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3D modelling of the Nagymányok coal deposit *A nagymányoki szénlelőhely 3D modellezése*

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ABSTRACT

Accurate geological modeling is essential for effective resource estimation and minimizing mining risks. This study presents the digital processing and 3D modeling of the Nagymányok coal deposit in Hungary, integrating diverse data sources—literature, regional and historical mine maps, and borehole logs—to enhance understanding of the region's structure and lithology. The preliminary model also aims to identify and resolve discrepancies among various hand-sketched and digitized datasets.

Seventeen georeferenced elevation maps from previous deep-mining operations, alongside ten cross-sections, were digitized and unified using QGIS and Leapfrog Geo software to model geological structures, including faults. Drift maps and a digital elevation model were incorporated to represent topography. Borehole well data were also analyzed, focusing on gabbro and black coal, known for elevated concentrations of germanium (Ge) and rare earth elements (REE). Additionally, radiometric and geodetic datasets—including thorium, potassium, and uranium data from Hungary's Geophysical Map Series—were georeferenced and incorporated into a GIS project.

Despite data limitations and inconsistencies across datasets, the model reveals significant structural complexities, notably vertical displacements from multiple thrusts, impacting both resource potential and mining challenges. This study emphasizes the need for rigorous data validation to establish a reliable framework for ongoing improvements, supporting accurate resource management and effective mine planning in structurally intricate deposits like Nagymányok.

Keywords: 3D modelling, Nagymányok, Coal, Thrust Wedge, Hungary.

INTRODUCTION

Nagymányok has been intensively studied for its geochemical characteristics and mapping the rare metal content of the coal assemblage in the area since 1950 by Szádeczky-Kardoss E. & Földváriné V. M (Horváth, Dries, et al., 2013). The area was continuously studied by different authors as well (e.g., Csalagovits & Vighné, 1969; Földessy et al., 2013; Horváth et al., 2013; Némedi-Varga, 1995; Simon, 2023; Szakáll et al., 2003). Despite the long research history of the area, reliable, modern geological model of the area have not been created yet, and the integration of basic geological data is also have not been made yet as most of the study were focused more on the geochemistry of the area.

Hence, creating an integrated 3D model of the area is the main purpose of this research. On top of merging all the available data, a precise 3D model would allow us to see the discrepancies and limitations of the old maps that were created using a hand-sketches, therefore a more reliable and precise model can give us a better understanding of the area. Moreso, this model can be used as a basis for further evaluation for the next exploration project in the area.

Most of the datasets are provided by Calamites Kft. and some other datasets were gathered from an open-source database. The digitization of the datasets is mostly done by rectifying the old mine maps and regional geology maps into a single GIS dataset before it is transformed into a 3D geological model using Leapfrog Geo program. These maps can currently be handled freely in the QGIS software, and if necessary, they can be further digitized if their integration into a geological model becomes necessary in the future.

REGIONAL GEOLOGY

The Mecsek Mountains are located in the Baranya and Tolna counties, north of the city of Pécs, South Hungary. The Mecsek area formed during the early stages of the Alpine evolutionary cycle within the Tisza Mega-unit (microplate), located at the southern margin of the European continental plate, as part of the northern shelf of the Tethys Ocean. The Mecsek Zone experienced significant terrigenous influence from the Permian to the Middle Jurassic periods (Fig. 1). Following the filling of Permian continental rift basins, a relatively uniform ramp developed during the Middle Triassic.

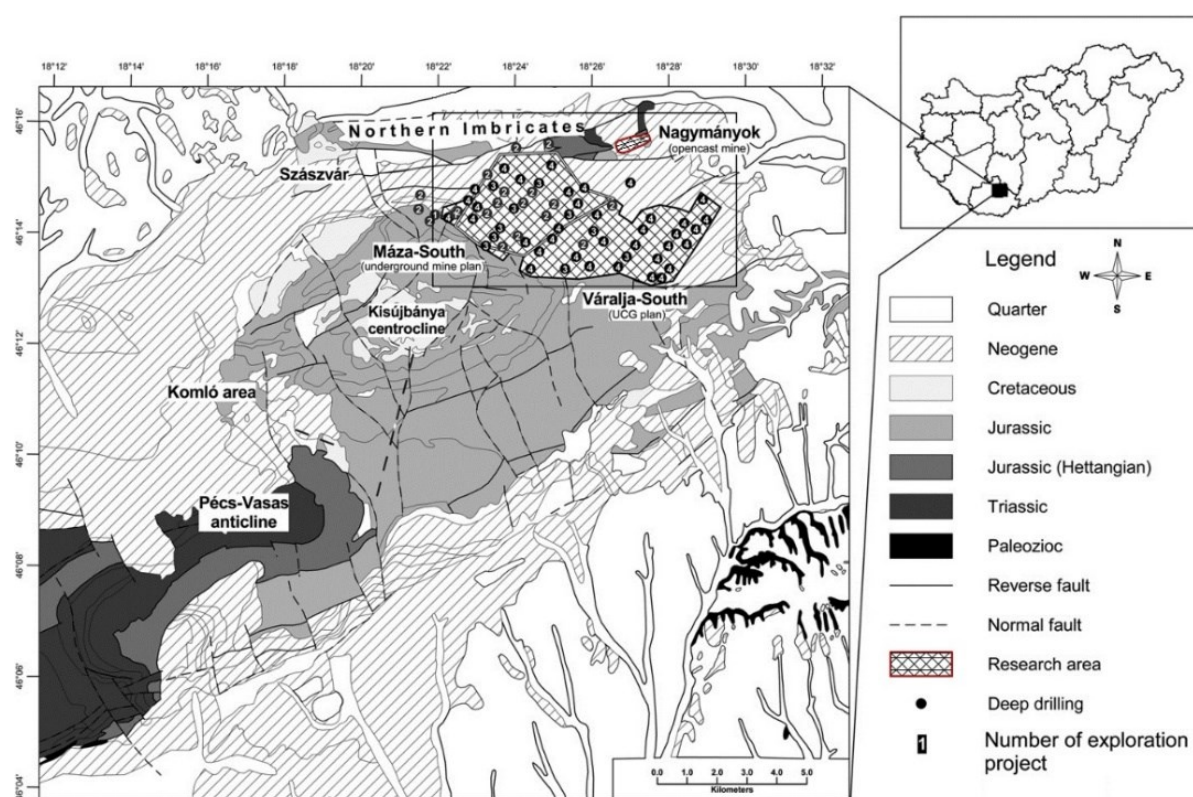


Figure 1. Simplified geological map of the Eastern-Mecsek area (after Püspöki et al., 2012).

Description of drilling exploration project is explained in the text (see The Máza-South structure on previous models' part).

Segmentation of this ramp in the Mecsek Zone began in the Late Triassic and became more pronounced by the Early Jurassic, resulting in a basement morphology characterized by a half-graben geometry (Szederkényi et al., 2012). Creating a region of uplifted Upper Paleozoic-Mesozoic block in the southwestern part of the Pannonian Basin (Tari, 1992). This half-graben geometry tilted the pre-existing carbonate and sandstone layers that form the Karolinavölgy Sandstone Formation, with the inclination of these layers ranging from 20° to

80°, depending on their position within the structure (Horváth, Dries, et al., 2013; ME Ásványtani-Földtani Intézet & Wildhorse Energy Kft., 2014). The coal basin comprises several sub-basins arranged from southwest to northeast in the following sequence: Pécsbánya, Szabolcs, Hosszúhetény, Vasas, Béta, Komló, and Váralja South (Horváth, 2014; Püspöki et al., 2012).

Stratigraphic Condition of the Mecsek Area

Mecsek Facies Unit

The Mecsek Coal Formation extends across the northeastern part of the Mecsek Mountains, from Pécs to Ófalu. During the late Rhaetian, thin coal interlayers appeared in the fluvial succession that began in the Early Triassic. These layers overlie the Karolinavölgy Sandstone Formation (deposited from the Carnian to the Rhaetian) and underlie the Vasas Marl Formation (Horváth, 2014; Horváth, Dries, et al., 2013; ME Ásványtani-Földtani Intézet & Wildhorse Energy Kft., 2014). At the onset of the Liassic, fluvial–lacustrine–palustrine sedimentation persisted, but paralic coal-swamp deposits became predominant (Mecsek Coal). The thickness of these coal-bearing series varies significantly (Horváth, Földessy, et al., 2013) (Fig. 2A): in the southwestern part of the Mecsek Mountains, the series can reach up to 1,200 meters, with 8–10% comprising workable coal layers (Horváth, 2014; Szederkényi et al., 2012). This thickness decreases towards the northeast, varying between 150 and 300 meters, with economically viable coal layers constituting 15–22% of the total thickness. In the Komló area, coal-bearing strata are 400–500 meters thick, whereas in the Szászvár-Nagymányok area to the north, they are only 150–200 meters thick (ME Ásványtani-Földtani Intézet & Wildhorse Energy Kft., 2014).

This asymmetrical thickening is attributed to the formation of an extensional half-graben structure (Fig. 2B), which is also evident in the Karolinavölgy Sandstone Formation (Nagy, 1969 in Szederkényi et al., 2012). Horváth et al., (2014) propose a different causative process for the significant thickness observed in the southward-dipping half-graben structure. The structure was further deformed by four main extensional and compressional phases during the Miocene, resulting in the current highly variable distribution of coal measures (Forgó et al., (1966) in Horváth et al., 2014). Additionally, Némedi-Varga (1995) explained that the Mecsek Coal Formation was segmented by normal faults, uplifts, and shearing.

