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New data on the Biharia Horst documented by deep drilling

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Abstract. The geology of the Apuseni Mountains and their related sedimentary basins was an ongoing challenge for the Romanian geological research. Amongst these basins, the Neogene basins Șimleu, Borod, and Beiuș stand out thanks to their geothermal and hydrocarbon potential. The structural evolution of the basement of these subsiding areas,

but also of their outlining orogenic rims that shape them, can be reconstructed in a more detailed manner, in order to get a better knowledge of the development and function of the deep hydro-geothermal systems. However, the misinterpretation of data from boreholes drilled in the area throughout time has resulted in a number of errors (e.g., the presence of the Paleogene deposits). This paper concerns a tectonic structure at a southern portion of the boundary between the Borod and Șimleu sedimentary basins, namely the Biharia Horst. The structure in question represents an important area for the hydro-geothermal systems located in the basement of the Neogene basins. Based on geological data from four deep geothermal wells and a petroleum one, we succeeded to outline more precisely the extent of the horst in a northerly direction, and to provide more concrete data on the basement tectonics of the previously mentioned Neogene basins as well as their hydrogeological recharge.

Keywords. Biharia Horst, Borod Basin, Șimleu Basin, Inner Dacides, Romania.

Introduction

At a time of climate fluctuations, human communities have begun to pay attention to the use of alternative energies instead of the use of fossil fuels. Among these types of energy there is obviously geothermal energy. Although its potential began to be reconsidered with the onset of the world energy crisis in 1973 (Țenu 1981), the exploitation of this type of resource for energy purposes in Romania began only in the 1980s, until then it had only been used for recreational purposes. The first project for the industrial use of geothermal water was started by direct use in Sânicolau Mare (Timiș County; engineer Ionel Mușiu, personal communication), then in Oradea (Bihor County) in 1982-1983. The first exploitation project through heat exchangers, specialized pumps and adequate infrastructure started in Oradea only in 1987, and was completed in September 1992. Currently, the exploitation of geothermal energy covers the north-western region as well as parts of the southern region of Romania. For all this to be possible, the most important role was played by the former national enterprises dealing with prospecting and other geological works (*i.e.*, IPEG,

IFLGS Bucharest, GFEAG Oradea, etc.). Thanks to the activities of these enterprises, important data related to the deep geological basement of the Romanian territory have been brought to light since the 1960s. This data has outlined or even concretely shaped previously unknown structural aspects. Some of this data was taken over by the Geological Prospecting and Exploration Enterprise Cluj (IPEG Cluj, now TRANSGEX SA). Before the fusion between the Drilling and Special Geological Works Enterprise Bucharest (IFLGS) and Drilling and Exploitation of Geothermal Waters Group Oradea (GFEAG Oradea), all three enterprises have carried out more than 200 deep boreholes in total, that remained classified as geothermal water wells.

Using the record data from four geothermal water boreholes drilled by TRANSGEX SA and data in the literature from a borehole drilled by the Ministry of Petroleum (Țenu 1981), in this paper we aim to: *i.* outline the Biharia Horst on a northern direction along the line of Oradea – Biharia – Satu Nou localities, *ii.* bring new contributions for the southern margin of Șimleu Basin along the line of Biharia – Satu Nou – Tămășeu localities, and *iii.* improve the knowledge on the water supply of the hydro-geothermal systems in the Neogene Șimleu and Borod basins. Although some data have been presented before in the literature (*i.e.*, Istocescu & Ionescu 1970; Țenu 1981 and references therein), all our interpretations will be made by using the internal data from TRANSGEX SA.

