MODELLING GEOLOGICAL STRUCTURE IN THE SOUTHERN PART OF SUHARD MOUNTAINS USING ELECTRICAL VERTICAL SURVEYS AND CONTINUOUS CORING BOREHOLES

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Abstract: *The trans-Carpathian flysch area was studied in detail in a perimeter of 25 km2 in the South of the Suhard Mountains, reaching the contact with the crystalline basement, by conducting vertical electrical surveys (EVS) along 8 profiles with a maximum penetration depth of 200 m. The electrical resistivity values were calibrated with the lithology described in 5 boreholes drilled by continuous mechanical coring, and with geological mapping results, improving the knowledge about local petrography and structural condition. The information thus collected was processed using specialized software, building up the three-dimensional geological model, which allows the identification of the favorable structures to groundwater accumulation.*

Key words: *vertical electrical surveys, continuous mechanical coring, 3D geological model*

1. Introduction

The objective of this scientific paper is to describe the detailed geological structure in the Southern part of Suhard Mountains, reaching the crystalline basement, in order to identify the favorable structures for groundwater accumulation. The studied perimeters is bordered to the South by Dorna river, to West by Cosna rivers, to North by the water divide between Catariga and Ciotina valleys until Livezii peak (1,389 m), continued to Ousorul creast (1,638 m), and the water divide towards Haju peak (1,238 m), and to the East by the water divide between Haju and Selesvar rivers. The perimeter was selected so that to overlay the hidrographic basins.

2. Methods

The work was done within a research contract for underground water sources, while the results were contained in the Ph.D thesis “Complex Hydrogeologic Research on the Fluss Area of Carpathian Orogene” – Ph.D student Valentin-Ion Boian.

2.1. Pole-Dipole electrical vertical surveys

There were eight electrical vertical profiles measured in the study area, using Zonge GGT3 IP/EM transmitter and eight channels receptors IPR12. The pole-dipole arrays was such designed to reach a theoretical depth of 200 m, having 13 depth levels and an additional one for 100 m, with 8 levels.

The pole-diploe array is presented (D1-D13) in Fig. 1, with dimensions, input current set-up and depth of reference points. The measurement resolution is 10 m along the profiles. The measurements were performed in continuous current, having electrical impulses at every 4 seconds.

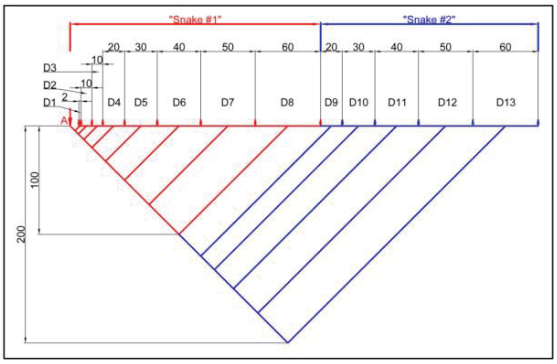

Fig. 1. *Pole-dipole array design*

2.2. Electrical measurements processing

During the first step of the processing the data were converted from IPR12 to .xls format; afterwards, the electrical resistivity values in each point were calculated based on potential/intensity values. The calculation considered topographical corrections. This primary processed data was used to create the apparent resistivity cross-sections. Second step was to convert the .xls file with apparent resistivity values into RES2DINV format. And in the third step, the apparent resistivity values were converted into real resistivity values, using RES2DINV software. During field measurement, there was no back noise recorded.

2.3. Geological research boreholes

In order to calibrate the results of electrical profiling, five boreholes were drilled by continuous mechanical coring, at a drilling diameter of 154 mm.

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The rock samples were kept in wooden boxes 1 m long, numbered and stored in a proper way, to allow further analyses. After each borehole was drilled, the geological column was described mainly by lithology, microstructures, traces of carbonate precipitate and/or oxides, fissure and faults, type of fault rocks.

All boreholes were drilled along the resistivity profiles, in order to avoid misinterpretation of results, due to high geological variability. As example, we are presenting the summary of borehole #4 geological log:

- 120 m depth, drilled on profile #25;
- Between 0-6 m soft and weather geological material, made up by calcareous sandstone and marls, with calcite dailies and oxidation traces;
- Hydrostatic water level at 13 m;
- Between 6-38 m the calcareous sandstone is intensely fractured, having calcite diaclases and oxidation traces;
- Thin sequences of sandy marls and conglomerates with metamorphic clasts between 38-50 m;
- Thin beds of sandy marls with vertical calcite diaclases between 50-120 m.

