

Public Response to Two Rare Earthquakes: Crowdsourcing Constraints on Crustal Structure in South Bohemian Massif

Pavla Hrubcová¹, Matěj Machek¹, Jiří Vackář², Anna Pohořalá¹, Hana Kampfová Exnerová¹, Petr Špaček³, Jan Zedník¹

¹Institute of Geophysics, Czech Academy of Sciences, Prague, 141 00, Czechia

²Institute of Structure and Rock Mechanics, Czech Academy of Sciences, Prague, 182 09, Czechia

³Institute of Physics of the Earth, Masaryk University, Brno, 602 00, Czechia

Correspondence to: Pavla Hrubcová (pavla@ig.cas.cz)

Abstract.

We analysed two rare earthquakes that occurred near Mírotice in south Bohemian Massif (Czechia) in March 2024 (M_L 3.5) and April 2025 (M_L 3.1), integrating seismological analyses with crowdsourced macroseismic observations. Both events originated at unusually large depths for the region (24.5 km) and were widely felt across southern and central Bohemia, attracting significant public attention. Independent of low population density, macroseismic effects were documented through extensive citizen participation, with over 1,500 questionnaires for each event collected by the Institute of Geophysics, Czech Academy of Sciences. Maximum macroseismic intensities reached IV; however, the spatial distribution of observations was distinctly non-circular, forming a pattern controlled by major tectonic structures. Areas underlain by granitoids of the Central Bohemian Pluton exhibited dense and far-reaching macroseismic responses, consistent with low seismic energy attenuation of the Moldanubian, whereas regions dominated by early Palaeozoic sedimentary rocks of the Teplá–Barrandian showed sparse observations, indicating higher attenuation. The results show that crowdsourced data can constrain deep geological structures and effectively complement instrumental observations in regions with sparse seismicity.

Short Summary

Two rare earthquakes in the Bohemian Massif in 2024 and 2025 were analysed from crowdsourced macroseismic and seismological data. Both events occurred at large depths (~24 km) and were widely felt. Non-even distribution of observations reflects contrasting attenuation and control on geology in the Bohemian Massif. Results show that crowdsourced data can effectively constrain deep geological structures and complement instrumental observations in regions with sparse seismicity.

1. Introduction

Involving citizens in science related to natural hazards helps people to better understand risks and prepare for them. It also supports disaster management and improves decision-making. Crowdsourcing uses information shared by many individuals,

35 providing valuable ground-level insights that strengthen scientific understanding and emergency response. In seismology,
citizen involvement has been especially effective in gathering and sharing important information, significantly contributing to
seismic risk mitigation (e.g., Guan and Chen, 2014; Hao and Wang, 2020; Kryvasheyeu et al., 2016).

Macroseismic questionnaires, pivotal in this context, gather information on ground shaking and its effects on buildings,
40 infrastructure, and populations. Online macroseismic questionnaires, supported by widespread internet access, have further
enhanced this process by enabling rapid, cost effective, and geographically extensive data collection (e.g., Kankanamge et al.,
2019). Compared to traditional paper-based methods, online approaches improve the efficiency, accuracy, and
comprehensiveness of macroseismic data.

45 Macroseismic data not only support the assessment of earthquake impacts but also offer valuable constraints on the character
of geological features. Their applicability to geological investigations depends on data quality, the representativeness of the
surveyed population, and the methodologies used for data collection and analysis. Crowdsourcing, facilitated by online
platforms, mobile applications, and widespread smartphone use, enables broad public participation and rapid data acquisition.
This methodology is particularly effective in regions with sparse seismic instrumentation or low seismicity, where instrumental
50 seismic data are often unavailable. In such settings, crowdsourced macroseismic observations offer a cost-effective means of
acquiring large volume datasets that reflect geological controls on seismic wave propagation (e.g., Toshinawa et al., 1997;
Cifelli et al., 1999). This approach is especially relevant for the Bohemian Massif, one of the largest exposures of the European
Variscan orogenic belt situated at its eastern periphery (Fig 1), where present-day seismicity is low.