Geological setting

The area of interest comprises the north-western sector bordering the Plopiș Mountains as well as the further away neighboring area of the Pannonian Depression. Hence, for the latter, we also refer to its related Borod and Șimleu Neogene sedimentary basins (Paucă 1954, 1967; Nicorici 1981; Popa 2000; Săndulescu 1984). The evolutionary geological context of the Plopiș Mountains is not one with tectono-stratigraphic specificity other than that of the whole Northern Apuseni area, more precisely of the Bihor Unit and the overlying thrusting nappe systems (*i.e.*, Inner Dacides in Săndulescu 1984, Apusenides

in Balintoni 1997). The focus of this paper strictly involves the Bihor Unit without the associated thrusting nappes. Its metamorphic bedrock (the Someș Lithogroup, part of the Pre-Apulian terrane, interpreted as an active plate margin, in Balintoni 2019), was considered Precambrian and possibly Cambrian (Săndulescu 1984 and related references). In more recent viewpoints (Balintoni & Balica 2013; Balintoni 2019) these rocks were considered as sequences that recorded two metamorphic events (Ordovician metamorphism followed by Variscan metamorphism). Afterwards, this bedrock was subject to long processes of weathering and erosion before the end of the Paleozoic. In the sedimentary cover of this basement the first sedimentary sequence is Permian, of Verrucano-type clastic deposits, and the last deposits are those accumulated in the post-tectonogenetic elongated grabens (the emplacement of the thrusting nappes in the Bihor Unit occurred in the pre-Gosau tectonic pulse, according to Săndulescu 1984) occurred at the end of the Cretaceous, which also involve Gosau-type, 'Senonian' deposits (Lupu & Lupu 1960, 1983; Săsăran & Săsăran 2007; Schuller et al. 2009) and volcanic inputs. The Mesozoic sedimentary succession was interrupted by the Old and New Cimmerian orogeny and the 'Austrian' tectonic pulse (Ivanovici et al. 1976; Bleahu et al. 1994; Săndulescu 1984; Ferry et al. 2022).

Concerning the tectonics of the Bihor Unit, it can be stated that in mid-Cretaceous, the thrusts become incipient, and some folds are formed, these being composed of mostly carbonate rocks (Istocescu & Ionescu 1970; Țenu 1981; Bleahu et al. 1994; Săndulescu 1984). The major thrusts occurred in the pre-Gosau tectonic pulse, when the Inner Dacides and mainly the Bihor Unit were also fractured into tectonic blocks. Finally, fractures and faults were also formed in the Cenozoic, particularly in the New Styrian tectonic pulse and subsequently, mainly related to the outlining of the sedimentary basins west of the Apuseni Mountains, filled in dominance by middle and late Neogene terrigenous deposits (Șimleu, Borod, Beiuș, Zărand) (Nicorici 1972, 1981; Visarion & Săndulescu 1979). It is important to note that among all these sedimentary basins trended NW-SE, located west to the Apuseni Mountains, lower Miocene sedimentary deposits are only in the Borod Basin, in its

easternmost area (Popa, 2000). For this paper, only the southern margin of the Șimleu Basin and the northern one of the Borod Basin are of interest.

It is important to note that in this area Paleogene sedimentary deposits are completely missing. Such age mentioned in various technical papers of the above-mentioned enterprises are devoid of any paleontological evidence. One may presume that in Paleogene all the region related now to the Bihor County was emerged.

As far as erosion is concerned, it is clear that the Quaternary has also left its mark (Fig. 1), and it is found in the form of mainly clastic deposits up to 100 m thick. The presence of the Pliocene rocks is not excluded in this pile of clastic rocks, but for instance there are not enough paleontological evidence for this geological age. Unfortunately, the mastodons from Păgaia (Codrea et al. 2005), which we might assume could be Pliocene, do not occur in a broader fossil vertebrate association that is clearly indicative of such an age.

Biharia Horst as seen from deep drilling data

Being located between the Șimleu Basin to the north and the Borod Basin to the south, the Biharia Horst represents the western extension in the form of a submerged step, of the Plopiș Mountains (Țenu 1981), being in fact part of the Bihor Unit (Bleahu et al. 1994).

