A GEOLOGICAL STUDY'S PREMISES FOR RESIZING THE GEOTHERMAL EXCHANGE FIELD WITHIN THE *TRANSILVANIA* UNIVERSITY PRO DD RESEARCH INSTITUTE

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Abstract: *Within the project for the PRO DD Research Institute, the Transilvania University intends to introduce a ground water heat pump system based on a well field. The premises that will underlie the preparation of a geological-hydrogeological study that will permit resizing the geothermal exchange field are put forward: the geological conditions of the Braşov region, the thermal energy calculation methods, the field analysis necessary to obtain the needed data and the long-term analysis of the system's evolution.*

Key words: *heat pump, geothermal, vertical well.*

1. Introduction

The *Transilvania* University, within the project for the PRO DD Research Institute, intends to develop a heating system for the future laboratories with the help of soil-water heat pump installations based on geothermal vertical probes. For the geothermal exchange field resizing, the preparation of a geological-hydrogeological study was proposed. Some of the premises that will be the base of this study's preparation are put forward.

99.5% of the earth's crust thermal energy derives from the sun in and 0.5% from internal sources - radioactivity, internal pressure.

Internal heat makes the geothermal gradient (temperature increase by one degree) to have an average of 33 meters, meaning 3 ºC/100 m up to a depth of about 2000 meters, after which the temperature has exponential rising towards 3000-5000 ºC at the nucleus. The average loss of internal heat (geothermal flux = the rock's thermal conductivity multiplied by the geothermal gradient) is 1.25·10-6 cal/cm^2/s in regards to which there are positive („hot-spots" in volcanic areas) or negative anomalies (for example from the oceanic trench).

The heat received from the sun varies according to latitude and season. Daily variations manifest themselves in the crust up to a depth of 75 cm and seasonal ones up to a depth of 10-20 m. These depths mark the balance area between the thermal radiation from the external source and the internal one and correspond to a constant temperature zone. Below these depths, the temperature is changing according only to the geothermal gradient with values between 30 and 35 meters.

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Climatic conditions grant Romania renewable energy sources on the medium and long term (solar energy, wind power, hydro energy, biomass and geothermal energy). Of the heat pumps (Figure 1) that use geothermal energy, soil-water pumps are the most widespread at the moment, probably over 1.5 million in the whole world.

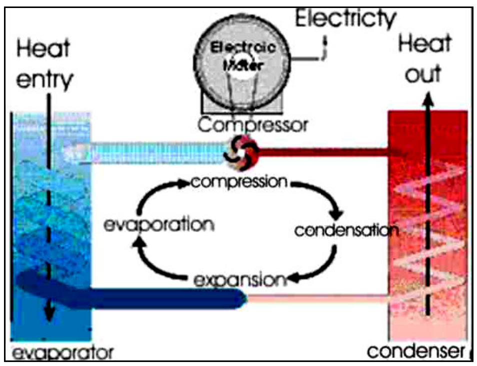

Fig. 1. *Heat pump* (*closed cycle*) *with mechanical vapor compression-principle*

A quick survey of the development of these systems starts with a Swiss patent issued in 1912 to Heinrich Zoelly which makes a reference to a soil-water heat pump [2].

Between WW1 and WW2 this system is introduced in the United States. After the war their development continues in parallel to laboratory investigations and surveillance of the existing systems. Ingersoll and others [7] lay the theoretical groundwork for the research to follow. Interest for these systems is in decrease in the 6th and 7th decades due to problems related to technological aspects, affected soil, installation undersizing [8] etc.

The 70's petrol crisis brought back attention to renewable energy sources. Research over heat pump systems has resumed with increased care to protecting the vegetal soil by improving the system and soil space filling techniques. Agent losses are reduced substantially by the introduction of high density polyethylene pipes and connecting them to the heat. The installations undersizing problems forced the introduction of new calculus algorithms [3] and their implementation on computers.

