SPATIAL MODELING OF SHALLOW AQUIFERS FROM GREEN SHALE AREA OF CENTRAL DOBROGEAN MASSIVE
CASE STUDY: FÂNTÂNELE, CONSTANȚA COUNTY

Emilia PESCARU, Daniel SCRĂDEANU**, Mihai MAFTEIU****

Abstract: *The shallow aquifers from the green shale area of the North Dobrogean Massive are accumulated in loessoid deposits and in the altered area of the green shale, being recharged by the infiltration of water from precipitations. The article presents the results of the investigation of shallow aquifer in the area of Fântânele, performed with 34 the vertical electric survey (EVS) calibrated with data from boreholes and outcrops. Hydrogeological potential of shallow aquifers at the base of loess deposits is solved using the thickness of permeable deposits and the thickness of the water saturated area determined wuth EVS. A 3D spatial model of the hydrostructure summarized the results of geophysical investigations, model that will be the basis for evaluating the total potential of the aquifer.*

Key words: *aquifer, loess, green shale, vertical electrical survey (EVS), 3D space model*

1. Introduction

The researched area, with a temperate-continental transition climate, is known for the absence of water resources. Extremely low rainfall (500 mm / year) and the extension of impermeable formations (green shales) are the determining factors of the absence of permanent hydrographic network and aquifers.

The only water resources are the underground ones, accumulated at the base of the loess, at the contact with the green shales, impermeable metamorphic rocks with a thin area of alteration, semipermeable, at the contact with the loess which is the only permeable formation in the area.

Potential of shallow aquifers situated at the base of loess deposits is solved using the vertical electrical survey that allows to determine the thickness of permeable deposits and the thickness of the water saturated area.

The results of the aquifer investigation in the Fântânele area were used to create the 3D spatial model of the aquifer and to design two underground water supply boreholes for Fântânele.

2. Geology of the investigated area

The investigated area falls within the perimeter of Fântânele in Constanţa county, located in the Dobrogean Central Massive (Fig.1). The Central-Dobrogean Massive is circumscribed in the middle third of Dobrogea, being delimited to the south by the Palazu Fault, and to the north by the Peceneaga-Camena Fault.

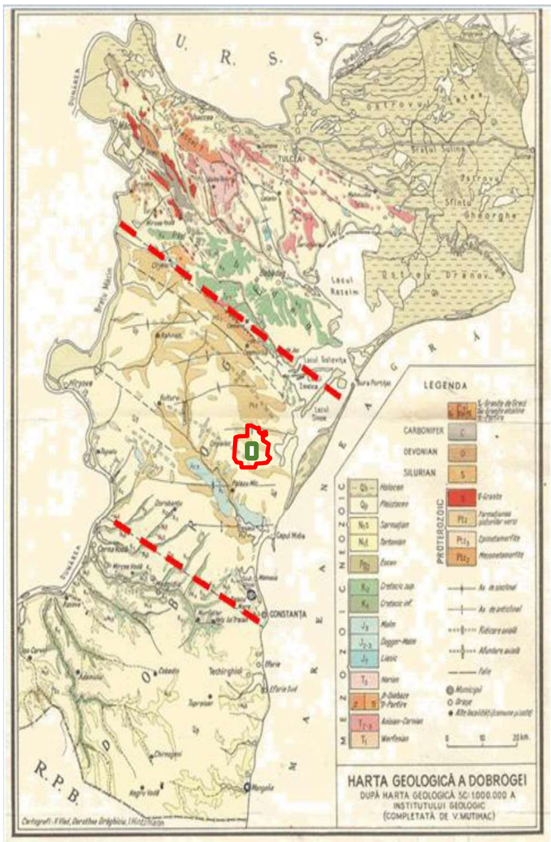

Fig.1 *The Central Dobrogean Massive between the Peceneaga – Camena and Palazu Mare faults (according to the map of the Geological Institute of Romania, scale 1:1000000)*

The distinctive feature of this unit is the nature and the Neoproterozoic age of a good part of the base and the fact that it emerges on very large areas. Hence the character of "massive" in the geostructural sense, meaning the area in which the Precambrian base, folded, emerges on large areas.

* Eng. Ph.D stud., University of București
** Prof.eng. Ph.D, University of București
*** Eng. Ph.D

In the investigated area, the object of the investigation is the formation of Proterozoic green shales and Quaternary sedimentary formations.

2.1. The formation of green shales

In the studied area (Fantanele, jud. Constanta; Fig.2) and in the surroundings, the geological formations of the base of the Central Dobrogean Massif emerge on large areas, namely the formation of green shales. Specifically, there is a portion of the upper Graywacke level, consisting of clay and graywacke, with thin intercalations of white quartzite. In the outcrops encountered they appear in different stages of alteration, depending on their petrographic constitution, which more or less favored this process. Green shales are found both on the surface of the ground and covered by a blanket of loess and loessoid deposits, with variable thicknesses.

