Smart Energy and Sustainable Environment

2020, *23*(1): 21-28, https://doi.org/10.46390/j.smensuen.23120.78

QUANTIFICATION OF GEOLOGICAL/GEOPHYSICAL/ GEOCHEMICAL DATABASES FOR THE MODELLING OF GEOTHERMAL WATER STRUCTURES

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Abstract:

The iterative 3D geological modeling/inversion program (GeoModeller Base - Geology Modelling and GeoModeller Full Gravity / Magnetics) from Interpid Geophysics (Australia) has been implemented (installed and tested), based on a partial academic license (modules: Geology, Magnetism , Gravimetry) valid until 31.01.2023. Geological, geophysical and geochemistry data modelling represents the construction of the geological model, based on all input data (processed geophysical data, with iterative algorithms for direct and indirect geophysical problems, digitalized geological data, geochemistry data), editing, visualization and advanced management. The direct problem (named modeling) and the indirect problem (named inversion) are solved iteratively based on the optimization of the properties of the combination of: gravity, magnetism and 3D geological constraints. An input database was created for the modelling program that include all knowledge data. These data have been supplemented from several sources, starting with the data from bibliography, published works and reports, digitization and quantification of information and detailing some of them by geological prospecting, mapping and geophysical field measurements. In paper is presented the geological framework of the study area from Pannonian Depression, an area with a strong geothermal potential. Also, an extended map for the North-West of Romania of the Bouguer anomaly, the Free Air anomaly, the temperature at 3000 m depth and the geothermal flow is presented. These data are supplemented by bibliographic sources with the description of water chemistry.

Article info:

Received 11 February 2020
Received in revised form 24 February 2020
Accepted 28 February 2020
Available online 06 March 2020

Keywords*:*
Geothermal resources, geology, geophysics, geochemistry, modelling.

How to cite: Asimopolos, L., Asimopolos, N.-S., Niculescu, V.-C., Asimopolos, A. A., (2020). Quantification of geological/geophysical/geochemical databases for the modelling of geothermal water structures. *Smart Energy and Sustainable Environment, 23*(1), 21-28.

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1. INTRODUCTION

An accessible and inexhaustible form of using the Earth`s internal energy is geothermal waters. Thermal waters have their own temperature independent of the place of occurrence, being at least 4°C above air average temperature and 20176°C above soil average temperature.

Depending on their temperature, the geothermal waters can be used for different purposes (spas - the waters with a minimum temperature of 40°C, heating - the waters with temperatures between 40°C-100°C, for the production of electricity - the waters over 100°C).

Groundwater resources are made up of existing water deposits in groundwater and deep-water layers. The distribution of the underground leak varies on the large tectonic units in the territory of the country as follows (Moldovan et al., 2011):

0.5-1 l/s km^2 in North of Dobrogea;
0.5-2 l/s km^2 in Moldavian Plateau;
0.1-3 l/s km^2 in Transylvanian Depression and Pannonian Depression;
0.1-5 l/s km^2 in Danube Plain;
5-20 l/s km^2 in Carpathian Mountain.

In the Pannonian Depression sector, between the western end of the Apuseni Mountains and the Hungarian border, the geothermal anomaly is the most intense. This area represents the hottest part of the entire alpine geothermal belt.

The most important geothermal water system in the Pannonian depression is the cantoned deposit in the Mesozoic limestone and dolomite areas, Baile Felix - Baile 1 Mai - Oradea. The importance of the presented study is represented by quantification of the geological, geophysical and geochemical data, before the iterative cycle modeling / inversion for the realization of a 3D model.

2. DESCRIPTION OF THE MAIN GEOLOGICAL, GEOPHYSICAL AND GEOCHEMICAL CHARACTERISTICS OF THE AREAS WITH GEOTHERMAL POTENTIAL FROM NORTH-WEST PART OF ROMANIA

One of the primary materials from which we were able to extract information necessary for the realization of the databases was the set of sections made in 1985 (Stefanescu-IGR), and their location were summarized in table 1.