Commercial heat pump based systems become common again in the United States and in the Western Europe they are increasing, being lead by Switzerland and the Scandinavian countries. The commercial aspect has forced putting research effort into computer simulation programs for cost reduction. Consequences over the affected terrain are studied with high priority for the system's long term behavior and from the ecological point of view. *In situ* research, especially in the case of commercial buildings reduce the uncertainty degree and can establish a resizing a lot closer to the real needs [1], [4], [5]. In some cases the cost difference from the direct analysis of the terrain can be of even about ten thousands of dollars [9].

2. Geological Context

The area that Braşov occupies is formed of two distinct parts: the Ţării Bârsei depression and the orogen mass in which this basin is carved. This structure's evolution implies two processes: the basin's sinking and then it's filling with Neozoic sediments.

The orogen is represented by the most internal units of the Carpathians bend area (Ciucaş, Piatra Mare, Postăvarul, Bucegi, and Piatra Craiului mountains). From a geotectonic point of view these units are situated in the Crystalline - Mesozoic zone and are formed of shales, Triassic, Jurassic (particularly carbonatate) and cretacic deposits, calcareous and detritus.

The forming of these massives was followed by the basin's sinking and it's filling with Neozoic-aged lacustrian sediments.

In the Quaternary, after the lake waters' receding from the Braşov region, the forming of piedmonts takes place: the Săcele piedmont formed of the dejection cones of the Tărlung and Timiş Rivers that have united, and the generator rivers were forced to deviate sideways towards lowest quotas; the Braşov's piedmont - formed of torrential waters and of smaller streams.

The forehead of the piedmonts is followed by large relief formations, „fields" or other rivers' terraces. The fields, like Măieruşului Field, Arcuşului Field, de la Reci Field, Bîrsei Field, Stupinilor Field are lacustrine plains joined by swamps, slops and deserted meanders. A lot of them have lost their initial state by being put into the agricultural circuit after draining.

3. Theoretical Premises

Heat flux (q) from the soil particle to another or through soil pore fluids is:

$$q = -\lambda \cdot \frac{\vartheta T}{\vartheta x}, \tag{1}$$

where: T - temperature; x - distance; λ - thermal conductivity of the soil.

The negative sign indicates that the temperature decreases in the direction of increasing the distance.

Conduction through cylinders (heat pump case) is, and the length denoted as:

$$T_1 - T_2 = \frac{q}{2 \cdot \pi \cdot \lambda \cdot L} \cdot \ln \frac{R_2}{R_1}, \tag{2}$$

where: λ - thermal conductivity of pipe's material; T_1, T_2 - temperature of internal and of the external surface of the pipe; R_1, R_2 - internal and the external radiuses of the pipe; L - pipe's length.

The amount of heat Q transferred in time t on the cross-sectional surface area A with a L thickness is:

$$\Delta Q = \lambda \cdot t \cdot \Delta T \cdot \frac{A}{L}. \tag{3}$$

- **Kersten's Model for Thermal Conductivity of Soils (1949)**

$$\lambda_u = 0.1442 \cdot \left[0.9 \cdot \log w - 0.2\right] \cdot 10^{0.6243 \cdot \rho_d}, \tag{4}$$

$$\lambda_f = 0.001442 \cdot 10^{1.373 \cdot \rho_d} + 0.01226 \cdot w \cdot 10^{0.4994 \cdot \rho_d}, \tag{5}$$

where: λ_u - thermal conductivity of unfrozen rocks (minerals); λ_f - thermal conductivity of frozen rocks (minerals); w - water content; ρ_d - dry density.