55 In this study, we present a crowdsourcing-based analysis of two unusual earthquakes near Mirovice in the southern Bohemian
Massif, Czechia: an M_L 3.5 event in 2024 and an M_L 3.1 event in 2025 (Figs. 1 and 2). Both earthquakes originated in the deep
crust and were widely felt across southern and central Bohemia, providing a valuable opportunity to investigate the spatial
distribution of macroseismic effects and their relationship to the regional geological structure. Studies of the deep European
Variscan crust indicate that pre-Permian thrusts exposed at the surface may root in the lower crust, at the Moho, or even within
60 the upper mantle (Meissner and Wever, 1986). This underlines the importance of investigating the deep structure of the
Bohemian Massif in order to better constrain its tectonic evolution and to delineate deep, steeply dipping tectonic boundaries
that are otherwise difficult to identify. Our results demonstrate the potential of crowdsourced macroseismic data to reveal
deep-seated geological structures that influence seismic-wave propagation in regions of sparse seismicity and limited
instrumental observations.

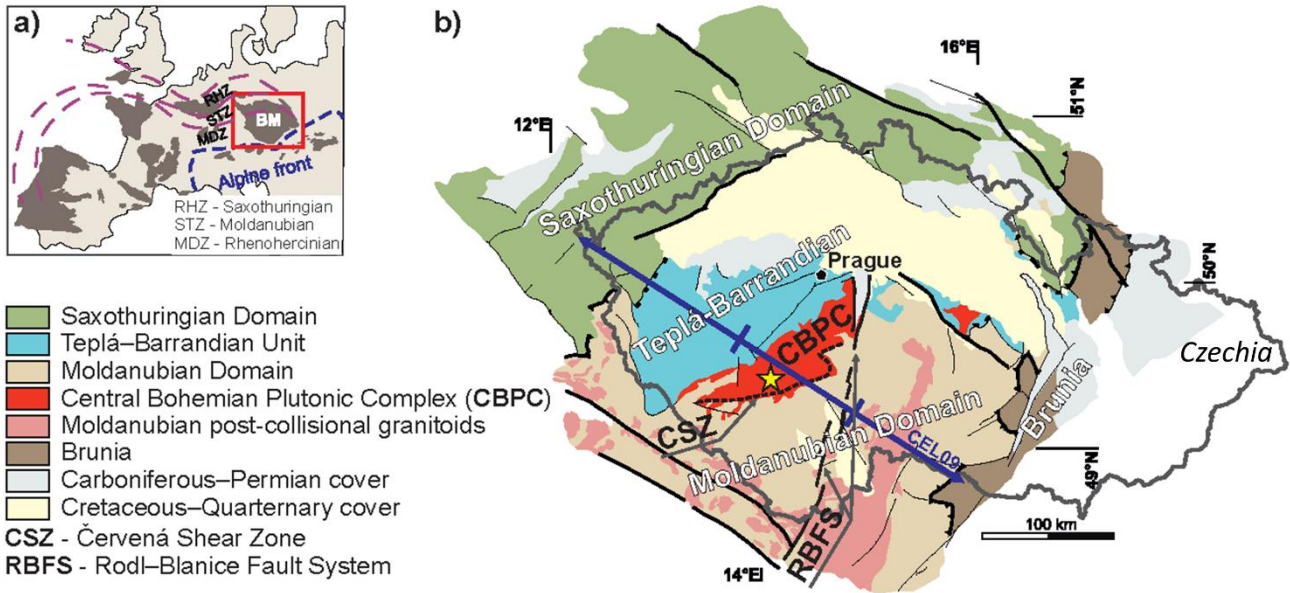


Figure 1. a) Schematic sketch of the European Variscides with the Bohemian Massif (red box) in the eastern edge. b) Simplified geological map of the Bohemian Massif with individual tectonic units (modified after Machek et al., 2022). The Mirotice earthquakes are marked by a yellow star; the violet line marks the CEL09 seismic profile from the CELEBRATION 2000 experiment (Hrubcová et al., 2005). The Czechia border is indicated by a grey curve.