The four boreholes whose data were used for the descriptions that follow are F-1709H, F-4021H, F-4022H and F-1021H (Fig. 1, Table 1). Three of these were drilled in 1967 and one in 1983, so it can be assumed that the stratigraphic interpretations of that period were not necessarily very accurate. Two very good examples are provided by the data obtained from the drilling of F-4021H and F-4022H, which would have intercepted 'Paleogene' blackish marly deposits with '*Globigerina* indet. and pyrite', which are lithologically similar to those of the Late Cretaceous from Băile Felix. A fifth well considered in our descriptions is borehole 501 executed by the Ministry of Petroleum (Fig. 1, Table 1). As far as this well is concerned, the only data we used, by extrapolation, are the depths

at which the borehole crossed the stratigraphic intervals of various ages, following Țenu (1981) and Ștefănescu et al. (1988), as we have no other specific data on this borehole. However, it is worth noting that these data are also useful for defining the extent of the horst in question.

The depths at which the boreholes were projected are not the same depths at which they were drilled. Thus, F-1709H was stopped with the sole in the Triassic, F-4021H and F-501MP encountered the first Permo-Werfenian sedimentary sequence, F-4022H was stopped in the 'Paleogene' rocks, and F-1021H in the Cretaceous ones. Other detailed data on the lithology of the encountered rocks cannot be made public. What we can say instead is that the lithology does not differ much from one well to another, and that the rocks associated with geological ages, except for the 'Paleogene' rocks which are rather Upper Cretaceous, were described with sufficient accuracy by Istocescu & Ionescu (1970).

Table 1. Deep drilling data concerning the thickness of the deposits of various geological ages.

WELL	F-1709H	F-4021H	F-4022H	F-1021H	F-501MP
ELEVATION	132 m	131 m	111 m	111 m	130 m
QUATERNARY	0 – 50 m	0 – 25 m	0 – 25 m	0 – 25 m	0 – 20 m
PANNONIAN	50 – 1059 m	25 – 1600 m	25 – 2150 m	25 – 2070 m	20 – 1200 m
MIOCENE	1059 – 1821 m	1600 – 1840 m	2150 – 2604 m	2070 – 2480 m	1200 – 1600 m
'PALEOGENE'		1840 – 2016 m	2604 – 2980 m	2480 – 3160 m	
CRETACEOUS	1821 – 2648 m	2016 – 2170 m		3160 – 3453 m	
JURASSIC	2648 – 2796 m				
TRIASSIC	2796 – 3448 m				
BASEMENT		2170 – 2276 m			

The knowledge gaps between the pre-drilling and post-drilling periods can be clearly seen graphically on the various geological cross-sections that have been developed over time. Probably, the last cross-section outlined just before the drilling started is the one shown on the 1:200 000 map, *folio* Oradea, published in

1965 by Giușcă et al. (Fig. 2). In this map it can be seen that the 'Biharea' area would represent a submerged area of the Pannonian Basin, while the Municipality of Oradea would lie over a large horst. Immediately after the drilling of the boreholes in the 1960s, using their acquired borehole data, Istocescu & Ionescu (1970) attempted to elucidate the tectonics and subsurface geology of the northeastern part of the Pannonian Basin, providing an alternative block-diagram sketch of the region (Fig. 3). As can be seen from the drawing, even this representation involves 'Paleogene' deposits, which have not been proven with hard bio-stratigraphic arguments. Another remark refers to the Biharia Horst, which is erroneously represented as inverted.

