CHPM2030 DELIVERABLE D6.2.3

REPORT ON PILOTS: EVALUATION OF THE CHPM POTENTIAL OF THE STUDY SITE, ROMANIA

Summary:

This report presents the data related to the Beius Basin - Bihor Mountains study area, evaluating for the potential of becoming a CHPM pilot area according to the concept presented in the CHPM2030 project; this pilot area has both geothermal potential and mineralization to enable their combined exploitation in a CHPM plant. In order to reach this goal, based on these data, further research can be initiated.

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Executive summary

The purpose of this study is to provide relevant information that leads to the selection of a pilot site, an area that has favorable preconditions for the existence of deep mineralization and high geothermal potential at the same place. In Romania the the Beiuș Basin – Bihor Mountains has been selected as study areas. The site is situated at the convergence of two major structural units and has characteristics similar those. Thus, the Beiuș Basin, which is a part of the Pannonian Basin, has high geothermal potential. At the same time, Bihor Mountains' structural unit is a part of the North Apuseni Mountains, and it is part of the metallogenic province Banatitic Magmatic and Metallogenetic Belt.

Both Pannonian Basin (Romanian part) and Beiuș Basin have the following relevant elements:

- The thin crust, (which is estimated at 25-27 km), and the thin lithosphere (60 -70 km) that resulted during regional extensional processes of Pannonian Basin that started in Miocene;
- Below Neogene deposits, Triassic deposits host a geothermal aquifer;
- The existence of intrusive magmatic bodies in the depth.

Both North Apuseni Mountains and Bihor Mountains have the following relevant elements:

- Existence of a granodiorite - granite pluton with regional extension that has been extruded during Late Cretaceous.
- The existence of important mineralized areas, specific to the Banatitic Magmatic and Metallogenetic Belt, among which we mention the skarns that have been formed at the contact between the pluton and the Mid-Triassic and Upper Triassic limestones.
- Existence of a large geothermal aquifer recharge area that is represented by karst deposits of mainly by Triassic deposits

Geothermal potential

For the eastern limit of the Pannonian Basin, Rădulescu and Dimitrescu (1982) estimated the mean heat flow of 96 mWm^{-2}. Geothermal gradients for **Pannonian Basin** are high, varying from 6.2 to 5.6 ^{0}C/100 m at 500 m and at 2000 m b.s.w.l respectively. Due to the thin crust and the thin lithosphere, Beiuș Basin is characterized by high heat flow, with values up to 90 mWm^{-2}.

In **Apuseni Mountains**, in areas affected by Tertiary tectogeneses usually referred to terrains younger than 50 Ma, the three components of the regional heat flow: crustal radiogenic, thermal transient perturbation, and background heat flow from deeper sources, contributes with 36, 27 and 27 mWm^{-2}, respectively, to the mean value 90 mWm^{-2}.

Thermal conductivity [10^{-3}cal/cm x ^{0}C x s] of the rocks belonging to the Romanian part of the Pannonian Basin and the surrounding areas has been determined through laboratory methods, and has high values varying from 3,5 – 12 for granites, 4.8 – 5.0 for diorites and 6 – 7 for dolomitized limestone.

Based on these data the conclusion is that in Bihor Mountains, the heat flow of granitic – granodioritic bodies from Pietroasa and Budureasa are supposed to have high values in the depth. Also the heat flow of the rocks that host the geothermal aquifer (limestone, dolomite and quartzite, marble) has high values. But an important cooling agent is represented by the continuous circulation of the surface water through the karst areas of Bihor Mountains into the geothermal aquifer from Beiuș Basin. It is expected that in the depth of 4 km, where the access of water is prevented by the aquiclude Lower Triassic layers the heat flow of the batholith to be considerable.

Deep metal enrichment

Mineralization is widespread in the mountainous area and is expected to be found in the basin area. In Bihor Mountains the mineralization is generated during the banatitic calcalkaline magmatism (Post-Lower

Masstrichtian-Palaeogene), which is represented by bodies of intrusive rocks, generally hypabyssal as well as plutonic ones, which are widely developed in the depth. Plutons of granodiorite-granite rocks, to which the main sulphide mineralization is genetically linked, constitute main mass of banatitic bodies in the Apuseni Mountains; in Bihor Mountains they crop out on small areas, but they develop in the depth.

Magmatic bodies intruded Permian-Mesozoic sequences and produced contact-metamorphic aureoles, at Pietroasa, Budureasa and, most extended at Baita Bihor. In the contact aureoles of the granodiorite-granites plutons, skarns with Fe, B, Bi, Mo have been formed. At Valea Seacă, Valea Mare-Budureasa etc., the skarns are overlapped by sulphide mineralization.

Brucite deposits from Budureasa and Pietroasa were investigated by surface pits, drillings and underground galleries. They have been formed at the contact of granodiorites with the Anisian dolomites and have a structure with four zones, ranging from granodiorites to pure dolomites containing holocrystalline hypidiomorphic granodiorites, magnesian skarns, Brucite-bearing zones, recrystallized Anisian dolomite.

Borate deposit is situated **i**n the middle basin of the Aleului Valley (Bihor Mountains), at its confluence with the Sebisel Valley, at the Gruiului Hill. The formation of the borates from the contact aureole of the Pietroasa granitoid body is the result of an infiltration metasomatic process.

W-bearing and base metal skarns are characteristic only for Baita Bihor. At Baița Bihor, some magnesian skarn bodies or ore pipes such as those at Antoniu, Bolfu-Tony, Hoanca Motului, Baia Roșie are **boron-bearing skarns** and represents well-defined metasomatic columns. A sole similar body, or metasomatic column, that from Dealul Gruiului was identified at Pietroasa.

Laboratory experiments performed during the implementation of this project lead to promising results.

- Two rock samples from Romania were used for **leaching experiments** by Chris Rochelle et al., in 2017 (CHPM2030 Project Deliverable 2.2): a skarn from Pietroasa and a mineralized rock from Cacova Ierii. The experiments used a range of fluid types and pressure/temperature conditions to identify fluid-rock reactions and quantify the potential for enhancing metal release. For conditions of temperature/ pressure of 100 °C, and 200 bar the efficient substances proved to be 0.6 M NaCl, and HCl/HNO3 mix for both samples. The main elements recovered are: **Co, Sr, Mo, Sb, Mn, Zn, W.**
- In 2018, using GDEx technology, Xochitl Dominguez et al. (CHPM2030 Deliverable 3.3) completed the experiments to **recover metals from the geothermal brine** provided by a Beiuș Basin well. According to this study, the results are promising. Especially the content of Sr in one of the brine samples and the content of Sr recovered are remarkable.
- A considerable enrichment of magnesium minerals was highlighted in the precipitate resulted from the geothermal water extracted from a Beiuș Basin well compared with spring and water coming from a mine. Thus, the magnesium content is less than 5% in surface, and at least 13% in the geothermal waters.

Integrated 3D model

Integrating all the data available in a 3D geological database and creating the 3D geological model provided an overview on the spatial distribution and the geometry of the middle and upper Triassic sedimentary deposits within Beiuș Basin and their contact with the Upper-Cretaceous intrusive body, from Bihor Mountains.

The 3D model shows the extension of Upper Triassic deposits, both in Beiuș Basin and in Bihor Mountains, linking the two structural units, generating magnesian skarns on one side and transporting geothermal water on the other. This dual role in the perimeter explains an increased content of magnesium in geothermal waters from Beiuș Basin.

The 3D model revealed the fact that there is a region bordering Beiuș Basin where the batholith is extended: at Budureasa, where there is an increased possibility to have both mineralisation and high geothermal potential within a small area.

The 3D model emphasizes the large areas on which Triassic deposits outcrop. Being represented by highly fissured karst deposits they, on one side, assure a continuous recharge of the geothermal aquifer, but, on the other side, they have an important contribution to the decrease of the geothermal potential of the rocks, being a cooling agent.

The batholith's apophyses that were detected by complex geophysical methods within Beiuș Basin, and can be taken into consideration for further investigations are represented by the model.

The 3D model helped us to visualize and understand the spatial relations at the border between the basin and the mountains and provides new data that are needed to set the parameters for planning new exploration works.

At the same time the 3D model helps us to reduce the original area for new future investigations to a smaller area with an increased probability that it is suitable for a CHPM system.

Hydrogeology

The geothermal aquifer from Beiuș and Ștei is hosted in fractured Triassic dolomites that have a regional extension. Triassic aquifer from Beiuș Basin is a confined aquifer with negative piezometric levels (- 18.48 m 3001 H Beiuş and unstable – 45m 3003 H Beiuş) or artesian (3002 H Ştei), depending on the position of the tectonic block. Beiuș aquifer is an open geothermal system, where recharge equilibrates with the mass extraction and its reservoir pressure stabilizes. Its recharge can be both hot deep recharge and colder shallow recharge. The latter can eventually cause reservoir temperature to decline and production wells to cool down. In fact, this second alternative was demonstrated when the increase of the volume of injected water was accompanied by the decrease of the water temperature within aquifer. More research is needed to improve the knowledge on this subject. The aquifer is exploited by 2 extraction wells and one injection well in Beiuș, and one extraction well in Ștei, situated at a distance of 18 km from Beiuș. The most productive well is 3001, from Beiuș, that has a wellhead temperature of 88^{o}C, coming from 2460 m depth.

Geothermal district heating system

Beiuş town has an extensive geothermal heating system (GDHS), which provides heat for approximately 70% of the population, covering about 60% of the urban heating demand. The previous system that used coal as a source of energy was completely replaced by GDHS. The geothermal heat energy is delivered to the consumers either indirectly via substations with heat exchangers feeding double closed loop distribution pipe networks, one for Domestic Heating (DH) and the other for Hot Sanitary Water (HSW), or directly to the individual buildings with their own heat exchangers. The exploitation license of Beiuș geothermal reservoir perimeter is owned by Transgex S.A.

Currently, the geothermal energy exploitation system consists of 2 geothermal water production wells drilled to a TVD of 2576 m and 2700 m, with a production capacity of 450 m^3 / h, and one re-injection well having a TVD over 2,000 m. The geothermal water transport network in the city includes 18 km pipelines. The GDHS has the following users: 120 block stairs connected to the centralized distribution of heat; public institutions are heated with geothermal energy (colleges, schools, kindergartens, municipal hospital, community centre, pharmacies, medical offices and laboratories, churches and places of worship, gymnasiums); undertakings with more than 1000 employees; 200 individual homes with their own thermal units connected to the transmission geothermal water.

In 2016 the energy of 74,452 of GJ/year has been delivered to the population. The value of water production was higher than 1 million m^3. In 2018 a partnership formed by the City Hall and private company submitted project proposals in order to get EU funding for the extension of the GDHS. They also showed their interested for the results of CHPM2030 project and expressed their will to be part of a consortium that could consider a CHPM installation in Beiuș in the future.

1. Overview of CHPM2030 study area in Romania

1.1 Objectives and role of the CHPM2030 project

The pilot mission objective of Task 6.2 in Work Package 6 is to "Combine metallogenic models with geothermal datasets to develop a database of suitable areas in selected case-study areas in Europe where such developments could be feasible". One of these study-case areas is Beiuș Basin - Bihor Mountains in Romania.

1.2 Selection of the CHPM2030 study area in Romania

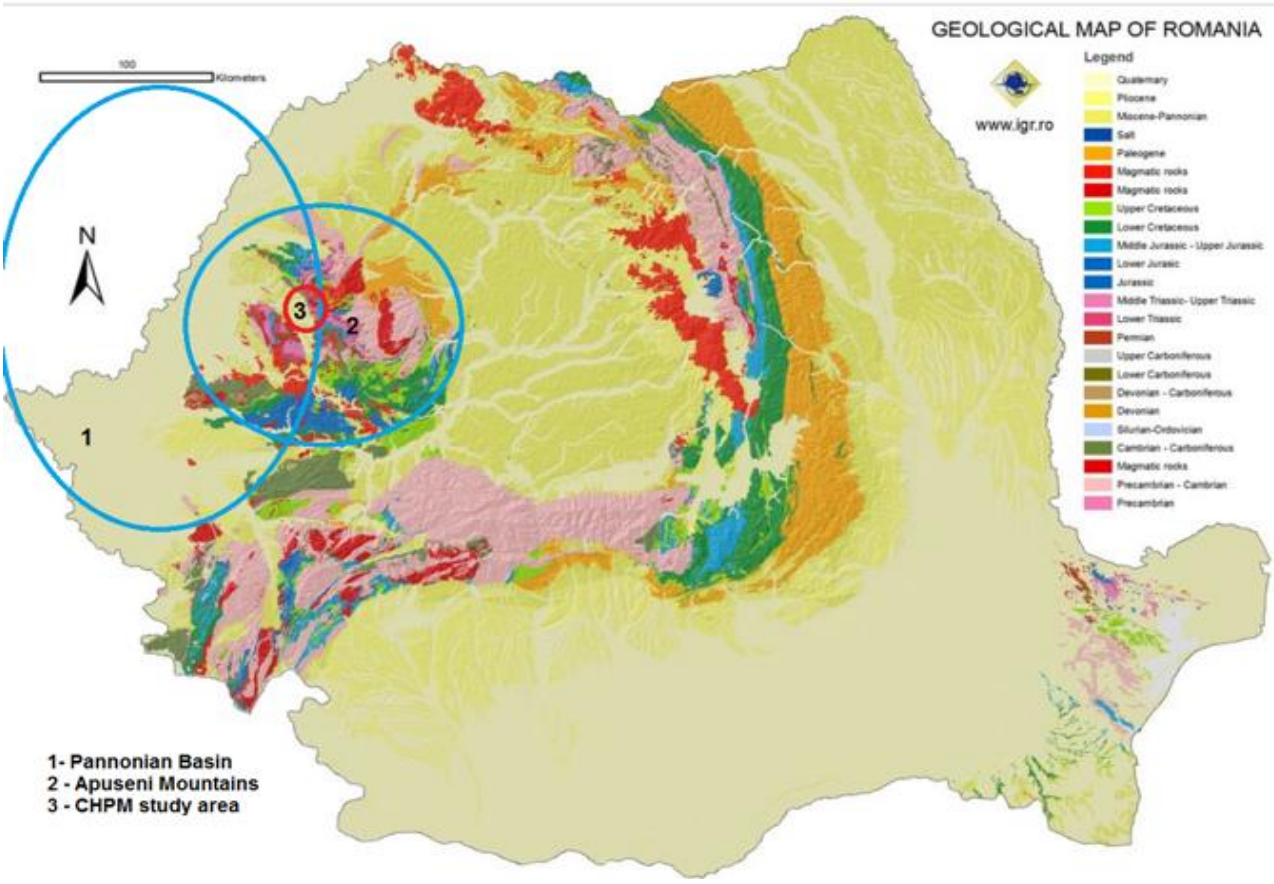


Figure 1 Location of the region Pannonian Basin – Apuseni Mountains

The CHPM study area, which includes Beiuș Basin and Bihor Mountains, is situated at the convergence of two major structural units and takes traits from each of them. Thus, the Beius Basin, which is an extension of the Pannonian Basin, has a geothermal potential similar to it. At the same time, Bihor Mountains structural unit is a part of the North Apuseni Mountains, and is included into the metallogenic province Banatitic Magmatic and Metallogenetic Belt (Figure 1).

The reasons why the study area was chosen in the junction region of the Pannonian Basin and the Apuseni Mountains (Figure 2) are:

- The high geothermal potential of the Pannonian Basin, being the highest in Romania, also found in the Beiuș Basin;
- Existence of a mineralization associated with the upper Cretaceous magmatism described both in the North Apuseni Mountains and in the Bihor Mountains;
- The existence of a granite – granodiorite batholith that outcrops in North Apuseni Mountains, but whose presence was also reported both in Beiuș Basin, at depth;

A map showing the relation between regional and local structural units we are referring to is given in Figure 2.

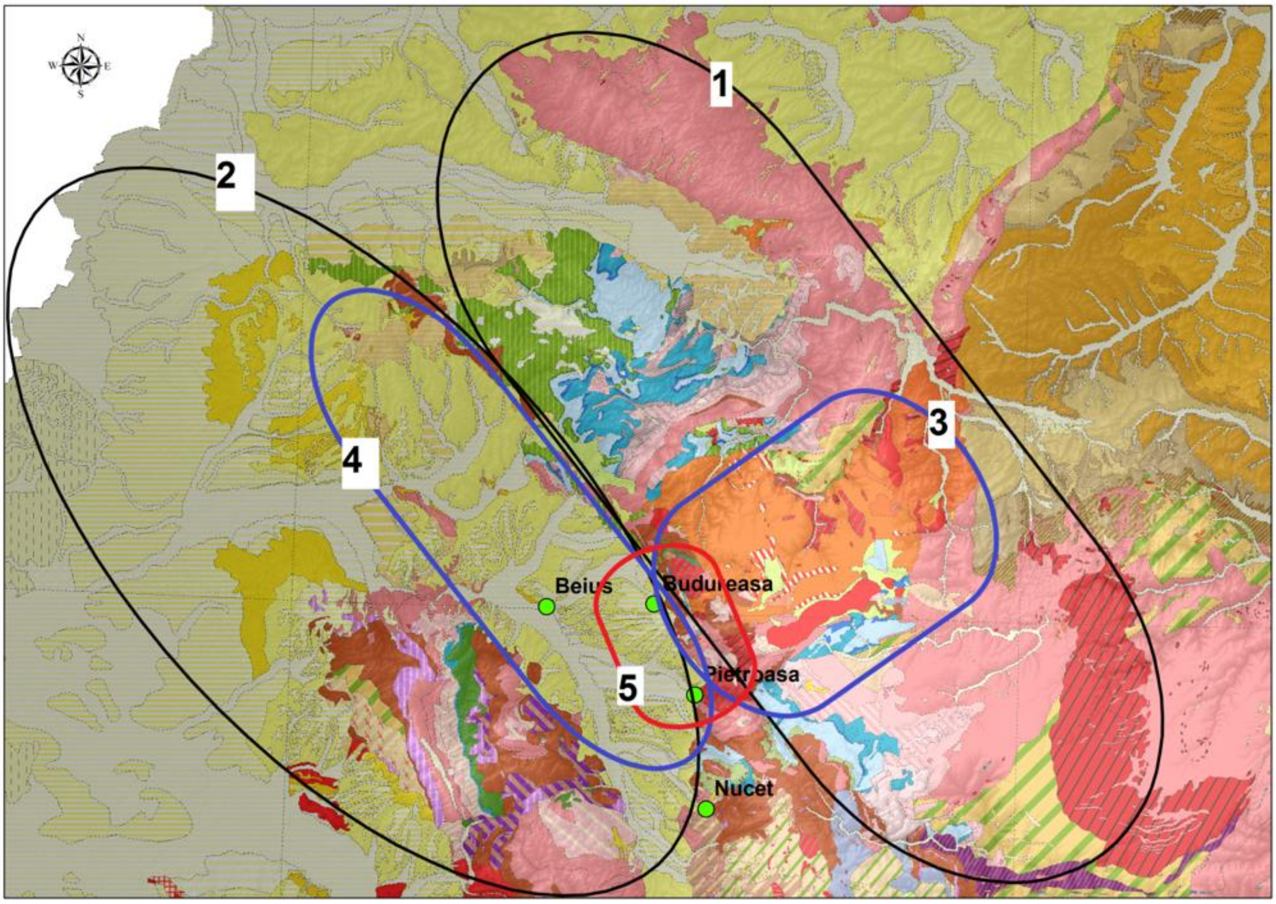


Figure 2 Relation between regional and local structural units that are described within the study. 1-North Apuseni Mountains; 2- Pannonian Basin; 3 – Bihor Mountains; 4 – Beius Basin; 5 – Potential pilot site.

1.3 Description of relevant features at regional level

Describing regional features leads to a better understanding of the study area situation.

1.3.1 Pannonian Basin

Pannonian Basin (Western Plain) is the largest area in Romania that exhibits heat flow density values exceeding 100 W/m^2. Here numerous hydrothermal systems exist, which are characterized by well-head temperatures of 60 - 120^0 C and by flow rates of 10 – 20 l/s. The regional high heat flow density was explained mainly by the thinning of the lithosphere as a result of the extension process produced since the Miocene time. Crustal fractures and also positive magnetic anomalies as reflecting the presence of pre-neogenic or neogenic volcanic masses have been considered too as having an important influence on the heat flow (Airinei et Pricăjan, 1976).

According to the lithology and structure of the water-bearing formations, in the eastern limit of the Romanian part of the Pannonian Basin (Western Plain) there have been distinguished four main hydrothermal systems with a regional extent exceeding 8600 km^2. Three of the structures have been formed owing to the sedimentation of a thick sequence constituted by sands and sandstones, within a post - Sennonian depression with deposits of maximum depth of 2000 m. Within these geothermal structures a decreasing of pressure has been observed during simultaneous exploitation of five or seven wells. , it is not the case of the Oradea and Beiuș geothermal systems which are hosted in fissured limestone and dolomites.

The central part of the Western Plain (Oradea and Beiuș zone) is underlain by the carbonate Mesozoic age which constitutes a distinct hydrogeologic unit. Here an active water recharge maintains the pressure in aquifer, and no pressure drop has been reported, even during intensive exploitation of geothermal wells.

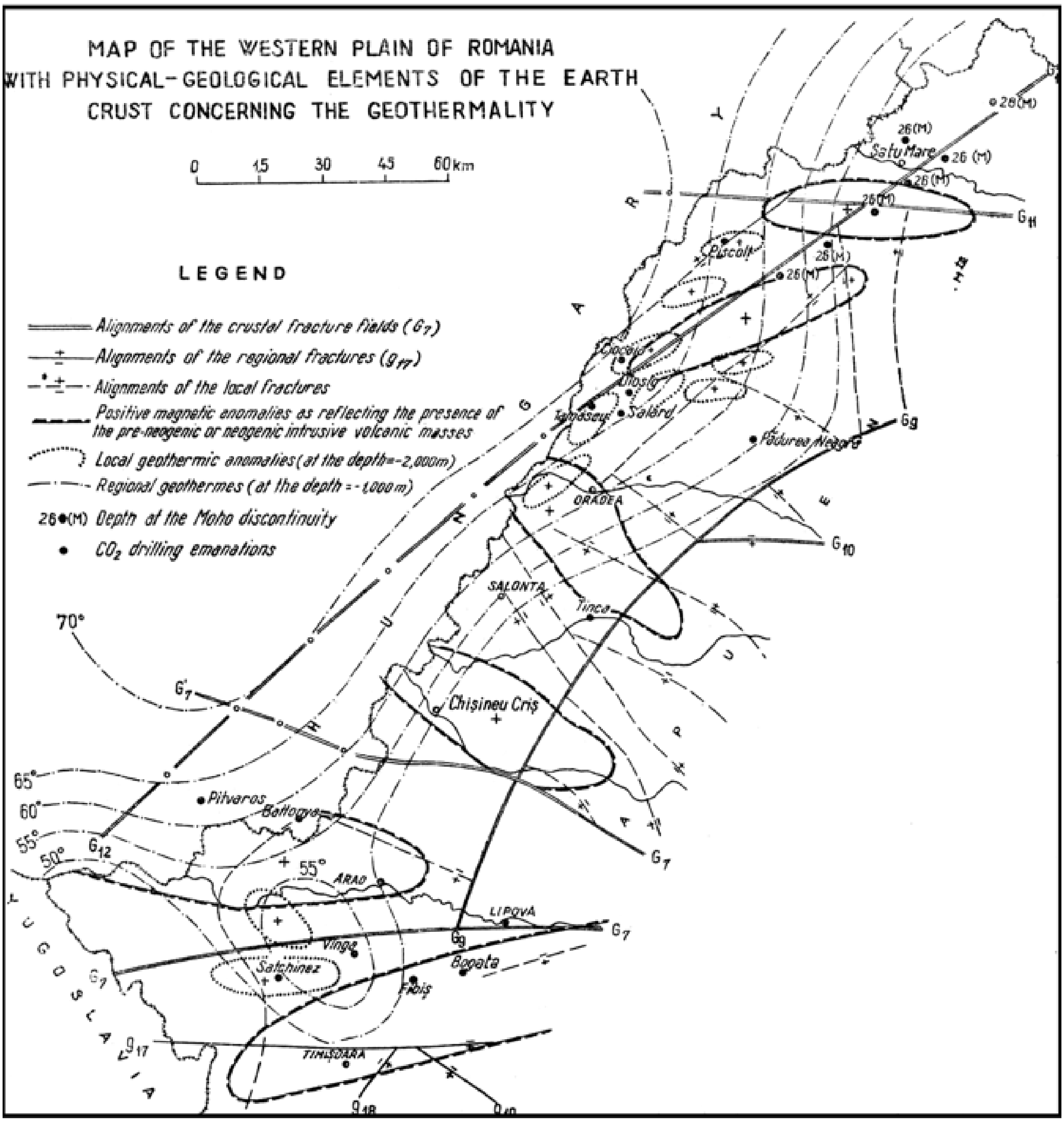


Figure 3 Map of Western Plain of Romania showing, reproduced after Airinei et Pricăjan, 1976:
- Isotherms at 1 000 m depth;
- Positive magnetic anomalies   indicating the presence of intrusive masses;

- Local geothermic anomalies at 2000 m depth;
- Alignments of fractures (local and crustal).

1.3.2 Apuseni Mountains

Apuseni Mountains a sector of the Late Cretaceous Banatitic Magmatic and Metallogenetic belt (BMMB) is subdivided into three zones: Vlădeasa (Pb-Zn ores of restricted metallogenetic potential); Gilău-Bihor (Fe, Bi, Mo, Cu, W, Au, Ni, Co, Pb, Zn, Ag, U, B ores / conspicuous peri-batholitic arrangement) and South Apuseni (only one minor Fe-skarn occurrence) (Figure 4).

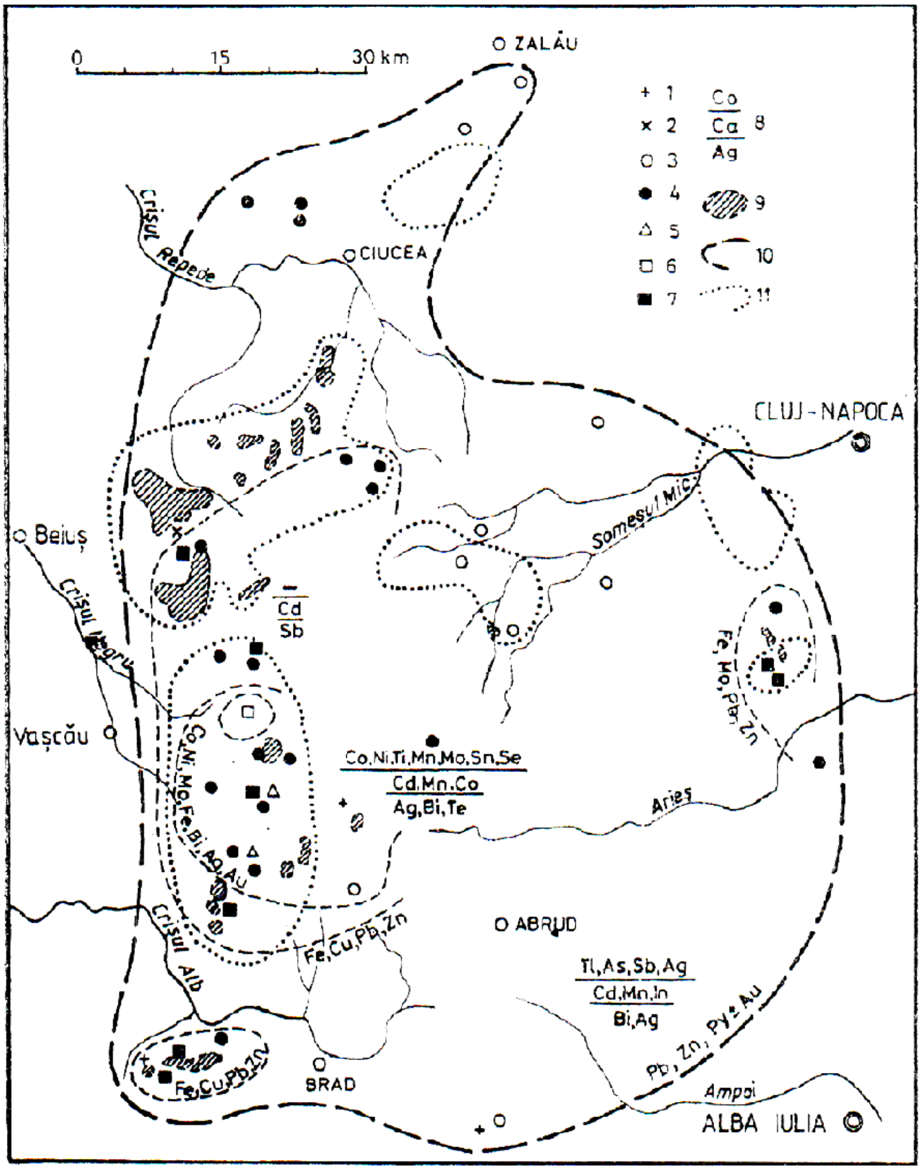


Figure 4 Sketch with regional distribution of the mineralization types in the Apuseni Mountains (Stefan et al, 1986).

1. Baritine occurrences;
2. Brucite occurrences;
3. Pyrite occurrences with, or without gold;
4. polymetalic occurrences (Cu, Pb, Zn);
5. occurrences with Co, Ni, As, Bi, Ag ore;
6. Bi, Mo, W, B, Cu, Pb, Zn occurrences;
7. Fe with, or without Cu occurrences;
8. minor elements characteristic (downwards) in pyrite, spalerite, galena;
9. outcrop, areas with hollocrystalline, equigranular rocks;
10. zones contours;
11. geophysical anomalies.

The sketch indicates mineralized areas according to the geological map of Figure 5.

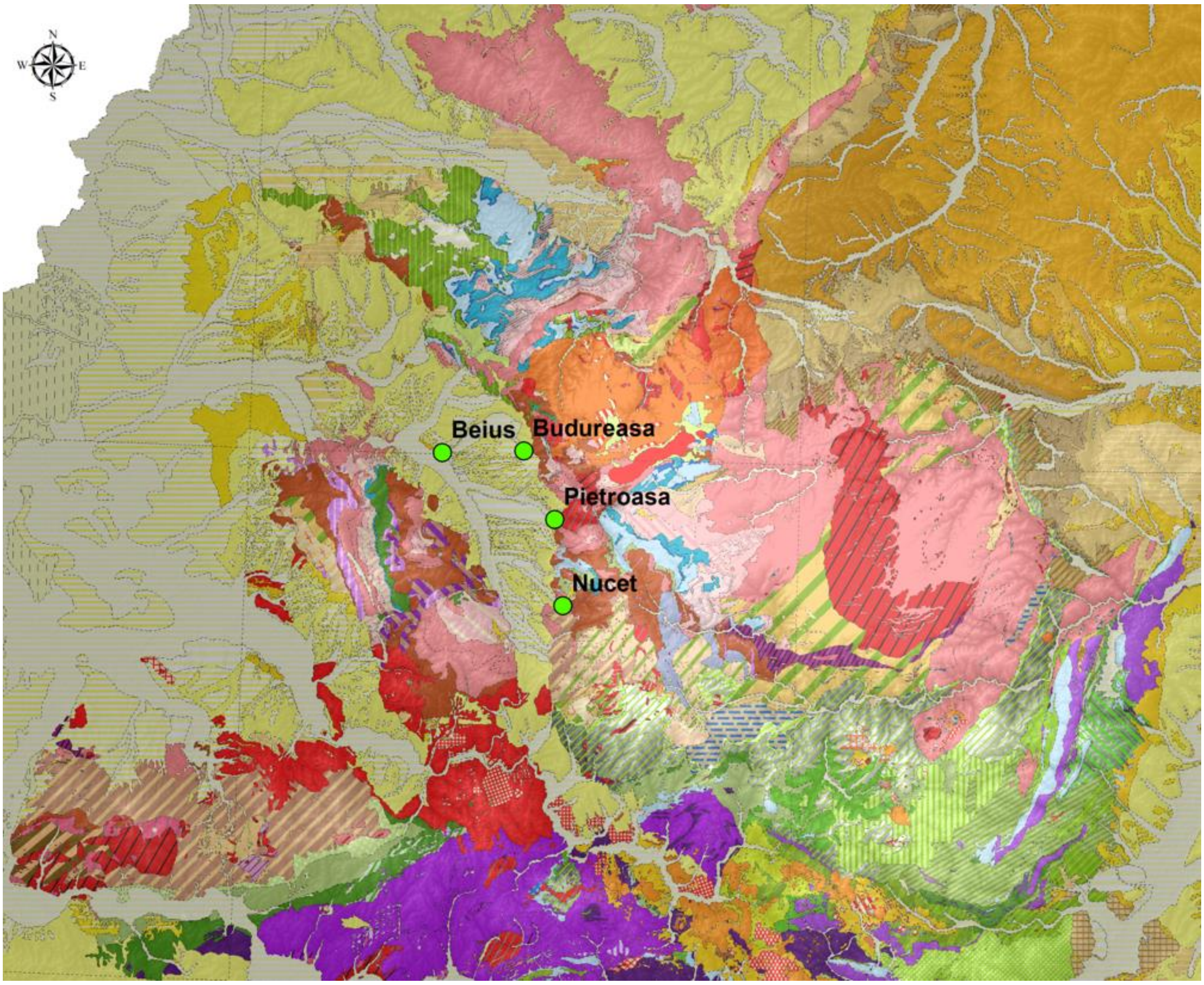


Figure 5 Geological Map of Apuseni Mountains, scale 1: 200 000. Source, Geological Institute of Romania. The legend is the same with that of Figure 6.

1.4 The CHPM study are Beiuș Basin – Bihor Mountains

Beiuș Basin – Bihor Mountains area, having the general features of the region, has, in a limited space the potential for the installation of a CHPM system, namely the existence of geothermal potential and mineralization. For this, it was selected as the CHPM study area. The arguments that led to this conclusion are as follows:

- Having temperatures of 84^{o}C at TVD 2460 m, it is expected that, at 5 km depth, the temperature can be above 150^{o}C.
- Mineralization is widespread in the mountainous area and is expected to be found in the basin area.
- It has already been demonstrated in WP3 that geothermal water contains metals that can be extracted.
- The existence of a geothermal energy exploitation system that could be extended.
- Both local authority and the economic agent that runs the geothermal water system expressed their interested for this.

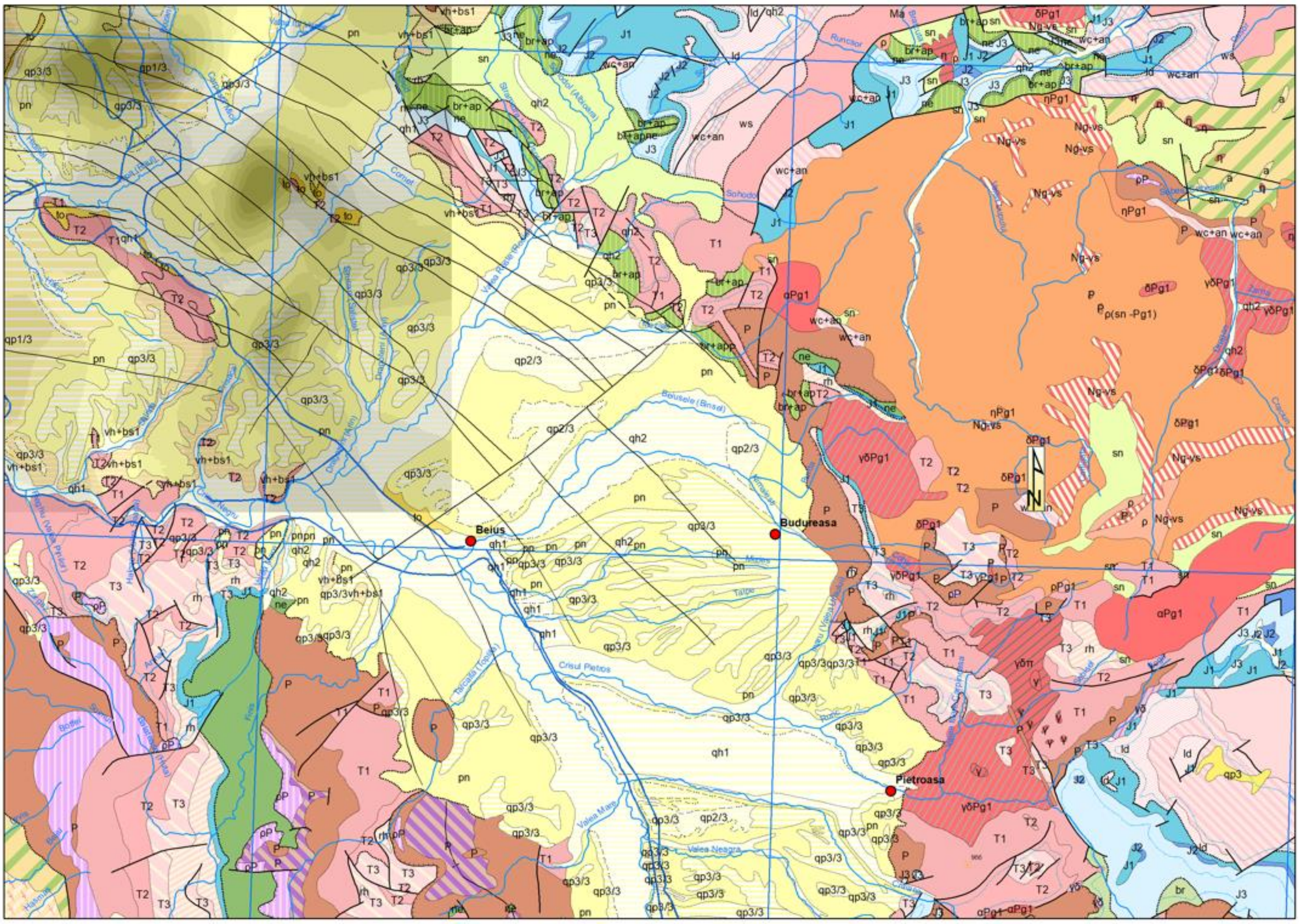


Figure 6 Map of the CHPM study area. Granite and granodiorite bodies outcrop in the eastern part, and aeromagnetic anomalies showing a magmatic intrusion are shown in the western part

Figure 6 bis Legend of CHPM Study area

2. Geology of the prospective area

2.1 Regional geological history

Since Bihor Mountains are part of the North Apuseni Mountains and Beius Basin is a prolongation of the Pannonian Basin, their tectonic evolution is linked to a wider area containing the two major structural units mentioned above.

