Muographic survey of the Tornaszentandrás iron ore mine

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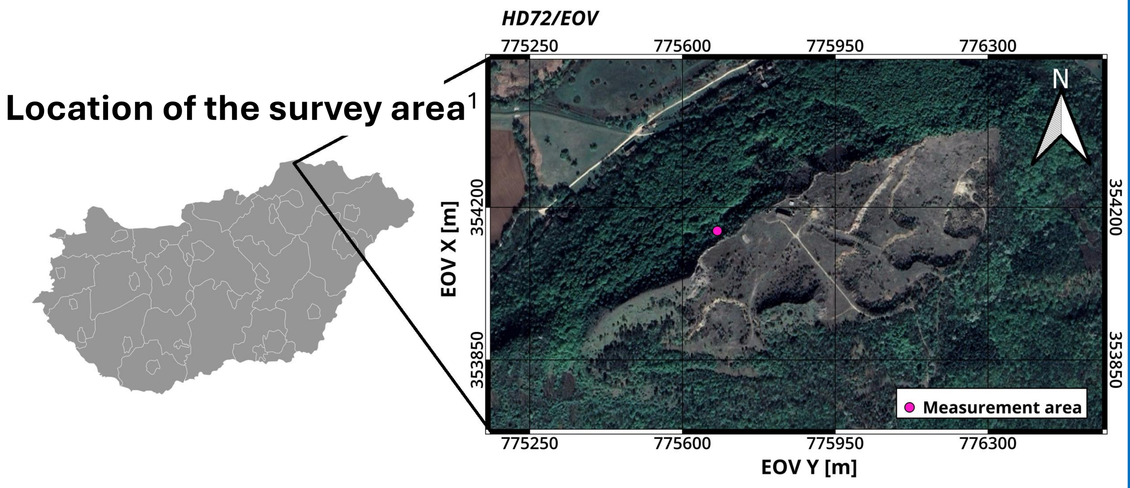
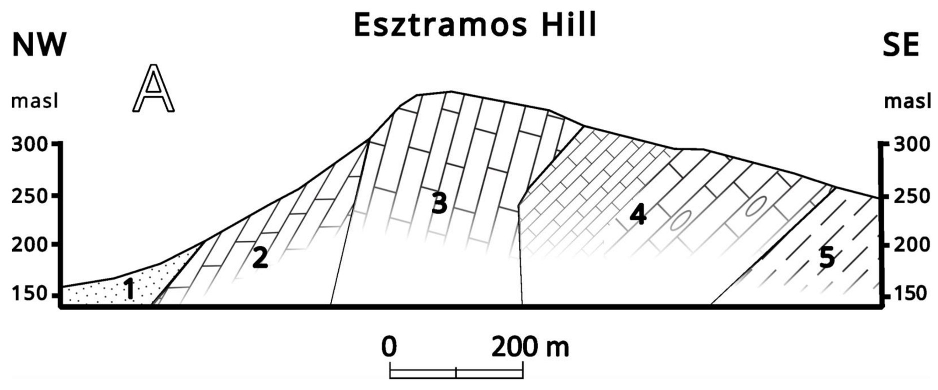
I. Survey area: Esztramos Hill

The history of the hill: iron ore mining began in 1893 and lasted until 1960, producing over 160,000 tons of iron ore[4]. Between 1948 and 1997 a limestone quarry was operating on top of the hill. **During the mining operations dozens of caves were discovered**[5,6], a few of them are currently part of the UNESCO World Heritage list[7].