- **Johansen's Model (1975)**

$$\lambda_{unsat} = (\lambda_{sat} - \lambda_{dry}) \cdot \lambda_e + \lambda_{dry}, \tag{6}$$

where: λ_{sat} - thermal conductivity of saturated soils; λ_{dry} - thermal conductivity of dry soils; λ_e = 0.7 logS_r+1, for coarse-textured soils; λ_e = logS_r+1, for fine-textured soils.

$$\lambda_{sat} = \lambda_s^{(1-n)} \cdot \lambda_w^n, \tag{7}$$

where: λ_s - thermal conductivity of soil; from the quartz content of the total solids content (q) and thermal conductivities of quartz (λ_q = 7.7 W m^{-1} K^{-1}) and other minerals (λ_0):

$$\lambda_s = \lambda_q^g \cdot \lambda_0^{1-q}, \tag{8}$$

where: λ_0 was taken as 2.0 W m^{-1} K^{-1} for soils with $q > 0.2$, and 3.0 W m^{-1} K^{-1} for soils with $q \leq 0.2$; λ_w - thermal conductivity of water; n - soil porosity; λ_{dry} = 0.039 n^{22}±25% (crushed particles) mean values:

$\lambda_{sand\ 7°}$ = 1.8 J/sec/m/ºC,
$\lambda_{sand\ 10°}$ = 1.94 J/sec/m/ºC,
$\lambda_{clay\ 7\text{-}10°}$ = 1.2 J/sec/m/ºC,
λ_{water} = 0.605 J/sec/m/ºC.

- **Geometric Mean Method - Sass et al. (1971) and Woodside and Messmer (1961)**

$$\lambda_s = \prod_{j=1}^{z} \lambda_{mj}^{xj}, \text{ with: } \sum_{j=1}^{z} x_j = 1, \quad (9)$$

where Π represents the product of the thermal conductivity of the minerals with λ_m conductivity each, raised to the power of their volumetric proportion x, and the sum of the volumetric proportion of the minerals is equal to 1. The subscript j refers to the j^{th} mineral, there being z minerals altogether. The quotation gives the best results when the thermal conductivity of each mineral does not contrast by more than one order of magnitude.

Typical range of thermal conductivities is shown in following tables:

Table 1
Thermal conductivity of solid particles of some minerals [6]

Mineral	**λ, [W/m°C]**
Amphibole	3.46
Chlorite	5.15
Feldspar	2.25
Olivine	4.57
Plagioclase (labradorite)	1.53
Quartz	7.69
Calcite	3.59
Dolomite	5.51
Mica	2.03
Plagioclase	1.84
Pyroxene	4.52

Table 2
Average thermal conductivity of rocks (*various sources*)

Rock	***R*, [kg/m³]**	***Ls*, [W/m°C]**
Basalt	2.90	1.7
Diabase	2.98	2.3
Dolostone	2.90	3.8
Gneiss	2.75	2.6
Granite	2.75	2.5
Limestone	2.70	2.5
Marble	2.80	3.2
Quartzite	2.65	5.0
Sandstone	2.80	3.0
Schist	2.65	<1.5
Shale	2.65	2.0
Syenite	2.80	2.0

The alluvial deposits' estimated stratification, according to the geophysical investigations in a drilled well (that will be confirmed by investigative drilling) is the following:
- 0.00-1.10 m top soil;
- 1.10-14.0 m boulders and coarse gravel;
- 14.0-15.5 m gravel and coarse sand;
- 15.5-30.0 m boulders and gravel;
- 30.0-30.8 gravel and sand;
- 38.0-41.8 m plastic clay;
- 41.8-48.7 m gravel and coarse sand;
- 48.7-55.0 m plastic clay;
- 55.0-60.0 m gravel and sand;
- 60.0-64.0 m blue plastic clay;
- 64.0-66.0 m gravel and sand;
- 66.0-90.0 m clay with sandy clay lamines;
- 90.0-100.0 m gravel and sand;
- 100.0-105.0 m plastic clay;
- 105.0-110.0 m gravel and sand;
- 110.0-115.0 m plastic clay;
- 115.0-118.0 m gravel and sand;
- 118.0-120.0 m plastic clay.