2.1.1 Geological and structural history of the Apuseni Mountains

The major geological events in North Apuseni Mountains are:

Formation of various basement tectonic units, made up of Early Proterozoic metamorphic rocks (mostly from high-grade metamorphic sequences) and associated granites (Late Cambrian 502–490 Ma, Middle to Late Devonian 372–364 Ma and Early Permian 278–264 Ma), with a Permo-Mesozoic sedimentary and volcanic cover (e.g., Stan, 1987; Dallmeyer *et al.*, 1999, Pana *et al.*, 2002a); The delineation of system of nappes (Bihor, Codru, Highis-Drocea, Biharia, Baia de Aries), named the Inner Dacides (Sandulescu, 1984), which have been juxtaposed during Late Paleozoic (Variscan) orogenic activity (when they recorded three distinct tectonic phases at mid-crustal levels); Crustal shortening within Alpine tectonic activity during the Turonian; Intra-Turonian ('Mediterranean') westward back-vergent thrusting, creating the retro-vergent side of the orogen in a series of four main nappe units: Mecsek, Bihor, Codru and Biharia (e.g., Săndulescu, 1984; Balintoni, 1994; Haas and Pero, 2004; Schmid et al., 2008); Deposition of formations within Gosau-type basins during the Senonian; Deformation was coeval with and followed by latest Cretaceous intrusive and extrusive (sub-) volcanic Banatitic magmatism.

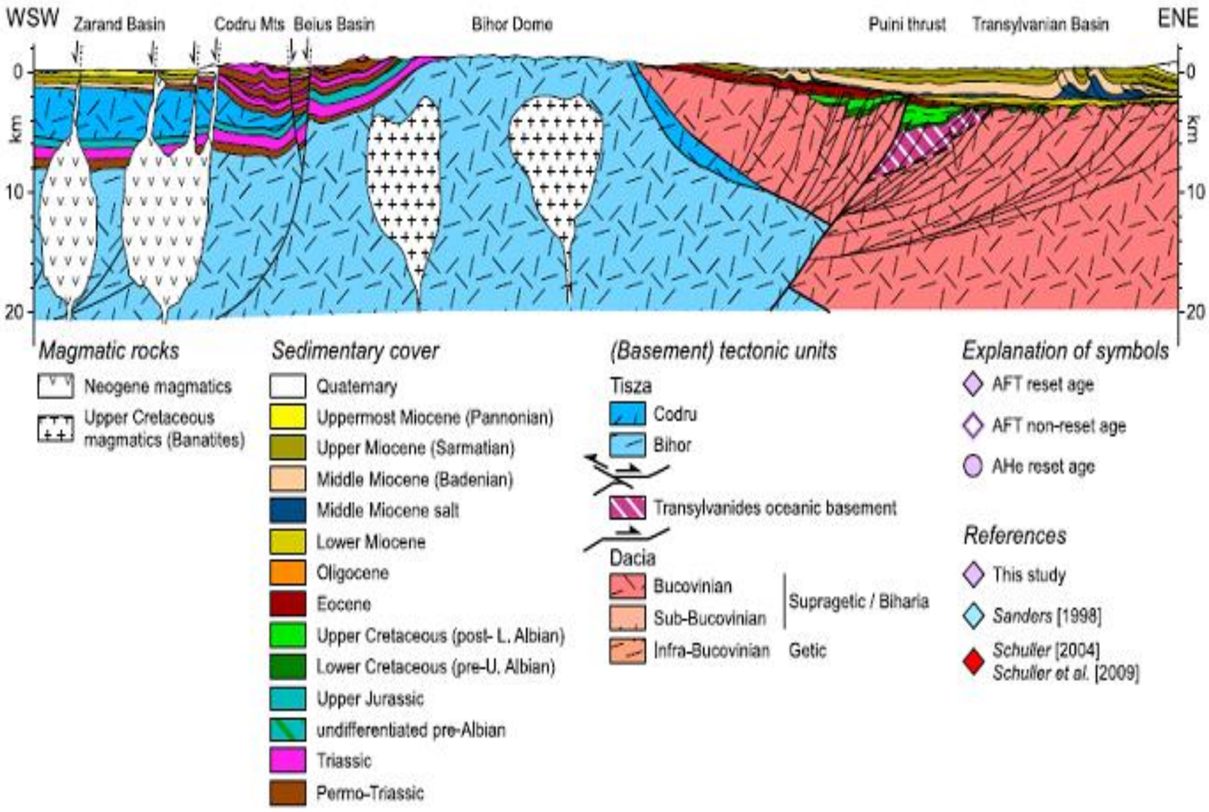


Figure 7 Cross – section illustrating magmatism processes within Apuseni Mountains, (Merten et al, 2011).

Re-Os ages of Banatitic magmatic activity range between 84–72 Ma for the Apuseni area (Zimmerman et al., 2008). For the Apuseni Mountains, K-Ar and 40Ar/39Ar ages indicate latest Cretaceous–Eocene cooling of the Banatites (Bleahu et al., 1981; Wiesinger et al., 2005). Based on 40Ar/39Ar amphibole and biotite ages ranging between 89 Ma in the South Carpathians to 61 Ma in the Apuseni Mountains, Wiesinger et al. (2005) suggested three consecutive magmatic events: Turonian–Santonian, Campanian and Maastrichtian.

The bulk of the Paleocene – Eocene ages are derived from older K-Ar measurements (Bleahu et al., 1981) and represent cooling ages.

2.1.2 Neogene structure of the Romanian sector of the Pannonian Basin

The structure of the Romanian sector of the Pannonian Basin was studied based on seismic research and borehole data (Visarion et al., 1979, Polonic, 1985). It is a subsidence and sedimentation basin; its formation began in the Middle Miocene. During the Miocene and Pannonian in the eastern part of the basin the sediments were deposited in shallow-marine environments. The faults affect both the basement and the sedimentary cover of Pannonian Basin, some of the blocks forming a graben-horst like structure. In the vicinity of Apuseni Mountains the Neogene formations lie directly on the crystalline or eruptive basement in the southern part, whereas in the northern part, they cover a more complex Mesozoic basement. The thickness of the Neogene sediments is shown up to 2000 m.

2.2. Tectonic framework

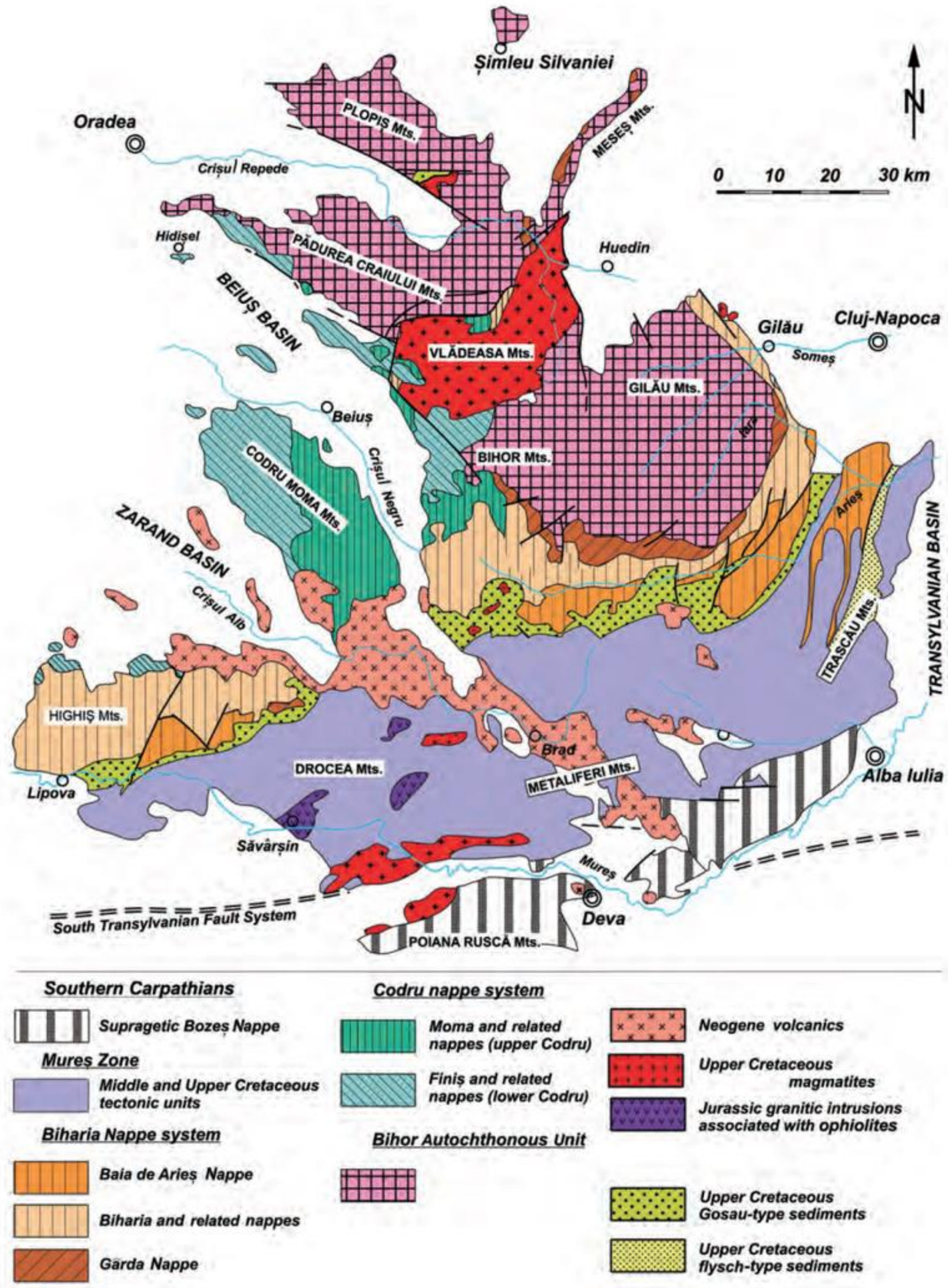


Figure 8 Simplified Alpine structure of the Apuseni Mt, from Ionescu et al. (2009) compiled by C. Balica from papers by Ianovici et al. (1976), Bleahu et al. (1981), Săndulescu (1984), Kräutner (1996), and Balintoni & Puşte (2002).

2.2.1. North Apuseni Mountains

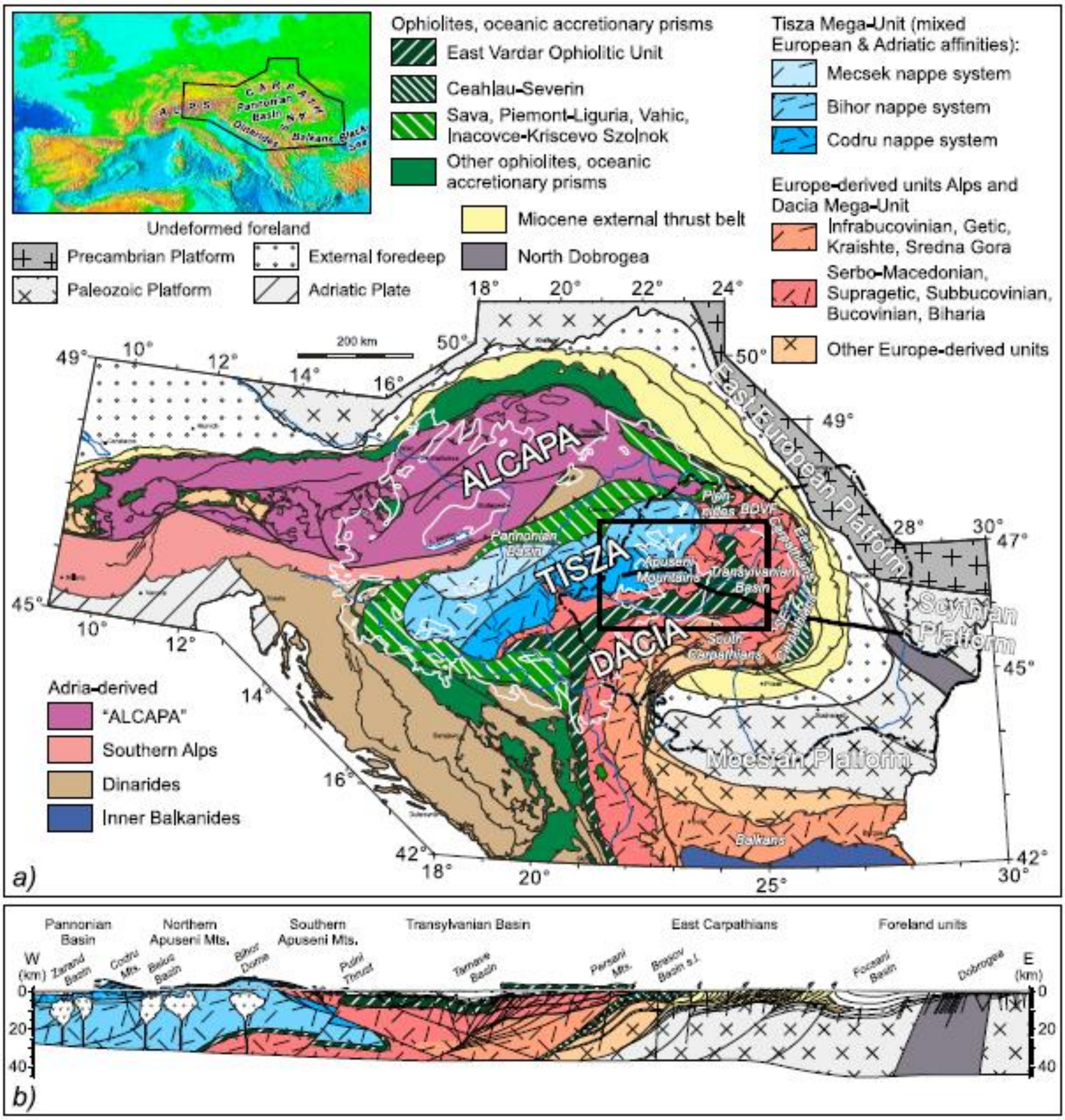


Figure 9 (a) Tectonic map of the Eastern Alps-Carpathians-Dinarides-Balkans region (simplified after work by Schmid et al. [2008]) and its location in the topographic map of Europe. Solid black line indicates the location of the cross-section and solid box indicates the location of the Apuseni Mountains. White lines indicate the outlines of the Pannonian and Transylvanian Basins and dashed black line indicates the border of Romania. (b) Conceptual cross-section through the Apuseni Mountains, Transylvanian Basin and SE Carpathians (simplified after work by Schmid et al. [2008]). Reproduced after Merten et al, 2011.

The tectonic units that build up the northern segment of the Apuseni Mountains are termed as *Apusenides* and are part of the Tisia unit (Kovács, 1982; Fülöp et al., 1987; Csontos, 1995; Csontos & Vörös, 2004; Császár, 2006). Tisia unit is built up of a crystalline basement and a Permo-Mesozoic sedimentary sequence ranging up to the Late Cretaceous. The architecture of the North Apuseni Mountains contains, as the structurally deepest unit, the "Bihor Autochthonous Unit" or the "Bihor Unit". It is of a regional extent and has a relative autochthonous position in respect to the higher nappe systems. The structurally higher units can be grouped, according to their origin and lithological content, in two nappe systems, thrust on top of the "Bihor Autochthonous Unit": the deeper Codru nappe system and the tectonically higher Biharia nappe system. Each system is believed to originate in different areas of the Tisia micro-continent.

During Mesozoic to Tertiary plate movements several mountain belts have been formed within the Alpine–Carpathian orogen. The Apuseni Mountains as part of this mountain belt have been formed during Cretaceous times as a result of the convergence and collision of the two microplates Tisia and Dacia.

In North Apuseni Mountains two main igneous stages of rocks belonging to Banatite Magmatic and Metallogenetic Belt are recognized (Ștefan et al., 1988, 1992): phase I having volcanic character, and phase II with intrusive character. The volcanic phase includes andesites, dacites and rhyolites, developed in time as follows: andesitic lavas at the beginning, followed by dacitic lavas. Rhyolites, sometimes with ignimbritic character, end the volcanic activity. The intrusive phase is represented by small bodies of diorite and quartz diorite as well as by granodiorite (+ granite) plutons (Budureasa, Drăganului Valley and Pietroasa). During the second phase of Ștefan et al. (1988, 1992), rhyolite, rhyodacite, aplite, microgranite, porphyrytic microgranite and micropegmatite dykes were emplaced along NW–SE faults. Towards the south, in the Băiţa Bihor area basic rocks (basalts, lamprophyres), probably originating from a deeper source, crosscut the main magmatic suite.

2.2.2. Pannonian Basin

According to Demetrescu (1989) the Romanian part of the Pannonian Depression is characterized by high heat flow (Demetrescu, 1978; Horvath et al., 1979), the lithosphere being hotter and thinner than in the surrounding areas. The lithosphere thickness was estimated at 60-70 km using magnetotelluric and heat flow data (Stegena et al., 1975; Adam, 1980; Demetrescu et al., 1984). Thinning of the lithosphere seems to occur in the entire depth interval, including the crust: deep seismic sounding studies indicate values of 25-27 km for the crustal thickness (Rădulescu et al., 1976). The extensional tectonics of Romanian part of the Pannonian Basin (Western Plain) is well documented by seismological data (Polonic, 1985).

In 1989 Demetrescu and Polonic described the formation and evolution of the Romanian part of Pannonian Basin as a result of a complex thermo mechanical phenomenon of lithosphere extension. As a result of the extension by tectonic forces, the lithosphere is thinned and, for reasons of isostasy, an initial subsidence occurs. Thinning of the lithosphere is accompanied by heating as a result of the elevation of the asthenosphere. The thermal anomaly induced by extension then tends to dissipate by conduction and the cooling lithosphere contracts, resulting in thermal subsidence. If these phenomena take place below the sea level, as the basin subsides sediments are deposited. The sedimentary load enhances the subsidence, the actual subsidence of the basin being larger than the tectonic subsidence-the sum of the initial and thermal subsidence.

Many studies referring to the evolution of Pannonian Depression confirmed the above mentioned theories and data. Horvath et al (2015) summarizes the current ideas on the evolution of Pannonian – Carpathian region with the following phrases: 'Alcapa and Tisza-Dacia as orogenic wedges detached from their mantle lithosphere in the Alpine and Adriatic/Dinaric collision zone during the Late Oligocene to Early Miocene. They suffered a dramatic thermal impact leading to crustal melting during extrusion, when these crustal flakes could have been directly superimposed on the asthenosphere in the Carpathian embayment. Since then, the large part of the Pannonian has been cooling and a new mantle lithosphere growing. Geothermal data show that the Pannonian basin with cessation of volcanic activity in the Late Miocene is still very hot and Miocene to Quaternary clastic basin fill, together with karstified Mesozoic carbonates form good geothermal reservoirs of regional extent. In addition to these gravity-driven aquifer systems, a strongly overpressured reservoir can be found below a regional pressure seal in synrift strata and fractured basement rocks.'

According to Maţenco, and Maţenco et al (2012) the Pannonian Basin is made up of a large number of Miocene (half-) grabens distributed in a wide area, from the Apuseni Mountains to the Alps in the west, Western Carpathians in the north and Dinarides in the south. In the east three basins were formed, Borod, Beiuș and Zarand. Maţenco published a transect connecting the Apuseni Mountains with the SE part of the basin Pannonan Basin (Figure 10) that indicates that the extensional mechanics was asymmetric and the deformation migrated in space and time across the basin, from Early Miocene to early Pontian and in space the extension started near the Dinarides during Early Miocene times, continued everywhere in the basin during the Middle Miocene and finished in the area close to the Apuseni Mountains and South Carpathians during the late Miocene.

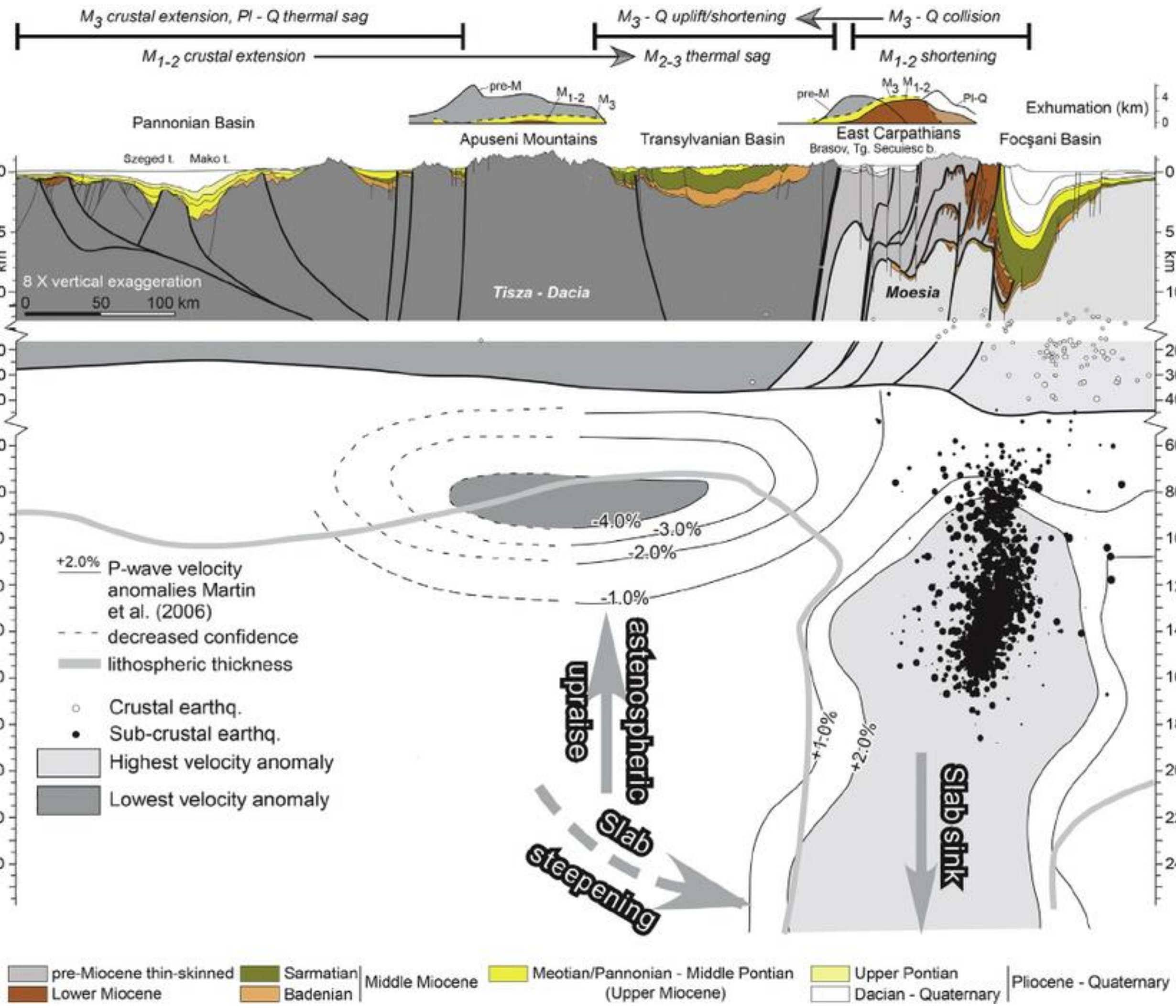
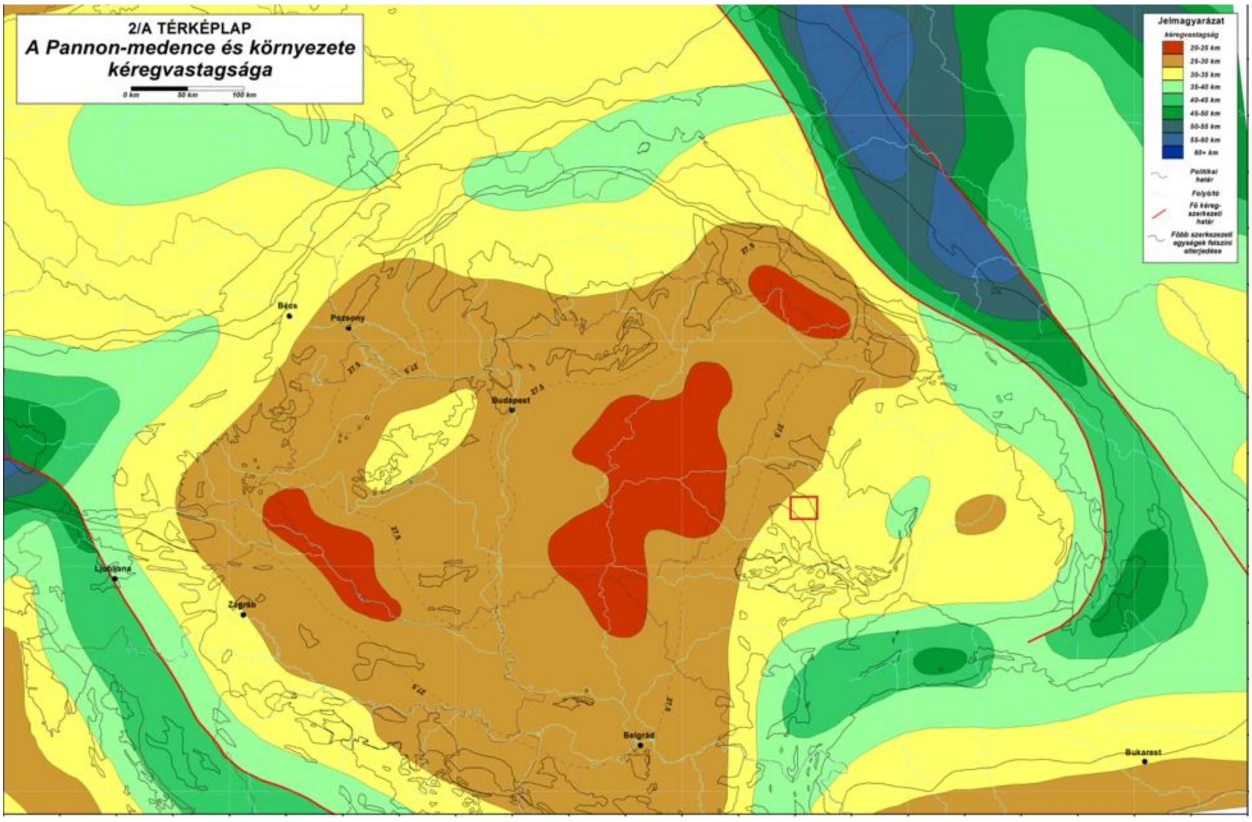
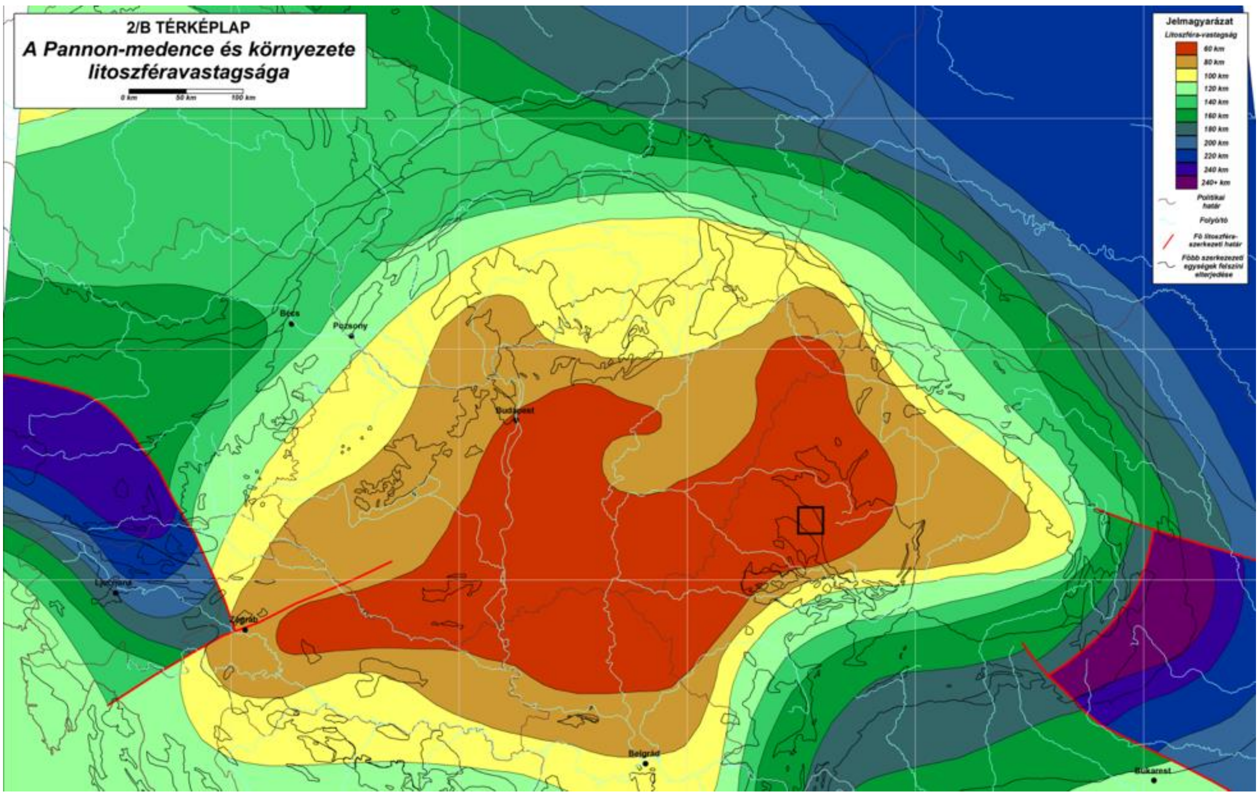


Figure 10 Simplified lithospheric scale cross section across the SE part of the Pannonian Basin, Apuseni Mountains, Transylvanian Basin and SE Carpathians and amounts of exhumation over the Apuseni Mountains and SE Carpathians derived from low-temperature thermochronology (modified from Maţenco and Radivojević , 2012). The geological cross section displays only Miocene – Quaternary sediments geometries and faults patterns. All pre-Miocene structures were ignored. The location of the cross section is displayed in Fig. 1. pre-M = pre-Miocene; M 1 = Early Miocene; M 2 = Middle Miocene; M 3 = Late Miocene; Pl = Pliocene; Q = Quaternary. The lower part of the figure is the crustal and upper mantle structure beneath the western Pannonian Basin – Carpathian Mountains with underlying the seismicity and the anomalies detected by high resolution, local teleseismic tomography.

Assessments of the crust and lithosphere thickness have been done in the 'Atlas of the present-day geodynamics of the Pannonian basin' ***http://geophysics.elte.hu/atlas/geodin_atlas.htm***. According to Horváth et al, (Figures 11, 12) the thickness of the crust is below 25 km, and thickness of the lithosphere is below 60 km in Apuseni Mountains.





Figures 11, 12 Maps of crustal and lithosphere thicknesses, reproduced after Horváth et al.,(2001 – 2004).

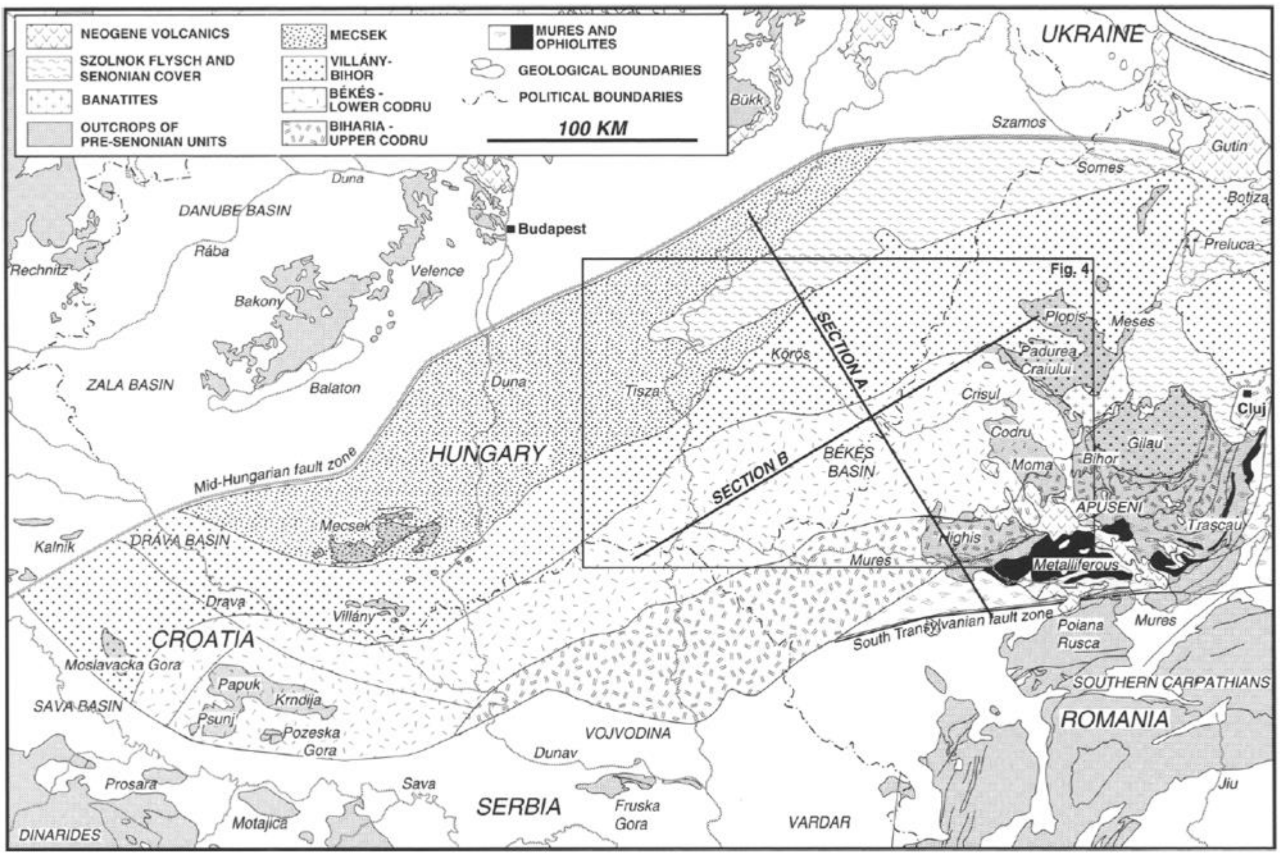
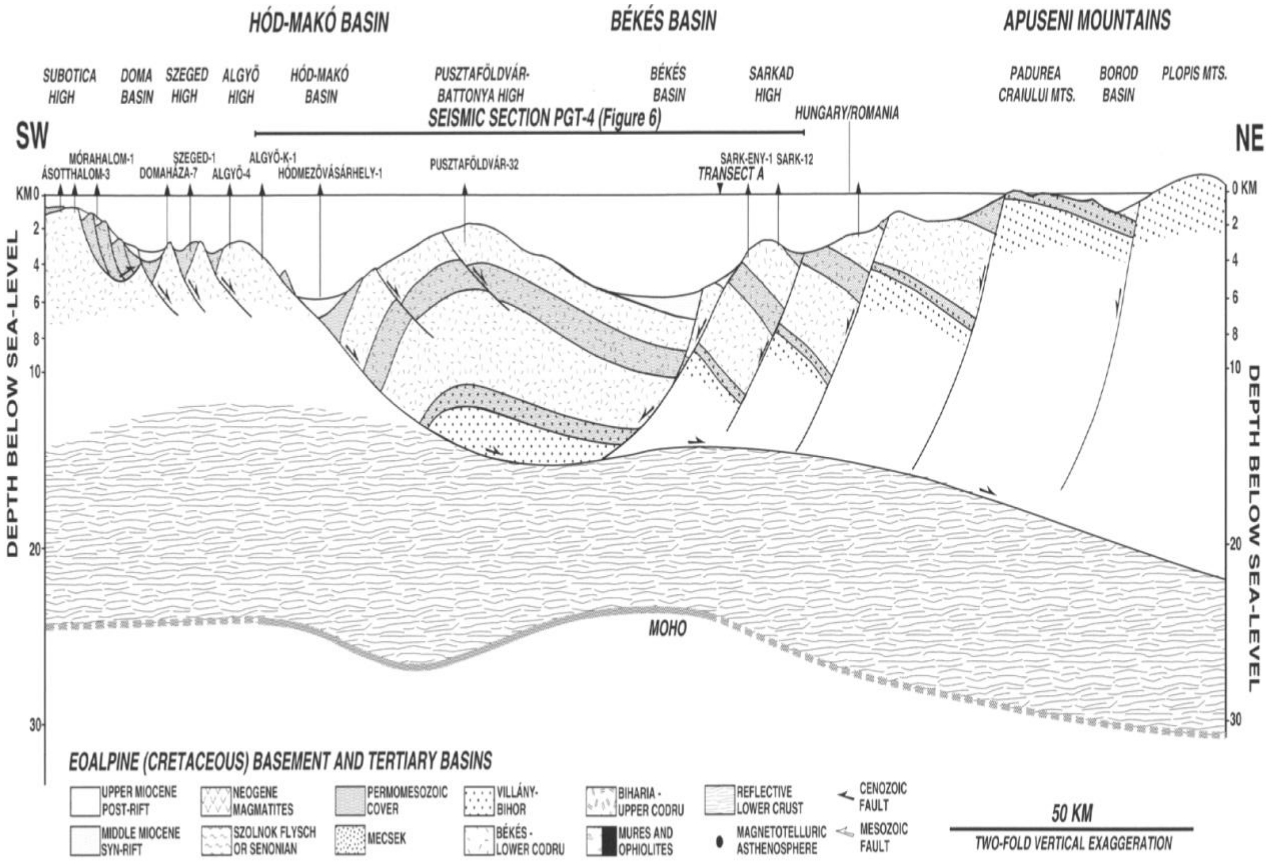


Figure 13 Regional geologic subcrop map of the SE Pannonian basin, modified from Csontos et al. (1992). Locations of a detailed map (Fig. 4) and structure transects A and B are shown.