Location of the survey area[1]

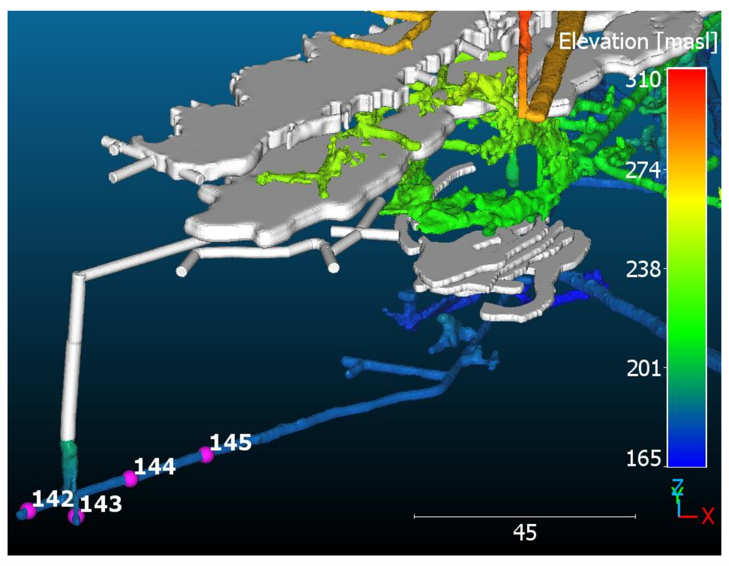


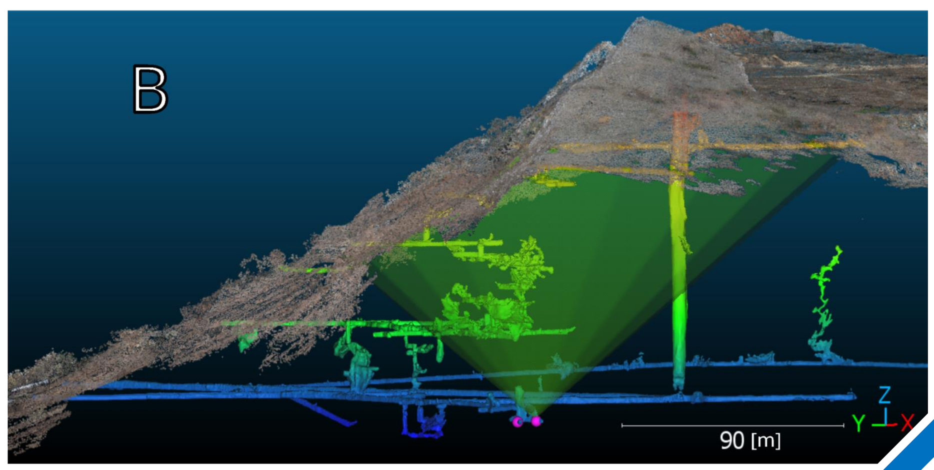
Current state of the mine: since the closing of the mine its state has greatly degraded. Large parts of the upper levels are now partially collapsed or too dangerous to enter. The iron ore deposits have been almost completely mined out.



Geological profile of Esztramos Hill[2,3]**:** 1: Edelényi Variegated Clay Formation - Pannonian, 2: Gutenstein Formation (dolomite) - Middle Triassic, 3: Steinalm Formation (crystalline limestone) - Middle Triassic, 4: Szentjánoshegy Limestone Formation (cherty limestone) - Middle Triassic, 5: Tornaszentandrás Shale Formation (shale) - Upper Triassic

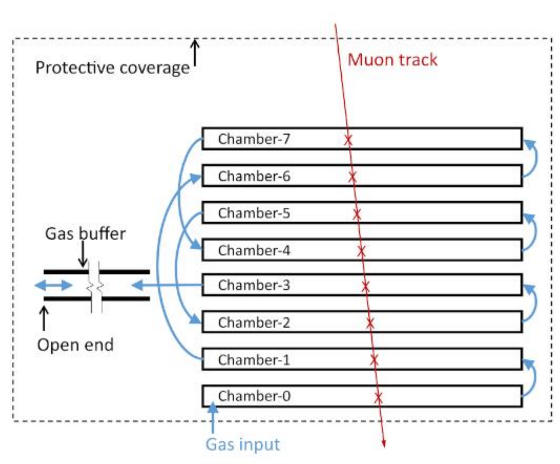
Laser scans: Accessible, scanned parts of the mine are colored by elevation on the digital scans, while white bodies mark inaccessible parts digitally **reconstructed** based on contemporary maps[8,9].