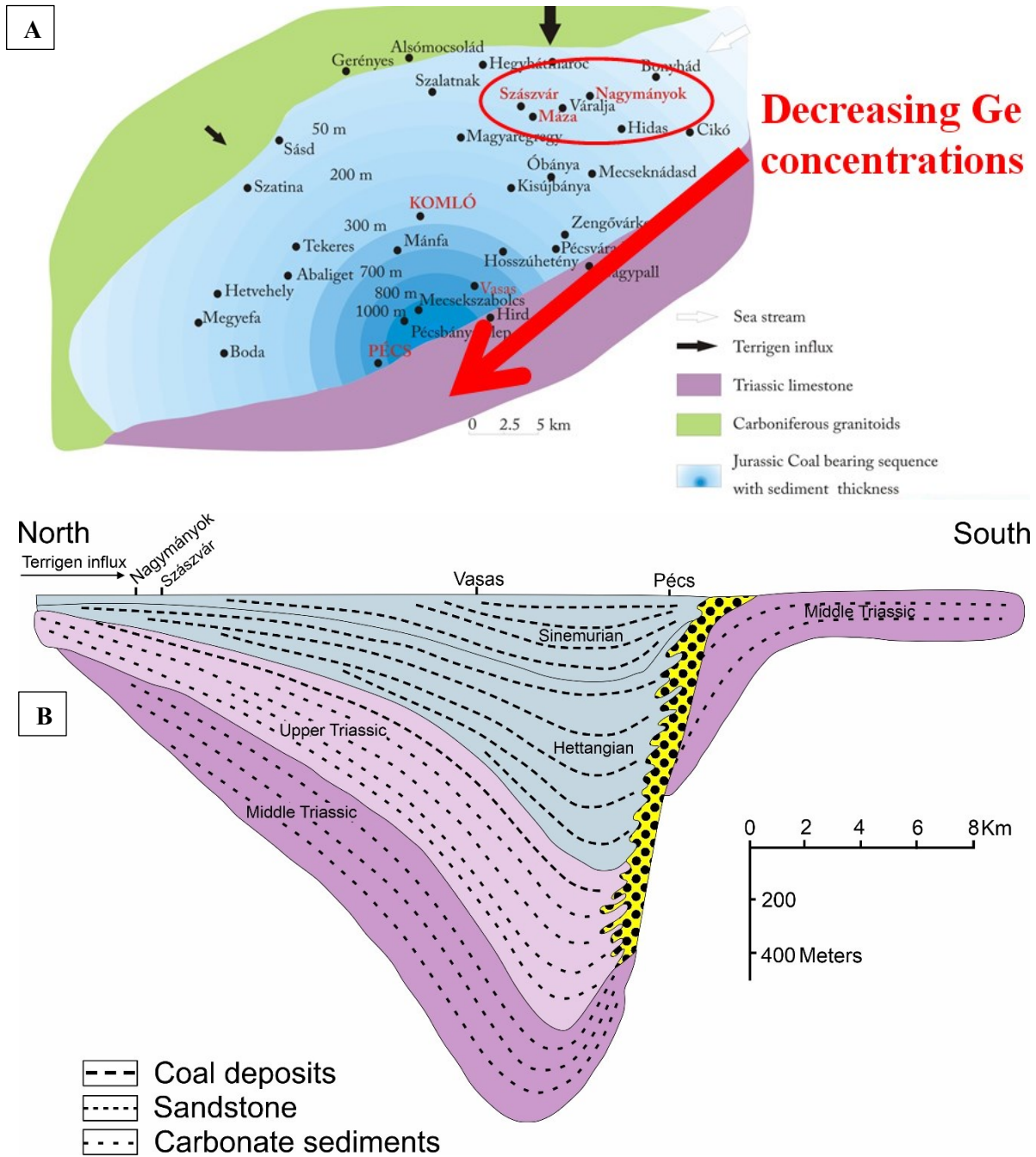


Figure 2. A. Territorial differences of different coal bearing sequence thickness and its position in the sedimentary basin with varying Ge concentrations (see Magmatism part for more explanation in decreasing Ge concentrations) (Horváth, Földessy, et al., 2013) and B. Schematic section of the sedimentary basin of the Mecsek Coal Formation (Horváth, Dries, et al., 2013).

The basal uppermost Triassic part of the Mecsek Coal Formation predominantly developed in lacustrine and lacustrine/deltaic facies (Fig. 3). The facies include fluvial environments with channels, flood plains, and swamps. However, moving upwards, the Hettangian middle member of the formation increasingly contains coquinas of brackish-water mollusks. Additionally, this member includes thin (0.5–1.5 m) rhyolitic tuffite interlayers (Némedi-Varga, 1983 in Szederkényi et al., 2012). During the Lower Sinemurian, the Mecsek Coal Formation might have been deposited in a tidal flat marsh environment, although some layers containing crinoids suggest temporary episodes of normal salinity conditions (Némedi-Varga, 1995).

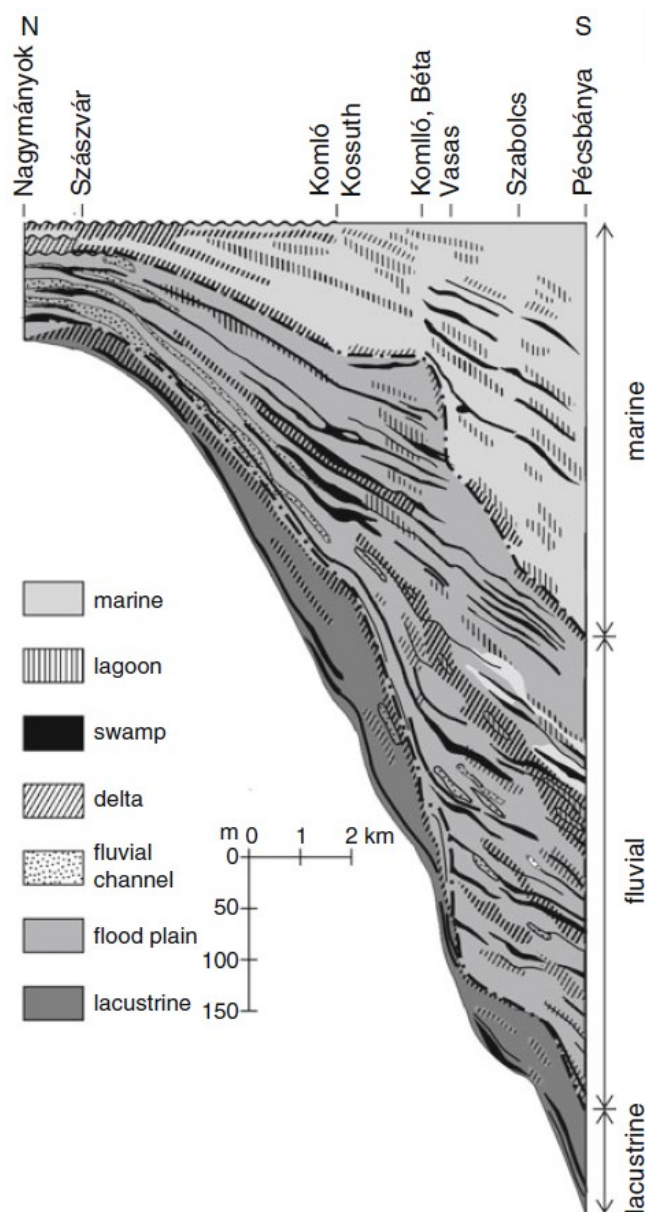


Figure 3. Variations in facies characteristics and thickness of the Mecsek Coal Formation in the Mecsek Mountains (after Nagy, 1969 in Szederkényi et al., 2012).

The entire sequence indicates gradual deepening and transgression. The rise in sea level likely led to a decrease in terrigenous input, and no deltas appear to have been located near the Mecsek Basin (Szederkényi et al., 2012). Basin-facies limestones were deposited from the middle of the Dogger to the end of the Jurassic (Horváth, Dries, et al., 2013). Nagy (1969) classified the formation into three divisions based on facies distinctions. The lower section exhibits lacustrine and alluvial freshwater facies, the middle section represents a transition from freshwater to brackish water facies, and the upper section shows paralic development. Similarly, Némédi-Varga (1995) as cited in Horváth (2014) categorized the Mecsek Coal Formation into three distinct groups based on their depositional environments and cyclic structure. The formation began in a limnic environment and gradually evolved towards a more paralic setting during the Hettangian. Thus, it is delineated as follows: the lower section deposited in a limnic environment (α -group), the transition zone from limnic to paralic (β -group), and the fully paralic environment (γ -group).

The lower (α) section dates to the Late Triassic Rhaetian age, with a thickness of approximately 100 meters. Within this, the α settlement group accounts for only 20 meters of coal, while the remaining 80 meters consist of barren lacustrine facies of gray-dark gray siltstone or sandstone. The middle (β) section, which is the thickest and most intensely tectonized, dates to the Early Liassic Hettangian age (Némédi-Varga, 1995). It predominantly comprises gray-dark gray claystone and siltstones, with subordinate occurrences of sandstones and greenish-gray siltstones, reaching a thickness of 90–100 meters. The coal seams in this layer are generally thinner and of lower quality, influenced by intercalated tuffite layers. The upper (γ) unit exhibits paralic development and belongs to the Early-Sinemurian stage of the Early Liassic. Its original thickness has been reduced due to erosion or tectonic thinning (ME Ásványtani-Földtani Intézet & Wildhorse Energy Kft., 2014).

The coal deposits in the Mecsek area and its surroundings range from lignite to bituminous coal and date to the Jurassic (Lias) period. The higher rank of these coal beds is attributed to thermal effects from intrusions of ultrabasic magmas into the underlying strata during the Early Cretaceous, along with folding and faulting during the Cretaceous period (Somos et al., 1985). The predominant types of coal in each well can be determined based on their volatile content and calorific value. However, Némédi-Varga (1995) concluded that the types and occurrence of coal in the Komló and Máza-South – Váralja-South areas are very similar.