The aquifer hydrostatic quota with free level was −3.20 m.

4. The Geological Investigation Schedule

In the first phase, *in situ* tests are proposed for establishing the studied area's lithology and the aquifer system's characteristics for the following purposes:

- the preparation of groundwater iso-line maps from which the water flow direction can be inferred;
- establishing the stratification and layers' characteristics (the nature from a granulometric point of view and by porosity);
- tracking the groundwater level variation from which pressure differences, the hydraulic gradient (*i*) and the flowing speed can be deduced.

These objectives imply the following investigative work:

- the execution of three drillings with tubing at 70-130 m at lest one with continuous core drilling and other two will be subsequently endowed with piezometers;
- granulometric analysis of the gathered samples;
- for determining the porosity, there will be dynamic penetrations in non-cohesive materials or down-hole tests and unperturbed samples will be taken from the cohesive materials.

The next phase will be the preparation of the geothermal study. The purpose will be remodeling the system on the basis of the measurement data and the definitive resizing of the exchange field.

The investigative work consists of:

- the execution of 2-3 drillings (at 5…10 m distance from the others made before), in the flow direction and transverse on it for the estimation of reciprocal influence (Figure 2);
- equipping the drills with thermal sensors for each, surveying the temperatures for the preparation of the geothermal profile;
- testing the water flow speed with traces and determining the permeability coefficient.

For illustrative purposes we present in Figures 3 and 4 the standard mineralogical composition for alluvial deposits in the Braşov depression, established during studies carried out in the area. Furthermore, the granulometric analysis situates these deposits in the soils named "gravel and sand", the deposits being of alluvial origin. The coarse fraction is made up of round gravel.

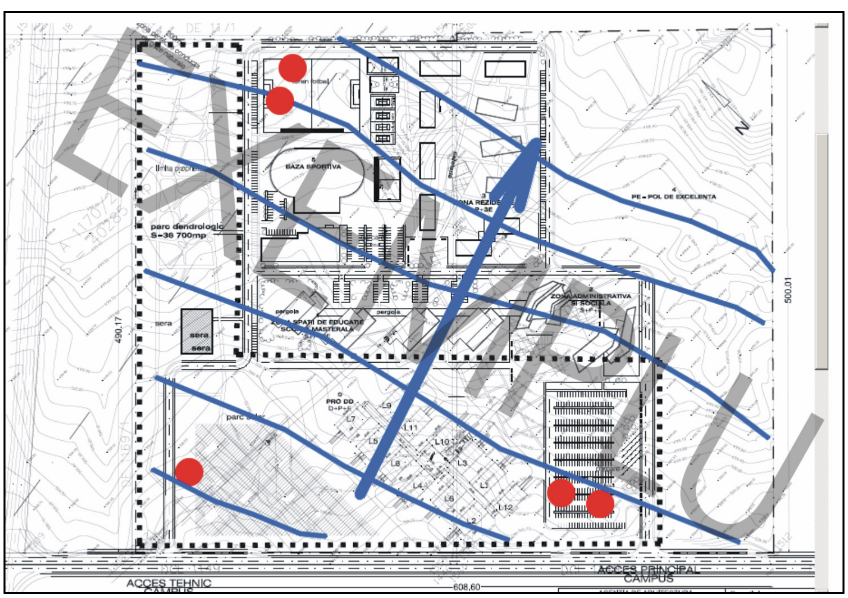

Fig. 2. *The placing proposal for the research drills and the hypothetical results. It can be seen the groundwater flow line and groundwater iso-lines*

Lithical fragment of quartzitic sandstone from alluvionary gravel:

