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3D Geological Modeling using VES Data. An Application on Methane-Bearing Neogene Deposits at Arkalochori Region, Messara

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SUMMARY

A preliminary 3D geological model was constructed in order to explore gas potential at Arkalochori, central Crete. The 3D model concerns shallow Neogene sediments. Apart from geological data we employed borehole and VES measurements as well as pseudo-boreholes in an effort to construct litho-stratigraphic model. This model honors the main structural characteristics and the spatial distribution of Neogene deposits, specifically those that belong to Tefelion Group. A 3D lithostratigraphical model in combination with sedimentological observations could assist in delineating possible locations of gas accumulation so that they could be examined thoroughly in the future.

Introduction

Recent software developments have given rise to a series of studies and projects regarding the 3D reconstruction and visualization of geological structures. 3D geological models are used to comprehend complex geological structures and to carry out volume calculations. A database which contains any useful information is constructed for the definition of a dynamic 3D geological model. The precision and reliability of the final model is in accordance with the amount and precision of the initial data. The more complex a geological structure is the more data should you import into database. Actually, this is a usual problem in 3D geological modeling. Geophysical survey provides valuable datasets for the construction of a 3D geological model that are gained more easily and with low budget in comparison to other methods.

This paper presents the interpretation of VES measurements into lithologies in order to construct a preliminary 3D geological model of the Neogene deposits in Arkalohori region of Messara basin in Crete (fig. 1) which host methane gases (Pasadakis et al., 2009). The VES method was selected to provide low cost data in a short period of time, covering an extended area of 60km^2 and reaching a maximum depth of about 280m. Fifteen VES along with four wells, fifteen pseudo-boreholes (Panagopoulos et al., 2011) and field observations were the base for the construction of a preliminary 3D geological model.