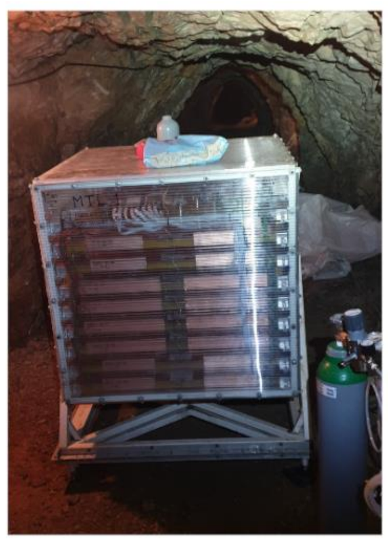




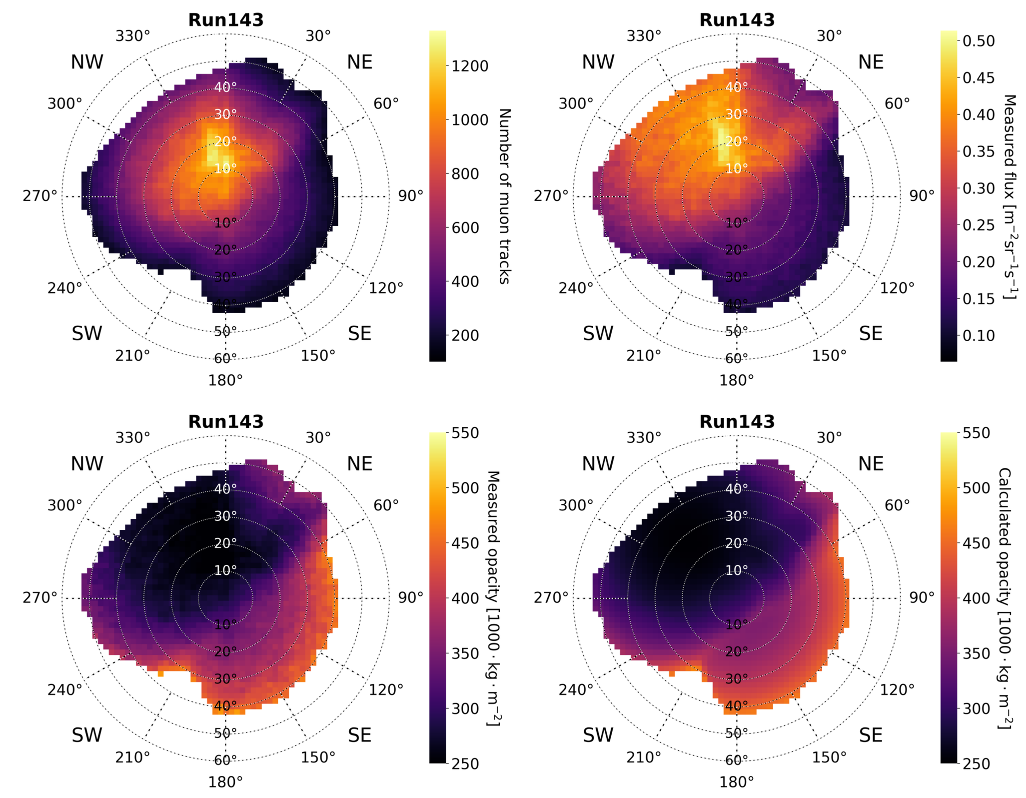
II. Applied muographic methods

Muography: Muography is a radiographic imaging technology based on the measurement of **cosmic muon particles** passing through the observed body. The method is sensitive to the inner density distribution of the observed body and it has been proven as suitable tool for cavity research in several projects[10]. It is a non-invasive, inexpensive technology that can be safely deployed in such **harsh** environments as mines and caves[11,12].





Data evaluation: The number of absorbed muons along a trajectory is a monotonically decreasing function of its length and the average density along it. The product of these two values is called opacity, and it can be derived from the measured muon flux[13]. This grants the opportunity to measure the length of rock in each direction if an average density is assumed. Muograms depict the difference of this measured rock length and detector-to-surface distance, calculated from the scanned digital models.