2.4. Informative boreholes

For better interpolation results, the geological logs for 35 additional informative boreholes were calculated. These boreholes were added in the general database, increasing the confidence level of the further interpolation process.

The location of these informative boreholes was selected along the main structural axes and geological borders. The theoretical depths for each stratigraphic level were calculated based on the previous geological mapping data.

2.5. Three-dimensional structural model

The three-dimensional structural model was created using HydroGeoBuilder software, free-trial version 2009.1. Previous data processing was done using AutoCad 2005, Surfer 8 and GlobalMapper softwares.

The perimeter border was digitized in AutoCad based on topographical maps 1:25.000, by following the rivers and water divides paths, and exported as poligonal shape in .dxf format.

The topographical surface data was exported from SRTM - Satellite Radio Topographic Mission - files (namely N47E025.hgt.zip), using GlobalMapper software, open on Stereographic 70 projection on S-42 Romania geoid. From this file, the terrain grid was exported at 10 x 10 m resolution, in .dxf format.

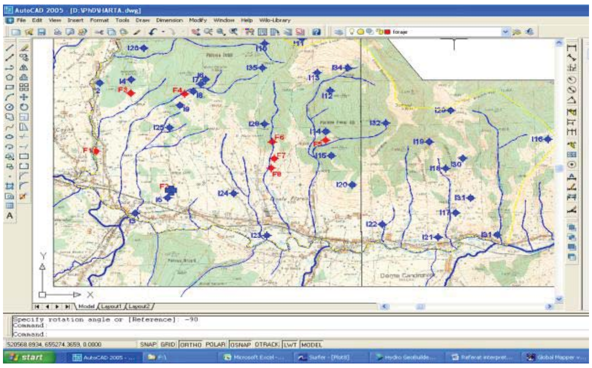

Fig. 2. *AutoCad processing*

The data about boreholes, geo-location, altitude, drilling depth, and depth of each stratigraphic layer was summarized in .xls format, according to import algorithm requested by HydroGeoBuilder.

Well ID	X	Y	Elevation	Bottom	Top Z	Top ID
[-]	*[m]*	*[m]*	*[m]*	*[m]*	*[m]*	*[-]*
I4	514558	654289	900	500	900	Quaternary
I4	514558	654289	900	500	860	Pg3
I4	514558	654289	900	500	800	Pg2
I4	514558	654289	900	500	760	Pg1
I4	514558	654289	900	500	670	K
I4	514558	654289	900	500	650	Cristalline
I4	514558	654289	900	500	500	Bottom

Fig. 3. *Stratigraphic database*

The second step in modelling was represented by calculating the surfaces of each stratigraphic layer. The crystalline basement was the first surface, and on top of it the thickness of each additional layer was added.

The working hypothesis is that the sedimentary cover follows the same structural deformation as the crystalline basement. This hypothesis is not generally applicable, knowing the different rheological properties of sedimentary rocks versus metamorphic ones, and the sliding of sedimentary cover over the basement as response to horizontal stress. For current purposes, the above mentioned hypothesis was accepted, considering that during VES data analyses, the same deformation of crystalline basement was found in the sedimentary cover as well, and that there is no impact of the crystalline basement in groundwater accumulation.

The stratigraphic surfaces were modeled in Surfer software, using as input date the entire database with boreholes, both drilled ones and informative. When a specific layer is missing from the stratigraphic sequence, or it was eroded, the 0 value was used in computation. Therefore, layers as Quaternary, with limited natural extension, have a horizontal footpring identical as others, but 0 thickness were it’s naturally missing. The surfaces modeled in Surfer were exported as .grd files.

HydroGeoBuilder software was created by Schlumberger Water Services to facilitate building conceptual models before being run in Visual ModFlow, and is capable of importing various types of files.

The working principle of the program is the following:

- Importing the basic data;
- Conversion of basic data into files with point type information (if applicable);
- Creation of surfaces by interpolating point type data;
- Creating stratigraphic horizons by cutting surfaces at the limit of the conceptual model;
- Defining the stratigraphic succession and the type of horizons (conformal, erosional, discontinuous or base);
- Creation of lithons between stratigraphic horizons;
- Attribution of properties to lithons or certain areas in lithons;
- Defining the boundary conditions.