Finally, Tari *et al*, (2015) based on seismic data, estimated that the thicknesses of the crust and lithosphere in the region of North Apuseni Mountains are of around 20 km, and almost between 60 and 80 km, respectively (Figure 13, 13 bis).



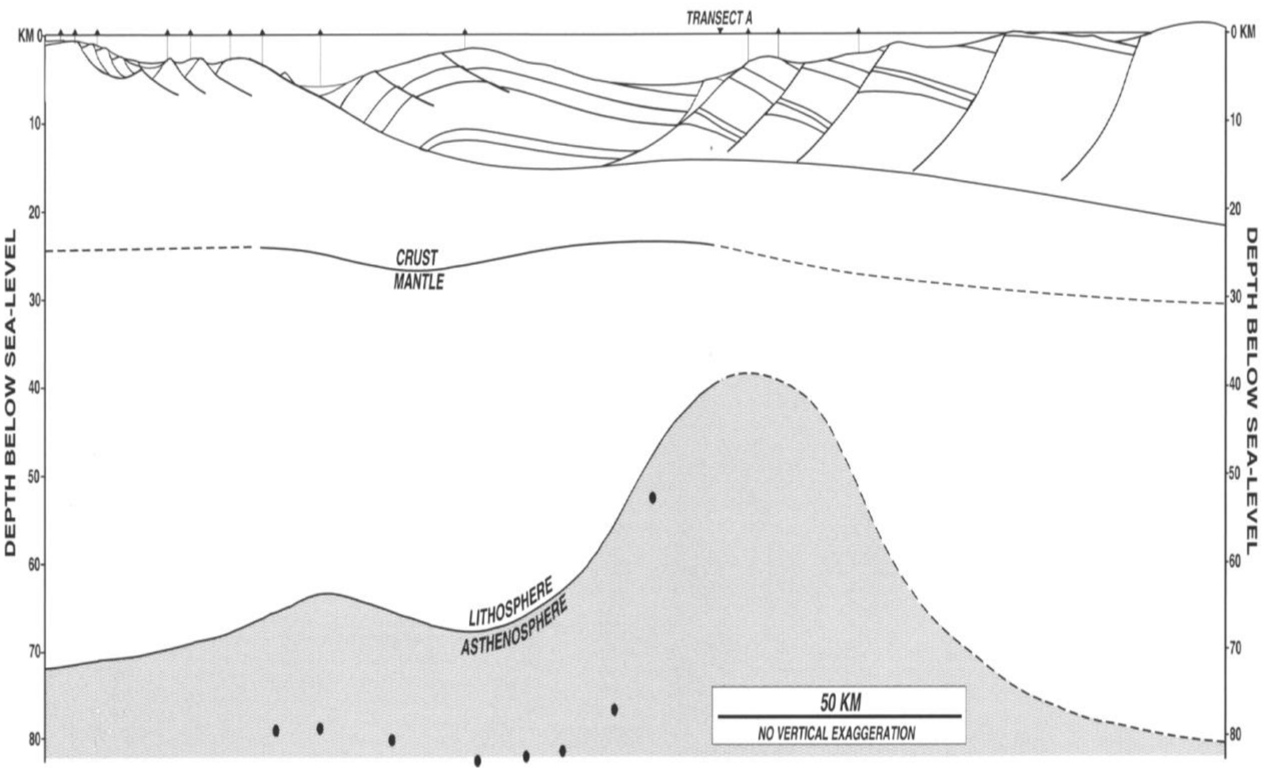


Figure 13bis Transect B with crustal and lithosphere thicknesses, reproduced after Tari et al, 2015.

2.3. Geology of CHPM2030 study area

2.3.1. Bihor Mountains

Bihor Mountains structural unit consists of “Bihor Autochthonous Unit” and two nappe systems, thrust on top of it: the deeper Codru Nappe system and the higher Biharia Nappe system.

- “Bihor Autochthonous Unit” consists of a metamorphic basement and a sedimentary cover. The basement is a lithostratigraphic unit comprising medium-grade micaschists and quartzites, gneisses, amphibolites and ultramafic rocks. One of its dominant features is the frequent occurrence of pegmatites, large-scale migmatization and the presence of large granitic intrusions such as the Codru and Muntele Mare plutons. The cover is represented by Permo-Mesozoic siliciclastic and calcareous sediments.
- The Codru nappe system comprises seven tectonic subunits, and, except for the Finiș Nappe subunit, contains only Permo-Mesozoic sedimentary sequences (Ianovici et al., 1976; Bleahu et al., 1981; Săndulescu, 1984).
- The Biharia nappe system is best exposed at south-western margin of the Bihor Mountains. It includes six tectonic units, which are built of metamorphic basement rocks. Only two units show a Permo-Mesozoic sedimentary cover.

During Late Cretaceous with the formation of the so called “banatites” took place. These comprise a sequence of calcalkaline intrusions ranging from granite to diorite, accompanied often by volcanic rocks. The banatitic magmatism gives rise to some important mineralization, for example in skarns which formed along the contact of the intrusions with mainly Mid-Triassic limestones (Ilinca, 2010). A characteristic feature of the banatites and in particular granodiorites is the frequency of the xenoliths of metamorphic, sedimentary and magmatic nature of various sizes, ranging from 1-2 cm to several cubic meters.

At the end of Cretaceous, during the “Laramian” orogenic phase, widespread intrusive, subvolcanic, as well as volcanic bodies were formed (Figure 14).

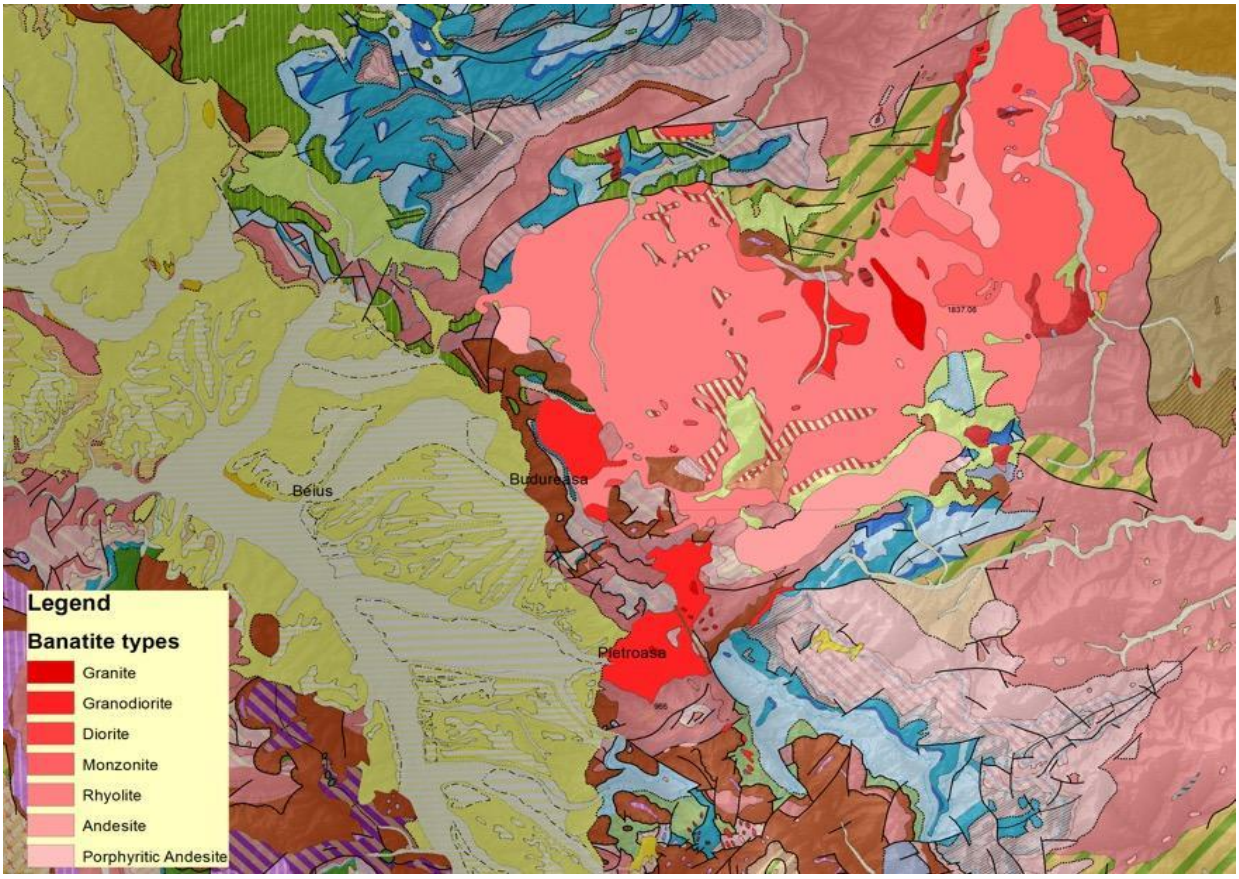


Figure 14 Types of banatites from Bihor Mountains

The batholitic body, which is of hypoabissal origin, extends within Bihor Mountains, both at the surface and in the underground, up to the Galbena fault. At the surface, within the Pietroasa - Aleului valley area, and further north, up to Budureasa, granodiorites outcrop. Associated with this banatitic intrusion, apophyses and bodies, of andesitic or basaltic composition, have been documented, especially in the upper reaches of Crișu Bãița along the valleys Hoanca Moțului, Corlatu and Fleșcuța, as well as in the Valea Seacã catchment area.

The intrusion of the banatites has resulted in contact processes that concerned the sedimentary deposits being traversed. At the contact of the banatites with the limestones, marbles and various types of calcic skarns have been formed, while at the contact with the detritic and pelitic rocks, hornfels, garnet skarns, etc. are met (I. Orășeanu, 2010).

Regional extension of a granodioritic batholith, as well as the existence of the extensive contact areas between magmatic intrusions and Triassic deposits are illustrated in Figure 15. Within these areas described in Bihor Mountains as well as in many other regions of the North Apuseni Mountains contact aureoles have been generated.

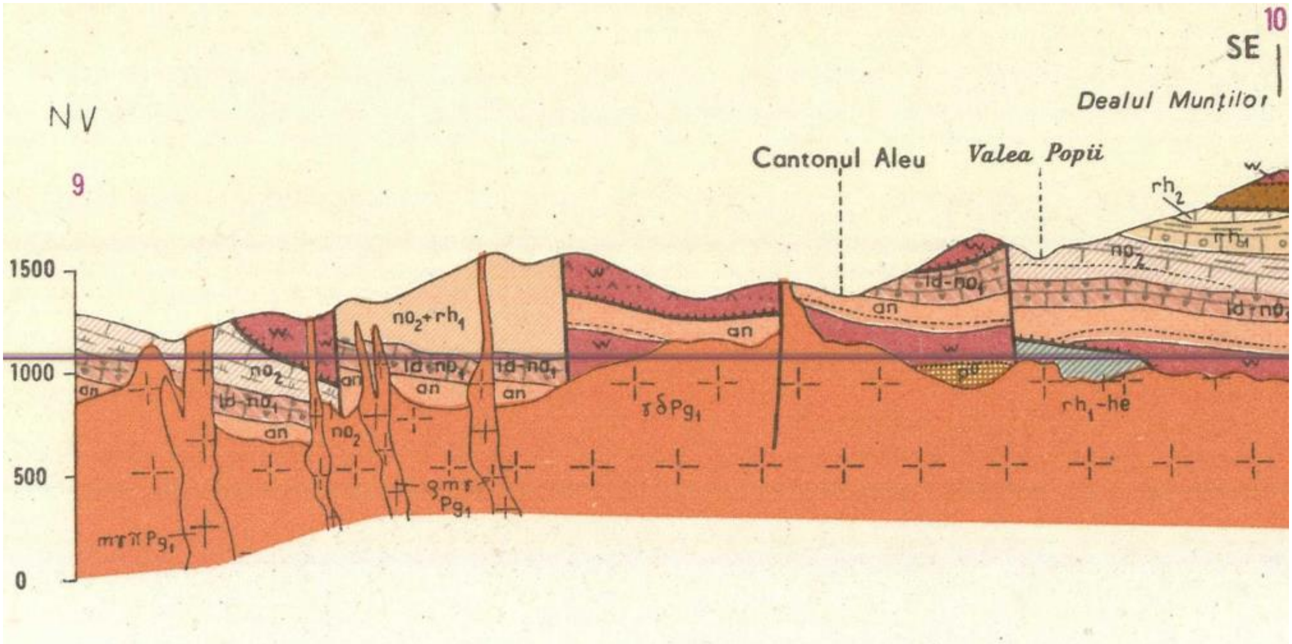


Figure 15 Bihor Mountains – cross section, reproduced after Bleahu et al, published with the map of Pietroasa, scale 1:50 000, 1985.

2.3.2. Beiuș Basin

A result of Neogene processes is Beiuș Basin. In 1991, based on geological and geophysical prospection (seismic, gravimetric, aeromagnetic), and *in situ* gravimetric measurements and geothermic measurements in boreholes, Dinu et al (1991), elaborated the structural map at the contact between the pre-Neogene and Neogene deposits of Beiuș Basin, that was accompanied by the isobaths map of the basis of Neogene deposits, and with isopachs map of Neogene deposits (Figures 16, 17).

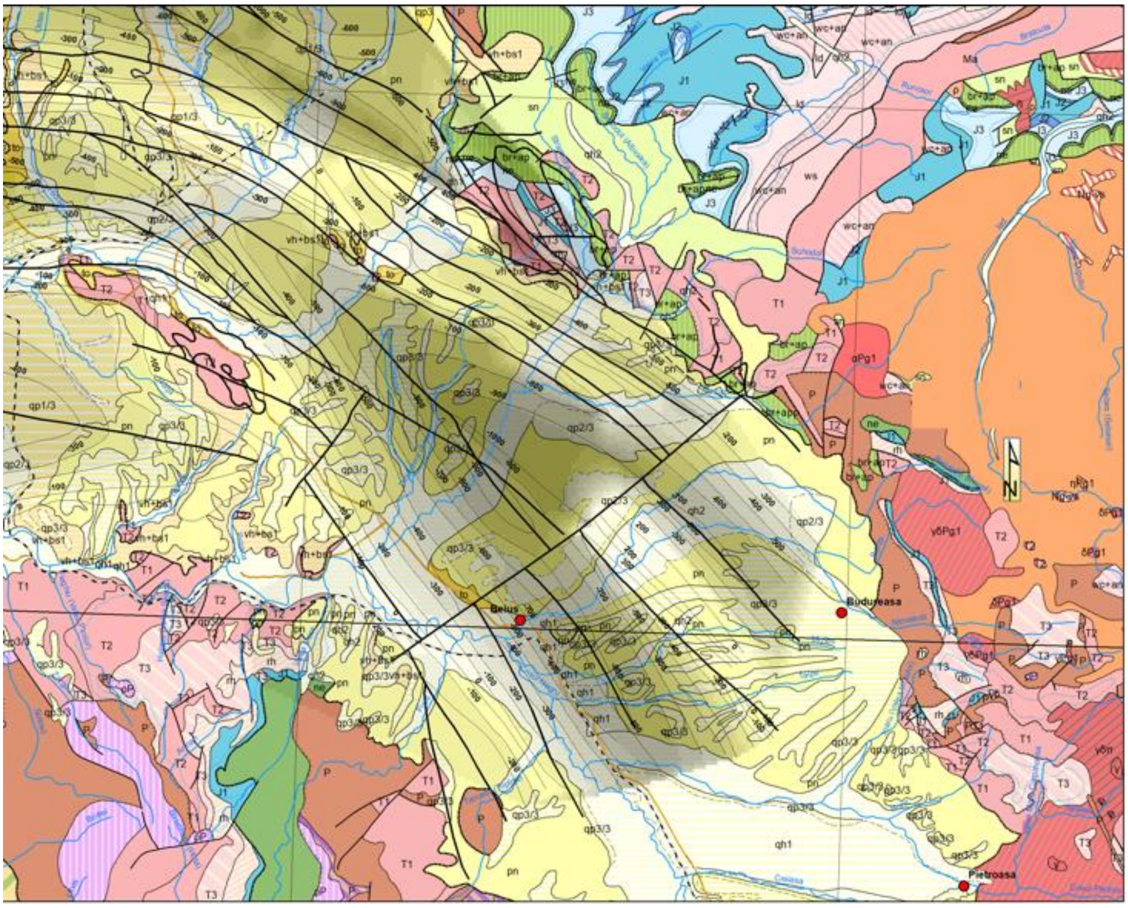


Figure 16 Isobaths map at the contact between pre Neogene and Neogene deposits from Beiuș Basin, modified after Dinu et al, 1991.

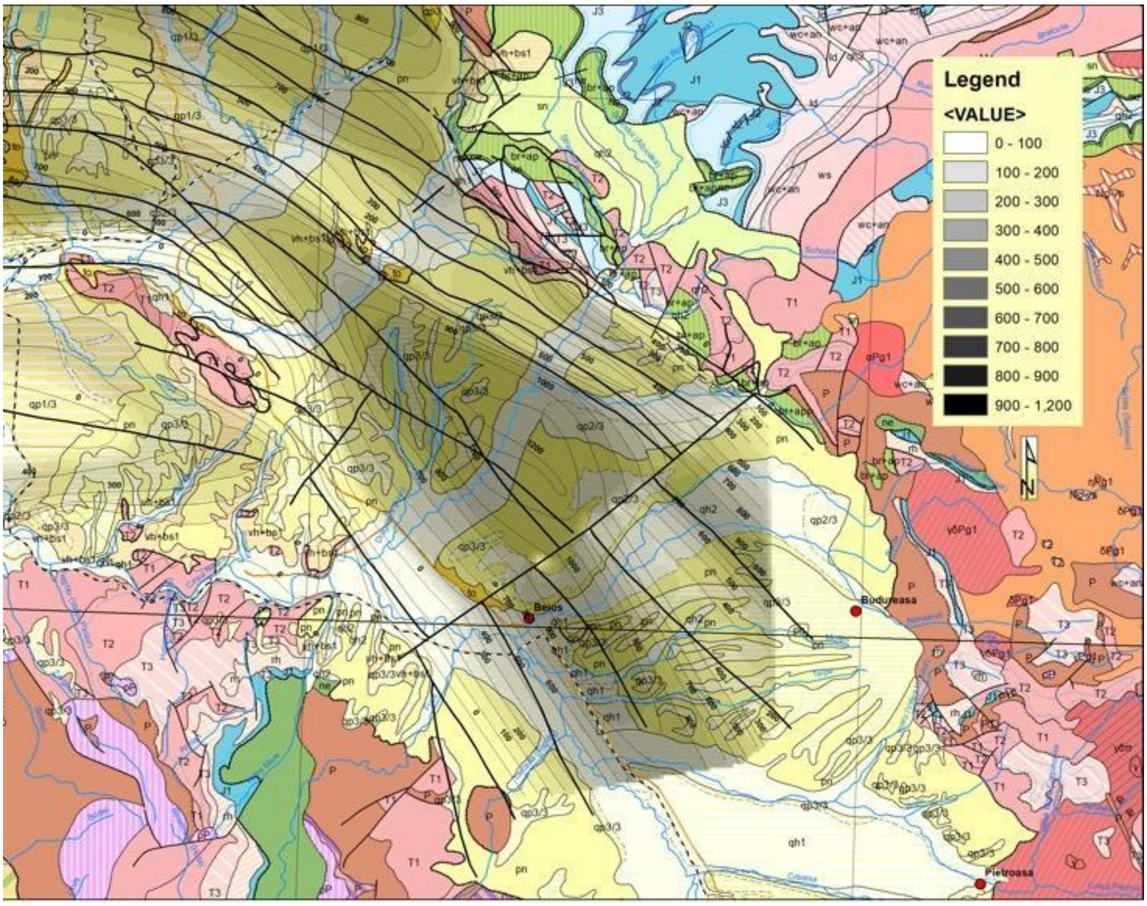


Figure 17 Isopachs map of Neogene deposits from Beiuș Basin, modified after Dinu et al, 1991.

Based on these data the following conclusions were drawn as a result: the overall structure of the Beiuș Basin is of collapse post-tectonic basin type, made by down going at the high-angle faults; there are many faults which give some particular features with uplift and down going sectors.
The structural map reveals two distinct sectors (in the north-west and south-east) separated by an uplift central zone with a transverse trend, which separates the basement of the Pannonian Basin and the basement of the Apuseni Mountains.

In the north-western sector, the basin is broadened, the trend of fractures and structures is east-westwards and the basin is sinking towards the Pannonian Basin where it has the tendency to bend and to connect with this basin`s structures. The structure of this sector is very complicated due to the great number of faults specific to extensional basins and to the existence of intrusive magmatic bodies in the depth (Figure 17).

In the south-eastern sector, the basin has a graben structure type, with the central part down going to isobathic values of about – 1000 m (Drăgoieni – Beiuș zone). The main down going sector rises gradually towards the orogenic belt. An important transverse strike-slip fault is to be mentioned to the North of Beiuș city.

The main structural trends are the same as the main trends of the eruptions centres in Apuseni Mountains, having north-eastern – south-western directions, showing that Beiuș Basin is the result of the collapse sectors due to important magma extrusions.

The isopachs of Neogene deposits map emphasize the sectors with thick sedimentary deposits which correspond to the basin axis.

In Beiuș Basin the faults system is well documented. Most of them, that disturbed both pre - Neogene and Neogene deposits, are considered to be (S. Bordea, Gh.Mantea, 1999) old fractures reactivated during the Neogene diastrophism phases. Old Austrian or intra-Turonian fractures have been reactivated and determined the individualization of Beiuș Basin, during the Styrian movements.

Many of the faults are marked by mesothermal waters, springs of mineralized (ferro-sulphurous) having between 17°C to 24°C have been reported at Răbăgani, Dobrești, Rotărești, Coșdeni, Holod.

The most important faults are to be menioned:

- Galbena fault – has about 100 km in length, being traced in Padurea Craiului, Bihor, and Metaliferi Mountains; it is accompanied by a system of parallel faults trending NW – SE; some of them are penetrated by the Banatitic magmatites of the Alpine subsequent magmatism, which form veins of 2 km length. Galbena strike slip fault, is a regional fracture, that is represented on the Deep Structure Map of Romania, scale 1:1 500 000. At the same time this fracture is a prolongation of a line of magnetic maximum that is linked to banatitic eruptions (Gavăt et al).
- Dobrești fault, along which Crișu Negru River runs;
- Beiuș – Răbăgani fault follows the axis of Beiuș Basin.

Many authors highlighted the existence of intrusive magmatic bodies in Beiuș Basin (Figure 18). Some of them consider that they are a banatites, manifestation of Upper Cretaceous magmatism like in North Apuseni Mountains, and others (Dinu et al, 1991, Seghedi et al, 2011) rather assume that they represent magmatic intrusions into an extensional basin during Neogene, similar with the ones from South Apuseni Mountains. Magnetic anomalies indicating intrusive magmatic bodies have been reported since the seventies in Pannonian Basin near the border with Hungary too (Figure 3). It means the intrusions from

Beiuș Basin are not singular appearances, and they are worth to be subject of investigations for EGS installation purposes in the future.

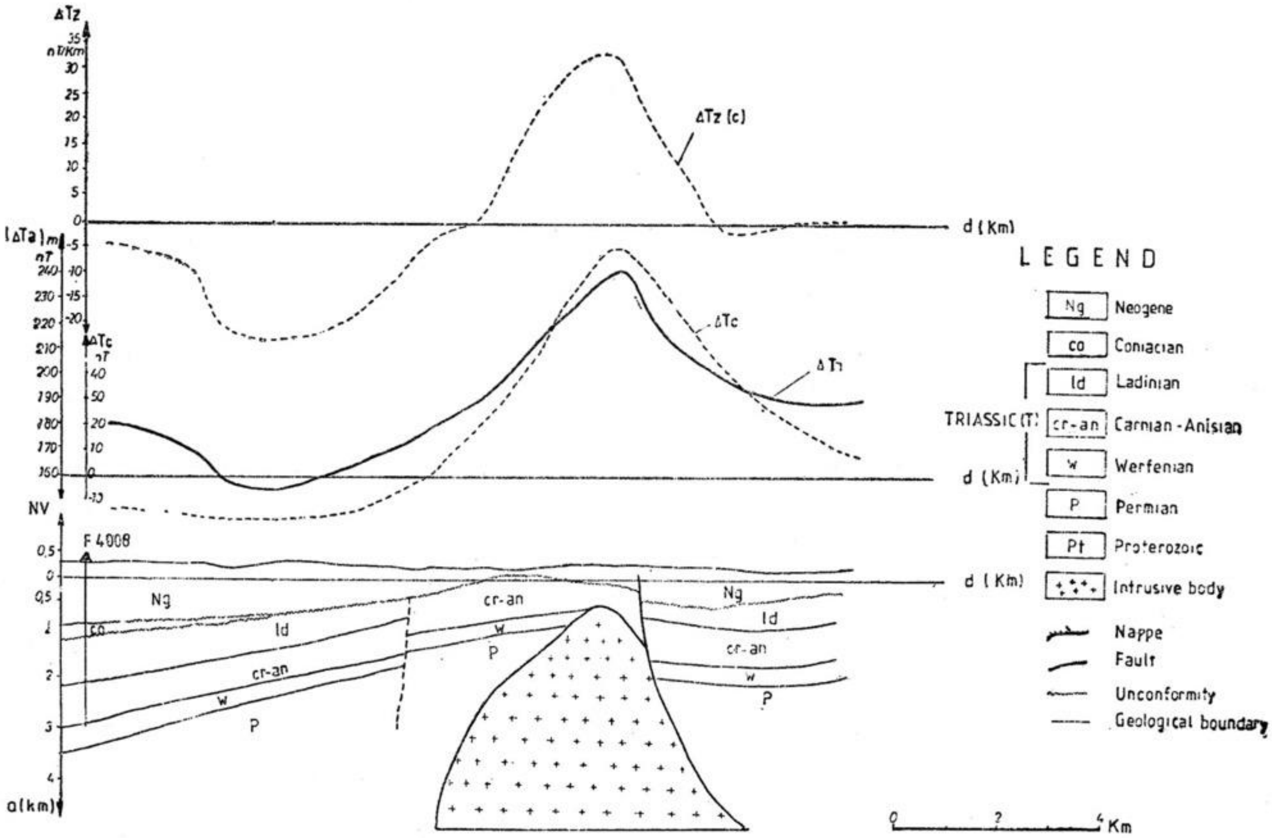


Figure 18 Beiuș Basin – longitudinal cross – section, correlated with aeromagnetic data, reproduced after Dinu et al, 1991.

3. Geophysics of the prospective area

3.1. Airborne data

For delineation of the regional batholith from Bihor Mountains we used ***Earth Magnetic Anomaly Grid*** *(https://www.ngdc.noaa.gov/geomag/emag2.html)* compiled from satellite, ship, and airborne magnetic measurements; the image has a 4 km altitude from the Earth surface (Figure 19). The image afferent to the batholith from Bihor Mountains was downloaded from the website, was georeferenced and than was included into GIS together with the countours of the batholiths, as defined by Andrei et al (1989). As can be seen the Romanian ground-based vertical component of geomagnetic anomaly data, which is used to define the countours of the batholiths, is consistent with the international data for example EMAG2v3, which highlights (by the red colour) the presence of the batholith in this location. In Figure 19 there is a continuous line with white circles that indicates the contour of the batholiths in the depth, and other contours that indicate the regions where the batholiths outcrops, or is near the surface.

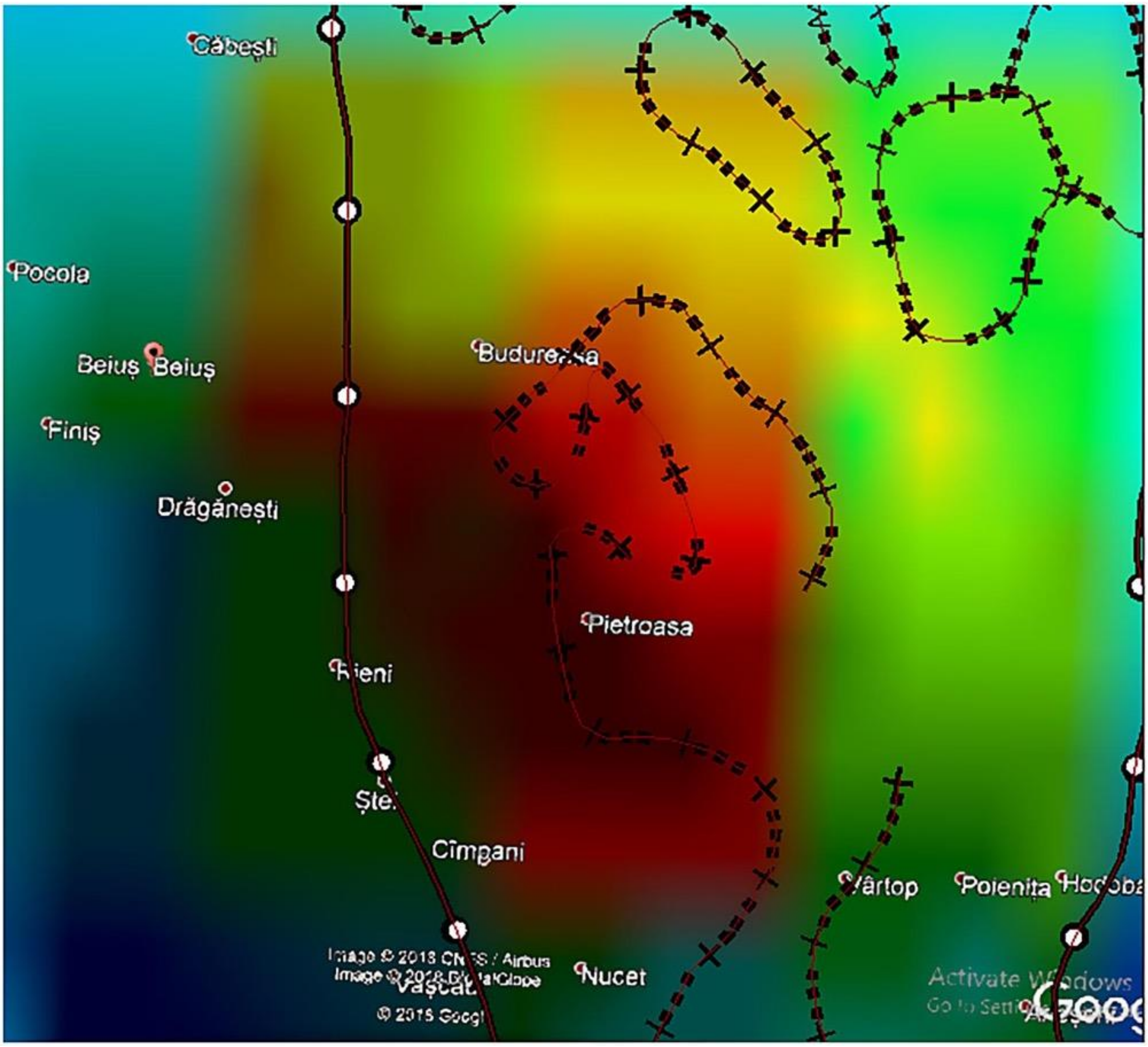


Figure 19 A fragment of Earth Magnetic Anomaly Grid compiled from satellite, ship, and airborne magnetic measurements; the image has a 4 km altitude from the Earth surface. The figure contains the contour of the batholith as defined by Andrei et al, (1989.)

In recent years Romanian researchers analyze the degree of confidence of older data integrating them in international datasets. For example, in 2012, Beșuțiu et al realized a critical analysis of Romanian geomagnetic data for the WDMAM Project purposes (http://geomag.org/models/WDMAM/WDMAM_NGDC_V1.1.pdf). 'Total intensity scalar geomagnetic anomaly for the 2007.5 epoch at the 3000 m altitude' map (Figure 20) is one of the results.

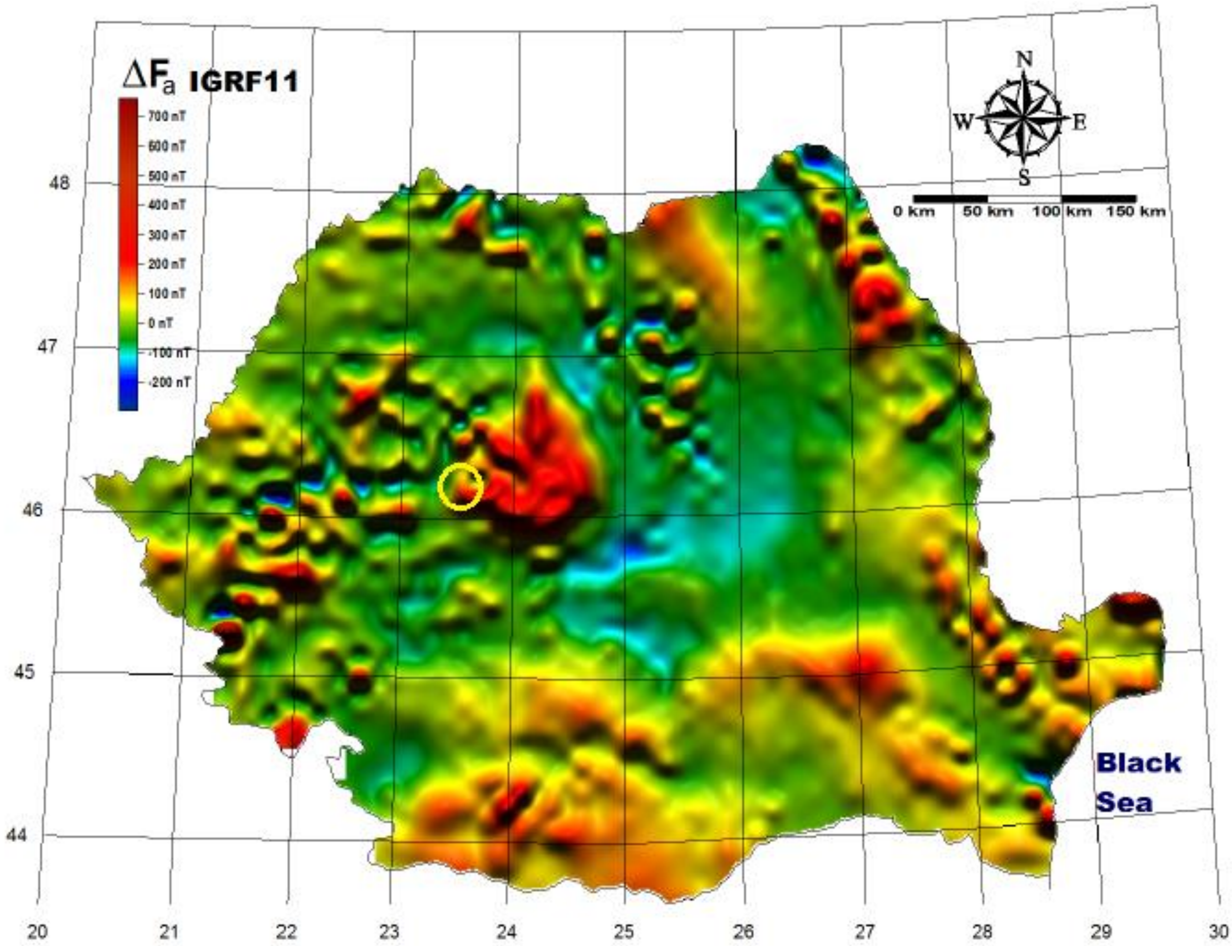


Figure 20 'Total intensity scalar geomagnetic anomaly for the 2007.5 epoch at the 3000 m altitude' map, reproduced after Beșuțiu et al, 2012. Location of study area is indicated.