Magmatism

The late intrusive magmatism in the area occurred from the Early Cretaceous to the Miocene (ME Ásványtani-Földtani Intézet & Wildhorse Energy Kft., 2014). This magmatism can be categorized as follows: (1) Late Triassic and Lower Jurassic volcanism, characterized by intercalated alkali basalt tuffs, which preceded the deposition of the coal-bearing sediments; (2) Lower Cretaceous intrusions of alkali basalt and phonolite, as observed in Pécs Vasas and Hosszúhetény; and (3) Paleogene-Neogene subvolcanic andesite intrusions, notably near Komló (see Fig. 1).

On the western margin of the region, the Cretaceous volcanism known as the Mecsek Alkali Basalt Formation consists of thick lava, tuff, and agglomerate. These volcanic materials occur sporadically within both the overlying and underlying formations of the coal layers, with varying frequencies in the coal formation itself, ranging from a few meters to 10–20 meters in thickness. According to drilling studies conducted by Némedi-Varga (1995), the occurrence of alkali basalt and phonolite veins varies between drill holes, typically with a total thickness ranging from 20 to 50 meters, occasionally displaying outliers. Many coal mines in the vicinity have encountered these volcanic rocks, which are partially or entirely coked (Némedi-Varga, 1995).

Towards the southwest boundary of the study area, phonolite intrusions have penetrated into the Middle and Upper Liassic formations of the Somlyó-Szamár hill (Némedi-Varga, 1995). The intrusion of alkaline basalt terranes into the coal deposits is believed to have contributed to a higher degree of coalification (Horváth, 2014). Moreover, the detrital material and the majority of rare metals (Be, Ga, Ge, Li, Mo, Nb, Pb, Sn, Ta, Tl, Zr) are thought to have originated from this geological process (Horváth, Dries, et al., 2013). Enrichment of such rare metals, especially germanium (Ge) can be found at the northern part of the area, especially at Máza-Szászvár-Nagymányok, as more carboniferous granites being exposed and weathering transports Ge from the north, hence enriched Ge concentration in the northern area (Horváth, Földessy, et al., 2013). Although, subsequent study done by Simon (2023) stated otherwise, a strong enrichment of K, U, Th, and Zr were found at the area affected the most by the anthropogenic activity on coal assemblages. Anthropogenic activities like coal assemblage milling, open pit mine, or even a debris dump believed to be the cause of “nugget effect” on such anomaly. Simon (2023) also confirms that the enrichment of REE and also the other above-mentioned rare metals are not derived from the volcanic rocks of Gyulakeszi Rhyolite Formation found at Közép-hill, which shows a weak thorium anomaly and did not differ from local averages.

Structural Regions of the Mecsek

The structure of the Eastern Mecsek Mountains is characterized by folded anticline–syncline formations, generally striking NE–SW. The limbs of the anticlines are intersected by north- and south-verging reverse faults. Additionally, perpendicular transverse faults further fragment these folded and faulted structures. Structural evolution during the Cretaceous to Paleogene periods led to uplift in the region's northern areas, resulting in the segmentation of coal deposits in the Máza-Váralja-South area (Debreczeni et al., 2018). The structural model for Máza-Váralja-South and its surrounding is based on the availability of deep drilling and seismic data.

Püspöki et al. (2012) outlined the main structural regions of the Eastern Mecsek Mountains as follows: (1) a broad anticline around Pécs-Vasas with a NE-dipping axis and a SE-dipping southern limb; (2) strongly folded structures around Komló, including anticlines, synclines, and steep reverse faults along the limbs; (3) a centrocline around Kisújbánya; (4) complex anticline–syncline folding at Máza-Váralja-South (MS–VS); and (5) the Northern Imbricates (NI), a highly folded and thrust-faulted belt from Nagymányok to Szászvár, regarded as the Mecsek's most structurally complex zone. This article focuses on the NI region at Nagymányok, as the presented 3D structural data centers on this area.

The Máza-South Structure on Previous Models

The structural conditions of Máza-South have been revisited nearly every decade since the 1960s. Forgács et al. (2011) reviewed the main stages of the area's structural model development along the SW-NE strike, assessing changes by comparing geological sections prepared by various authors:

1. **Gy. Wein (1962)** identified key structural displacements in the southern area based on limited borehole data, suggesting northward verging structures. From borehole M-5, he identified two distinct thrusts, while presuming additional ring structures to the north (Fig. 4A).
2. **Z. Némédi-Varga (1979)** confirmed the existence of uplift structures, noting two uplifts in the southern part with relatively stable conditions to the north. His model adjusted the previous interpretation by assigning a westward vergence to the twofold thrusts based on boreholes M-15 and M-5 (Fig. 4B).
3. **T. Szilágyi (1985)** expanded on these findings, using boreholes M-19, M-25, and M-27 to identify northward-vergent uplifts in the southern area. His model proposed a

fourfold imbricate structure based on observed stratigraphic repetitions, while suggesting a stable layer sequence in the north (Fig. 4C).

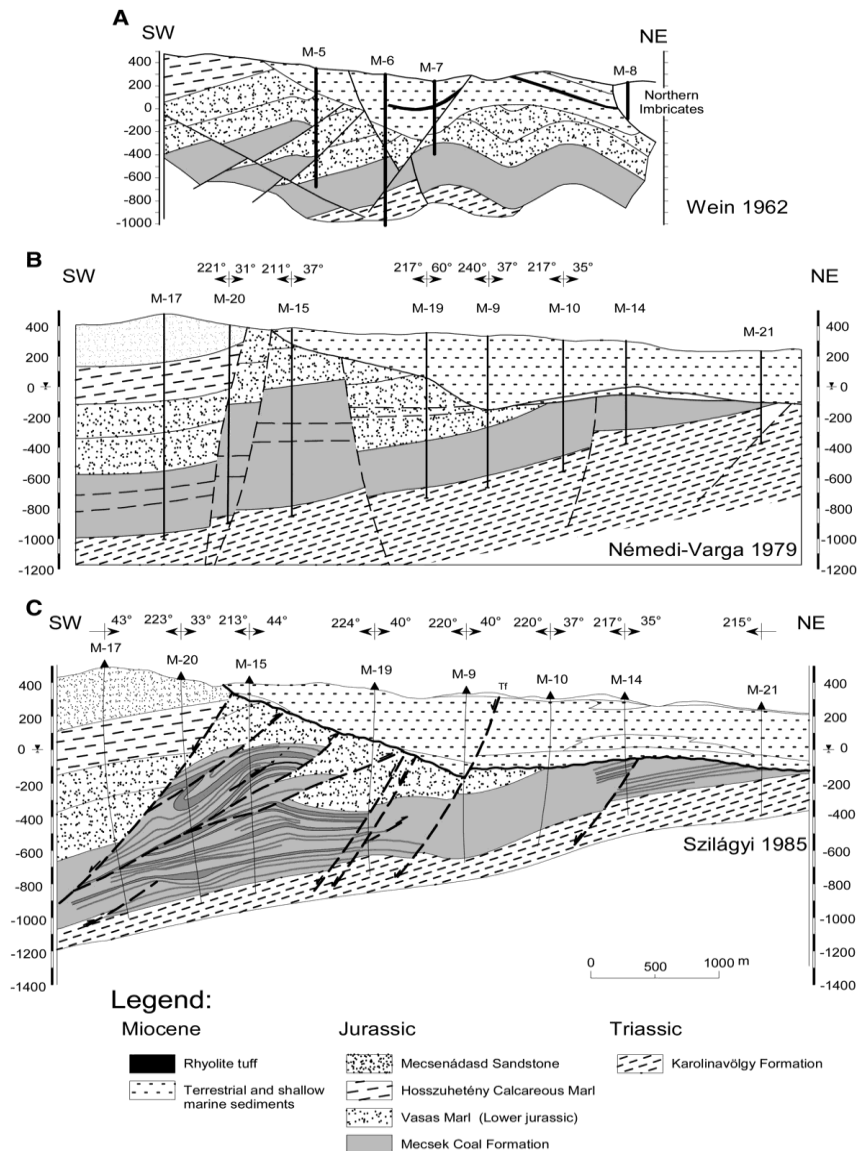


Figure 4. The structural relations of Máza-South as interpreted by different authors (compiled after Debreczeni et al. 2018; Forgács et al. 2011; Püspöki et al. 2012).

Structural Model of The Northern Imbricates (NI)

The first unified structural interpretation of the Northern Imbricates (NI) was proposed by Tari (1992), who reinterpreted the bidirectional reverse fault system as a flower structure associated with transpression (Fig. 5A). Although initial thrusting of the area already proposed by Vitális, (1939), and further developed by Wein (1965, 1967). Given the northward thrusts in the Máza-Váralja-South (MS–VS) area, an alternative interpretation of the NI is possible, attributing it to compressional forces. Figures 5B and 5C illustrate re-interpretations that view the bidirectional reverse fault system as comprising fore- and back-thrust elements.