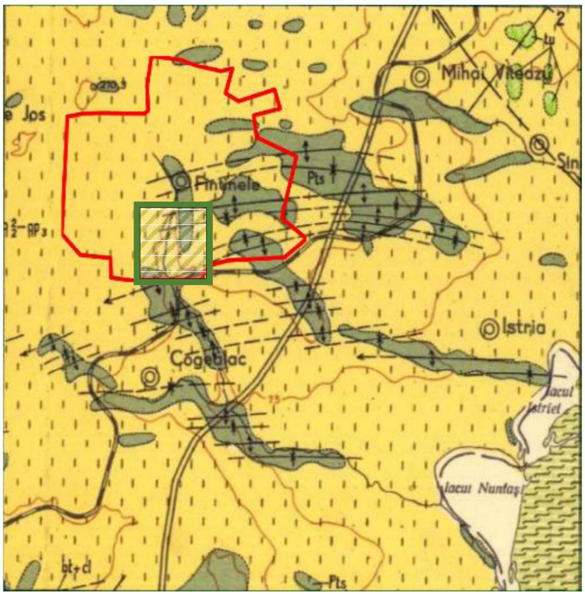

Fig. 2 *Geological map of the Fântânele area (IGR, scale 1: 200,000.)* $qp_2^2 + qp_3$ *loess; Pts green shists*

Green shales are known to be made up of impermeable geological formations that do not allow water to circulate or be stored. The exceptions are the areas of alteration and cracking of the land surface, formed by the action of exogenous agents, but they have small thicknesses (at most a few meters, usually less than one meter) and doe not accumulate significant amounts of water.

2.2. Sedimentary formations

The only existing geological sedimentary formations in the Fântânele area and in the nearby surroundings are those that originated during the Quaternary period and are represented by alluvial and slope deposits, as well as by loessoid formations.

Alluvial deposits were formed due to the erosion of crystalline shales and the transport of the resulting material, performed by rivers. They do not appear on the surface of the land in the Fântânele area, but it is possible that they exist, with very small extensions in surface and thickness, under the cover of loessoid deposits formed in the Lower Pleistocene.

The Fântânele River, flowing through loessoid deposits, submit fine holocene deposits and insignificant alluviums, resulting from their erosion and washing.

Slope deposits, sometimes even rubble (reported in other perimeters) were not found in the Fântânele area. They are, probably, deposited in the lower parts of the paleovalley, being covered by loessoid deposits.

The most important, in terms of surface area and thickness, are the loessoid deposits, with wind sedimentation in the Pleistocene epoch (Middle Pleistocene and Upper Pleistocene) over the relief of crystalline schists. They are generally dusty, porous, unconsolidated deposits (component particles are not cemented), yellow or reddish-yellow. In their contents can be found clayey and sandy areas, as well as levels of fossil soils (paleosols).

Dust particles (granulation 0.05 - 0.01 mm) predominate in the composition of loessoid deposits, always exceeding 50%. Next are the clay particles (granulation below 0.002 mm), with proportions of 15 - 50%.

From a mineralogical point of view, quartz predominates (60 -70%), the other minerals being represented by carbonates (20-27%), feldspar, mica and clay minerals. Among the carbonates, the primary ones dominate, especially the calcium carbonates, evenly distributed in the rock mass. Secondary carbonates are concretionary deposits (loess dolls) or in the form of veins.

At their base (the portion formed in the middle part of the Pleistocene), loessoid formations may also present fragments of green, altered schists, coming from the metamorphic rocks at the base.

The recent Quaternary sedimentary formations are the alluvium deposited (Holocene epoch) by the Fântânele river. In some parts of its bed there is the existence of steep walls, resulting from the characteristic of the loess to break on vertical faces.

3. Hydrogeology of the investigated area

Loess and loessoid formations, which mostly cover green shales, have a high porosity (40-50%), which gives them a high water storage capacity and the possibility to form aquifers.

The dominant vertical and tubular arrangement of the pores determines a good infiltration of rainwater but not a good horizontal circulation. This, like the very small diameters of the pores (which causes a low yield capacity) leads to low flow rates of the capture works.

Aquifers arise by the accumulation of water at the base of the loess, where they meet the impermeable surface of green shales. If these shales are strongly altered and cracked or above them there are alluvial deposits or porous resedimentation of the paleorelief (rarer case), aquifers are born and in their case with higher yields.

A major deficiency of these aquifers is their small extension, in area and depth, which causes their depletion and drying during the dry periods of the year. In the Fountains area, most fountains dry in the seasons without precipitation.

A special case is the suspended aquifers in loessoid formations. It is water from precipitation that infiltrates deep vertically but does not reach the base of the formation because they meet well-individualized levels of clay, impermeable. Usually drying in dry seasons and not having too much surface expansion, these aquifers are not a viable solution for water supply.

4. Method of investigation by vertical electrical survey

The objective of the investigation by vertical electrical survey of the Fântânele area was the vertical separation of the units of the 3D spatial model of the hydrostructure based on the apparent resistivity of the vadose zone, the aquifer and the aquifer bed.

To determine the apparent resistivity ρa, a quadripolar AMNB device is used (Fig. 3) which consists of a measuring line AB through which a current (continuous or pulsed) of intensity I is injected and a measuring line MN which determines the potential difference ΔV produced as a result of the current injection.

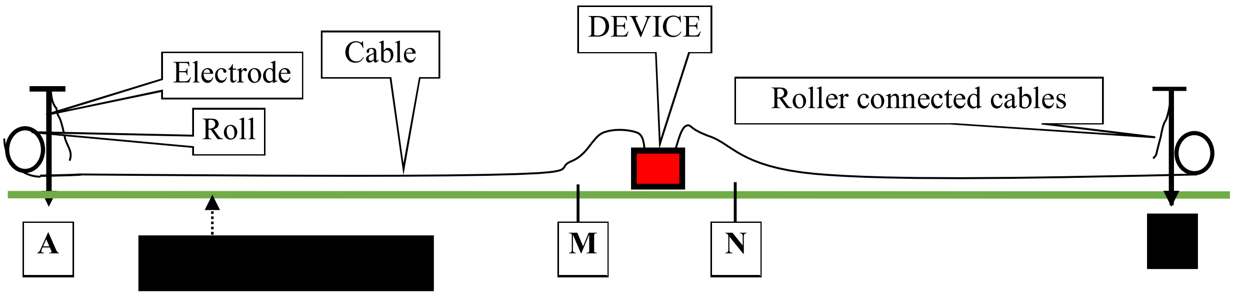

Fig.3. *The classic measuring device, with its component elements, located in the field*

The depth of investigation is determined by the length of the device (1/3 of the length A-B through which electric current is introduced into the ground (Fig.4).