2. Seismicity in the Bohemian Massif

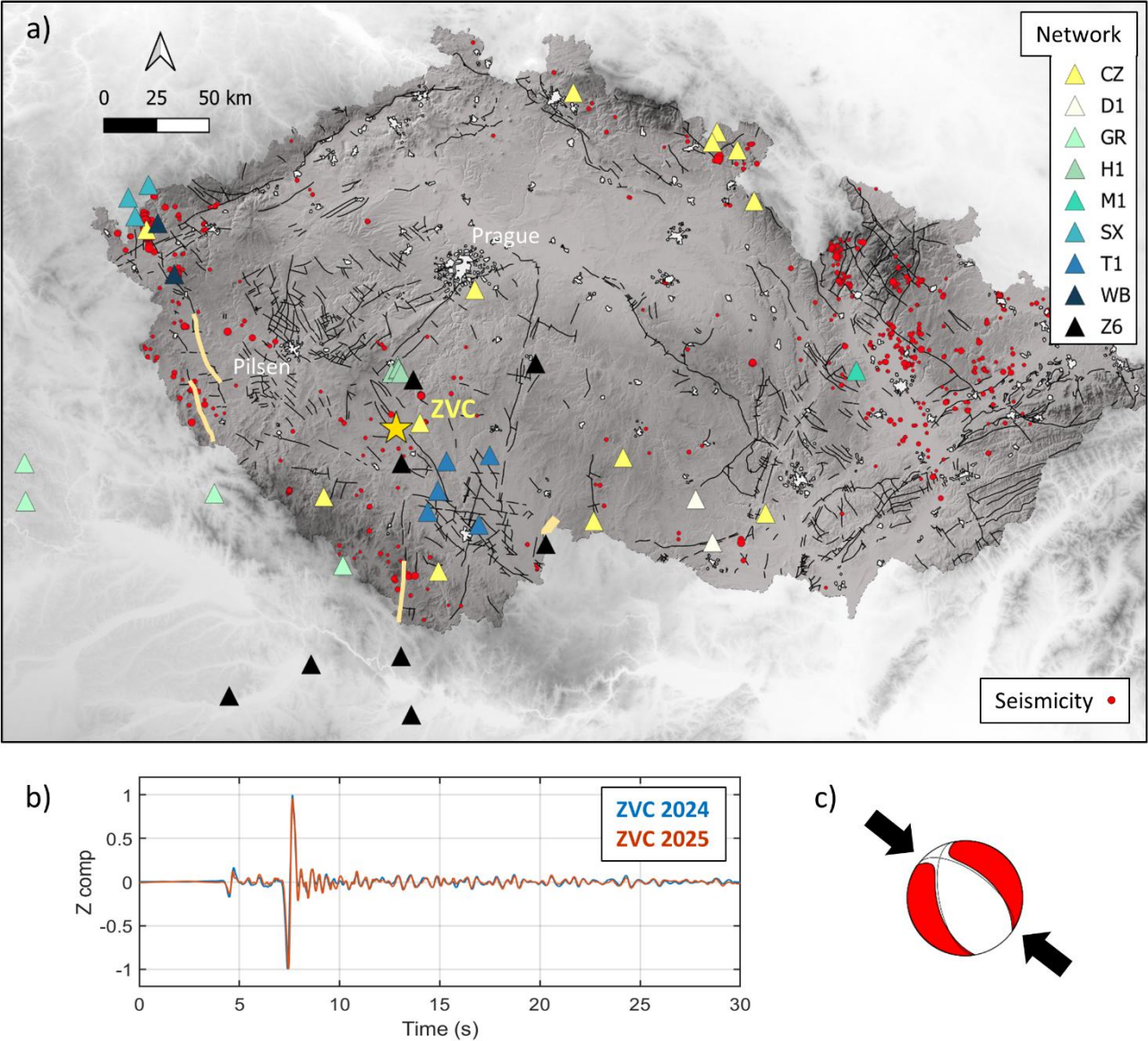
Present-day seismicity within the Bohemian Massif is low, dominated by weak intraplate earthquakes, mostly confined to the upper crust (<12 km), and concentrated mainly along the massif margins (CZEQ catalogue, 2024; Fig. 2). In central and southern Bohemia, no seismotectonically active structures have been documented and only very few seismotectonic structures were observed in SW Bohemian Massif (Málek et al., 2018). More significant seismicity is limited to western Bohemia/Vogtland, where earthquake swarms are linked to the ascent of mantle-derived fluids migrating along deep crustal structures (Fischer et al., 2014), and to the eastern Sudetes (Fig. 2). Consequently, large parts of the internal structure of the Bohemian Massif remain seismically inactive. For this reason, seismic stations within the Bohemian Massif (excluding the above active regions) primarily serve regional seismic monitoring.