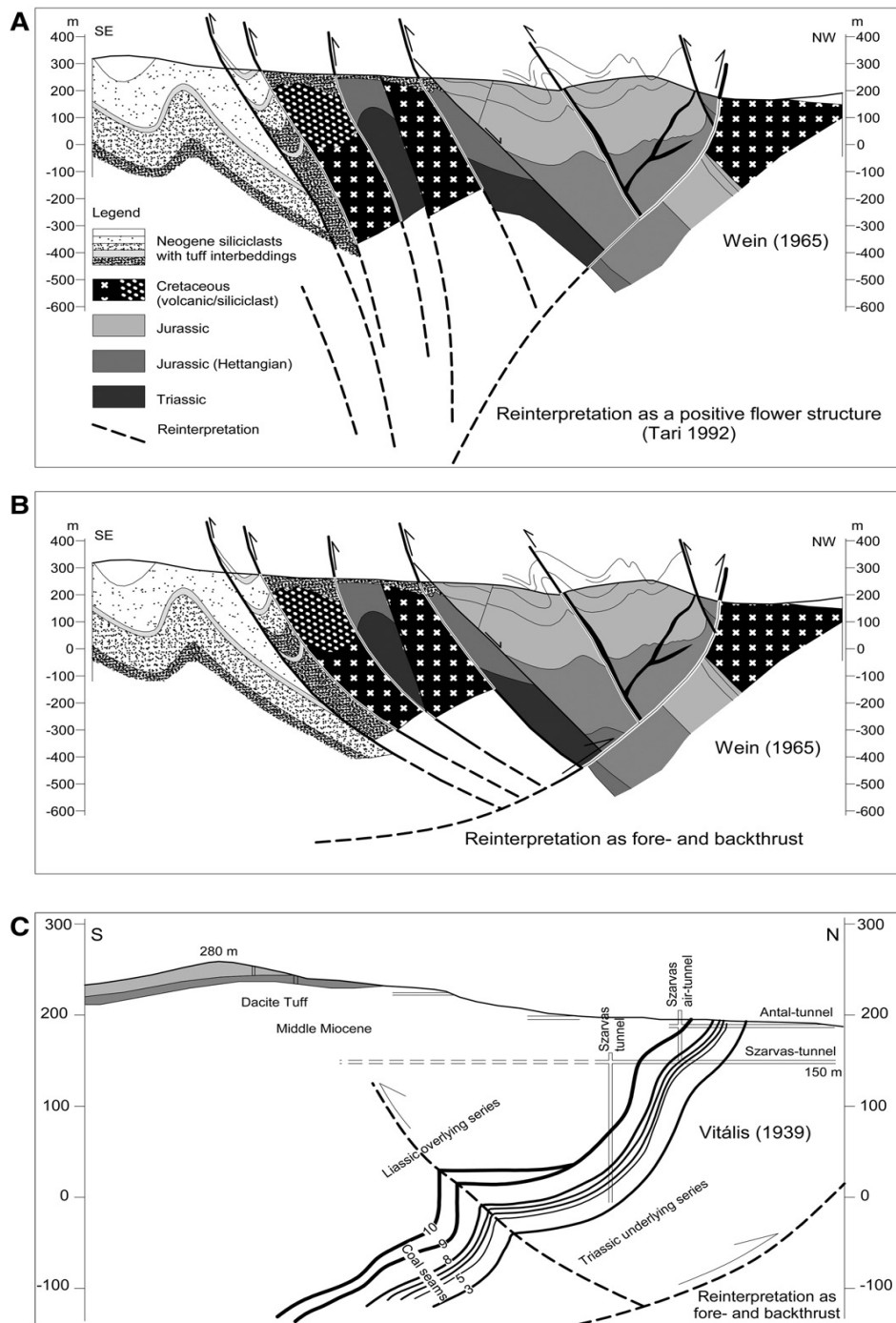


Figure 5. Reinterpretations of geological cross-sections in the Northern Imbricates as interpreted by different authors (compiled after Püspöki et al. 2012).

METHODS

Most of the works are done by analyzing and interpreting secondary data through literature review and combining old regional geology maps. Such works also combined with selecting useful data from previous exploration projects done by Calamites KFT, like old mine maps and several boreholes' data. As most of the data have not been digitized earlier, therefore, rectifying and compiling such data into one single GIS format is necessary to have more integrated datasets. Other than that, geological logs scanned from paper for deep boreholes with the codes Nm-13, Nm-14, Nm-15, Nm-16, Nm-17, Nm-18, and Nm-20 were summarized into basic well data (Appendix 1, Table 1). This summary focused on favorable units such as gabbro (Gabbro) and black coal, or mixtures of these lithologies with other types, like carbonaceous claystone or clayey bituminous coal, as they are the main object of interests that is believed to contained the high concentrations of germanium (Ge) and rare earth elements (REE).

In the regional overview, the thorium, potassium, and uranium data from the Geophysical Map Series of Hungary were georeferenced. The geophysical map series also integrate previous works by Simon (2023) regarding the digitization of the area and a newly added instrumental measurements using a gamma spectrometer and a hand-held XRF instrument. Additionally, the map includes a switchable background layer featuring the 1:100,000 Geological Map of Hungary L-34-61 (Pécs), which offers a high-quality, modern representation of the geological environment. For a comprehensive topographical overview, a contour line raster of the area has also been incorporated beneath the map.

Additionally, 17 level maps were georeferenced, based on data from the former deep-mining operations, each representing different elevation levels. These maps were digitized in QGIS software and incorporated into the Leapfrog Geo program to create a geological model, alongside 10 cross-sections that were also digitized. Furthermore, drift maps were digitized in Leapfrog Geo to represent drifts at various elevation levels. The digital elevation model was also included in the geological model to depict the topography of the mapped area.

RESULTS AND DISCUSSION

The 3D modeling of the Nagymányok coal deposits began with the creation of a unified QGIS project incorporating available maps, including the elevation map of the Nagymányok mine (Fig. 6), Drift Map (Fig. 7), Regional Geology Map of the Mecsek Area, Geological Map of the 150 m level of the Rezső and Szarvas mines (Fig. 8), as well as a heat map of K, Th, and U radiometric measurements, and the digital elevation model of the Nagymányok area.

Digitizing the elevation map required meticulous care, as most maps provided by Calamites Kft. were hand-drawn and thus susceptible to misalignments or shifts in lines representing lithologies or faults. In Figure 6, an overlay of the +165 m, +180 m, and +195 m elevation maps shows noticeable shifts in the fault lines. If these shifts result from the fault dip geometry, such discrepancies are acceptable. However, some fault lines cross themselves, changing direction, which could create distinct orientation errors when modeled in 3D software.

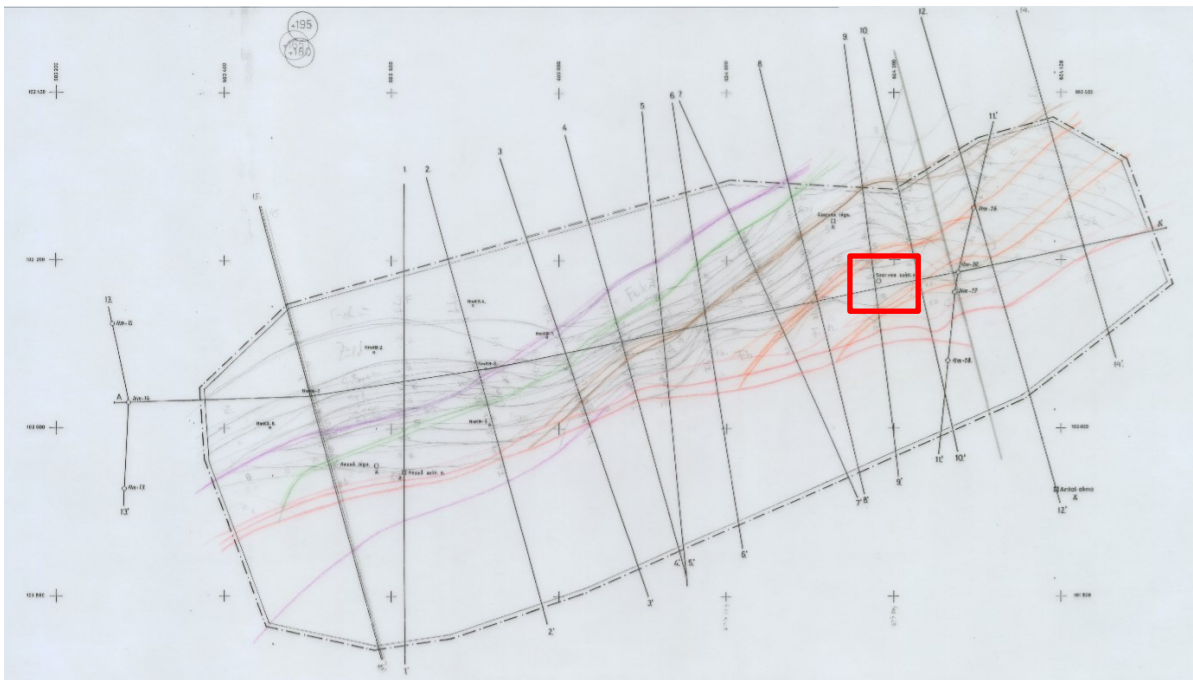


Figure 6. Scanned elevation map of the Nagymányok coal deposits (+165 m, +180 m, and +195 m) displays the lithological sequence of the Mecsek Coal Formation along with cross-cutting faults (used with permission from Calamites Kft.). The red-squared area highlights a distinct orientation in the fault line.

Similar discrepancies are evident in the drift map of the Nagymányok coal deposits when overlaid with the elevation map (Fig. 7B) and the regional geology map of Mecsek (Fig.

7C). These inconsistencies could lead to varying interpretations of the geological or mining model, creating uncertainty about which map should serve as the benchmark for further 3D modeling.