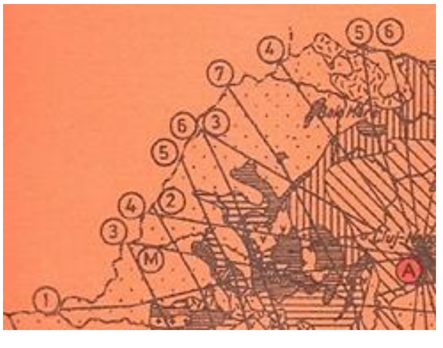

Figure 1. Geological sections

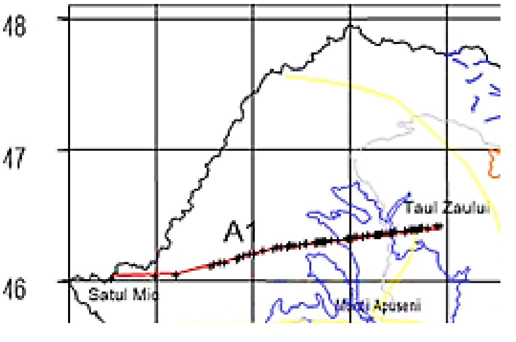

Figure 2. Section A1

We digitized the elevation of the terrain for section A 1 (fig. 2), in geographical coordinates (WGS84) and we transformed these geographical coordinates into metric coordinates in the Stereographic Projection 1970, Dealul Piscului. We digitized the geological formations in the geological section A1. We proceeded to transform the coordinates on the map (digits) into metric coordinates, considering the western limit of the profile as the point of origin and represented the geological formations on the profile in the form of polygons positioned along the profile in coordinates (horizontal distance versus altitude/depth).

We digitized 35 separate bodies according to lithological criteria and age criteria (fig. 3). In choosing and grouping them, we took into account, first of all, the physical properties of the component rocks.

The formations with the highest densities are crystalline ones, of Proterozoic age and the formation with the lowest density is salt. The basic volcanic formations and the Transylvanian ophiolites have densities between 2.65-2.68 g/cm^3. Banatites and Permian volcanic formations have densities between 2.62-2.63 g/cm^3. Mesozoic sedimentary formations, with a predominantly carbonate component and subordinate clay, have an average density of 2.6 g/cm^3.

These properties are summarized in the following table:

Table 1. Density and magnetic susceptibility on section A1

Geological formation	Density (g/cm^3)	Magnetic susceptibility
Crystalline	2.74	120 CGS
Permian up	2.62	150 CGS
Permian down	2.68	600 CGS
Ophiolite	2.68	600 CGS
Salt	2.17	0 CGS

The figure 3 shows section A1, which has been fully digitized and included in the databases. Thick black lines delimit the bundles of formations, to which the physical properties (density and magnetic susceptibility) have been attributed.

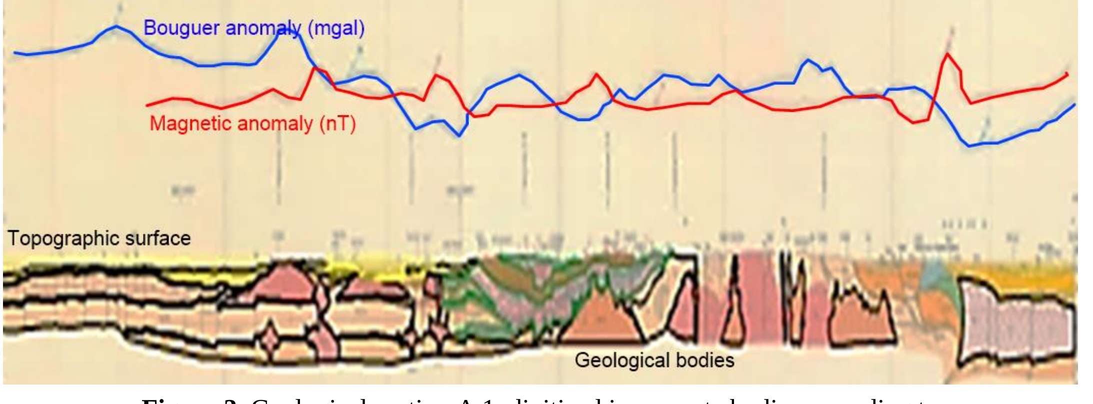

Figure 3. Geological section A 1, digitized in separate bodies according to lithological criteria and age criteria

The same process for extracting deep geological information was used for all seismic sections in the working perimeters.