Remote sensing research has been developed since 1975 (S.Veliciu et al., 1975, 1976, V. Vîjdea et al., 1977 – 1996, A.Vîjdea et al. 1996 – 2018). For Apuseni Mountains studies have been developed by A.Vîjdea, which emphasized that, for, North Apuseni Mountains, the system of lines representing faults has N 60° - 70° E as a major dominant direction, that suggest the over thrusting of two nappes systems (Figure 21). The 6-line systems groups have been confronted with geophysical maps, and the conclusion was that 80% of gravimetric and magnetometric anomalies have a correspondent in the maps with linear elements.

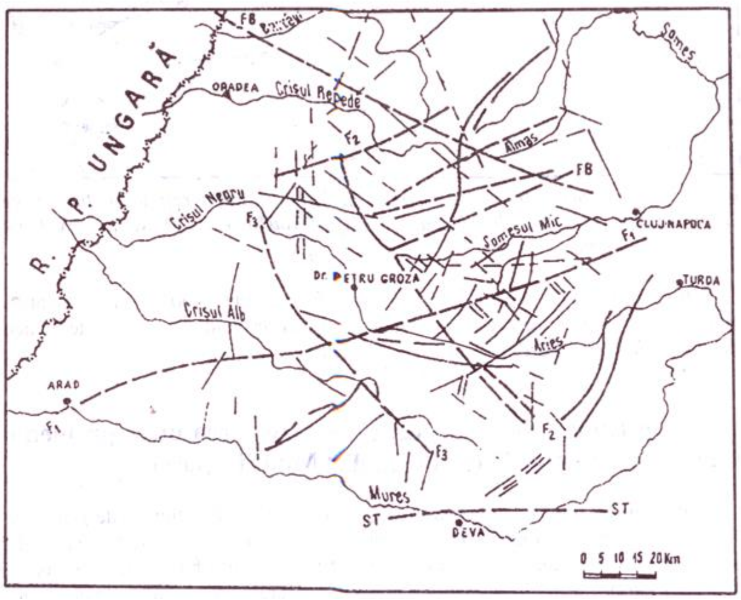


Figure 21 Sketch with major liniar elements deciphered on sattelite images. Reproduced after Visarion, 1997.

3.2. Ground-based data

The detailed interpretation of the magnetic anomalies situated on Romania's territory has been made by several authors (Gavăt et al., 1965; Constantinescu et al., 1972; Airinei, 1985; Visarion et al., 1988, 1998; Beşuţiu, 2001). The map of anomaly of the vertical component of the magnetic field and Bouguer Anomaly map were compiled and the values of ɣ isolines (or mgal isolines) were transposed to a grid with 200 meters cells. These compiled maps are to be found on the IGR's website, at to following address: http://harti.igr.ro/geofizica-v1/. Figures 22 and 23 show fragments of these maps selected for Beiuș Basin and Bihor Mountains.

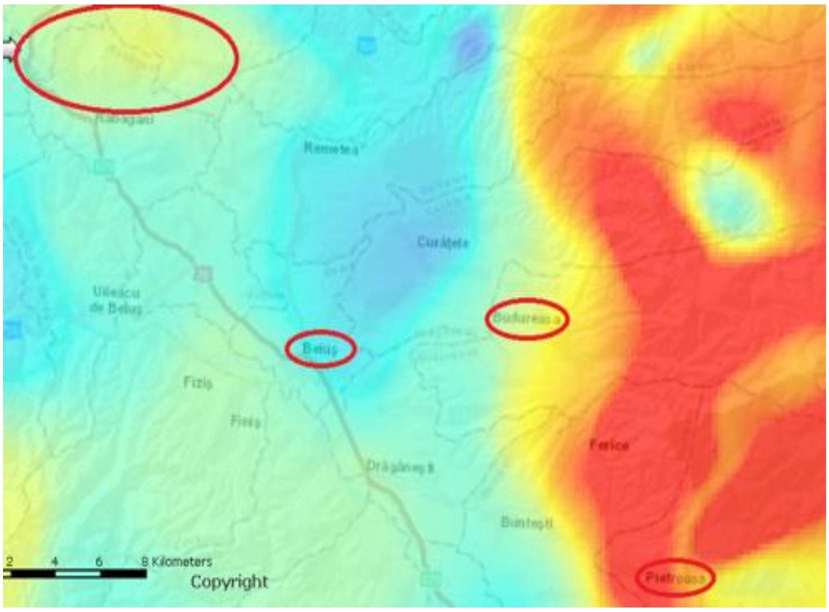


Figure 22 Fragment of vertical component of the geomagnetic anomaly map (DZa), (Authors Airinei et al, (1983) *published by IGR. Locations of Beiuș, Budureasa and Pietroasa are indicated, as well as the location of the anomaly from Beiuș Basin.*

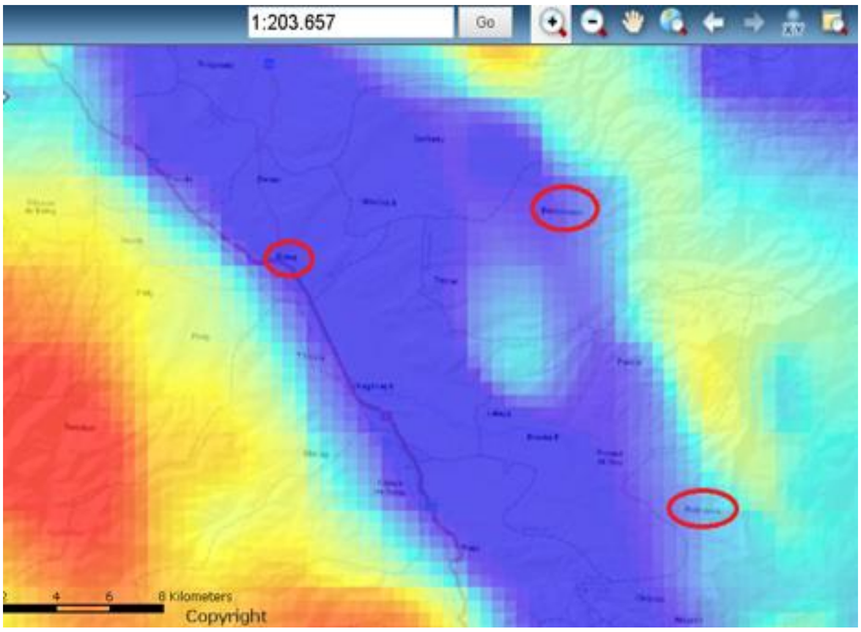


*Figure 23 Fragment of local gravimetric anomaly map, (*Bouguer Anomaly for δ = 2.67 g / cm3, Source: Nicolescu et al, 1991) *resulted from interpretation in ArcGIS Spatial Analyst by using Bouguer anomaly and regional gravimetric anomaly. Values are given in mgal. Locations of Beiuș, Budureasa and Pietroasa are indicated.*

In 2005 Ioane and Ion, elaborated a 3D crustal gravity modelling of the Romanian territory. The completion of the Bouguer gravity map for the Romanian territory, as well as the calculation of the mean gravity dataset in a 5’ x 7.5’ grid, enabled a 3D modelling approach for the crustal structure. The geophysical model has been built using information derived from published crustal models based on refraction seismic and borehole data, each layer getting a mean density value describing the main density contrasts. The 3D stripped gravity map was derived from the above mentioned gravity maps (Figure 24).

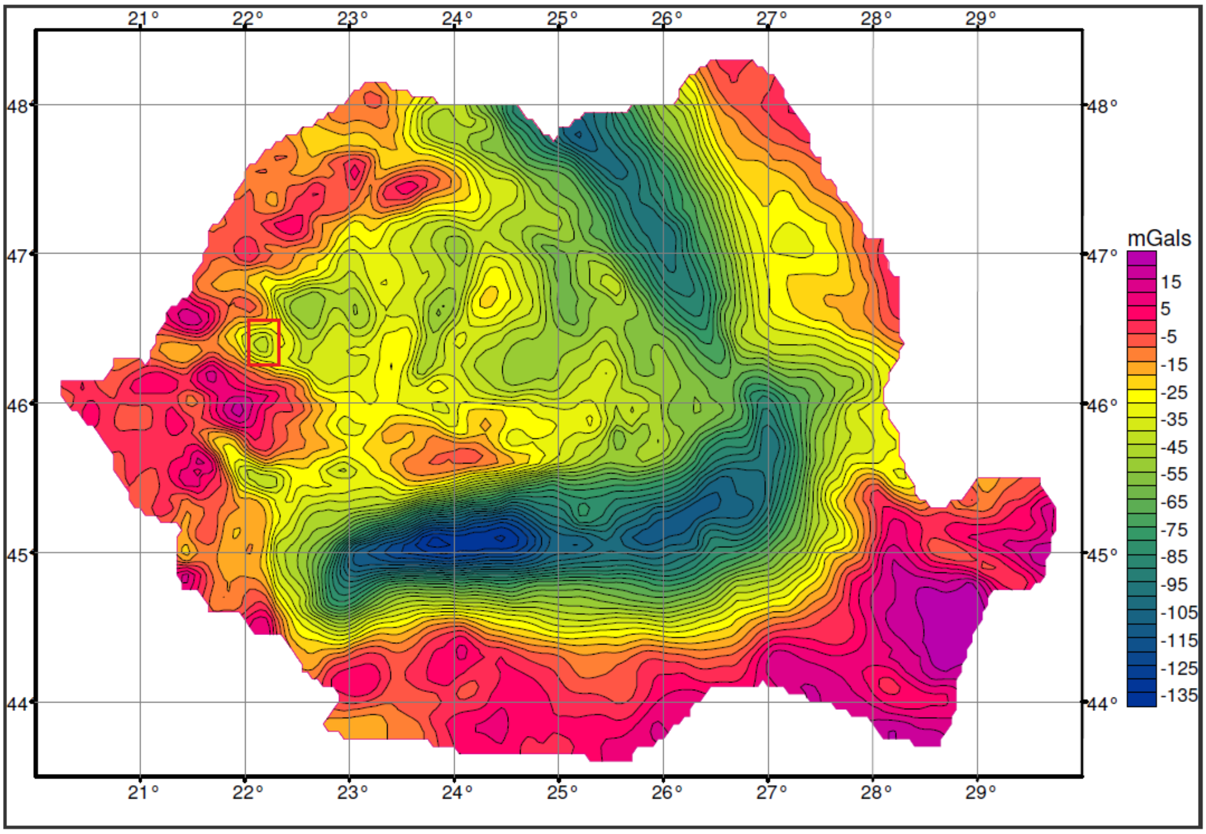


Figure 24 Bouguer gravity anomalies (Romania)

The delineation of the Bihor – Vlădeasa banatitic batholith is showed by the Vertical component of the geomagnetic anomaly map (ΔZa), on the scale 1: 1 000 000, published in 1983 by IGR (Figure 22). According to Beșuțiu et al (2012), for the study case region, the aeromagnetic survey was realized at 1000 m altitude.

Moreover, local gravimetric anomaly data (Figure 23) are available on the IGR’s map scale 1:1 000 000, for the interpretation.

In most cases the structures of Bihor – Vlădeasa Mountains, being of acid composition (granite – granodorite) are pointed out by maximum aeromagnetic anomalies coupled with gravity minima. For Bihor – Vlădeasa, one of the most important banatitic structures in Romania, gravity and magnetic simulation models have been realised, showing an extension along north – south direction over 60 km, with a mean width around 25 km. The etimated hight of the intrusive mass is 7 – 10 km.

The banatitic structures from the Bihor – Vlădeasa pluton have been identified by drilligs reaching as far as 1300 m depth. At the same time mining works have been realised but at smaller depths. Cross-sections have been elaborated too.

For Bihor Mountains, in IGR's archive there are regional and also local maps at 1:25 000 and 1:5 000 scales, which are based on gravimetric and magnetometry measurements. They have been elaborated in search for ore deposits.

The most important results of research on banatitic magmatites (Upper Cretaceous – Paleogene), that has been carried out since 1962, are the geological maps, scale 1:50.000, the afferent profiles, and the profiles scale 1: 200.000 published by M. Ștefănescu et al, e.g. the one showed in Figure 25.

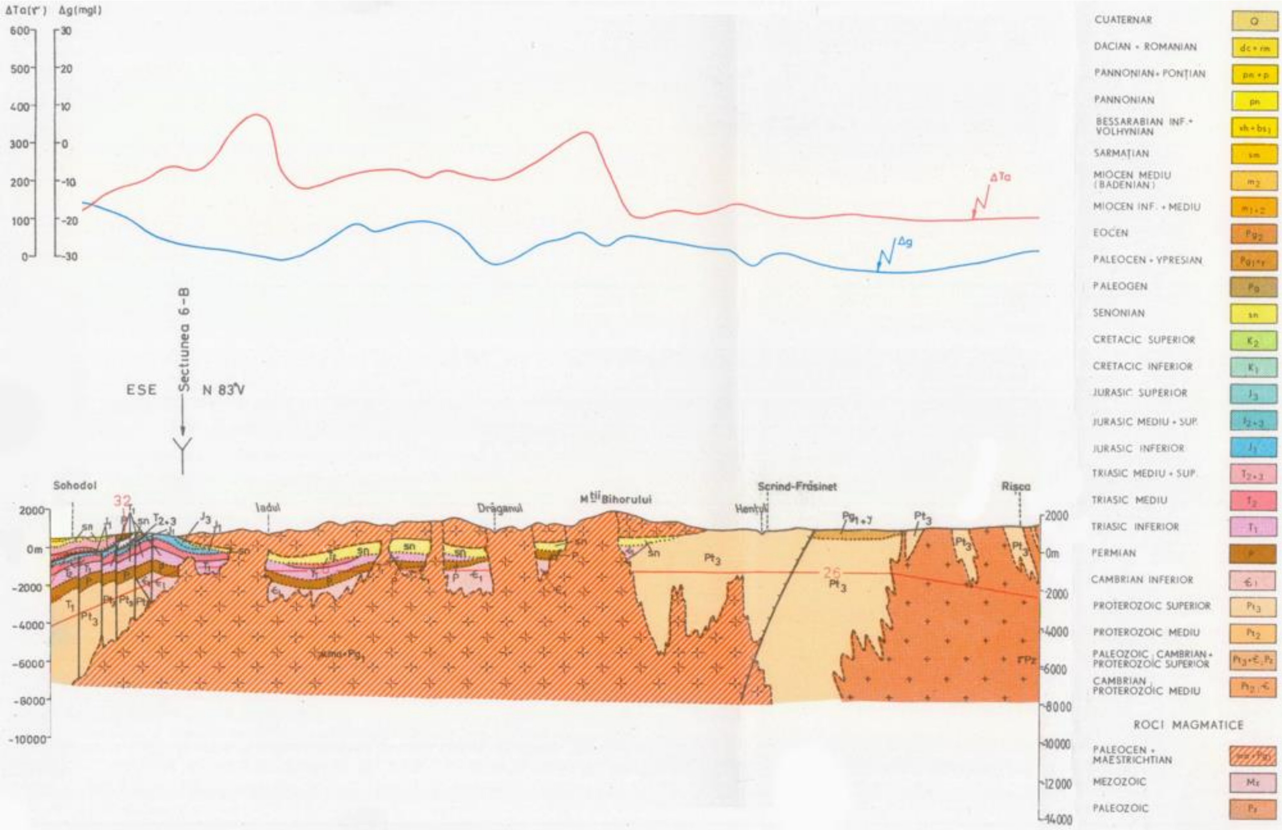


Figure 25 Bihor Mountains – cross section, scale 1:200.000; reproduced after Ștefănescu et al, – IGR's cross sections, 1988.

The above mentioned input is the primary data for the 3D model of Bihor – Vlădeasa batholith distribution that is realized within the project and will be reported in another chapter. An example of the contour of the batholith is given in the Figure 26.

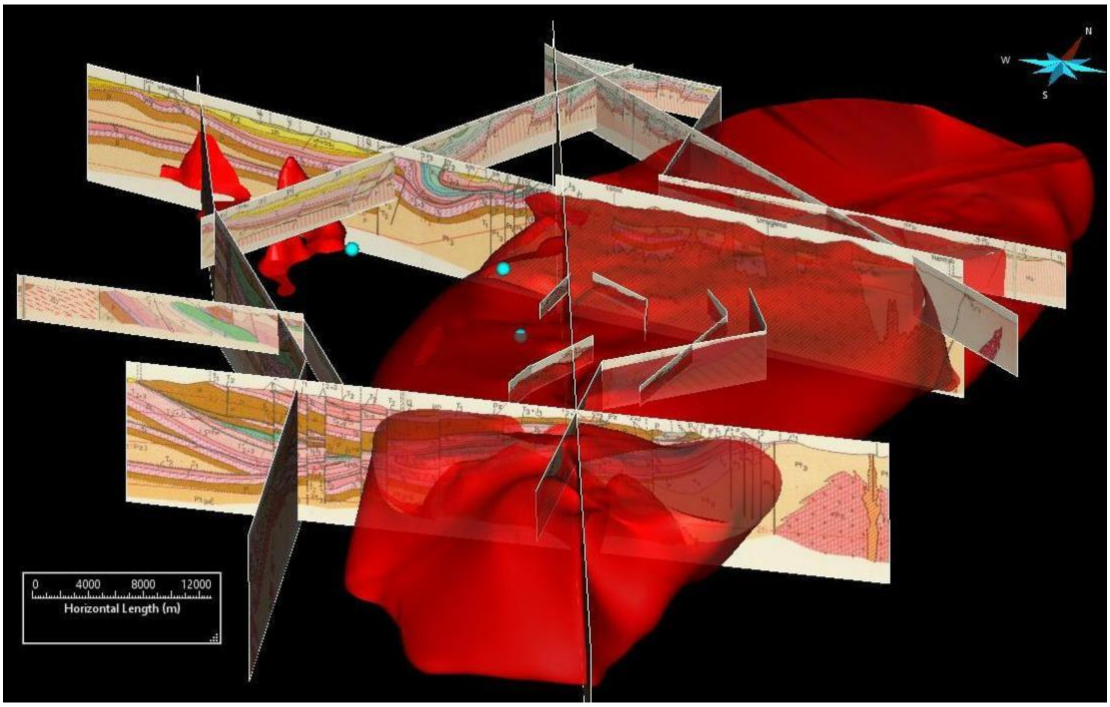


Figure 26 3D model of the batholith contoured based on cross-sections and magnetometry maps.

For the purpose of 3D modelling for Bihor Mountains, the maps scale 1:25 000, contained in the following report is used: ***'Report on geological, geochemical, magnetometric and electrometric prospection works in Budureasa - Bihor Mountains'***, authors: Manea el al, 1973, that contains maps at 1:25 000 scales.

Seismic refraction prospecting has been developed in order delineate the areas that contain mineral deposits. For example, since the seventies it has been revealed the existence of a batolith in Apuseni Mountains (Figure 27).

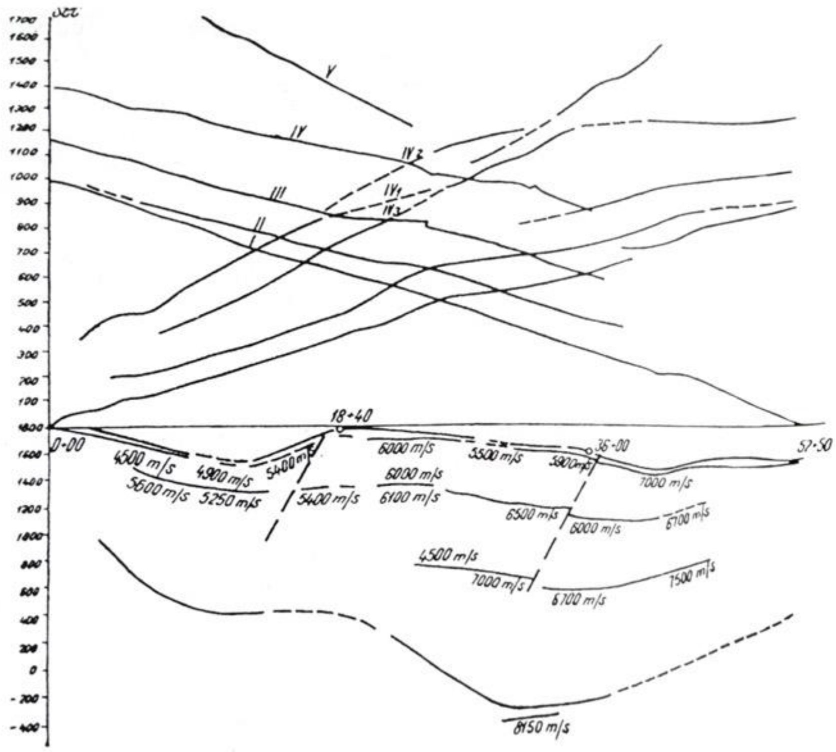


Figure 27 Refraction seismic profile in Apuseni Mountains that show a grandioritic body intruded into crystalline schists. Reproduced after Paicu and Patrichi, 1961.

Based on north-west part of the regional crustal profile XI in Romania, continue seismic surveys of the Romanian National Seismic Network and punctual seismic recording, a joint inversion method of receiver function and Rayleigh wave dispersion was employed by Bala et al, in order to derive the 1D seismic velocity models for several seismic station locations in western part of Romania. The study uses new data emerged from permanent network of broadband stations in Romania, as well as data from temporary networks established during the joint projects with European partners in the last decades.

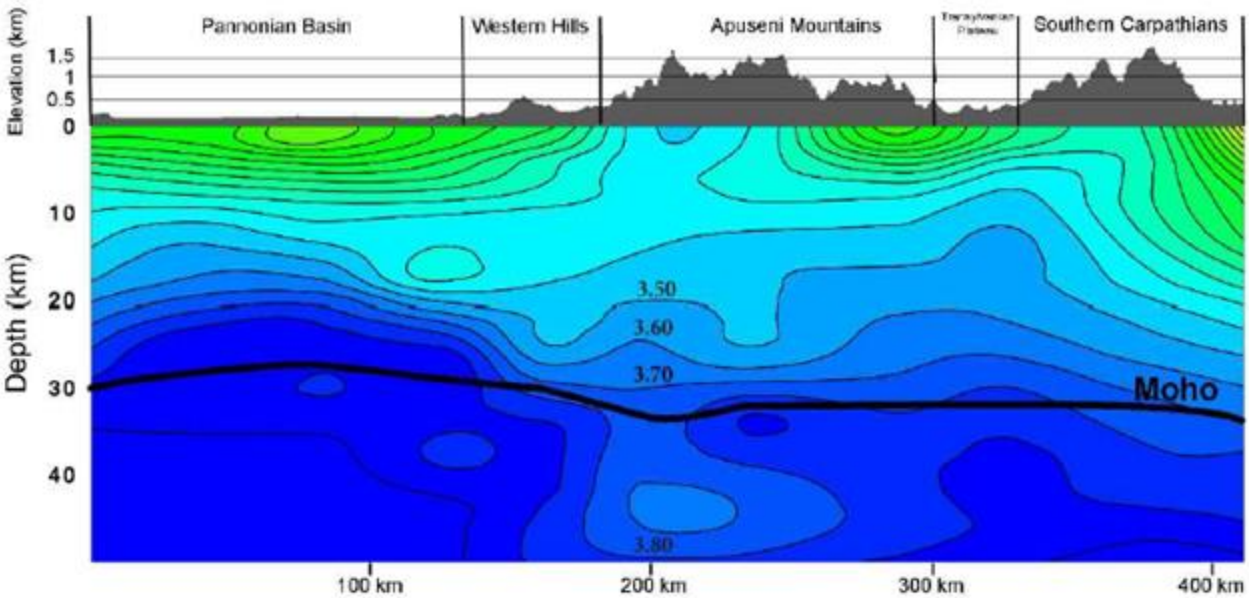


Figure 27 bis Seismic profile across Pannonian Basin and Apuseni Mountains. Reproduced after Bala et al, 2018.

In Figure 27 bis the profile is crossing an important section of Pannonian basin, the contact with Apuseni Mountains and crossing even the Southern Carpathians. The Moho depth is at about 29-30 km in the west, then a section with reduced velocities of 27- 28 km. In the central part of Apuseni Mountains the Moho is at 31-32 km depth followed by a flat section and decreasing to 33 km depth in the Southern Carpathians. The authors stress that comparing the data with crustal thickness determined in other areas belonging to Carpathian Orogeny, the Apuseni Mountains shows unusually reduced crustal depths. This bring up the hypothesis according to which these mountains represent in the Carpathian geosyncline zone, an area with an independent tectonic crustal structure with low crustal depths, compared to other areas belonging to Carpathian Orogeny.

4. Deep metal enrichment

North Apuseni Mountains Alpine magmatism is integrated within a broader context, defined by the term **Banatitic Magmatic and Metallogenic Belt – BMMB**, which represents a series of discontinuous magmatic and metallogenic occurrences of Upper Cretaceous age, which are discordant in respect to Mid-Cretaceous nappe structures of the region (Cioflica & Vlad, 1973; Ciobanu et al., 2002). The metalogenesis of Bihor Mountains is closely linked to the evolution of banatitic magmatism in the North Apuseni Mountains.

The data on **evolution of banatitic magmatism and the metallogenesis of North Apuseni Mountains**, were adapted from Ștefan et al, (1992), which synthetised the works conducted in the region before 1989 by:

Mureșan, 1971; Lazăr et al., 1972; Istrate, Bratosin, 1976; Istrate, 1978; Ştefan, 1980; Udubașa et al., 1980; Istrate, Udubașa, 1981; Ştefan el. al., 1985, 1986, 1988; Ştefan et al., 1989, unpublished report.

The banatitic calcalkaline magmatism (Post-Lower Masstrichtian-Palaeogene) which is widely developed in the Bihor Mountains was emplaced within two important cycles. **The first cycle** is characterized by lava flows (Vlădeasa) sometimes accompanied by pyroclastics (Vlădeasa); simultaneously superficial subvolcanic bodies have been emplaced (Vlădeasa, Bihor). The typical development area of the first cycle volcanism – the Vlădeasa Mts – contains the greatest volume of rhyolites forming the volcano-plutonic massif of Vlădeasa (Giușcă et al., 1969). The rocks of the Vlădeasa main eruptive body cut and include andesites, dacites and two older rhyolite rock types producing contact breccias with them.

Within **the second cycle** there have been emplaced bodies of intrusive rocks, generally hypabyssal as well as plutonic ones which are widely developed in the depth (Proca, Proca, 1972; Cioflica et al., 1982). Late alkaline vein differentiation products of granodiorite-granitic magma were reported too. Magmatic banatitic activity in the Bihor Mts ends with dykes of basic rocks (very abundant in Bihor).

The second cycle of banatitic magmatism contains a large range of quartz-diorites rocks and granodiorite - granitic rocks, accompanied and proceeded in crystallization succession by their porphyritic varieties, which are placed at the periphery of plutons, both as marginal facies of big bodies and as their apophyses. Swarms of subvolcanic bodies of porphyritic, quartz-diorite, granodioritic or granitic rocks are supposed to be associated to some profound plutonic bodies; such a supposition which is on account of geophysical data was confirmed by deep drillings, which have done in the area of Hălmăgel - Valea Seacă pluton (Cioflica et al., 1982).

Petrographically, the intrusive banatitic rocks in the Budureasa and Pietroasa areas range from granites to quartz diorites, with a prevalence of monzogranites and granodiorites (Istrate & Udubașa, 1981; Ionescu, 1996a; Ionescu & Har, 2001). Quartz monzonites, quartz monzodiorites and diorites occur as well (Istrate & Udubașa, 1981). Granodiorites are hypidiomorphic-granular, whereas porphyritic textures are restricted to the marginal facies. Granodiorites have a grayish to yellowish or pinkish color and consist of K-feldspar, quartz, plagioclase (mostly oligoclase or oligoclase/andesine), biotite, magnesiohornblende and rare clinopyroxene. Titanite, zircon, apatite and allanite-(Ce) occur as accessory minerals.

In Bihor Mountains diorites and their porphyritic varieties are displayed at the periphery of a granitic pluton or in its cover. In Pietroasa, Budureasa and Western Vlădeasa massif, quartz- dioritic rocks occur either as some independent bodies or at the periphery of granodiorite – granitic - monzodioritic rocks. Porphyritic micro diorites are also met in the northern extremity of eastern Vlădeasa eruptive massif, north of Crișul Repede River, at the periphery and in the cover of a granodiorite porphyry dyke.

Granodiorite-granites, to which the main sulphide mineralization is genetically linked, constitute main mass of banatitic bhey crop out on small areas; their development in the depth was emphasized (in Bihor Mountains).
Based on complex studies and reserves calculations performed by Cioflică et al (1989) the table given below was published (Table 1):

Table 1 Ore deposits connected to laramian magmatism

Location	Rock samples	Mineralization
Băița Bihor – Valea Seacă	Ca skarns; Mg skarns; granodiorites	Mo-Bi, B, Cu–Bi–W, Pb-Zn-Cu, Cu-Py
Borod – Cornițel	Rhyolites	Pb - Zn

Rănușa, Zimbru	Metarhyolites; meta conglomerates	Cu; Cu-Mo
Avram Iancu	Epimetamorphic rocks (limestones)	Cu-Ni-Co
Brusturi – Luncșoara	Epimetamorphic rocks (limestones)	Pb-Zn-Cu
Băișoara	Ca skarns	Fe (Pb-Zn)
Măgureaua Vaței	Ca skarns	Fe (Cu)
Săvârșin	Granites	Mo
Cerbia	Granites	Mo (Pb-Zn)
Căzănești	Basalts	Cu-Py

Source: Map of the distribution of the ore deposits in the Apuseni Mountains after Cioflică et al.

Budureasa - Valea Fagului is also added to this list by Borcoș (1997) who mention the following comodities: Pb+Zn, Cu, Au+Ag, Fe.

A map showing the location of these mineralization areas within Apuseni Mountains is given in Figure 28.

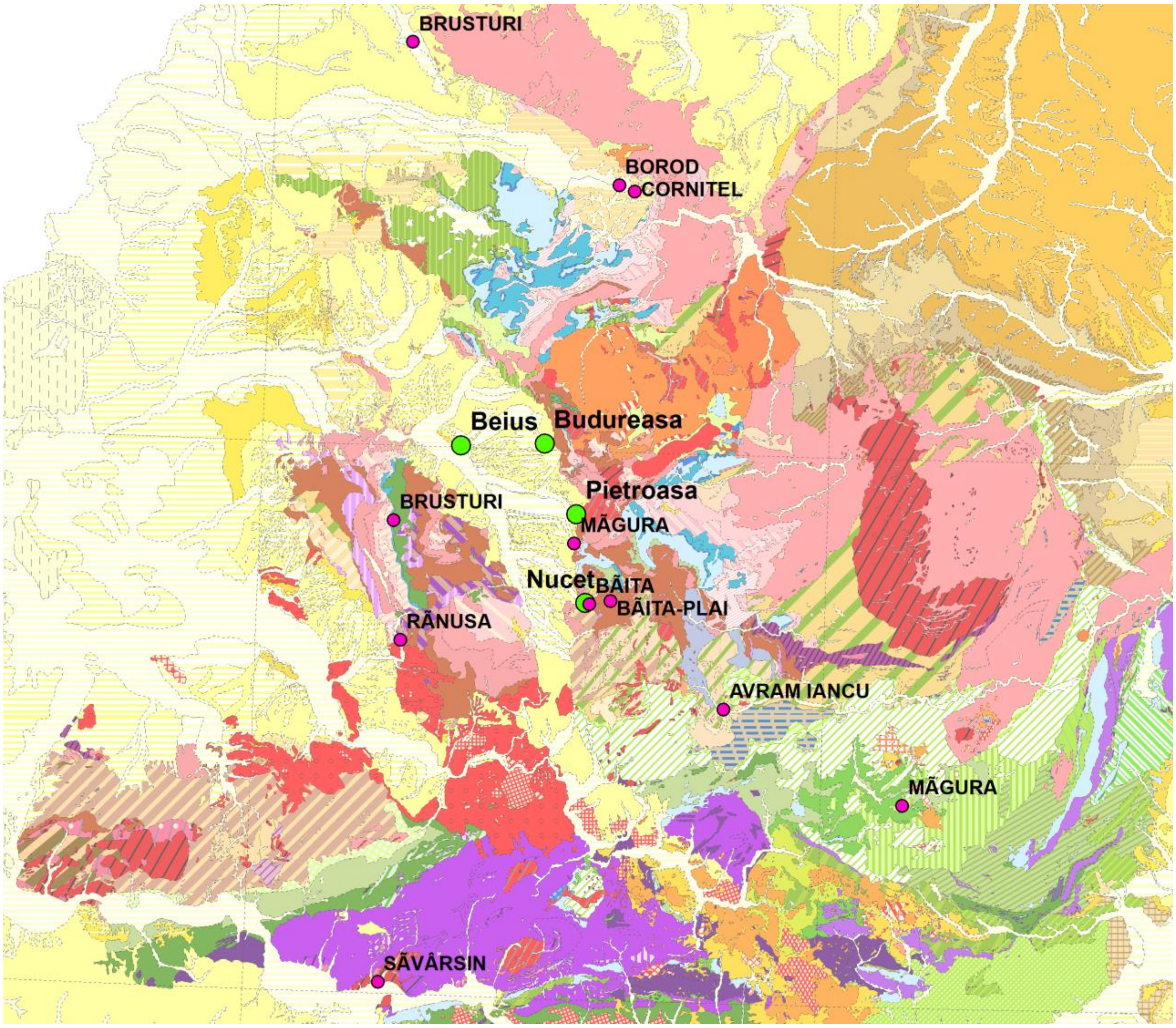


Figure 28 Apuseni Mountains and locations of mineralization areas.

Ştefan *et al.* (1992) has studied in detail the petrochemical and geochemical features of the banatites from the North Apuseni Mountains. In 2001 a study by Ionescu and Har, described the global geochemical characteristics of the rocks from this region. Some results of this study for granodiorites (chemical analyses and trace-elements and RE contents) are given below:

Table 2 Chemical analyses of the granodiorites from Budureasa and Pietroasa

Sample location	Chemical composition %											
	SiO2	Al2O3	Fe2O3	FeO	CaO	MgO	K2O	Na2O	TiO2	P2O5	MnO	H2O
BUDUREASA												
Gallery 8	70.83	14.79	2.55	0	2.73	0.85	3	3.64	0.24	0.41	0.59	0.37
Gallery 8	72.1	13.82	1.91	0	2.31	1.12	2.84	3.6	0.24	1.74	0.36	0.06
Gallery 8	70.69	14.6	2.76	0	2.13	1.37	2.92	3.08	0.38	1.05	0.57	0.45
Gallery 6 bis	69.8	14.51	2.68	0	2.87	1.3	3.08	3.04	0.32	1.78	0.69	0.08
Lateral drift no. 350/Gallery 6 bis	69.31	14.01	2.7	0	2.75	1.7	3.4	2.8	0.46	0.6	0.58	1.69
Gallery 6 bis	69.6	14.61	2.9	0	2.42	1.5	3.2	3.2	0.46	0.66	0.59	0.86
Lateral drift no.250/Gallery 6 bis	69.04	14.54	2.8	0	2.61	1.3	3.3	2.9	0.52	0.58	0.85	1.56
Lateral drift no. 350/ Gallery 8	70.06	14.37	2.55	0	2.08	1.7	3.8	2.8	0.52	0.04	0.41	1.7
Gallery 8	69.84	14.93	2.8	0	2.33	1.5	3	3.5	0.52	0.18	0.46	0.94
PIETROASA												
Sebisel Valley	66.13	12	4.2	1.81	3.4	3.2	2.79	3.93	0.75	0.16	0.09	1.01
Sebisel Valley	66.82	12.35	3.57	1.67	3.08	2.8	2.72	3.31	0.75	0.16	0.09	1.71
Sebisel Valley	67.53	13.06	3.43	1.81	2.46	2.3	3.39	4.25	0.8	0.16	0.1	0.25
Gallery 3	67.83	11.42	3.18	1.67	3.01	2.4	3.88	4.12	0.9	0.16	0.11	0.8
Gallery 3	66.35	13.22	3.81	1.81	3.4	2.4	3.49	3.31	0.75	0.16	0.09	0.71
Gallery 3	66.86	12.54	3.73	1.54	2.41	2.3	3.66	3.69	0.8	0.15	0.08	1.22
Gallery 3	67.07	13.04	3.42	1.81	2.71	2.4	3.56	3.69	0.65	0.14	0.07	0.94
Gallery 3	66.25	12.14	3.73	2.23	3.18	3	3.32	3.82	0.85	0.2	0.08	1
Gallery 3	66.33	12.52	3.65	1.95	2.76	3.1	3.37	3.93	0.85	0.2	0.09	0.86
Gallery 3	67.37	11.34	3.57	1.67	3.37	2.5	3.54	3.93	0.75	0.16	0.08	0.7
Aleu Valley	67.45	11.82	3.72	2.09	2.67	2.6	3.61	4.58	0.75	0.18	0.09	0.31
Aleu Valley	63.53	11.9	3.65	1.95	2.08	3.5	3.06	3.18	0.8	0.18	0.08	2.18
Prislop Hill	66.76	12.8	3.65	1.96	2.44	2.9	3.18	3.63	0.8	0.16	0.07	0.93
Prislop Hill	66.73	12.54	4.03	1.96	2.99	2.6	3.23	3.66	0.85	0.19	0.1	0.31
Aleu Valley	65.72	12.47	4.03	1.96	2.82	3.3	3.01	3.93	0.8	0.2	0.1	0.35
Aleu Valley	64.4	11.68	3.81	1.11	3.51	2.9	3.9	3.63	0.8	0.16	0.09	0.35

Table 3 Trace-elements and REE contents of the granodiorites and diorite from Budureasa-Pietroasa area*

Sample location	TiO2	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Hf	Pb	Th
	%	ppm													
Limit of detection	0.1	5	3	5	2	2	2	2	3	15	15	15	3	3	5
Budureasa granodiorite Sârca Valley	0.8	uld*	67	20	38	535	31	712	8	346	18	52	17	49	uld
Budureasa granodiorite Sârca	0.4	6	41	17	178	133	35	203	11	577	43	78	10	20	uld

Valley														
Pietroasa diorite Quarry	0.9	19	48	21	164	290	37	287	19	567	40	86	10	24	uld
Pietroasa granodiorite Quarry	0.6	21	44	19	149	273	21	202	8	945	43	81	6	29	uld

** Chemical analyses for trace elements were made by ED-XRFA (the X-ray Fluorescence Neutronic Thermic Activation method) by Prof. dr. Doris Stüben (Institut für Petrographie und Geochemie, Karlsruhe University, Germany).*

The granodiorites acidity varies between 63.53 % and 70.83 % SiO2. The Na2O contents range between 2.80 % and 4.58 %, while K2O range between 2.72 and 3.90 %. A quite obvious difference can be noticed between the rocks of the two areas: granodiorites from Budureasa are a little more acid and contain more Al and Mn than those of the Pietroasa body. In return, they are poorer in Fe, Ca, alkalies and Ti (Ionescu and Hae, 2001).