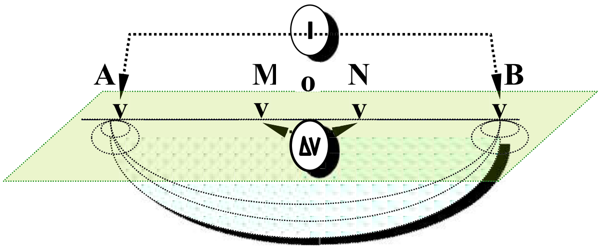

Fig. 4. *The main sketch of the electric current circulation basement*

In the special case of the symmetrical collinear device, the following formula for calculating the apparent resistivity has been developed and used:

$$\rho_a = k \cdot \Delta V / I$$

where:

$$k = \pi \, (AM \cdot AN / MN)$$

and K represents a coefficient that depends on the geometry of the AMNB measuring device deployed at a given time.

The apparent resistivity (ρa) of the investigated formations (Fig.5) represents a complex average of the resistivities in the immediate vicinity of the working device and can be considered equal to the longitudinal resistivity of a layer pack whose thickness is considered AB / 3.

The vertical electrical survey (EVS) consists in performing, at a certain observation point, several measurements of apparent resistivity with continuously increasing lengths of the emission line AB. In this way a curve of variation of the apparent resistivity depending on the half-distance AB is obtained, considered to represent the average investigation depth of the device. This curve (EVS curve) illustrates how the real resistivity varies on the vertical of the observation point. By performing vertical electrical surveys in several observation points, located along a profile, an apparent resistivity section is obtained, which interpreted quantitatively and qualitatively leads to an interpretive geoelectric section as a reflection of the geological structure on the route of the researched profile.

In order to obtain a three-dimensional image of the investigated basement, it is necessary to make a relatively large number of EVS, as evenly distributed on the investigated area. This style of interpretation must always be "calibrated" based on direct information obtained from boreholes, outcrops or resulting from anthropogenic activity, existing in the researched field.

The study of rock lithology, buried reliefs, the degree of alteration of the bedrock and the thickness of the coating using these methods is based primarily on the fact that the resistivity of materials involved in this natural process is a parameter that depends largely of the nature and physical condition of the geological formations detected in the lithological column.

The method is approved by STAS 1242 / 8-75 and STAS 11 156-78 / CNST-IRS.

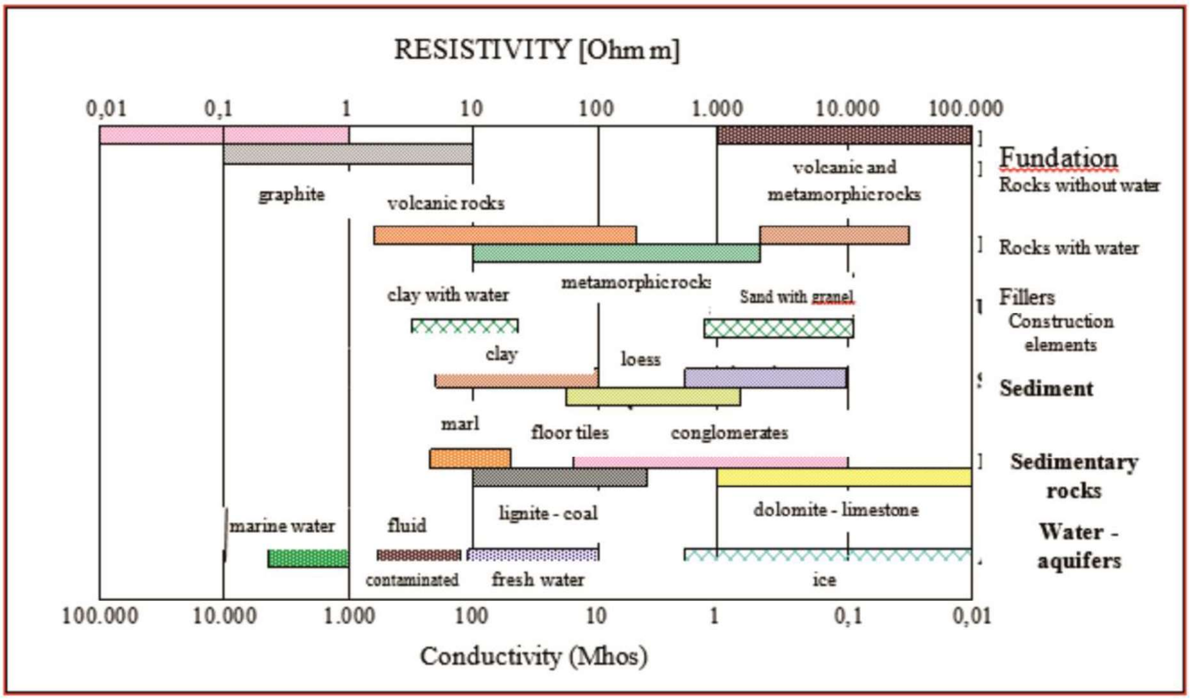

Fig. 5. *Resistivity of different types of rocks and groundwater, expressed in Ohm m*

5. The results of the investigation of the Fântânele area

To perform the measurements, a symmetrical Schlumberger geoelectric survey device was used, with a length of 300 m, with a depth of 100 m of investigation. The distribution of the 34 EVS performed was conditioned by local conditions (Fig.6)

The processing of all data obtained from geoelectric field measurements was performed on the computer, using the software of the investigation equipment.