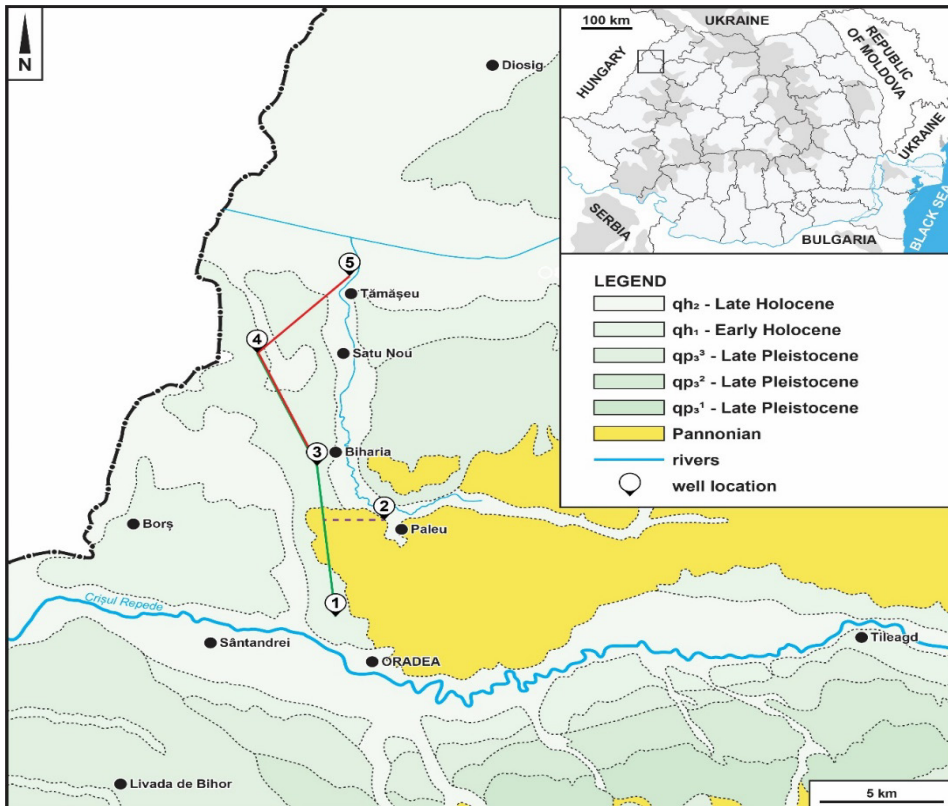


Fig. 1. Geological map of the studied area (modified after Giușcă et al. 1965 and Giușcă et al. 1967), with the direction of the cross sections from Fig. 7. Section A: well points 1 – 2 (projected) – 3 – 4; Section B: well points 3 – 4 – 5.

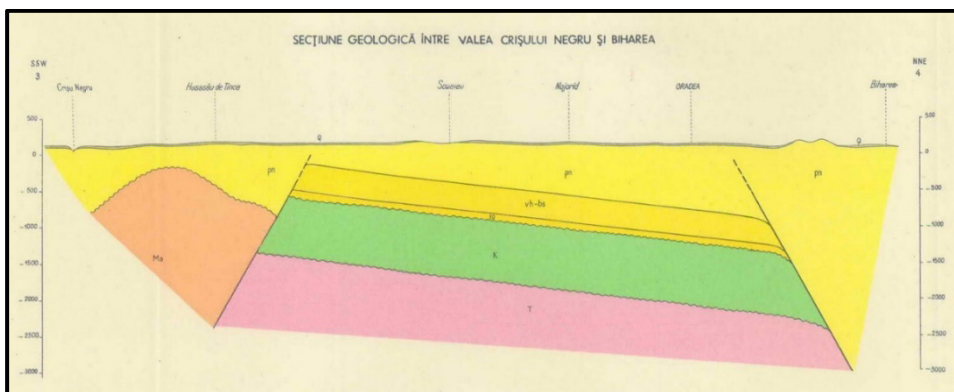


Fig. 2. Geological cross-section between the Crișului Negru Valley and Biharia (by Giușcă et al. 1965). Ma = Precambrian; T = Triassic; K = Cretaceous; to = 'Tortonian' (i.e., Badenian); vh-bs = Volhynian-Bessarabian; pn = Pannonian s.l. (including Pontian); Q = Quaternary.