Another important stage of work was the completion of the geological information for the improvement of the 1:50000 scale geological maps of the working areas.

Geological maps (http://www.igr.ro), scale 1:200000 are presented in fig. 4 and fig. 5.

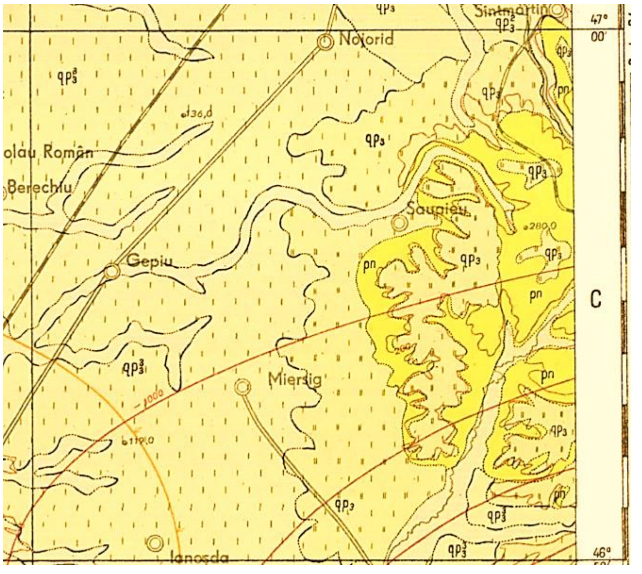

Figure 4. Extract from the geological map, scale 1:200000, name Oradea, L-34-X and L-34-IV, geographical coordinates: 47°00’-46°50’ and 21°45’-22°00’, (1965-IGR)

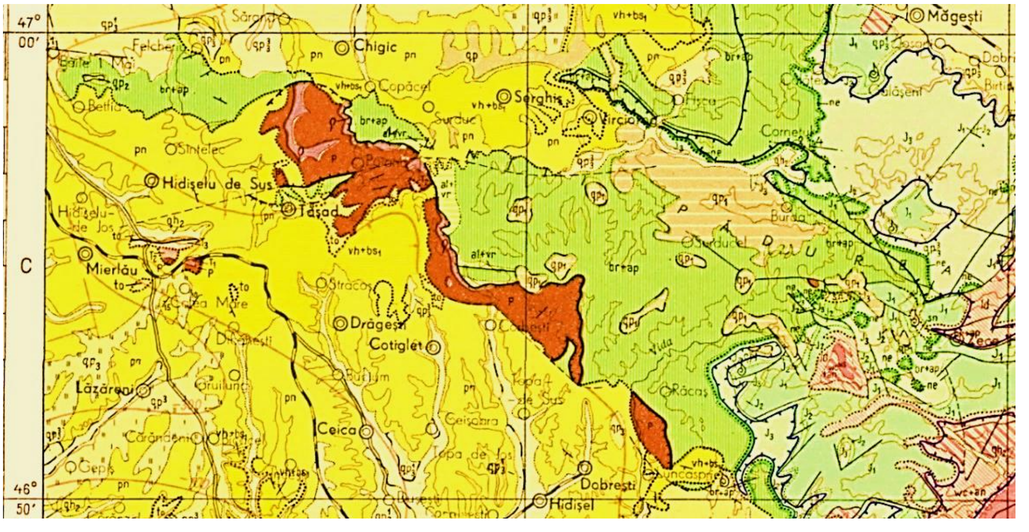

Figure 5. Extract from the geological map, scale 1:200000, name Simleul Silvaniei, L-34-XI, geographical coordinates: 47°00’-46°50’ si 22°00’-22°30’ (1967-IGR)