Geoelectric image, a pseudosection of electrical survey, becomes interpretative from the moment when the structural, lithological and hydrogeological elements are drawn. Six interpretive geoelectric sections resulted.

Fig. 6. *Position of EVS made in the Fântânele area*

ISSN-L 1220-2053 / ISSN 2247-8590
Universitas Publishing, Petroșani, Romania

5.1. Geoelectric sections:

- *The geoelectric section P1* (Fig.7) is performed by the vertical electrical survey S24, S26, S21. It has a northeast-southwest direction. The depth of the loess, as well as the greatest depth of the green shale alteration area (S24 - S26) indicates the presence of the most important water reservoir that decreases as we descend to the south (S21). The most promising part is between points S24 and S26 (adjacent to the Izvoarelor Valley), where the depth of the green shale alteration area and the thickness of the loess present the maximum values. The approximate depth is over 20 m.
- *Geoelectric section P2* (Fig.7). It consists of electrical survey from north to south: S33, S34, S29, S30 and S31. Analysis of this section indicates a thickness of the loess and the green shale alteration area from S33 to S34, where there is probably a small paleoval. It seems that in this area the groundwater flows on the bottom of the old valey of the river, but in small quantities. Then the green shales rise to the surface (S29), the water completely missing, as well as in the following S30 and S31 survey.