The above mentioned study emphasizes the main conclusions with a special reference to Pietroasa and Budureasa intrusive bodies:

- The banatites from the North Apuseni Mountains are the result of the oceanic crust subduction in the western basin (Rădulescu, 1974).
- The Budureasa and Pietroasa banatite bodies belong to the second stage (Istrate and Udubaşa, 1980; Ştefan *et al*., 1988) of the Laramian magmatism, which has a calco-alkalin character.
- The petrochemical studies show some differences between the Budureasa and Pietroasa igneous bodies: generated in the same structural frame (continental arc granitoids), the Budureasa magmas preceded in time the more alkaline Pietroasa magmas.
- The petrochemical differences observed between the Budureasa and Pietroasa banatitic bodies are at variance with the presence of a single, deep situated, batholith with large apophyses (as the Budureasa and Pietroasa bodies were considered).
- The magma genesis begun closer to the subduction front (the Budureasa body) and continued further in time with the Pietroasa body.
- The rocks from Budureasa area reveal a long-time evolution, emplacement and crystallization of the diorite-granodiorite-granite magmas: from 88 to even 54.5 Ma.

Around big bodies of granodiorite-granitic composition, **phenomena of thermal metamorphism are reported.** Their extension around the pluton is 1500 m as in the Bihor Mountains (Cioflică et al., 1974). Although products of thermal metamorphism are widely spread in the Bihor, intensity of thermal metamorphism reached only the facies of hornfels.

Under geologically favorable conditions, i.e. in the contact aureole of the granodiorite-granites plutons, Fe, B, Bi, Mo bearing skarns have been formed, locally overlapped by sulphide mineralization, sometimes independently developed, such as the vein occurrences with Cu, Zn and Pb sulphides at Valea Seacă, Valea Mare-Budureasa etc.

Skarns often accompanied by magnetite concentration occur almost everywhere at the contact between diorite and carbonate rocks, sometime base metal sulphides associate with the skarns. So, at Măgureaua Vaței skarns of a very rich paragenesis (gehlenite, spurrite, tilleyite, garnets, pyroxenes, wollastonite, and vesuvianite) are associated to Fe ± Ba metasomatic mineralization in the western extremity of quartz-mondozodioritic body and sulphide veins in the eastern extremity on the magmatic body, where granites - granodiorite prevail. On Martin hill at Sârbi-Hălmăgel, in the aureole of dioritic body, which is crossed by granodiorites, iron oxides and sulphide mineralization occur. Magnetite associated with banatitic magmatites are also found at the spring of Arieșul Mic, Valea Seacă and Budureasa; at Valea Seacă and Budureasa, sulphide mineralization overlies this kind of mineralization.

Magmatic bodies intruded Permian-Mesozoic sequences and produced contact-metamorphic aureoles, at Pietroasa, Budureasa and, most extended at Baita Bihor, where the surface exposure of the contact rocks reach many square kilometers, being the largest in Romania.

Brucite deposits

Between 1982 and 1990 the **brucite deposits** from Budureasa and Pietroasa were investigated by surface pits, drillings and underground galleries. A schematic and idealized view of the contact of granodiorites with the Anisian dolomites shows a structure with four zones, ranging from granodiorites to pure dolomites (Ionescu & Hoeck, 2005):

- Granodiorites are holocrystalline hypidiomorphic, sometimes porphyritic, with large feldspar phenocrysts. Various magmatic, metamorphic and sedimentary xenoliths are common at the periphery of the intrusion.
- Magnesian skarns, forming the innermost zone of the contact aureole, consist mainly of forsterite, garnet (andradite) and clinopyroxene (diopside, hedenbergite). Periclase and spinel occur as well. A wealth of hydrated minerals mainly serpentine minerals, phlogopite, talc, chlorite, epidote–zoisite, apatite, tremolite–actinolite and subordinately hydrogarnet, vesuvianite, chondrodite, clinohumite, hydrotalcite, brucite, hydromagnesite and pyrophyllite were also formed. Younger veins with quartz, magnesite, sepiolite, calcite, pyrite, pyrrhotite, sphalerite, chalcopyrite, galenobismutite, and galena are common. The skarn thickness around the granodioritic body is relatively small, ranging from 0.5 up to maximum 7 m. The first occurrence of hydrogarnet and magnesioferrite in Romania was described from the Budureasa area by Ghergari & Ionescu (2000).
- Brucite-bearing zones occur only at some distances (0.5 to 7 m) from the contact. The irregular, sometimes lens-shaped brucite-bearing zones range from several metres up to tens of metres in width and from tens to several hundreds of metres in length, respectively. The thickness of the brucite-bearing zone can significantly vary within the short distance. The variation of brucite content across the contact aureola around the granodioritic intrusion is highly inhomogeneous, ranging from brucite-rich, with up to 40 wt% brucite to brucite-poor domains, with less than 5 wt% brucite. The average content of brucite is around 10.5 wt% in the Budureasa area and 7.5 wt% in the Pietroasa area, respectively (Ionescu, 1999).
- Recrystallized Anisian dolomite, without or with only very low Si and Al content, follows the brucite-rich zones. Brucite forms small lamellae of 20×20×2 µm up to 80×50×6 µm (length, width, thickness). Large individual lamellae, over 1 mm in length are only exceptionally found. Brucite lamellae group in clusters of various shapes and sizes (in average from 0.05 to 1.3 mm). Fillings of small veinlets or isolated lamellae are rare.

Borate deposit

In the middle basin of the Aleului Valley (Bihor Mountains), at its confluence with the Sebisel Valley, at the Gruiului Hill, an important endogene borate deposit, including ludwigite and szaibelyite, pointing to the kotoite presence, was identified. The mineralized site is situated at about 4 km NE of the locality of Pietroasa (Bihor District). The occurrence, investigated by mine workings, had also been pointed out (Stoicovici, Stoici, 1969; Stoici, 1974). In 1992 this deposit constitutes the study object of a thorough mineralogical study, realised by S. Marincea.

The ore deposit is hosted in a zone with magnesian hornfels (sensu Turner, Verhoogen, 1960), at the contact of the Pietroasa banatitic pluton with Anisian dolomite limestone of the Ferice Nappe (see Bordea, 1973, for details).

The data analysed by Marincea, (1992) consisting of mineralogical and physico-chemical study of szaibelyite and associated minerals in the Gruiului Hill occurrence, correlated with general geological aspects led as to the following conclusions:

- The formation of the borates from the contact aureole of the Pietroasa granitoid body is the result of an infiltration metasomatic process. This process explains the frequency of the occurrence of ludwigite in other parts of the contact aureole of the body (Rafalet, 1963). In case of the Gruiului Hill occurrence the significant boron-fluorine supply implies large metasomatic processes compatible only with an intense diffusion metasomatism.
- The hypothesis of a diffusion metasomatism implies the tectonic control of the boron minerals disposition in case of the Gruiului Hill occurrence. This hypothesis, also supported by Stoicovici and Stoici (1969), is based on the location of the mineralized zone nearby a Major fault of the Galbenii fracture system (with a NW-SE disposition): Tirău-Măgura Guranilor Fault, at its intersection with a network of conjugated fractures.
- The presence of minerals with potential fluorine contents (clinohumite can contain up to 4 per cent F according to Aleksandrov, 1982) makes plausible the hypothesis of the boron transport as fluoro-boric compounds with alkaline solutions as an age. (Barsukov, Egorov, 1957). The interaction with the dolomitic background makes possible the decrease of the alkalinity of such solutions, necessary for borate precipitation.
- Iron seems to be the primary precipitant of boron, as indicated by ludwigite formation before the pure magnesian borates. The iron deficit in the system would make possible the synchronous crystallization of such borate (that is of suanite or fluoborite) as well as the later crystallization of kotoite (Barsukov, Egorov, 1957).
- Boron-(fluorine) metasomatic supply is unique, influencing the preservation of the pure magnesian character of the primary borates, imprinted by the paleosome origin. The character of these borates, highly susceptible to the acceptance into the network of cations like Mn^{+}, Sn^{4+}, Ti^{4+}, induces the extreme magnesian character of the Gruiului Hill szaibelyite, for which the secondary genesis has been admitted.
- The constancy of the magnesian contents in calcites occurring in areas with hornfels affected or unaffected by the boron metasomatism leads to the conclusion of the extension of this metasomatism in zones where the limited development of the silicate minerals made possible the formation of an "excess" of magnesium available in the carbonate phases. The reverse correlation between the abundance of the silicates and the abundance of the boron minerals implies the active role of the lithologic control in the location of the Gruiului Hill mineralization.

W-bearing and base metal skarns

W-bearing and base metal skarns are characteristic only for Baita Bihor. Triassic dolostones, that discordantly overlies the Permian — Lower Triassic quartz sandstones and micro-conglomerates, form in both cases the protolith of the **magnesian skarns**. At Baița Bihor, some magnesian skarn bodies or ore pipes such as those at Antoniu, Bolfu-Tony, Hoanca Motului, Baia Roșie are **boron-bearing skarns** and represents well-defined metasomatic columns. A sole similar body, or metasomatic column, that from Dealul Gruiului was identified at Pietroasa.

The magnesian skarns are hosted by Anisian — Carnian or Carnian — Norian dolostones at Băița Bihor (Bordea et al. 1988) and by Anisian dolostones of the Ferice unit at Pietroasa (Bleahu et al. 1985); the country rock is folded by traversing faults, which are more evident at Băița Bihor. The skarn bodies crop out on very small areas, but were extensively investigated by mining works.

*

Two rock samples from Romania were used for leaching experiments by Chris Rochelle et al., in 2017 as part of the CHPM2030 project's laboratory work: a skarn from Pietroasa **(HTL320)** and a mineralized rock from Cacova Ierii **(HTL321)**. The experiments used a range of fluid types and pressure/temperature conditions to identify fluid-rock reactions and quantify the potential for enhancing metal release. For the 2 samples the results are showed in Figures 29 – 32. We can see that for conditions of temperature/ pressure of 100 °C, and 200 bar the efficient substances proved to be 0.6 M NaCl, and HCl/HNO3 mix for both samples. The main elements recovered are: Co, Sr, Mo, Sb, Mn, Zn, and W.

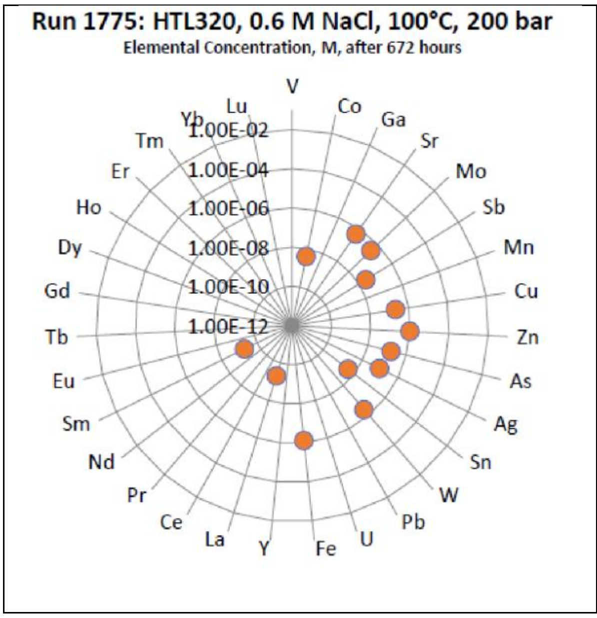


Figure 29 Selected metal concs. For Run 1775 final fluid (partner sample HTL320: 0.6 M NaCl, 100 °C, 200 bar)

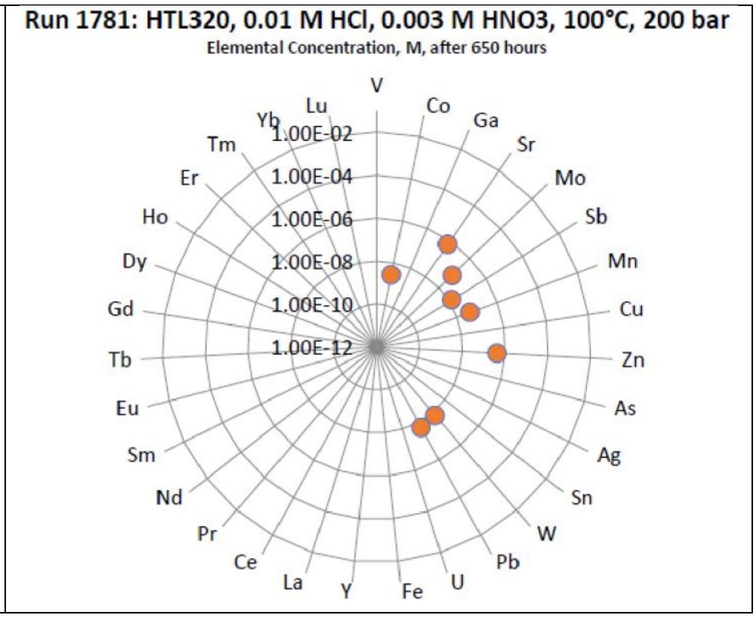


Figure 30 Selected metal concs. For Run 1781 final fluid (partner sample HTL320: HCl/HNO3 mix, 100 °C, and 200 bar).

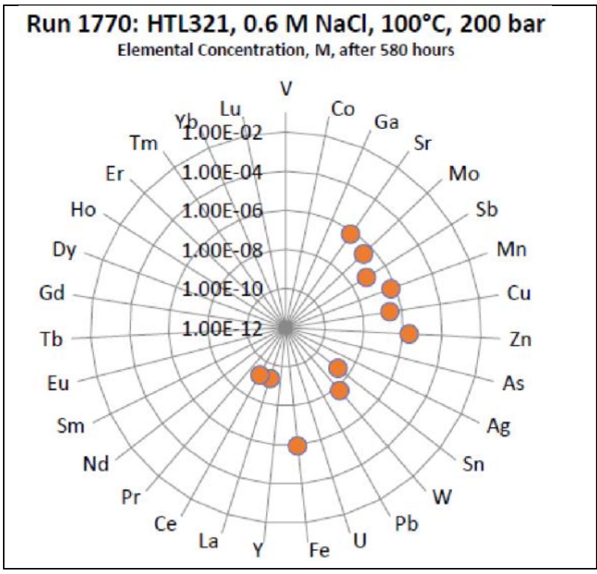


Figure 31 Selected metal concs. For Run 1770 final fluid (partner sample HTL321: 0.6 M NaCl, 100 °C, and 200 bar).

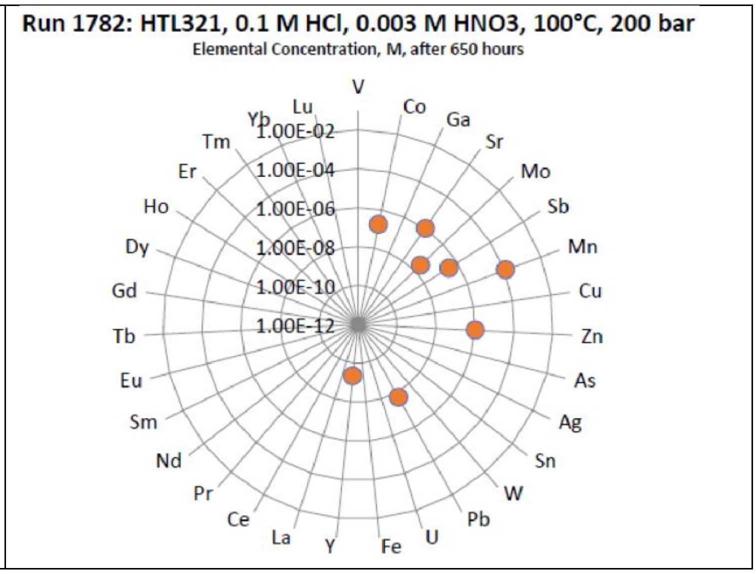


Figure 32 Selected metal concs. For Run 1782 final fluid (partner sample HTL321: HCl/HNO3 mix, 100 °C, and 200 bar).

5. EGS potential

The heat flow map of Romania and the map of temperatures at 3000 meters depth are based on temperature measurements in 4000 deep wells, the determination of thermal conductivity of the rocks, thermometric prospection and thermometry of ground waters. Also information on deep geological structure, the heterogeneity of the subsoil, the basement faults, the intrusive masses, the structures liable to underground accumulations, have been considered (Figures 33,34). For the study-case area the heat flow map indicates around 90 mW/m^2 and the temperature at 3000 m depth map is around 85^{0}C.

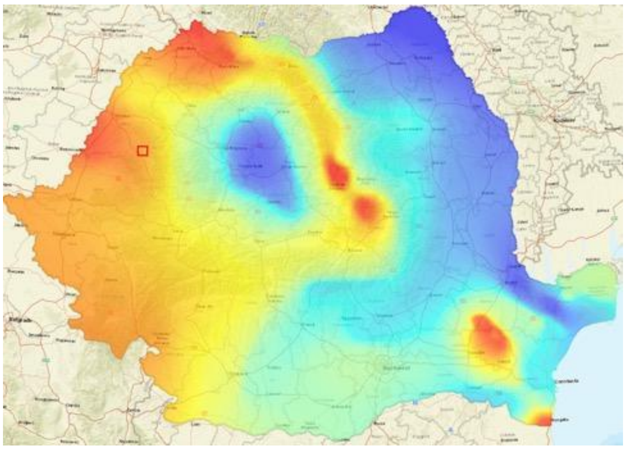


Figure 33 Heat flow in Romania (Raster resulted by interpolation of heat flow isolines - mW/m^2 -from Map of heat flow, Visarion et al, 1985)

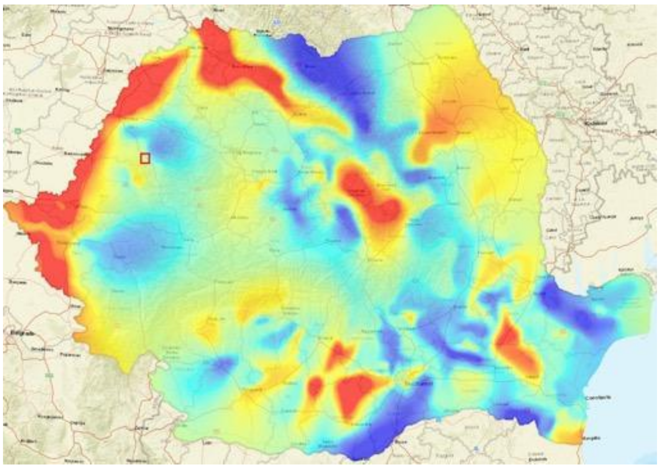


Figure 34 Map of temperatures at 3000 meters depth (Raster resulted by interpolation of geoisotherms - °C - from Map of heat flow, Visarion et al, 1985)

Previous to 2006 153 new reliable heat flow density determinations, 100 measurements in thermally stabilized boreholes (deeper than 1000 m), collection and interpretation of temperature from oil industry boreholes lead to the improvement of knowledge on geothermal potential for each region (Veliciu *et al,* 2006).

In Romania the mean heat flow varies between 21 and 120 mW/m^2 and the estimated temperature at 3000 meters depth varies between 44 and 163^0 C. There are over 250 wells drilled with depths down to 3,500 m, which show the presence of low enthalpy geothermal resources (40-120°C). In Romania, the average thermal gradient is 2.5 ^{0}C/100 m, and it can exceed 6.6^0 C/km in Pannonian Basin (Paraschiv et Cristian, 1976). In Romania three main areas having a high geothermal potential are to be mentioned, in East Carpathians, Moesian Platform and, the most important, Pannonian Basin.

In Bihor Mountains a regional batholith of banatitic origin outcrops and has been contoured in the depth. At the same time geophysical measurements highlighted the existence of a batholith in Beiuș Basin.

Beiuș Basin is a part of the Pannonian Basin being formed by the same thermochronological processes that transformed the whole region during Neogene. That is why Beiuș Basin is expected to share the general favorable conditons as regards to the high heat flow, and temperature in the depth as Pannonian Basin. On the other hand Bihor Mountains, which are bordering the Pannonian Basin differ both in structure and termocronological processes history from the basin. Consequently, a special attention has to be given to local conditions.

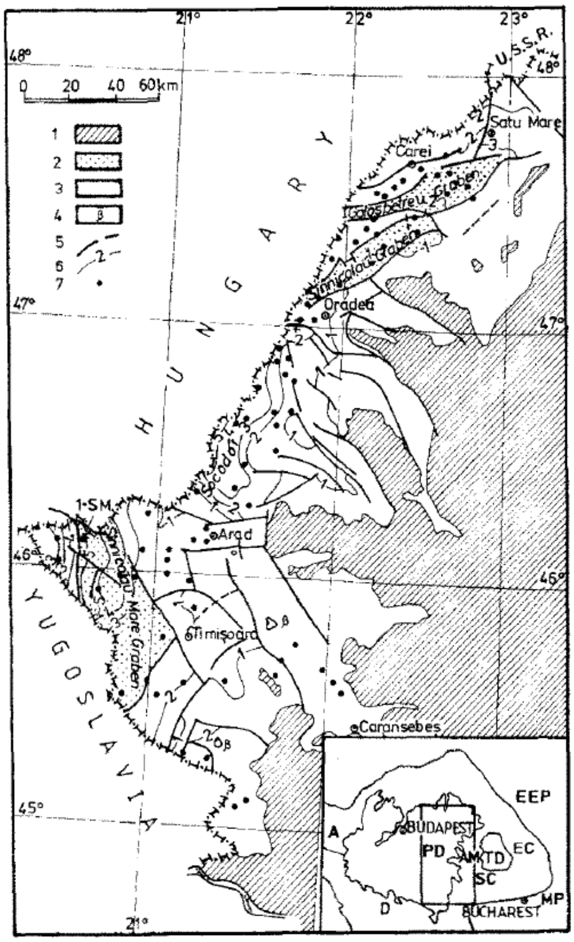


Figure 35 Location of geothermal wells; Reproduced after Demetrscu and Polonic

For the estimation of geothermal potential for Beiuș Basin and Bihor Mountains we will review the Romanian studies on these two areas. Then, as local data have been integrated into regional and European analyses offering a larger perspective on this theme, we shall refer to some of these studies.

In 1989 Demetrescu and Polonic described the formation and evolution of Romanian part of Pannonian Basin as a result of a complex thermomechanical phenomenon of lithospheric extension. The connection between heat flow, subsidence and sedimentation has been studied by Demetrescu based on data from 75 boreholes generally uniformly distributed over the study area (35). The conclusions are given below:

- The water-loaded tectonic subsidence in the Romanian part of Pannonian Depression at the end of the Badenian, Sarmatian and Early Pannonian until present is registered. The formation of the basin began in the Badenian, reaching depths of 300-400 m, and continued in the Sarmatian. The deepening of the basin extended to the east and south in the Pannonian and Quaternary. The present tectonic subsidence reaches values of 1200-1400 m.

- The quasi-linear time dependence of the tectonic subsidence suggests a finite rate extension since the Badenian, with extensional strain rates of 1-2%/m.y. Pre-Badenian instantaneous extension followed by a Badenian-Present thermal subsidence (Slater et al., 1980) can be accommodated with extension factors of 1.2-1.4 if initial altitudes were up to 1 km.

- Heat flow data suggest a contribution to the surface heat flow of 15-30 mWm^{-2}. This contribution is due to the heat coming from the convective transfer of heat by lithosphere material ascending during extension.

To compensate for the lack of measurements, Demetrescu used different types of data to produce patterns that would lead to the estimation of heat flow for the various structural structures, including the Pannonian Basin and the Apuseni Mountains. Thus, he was able to estimate that in areas of the Carpathians, affected by Tertiary tecto - geneses, usually referred to terrains younger than 50 Ma, the three components of the regional heat flow: crustal radiogenic, thermal transient perturbation and background heat flow from deeper sources, contribute with 36, 27 and 27 mWm^{-2}, respectively, to the mean value 90 mWm^{-2}.

Time - dependent history of the Neogene sedimentary formations chart used by Demetrescu for his models is given below (Figure 36).

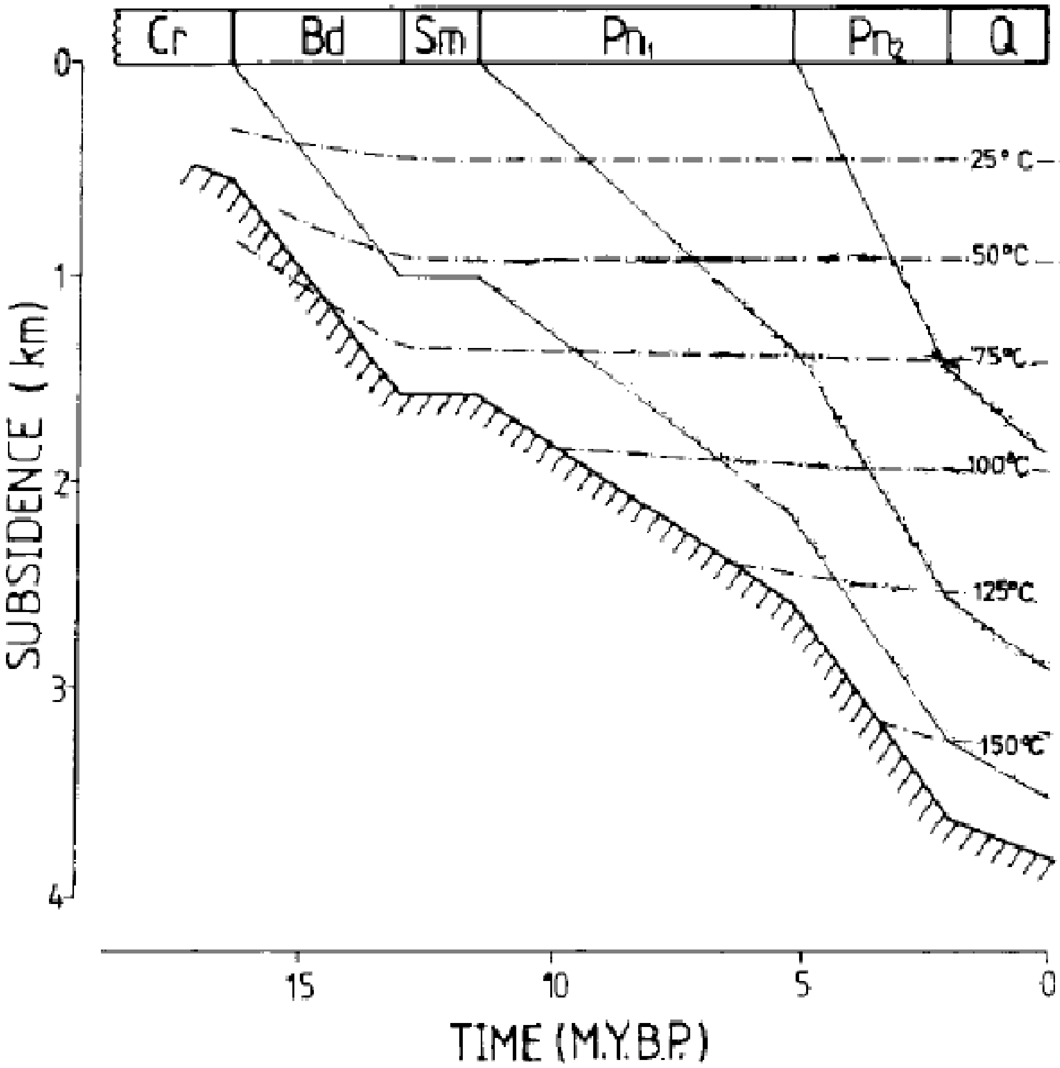


Figure 36 Time - dependent history of the Neogene sedimentary formations. Reproduced after Demetrescu and Polonic, 1989; Data were acquired from a borehole that is considered representative for Pannonian Basin.Continuous line – depositional isochron; dashed and dotted line – temperature; Cr. Cretaceous; Bd – Badenian; Sm – Sarmatioan; Pn_1 – Lower Pannonian; Pn_2 – Upper Pannonian; Q – Quarternary.

Rădulescu and Dimitrescu (1982) highlighted a correlation with the age of the last tectono-thermal event that mobilized the region in which the heat flow values were determined. For the eastern limit of the Pannonian Basin, where last tectono-thermal event was Post-Miocene extension (age 10 – 25 Ma) the mean heat flow is 96 mWm^{-2} (standard deviation 8).

The radiogenic heat generation of the region, for each type of rock was calculated by Veliciu, (1987), using the heat generation constants revised by Rybach (1976). Table 4 lists the average heat generation values from the Carpathians grouped according to the petrographic facies. For comparison, characteristic values for the Swiss Alps (Rybach 1976) are given. In terms of the surface radiogenic heat generation of the rocks, the differences found between these two Alpine orogenic regions are minor.

Table 4 Heat generation values for the Carpatians (Reproduced from Veliciu, 1987)

Rock Type	Romanian Carpathians (Veliciu 1987)			Swiss Alps (Rybach 1976)		
	Number of samples	Range (μWm^{-3})	Mean	Number of samples	Range (μWm^{-3})	Mean
Granitic rocks:						
Granite	50	1.94 – 3.10	2.52	8	1.88 – 6.06	2.50
Granodiorite	41	1.71 – 1.99	1.87			1.50
Andesite	61	0.52 – 1.18	0.85			1.10
Basalt	53	0.14 - 0.57	0.35	8	0.08 – 1.05	0.30
Metamorphic rocks:						
Green schists facies (epizone)	22	0.70 – 1.49	1.09	18	0.25 – 2.42	1.50
Amphibolites facies (mezozone)	391	1.74 – 3.11	2.43	55	0.86 – 5.02	2.42
Sedimentary rocks:						
Cretaceous flysch (sandstones)	91	0.86 – 1.31	1.09			
Carbonate rocks				12	0.03 – 0.92	0.33
Continental crust			0.72			0.80

In 1986 Neguț and Pauca determined the thermal conductivity of the rocks belonging to the Romanian part of the Pannonian Basin and the surrounding areas through laboratory methods. The results for the rock encountered in our perimeter are given in the Table 5:

Table 5 Thermal conductivity of the rocks from Pannonian Basin

The rock	Thermal conductivity (10^{-3}cal/cm x ^{o}C x s)
Magmatic rocks	
Granite	3.5 - 12
Granodiorite	3.5 – 7.8
Diorite	4.8 – 5.0
Basalt	2.0 – 8.0
Gabbros	4.0 – 9.4
Metamorphic rocks	
Quartzite	8.2 – 19.0
Marble	6.0 – 8.0
Sedimentary rocks	
Limestone	1.5 – 7.0
Dolomitize limestone	6.0 – 7.0
Dolomite	2.0 – 12.0
Geothermal water	1.0 – 1.2
Water (0 - 100^{o}C)	0.9

Based on these data the conclusion is that in Bihor Mountains, the heat flow of granitic – granodioritic bodies from Pietroasa and Budureasa are supposed to have high values in the depth. Also the heat flow of the rocks that host the geothermal aquifer (limestone, dolomite and quartzite, marble) has high values. But an import cooling agent is represented by the continuous circulation of the water that comes from the karst areas of Bihor Mountains into the geothermal aquifer from Beiuș Basin. It is expected that in the depth of 4 km, where the access of water is prevented by the aquiclude Lower Triassic layers the heat flow of the batholith to be considerable.

Paraschiv and Cristian (1976) realised measurements in a stabilized regime at 3000 oil exploration drilling and in unstabilized regime at 170 more. For Pannonian Basin (Romanian part) the following results are given below:

Table 6 Geothermal gradients for Pannonian Basin

Pannonian Basin	No. of oil structures	No. of temperature measurements	Depth of 500 m b.s.w.l.		Depth of 1000 m b.s.w.l.		Depth of 2000 m b.s.w.l.	
			Gradient (°C/100 m)	T (m/°C)	G(°C/100 M)	T (m/°C)	G (°C/100 m)	T (m/°C)
South	8	300	6.2	16.3	5.8	17.4	5.6	18.1
North	10	259	6.9	15.2	6.5	16.5	5.8	17.8

The following chart expresses the difference that exist between the Pannonain Basin and the other important basins from Romania (Figure 37)

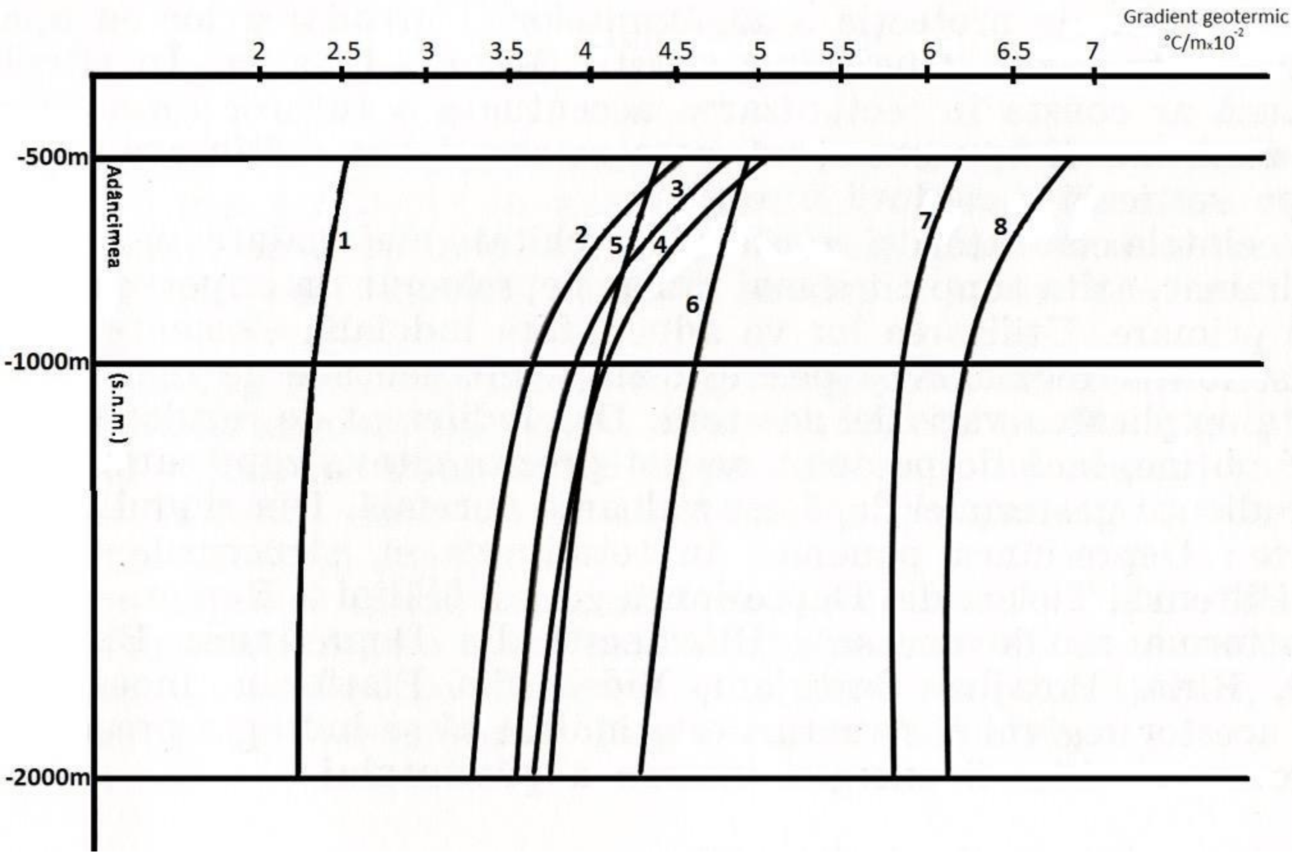
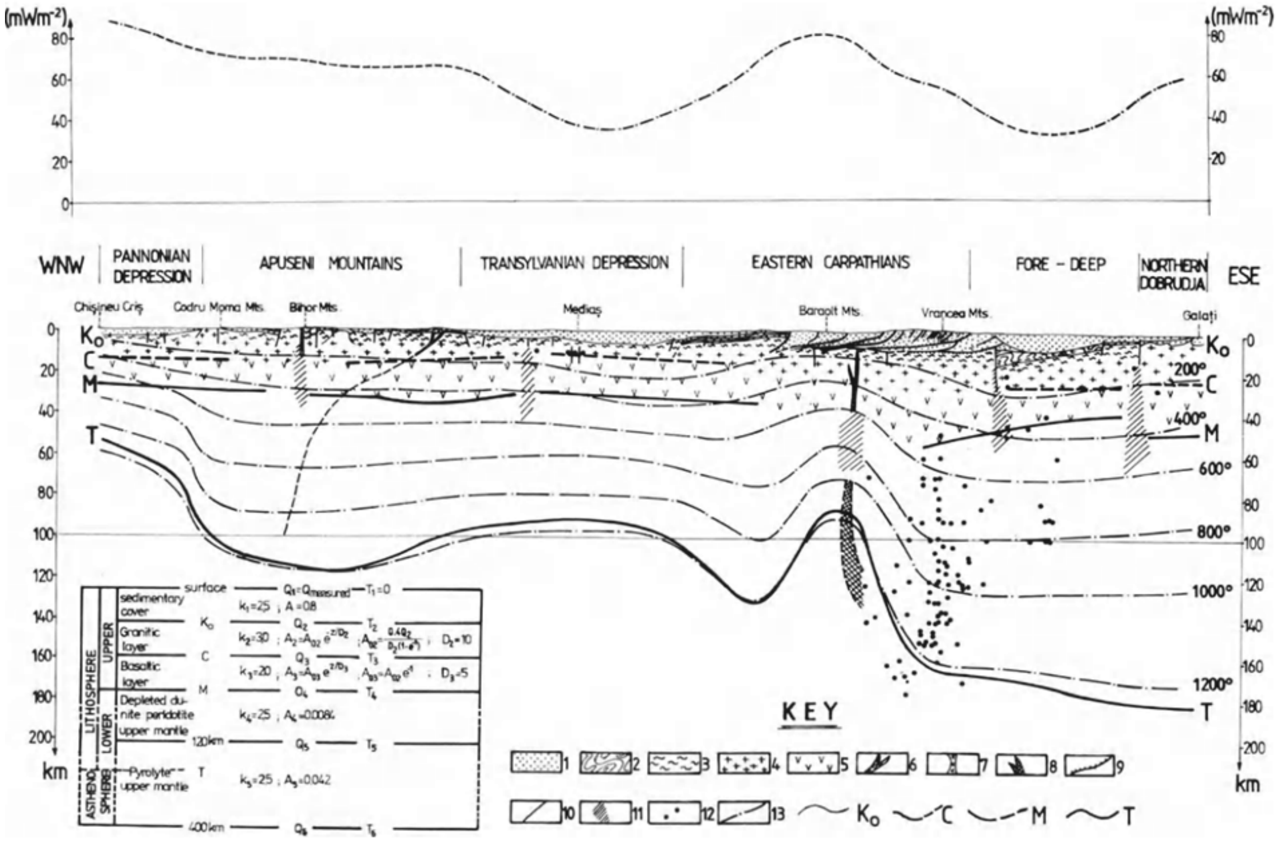


Figure 37 Geothermal gradient of different basins from Romania, reproduced after Paraschiv and Cristian (1976); 7 and 8 are the values afferent to Pannonian Basin

In the volume *Terrestrial Heat Flow and the Lithosphere Structure* edited by V. Cermak, and L. Rybach the international profile running WNW-ESE Romania has been published. The thermal structure of the lithosphere was considered by Demetrescu (1984) and Rădulescu (1985). As far as the crust alone is concerned, steady – state conduction models are justified for the most of the Romanin territory considering the age of the last thermal event affecting the various tectonic units (Figure 38).