It is a proven fact for a long time (Oraseanu, 1998; Oraseanu and Iurkiewicz, 2011) that the thermal system in the Baile Felix-1Mai area is fed from the karst area Padurea Craiului, through a complicated and unknown system of karst paths, favoured by the thick levels of Mesozoic limestone and by tectonic rupture in several tectonic phases. The last tectonic phase seems to be very new, poor at the base of the Quaternary, that many faults are constituted in open water circulation paths between various limestone levels. The result is that although the different levels of limestone are separated by impermeable sediments, in fact the limestone bodies are connected to each other and form a unitary system from a hydrogeological point of view. Based on hydrogen isotopes (Papp and Cociuba, 2011), it has been established that most of the sources of groundwater in the area (springs and geothermal waters) are of meteoric origin, but a source of fossil water of marine origin could be highlighted. Also, it has been established that the residence time of the geothermal waters is relatively low and that their mineralization occurs mainly in the karst area in the cold-water stage.

The gradual sinking of the Mesozoic formations under the cover of newer Neozoic sediments of the Pannonian basin carries karst waters to increasing depths, where they become thermal, then leaving the Baile Felix area, due to high compartments that rise up to Neozoic sediments, Cretaceous limestone or Triassic limestone.

For this purpose, we detailed the sedimentary cover of the Bihor Unit and the Codru Units skipped over it, respectively: Valeni Nappe, Finis Nappe and Arieseni Nappe, insisting especially on the limestone levels likely to be the host rocks of the aquifer that feeds the thermal system.

Bihor Unit has on base of its sedimentary cover, coarse red debris deposits, consisting of conglomerates, sandstone, systems and volcanic-sedimentary formations. These were attributed to the Lower Permian and Triassic and have thicknesses from several tens to several hundred meters. They are generally impermeable rocks. They end with dolomitic systems, sometimes with anhydrite.

Middle Triassic is represented by a horizon of dolomites below 100 meters, Guttenstein Limestone, in tiles, dark grey with thicknesses of 250-500 meters, in the central part of the Bihor Unit, at the lower part of these limestones develops the Padis Limestone, white or light grey, stratified in tiles with intercalated systems of black limestone.

The formations within the Jurassic stack are diachronous and replace each other. They reflect different sedimentation environments within a carbonate platform (outer slopes, reef areas or internal lagoons), which migrates from south to north.

The sediments attributed to the Lower Cretaceous represent an alternation of thick levels of limestone and marshy rocks.

In several formations have been described the grey limestone and marns the under are beneath the sedimentary cover that begins with thick Permian debris deposits, followed by a discontinuity of sedimentation of quartzite sandstone, massive conglomerates, then of red clay-silt systems.

The Finis Unit has over the crystalline systems, the laminated conglomerates, with a thickness of 500 meters whose age is upper-Carbonifer to Permian, established on the basis of pollen.

Next level is the sandstone, an alternation of purple micaceous sandstone and clay systems of the same colour. By lithological parallelization, the lower Permian age is attributed to them.

Above the latter is formed the formation of porphyry quartziferous consisting of volcanogenic material of rhyolitic nature. At its top are sandstone that alternates with violet clay systems. All this formation is attributed to the upper Permian.

The lower Triassic is represented by massive quartzite conglomerates and tiles, 300 meters, quartzite tiles in slabs, 130-150 meters, red clay-silt series with thin interlayers of sandstone, 100-125 meters and dolomites in plates present only sometimes.

The Unit Finis is represented by Anisian dolomite, 350 meters in the Rosia area, grey limestone, stratified, 10-20 meters, grey layered limestone with silicon accidents.

The thickness of these deposits reaches 700-800 meters.

The lower Triassic contains to the east of Padurea Craiului, massive breccias with elements of Permian rocks, 200 meters, quartz conglomerates, 200 meters and quartzite sandstone 200 meters.