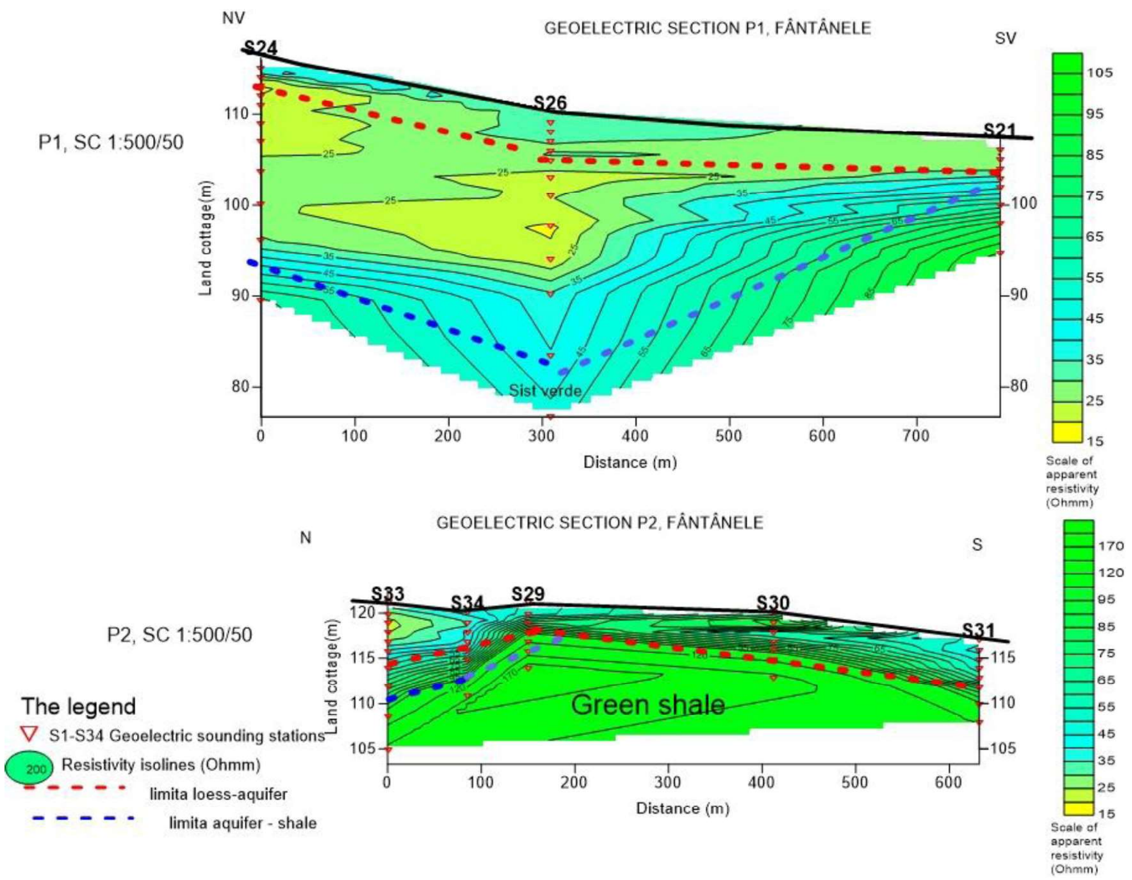

Fig. 7. *Geoelectric sections P1 and P2 from the Fântânele area*

- *P3 geoelec- The geoelectric section P3* (Fig. 8). It has a northwest-northeast direction and joins the vertical electrical survey S25, S24, S13, S12, S32 and S28. The thickness of the loessoid formations and the green shale alteration zone is noticeable, which between the vertical electrical survey S25 (adjacent to the Izvoarelor Valley) and S24 is maximum, decreasing towards S13, S12, S32 and S28 where the green shales rise to the surface and where the minimum depth of loess, as well as the area of alteration of green shales, present in the northern part, shows little chance of existence of an aquifer.
- *The geoelectric section P4* (Fig.9) investigates from west-south-west to east-north-east the central part of the studied area and includes survey S23, S22, S21, S16, S14, S11 and S31. It has a west-south-west-east-north-east direction, crossing the vertical electrical wells S23 where the depth of sedimentary deposits is minimal, increasing slightly in S22 and S21 and as we go east S16 they, crossing the Izvoarelor Valley (between S16 and S14) reach maximum in S14 where it appears to be an old valey of the river and where the depth of the base of the loess, the paleorelief and the thickness of the alteration zone of the green shale formation (probably cumulated with some permeable alluvial deposits on the paleoval) are maximum (exceeding 10 m). Again it has a decrease even if we approach the area with springs on the Fântânele Valley, S11 where the shales are far to surface and this situation continues to persist until the last survey of the S31 profile, without water.