Lithosphere cross-section 1 Undivided sedimentary; 2 greenschists; 3 crystalline basement; 4 "granitic" layer; 5 "basaltic" layer; 6 ophiolites; 7 banatites; 8 Neogene volcanites; 9 overthrust line; 10 fault; 11 deep fracture zones; 12 hypocentres; 13 isotherm; K_o sedimentary/crystalline basement boundary; C Conrad discontinuity; M Mohorovičić discontinuity; T lithosphere/asthenosphere boundary

Figure 38 Lithosphere cross – section of Romanian structural units – reproduced after Demetrescu (1984) and Rădulescu (1985).

According to the Demetrescu and Rădulescu for Beiuș Basin values above 80 mWm^{-2} and for Apuseni Mountains values are above 70 mWm^{-2} for the heat flow have been estimated.

These values have been confirmed by researchers that, using different multidisciplinary approaches, reached similar results. We want to give some examples. In 2006 Dererova *et al* applied integrated lithospheric modelling combining the interpretation of surface heat flow, geoid, gravity, and topography data for the determination of the lithospheric thermal structure along four transects crossing the eastern Carpathians from the European Platform to the Pannonian Basin and propose a new map of lithospheric thicknesses. The heat flow values for Beiuș Basin and Bihor Mountains that are represented in these transects, are around, or above 80 mWm^{-2}. For densities and thermal properties values from the Table 7 have been used.

Table 7 Densities and Thermal properties

Densities and Thermal Properties of the Different Bodies Used in the Transects[a]

No.	Unit	HP	TC	ρ_0
1	Neogene sediments	3.0–3.5	2.0–2.5	2400–2550
2	flysch, foreland basin, sedimentary cover of European Platform	1.0–2.5	2.0–2.5	2550–2650
3	volcanics	2.0–3.5	2.5–3.0	2600–2800
4	Carpathian and Pannonian upper crust	1.0–3.5	2.0–3.0	2740–2750
5	European Platform upper crust	1.5–2.5	2.0–2.5	2650–2820
6	European Platform lower crust	0.2	2.0	2950–2980
7	Carpathian and Pannonian lower crust	0.2	2.0	2930
8	Carpathian and Pannonian mantle lithosphere	0.05	3.40	3200
9	European mantle lithosphere	0.05	3.40	3200
10	mantle lithosphere anomalous body	0.05	3.40	3210
11	main suture zone	0.1	2.50	3000

[a]No., reference number in Figure 3; HP, heat production ($\mu W/m^3$); TC, thermal conductivity (W/(m K)); ρ_0, density at room temperature (kg/m^3).

In 2013 in his PhD thesis Grinc focused on the application of integrated modelling of the lithosphere in the Carpathian - Pannonian Basin region to study and clarify the tectonic evolution and lithospheric structure. He used joint interpretation of 4 geophysical data sets at the same time: potential field data (gravity–Bouguer or free air–and geoid), topography and corrected heat flow data, and corroborated them with the results of the seismic interpretation and borehole data. One of the profiles that resulted from this analysis showed the heat flow value for Bihor Mountains higher than 70 mWm^{-2} (Figure 39).

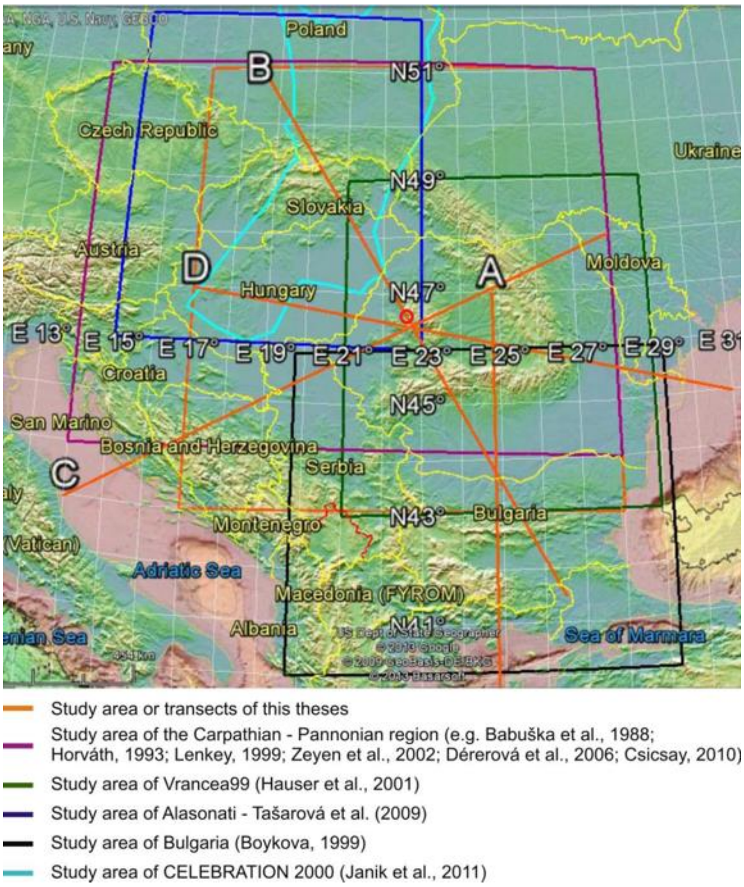
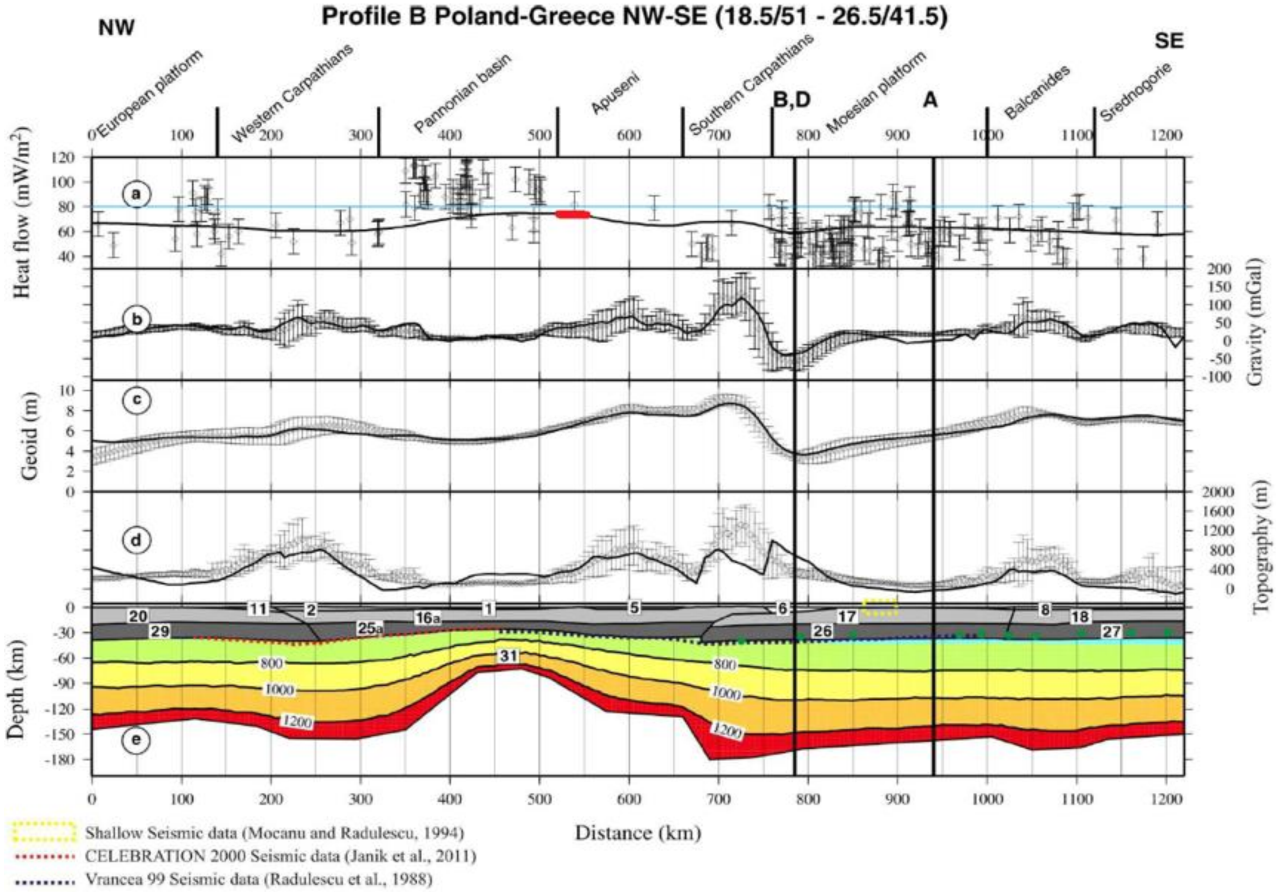


Figure 39 - 1) Topographic map of central Europe and Balkan shows the geographical location of the previous and current geophysical investigations. Position of the Transect B-B' is indicated. Reproduced from Grinc, 2013.

2) Lithospheric model for transect B. (a) Surface heat flow density, (b) free-air gravity anomaly, (c) geoid, (d) topography with dots corresponding to measured data with uncertainty bars and solid lines to calculated values; (e) lithospheric structure; In the lithospheric mantle, isotherms are drawn every 200°C. Numbers in the figure title indicate the starting and endpoint coordinates of the transects. The black dashed lines correspond to the results of a model with flat lower-upper-crustal limit and Moho underneath the Moesian Platform. Dotted lines and dots show positions of interfaces obtained from different seismic experiments. Black fat capital letters denote crossing points with the other interpreted transects. Reproduced from Grinc, 2013. Heat Flow of Bihor Mountains is indicated with a red line



6. Hydrogeology and ground district heating system

The geothermal aquifer from Beiuș and Ștei is hosted in fractured Triassic dolomites that have a regional extension. These Triassic rocks are intercepted at different depth, the blocks being separated by fractures. There is a hydrodynamic link between the blocks, which is confirmed by dynamic level stabilisation in a relatively short time after the beginning of drilling or groundwater pumping (Figure 40).

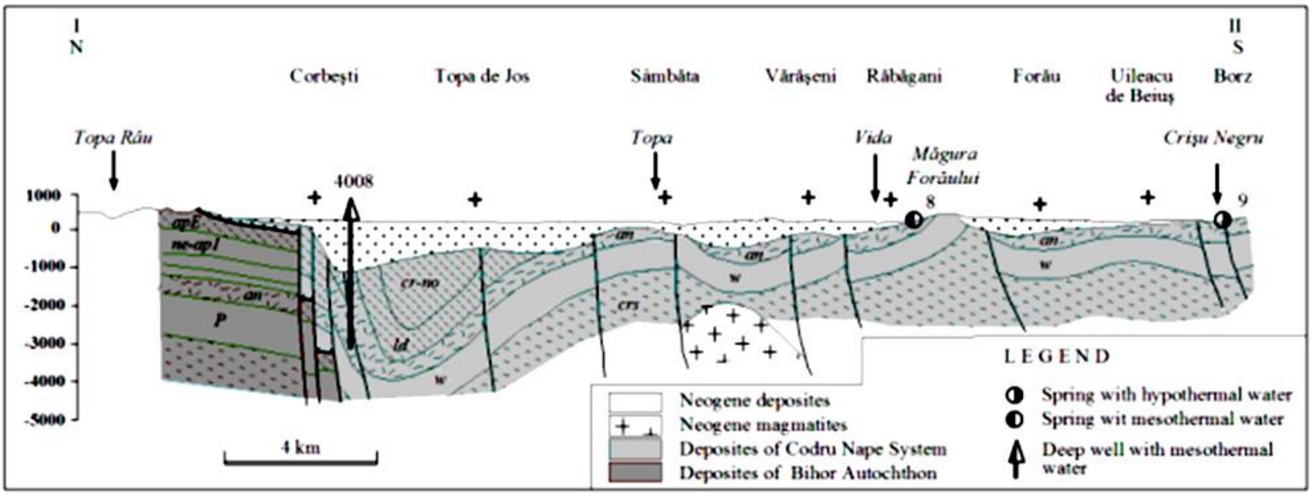


Figure 40 Beiuș Basin transverse ladinian – anisian deposits host the geothermal aquifer - reproduced after Orășenu, 2015.

The 3 wells, 3001 H Beius (TVD 2576 m), 3003 H Beius and 3002 H Ştei (TVD 2790m) that intercepted the Triassic collector encountered two types of faults reversed (Mesozoic) and normal gravitational (Neozoic). Reversed faults were generated during over thrusting processes, while normal faults were formed at the same time with the deepening of the Beiuș Basin. Between 3001 H and 3003 H drillings there is at least one normal faults going down towards SE, in a NE-SW direction with amplitude of approximately 360 m (Figure 41).

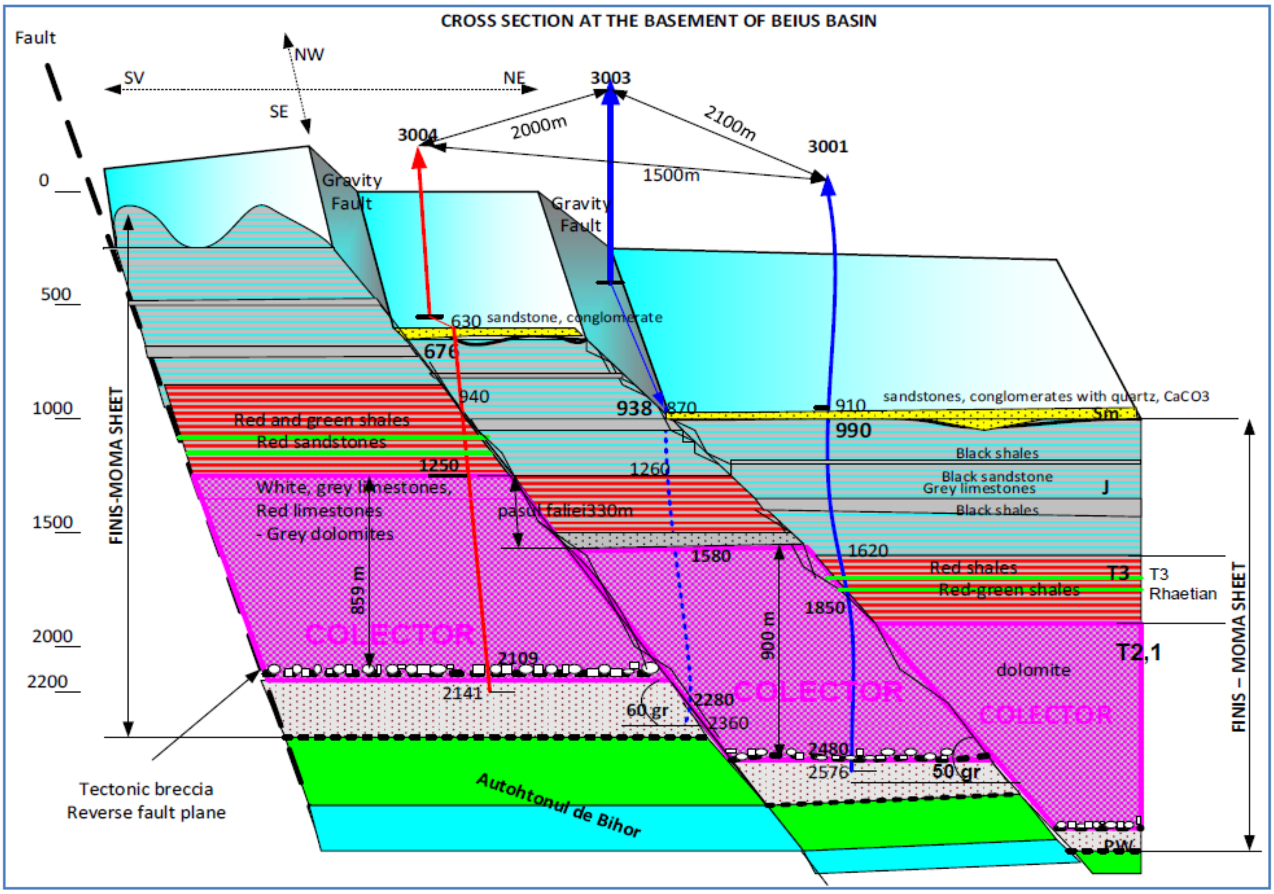


Figure 41 A SW-NE cross-section through the part of the Beius basin lying directly below the town of Beius, showing the location and trajectories of wells F-3001, F-3003 and F-3004 (Transgex, 2015)

Reversed faults system usually follows the W-E direction, while normal gravitational faults system with influence over the reversed ones has both NW-SE (basin frame) and W-E (central area of the basin) directions. The two types of fractures as well as the accompanying fissures represent the main water flow channels.

Triassic aquifer from Beiuș Basin is a confined aquifer with negative piezometric levels (- 18.48 m 3001 H Beiuş and unstable – 45m 3003 H Beiuş) or artesian (3002 H Ştei), depending on the position of the tectonic block.

The map of piezometric contours of the Triassic thermal aquifer of Beiuş Basin basement was elaborated by Oraseanu, (2015) on the basis of the thermal emergence elevations from the basin border and central part and of the water level elevations measured in the wells from Corbeşti, Beiuş and Ştei after drilling operations.
The general flowing direction is from south – west to north - east, from Bihor Mountains to Beiuș city (Figure 42).

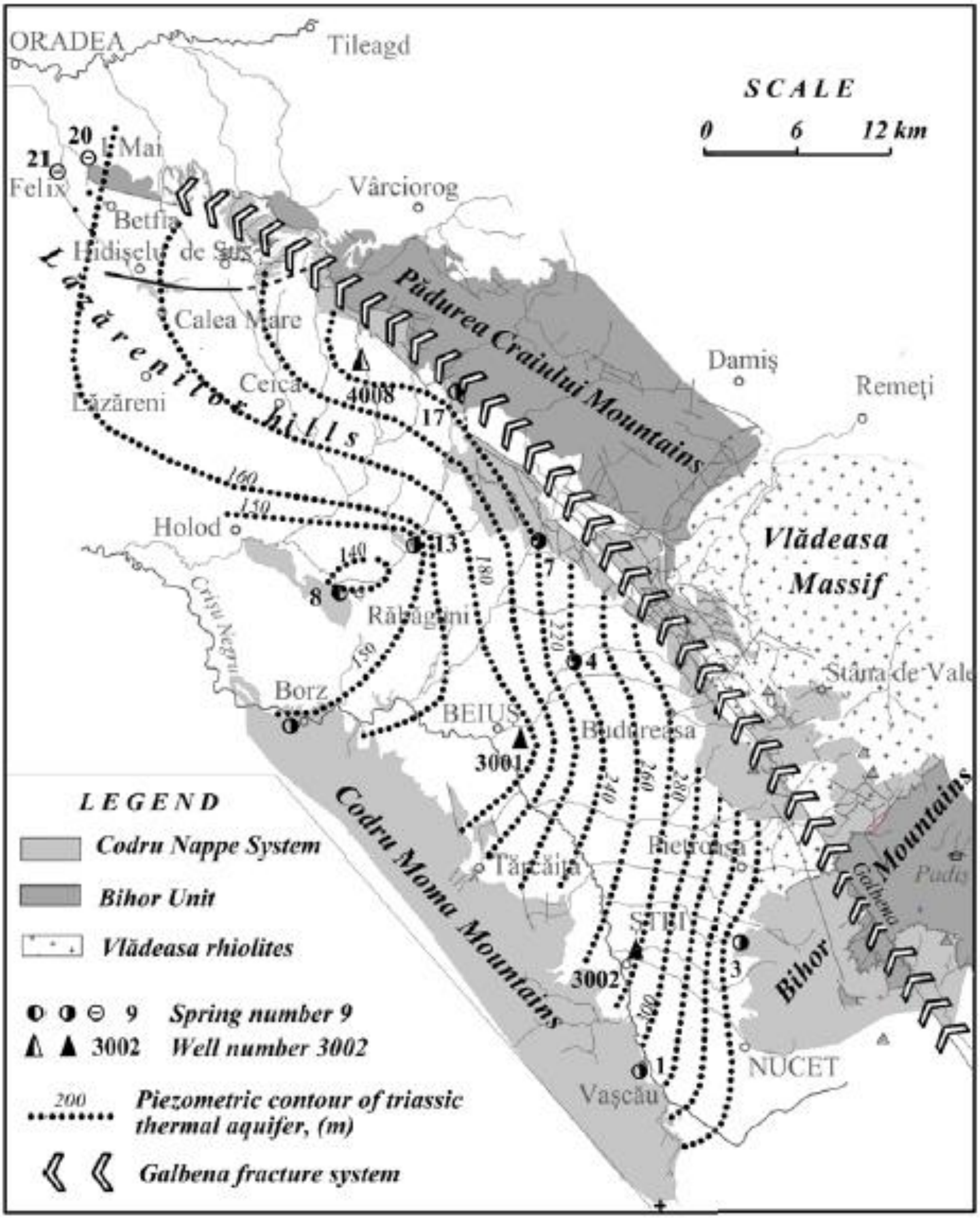


Figure 42 Piezometric contour of the Triassic aquifer in the Beiuş Basin basement. Reproduced after Oreseanu, 2015.

The calculation of hydro-geologic parameters has been carried out by processing the data in efficacy and performance tests, as well as by base measurements.

Hydro-geologic parameters for 3001 H well	Hydro-geologic parameters for 3003 H well
- TVD 2576 m - Stabilised hydrostatic level NH = - 18.48m - Transmissivity T=132.46 mc/m/day - Hydraulic conductivity K=0.64m/day - Average static pressure per resource Ps=196.73at - Flow capacity kh=47 Darcy/m. - Drilling hydrodynamic efficiency 3001 H E=77.5%. - Base temperature measured at 2460 m depth is 88°C, while temperature at well head is 84°C.	- TVD 2500 m - Unstable hydrostatic level NH = - 45m - Flow rate obtained Q = 7 l/s - Unstable dynamic level Nd = - 27m - Unstable temperature T = 600C - Clear water PH = 7 - The water type is bicarbonate-sulpho-sodium of low mineralisation with no significant sediments.

In the 3001 H Beius drilling equipped with a high capacity long axis pump (Qmax=50 l/s). The parameters show a good potential of the Triassic aquifer.
In the 3003 H drilling, pumping has been made with a low capacity submersible electric pump (Qmax=10l/s). Up to this flow rate, there is an increase of the dynamic level due to the thermolift generated by increasing temperature. The phenomenon persists until reaching maximum temperature at exploitation head (approximately 80°C) obtained with flow rates exceeding 15 l/s.

The pumped geothermal water has been analysed in authorised laboratories – Institute of Physical Medicine and Balneoclimatology Bucharest, A.P.M. Oradea, Radiation Hygiene Laboratory Oradea – from the point of view of both chemical reactions and radioactivity.

Physical characterisation:	Chemical characterisation:
- Base temperature 83°- 88°C - Specific weight 970 – 972 Kgf/m3 - Clear aspect	- Water type bicarbonate-sulpho-sodium - Low mineralisation 0.4-0.9 g/l - Total hardness 12 - 13G - Bicarbonate 250 - 300 mg/l - PH = 7

The springs water of the Mesozoic carbonate deposits is of the Ca(Mg)-HCO3 type, and the water of springs and wells drilled in the Neogene deposits is Na-HCO3 type. Most of the waters from thermal sources of the basin range between these two types, indicating a mixed genesis. The warmer waters, which are in contact with the batholith, and come from the depth, are mixed with colder waters coming from precipitation that pass through the karst Triassic deposits. The waters coming from the surface represent a cooling agent for the aquifer. Also, the presence of radioactivity may be explained by contamination in contact with Banatitic and Neogene magmatic rocks in the area.

6.1 Fresh water supply from the surface

According to Orășeanu, the rainfall across Bihor Mountains area has an uneven distribution. Multiannual average values display an increase of the annual amounts from the Beiuș basin (Budureasa - 941.3 mm, Pietroasa - 948.6 mm, Băița - 884.2 mm) eastward, up to the Stâna de Vale - Piatra Graitoare ridge area (Stâna de Vale - 1608.5 mm).
The fresh supply will be assured by Crișu Negru River and its tributaries, as Table 8 indicates.

Table 8 Morphometric and hydrometric data for main rivers

No.	River	Gauging station		F km²	H m	Q m³/s	q l/s/km²	Bf	ME, days	RT, days	TF
1	2	3	4	5	6	7	8	9	10	11	12
1	Someşu Cald	Beliş	1950-1967	320	1247	6.22	19.4	0.24	48	37.1	0.196
2	Someşu Cald	Smida		110	1293	2.35	21.4	0.25			
3	Beliş	Beliş		119	1249	2.32	19.5	0.27	47	34.2	0.208
4	Beliş	Poiana Horea		83	1259	1.69	20.4	0.28			
5	Drăgan	P. Crucii am.		119	1228	3.74	31.4	0.25			
6	Sebişel	P. Crucii		39.4	1172	1.19	30.2	0.25	123	81	0.092
7	Iad	Leşu		101	979	2.83	28.0	0.20			
8	Iad	Stâna de Vale		27	1210	1.10	40.9	0.25	24	24.7	0.192
9	Crişu Pietros	Pietroasa		123	956	4.15	33.7	0.21	15	21.4	0.208
10	Crişu Băiţa	Băiţa		36	892	0.86	23.9	0.19			
11	Arieş	Scărişoara		200	1099	5.45	27.25	0.27	35	29.8	0.232
12	Crişu Pietros	Pietroasa	X.1984-IX.1985			4.28	34.8	0.30			
13	Crişu Băiţa	Băiţa				0.80	22.2	0.27			
14	Sighiştel	Sighiştel				0.46		0.26			
15	Crăiasa	Giuleşti upstream				0.41		0.18			
16	Galbena	Intre Ape				1.92		0.29			
17	Bulz	Canton silvic				0.92		0.25			
18	Arieş	Scărişoara				5.34	26.7	0.28			
19	Beliş	Poiana Horea				1.83	22.0	0.30			
20	Someşu Cald	Smida				3.34	30.4	0.28			

F - surface of hydrographic basin (h.b.); H - mean altitude of h.b.; Q - mean multiannual discharge;
q - mean multiannual specific discharge; Bf - base flow index; EM - memory effect. TR - Regulation time;
FT - truncation frequency (EM, TR and FT computed for 1971-1975 period).
Note: Data in columns 5-9 after "Râurile României". 1950-1967 time period

6.2 Salinity of expected geothermal brine

The type of the geothermal water is bicarbonate-sulpho-sodium, with low mineralisation 0.4-0.9 g/l. Total hardness is 12 - 13G, bicarbonate is between 250 - 300 mg/l, and pH=7. It is expected that the salinity of the brine that will circulate inside the CHPM system to have much higher values.

*

In 2017, from 3 extraction wells from Beiuș geothermal aquifer water samples were collected. A spring and the water coming from a mine were sampled too. The residuum which precipitated after evaporation was studied by scanning electron microscopy (SEM-EDAX), FTIR and X-ray powder diffraction. This study led to the following conclusions:

The mineralogy of geothermal samples is characterized by the presence of aragonite, brucite, dolomite, clay minerals and probably amorphous hydrated silica. This conclusion is based on:

- the broad hump registered between 15 and 20° 2 theta on the XRD patterns,
- the characters and intensities of the bands centered around 3350 and 1630 cm^{-1} in the FTIR spectra.

The SEM analysis of the dried samples shows the presence of needle-shaped crystals of bassanite with parallel accretion of trigonal crystals of aragonite or brucite. Hydroboracite, nitrocalcite, epsomite and halite were also identified. Fig. 28 shows the images of minerals resulted from geothermal brine precipitate and Figure 43 shows SEM images and the chemical composition of a sample of geothermal brine precipitate from 3001 well from Beiuș. A considerable enrichment of magnesium minerals was highlighted in the geothermal water as compared with spring and water coming from mine. Thus, the magnesium content is less than 5% in surface, and at least 13% in the geothermal waters (Table 9**).**

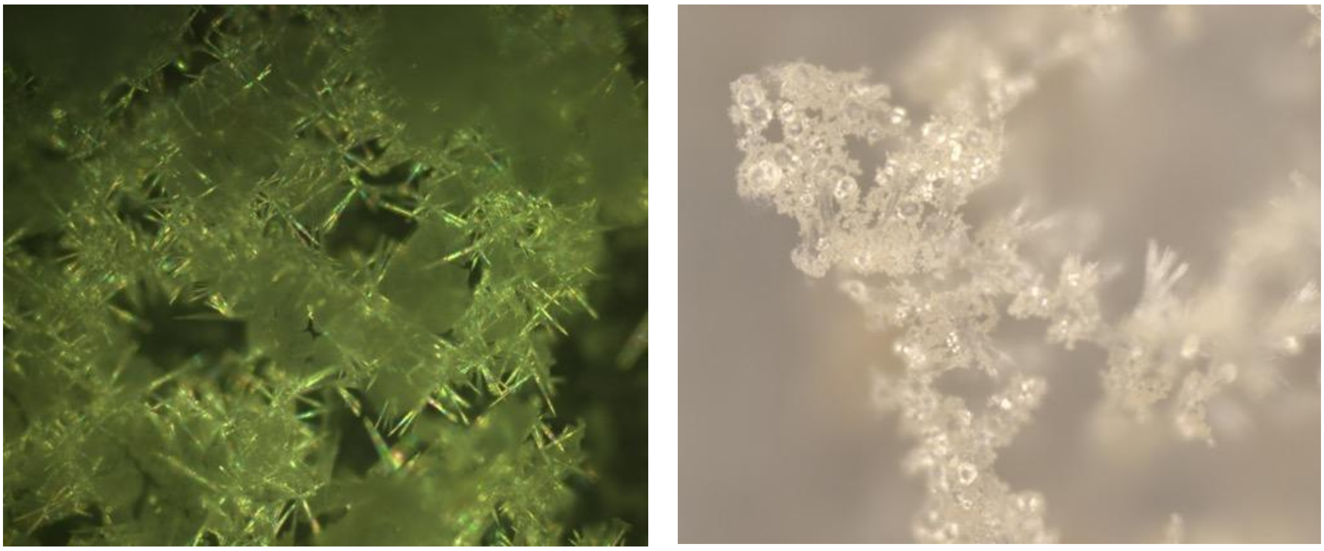


Figure 43 Images of the minerals precipitated from the geothermal brine – optical microscope

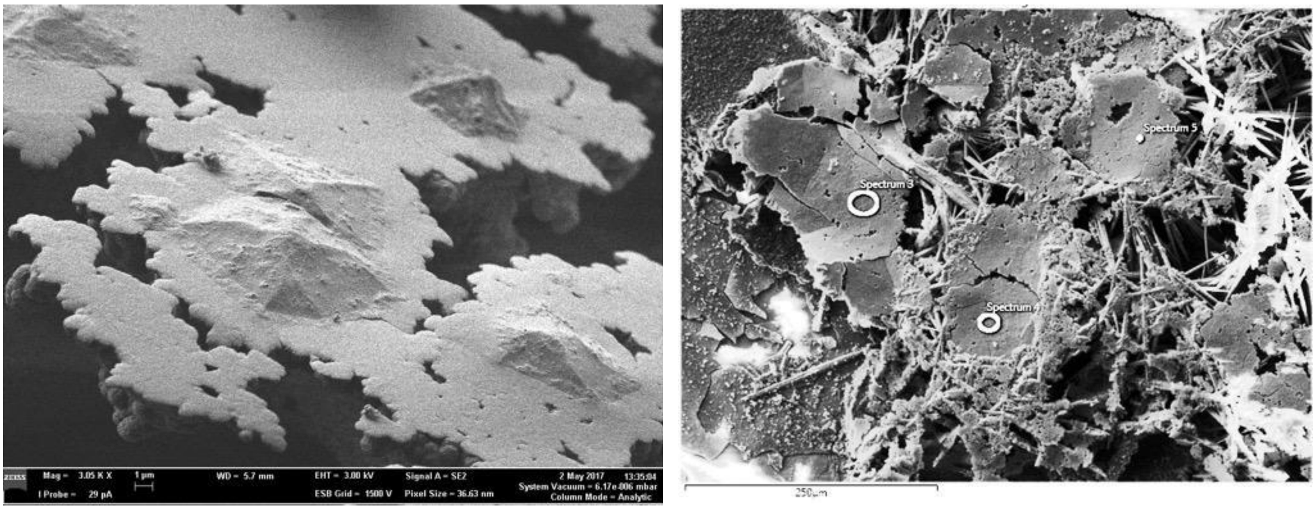


Figure 44 SEM images 1 and 2 of the precipitate of the geothermal brines of Beiuș

Table 9 Elements content for 3 analysed points of image 2

Result Type	Weight %		
Spectrum Label	Spectrum 3	Spectrum 4	Spectrum 5
O	46.63	47.94	48.85
Mg	22.45	22.05	22.16
Si	30.93	29.41	28.45
Ca		0.59	0.53
Total	100.00	100.00	100.00

In 2018, using GDEx technology, Xochitl Dominguez et al., also as part of the CHPM2030 projects's laboratory experiments, completed experiments for the recover of metals from the geothermal brine provided by a Beiuș Basin well. The results are showed in the Figures 45 - 48. According to this study, that compared the results for Beiuș with the international ones, the results are promising. Especially the content of Sr in one of the brine samples and the content of Sr recovered are remarkable.

Real brine	Energy used (kWh m^{-3})	Energy used (kWh kg^{-1} metal rem.)	Current efficiency (%)
Sample 1	10.26	0.04	44.48
Sample 2	16.86	0.05	52.06

Figure 45 Energy balance during experiments using GDEx for the treatment of real geothermal brines (i.e., sample 1 and sample 2) from Romania.