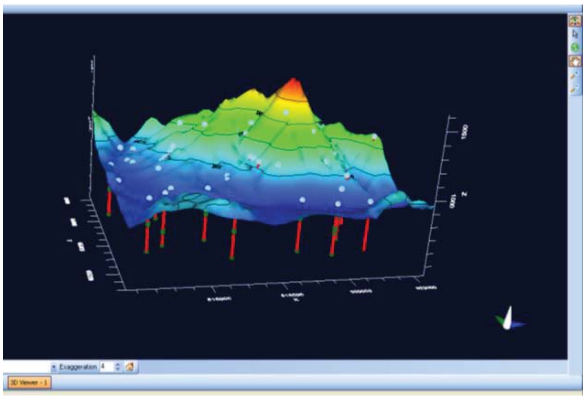

Fig. 4. *3D view of boreholes and ground surface*

3. Results

3.1. Principles of interpreting the electrical resistivity section

The most important stage in interpreting the resistivity profiles is the correlation of the resistivity values with a certain lithological type. Comparison of the lithological columns of the 5 boreholes with the apparent resistivity values led to the following interpretation:

> 1000 Ωm: crystalline schist
500-1000 Ωm: fractured calcareous sandstone
~ 500 Ωm: fractured sandstones
200-500 Ωm: marly sandstones beds
<100 Ωm: marly clayish beds

In the geological interpretation, the influence of groundwater must be considered, in the sense of decreasing the resistivity values. It should be mentioned that low resistivity values can mean rocks with high water content, such as clays, but this is not a prerequisite for developing water flows. The presence of groundwater flows generates a contrast by decreasing the resistivity values within the same lithological complex.

The real resistivity sections do not exactly represent the shapes of the lithons, since through the interpolation there is a tendency to homogenize the transitions between bodies with different geo-electric properties.

3.2. Converting electrical resistivity profiles in hydrogeological sections

Profile #11. It highlights a brownish clay complex without clear stratigraphy. Towards NE there is a covering area of approx. 15 m thick that accumulates surface water. In the SW part the section is intersected by a fault which develops a tectonized area with surface water infiltration.

Profile #23. This profile shows the crystalline basement at a depth of approx. 140 m, above which there is a marly sandstone complex and then a calcareous sandstone complex with different degrees of faulting. In the central part of the section, there is a fault zone that corresponds to the surface with a temporary water course, through which shallow surface water infiltration is carried out. Towards NW there is a fault that generates a morphological step on the surface. The calcareous limestone formation is intensely faulted from the surface to approx. 50 m, which favors the lateral development of water accumulations. Starting with 50-120 m there are successive layers of limestone poorly fissured with thin beds of marls, which constitute an impermeable horizon.

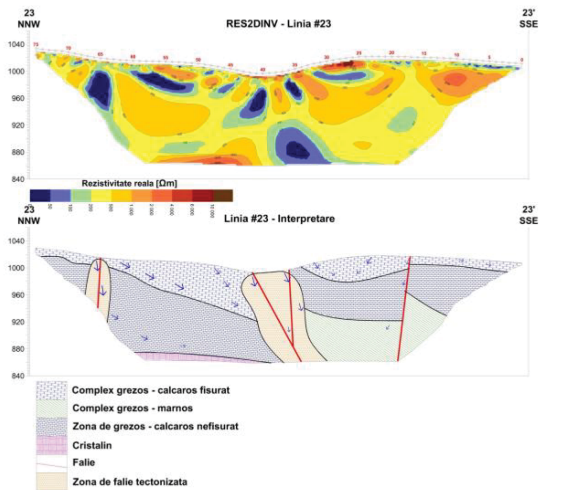

Fig. 5. *SEV #23*

Profile # 25. This profile crosses Floreni stream, which influences the measured resistivity values. In the NE corner the crystalline basement is intercepted at a depth of cca. 50 m. Also in the NE part is the fissured calcareous sandstone complex that allows the accumulation of water, which is located directly on the crystalline foundation. In the central area, there is a fault complex in correspondence with the valleys, which generates an area of intense tectonization and infiltration of surface waters. In the SW part of the profile, the fissured and un-fissured marly sandstone complexes follow one another vertically.

Profile # 27. It reveals a simple structure, from the base to the surface: marly sandstones complex, clayish marly complex and top the Quaternarry terrace formation. The terrace formation accumulates groundwater but due to the clay matrix the flows are very slow.

Profile # 28. The most important feature of this profile is the fault underneath Paraul Alb valley. In the SE part the crystalline basement is intercepted at a depth of approx. 50 m, above which lies the fissured calcareous sandstone complex that allows the development of groundwater flows. The NW part of this profile is located underneath a surface torrent, which causes surface water infiltration, however without important lateral development of aquifers. Towards the surface there is a compact calcareous sandstone complex which becomes fissued at deeper depths. The fault zone induces an intense tectonization that allows the vertical infiltration of the surface waters.