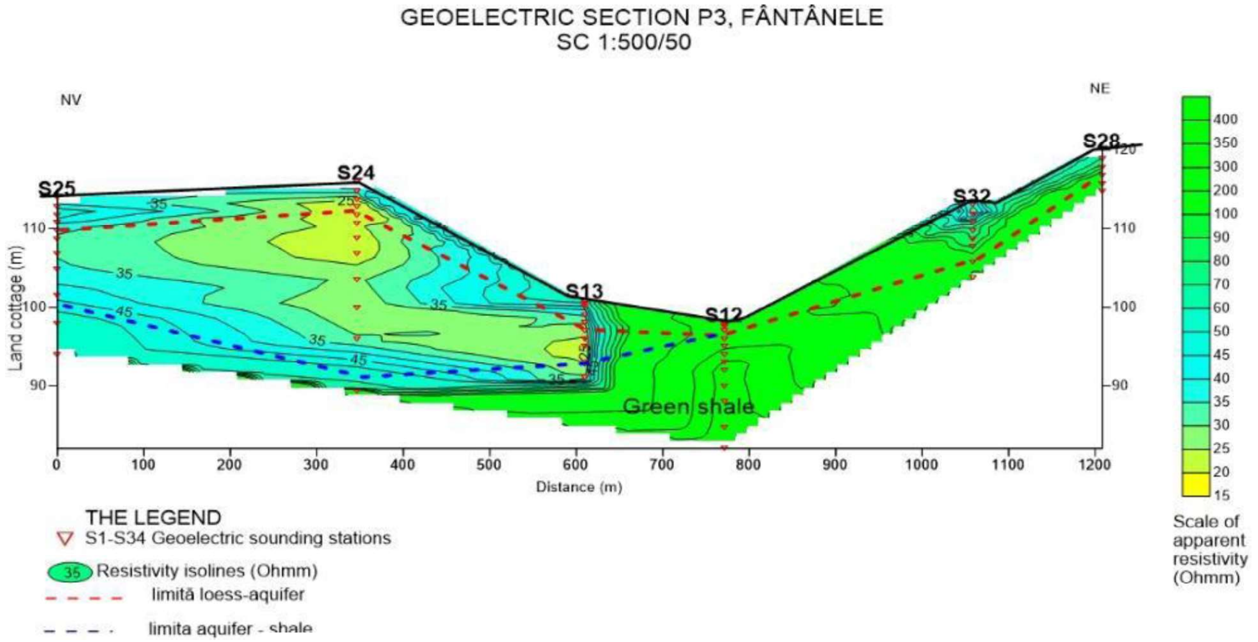

Fig. 8. *Geoelectric section P3 from the Fântânele area*

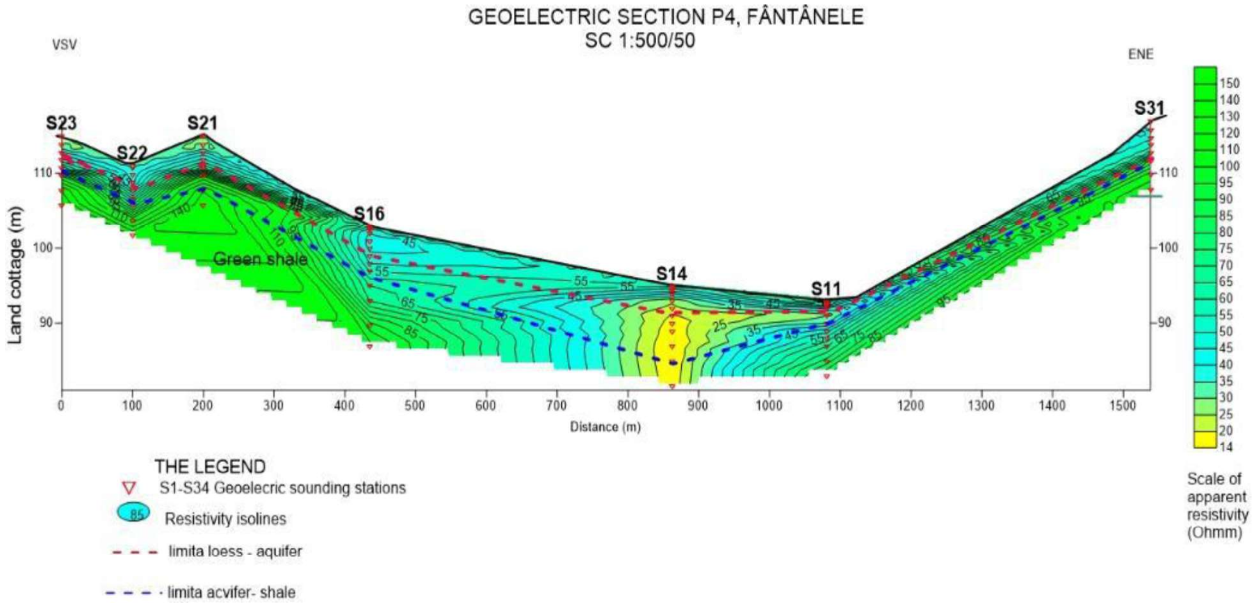

Fig. 9. *Geoelectric section P4 from the Fântânele area*

- *The geoelectric section P5* (Fig.10) starts from the electrical survey point S24 and, as in profile P1, has the same beginning of section, namely S24-S26. This portion of the profile has the highest depth of the sedimentary layer of the studied area, almost 30 m (S26). It decreases a lot in S16 where the green shale rises to the surface, keeps its level low and in S1 as in S7 near the axis of an anticline, on a high portion (a paleodeal) of the green shale foundation, with the accentuated slope of the paleorelief and relief, the area is without water. Again there is an increase in S6 (approx. 8 m). It seems that in the eastern extremity of section S7 there are water accumulation conditions (paleorelief trench, large loess thickness), which would flow on the underground slope of the paleorelief from west to east, and could form an aquifer.

- *The geoelectric section P6* (Fig.11) crosses and investigates points S27, S7, S2, S9, S31. It is a portion of land near a syncline, in which the slope of the relief (which descends sharply to the east, towards Fântânele Valley) agrees with the slope of the loessoid formations and the area of alteration of the crystalline schists - S9.

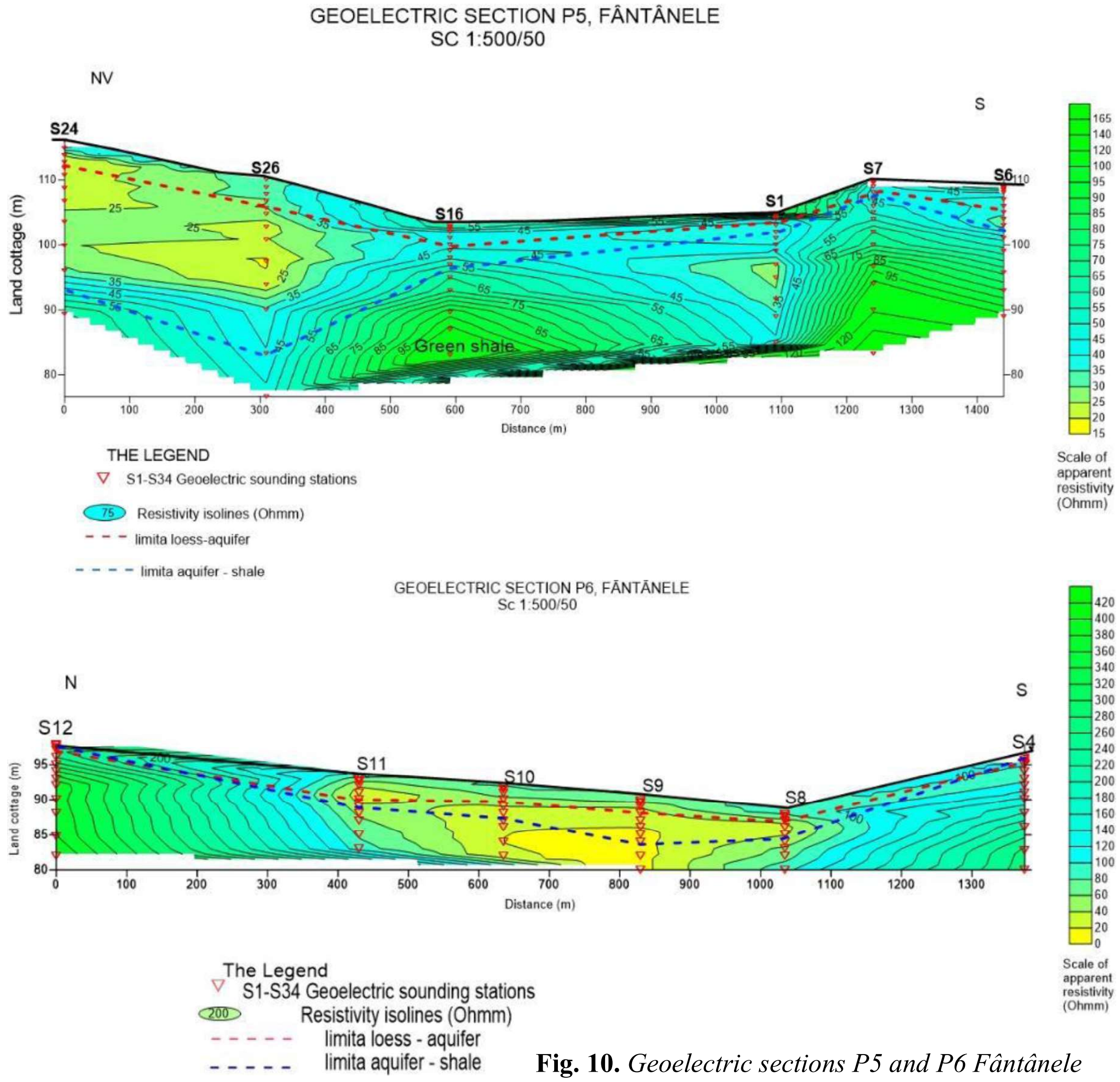

Fig. 10. *Geoelectric sections P5 and P6 Fântânele*

5.2. 3D spatial model of the Fântânele hydrostructure

The 3D spatial model was made based on the thicknesses of the three components of the hydrostructural model:

- vadose zone
- aquifer
- bottom of aquifer represented by impermeable green shales.