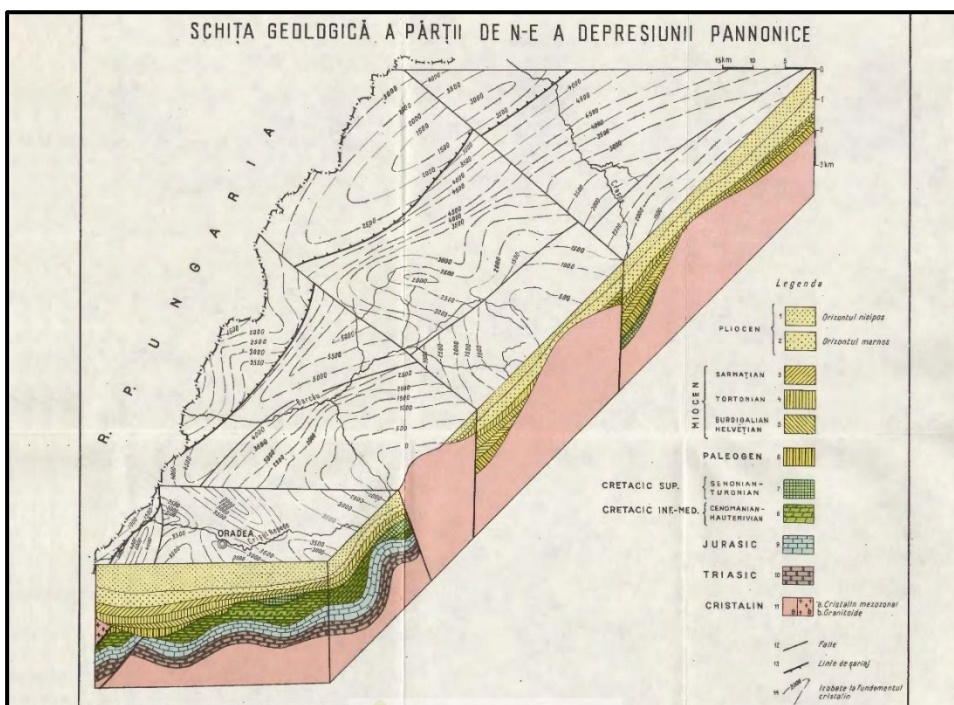


Fig. 3. Block-diagram of a northeastern area of the Pannonian Basin (by Istocescu & Ionescu 1970).

Țenu (1981), in his paper on hyperthermal waters in northwestern Romania, made the most accurate graphical interpretations for that period (Figs. 4, 5), based on a richness of borehole data. However, other borehole data have been collected since then, and with these, new ways of interpreting the structural geology could be brought to light. In contrast, the author is the first to exclude the 'Paleogene' deposits in this region (Fig. 5), even though they appeared in the drilling documentation.

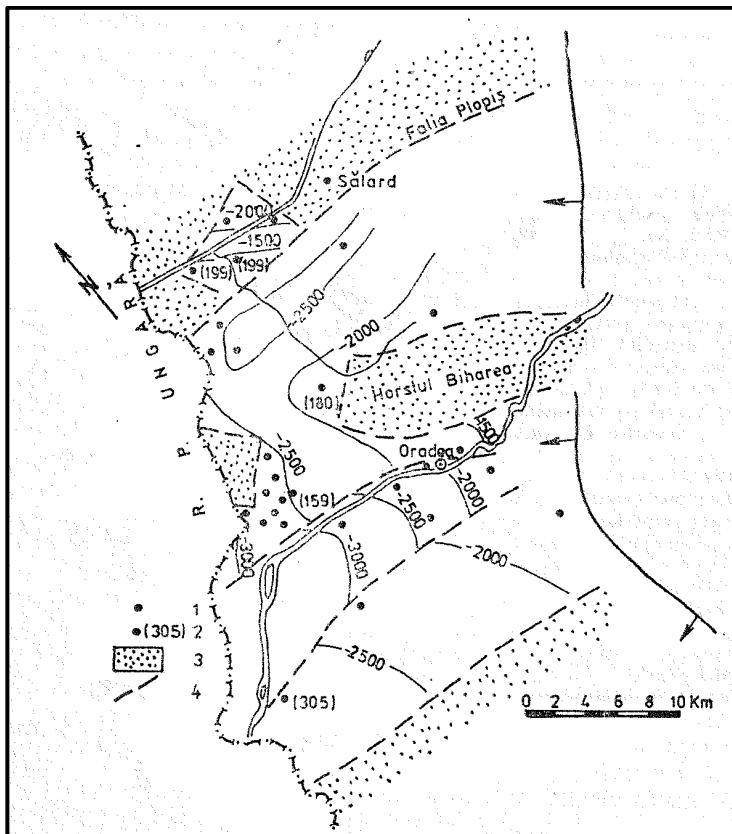


Fig. 4. Structural map depicting the top of the Triassic deposits (by Țenu 1981). The dotted areas refer to areas devoid of Triassic deposits.