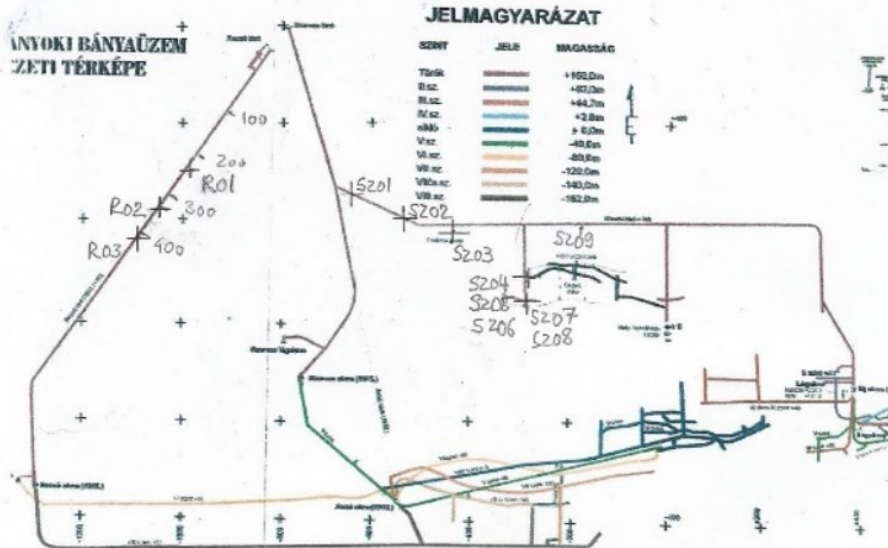
A

Térképmelléklet

NYOKI Bányászati ZETI TÉRKÉPE

JELMAGYARÁZAT

SZINT	JEL	MAGASSÁG
Török		+160,0m
II.sz.		+157,0m
III.sz.		+144,7m
IV.sz.		+12,8m
V.sz.		+10,0m
VI.sz.		-40,0m
VII.sz.		-120,0m
VIII.sz.		-140,0m
IX.sz.		-162,0m



B



Figure continues in next page

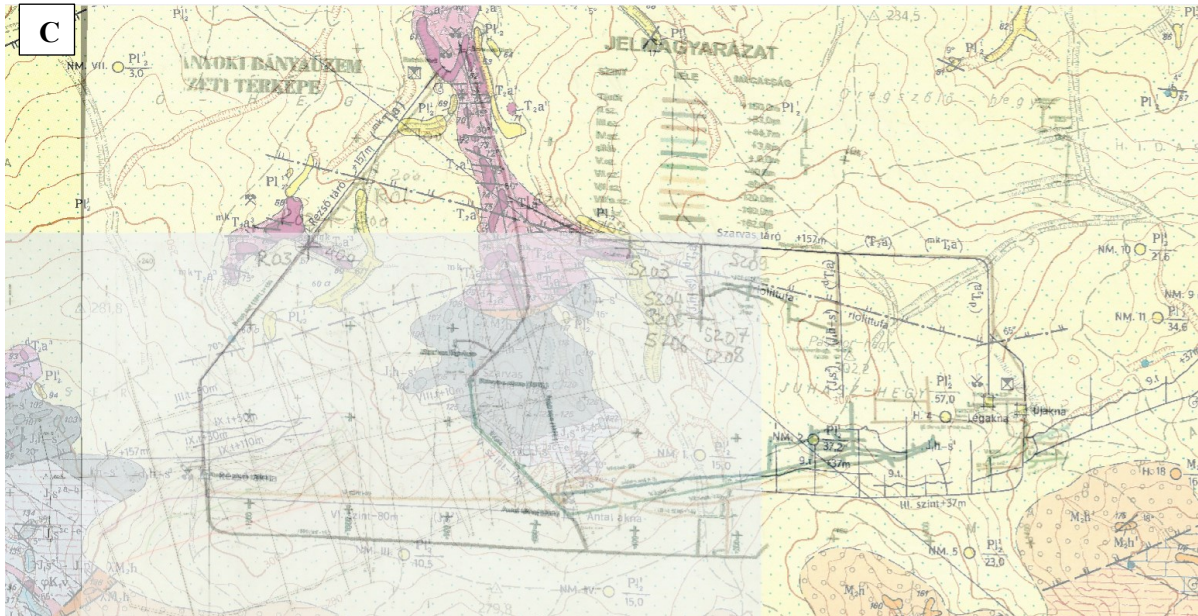


Figure 7. A. Scanned Drift Map of the Nagymányok coal deposits illustrate the drift at each elevation level (used with permission from Calamites Kft.). B. Notes there is misalignment between the drift map and the shaft locations indicated on the elevation map. C. While some sections of the drift map align with the Regional Geology Map of Mecsek, other drift sections are absent from the regional geology map, highlighting inconsistencies between these sources.

Another mismatch is observed in the Geological Map of the 150 m level of the Rezső and Szarvas mines, as it cannot necessarily be used as a benchmark for comparison with other maps to identify discrepancies (see Fig. 8).

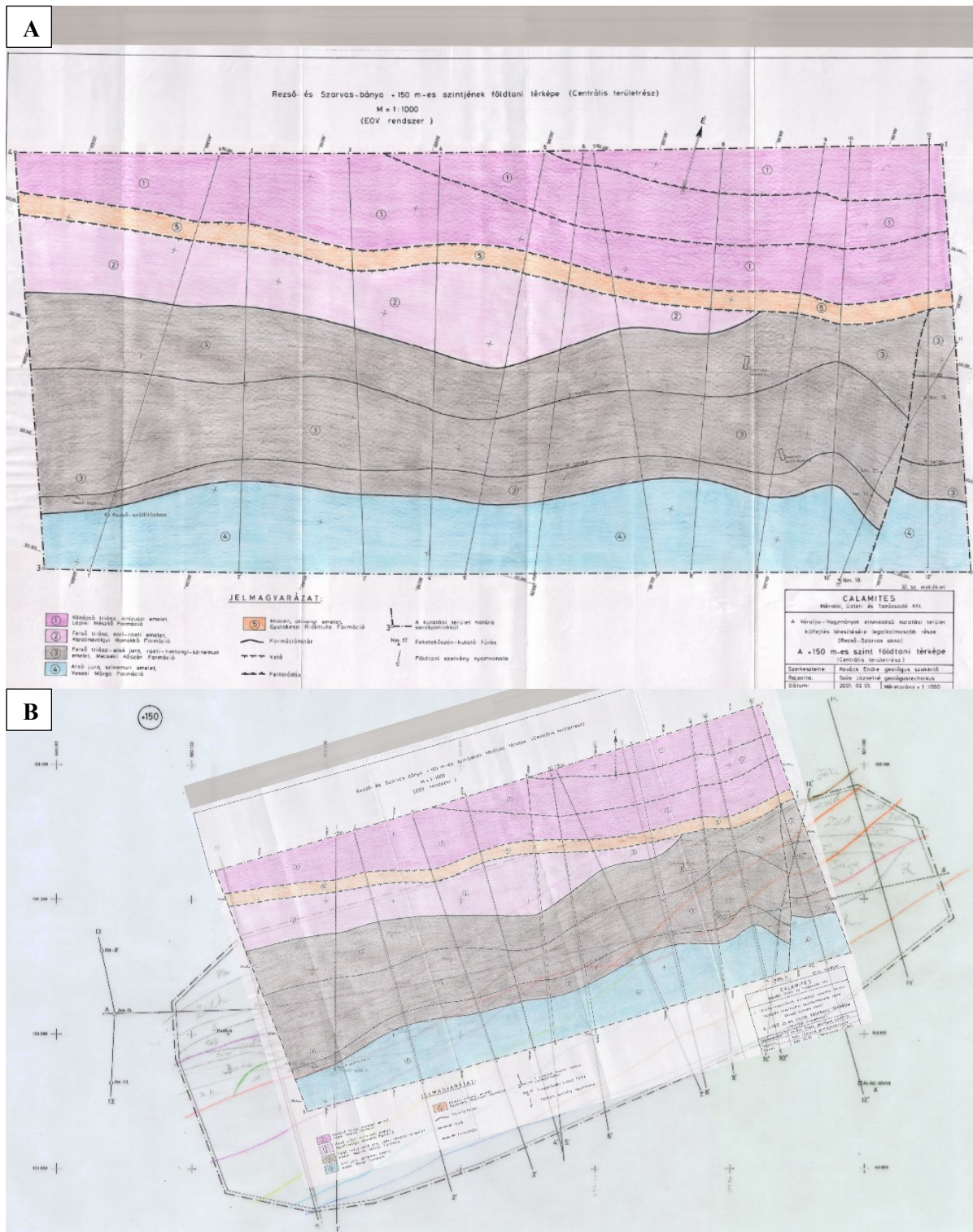


Figure 8. A. Scanned geological map of the 150 m level of the Rezső and Szarvas mine (used with permission from Calamites Kft.). B. Geological Map of the 150 m level of the Rezső and Szarvas mine overlaid on the +150 m elevation map of the Nagymányok coal deposits. This comparison highlights the significant differences between the surface geological map and the elevation map at the same level.

3D Modelling

The challenge in integrating all available datasets into a single map, as discussed in previous steps, lies in the absence of a benchmark geological map for the lithology block model, due to the limited and scattered lithology data from drillhole analysis. As a result, the available datasets can only support or initiate a preliminary 3D model of the area, primarily for constructing the fault model. However, this approach carries some caveats, as the existing fault data is based on a hand-drawn map without structural measurement data. Despite this, the cross-sections (Fig. 9) and elevation maps are well-distributed, providing useful input for the model.