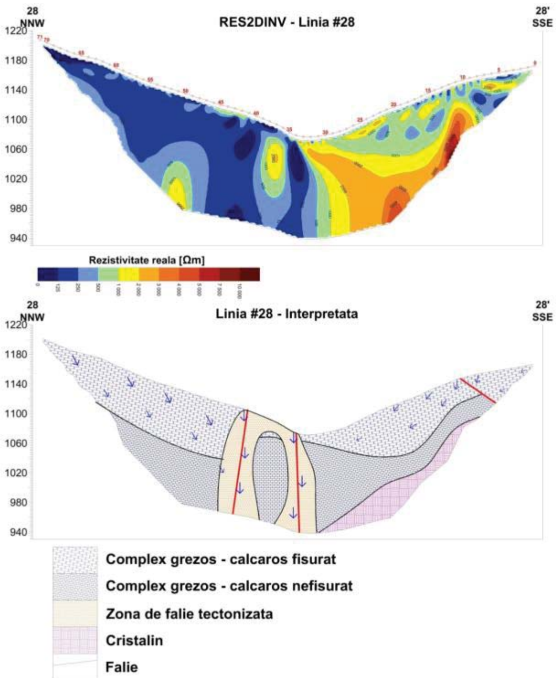

Fig. 6. *SEV #28*

Profile #29. This profile completely crosses the crystalline basement. Being located in the vicinity of the crystalline-sedimentary contact, the intense tectonization generated the formation of an alteration zone from the surface to approx. 30-40 m depth, through which there is weak groundwater flow. NE of the profile is faulted; this could be correlated with the footprint of the Negrisoara fault, as depicted from the literature. The fault zone develops an intense tectonization that allows the accumulation of groundwater.

Profile #19. Similar to the previous section, there is a single clayish marly complex. In the northern part there are thick floodplain deposits, approx. 5 m, and in the southern part due to the proximity of Cosna river, the water content of rock increases.

3.3. Three-dimensional geological model

The three-dimensional geological model represents the purpose of the works described above, by integrating the entire volume of knowledge data. The process of realizing the three-dimensional geological model is an iterative one, by validating the results in comparison with the input data and resuming the initial process. The validation of the model mainly followed the contouring accuracy of the structural axes.

The 3D geological model shows a much greater variability of the structure (comparing to the classical map), most probably justified by the existence of faults separating compartments that can be slipped, raised / lowered, or rotated. In the development of the model, the fault systems identified in the area have not been integrated, because the purpose of the model is a hydrogeological one, and the faults affecting the competent rocks (such as the Pg2 and Pg3 horizons, the main aquifer structures in the area) generate preferential water circulation paths, thus continuity between neighboring blocks.

The variability induced by fault systems throughout the conceptual model will be managed by defining alignment type areas with different properties within the same litho-stratigraphic complex, which will be part of a later work stage.

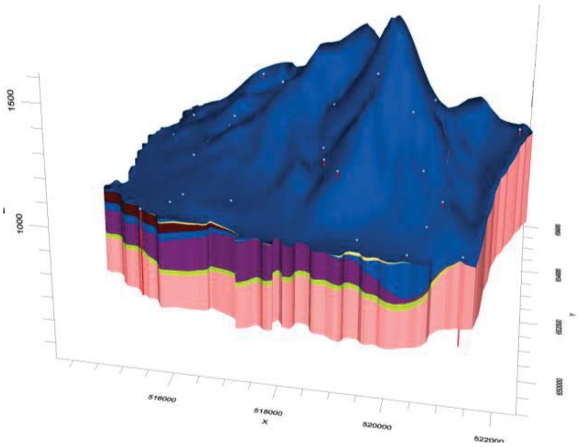

Fig. 7. *3D model, as seen from SE*

4. Conclusions

The geological model resulted by the processing of the geo-electric measurements and their calibration with the research boreholes reveals a folded structure, generally transgressed over the crystalline basement, with the NV-SE orientation.

The results of the geo-electric measurements can be correlated very well with the direct observations through drilling, and the high density of the profiles allows a good understanding of the vertical succession of the lithological complexes and their hydrogeological characteristics.

In the southern central part of the studied perimeter, no geo-electric measurements have been made since there is a group of four older drillings through which the continuity of the interpretations can be realized.

The scientific importance of this paper is constituted on the one hand by the identification of the detailed geological structure on the south of the Suhard mountains, and on the other by the establishment of a working methodology by integrating complex techniques, validated with the real results.

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