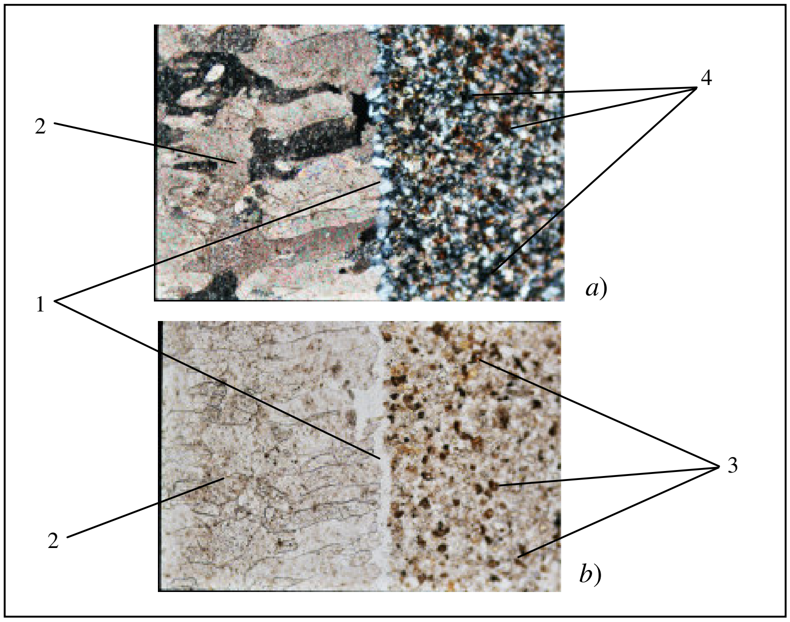

Fig. 3. *Quartzitic sandstone with carboantic cement, crossed by calcite seam: a) N+45x; b) 1N 45x.* 1- *Quartz;* 2 - *Calcite;* 3 - *Siderite;* 4 - *Opac minerals*

A sediment constituted of pelite fraction impregnated with iron hydroxides in which claste (50%) of variable composition are caught.

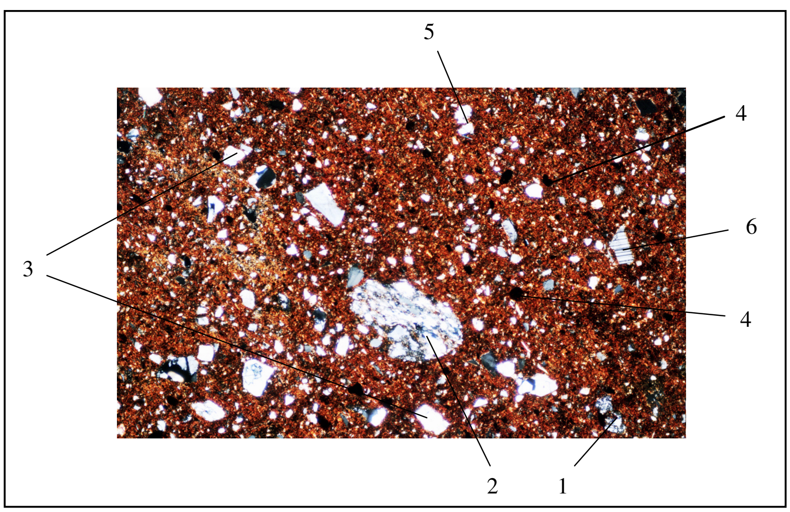

Fig. 4. *Silty clay consisting of clayey matrix, lithic fragments and crystalloclasts* (*N*+, *35x*): 1 - *quartzite;* 2 - *gneiss;* 3 - *quartz;* 4 - *opaque minerals;* 5 - *biotite;* 6 - *plagioclase*