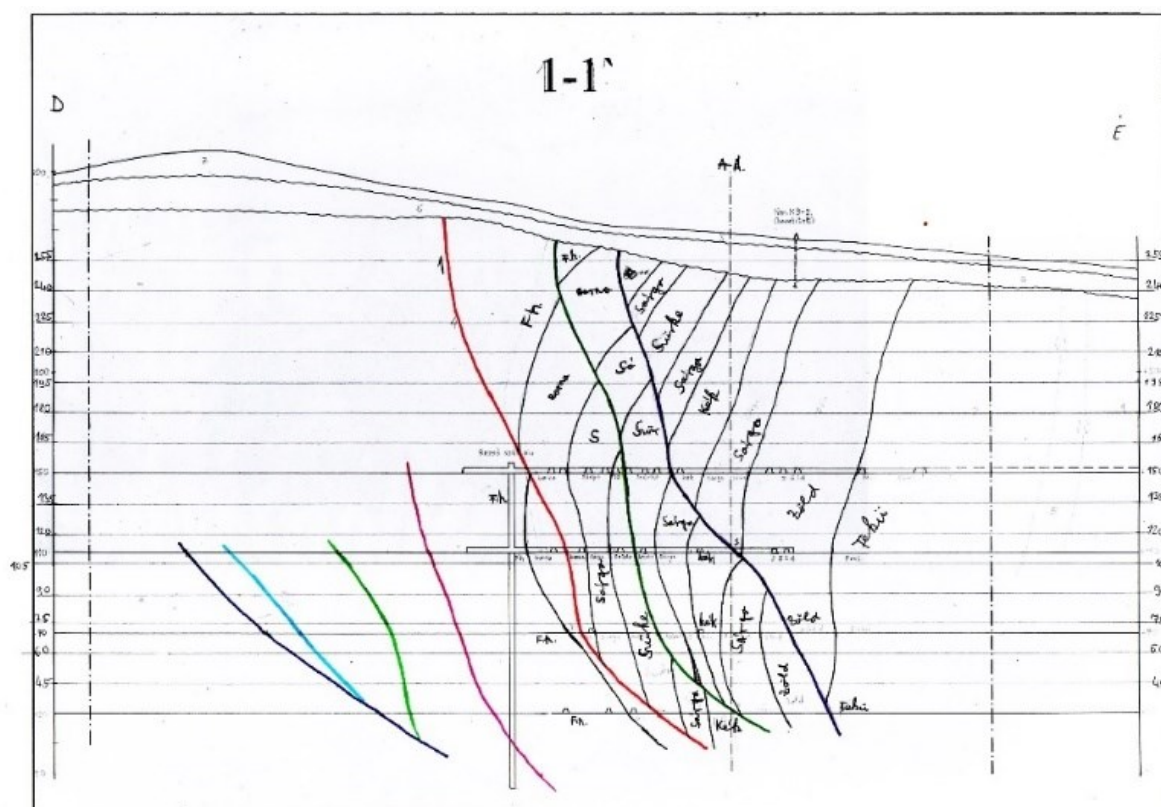


Figure 9. Scanned cross-sections of 1-1' for the elevation map of Nagymányok coal deposits
(by permission of the Calamites Kft.).

The data included in the Leapfrog Geo program consist of the elevation maps, cross-sections, digital elevation model of the Nagymányok coal deposits, and the drift map, as these are the available datasets that can support the initial creation of a 3D model for the Nagymányok coal deposits. The Regional Geology Map of Mecsek serves as the ‘benchmark’ to assess the fault line trend. All digitized elevation maps are inserted into the program at their respective elevations, along with the cross-sections, which can be easily digitized using markers such as shafts at specific depths or boundary lines that define the end of the cross-

section and the study area (Fig. 10). Given this approach, it is expected that there will be some 'shift' during digitization, and no specific acceptable error margin has been established, as such parameters may not always be accurate.

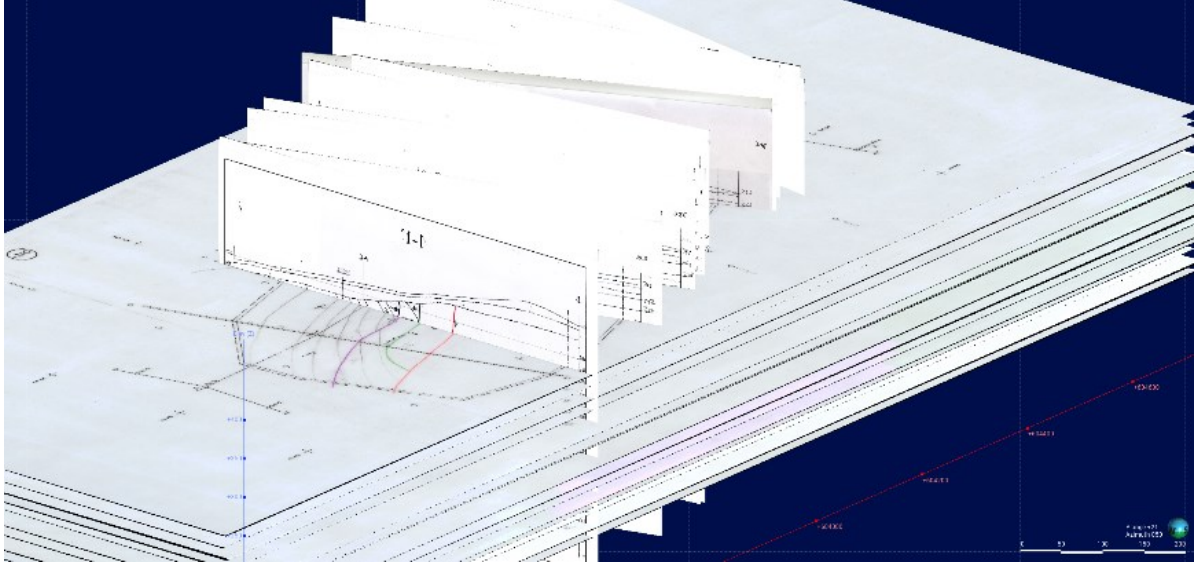
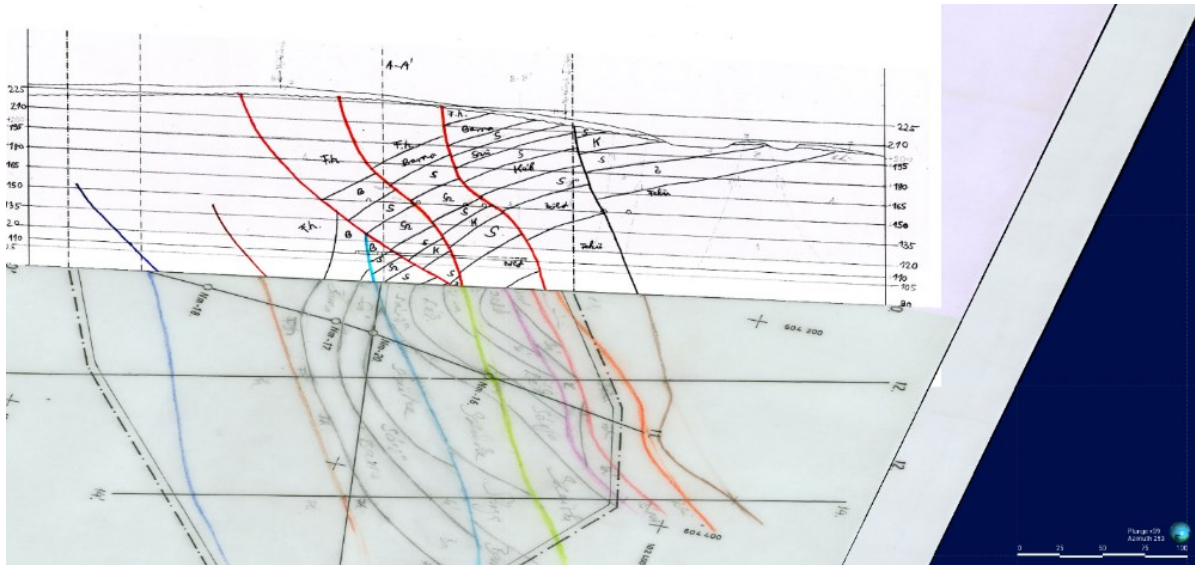


Figure 10. Stacked elevation map along with the adjacent cross-sections of the Nagymányok coal deposits in Leapfrog Geo program.

The discrepancies in the previously mentioned fault line at each elevation level become evident when the maps are overlaid and crosscut with the cross-section (Fig. 11). Not only does the fault line drift between the elevation map and the cross-section, but there are also several additional fault lines in the elevation map that do not have corresponding counterparts in the cross-section. Furthermore, the different coloring of the fault lines has caused confusion when constructing the fault planes.



Since no structural measurements are provided for each cross-section, the polarity of the ‘structural discs’ in the Leapfrog Geo program is determined based on the visual representation of the fault line in each cross-section. For areas between cross-sections, the orientation of the structural discs is highly interpretative, relying on the nearest cross-section as a visual reference point (Fig. 12). Additionally, the fault line chosen for modeling is based on the fault that is consistently represented across the cross-sections, while smaller, parallel fault lines are neglected in favor of the ‘major’ fault.