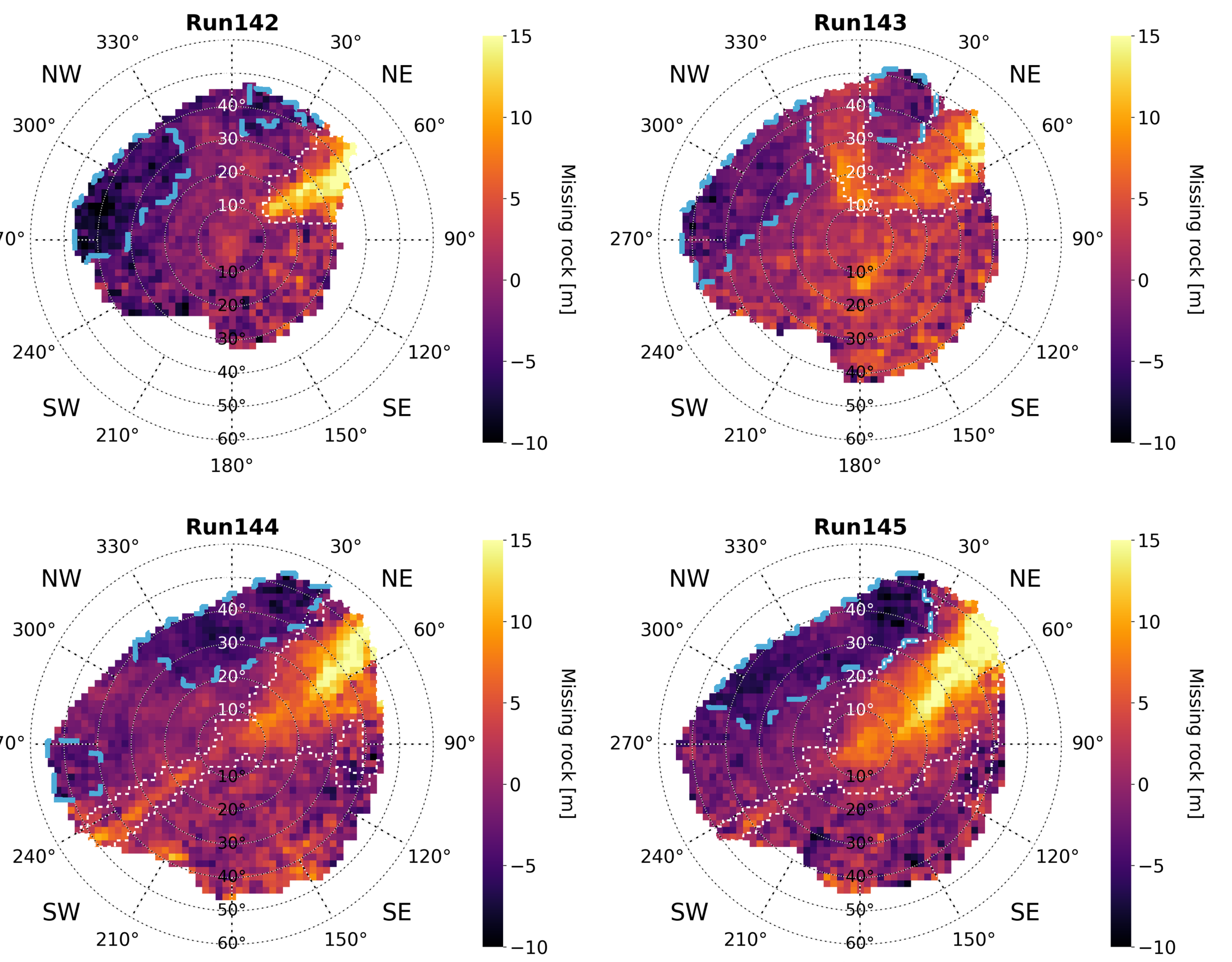


3D Inversion: A mathematical method of solving the 3-D muographic inversion problem was developed and validated on high precision underground muographic measurements conducted by the HUN-REN Wigner RCP[14]. **The problem is largely underdetermined and ill-posed**, due to the low number of measurements compared to the high number of voxels and narrow angle mapping, but by introducing **geologically relevant Bayesian constraints**, such as the characteristic density of the surrounding rock as a prior assumption, **the inversion can be stabilised.**