Parameter	Units	Sample 1		Sample 2		Parameter	Units	Sample 1		Sample 2	
		Total	Filtered	Total	Filtered			Total	Filtered	Total	Filtered
						Metals					
Ph		7.9		8.2		Sr	µm L^{-1}	12040	12040	760	760
Sulfate	mg L^{-1}	1100	1100	60	59	Fe	µm L^{-1}	2300	<10	33	<10
NO_2-N	mg N L^{-1}	<0.1	<0.1	<0.1	<0.1	Li	µm L^{-1}	129	129	33	33
NO_3-N	mg N L^{-1}	<2.5	<2.5	<2.5	<2.5	Al	µm L^{-1}	44	<10	<10	<10
Bromide	mg L^{-1}	<0.5	<0.5	<0.5	<0.5	Mn	µm L^{-1}	40	39	<1	<1
Fluoride	mg L^{-1}	1	1	0.52	0.52	Ba	µm L^{-1}	32	32	81	81
Chloride	mg L^{-1}	<5	<5	<5	<5	Rb	µm L^{-1}	16	16	14	14
Ca	µm L^{-1}	303000	303000	50900	50800	As	µm L^{-1}	9	3.8	5.7	5.7
K	µm L^{-1}	12800	12800	5790	5760	Cs	µm L^{-1}	2.5	2.5	2.3	2.3
Mg	µm L^{-1}	85600	85600	20500	20500	Zn	µm L^{-1}	1.5	1.5	62	62
Na	µm L^{-1}	29600	29600	12100	12100	Mo	µm L^{-1}	1.3	1.3	1	1
Sr	µm L^{-1}	12400	12400	727	727	Cu	µm L^{-1}	<1	<1	8	8
REE	µm L^{-1}	<1	<1	<1	<1	Os	µm L^{-1}	<10	<10	<10	<10
						Be	µm L^{-1}	<10	<10	<10	<10
						Ni	µm L^{-1}	<1	<1	13	12
						Pb	µm L^{-1}	<1	<1	1.3	<1

Figure 46 Chemical characterization from real geothermal brines from Romania

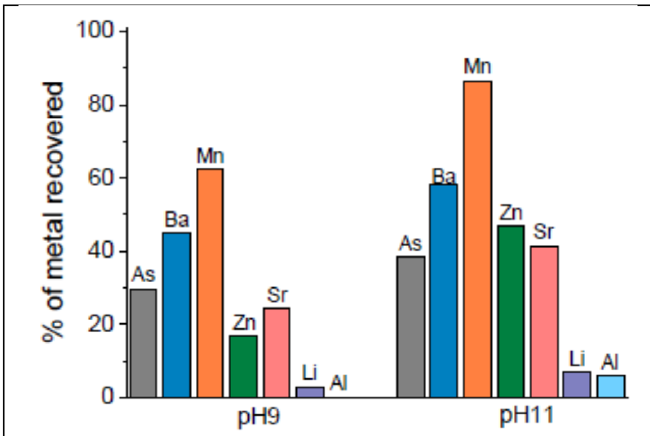


Figure 47 Percentage (%) of the initial metal recovered in the precipitated product from sample 1 at different pH values.

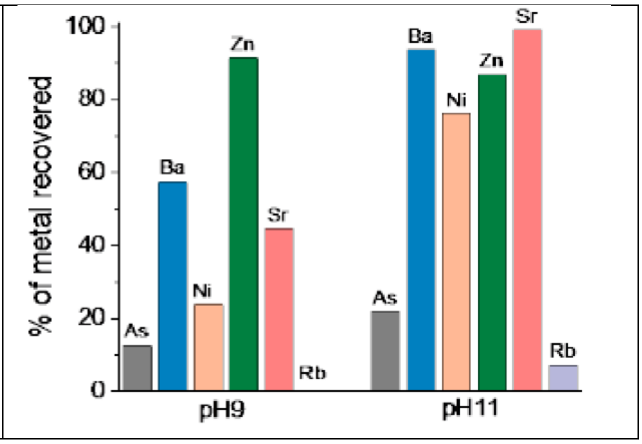


Figure 48 Percentage (%) of the initial metal recovered in the precipitated product from sample 2 at different pH values.

6.3 GDHS

It is very important to refer to the extensive presence in Bihor Mountains of Mesozoic carbonates series, and Palaeozoic limestones and dolomites, highly fractured and karstified, having a very high effective infiltration and porosity, that host the geothermal aquifer which has a regional extension and with intensive groundwater flow. Beiuș aquifer is an open geothermal system, where recharge equilibrates with the mass extraction and its reservoir pressure stabilizes. Its recharge can be both hot deep recharge and colder shallow recharge. The latter can eventually cause reservoir temperature to decline and production wells to cool down. In fact, this second alternative was demonstrated when the increase of the volume of injected water was accompanied by the decrease of the water temperature within aquifer. More research is needed to improve the knowledge on this subject.

The Beiuș city has an extensive geothermal district heating system (GDHS) that supplies heat to about 70 % of the population, covering around 60% of the city heating demand. The old system has been entirely replaced by GDHS.

The geothermal heat energy is delivered to the consumers either indirectly via substations with heat exchangers feeding double closed loop distribution pipe networks, one for Domestic Heating (DH) and the other for Hot Sanitary Water (HSW), or directly to the individual buildings with their own heat exchangers. The biggest individual closed loop distribution systems are old, remains from the time when the central part of the city was heated by three oil fired heat stations. Additionally, around 35 modern compact micro modular substations have been installed. The layout of the main district heating pipe system in the city is shown on street map in Figure 49. The exploitation license of Beiuș geothermal reservoir perimeter is owned by Transgex S.A.

Currently, according to Transgex S.A the geothermal energy exploitation system consists of:

- 2 geothermal water production wells drilled at 2576 m and 2700 m respectively, with a production capacity of 450 m^3 / h;
- 1 re-injection drilling depth of over 2,000 m;
- 18 km from geothermal water transport network in the city;
- 120 block stairs connected to the centralized distribution of heat;
- Public institutions are heated with geothermal energy (colleges, schools, kindergartens, municipal hospital, culture house, pharmacies, medical offices and laboratories, churches and places of worship, gymnasiums);
- undertakings with more than 1000 employees;
- 200 individual homes with their own thermal units connected to the transmission geothermal water.

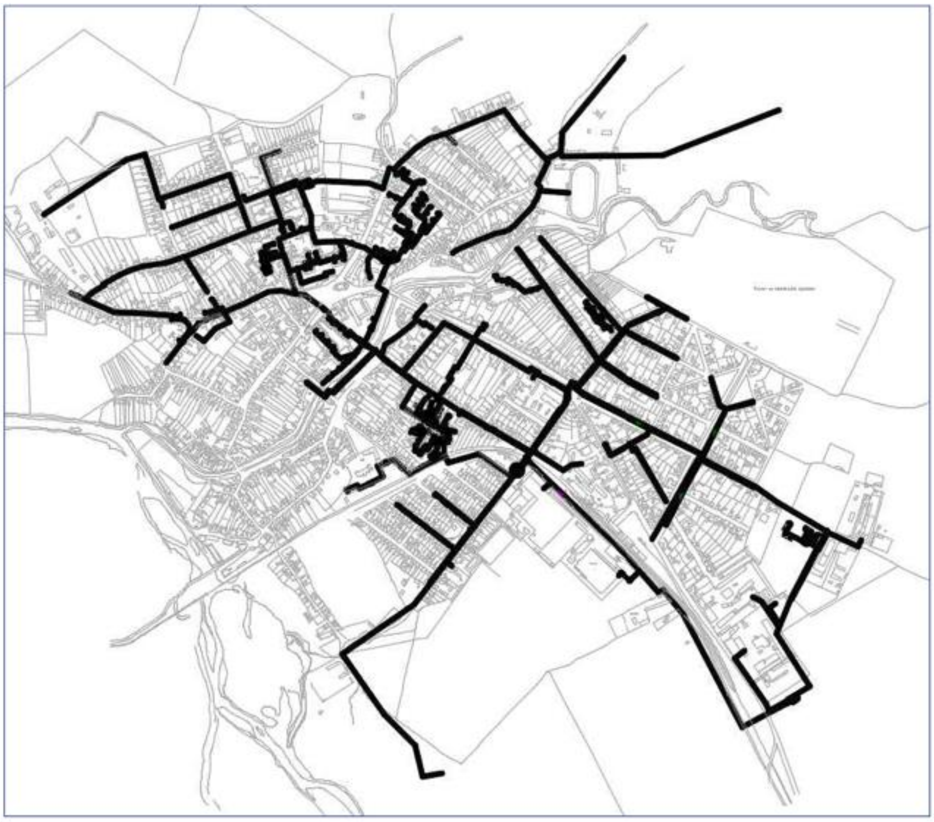


Figure 49 Map of the GDHS pipeline of Beiuș; reproduced after Orkustofnun, 2017

In 2017 Orkustofnun published a pre-feasibility study that, besides a description of the existing situation, contains the financial analysis for the necessary investments that can lead to the optimal use of energy for the whole city and for the surrounding areas.

The supply of geothermal heat to the GeoDH system in 2016, measured at the end users, is summarized in Table 10:

Table 10 Operational parameters of the GeoDH system in 2016

Year	Production well	Energy delivered 2016		Volume delivered	2016 production/ well	2016 production/ well	2016 average / well
Beius Geothermal		[GJ/year]	[m3/year] calculated	[m3/year]	[m3]	[GJ/year]	[l/s]
2016	3001	49 591	305 144	338 038	643 182	104 529	20,4
	3003	24 861	202 713	193 084	395 797	48 541	12,6
TOTAL		74 452	507 857	531 122	1 038 979	153 070	32,9

Solutions for extend the GDHS have been proposed within the pre-feasibility study. According to this study estimated annual heat consumption in Beius is 246 TJ/year which corresponds to annual burning of wood around 25,600 [m3/year], emitting 27,000 [t CO2/year]. Also, with current market prices for wood for heating and GeoDH state regulated heating tariffs the citizens of Beius enjoy between 30% - 50% reduction in annual heating cost, when connected to the GDH system.

In Beiuș the production of geothermal water increased (Figure 50), partially due to the utilization of the reinjection well (F-3004), that has only been utilized at the nominal flow-rate of 1 – 3 l/s.

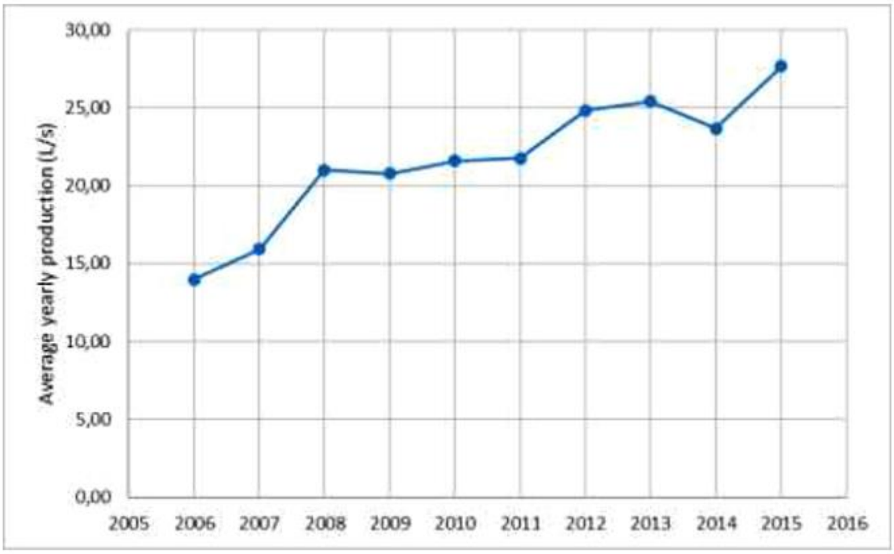


Figure 50 Production of geothermal water in Beiuș

7. Integrated 3D Model

The main reason for creating a 3D model is to integrate all available geo-data (geological, structural, and geophysical) for Beiuș Basin and its adjacent area. The 3D model is meant to illustrate the main features that are important in order to decide to what extent the chosen perimeter is proper for a CHPM system installation. The model focuses on the geometry of the middle and upper Triassic sedimentary deposits within Beiuș Basin and their contact with an Upper Cretaceous – Paleogene intrusive body where contact aureoles have been formed.

The 3D geological model of both the batholith and Triassic deposits was built using Paradigm™ GOCAD® 17 in order to observe their spatial distribution and to know if the requirements of the CHPM system are met (existence of heat and mineralisation in the same place).

7.1. Input dataset

- Creating the 3D geological database and building the three-dimensional model requires the integration, digitalisation, organisation and visualisation of all types of input data available such as geological maps and cross-sections, lithological columns, geophysical maps, wells, etc. The existing national datasets that are used in creating the 3D model are:
- Geological map, Brad and Șimleul Silvanei sheets, scale 1:200 000 with theirs cross sections, 1967, Giușcă et Bleahu
- Geological map, Pietroasa sheet, scale 1:50 000 and its cross sections, 1985, Bleahu et al.,
- lithological columns of 1 injection and 2 geothermal water extraction wells from Beiuș up to 2500 m depth
- Geological cross sections A1, A2, B6, scale 1:200 000, elaborated by M. Ștefănescu et al
- Structural map at the contact between the pre-Neogene and Neogene deposits of Beiuș Basin, accompanied by the isobaths map of the basis of Neogene deposits, and with isopach map of Neogene deposits, 1991, Dinu et al,.
- Geological sketch map of the distribution of the depth banatitic structure of Romania deduced from aeromagnetic and gravity data.

7.2. Methodology

The key input information for building the 3D model was the geological and geophysical maps and sections. The first step, before the modelling itself, was georeferencing the geological, geophysical and structural maps in ArcMap 10.3 using the Dealul Piscului 1970/ Stereo 70 coordinate system. Dealul Piscului 1970/ Stereo 70 is suitable for use in Romania – onshore and offshore and uses the Dealul Piscului 1970 geographic 2D CRS as its base CRS and the Stereo 70 (Oblique Stereographic) as its projection. The next step was to create the project in GOCAD defining the coordinate system and the bounding box of the study area. After that, the georeferenced maps were imported in GOCAD

After importing the georeferenced maps in GOCAD, a digital elevation model was created using ASTER Global Digital Elevation Model from USGS database (https://earthexplorer.usgs.gov/). The ASTER GDEM has been downloaded as tiff file and converted to the Dealul Piscului 1970/ Stereo 70 coordinate system using ArcMap and after that, the dataset containing the elevation has been imported in GOCAD.

Before importing the geological cross-sections, they have been rectified in a photo editing software in order to fit them to the coordinate system. The sections were imported and placed in GOCAD according to geological maps and digital elevation model.

The modelling started with digitalization of the tops of middle and upper Triassic sedimentary deposits within Beiuș Basin and their contact with the intrusive body, the faults and the intrusive body itself reported on the vertical cross-sections. Also, the outcropping middle and upper Triassic deposits, the upper Cretaceous – Paleogene intrusive body and the faults were digitalised on the geological maps and projected on digital elevation model.

The next step was the creation of fault planes using the Fault Construction Wizard application from GOCAD. The modelling of the layer horizons started with the digitalization of the layer boundaries on the geological cross sections. The creation of the horizon surfaces has been done with the Faulted Horizon Construction Wizard from GOCAD.

Building the intrusive body started with the digitalization of the intrusion boundary on the geological cross-sections and geological maps. The depth extension of the intrusive body was delineated from the map of banatitic structures from Romania as inferred from aeromagnetic and gravity structures, elaborated by Andrei et at., (1989) and from Earth Magnetic Anomaly Grid (https://www.ngdc.noaa.gov/geomag/emag2.html) compiled from satellite, ship, and aiborne magnetic measurements. Beside those data, for modelling the batholith, we used the maps 1:25 000, contained in *'Report on geological, geochemical, magnetometric and electrometric prospection works in Budureasa - Bihor Mountains'*, authors: Manea el al, 1973.

The presence of the intrusive body within Beiuș Basin was identified based on aeromagnetic, surface magnetic, gravimetric and seismic (refraction methods) data by Dinu et al., 1991. The creation of the intrusive body started with the digitalisation of the magnetic anomaly from the map. Then, the data was extrapolated in depth and correlated with the longitudinal cross sections from the map of vertical gradient of magnetic anomaly (Tz) from the Beiuș Basin.

7.3. 3D modelling results

Integrating all the data available in a 3D geological database and creating the 3D geological model provided an overview on the spatial distribution and the geometry of the middle and upper Triassic sedimentary deposits within Beiuș Basin and their contact with the upper-Cretaceous intrusive body, from Bihor Mountains.

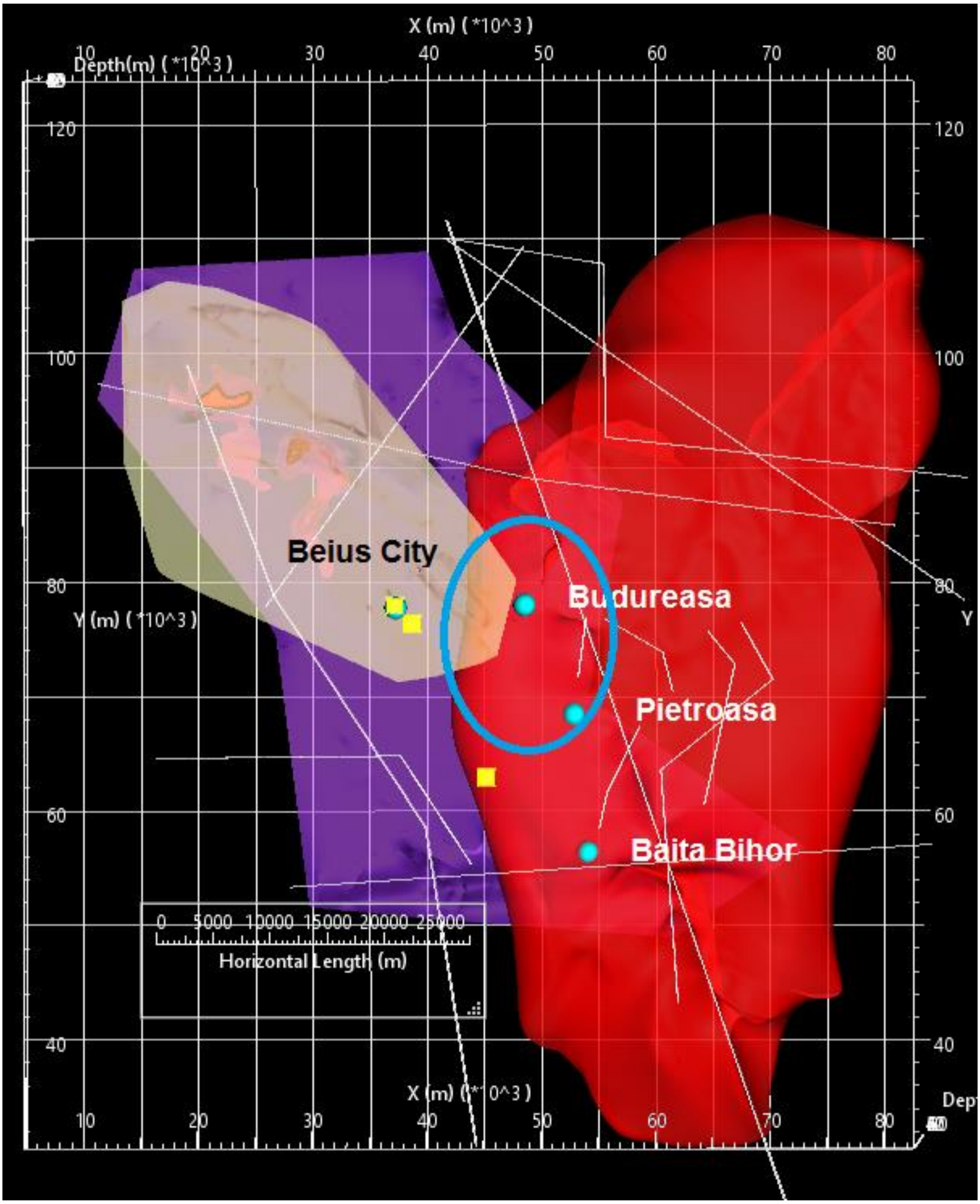


Figure 51 Spatial distribution of Batholith (red), Triassic deposits (violet) and Neogene deposits (beige); blue bullets are sites with mineralization, plus Beius city; yellow squares represent the geothermal wells from Beiuș and Ștei. The blue circle is the selected pilot site.

As can be seen in Figure 51, there is a region bordering Beiuș Basin where the batholith is extended: at Budureasa. The same is showed in Figure 52.

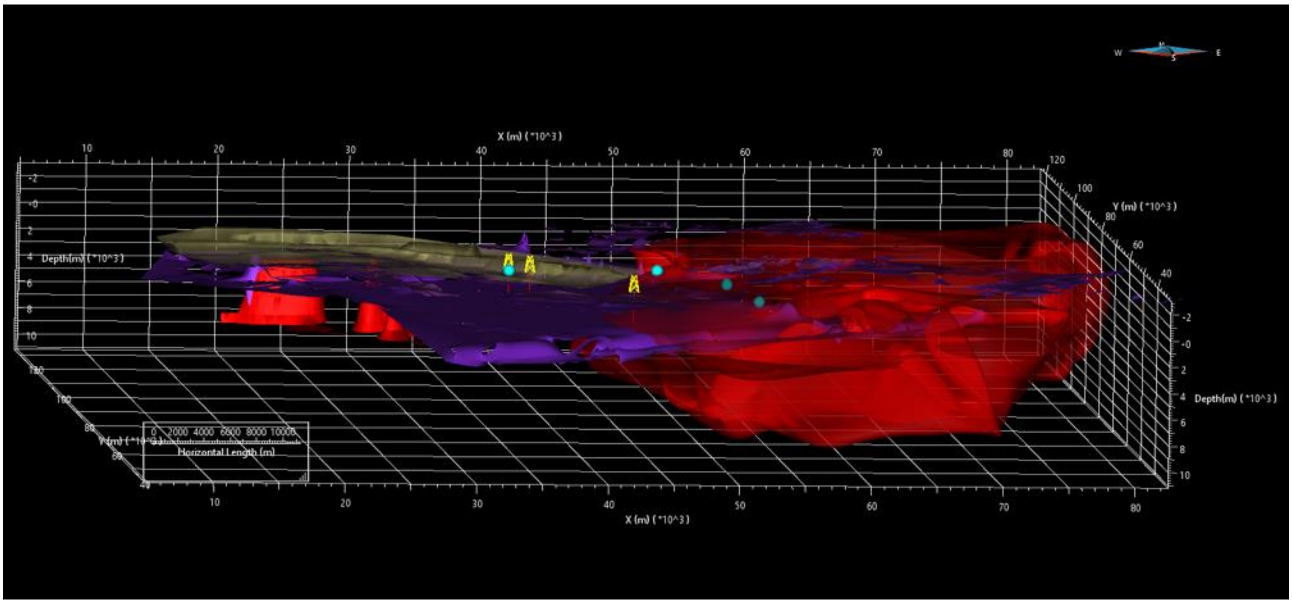


Figure 52 Areas where the batholith (red), Upper Triassic deposits (violet) and Neogene deposits (beige) interact; blue bullets are Pietroasa, Budureasa and Baita Bihor sites with mineralization, plus Beius city; yellow squares represent the geothermal wells from Beiuș and Ștei.

From the structural point of view, an increased possibility to have both mineralisation and high geothermal potential within a small area exists at Budureasa.

Figures 52 and Figure 53 show the extension of Upper Triassic deposits, both in Beiuș Basin and in Bihor Mountains, linking the two structural units, generating magnesian skarns on one side and transporting geothermal water on the other. This dual role in the perimeter explains an increased content of magnesium in geothermal waters from Beiuș Basin.

Figure 53 emphasizes the large areas on which Triassic deposits outcrop. Being represented by highly fissured karst deposits they, on one side, assure a continuous recharge of the geothermal aquifer, but, on the other side, they have an important contribution to the decrease of the geothermal potential of the rocks, being a cooling agent.

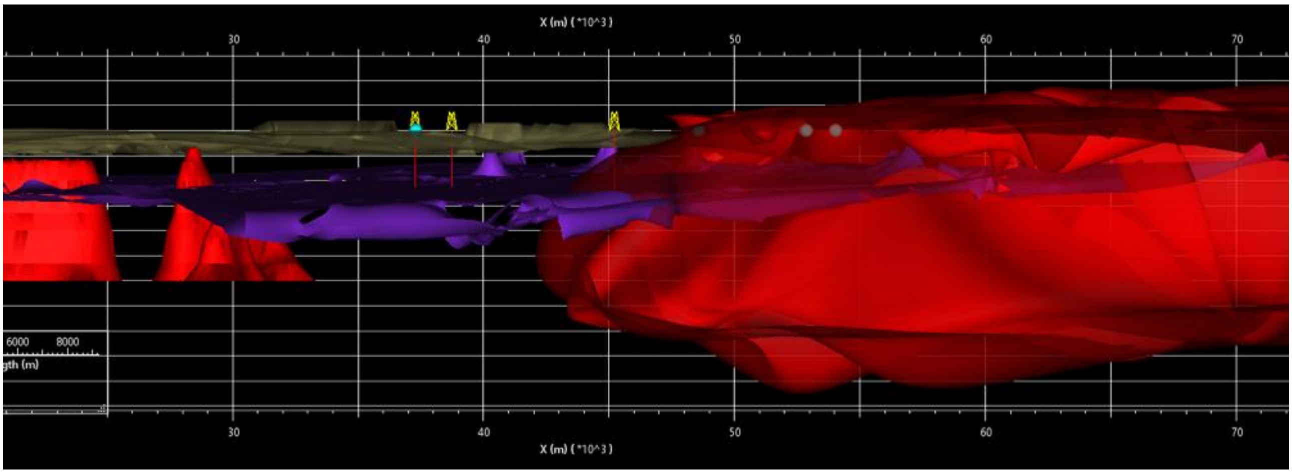


Figure 53 Existence of batholith's apophyses within Beiuș Basin. The legend is like in Figure 52.

The batholith’s apophyses that were detected by complex geophysical methods within Beiuș Basin, and can be taken into consideration for further investigations are shown in Figures 52 and 53.

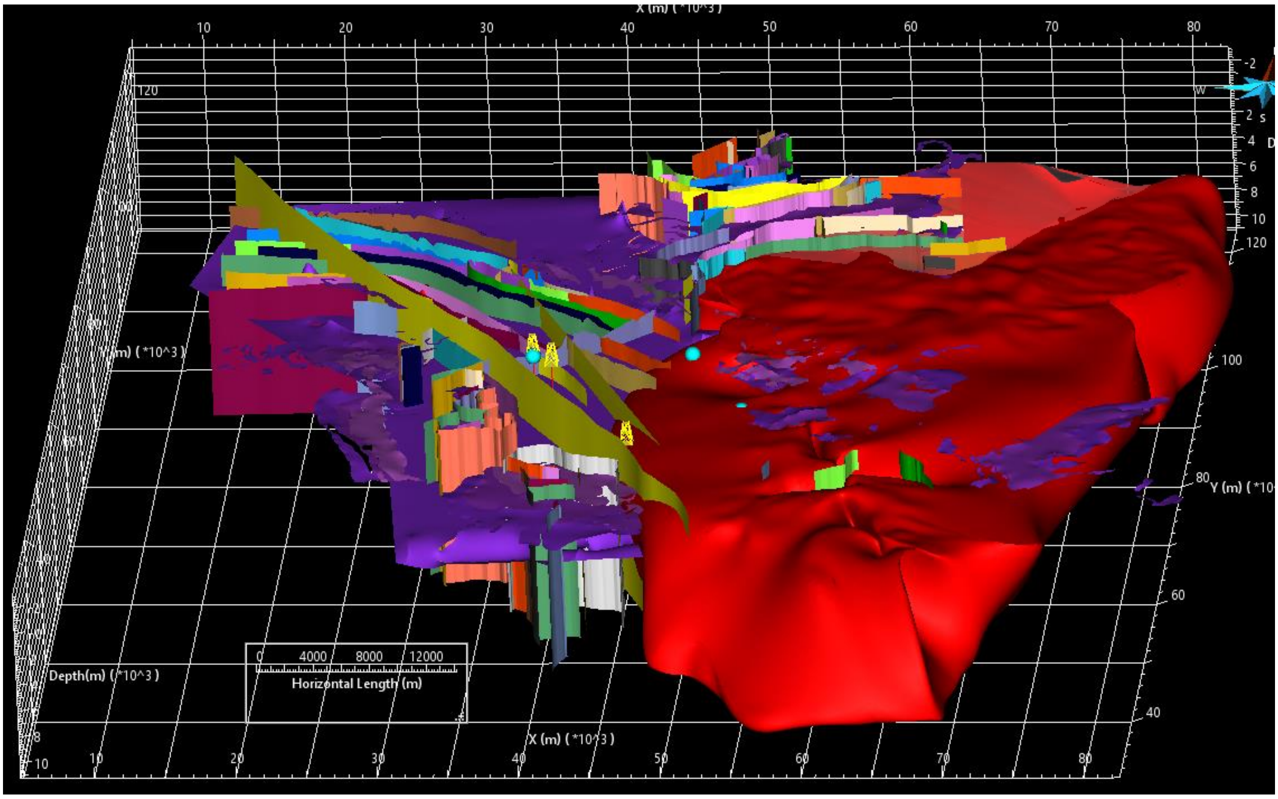


Figure 54 Main faults reported in the region; in red is the batholiths that outcrops in Bihor Mountains; in violet Upper Triassic layer is represented.

Many faults afferent to Beiuș Basin are inventoried and reported, and very few for Bihor Mountains, as Figure 54 shows.
These numerous faults are explainded by the extension processes of the entire Pannonian Basin during its Miocene evolution. Galbena strike slip fault is a deep structure fracture, which is reported in Bihor Mountains.

The 3D model helped us to visualize and understand the spatial relations at the border between the basin and the mountains and provides new data that are needed to set parameters for planning new exploration works.

At the same time the 3D model helps us to reduce the area of new planned investigations to a smaller area with an increased probability that fits conditions of a CHPM system.

8. Information for CHPM technological elements

The integration of all the available data afferent to Beiuș Basin – Bihor Mountains and performing the 3D modelling of the region led to the selection of a restricted area compared to the initial one proposed for the project, an area where further research need to be developed (Figure 55). It is estimated that this pilot site offers the possibility to find geothermal potential and metals in a single place.

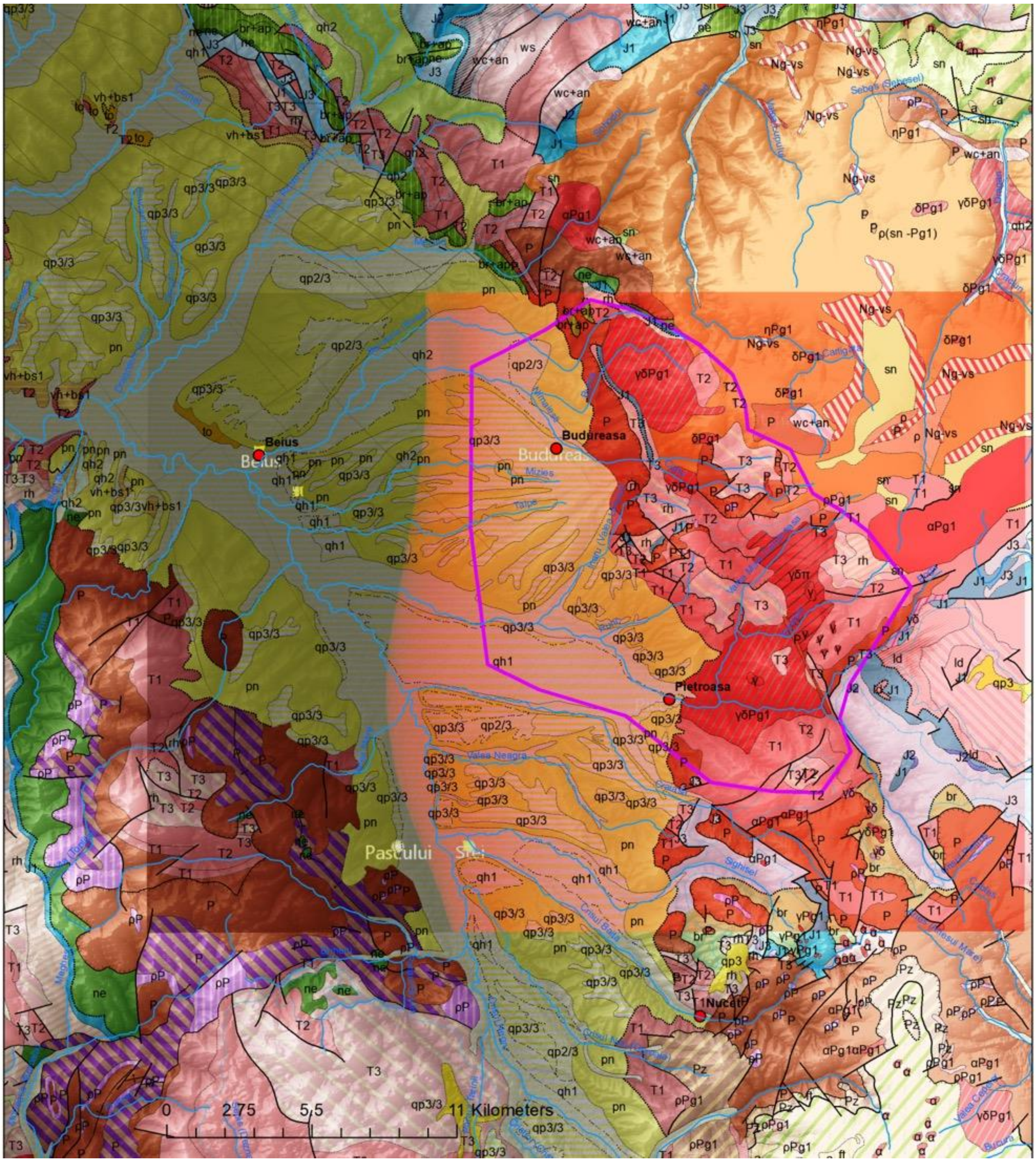


Figure 55 Initial perimeter and the pilot site contour (violet line)

One of the main findings of the project is that, although it was not intercepted by drillings, there is a great probability that the batholith, which outcrops in the mountains, to be intercepted in the Beiuș Basin, where the hydrothermal energy is already exploited.

The new CHPM technology determines us to look for additional sites, other than classical ones, from where it is possible to extract metals. In Romania's case the selected site is at the margin of a sedimentary basin, where in the depth a batholith it is possible to be intercepted, and where geothermal potential is higher. For this, magnetometric and gravimetric studies have been used that helped us to delineate the contour of the batholith at a distance of cca 8 km from the city of Beiuș (Figure 56).

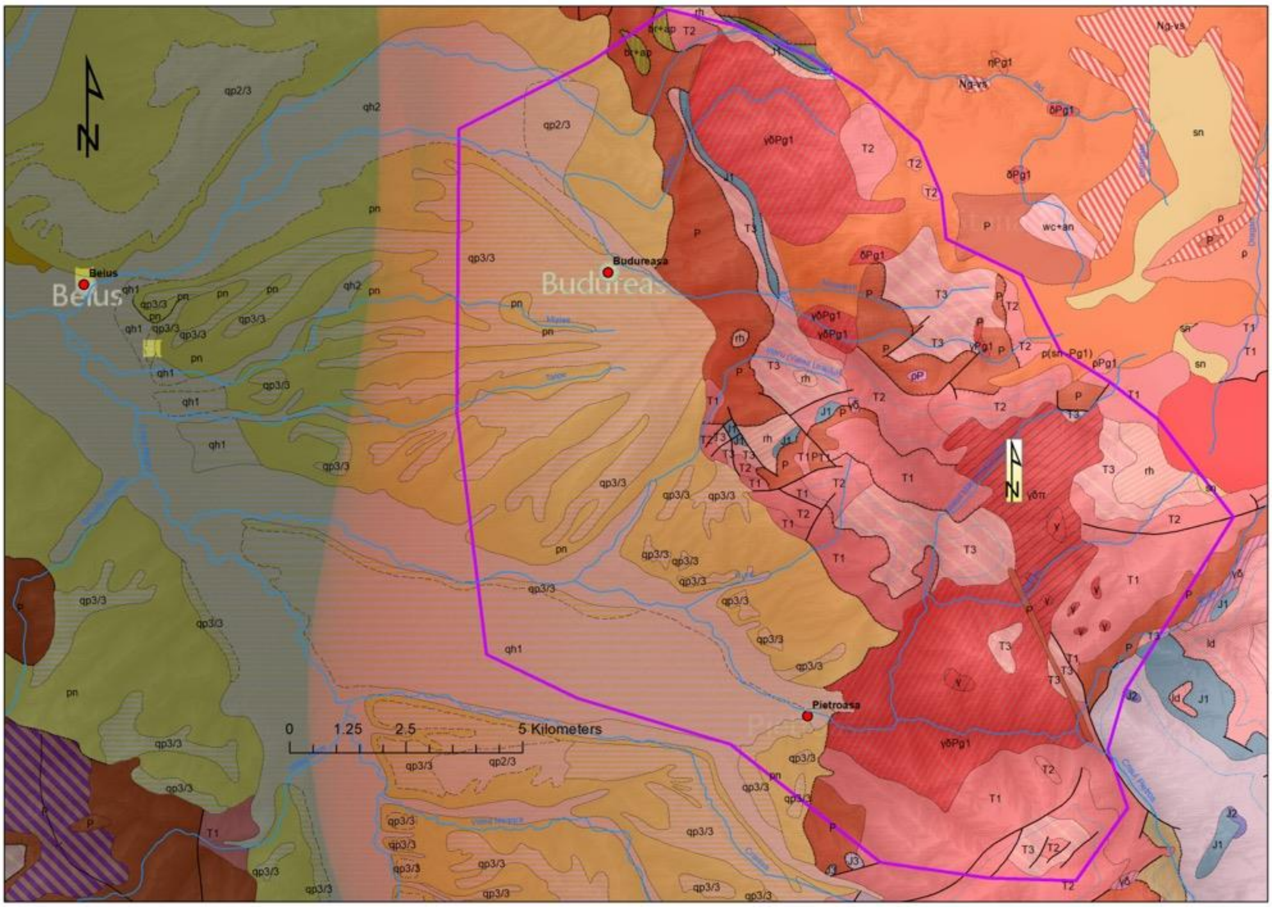


Figure 56 Contour of the batholith in Beiuș Basin. The shape of the batholith is modeled by the measurements synthesized by Proca (1979) and Andrei (1989).