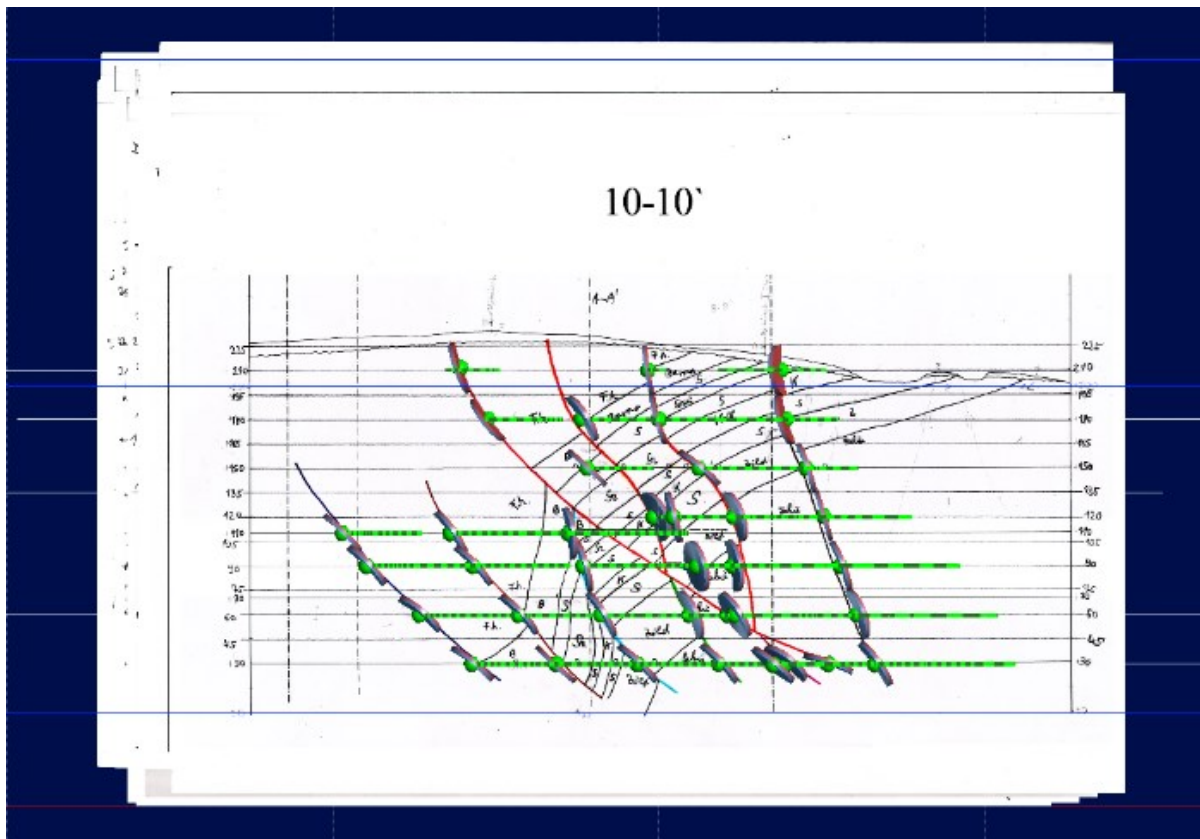


Figure 12. Structural discs and lines representing the structural properties and measurements of a fault in the cross-section.

The extrapolation of the structural discs results in a fault plane that follows the orientation of each structural disc in a continuous line, which dictates the geometry of the fault plane (Fig. 13). However, when superimposed with the cross-sections, it becomes evident that the fault plane is extrapolated to a certain degree and does not necessarily align with the projected fault line in the cross-section (Fig. 14).

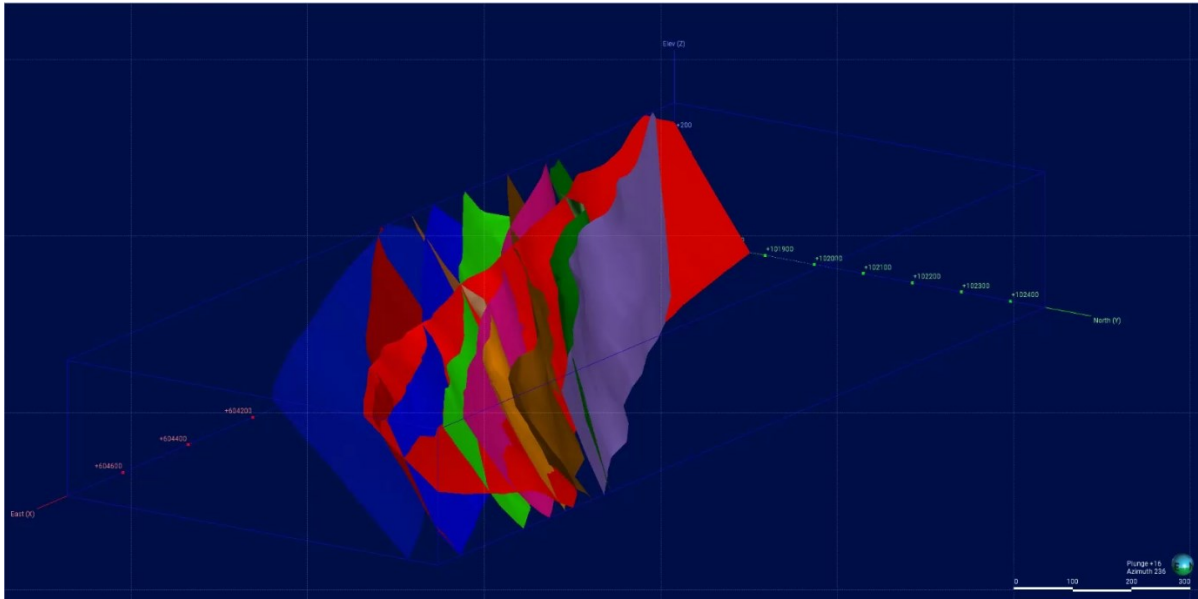


Figure 13. Constructed 3D fault planes of the Nagymányok coal deposits.

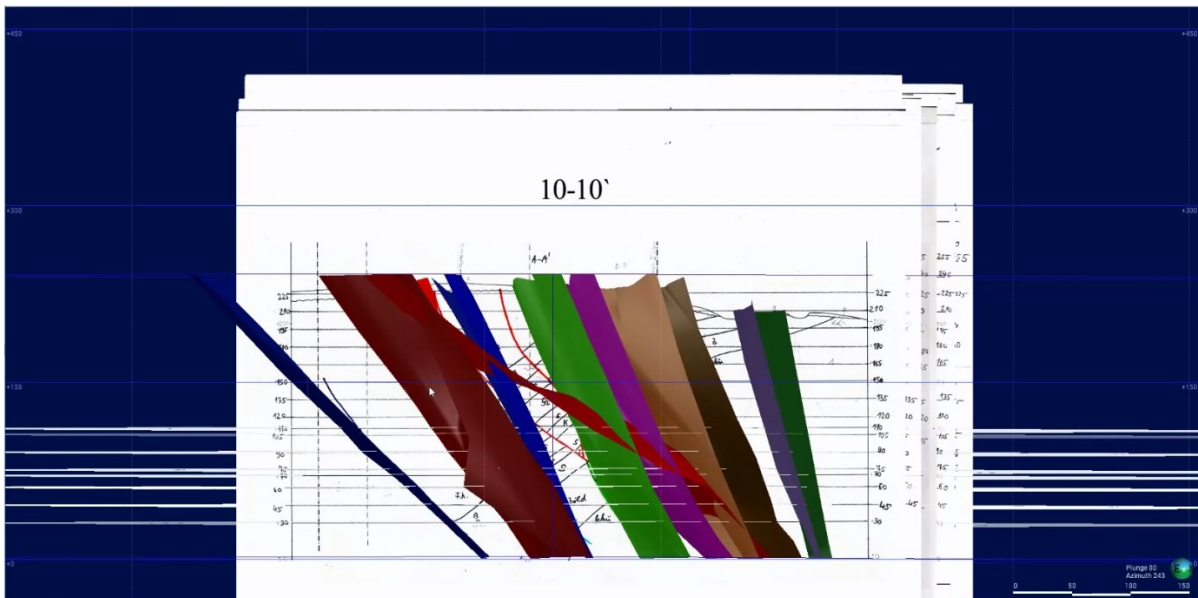


Figure 14. Constructed 3D fault planes of the Nagymányok coal deposits superimposed to cross-sections and the elevation map.

Structural Model Discrepancies and its Consequences

Initial ground measurements, along with drillhole analysis in the Northern Imbricates area, suggest a multiphase thrust wedge development of the Mecsek Coal Formation, resulting in vertical displacement due to sequence thrusts and back-thrusts that accommodated shortening during the Cretaceous–Paleogene period, as shown in Figure 9. This displacement significantly increased the amount of coal available for mining, thereby enhancing its inferred resources (Püspöki et al., 2012). However, the increasing complexity of the stratigraphic and structural conditions will pose greater challenges. Therefore, careful planning and a detailed,

regulated exploitation program are essential to ensure the development of a reliable mine plan, which in turn depends on an accurate geological model.

Vertical displacement will also lead to large-scale settlement repetitions, increasing the coal thickness in localized areas. However, the back-thrust will disrupt modeling and mining activities by fragmenting the coal seams, potentially causing stronger deformation (Debreczeni et al., 2018). The complex structure in this area does not necessarily explain the enrichment of the Mecsek Coal Formation, although such structures could provide a potential pathway. No study has definitively proven this hypothesis, as the neighboring granitic rocks may be the primary cause of the enrichment (Horváth, 2013; Horváth et al., 2014).

Further lithology modeling can be incorporated into the model if additional data, such as drilling information, become available. Lithology data included in the cross-sections can also be used, although the validity of such interpretations may be questioned. However, it is noted that several well logs, such as those for Nm-15 and Nm-18, do not include these lithologies. The distribution of well log data is insufficiently widespread to cover the entire mapped area. Consequently, importing this data into the Leapfrog Geo program is unlikely to produce a useful model. Additionally, drift map is included in the model to better illustrate how the fault planes are affecting the drifts (Fig. 15). The Rezső shaft does not cross-cut the fault planes; however, the drift does intersect the fault planes, similar to the Szarvas's shaft and its drift.