3. Unusual Earthquakes near Mirotice

3.1. Mirotice 2024 Earthquake

On 7 March 2024, shortly before noon local time (10:41:41 GMT), an earthquake of magnitude M_L 3.5 occurred in southern Bohemia (Czechia). The epicentre (49.42° N, 14.05° E) was located southeast of Mirotice town with the hypocentral depth of

85 24.5 km $\pm$ 1.5 km. Subsequent analysis identified four minor aftershocks with M_L 0.5 occurring within one hour of the main shock, followed by a very weak event (M_L -0.1) about 12 hours later. The latest aftershock (M_L 0.4) was recorded more than three weeks later, on 29 March 2024 at 17:51 GMT.



90 **Figure 2.** a) Seismicity in Czechia with M_L in range 0.5–4.8 during the 2000–2024 period (CZEQ catalogue, 2024; red circles scaled by magnitude); Mirotice earthquakes denoted by yellow star. Triangles indicate seismic stations used for earthquake location and focal mechanism calculations color-coded by network (for network codes see text). Orange lines indicate seismotectonic lines in central and southern Bohemia (after Málek et al., 2018). b) Seismic waveforms

(filtered 0.5–2.0 Hz and scaled to maximum amplitude) of the Mirotice earthquakes in 2024 (M_L 3.5) and 2025 (M_L 3.1) recorded by station ZVC. Note similar waveform shape that suggests a similar source location and focal mechanism for both events. c) Source mechanism of the Mirotice earthquakes; the arrows indicate the orientation of the regional maximum horizontal stress (SHmax; after Heidbach et al., 2016).

3.2. Mirotice 2025 Earthquake

The second earthquake (magnitude M_L 3.1) occurred on 24 April 2025 at 17:32:47.3 GMT. This event originated essentially at the same location (49.42° N, 14.04° E) and at a comparable hypocentral depth of 24.5 km $\pm$ 1.5 km. The main shock was followed by four weak aftershocks (maximum M_L 0.3), two occurring immediately after the main shock and two recorded one day later.

Due to sparse seismicity and limited seismic stations, the earthquake locations and focal mechanisms (Fig. 2) were calculated from stations belonging to various networks: the Czech Regional Seismic Network (CZ), Saxon Seismic Network (SX), German Regional Network (GR), and two Czech local seismic networks (WB and M1). Additionally, we incorporated data from temporary station network (Z6) from the ongoing AdriaArray experiment (Kolínský et al., 2025; Vecsey et al., 2025), as well as stations from local industrial networks (D1, H1, and T1).

The epicentral coordinates of both events were obtained from the bulletin of the Institute of Physics of the Earth (IPE, 2025). Hypocentre locations were determined using the Hypo3d program (Firbas and Werl, 1988), based on the arrival times recorded at 23 stations. The calculations used a simple 1D gradient velocity model, regionally calibrated using observed travel times from deep seismic refraction experiments (Hrubcová et. al, 2005) and quarry blasts. The reliability of the depth estimates was further assessed by comparing the observed travel times of the depth phase (sP) at epicentral distances of 140–210 km with theoretical travel times derived from several alternative velocity models. Additional support for the accuracy of the depth determination was provided by the consistency of the optimal focal mechanism solutions derived from both full-waveform and first-arrival inversions.