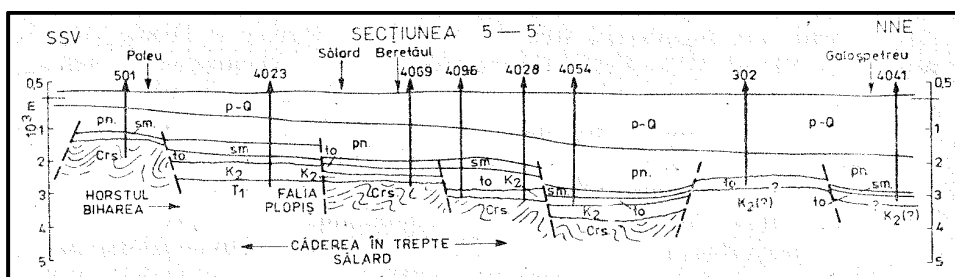


Fig. 5. Longitudinal geological cross-section with deep drilling data between Paleu and Galošpetreu (by Țenu 1981).

Ștefănescu et al. (1988), while producing a series of geological sections for the whole Romanian territory, used both data from literature (documents and published papers) and maps, supported by boreholes, as well as by geophysical data taken by aeromagnetism, gravimetry and seismometry, and managed to include the Satu Nou - Biharia - Oradea and the Biharia Horst area in the NNW extremity of section 5-B. The representation of the horst is however incorrect, as its outlining faults are considered vertical. Instead, it is noteworthy that the editors excluded, as did Țenu (1981), the 'Paleogene' deposits from the section, relating them either to the Early Cretaceous in F-4022H or to the Middle-Late Miocene in F-4021H (Fig. 6).

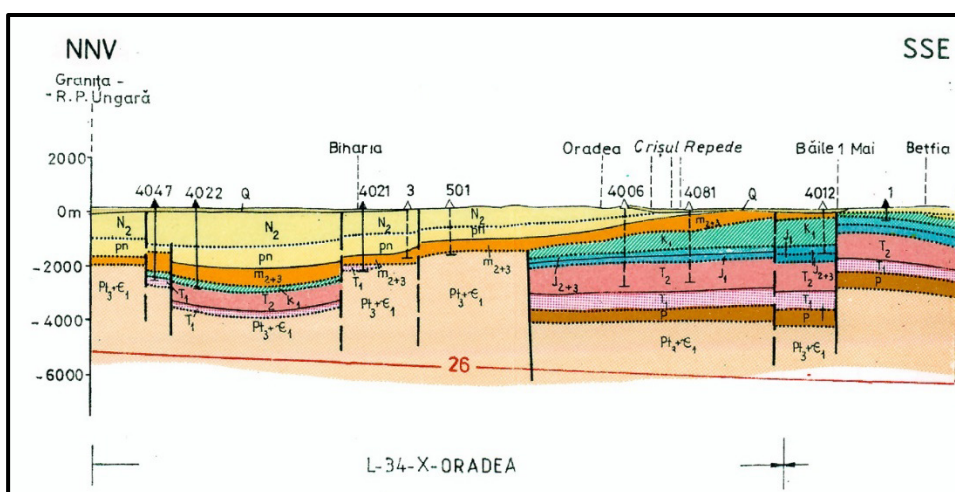


Fig. 6. Geological cross-section between the Romanian-Hungarian border and Bettfia (after Ștefănescu et al. 1988).