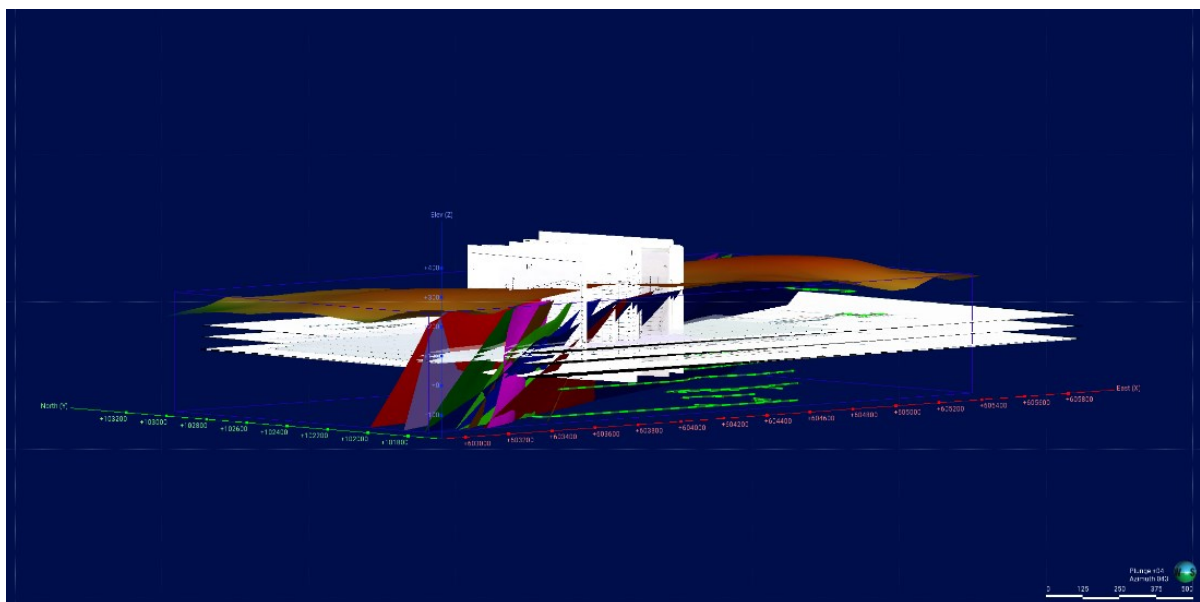


Figure 15. Compiled image of Nagymányok area modelling in Leapfrog Geo program.

SUGGESTION FOR FUTURE STUDY

The lack of a benchmark map and cohesive datasets presents a significant challenge for generating a reliable model essential for further investigation and informed decision-making. As the 3D model of the area was developed and archived datasets from Calamites Kft. were reviewed, inconsistencies and a lack of continuity between initial exploration data and more recent reconnaissance studies became apparent. Establishing an organized and coherent dataset would greatly facilitate the digitization process. Moreover, existing datasets are poorly integrated; for instance, drill logs and geochemical sample locations are not consistently represented on the provided elevation maps, and some digitized cross-sections do not align with available elevation maps, making it necessary to rely on hand-drawn maps and cross-sections. Rather than initiating a new study, a thorough verification of existing data is recommended to identify and resolve discrepancies, thus creating a more reliable, cohesive dataset for future modeling.

A detailed structural analysis of the 3D model would provide an easily interpretable initial geological framework, particularly valuable in this structurally complex area. Incorporating lithological and geochemical data from drilling into the 3D model would enhance understanding of the deposits and support a more comprehensive geological model, crucial for future exploration activities, especially in evaluating trace metal extraction from coal seams.

CONCLUSIONS

The Nagymányok area's substantial structural complexity—characterized by vertical displacements from multiple thrusts and back-thrusts—results in vertical stacking and repetition of coal seams, which enhances inferred coal resource potential. To effectively manage this complexity, a cohesive integration of available datasets is essential, as it enables better planning for exploration and future mining operations. Digitizing hand-drawn maps and incorporating measured orientations of coal seams and other structural data would help reduce misalignments and inaccuracies. However, the scattered and incomplete nature of lithological data from drillholes, elevation maps, and cross-sections constrains the accuracy of the 3D model, leading to a high degree of uncertainty. Without a reliable benchmark, building a precise structural and lithological framework remains challenging.

Further validation of hand-drawn maps, combined with the integration of borehole data, lithology descriptions, and geochemical measurements, would greatly enhance the model's accuracy. Adding a detailed lithological model could clarify the distribution of coal and trace elements within the deposit, potentially identifying zones with high concentrations of economically valuable germanium (Ge) and rare earth elements (REE). This approach would also support preliminary testing of the hypothesis that coal seams act as host rocks for these elements, laying the groundwork for targeted exploration.

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APPENDIX

Table 1. Basic Well Data for Coal and Gabbro at Nagymányok.

Name	Coordinates (in HDR)		Lithology	Depth	Apparent Thickness	True Thickness	Inclination
Nm-13	X	-76018.40	Gabbro	31.5–32.7	1.2	0.41	
	Y	46722.29	Gabbro	39.20–40	0.8	0.27	
	Z	238.21	Coal Bearing Clay Contact	40.30–43.80	3.5	1.2	
			Gabbro	43.80–44.20	0.4	0.14	
Nm-14	X	-76120.43	Interbedded Carbonaceous Claystone	2.9–3.1	0.2	0.19	
	Y	46716.96	Gabbro	20.80–22.40	1.6	0.8	
	Z	248.63	Gabbro	38.2–40.9	2.7	1.35	
			Bituminous Coal	46–46.9	0.9	0.45	
			Bituminous Coal	47.8–48	0.2	0.1	
			Clayey Bituminous Coal	48.6–48.9	0.3	0.15	
			Bituminous Coal	48.9–49.6	0.7	0.35	
			Bituminous Coal	50.2–51.8	1.6	0.8	50
			Bituminous Coal	52.8–53.4	0.6	0.3	
			Bituminous Coal	56.4–56.7	0.3	0.15	
			Broken Gabbro + Organically Colored Claystone	56.7–56.85	0.15	0.08	
			Bituminous Coal	56.9–57	0.1	0.05	
			Bituminous Coal	62.4–63	0.6	0.3	
			Carbonaceous Claystone	63.1–63.3	0.2	0.1	
			Clayey Bituminous Coal	63.3–63.4	0.1	0.05	
			Bituminous Coal	64.6–64.7	0.1	0.05	
			Bituminous Coal	66.9–67.4	0.5	0.35	
Nm-15	X	-76213.47	None				
	Y	46736.49					
	Z	254.22					
Nm-16	X	-76351.20	Clayey Bituminous Coal	22.5–22.8	0.3	0.19	
	Y	45708.73	Carbonaceous Claystone	22.8–22.85	0.05	0.03	
	Z	209.24	Clayey Bituminous Coal	22.85–23.10	0.25	0.16	
			Bituminous Coal	43.8–44.2	0.4	0.31	
			Clayey Bituminous Coal	44.2–44.7	0.5	0.38	
			Bituminous Coal	44.7–45.20	0.5	0.43	
			Gabbro	45.4–45.7	0.3	0.26	
			Gabbro + Organically Colored Claystone Contact	45.7–45.85	0.15	0.13	
			Clayey Bituminous Coal	46.9–47.1	0.2	0.17	
			Bituminous Coal	56.4–57	0.6	0.56	
			Carbonaceous Claystone	71–73.6	2.6	2.44	
Nm-17	X	-76251.43	Gabbro	47.2–47.4	0.2	0.1	

	Y	45730.66	Bituminous Claystone	50.2–50.4	0.2	0.1	20 - 50
	Z	219.71	Clayey Bituminous Coal	50.4–50.8	0.4	0.2	
			Gabbro	56.5–57	0.5	0.38	
			Old Operation/Mixture of Loose Rich Coal Block Material & Carbonaceous Claystone, Soft Gabbro	57–57.2	0.4	0.31	
			Clayey Bituminous Coal	57.2–57.3	0.1	0.08	
			Gabbro	57.3–57.4	0.1	0.08	
			Clayey Natural Coke	57.4–58.4	1	0.77	
			Old Operation/Mixture of Clayey Pulverized Black Coal and Claystone	60.4–60.6	0.2	0.15	
			Old Operation/Fragment Material and Powdered Black Stone and Claystone	61.5–62	0.5	0.38	
			Bituminous Coal	62–62.2	0.2	0.15	
			Old Operation/Carbonaceous Claystone	65.4–66	0.6	0.42	
			Bituminous Coal	66.4–66.8	0.4	0.31	
			Carbonaceous Claystone	68.3–68.9	0.6	0.46	
			Bituminous Coal	73.10–73.5	0.4	0.31	40
			Clayey Bituminous Coal	73.5–77	3.5	2.68	40
			Bituminous Coal	77–77.2	0.2	0.15	
			Clayey Bituminous Coal	77.2–78.8	1.6	1.23	
Nm-18	X	-76169.61	None				
	Y	45.735.72					
	Z	222.73					
Name	Coordinates (in EOVS)		Lithology	Depth	Apparent Thickness	True Thickness	Inclination
Nm-20	X	102185.27	Bituminous Coal	26–26.2	0.2	0.19	
	Y	604276.08	Clayey Bituminous Coal	27.1–27.8	0.7	0.66	
	Z	218.5	Bituminous Coal	28.3–28.5	0.2	0.19	
			Bituminous Coal	29–29.15	0.15	0.14	
			Bituminous Coal	29.55–29.8	0.25	0.23	
			Bituminous Coal	30.6–30.7	0.1	0.09	
			Clayey Bituminous Coal	31.1–31.3	0.2	0.19	
			Clayey Bituminous Coal	34.4–34.7	0.3	0.28	

Declaration of authenticity

The undersigned Rayhan Aldizan Farrenzo, a student of the University of Miskolc, aware of my criminal and disciplinary liability, I declare and confirm with my signature that I have prepared this thesis myself, that I have carried out the tests described in it – if not indicated separately – myself, and that I understand the presented results myself away. I used data and information only from the sources listed in the bibliography. All parts that I have taken verbatim or paraphrased from another source have been clearly marked with the source.

Luleå, November 11, 2024



Rayhan Aldizan Farrenzo

Declaration of the supervisor

I, the undersigned Dr. Norbert Zajzon, University of Miskolc, Institute of Exploration Geosciences consider the TDK thesis suitable for submission.

Other comments, recommendation:

Miskolc, November 11, 2024



Dr. Norbert Zajzon