3.3. Mirotice 2012 Earthquake

The 2024 and 2025 Mirotice earthquakes were preceded by an earlier event in 2012. This earthquake occurred on 17 March 2012 at 00:56:31.8 GMT and was located at nearly the same epicentral position, at 49.401°N, 14.026°E. According to catalog of IPE MU (2026), the event originated at a depth of 19 km and had a small magnitude of M_L 1.7.

3.4. Focal mechanisms

Focal mechanisms were determined through full waveform moment tensor inversion using the Bayesian ISOLA method (Vackář et al., 2017), based on waveform data from 12 broadband seismic stations at epicentral distances of 11–70 km. The

inversion employed velocity model derived from nearby CEL09 refraction and wide-angle reflection profile (Fig. 1) of the CELEBRATION experiment (Hrubcová et al., 2005), which improved the waveform fit. The results indicate that both events were characterized by normal faulting on a NW–SE striking fault plane with strike 160° and dip 59° (Fig. 2c). Similar focal mechanism was obtained from P-wave first-motion polarities recorded at 47 stations with slightly different velocity model (strike 164°, dip 51°; see Table 1).

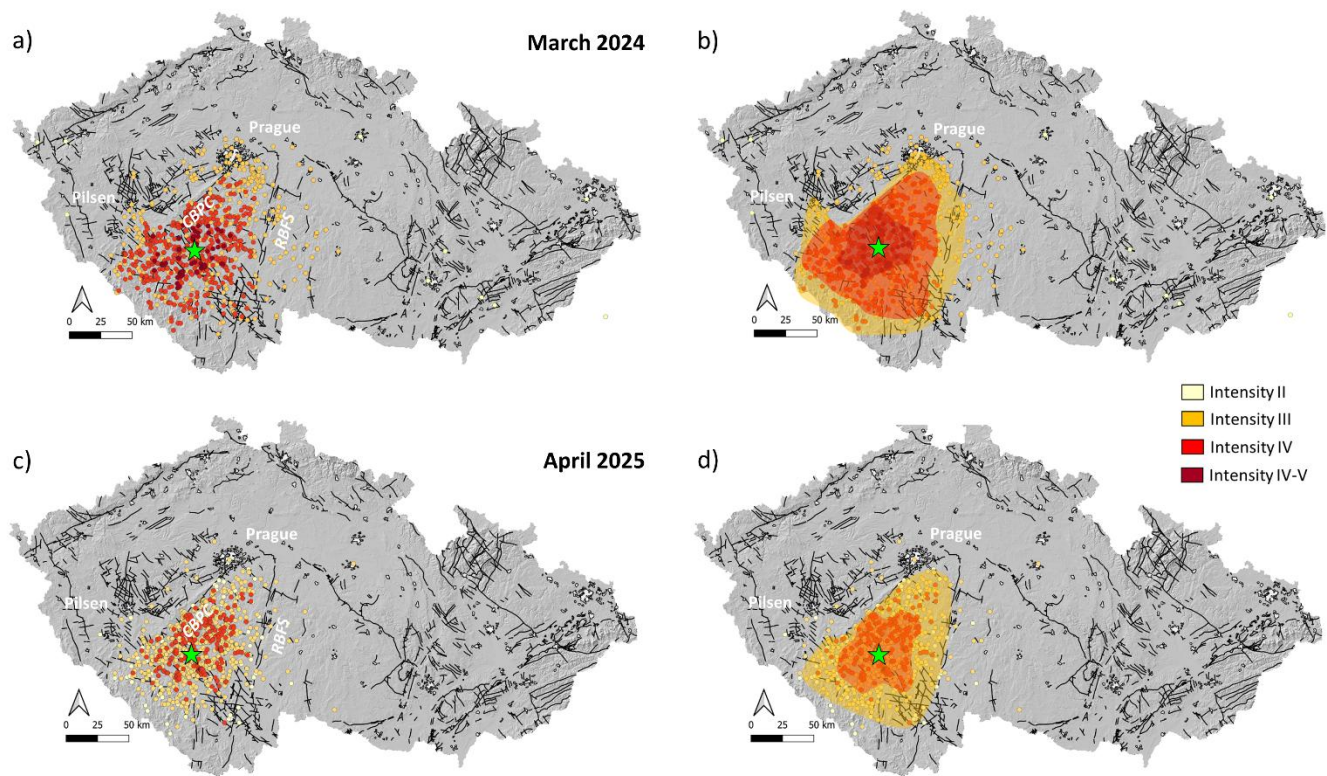


Figure 3. The Mirovice earthquakes. (a,b) The M_L 3.5 event in March 2024; (c,d) the M_L 3.1 event in April 2025. (a,c) Spatial distribution of macroseismic observations (color-coded by individual intensities) collected by IG CAS. (b,d) macroseismic intensity according to the EMS–98 scale. The epicentres are marked in green. CBPC, Central Bohemian Plutonic Complex; RBFS, Rödl–Blanice Fault System.

4. Macroseismic Observations

The earthquakes that occurred near Mirovice in 2024 and 2025 were unusual for the region in terms of their location, depth, and felt intensity, and therefore attracted considerable scientific interest as well as public attention. Macroseismic effects were documented through 1,512 questionnaires for the 2024 event and 1,679 questionnaires for the 2025 event, collected via online

forms or smartphone application provided by the Institute of Geophysics of the Czech Academy of Sciences (IG CAS) (<https://www.ig.cas.cz/makroseismicky-dotaznik/>). In both cases, observations were submitted voluntarily. The public participation was encouraged through media interviews regularly following stronger or unusual events in Czechia, in which people are invited to complete this questionnaire. The approach supports the reliability of the dataset, as evidenced by the even higher reporting rate for the weaker 2025 event.