The Biharia Horst as seen in our perception

A major factor to consider when discussing high depth drilling is keeping track of drilling fluid losses. The only data we have in this regard are the considerable losses that occurred during the drilling of wells F-4021H and F-1709H on the Mesozoic intervals or at the contact with the basement. Using this information, together with the drilling data from the records held by TRANSGEX SA (depth and stratigraphic intervals), we were able to outline the Biharia Horst more precisely (Fig. 7). As for the F-501MP borehole, we used its data as a projection for a distance of ca. 2.5 km to the west. As it is located on the inner margin of the Borod Basin, we can say without difficulty that, since the horst represents a submerged step of the Plopiş Mountains, thus of the Bihor Unit, the stratigraphic intervals in its depth should not differ too much on the basin margins in the east-west direction.

The data provided by the F-1709H well are in accordance with the data held by TRANSGEX SA for the other wells in the Oradea area, and their geological interpretation does not rise any difficulties at the contact level with the Biharia Horst. On the other hand, also from the internal data accumulated from the execution of dozens of boreholes, we could notice a very important aspect that can lead to a much more spatially correct interpretation of the fault structures related to the tectonic steps in the northwestern basins. These refer to the fact that faults have a dip angle between 45° and 60° relative to the horizontal. While in the Beiuş Basin the inclination angle is considerably closer to 60°, in the Borod and Şimleu basins it is smaller. Thus, in our representation (Fig. 7) the tilt angle of the step faults is ca. 45°.

Since the F-4021 well crosses from the Cretaceous directly into the basement, and has faced issues of drilling fluid loss at the contact between these two intervals, with no Jurassic or Triassic intervals encountered, the presence of another step submerged in the south-north direction, just at the entrance to the Şimleu Basin, is justified. Also, regarding the Şimleu Basin, the question of the lack of other Mesozoic deposits (*i.e.*, Triassic and Jurassic) must be raised. Insofar as the thickness of Cretaceous deposits does not differ much between the Borod and Şimleu basins, since in the Borod Basin the whole Mesozoic stratigraphic succession was

encountered, while in the Șimleu Basin no Jurassic deposits were crossed, or some very restricted Triassic deposits were encountered (Ștefănescu et al, 1988), the lack of these geological ages could be related either to the fact that the drilling in the latter basin was not deep enough, that the well data collected during drilling were not correctly retrieved or misinterpreted, or that there are other series of submerged Mesozoic steps, which could not be highlighted for interpretation reasons.