The thicknesses were determined in the 34 EVS analyzed in the 6 geoelectric sections, completed with additional geoelectric sections (fig. 11) made by interpolation (using indicator kriging and ordinary kriging) for detailing.

The preliminary analysis of the 3D spatial model was performed, for the thickness of the vadose zone and the thickness of the aquifer, in two stages:

- **the analysis of the global variability** that had as objective the determination of the most probable values of the thicknesses and their confidence interval for assumed risc α=5%:

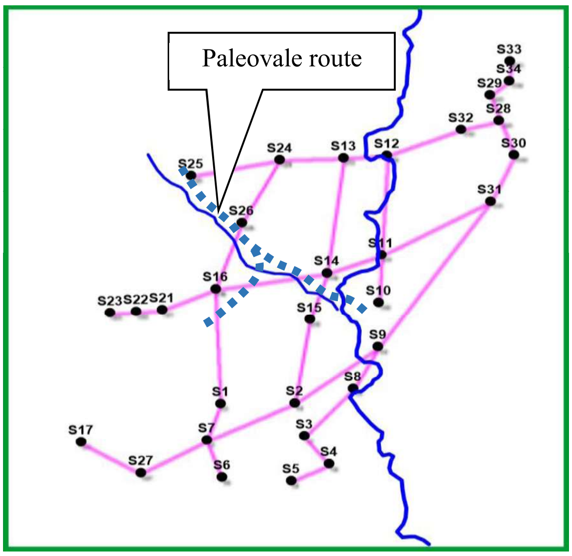

Fig. 11. *2D representation of the routes of the sections used to create the 3D spatial model of the Fântânele hydrostructure*

- thickness of vadose zone: 3.8 m +/- 0.7 m
- thickness of aquifer: 3.0 m +/- 1.0 m

- **2D variability analysis** completed with two 2D models for:

- the thickness of the vadose zone (Fig.12 a)
- the thickness of aquifer (Fig.12 b)

The thickness of the aquifer bed, consisting of green shales could not be determined because it exceeds the depth of investigation of the device used to perform EVS and is not a parameter of the evaluation of aquifer resources, final objective of the conceptual model of the Fântânele hydrostructure.

The synthesis of the results in a 3D spatial model for the Fântânele area (Fig.13) leads to the following quantitative elements, necessary to evaluate the aquifer potential of the hydrostructure:
- volume of the vadose zone:17,9 x10^6 m^3
- volume of the aquifer: 21,4 x10^6 m^3

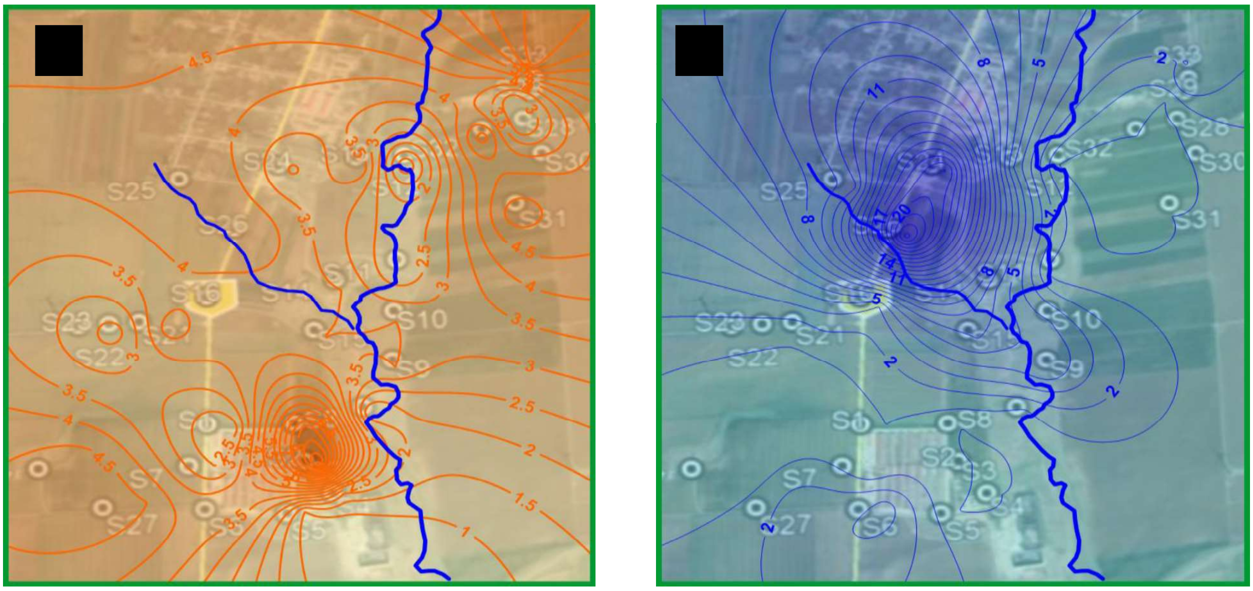

Fig. 12. *2D spatial analysis of the distribution of the thickness of the muddy area (a) and of the thickness of the aquifer (b) in the Fântânele area*