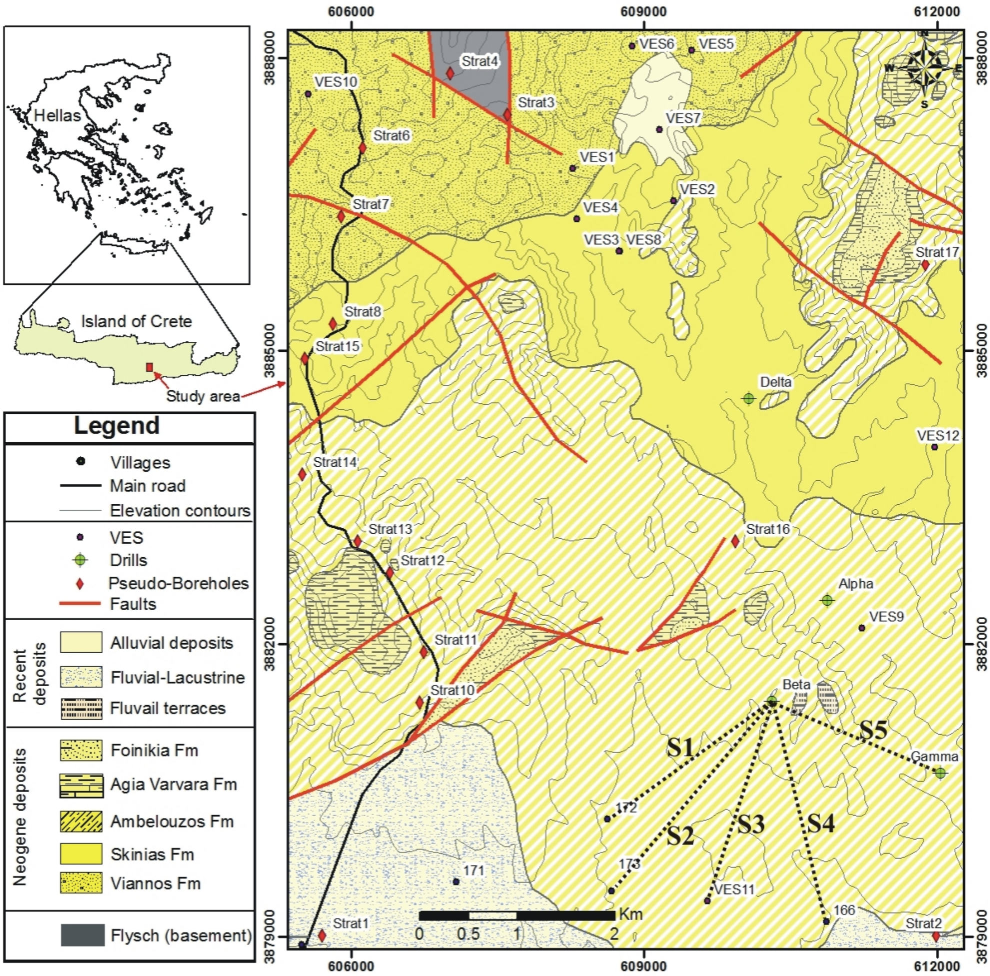

Figure 1 *Geological map of Crete and the study area showing the location of 4 boreholes, 15 pseudo-boreholes and 15 Vertical Electrical Soundings (modified after Vidakis et al., 1994). Profiles S1 to S5 are presented in Figure 4.*

Geological setting

Crete consists of a pile of nappes that contain rock units from various paleo-geographical zones being the basement of Neogene sedimentary basins. The formation of the sedimentary basins took place in the lower to middle Miocene. Meulenkamp et al. (1979) subdivided Neogene sediments into six lithostratigraphic groups, namely Prina, Tefelion, Vrysses, Hellenikon, Foinikia and Aghia Galini. Their depositional characteristics were influenced mainly by multidirectional extensional and compressional tectonic events (ten Veen & Meijer, 1998, van Hinsbergen & Meulenkamp, 2008, Tortorici et al., 2010, Papanikolaou & Vasilakis, 2010).

The study area comprises Tefelion, Vrysses and Foinikia Groups, among which Tefelion is the main one regarding coverage and depth. Tefelion Group deposited during Middle to Upper Miocene (Serravallian – Tortonian) is further subdivided in three formations (Tab. 1) consisting of marl, mud layers at the base and sand layers at the top of each cycle (Fig. 2) These formations dip southward with 20^{o} dip angle and could act as potential stratigraphic traps. In addition, terrestrial floral relics were found in the upper clayey layers of Viannos and Ampelouzos Formations. Ampelouzos Formation is considered as an undivided unit in the final 3D geological model, since it contains limited clay and silt strata to act as cap rocks (Fig. 3).

Table 1: Description of the formations of the Tefelion Group. Lithologies of the deposits are given according to their frequency in occurrence.

Formation	Age	Deposits	Thickness
Ampelouzos	Tortonian	Loose sandstones, sandstones, mudstones, claystones, conglomerates	300m
Skinias	Serravallian-Tortonian	Claystones, Mudstones, sandstones, loose sandstones	150m
Viannos	Serravallian	Loose sandstones, sandstones, mudstones, conglomerates, claystones	600m