The middle Triassic is represented by carbonate rocks and clay systems totalling 170 meters.

The successions described above are the result of research into wells, being a collation of all information. In fact, these synthetic stratigraphic columns are only rarely found on the ground in a particular area.

The Quaternary although considered for the mountain areas, it is present only along the valleys and as terrace deposits, in the plain area it reaches large, even considerable thicknesses (over 1000 meters in some areas of the Pannonian Basin). At the edge of the mountains the greatest development is provided by deposits consisting of gravel, sands and clays with cross stratification, which extend much into basin from the main valleys that emerge from the mountains.

In figures 6-9 there are represented geophysical parameters (temperature of 3 Km deep, geothermal flow, Bouguer anomaly and Free Air anomaly). These maps are presented with details for territory of Romania in Asimopolos N.-S. et al., (Asimopolos and Asimopolos, 2018).

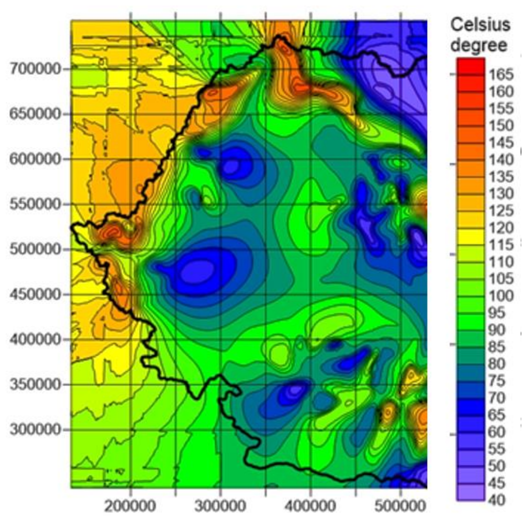

Figure 6. Temperature of 3000 m

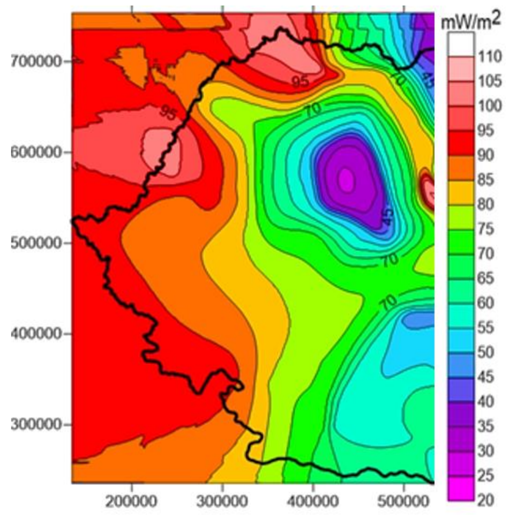

Figure 7. Geothermal flow

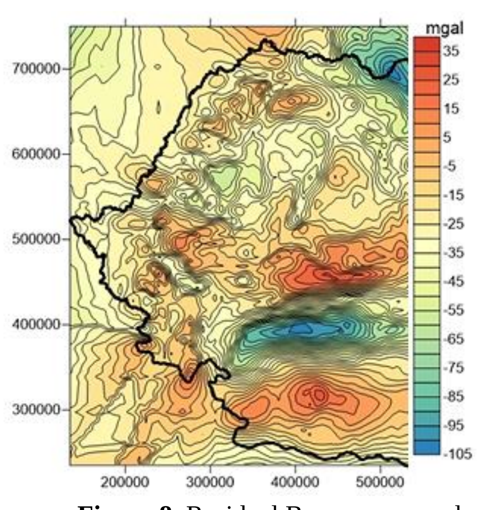

Figure 8. Residual Bouguer anomaly

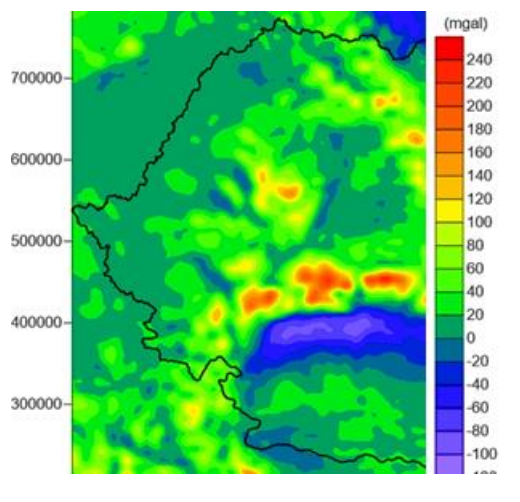

Figure 9. Free Air anomaly

These maps are represented with Surfer software with data from www.igr.ro and http://bgi.obs-mip.fr , using https://www.mathworks.com.

3. CONCLUSION

Quantification of databases and making lithological model using the iterative 3D modelling/inversion program GeoModeller includes the following steps:

- Defining the laws regarding physical properties;
- Specifying the properties for the geological constraints for each geological unit;
- Construction of the first geological model;
- Model discretization in a lithological model based on 3D geometry;
- Specification of "fixed" cells, whose lithology cannot be modified;
- Creating lists with geological boundary cells between formations;
- Calculation of a response functions for the unit of gravitational field and / or magnetic field and / or the components of the tensor for each observation point;
- Initialization of density distribution, remaining magnetization, magnetic susceptibility and geological constraints based on lithology;
- Calculation of geophysical effects of the model;
- Select parts of the model to be modified;
- Resumption of the iterative cycle of modelling/inversion until we obtain a minimum difference between the calculated geophysical values and the measured geophysical values.