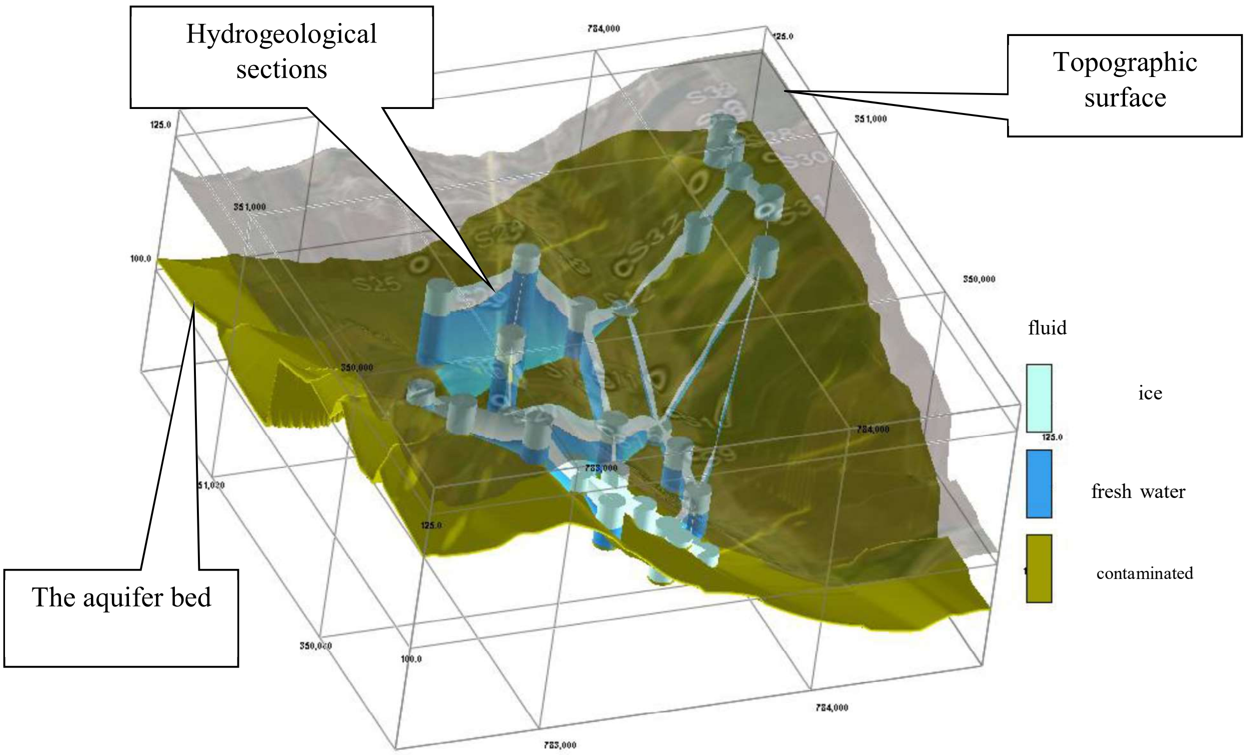

Fig. 13. *3D model of the Fântânele hydrostructure*

6. Conclusions

Using geoelectric methods, we obtained the necessary informations to evaluate the potential of shallow aquifer:

• the thickness of the vadose zone of the aquifers
• thickness of shallow aquifers
• hydrostatic level position
• paleorelief of the studied area.

These elements are used to achieve the conceptual model of hydrostructure, support for modeling the dynamics of the aquifer, calculating groundwater reserves and assessing the vulnerability to pollution of these reserves.

The most important area for the groundwater aquifer of loessoid deposits, with permanent water, is an old valley of the river located along the valley of Pârâului Izvoarelor, parallel to it, moved 100-150 m further north. It starts from the northwest, from the electrical survey point S25 and continues with S26 to the southeast, continues with S14 north of the stream Izvoarelor Valley and S16 south of it, passing to the east the valley of the river Fântânele (fig. 11).

The aquifer in the loessoid deposits is of phreatic type, having a variable hydrostatic level depending on the season (higher in periods with more abundant precipitation), located at the bottom of the loessoid deposits. The hydrostructure develops in depth, in continuity with the phreatic aquifer from the loessoid deposits, or separated from it by a level of red clays, below the base of the loessoid deposits, on a thickness of 1 - 3 m, in the porous-permeable alluvial deposits of the old valley of the river and in the altered part of the green shales.

Geoelectric measurements provide the most efficient method for determining the extreme variation of loessoid deposits in this area, the costs of a detailed investigation by hydrogeological drilling being onerous.

References

1. Anastasiu N.
Sedimentary petrology, Editura Tehnică, București, 1988

2. Cineti A.
Romania's groundwater resources, Editura Tehnică, București, 1990

3. Georgescu, P., Gavrila, I.
Influence of electrical prospecting arrangement on apparent resistivity anomalies, Rev. Roum. Geophy. Geogr., serie de Geophysique, 33,1, 1989

4. Loke, M.H.
Electrical imaging surveys for environmental and engineering studies - a practical guide to 2D and 3D surveys, unpublished short training course notes, Penang, Malaysia, Universiti Sains Malaysia, 1997

5. Mutihac V, Mutihac G.
Geology of Romania in a Central-Eastern European geostructural context. Editura Didactică și Pedagogică R A. București, 2010

6. Pascu M.
Groundwater in Romania, Editura Tehnică, București, 1983

7. Scrădeanu D., Gheorghe A.
General hydrogeology, Editura Universității din București, 2007

8. Scrădeanu D.
Geostatistical models in hydrogeology, Editura Didactică și Pedagogică, 1997