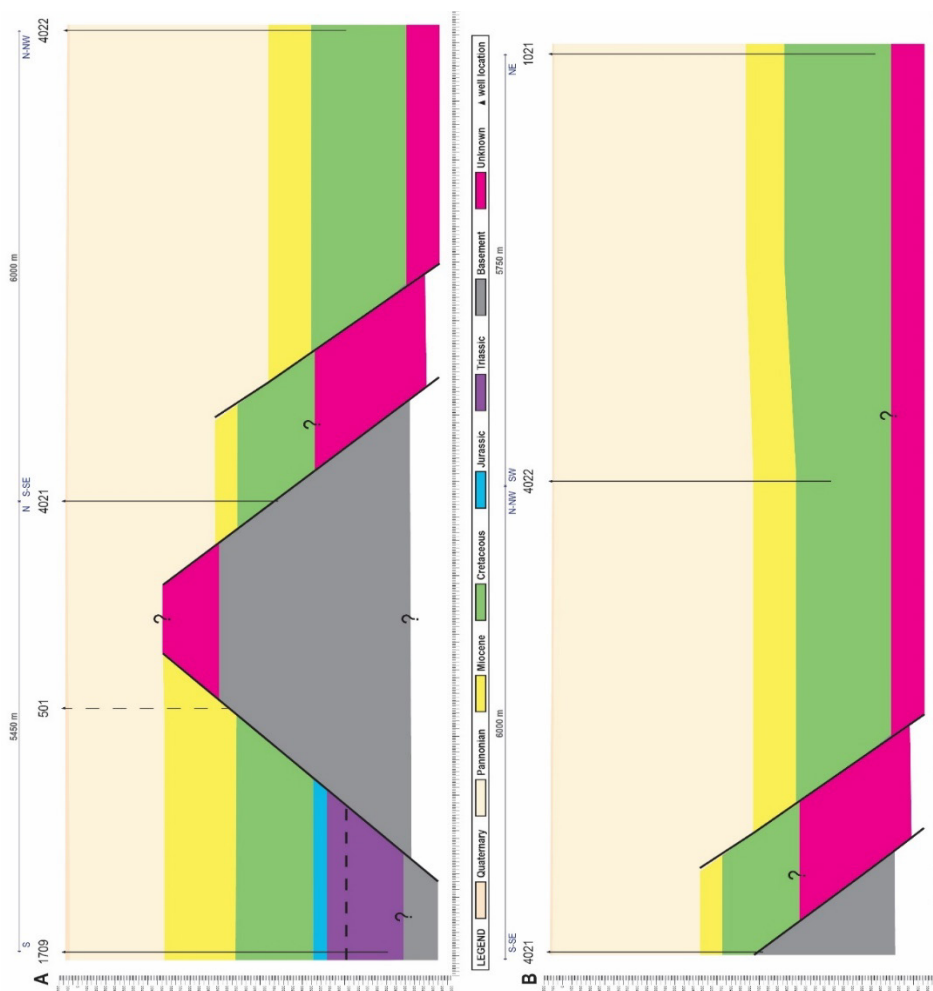


Fig. 7. Geological cross-sections: A = Borod Basin – Biharia Horst – Șimleu Basin (well points 1 – 2 (projected) – 3 – 4); B = Biharia Horst – Șimleu Basin (well points 3 – 4 – 5). ? = unknown. Scale bar in meters.

TRANSGEX SA enterprise data suggests that the water supply to the hydro-geothermal systems in the Neogene basins of northwestern Romania can follow two paths: one from the basin margins towards central areas, and the second from the depth. As far as the Șimleu and Borod basins are concerned, we can say with certainty that the fault areas around the Biharia Horst represent a water migration path from the surface to the underground. At the same time, we do not exclude the fact that the horst in question may harbor a magmatic body beneath it, intruding into the bedrock with remnant heat, or that it may lie just above the mantle. In the former case, only the presence of a batholith would be justifiable for the heat being distributed in the hydro-geothermal systems in the basins, while smaller sill, dyke or laccolith structures are excluded in this context, as they would have cooled faster over time and the heat would have dissipated. In the second case, another problem would be raised, namely that of the Bihor Unit, its thickness at bedrock level, at depth, and the lack of heat remaining towards the surface of the unit's margins. In this scenario, many unknowns remain to be solved: what is the age of the magmatic body, what was the scenario of its emplacement, which rocks are intruded and what are the thermal contact influences, etc.

Conclusions

Using data from four deep boreholes drilled by TRANSGEX SA and data from a borehole drilled by the Ministry of Petroleum, we were able to outline the approximate shape and size of the Biharia Horst on a south-north section, and the closest contact between this tectonic structure and the Neogene Borod and Șimleu basins. Since the interpretations made over the years on the Mesozoic deposits in the Șimleu basin have sometimes proved erroneous for various reasons, we leave open the option of the existence of a whole suite of Mesozoic sedimentation in this area.

The present paper underlines once more the missing Paleogene deposits in these boreholes. This detail is important for reconstructing the Paleogene

paleogeography and bio-events (e.g., Grande Coupure): it is obviously clear that this part of the Apuseni Mountains and the neighboring depressions were a wide terrestrial realm in the Paleogene, allowing the expansion of immigrants of Asian origin towards western Europe (Codrea & Fărcaș 2002; Fărcaș & Codrea 2004, 2005; Tissier et al. 2019; Codrea et al. 2019, 2022).

As far as the recharge of the hydro-geothermal systems of the Borod and Șimleu basins is concerned, we consider that the Biharia Horst is meaning a migration path of surface and meteoric waters towards depth, the horst most probably hosting underneath a batholith with remnant heat, partially intruded into the bedrock. The age, the extension and the heat of this presumed magmatic structure remain to be solved in future, based on geophysical data and more wells drilled for geothermal water and petroleum.

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