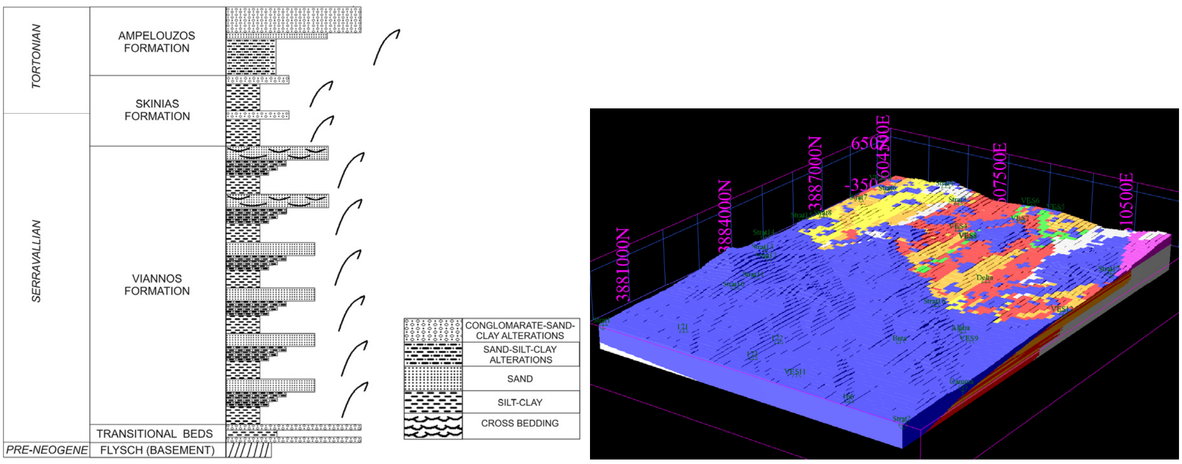

Figure 2 *Sedimentary succession of Tefelion Group (left) and perspective view from SE of the lithological model (right). Red=claystone/mudstone, orange = marly mudstone, yellow = loose sandstone, green = sandstone. Ampelouzos Formation is shown undivided in blue.*

VES interpretation

Vertical Electric Sounding (VES) determines the distribution of the resistivity in the vertical direction (depth). The interpretation of VES data could come up with ambiguous characterizations, since there is overlap of resistivity values for different lithologies (Tab. 2).

Table 2 *Resistivity of the Lithologies present in the area under investigation.*

Lithologies		Electrical Resistivity (Ohm.m)
Alluvial deposits		45-950
Neogene deposits	Claystone/Mudstone	2-15
	Marly mudstone	15-40
	Loose Sandstone	30-60
	Sandstone	60-370
Flysch (Basement)		85-140

To deal with that problem some kind of conceptual model must be defined in advance. Such a model should be based on field observations and will be subjected to the knowledge and experience of geologists. In this study, based on sedimentological evidences we construct the sedimentary succession of Neogene deposits belonging to Tefelion Group (Fig. 2). This model comprises totally nine coarsening upward cycles, six for Viannos Formation, two for Skinias Formation and one for Ampelouzos Formation. Sound differences are expected to be recorded in case of measuring the transition from Neogene deposits to pre-Neogene basement.

Results

The modelling resulted in a first coarse estimation of the volume of the gas-hosting lithologies (loose sands, sandstones) inside the Shinias and Viannos formations. Also a visualisation of the spatial distribution of the lithologies is produced.

Potential areas for gas deposits in Neogene formations have been detected using existing geological, geochemical and geophysical information as well as new data collected during a demonstration project funded by the GSRT of Greece and the Alkalochori municipality.

The construction of a 3D geological model would help us to define the location where gas is accumulated. Insufficient qualitative and quantitative data was the main problem we faced trying to construct a 3D lithostratigraphic model that honors sand deposits/reservoirs and potential gas traps. The 3D lithostratigraphic model is based on the existing geological map (scale 1:50.000 [Vidakis et al., 1994]), data from geoelectrical survey (Vertical Electrical Soundings), drilling data and detailed field work. This model provides a preliminary approach of the spatial distribution of the Neogene lithotypes observed in the study area and is the basis for the construction of new models dealing with properties such as porosity and organic-carbon content. In combination with sedimentological and tectonic evidence, this 3D model could be used in order to conclude on the most favorable places to host shallow methane gas.

Conclusions

A 3D geological model of the Alkalochori subbasin was developed using data from geological mapping, geophysical measurements and drillings. This model takes into account the stratigraphic and tectonic evolution of the Messara basin. The proposed approach demonstrates a preliminary way to estimate the biogenic gas potential of shallow Neogene sediments, based on a variety of data. The preliminary model builds the basis for future detailed work based on additional drillhole data and quantitative measurements (grain size distribution, hydraulic properties etc).

Acknowledgements

The drilling program and VES were conducted between 2007-2008 time period in the context of a research program that funded by the GSRT of Hellas and the Alkalochori municipality, except from 4 of the VES that have been held by FAO in 1969.

Figure 4 *The location of the sections presented in figure 1.*

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