3D modelling of the sector between the karst area of the Padurea Craiului and the Baile Felix area, based on mapping data, geophysical information and stable isotopes data (H, O, C) tries for the first time to estimate the depth of water circulation and establishing the supply areas for geothermal water.

In order to evaluate the chemical state of the geothermal water bodies and their utilization, a series of analysis must be performed that attest that the thresholds stipulated in the methodological norms are not exceeded (Moldovan et al., 2011).

The geochemical indicators that determine the state of the geothermal water body are: Nitrogen (NO_3, NO_2), Ammonium (NH_4), Chloride (Cl), Sulphates (SO_4), lead and pesticides.

Also, according to the legal norms, a series of physical-chemical parameters were monitored, such as:

- Thermal regime and acidification: temperature, pH;
- Oxygen regime indicators: dissolved oxygen, permanganate index;
- Indicators of salinity, general ions: conductivity, total alkalinity, total hardness, fixed residue, bicarbonates, sodium, potassium, calcium, magnesium and orthophosphates;
- Metals: As, Cd, Hg, Total Fe, Cr, Ni. Total Mn, Pb, Zn, Cu, Cr, Al, Co, Ba.
- Organic micro-polluants: hexachlorobenzene, trichlorobenzene, chlorinated solvents, pesticides: triazines, anilines, organophosphorus, thiourea, PCBs;
- Other specific non-priority pollutants: phenols, cyanides.

Acknowledgements: We thank the support of the Ministry of Education and Research for the funding of the project: “The realization of 3D geological/geophysical models for the characterization of some areas of economic and scientific interest in Romania”, with Contract no. 28N/2019 and project No. 16PCCDI/2018: „Institutional capacities and services for research, monitoring and forecasting of risks in extra-atmospheric space”, within PNCDIII.

Funding: This paper was prepared in connection with the project: “The realization of 3D geological/geophysical models for the characterization of some areas of economic and scientific interest in Romania”

Author Contributions: Laurentiu Asimopolos and Natalia-Silvia Asimopolos performed the geophysical data processing and the geological documentation. Violeta-Carolina Niculescu performed the geochemical documentation regarding the geothermal waters. Adrian-Aristide Asimopolos had an important role in the implementation of the 3D modeling program and the data processing programs.

Conflict of Interest Statement: There is no conflict of interest on this article.

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