The shaking was reported over distances of several tens of kilometres. Responses were collected up to 70–100 km from the epicentre, including Písek, Strakonice, and Tábor regions, as well as the Šumava Mountains (Fig. 3a,c). Respondents reported ground shaking of varying intensity (strong shaking in 17% of cases and light shaking in 66% for the 2024 event; light shaking in 58% of cases for the 2025 event), swaying of lightweight objects, and clinking of dishes (30% in 2024; 18% in 2025), and, in some cases, hairline cracks in walls or plaster, particularly near the epicentre (2.5% in 2024; <1% in 2025). The shaking was frequently accompanied by rumbling to booming sounds, many residents also reported sounds resembling the passage of heavy vehicles or an explosion (~90% of cases both in 2024 and 2025). Earthquake-related sounds are commonly perceived near epicentres, even for very small events (e.g., Tosi et al., 2012). In our case, the large number of reports across the wide area where these sounds were detected suggests unusually efficient seismic wave propagation.

Individual questionnaire responses were converted into macroseismic intensities according to the EMS–98 scale criteria (Grünthal, 1998). Intensities were initially assigned to individual reports and subsequently interpolated from individual values. Qualitative terms such as “few”, “many”, and “most” were quantified using three percentage not-overlapping ranges (0–20%, 20–60%, and 60–100%), enabling a more quantitative assessment (Tosi et al., 2015). No correction for surface conditions like sedimentary effects was applied, as the area is generally underlain by crystalline rocks. Questionnaires lacking sufficient diagnostic information, containing inconsistent timing, duplicates, or those reporting effects not clearly attributable to the earthquake were excluded from the analysis (after Tosi et al., 2024). On average, only ~2% of the questionnaires were discarded, which demonstrates the reliability of the data provided by citizens.