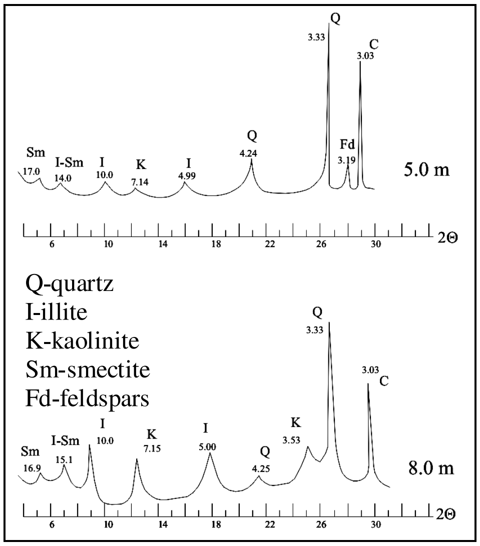

Fig. 5. *X-ray diffraction specters - CET Drill; ethylene glycol treated samples*

It can be observed in Figure 5, in which the x-ray diffraction specters of the ethylene glycol-treated clay samples are presented, the most intensive diffraction maximums are the ones that belong to primary minerals: quartz (4.25; 3,33 Å), calcite (3.03 Å) and feldspars (3.18 Å). Quartz and carbonates are found in all samples.

The diffraction maximums characteristics of clay minerals have low intensity, suggesting low content, being expanded on the base, which suggests a low degree of crystallinity.

Also in Figure 5 it can be observed the identified clay minerals are illite (10.0; 4.99 Å), kaolinite (7.14; 3.54 Å) and smectits (17 Å). The existence of a diffraction maximum of about 14.7 Å in the glycolate samples specters suggests the presence of an illite-smectite interstratification that presents a decreased degree of expansion upon ethylene glycol treatment. The intensity of the clay minerals diffraction maximums shows that illite is one of the main components. Kaolinite offers a similar image. It is most likely that smectite minerals of montmorillonite type and interstratifications have the lowest prevalence.

Establishing the mineralogical composition of the deposits and estimating the thermal conductivity of the minerals on the basis of the mean values from literature, with the help of the algorithms presented above, leads to the computing of the heat quantity from the terrain.

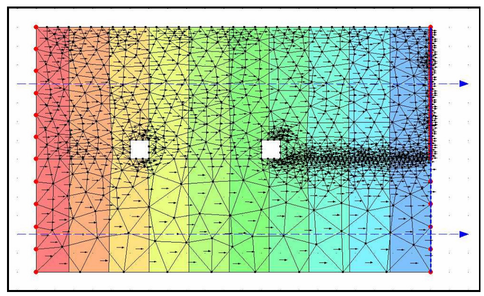

Fig. 6. *Representation of the groundwater flow in the area of the two drillings*

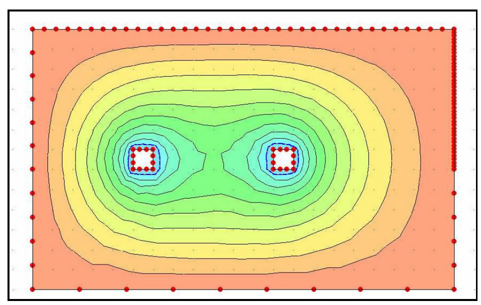

Fig. 7. *Temperature distribution. An elongation of the halos in the direction of the water flow can be observed*

The flowing of groundwater, induced by porosity and permeability, complicates the calculation of the heat transfer but is a major element that needs to be taken into account (see Figures 6 and 7); the existence or non-existence of the aquifer can influence the heat quantity transferred from simple to quadruple.

5. Conclusions

According to the results to the geophysical investigations, which indicate some ground characteristics, it can be chosen tests for a more reliable dimensioning of the exchange field.

For calculating the heat quantity that can be extracted from the ground it is necessary to determine the volumetric water content, the porosity, the mineralogical composition of the ground, and also the groundwater characteristics.

For non cohesive soil only indirect methods can be used to find out volumetric water content, the porosity. The most reliable results come from piezometric tests for the water, and geophysical (down-hole test) for porosity. Continuous core drilling with undisturbed samples can be used successfully for cohesive soil.

Analysis through the finite element in transitory regime method can offer an image of the evolution in time of the geothermal exchange field.

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