III. Results – Muographic images

Conclusions: On all of the muograms areas with large amount of missing rock appear. These are caused **by the inaccessible parts of the iron mine.** The reconstructed parts of the mine were projected onto the muograms, their edges are highlighted by **white dotted lines**. Their shapes correlate well with the muographic results.

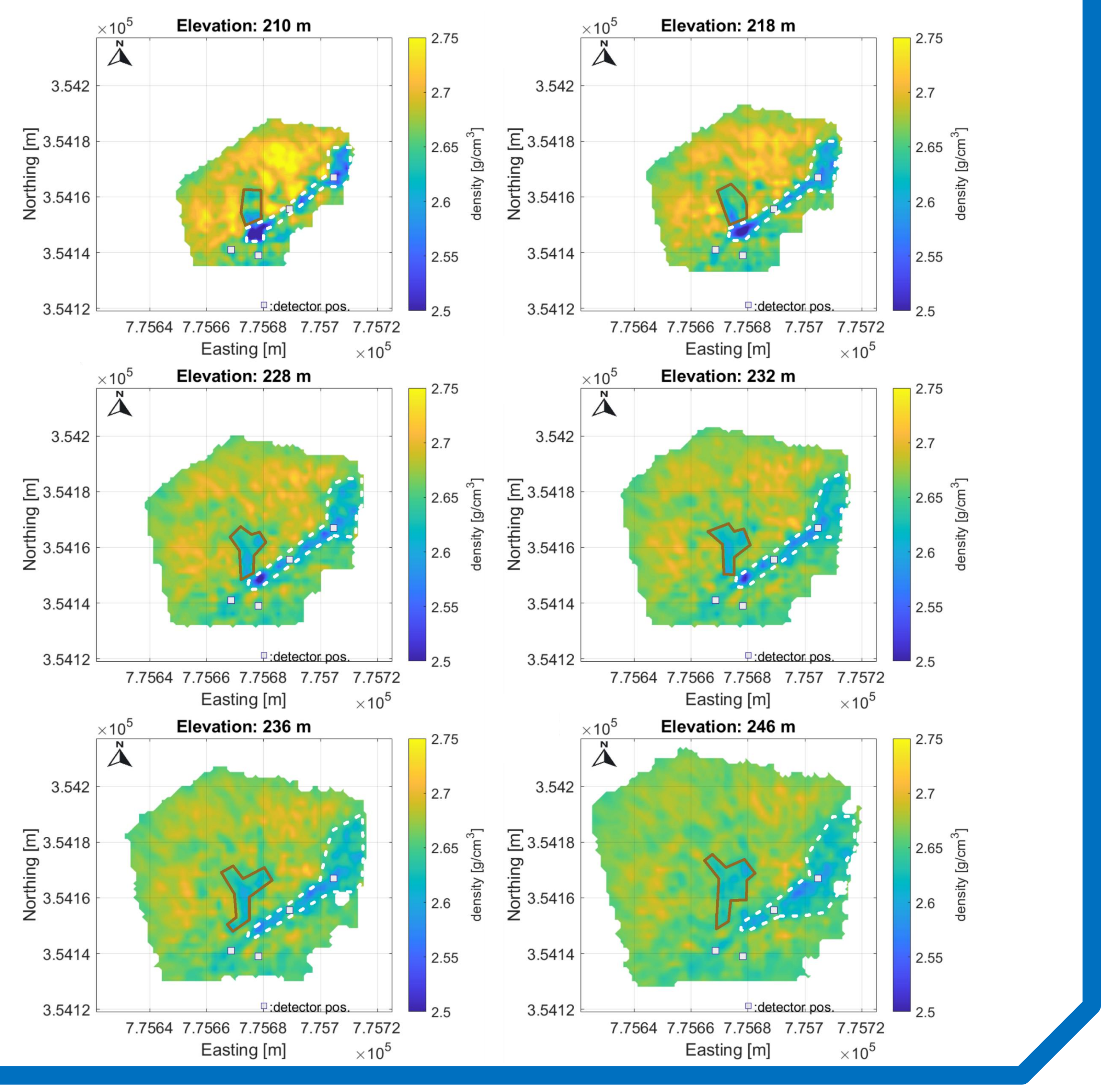
In the northwestern direction areas with apparent excess rock can be seen, highlighted by **blue dashed lines.** This is caused by using the limestones density for the conversion between density length and rock length. **The higher density of the nearby dolomite** causes the measured rock length to increase. This is a suitable indicator for **the dolomite-limestone boundary's location.**