Reports indicating light shaking felt by few persons at rest, but without movement of objects, were assigned intensity III (“weak”); scarcely felt earthquake, perceived only by very few individuals with no reported object effects or damage were assigned intensity II. Reports of strong shaking felt by many indoors, accompanied by rattling of windows, doors, or dishes and slight movement of lightweight objects, were assigned intensity IV (“largely observed”). An intensity of IV–V was assigned in areas with numerous reports indicating clear movement of unsecured objects, overturning of small items, or rare non-structural damage (e.g., hairline cracks in plaster), but without fully satisfying the criteria for intensity V (“strong”). Reports indicating that the earthquake was “not felt” are particularly valuable for estimating macroseismic intensity at lower intensity levels, where the assessment is commonly based on the proportion of people perceiving the shaking (e.g., Grünthal, 1998; Tosi et al., 2015). In our case, the “not felt” reports referred to cases with no perceived shaking, no object motion, and

no damage, but only acoustic effects resembling heavy transport vehicles or explosion. Because acoustic effects alone are not diagnostic for the EMS-98 intensity assignment, these reports were treated separately as “heard-only” observations and were not used in determining locality intensity. When multiple effects were reported, intensities were assigned conservatively, based on object or damage-related indicators. The final locality intensity was taken as the modal value of all retained responses.

The maximum macroseismic intensity, assessed using the EMS-98 scale (Grünthal, 1998), reached IV–V for the stronger 2024 earthquake and IV for the weaker 2025 event (Fig. 3b,d). However, the most notable feature was not the intensity level itself, but the distinctly non-circular distribution of reported observations. Although the 2024 event was observed farther west than the 2025 event, both earthquakes showed an uneven spatial pattern that was not controlled by population density (Fig. 4).

The area near epicentre is rural, sparsely but relatively evenly populated, with population densities of approximately 20–50 persons/km² and only a few towns present (Fig. 4 inset). Therefore, we did not apply any correction for population density. In contrast, farther west, particularly towards the Pilsen region, population density increases markedly, yet macroseismic observations were largely absent (Fig. 4). Normalizing the macroseismic observations by population density would make this contrast even more pronounced, further emphasizing the anomalous character of the observed spatial pattern.

