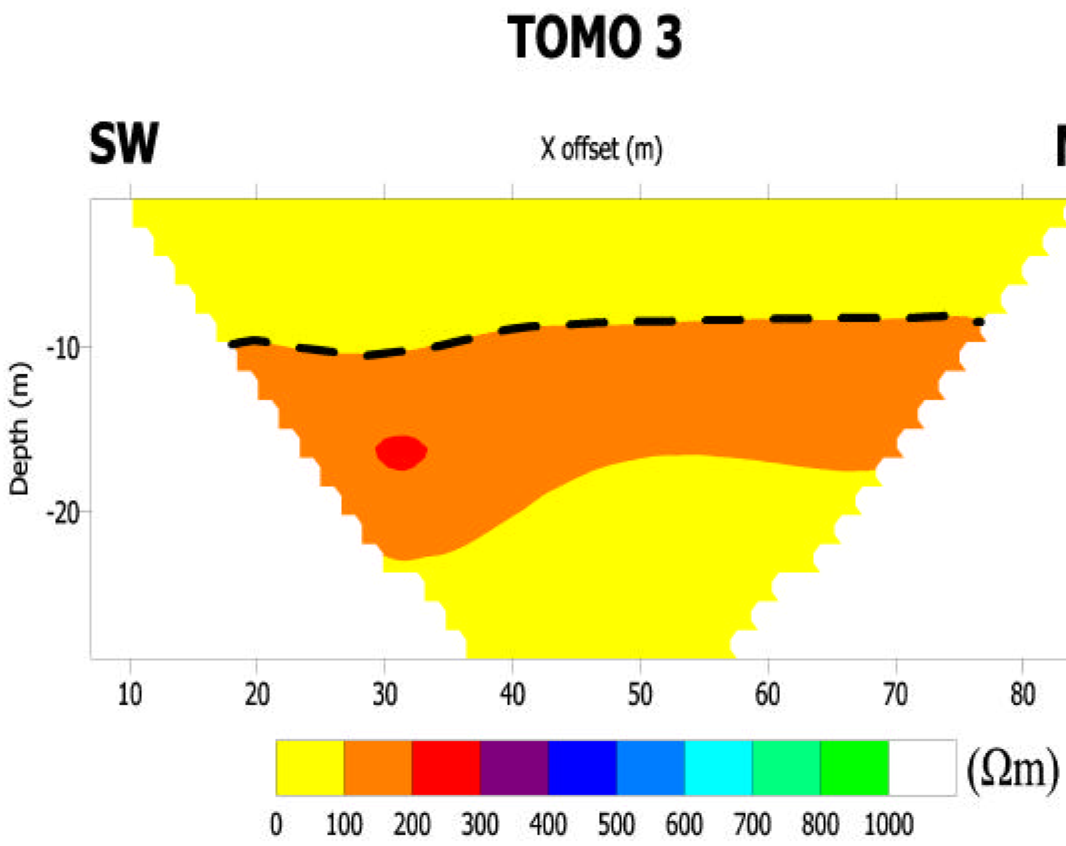

FIG. 10. Proposed subsurface resistivity image for the tomography line TOMO3.

CONCLUSIONS

The use of geophysical methods in the dam foundation shows their importance in geotechnical works. The case discussed here shows that the geophysical methods can provide solutions to the issues rising during the foundations of a dam.

The seismic data complemented by the resistivity tomographs revealed the boundary between the colluvial deposits as well as the main direction (i.e. WNW-ESE to NW-SE) of the faults in the area. Also, the thickness of the colluvial deposits was defined. These results agree with the stratigraphic column inferred by the existing borehole (B) in the area.

The depth to the top of the basement was inferred by the interpretation of VES carried out in the same area. The model inferred suggest the existence of a possible fault of the basement which, is between soundings S1 and S2.

The low cost of the geophysical methods along with the swift operation justifies their necessity, cost-effectiveness and availability at the construction stage of a dam.

REFERENCES

Burnett, D. S., 1989, Finite Element Analysis: Addison-Wesley Publishing Co.

Constable, S. C., Parker, R. L., and Constable C., 1987, Occam's inversion: A practical algorithm for generating smooth models for electromagnetic sounding data: Geophysics, **52**, 289-300.

Gardner, L. W., 1967, Refraction seismic profile interpretation: In. Seismic Refraction Prospecting, A.W. Musgrave, ed., Tulsa: Society of Exploration Geophysicists, 338-347.

Hagedoorn, J. G., 1959, The plus-minus method of interpreting seismic refraction sections: Geophysical Prospecting, **7**, 158-182.

Scott, J. H., 1973, Seismic refraction modeling by computer: Geophysics, **28**, 271-284.

Scott, J. H., and Markiewich, R. D, 1990, Dips and chips-PC programs for analyzing seismic refraction data: Proceedings, SAGEEP 1990, Golden, Colorado, 175-200.

Tsourlos, P., Szymanski, J. and Tsokas, G., 1998, A smoothness constrained algorithm for the fast 2-D inversion of DC resistivity and induced polarization data: Journal of the Balkan Geophysical Society, **1**, 3-13.

Ward, S., 1989, Resistivity and induced polarization methods: in Investigations in Geophysics No 5, Geotechnical and Environmental Geophysics, Vol. I, ed. S. Ward, SEG, Tulsa, 147-189.

Wessel, P. and Smith, W., 1995, New version of the generic mapping tools released: EOS Trans. Amer. Geophys. Union., 76-329.