IV. Results - 3D Inversion

Conclusions: The results of the opacity-based inversion show the effects of known, but inaccessible parts of the mine, **highlighted by white dotted lines.** The cavities appearing in the results are the results of inversion, as the a priori model did not include known cavities, so their appearance provides an opportunity for verification.

A **newly identified low-density zone** can be seen on the images, highlighted by brown lines. This anomaly does not correspond with any of the known cavities and might **indicate the existence of an unknown void, possibly a nearby cave.**



This poster is a summary of the scientific paper ‚B. Rábóczki et al.: Void discovery inside Esztramos Hill using muographic methods' soon to be published in Scientific Reports.

References:

1.: Google Satellite image: Az Esztramos-hegyi volt kőfejtő (Imagery date: 2018-Apr-18)
2.: Kovács, S., Réti, Z. & Róth, L.: Az Aggtelek-Rudabányai-hegység földtana, Magyar Állami Földtani Intézet (2006)
3.: Turtegin, E.: Geological setting of the iron mine at the Esztramos Hill. Topogr. Minerol. Hungariae V, 37–50 (1997)
4.: Turtegin, E.: History of iron ore mining on the basis of archive records at the Esztramos Hill. Topogr. Minerol. Hungariae V, 31–36 (1997)
5.: Lénárt, L.: Results of the hydrogeological and speleological research of the Esztramos Hill. Topogr. Minerol. Hungariae V, 55–74. (1997)
6.: Koleszár, K.: A bányászat során föltárult esztramosi barlangok megismerésének története a kezdetektol 1965-ig, Karsztfejlődés 5, 293–308 (2000)
7.: UNESCO. World Heritage list: Caves of Aggtelek Karst and Slovak Karst. *https://whc.unesco.org/en/list/725/* (Accessed: 2025-Jan-16).
8.: Pantó, D.: Zárójelentés a tornaszentandrási barnavasércbánya termeloüzeméről, Databank of SARA (1961).
9.: Turtegin, E.: A tornaszentandrási vasérbánya átnézeti térképe. Manuscript (2009).
10.: Morishima, K. et al. Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons. Nature 552, 386–390, (2017).
11.: Nyitrai, G., et al.: Towards low gas consumption of muographic tracking detectors in field applications. Adv. High Energy Phys. 129, (2021)
12.: Gera, A., et al.: Gaseous detectors for field applications: Quality control, thermal and mechanical stability. Instruments 6, 74 , (2022)
13.: Lesparre, N., et al.: Geophysical muon imaging: Feasibility and limits. Geophys. J. Int. 183, 1348 – 1361. (2010)
14.: Balázs, L. et al. 3-D muographic inversion in the exploration of cavities and low-density fractured zones. Geophys. J. Int. 236, 700–710, (2023).

Acknowledgements: This work was supported by the Hungarian NKFIH research grant under identification number TKP2021-NKTA-10, the HUNREN Welcome Home and Foreign Researcher Recruitment Programme KSZF-144/2023 and the "Mine.io" HEU project GA No. 101091885. Detector construction and testing was completed within the Vesztergombi Laboratory for High Energy Physics (VLAB) at Wigner RCP. The technical support provided by the members of the REGARD group is gratefully acknowledged.

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