In the situation that further research confirms these presumptions, a near-field EGS could be created, which by association with metal extraction would become profitable in the long run. The new pilot site, being situated near the perimeter for which Transgex S.A. has the geothermal water exploitation license, has a surface of almost 150 sqkm.

8.1 Underground heat exchanger (deep metal enrichment + potential reservoir)

Extension of the metal enrichment

At more than 4 km depth the contact between the granodiorite - granite extensional batholith with the Codru Nappe System (Finiș or Vălani Nappe) is probably to be encountered, or, even the contact of the batholiths with the Bihor Autochtonous Unit. In the first case, *Finiș-Gârda Nappe* is represented mainly by mezozoic rocks and has a metamorphic basement consisting of the Codru Granitoids and Migmatites, which are the oldest basic intrusions being pre-Hercynian, according to Dallmeyer et al. (1994). As specific lithostratigraphic features, the following are to be mentioned:

- large development of the Permian, with felsic ignimbritic volcanism;
- complete development of the Triassic sequence, with Carpathian Keuper and Kössen facies in the Late and latest Triassic;
- marine, marly-calcareous facies of the Lower Jurassic;
- development of a flysch-type sequence in the Tithonian-Neocomian;

In the second case *The Bihor Unit* is represented by a crystalline basement, and a sedimentary cover. The basement consists of the medium-grade Somes Series (micaschists, amphibolites, leptynites) and the retrogressive Arada Series (chlorite-sericite-albite schists, metarhyolites), both intruded by the Muntele Mare granitic massif. The ages of the metamorphism and of the intrusion are Paleozoic. The sedimentary sequence of the Bihor Unit includes, (besides very scarce Permian) Triassic, Jurassic and pre-Senonian Cretaceous formations. The following specific lithostratigraphic features must be underlined:

- development of a carbonatic platform series from the Upper Werfenian to the base of the Carnian;
- absence of the major part of the Upper Triassic;
- Gresten paralic facies of the Lower Jurassic;
- marine sequence of the Middle Jurassic and of the base of the Upper Jurassic;
- development of a carbonatic platform in the Kimmeridgian and the Tithonic;
- lag of sedimentation at the base of the Cretaceous, marked by bauxites;
- calcareous neritic lithofacies of the Barremian and Aptian, passing into a marly sedimentation which continues in the Turonian;

The post-tectonic cover formed of Senonian formations in Gosau facies masks the thrust contacts of the Codru Nappes, especially in Bihor Mts.

Expected type and porosity/permeability of the reservoir;

The reservoir that hosts the geothermal aquifer was intercepted up to 2700 m depth where there is the Werfenian impermeable layer forming the bed of the aquifer, and where the drilling of the wells stopped. The transmissivity for Middle and Upper Triassic deposits in the well 3001 is T=132.46 mc/m/day, and hydraulic conductivity is K=0.64m/day. There is no information on deeper layers from Beiuș Basin. No studies regarding the fissures systems have been found for this pilot site, they are to be included into the research plans for the future.

Type of mineralization and expected metals

The granodioritic – granite rocks of the batholith itself have a high content of elements such as: Sr, Ba, Rb, Cs (see Table 3). Also, the boron content is as follows:

Table 11 Boron content of the magmatic rocks in the Bihor Mountains

Rock type	Location	Boron (g/t)
Granodiorite	Valea Seacă	10
Granite	Băița Plai (foraj struct.)	20
Porphyry granite	Budureasa	30
Granite with orthoclase	Budureasa	10
Granodiorite with biotite	Pietroasa	20
Porphyry granite	Gârda	50
Diorite	Valea Seacă	10

Quantitatively, Alpine ores are the most important, and represent 80% of the Romanian national resource estimates (mined out/ and present resources/reserves). The main stages are connected with the Laramian (Banatitic) magmatic products especially skarn deposits and porphyry deposits (Vlad, Borcoș, 1997). In the pilot site metallogenesis in subduction – related setting is represented. Widespread westward subduction during the Upper Cretaceous – Paleocene gave rise to polyphase calc-alkaline magmatism (Laramian magmatism, known also as Banatitic). The major intrusive event in the region has a granodiorite – granite evolutionary trend, the magmatism of this granodiorite – granite type generally yielded base – metal ores in non-porphyry environment: skarn deposits predominate, whereas vein deposits are rare.

The inner zone corresponding to a northwestward direction of subduction exhibits a complex metallogenesis in Bihor – Gilău Mountains.

The area we envisage contains skarn deposits and prospects related to granodiorite – granite plutons.

- When wall rocks are mainly calcareous, Fe-Cu skarn deposits occur near the contact zones, and Pb – Zn skarn deposits occur far from the contact zone.
- When wall rocks are various sedimentary rock and coeval or older ingenous rocks, magnesian and calcic skarns with Mo, W, Bi, Cu, Pb, Zn and B mineralization are found near and away from the pluton.

The main types of deposits reported within the pilot site are: skarns, brucite deposits and borate deposits.

Table 12 Chemical composition of Skarns*

	Skarn calcic-magnesian	**Skarn magnesian**
SiO_2	23,72	40,82
TiO_2	0,03	0,01
Al_2O_3	1,36	0,31
Fe_2O_3	2,07	3,86
FeO	0,82	1,23
CaO	26,82	16,83
MgO	17,18	19,68
MnO	0,55	0,93
Na_2O	0,48	0,51
K_2O	0,21	0,30
P_2O_3	0,05	0,04
p.p.c.	26,31	15,98
Total	99,60	99,49

Analist: L. Stoici

According to Stoicovici et Soici, magnesian and also calcic – magnesian skarns from Triassic dolomites contain the following metallic elements: Zn – 0,26%; Ga – 0,0005%; Pb – 0,68%; In – 0,034%; Bi– 0,06%; Sn – 0,0005%; Cu – 0,83%; W – 0,001%; Mo – 0,001%.

8.2 Production and injection wells

Production and injection wells

The two production and one injection wells that are used in Beiuș Basin for the exploitation of the geothermal aquifer have been described in the chapter 6. A new information must be added as follows: in April 2019, SC Transgex SA announced the public about the Environmental Impact Assessment (EIA) revision in Beiuș determined by the project '**Increasing the production of geothermal water in Beiuş by drilling a production well and interconnecting it to the geothermal water transport network N. Cristescu street intersection St. Gen. L.Mociulski**' which is located in Beiuș city. Given the close cooperation with this company, we hope to get rock samples and other information belonging to this new well.

Depth of potential wells

Based on geophysics and geological cross – sections, there is the possibility to intercept the metal – bearing intrusive – body at a depth of cca 4 km. The main condition, this of having a temperature higher of 150 ^{0}C for the fluids extracted from this ore-body determines us to create a geothermal model specific to this area, before knowing which is the depth of the two (injection and extraction) wells. We hope that data obtained from the new well of Beiuș to help us with this model.

Conceptual drill and well design (based on the stress field and the area specifics)

Data obtained from the new well of Beiuș can provide valuable information for the new projected EGS system. Before drilling, research must be developed in many domains, including stress field. After the necessary preliminary data are obtained the construction of the wells follows 3 s**tages:** drilling and casing the wells, development of the wells and testing the wells.

Wells connection

Beiuş town, with 12,000 inhabitants, is one of the few cities from Europe that are heated entirely with geothermal water. There are two production wells at Beiuş which are equipped with Icelandic line shaft pumps and 1 re-injection well (Figure 57). A new geothermal extraction well is going to be drilled starting with 2019.

Expected temperature/pressure at the bottom/wellhead

The location of the pilot site is at the border between Beiuș Basin and Bihor Mountains, and both structural units are characterised by thin crust and litosphere. Also, other elements, like geothermal gradient of the region, or radiogenic type of the batholith encourage us to expect that at 5-6 km depth to obtain temperatures higer than 150^{o}C. A geothermal model is necessary for a better estimation.

Figure 57 Pumping installation from Beiuș

8.3 Electrolytic metal recovery and gas diffusion electro-precipitation

Potential target metals/products to be recovered

During the CHPM2030 project's implementation by using GDEx technology VITO succeeded to recover **high content of Sr** from a geothermal brine of the well 30001 from Beiuș.

Also, during the CHPM2030 project's implementation **a high content of Magnesium** has been highlighted in the precipitate resulted from the evaporation of the geothermal brine from Beiuș.

Based on these data at least an enrichment of the fluid with magnesium and strontium is to be expected.

Brine: foreseen chemical composition and physical parameters

Laboratory leaching experiments performed by BGS on 2 samples from the pilot site during the CHPM2030 project implementarion indicate that by adding ***0.6 M NaCl, 100 °C, at a preassure of 200 bar, or adding HCl/HNO3 mix, 100 °C, at a preassure of 200 bar*** good results are obtained for Co, Sr, Mo, Sb, Mn, Zn, and W.

In the future, by using mild leaching substances it is expcted that the above mentioned elements to be found in the fluid that is extracted.

8.4 Power plant

Figures 58, 59 District modules belonging to GeoDHsys of Beiuș.

In Beiuș there are 20 thermal modules, where the geothermal water is led to the heat exchanger and heat is produced. The total heat supplied to consumers overpass 40,000 Gcal/year (Figures 58 – 59). These modules replaced an old coal-fired thermal power plant.

Local heat and electricity demand (industrial, municipal, agricultural, etc.)

There are no known administrative or resource-based barriers, for further extension of the geothermal district heating system in Beiuș city. At present the combined capacity of the deep well pumps in both production wells cannot sustain further increase of the GeoDH system. During winter months 2016 its capacity was not enough during peak demand of the system. Connection of new consumers to the system has been put on hold until its geothermal production capacity has been increased.

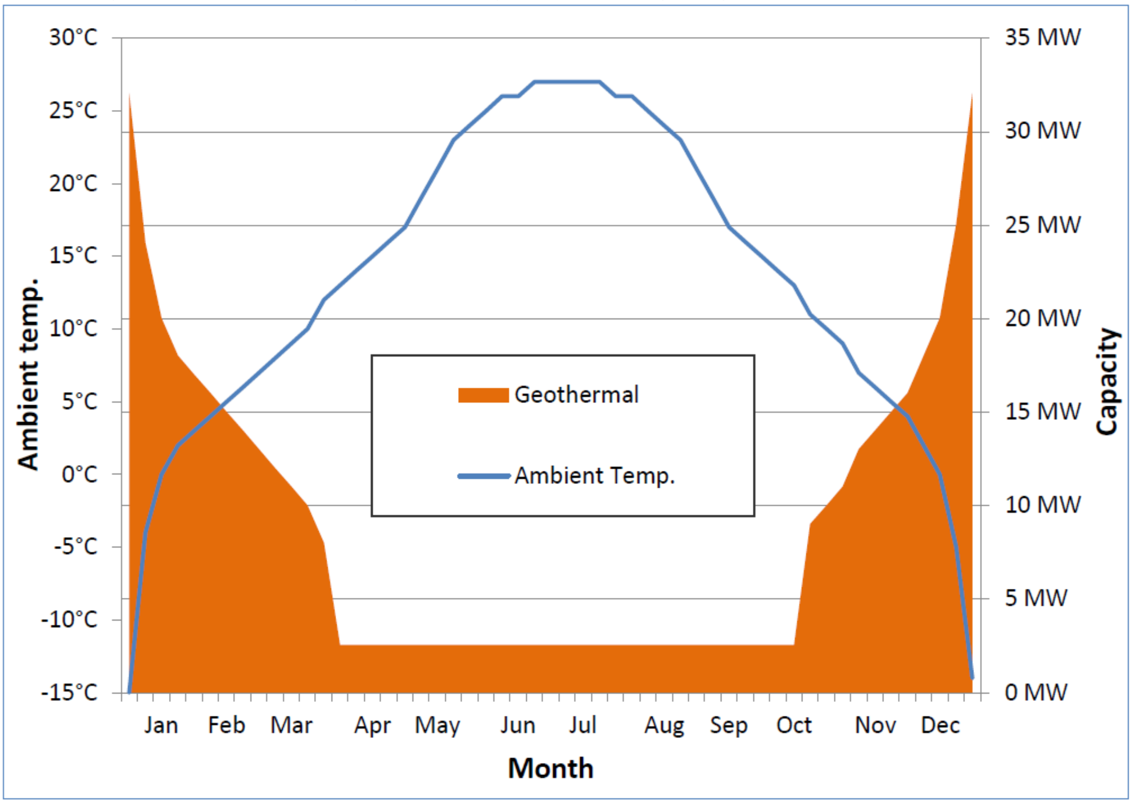


Figure 60 Monthly GeoDH heat demand MWth based on ambient temperature

According to the Pre-Feasibility study elaborated by Gunnarsson (2017), there is no central gas supply system in the city. Some single houses use gas for heating of hot sanitary water (HSW) but major heat source for HSW and domestic heating (DH) is wood burning.

Their estimated annual heat demand is 93 TJ/year to be compared to 153 TJ/year consumption of geothermal heat delivered (measured at consumers) in 2016 in existing GeoDH system. For the existing GeoDH system to serve those not yet connected it needs to increase its annual production by 60 %.

Table 13 Estimated heat demand for potential new GeoDH consumers

Houses not yet connected to GeoDH Heated with wood	Annual heat demand TJ/year	Annual wood consumption m3/year (wood)	Annual CO_2 emission t CO_2/year
733 single houses	72,6	7 559	7 982
One block house with 12 apartments	0,8	81	86
10 Warehouses and institutions	19,2	2 000	2 112
Total	92,5	9 640	10 621

In 2019 a solution for expansion of the GeoDH by drilling an additional production well has been chosen. But still the need for geothermal energy remains for the neighboring villages:

Table 14 Villages around Beiuș city

Distance between Beius and surrounding villages		Population
Beius – Delani:	3 km	369
Beius – Draganesti:	5 km	2 800
Beius – Curatele:	7 km	2 700
Beius – Pocola:	6 km	1 600
Beius – Budureasa:	12 km	2 600
Beius – Finis:	4 km	3 600
Beius – Tarcaia:	5 km	2 100
Beius – Remetea:	9 km	3 100

A new potential CHPM plant that can be located at Budureasa, would be able to provide geothermal energy for the neighboring villages, or electricity to the national grid.

Access to the grid

There are clear laws that allow and encourage the production of electricity from renewables. Among other incentives there are the Green Certificates. The Law **220/2008 stipulates the inclusion in the consumer's invoices the payments for green certificates. In Romania each consumer pays 11Eur/MWh/month for green certificates.**

9. Environmental, social and political background:

In 2017 a Pre-Feasibility study on Beiuș GeoDHsys extension (Gunnarsson et al, 2017) has been completed. In this chapter we took data from this study and would like to thank the authors.

Environmental

The use of low temperature geothermal energy in Beius has very limited CO2 equivalent emission, coming indirectly mainly from the production of the electricity used for its pump operations, in case it is produced by burning fossil fuel. Limited amount of GHG follow the geothermal water and leave it during utilisation.
It must only be a question of short time for Beius city to reach its goal of being 100% heated with geothermal water from its geothermal reservoir underneath its grounds. When accomplished, the local air pollution from district heating will come to an end in the city with enormous improvement in air quality, especially during the heating season. Estimated annual heat consumption in Beius is 246 TJ/year which corresponds to annual burning of wood around 25,600 [m3/year], emitting 27,000 [t CO2/year].
Multidisciplinary studies must be done in order to prevent environmental risks such as: water and noise pollution, induced seismicity, land use/subsidence, induced seismicity/landslides, water use, thermal pollution, etc.
An issue for the future to be considered will be local competition for water availability. Local community has the right to decide how to manage this problem, based on correct information.
The risk of mobilizing radioactive/toxic materials exists especially at Băița Bihor, and, although existence of mineralization is a proven fact, we consider that Romania is not prepared to be prepared for such a challenge, and we did not include this site into the pilot site.

Social

The geothermal heat production has several advantages, such as:

1. Economic opportunity and savings.
2. Improvement of energy security.
3. Reducing greenhouse gas emissions.
4. Harnessing local resources
5. Reducing dependency on fossil fuels for energy use.
6. Local payback in exchange for local support for deep drilling.
7. They complement existing district-heating networks offering an alternative to other fuels.
8. They can be combined with smaller binary cycle (if reservoir and economics allow) electricity generating plants to bring the utilisation of the reservoir to the maximum.
9. May be a useful complement to regional and local economic development programmes with positive effect on employment and the viability of public infrastructure.
10. They raise public awareness for the geothermal energy to a broader section of the public
11. Improving quality of life based on economic and environmental / climate benefits.

The inhabitants of Beiuș are used to benefit for the existance of the GeoDHsys in their city, because they pay less than the rest of Romania’s inhabitants, and they have a cleaner air, they do not have to care for making wood provisions for the winter, etc.
Regarding a CHPM system installation, information sessions are needed in order to explain which are the risks for the population. The whole range of activity connected to SLO have to be provided into a future project.

Political

1. Authorities and Regulatory Factors

- Simplify the administrative procedures to create market conditions that facilitate development;
- Separate law regarding geothermal resources and other fossil fuels resources.
- Improve access to geothermal data - to improve development of geothermal utilization.
- Publicise the characteristics and benefits of geothermal energy for regional development

- Design regulation specific to the promotion of direct uses of geothermal energy.
- Promote cooperation with international organisations.

2. Geothermal Resources

- Improvement of geothermal regulation.
- Separate law on geothermal and fossil fuels – to speed up access to geothermal data and avoid hindering geothermal development, and problems due to secrecy of oil and gas information.
- Improvements for data analysis of reservoirs in regions.

3. Scientific and Technical Factors

- Promote relationships with industry.
- Promote alliances with research centres and educational institutions for the formation of specialised human resources.

4. Companies, Management, Expertise – Industry Clusters

- Promote alliances with research centres and educational institutions for the formation of specialised human resources.
- Promote cooperation with IFI for financing, donor support and consulting.
- Organize workshops and conferences to improve knowledge on geothermal energy.
- Identify geothermal energy-related productive chains.

5. Educational and Human Factors

- Support for the generation of the human resources needed for the geothermal industry.
- Creating seminars and specialized courses on the different stages of a geothermal project and adding them to the existing engineering degrees.
- Give the personnel technical training to participate in the different stages of a project.
- Implement programs for scientific and technical development.

6. Access to finance, and Cost of Capital

- Promote additional access to financing geothermal projects – domestic and international.
- Increase access to capital by providing capital to exploration and test drilling and DH networks e.g. soft loans or donor grants, to lower the risks at the beginning of projects.

7. Infrastructure, Access to Markets, Sectors and Clusters

- Promote training in the banking system for the development of financial mechanisms specific to geothermal energy.
- Awareness; organize workshops & conferences to improve knowledge of geothermal energy.
- Increase the available knowledge about opportunities and benefits of geothermal resources.

8. Access to International Markets and Services

- Support international cooperation in area of geothermal knowledge, training and service.
- Promote international cooperation with IFI and donors on finance, grants and funding.
- Support international consulting cooperation on various fields of geothermal expertise.

10. Financial aspects

District Heating Costs

The Beiuș city council has contracted SC Transgex S.A., which holds the local geothermal utilisation licence, to operate and expand the GeoDH system. The tariffs for the delivery of central geothermal district heating in Beius are regulated by the state authorities reflecting the real cost of its operation. The way to evaluate the economic advantages of the GeoDH operation is to look at it from the consumer perspective and compare it with the cost and user friendliness of other heating alternatives, being mainly wood burning in Beius.

The geothermal energy is delivered and consequently charged in two different ways at the Beius consumers. Those who receive the heat from a secondary distribution loop from a substation are charged per used energy, which is metered in Gcal.

Those who receive the heat directly from the GeoDH system are charged per used amount of geothermal water metered in m3. The existing two production wells, 3001 and 3002, have different water temperature, hence two different prices/m3, depending on wherefrom the geothermal water comes, see Table 15.

Selling prices for the GeoDH system are regulated by the state organization, National Authority of Regulatory for Community Services (NARCS), according to the Romanian law no. 325/2006.

Table 15 GeoDH consumer heat tariffs for Beius in 2017

Secondary deliv. PT-substations	Price	Direct delivery to houses	Price	Price w/ 19% VAT	Price w/ 19% VAT	Utilisation	Energy content
Energy metering	RON/Gcal	Volume metering	RON/m3	€/m3	€/GJ	DT [°C]	MJ/m3
Production	40.92	From Well 3001	3.30	0.86	5.31	80-40	163
Transport	19.79	From Well 3003	2.75	0.72	5.86	70-40	123
Distribution	19.57		NARCS-price regulation 2017				
Total w/ 19% VAT	95.53	Exchange rate RON/€ = 4.55			Based on information from Transgex/ANRM		
€/Gcal incl. VAT	21.00						
€/GJ incl. VAT	5.01						

In the last years there was a market price escalation for wood, see Table 16.

Year	2013	2014	2015	2016	2017
€/m³	26	33	33	38	63

The effect was that inhabitants became more and more interested in using geothermal energy because with current market prices for wood for heating and GeoDH state regulated heating tariffs the citizens of Beius enjoy between 30% - 50% reduction in annual heating cost, when connected to the GeoDH system, a tremendous advantage for the citizens in addition to better air quality, clean, safer and almost zero manpower operation of their house heating.

For new investments the financial tools developed in WP5 will be used in order evaluate all the economical elements that are needed for a new project.

As potential investors that expressed their intent to be partners in such a project we can mention:

- Local public authority – City hall of Beiuș
- Transgex S.A.
- Geological Institute of Romania

Given the fact that the costs for such a project are high, we think that the best solution is to use EU funding for different stages of project development that follow in the future.

11. Conclusions

The data from several domains converge to the conclusion that there are prerequisites that allow considering part of the study area as a pilot area. Thus, the data analysed in the CHPM2030 project led to the delineation of a perimeter in the Budureasa area that is situated at the border between Beiuş Basin and Bihor Mountains. This perimeter has the following features that encourage the design of new research:

- High geothermal potential characteristic to the eastern border of the Pannonain Basin;
- Existence of granite – granodiorite batholith in the depth that can be intercepted on a width of more than 10 km in Beiuș Basin;
- Mineralization well documented and delineated by detailed magnetometric measurements;
- Based on laboratory experiments that have been performed during the project at least an enrichment of the fluid with magnesium and strontium is to be expected.
- In the future, by using mild leaching substances it is expcted that Co, Sr, Mo, Sb, Mn, Zn, and W to be found in the fluid that is extracted.
- Existence of the geothermal aquifer that, having a regional extension in Beiuș Basin, can provide geothermal energy to an increased number of localities;
- The expertise of the private company in geothermal water exploitation in Beiuș, and other places in Romania;
- Both public local authority and private company expressed their interest to be partners into a project that envisages energy production (and metals) from dry hot rock.
- Existence of surface waters that can be used for a CHPM installation;
- A lower cost of geothermal energy for the population as compared to the energy resulted from burning wood;
- High energy demand for heating and for electricity at local and national level;

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References

Andrei, J., Cristescu, T., Calotă, C., Proca, A., Românescu, D., Russo-Săndulescu, A., et al. (1989). Spatial distribution and structural images of banatites from Romania deduced from gravity and magnetic data. *Rev. Roum. Geol., Geophys. et Geogr.- GEOPHYSIQUE, Vol. 33*, 79-85.

Antal, C., Setel, A., & Gavrilescu, O. (2009). Exploitability of geothermal resources in Pannonian Depression. *Analele Universității Oradea, Fascicula de Energetică, Vol. 15*.

Bada, G., Cloetingh, S., Gerner, P., & Horváth, F. (1998). Sources of recent tectonic stress in the Pannonian region: inferences from finite element modelling. *Geophys. J. Int., Vol. 134*.

Bala, A., & Răileanu, V. (2017). Assessing of the crustal models and active faults systems in western part of Romania with applications in seismic hazard. *Romanian Reports in Physics, Vol. 69*.

Bala, A., & Toma-Dănilă, (2017). Crustal models assessment in western part of Romania employing active seismic and seismologic methods: http://www.rrp.infim.ro/IP/A362.pdf.

Balázs, A. (2017). Dynamic model for the formation and evolution of the Pannonian Basin : The link between tectonics and sedimentation. *Utrecht Studies in Earth Sciences, Vol. 132*.

Balázs, A., Magyar, I., Matenco, L., Sztanó, O., Tokés, L., & Horváth, F. (2018). Morphology of a large paleo-lake: Analysis of compaction in the Miocene-Quaternary Pannonian Basin. *Global and Planetary Change, Vol. 171*.

Balázs, A., Matenco, L., Magyar, I., Horváth, F., & Cloetingh, S. (2016). The link between tectonics and sedimentation in back-arc basins: New genetic constraints from the analysis of the Pannonian Basin. *Tectonics, Vol. 35*.

Balázs, A., Matenco, L., Vogt, K., Cloetingh, S., & Gerya, T. (2018). Extensional Polarity Change in Continental Rifts: Inferences From 3-D Numerical Modeling and Observations. *Journal of Geophysics Research: Solid Earth, Vol. 123*.

Balázs, A., Mațenco, L., Magyar, I., Horváth, F., & Cloeting, S. (2016). The link between tectonics and sedimentation in back-arc basins: New genetic constraints from the analysis of the Pannonian Basin. *Tectonics, Vol.35*.

Balintoni, I., & Puște, A. (2001). Probleme tectonice în partea de vest a Masivului Pădurea Craiului (Munții Apuseni). *Studia Universitatis Babes-Bolyai Geologia, XLVI,1*.

Békési, E., Lenkey, L., Limberger, J., Porkoláb, K., Balázs, A., Bonté, D., et al. (2017). Subsurface temperature model of the Hungarian part of the Pannonian Basin. *Global and Planetary Change, Vol. 171*.

Bordea, S., & Mantea, G. (1999). The main structural elements of Beiuș Basin and of the adjacent zones (Apuseni Mountains), . *Rev. Roum Geologie, Tome 43*, 101-108.

Bordea, S., & Mantea, G. (1999). The main structural elements of Beiuș Basin and the adjacent zones, Apuseni Mountains. *Rev. Roum. Geol., Geophys., Vol. 43*, 101-108.

Cermak, V., & Rybach, L. (1991). *Terrestrial Heat Flow and the Lithosphere Structure.* Springer-Verlag Berlin Heidelberg.

Cermak, V., Rybach, L., & =. (1991). *Terrestrial Heat Flow in Europe - Heat Flow and itospheric Structure in Romania.* Berlin: Springer Verlag.

Daoxian, Y., & Zaihua, L. (1998). *Global Karst Correlation .* Science Press.

Demetrescu, C. (1982). Thermal structure of the crust and upper mantle of Romania. *Tectonophysics, Vol. 90*.

Demetrescu, C., & Andreescu, M. (1994). On the thermal regime of some tectonic units in a continental collision environment in Romania. *Tectonophysics, Vol. 230*.

Demetrescu, C., & Polonic, G. (1989). The evolution of the Pannonian Depression (Romanian sector) as derived from subsidence and heat flow data. *Tectonophysics, Vol.164*.

Dererova, J., Zeyen, H., Bielik, M., & Salman, K. (2006). Application of integrated geophysical modeling for determination of the continental lithospheric thermal structure in the eastern Carpathians. *Tectonics, Vol. 25*.

Dominguez, X., et al, (2018). CHPM2030 DELIVERABLE D3.2. Report on performance, mass and energy balances and design criteria for gas-diffusion electroprecipitation and electrocrystallization. https://www.chpm2030.eu/wp-content/uploads/2019/03/CHPM2030_D3.3.pdf

Gallhofer, D., Quadt, A. v., Peytcheva, I., Schmid, S. F., & Heinrich, C. A. (2015). Tectonic, magmatic, and metallogenic evolution of the Late Cretaceous arc in the Carpathian-Balkan orogen. *Tectonics, Vol. 34*.

Gavat, I., Airinei, Ș., Botezatu, R., Socolescu, M., Stoenescu, S., & Vencov, I. (1963). The deep geological structure of the territory of the Romanian people's republic according to the present geophysical data (gravimetric and magnetic data). *Tomul 1, Vol.1*, ISSN 1220 - 5265.

Genter, A., Guillou-Frottier, L., Feybess, J., Nicol, N., Dezayes, C., & Schwartz, S. (2003). Typology of potential Hot Fractured Rock resources in Europe. *Geothermics, Vol. 32*, 701-710.

Gunnarsson, A., et al, (2017). Pre-Feasibility Study Geothermal District Heating Beius, Romania. National Energy Authority, ISBN 978-9979-68-426-8.

Horváth, F., Bada, G., Szafián, P., Tari, G., Ádám, A., & Cloetingh, S. (2006). Formation and deformation of the Pannonian Basin: constraints from observational data. *Geological Society, London, Memoirs, Vol. 32*.

Horváth, F., Dulić, I., Vranković, A., Koroknai, B., Tóth, T., Wórum, G., et al. (2018). Overview of geologic evolution and hydrocarbon generation of the Pannonian Basin. *Interpretation*.

Horváth, F., Musitz, B., Balázs, A., Végh, A., Uhrin, A., Nádor, A., et al. (2015). Evolution of the Pannonian basin and its geothermal resources. *Geothermics, Vol. 53*.

Horváth, F., Musitz, B., Balázs, A., Végh, A., Uhrin, A., Nádor, A., et al. (2018). Evolution of the Pannonian basin and its geothermal resources. *Geothermics, Vol. 53*.

Iancu, V. (2011). Field Trip Guidebook. The Late Cretaceous magmatic and Metallogenic Belt and Alpine structures of the western South Carpathians. *Conference: 3rd International Symposium on the Geology of the Black Sea Region, At Bucharest, Volume: Field Trip Guidebook.*

Ivanovici, V. (1976). *Geologia Munților Apuseni.* Editura Academiei Republicii Socialiste România.

Jarosinski, M., Beekman, F., Mețenco, L., & Cloetingh, S. (2011). Mechanics of basin inversion: Finite element modelling of the Pannonian Basin System. *Tectonophysics, Vol. 502*.

Lankreijer, A., Mocanu, V., & Cloetingh, S. (1997). Lateral variations in lithosphere strength in the Romanian Carpathians: constrains on basin evolution. *Tectonophysics, Vol. 272*, 269-290.

Lenkey, L., Dovenyi, P., Horvath, F., & Cloetingh, S. (2002). Geothermics of the Pannonian basin and its bearing on the neotectonics. *Stephan Mueller Special Publication Series, Vol. 3*.

Matenco, L., Munteanu, I., ter Borgh, M., Stănica, A., Tilita, M., Lericolais, G., et al. (2015). he interplay between tectonics, sediment dynamics and gateways evolution in the Danube system from the Pannonian Basin to the western Black Sea. *Science of The Total Environment, Vol. 543*.

Matenco, L., Vogt, K., Cloetingh, S., & Gerya, T. (2018). Extensional Polarity Change in Continental Rifts: Inferences From 3-D Numerical Modeling and Observations. *Journal of Geophysical Research: Solid, Vol. 123*.

Mațenco, L. (2016). Tectonics and Exhumation of Romanian Carpathians: Inferences from Kinematic and Thermochronological Studies. In M. Radoane, & V. A. Stroe, *Landform Dynamics and Evolution in Romania.* Springer Geography.

Mațenco, L., & Radivojević, D. (2012). On the formation and evolution of the Pannonian Basin: Constraints derived from the structure of the junction area between the Carpathians and Dinarides. *Tectonics, Vol. 31*.

Merten, S., Mațenco, L., Foeken, J., & Andriessen, P. (2011). Toward understanding the post-collisional evolution of an orogen influenced by convergence at adjacent plate margins: Late Cretaceous–Tertiary thermotectonic history of the Apuseni Mountains. *Tectonics, Vol. 30*.

Michal, G. (2013). Détermination d'un modèle lithosphérique en Europe centrale: modélisation géophysique intégrée. *University of Paris-Sud, Vol. XI*.

Nemcok, M., Pospisil, L., Lexa, J., & Donelick, R. (1998). Tertiary subduction and slab break-off model of the Carpathian-Pannonian region. *Tectonophysics, Vol. 295*, 307-340.

Neubauer, F., Lips, A., Kouzmano, K., Lexa, J., & Ivășcanu, P. (2005). 1: Subduction, slab detachment and mineralization: The Neogene in the Apuseni Mountains and Carpathians. *Ore Geology Reviews, Vol. 27*.

Orășeanu, I. (2015). Groundwater dynamics of Beiuş Basin basement and its surrounding mountain areas. *Groundwater dynamics of Beiuș Basin basement*.

Orășeanu, I. (2015). Groundwater dynamics of Beiuș Basin basement and its surrounding mountain areas. *Nymphaea Folia naturae Bihariae, Vol. XLII*, 5-18.

Pătrașcu, Ș., Bleahu, M., & Panaiotu, C. (1990). Tectonic imiplications of paleomagnetic research into Upper Cretaceous magmatic rocks in the Apuseni Mountains, Romania. *Tectonophysics, Vol. 180*, 309-322.

Pătrașcu, Ș., Panaiotu, C., Șeclăman, M., & Panaiotu, C. E. (1994). Timing of rotational motion of Apuseni Mountains (Romania): paleomagnetic data from Tertiary magmatic rocks. *Tectonophysics, Vol. 233*, 163-176.

Proca, A., Albaiu, M., (1979). Contribuții gravimetrice la cunoașterea structurilor eruptive din Munții Bihor – Gilău. Institutul Geologic al României - Studii tehnice și economice, Seria D, nr.13, 1979.

Rădulescu, F., Biter, M., Diaconescu, C., & Nacu, V. (1994). Geological structure and seismicity of Romania. *Mitteilungen aus den Geodatischen Instituten der Rheinschen Friedrich-Wilhems Universitat Bonn, Nr. 82*.

Ren, Y., Stuart, G. W., Houseman, G. A., Dando, B., Ionescu, C., Hegedűs, E., et al. (2012). Upper mantle structures beneath the Carpathian–Pannonian region: Implications for the geodynamics of continental collision. *Earth and Planetary Science Letters*.

Rochelle, C., (2017). CHPM2030 DELIVERABLE D2.2. Report on metal content mobilisation using mild leaching. https://www.chpm2030.eu/wp-content/uploads/2018/03/CHPM2030_D2.2.pdf

Roșu, E., Seghedi, I., Downes, H., Alderton, D., Szakacs, A., Pecskay, Z., et al. (2004). Extension-related Miocene calc-alkaline magmatism in the Apuseni Mountains, Romania: Origin of magmas. *SCHWEIZERISCHE MINERALOGISCHE UND PETROGRAPHISCHE MITTEILUNGEN, Vol. 84*.

Schwarz, G. (2016). *Report on data availability - CHPM2030 Deliverable 1.2.* Hungary: Published by CHPM 2030 project.

Seghedi, I. (2018). 2. GEOLOGICAL EVOLUTION OF THE APUSENI MOUNTAINS WITH EMPHASIS ON THE NEOGENE MAGMATISM – A REVIEW.

Seghedi, I., & Downes, H. (2011). Geochemistry and tectonic development of Cenozoic magmatism in the Carpathian–Pannonian region. *Gondwana Research, Vol. 20*.

Sferle, M. (2018). Transgex. Power Point presentation.

Ștefan, A., Lazăr, C., Berbeleac, I., & Udubașa, G. (1988). Evolution of Banatitic Magmatism in the Apuseni Mts. and Associated Metallogenesis. *D.S. Inst. Geol. Geofiz., Vol. 72-73*.

Ștefan, A., Roșu, E., Andar, A., Robu, N., Bratosin, I., Grabari, G., et al. (1992). Petrological and geochemical features of banatitic magmatites in northern Apuseni Mountains. Rom. J. Petrology, Vol. 75, 97-115.

Ștefan, A., Roșu, E., Audăr, A., Robu, L., Robu, N., Bratosin, et al. (1992). Petrological and Geochemical Features of Banatitic Magmatites in Northern Apuseni Mountains. Rom. J. Petrology, Vol. 75.

Stoicovici, E. & Stoici S. (1970).Contribuții la cunoașterea mineralizației de bor din bazinul superior al Crișului Negru (Băița Bihorului). Studia Universitatis Babes Bolyai, XV nr.2,-15.

Tari, G., Dövényi, P., Dunkl, I., Horváth, F., Lenkey, L., Stefanescu, M., et al. (1999). Lithospheric structure of the Pannonian basin derived from seismic, gravity and geothermal data. Geological Society London Special Publications*, Vol. 156*.

Tiliță, M. (2018). Heat flow modelling in the Transylvanian basin: Implications for the evolution of the intra-Carpathians area. *Global and Planetary Change*.

Tiliță, M. S. (2015). Evolution of the Transylvanian Basin: inferences from seismic interpretation and numerical modelling. *Utrecht Studies in Earth Sciences, Vol. 89*.

Visarion, M., Veliciu, Ș., Constantinescu, P., & Ștefănescu, M. (1978). Crustal temperature - depth profile across Romania derived from heat flow amd other geophysical data. *Rev. Roum. Geol. Geophys. et Geogr. - GEOPHYSIQUE, Vol. 22*, 33-38.