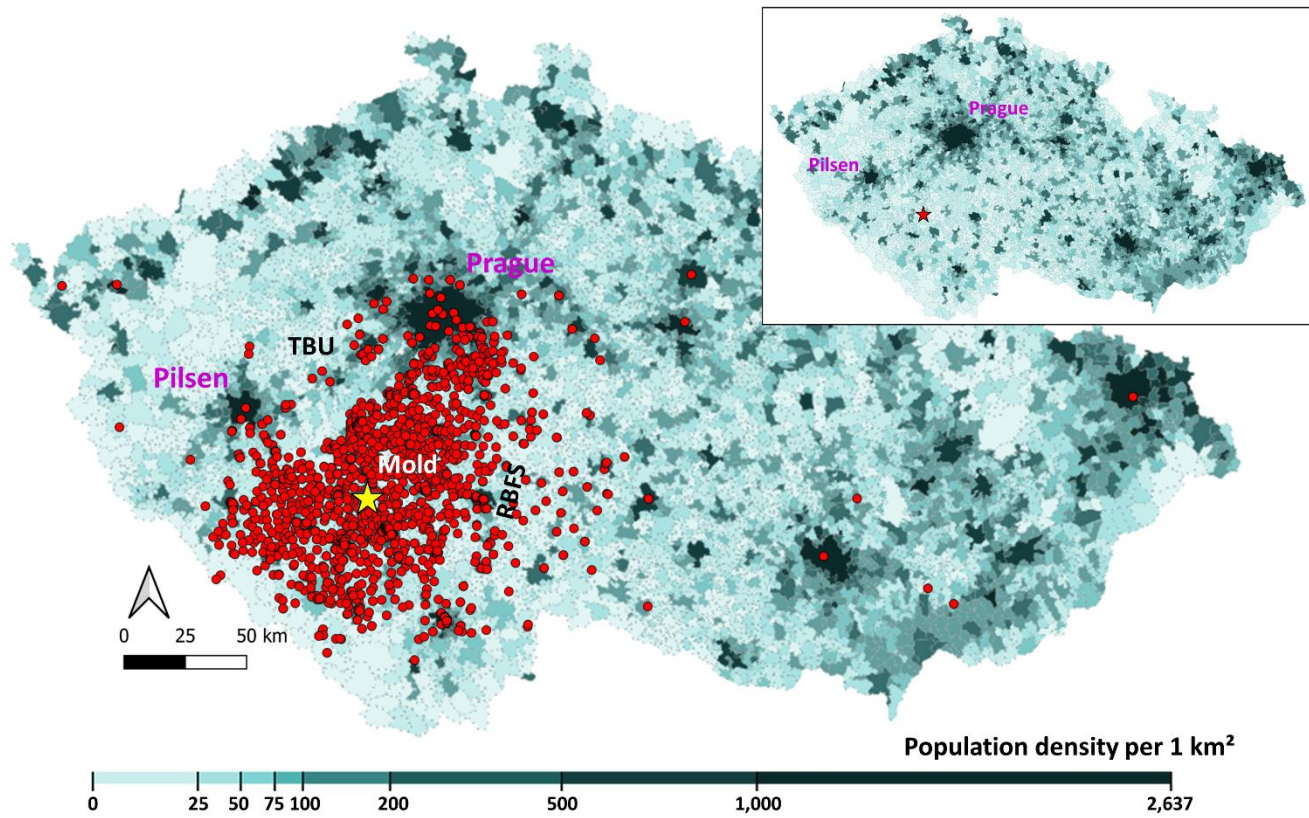


Figure 4. Spatial distribution of macroseismic observations (red points) for both 2024 and 2025 Mirovice earthquakes (yellow star), superimposed on map of population density (people per km²; <https://data.gov.cz/>). Note trapezoidal pattern of the observations delimited from the west by the Teplá–Barrandian (TBU) / Moldanubian (Mold) boundary and from the east by the Rödl–Blanice Fault System (RBFS) independent of population distribution. Inset shows the population density without observations. Note generally low population density in southern Czechia with high observations and higher population density in the west at Pilsen region with sparse observations.

6. Tectonic and Structural Context

6.1. Tectonic setting

The earthquakes occurred in the southern Bohemian Massif, which formed between 500–250 Ma during the convergence of Gondwana and Baltica. Its development was shaped by Neoproterozoic active margin of northern Gondwana, Cambro-Ordovician extension, Devonian subduction, and the Carboniferous underthrusting of the Saxothuringian microcontinent (Edel et al., 2018; Schulmann et al., 2014; Soejono et al., 2020). The Bohemian Massif is divided into four west-to-east lithotectonic units: the Neoproterozoic to Palaeozoic Saxothuringian Domain, the Ediacaran to Lower Palaeozoic Teplá–Barrandian Unit (TBU), the Variscan crustal Moldanubian Domain, and the Neoproterozoic to Palaeozoic Brunovistulicum (Hajná et al., 2017;

Hanžl et al., 2019; Schulmann et al., 2014). The closure of the Saxothuringian ocean and subsequent continental underthrusting created the Central Bohemian Plutonic Complex (CBPC) magmatic arc at the TBU–Moldanubian boundary (Schulmann et al., 2014; Žák et al., 2014).

215 The earthquake epicentral area is located within the Central Bohemian Plutonic Complex (CBPC), specifically in the Mirotice complex, near the NE–SW trending boundary (~25 km east) between the Teplá–Barrandian Unit and the Moldanubian Domain (Fig. 1). The evolution of CBPC is characterized by the intrusion of Late Devonian plutons of magmatic arc affinity and voluminous syntectonic early Carboniferous arc plutons during regional vertical transpression into Neoproterozoic and Early Palaeozoic metasedimentary successions of subhorizontal structural record (Žák et al., 2014; Tomek et al., 2015). This resulted
220 in deep-seated steeply dipping NE–SW oriented boundary separating CBPC in the east from contrasting lithologies of the Teplá–Barrandian Unit in the west.

The transpression regime was later replaced by ductile normal shearing along the Červená Shear Zone, which facilitated exhumation of high grade Moldanubian Domain and formed eastern boundary of CBPC (Žák et al., 2014; Fig. 1). In the study
225 area, the Moldanubian is characterized by mostly shallow to subhorizontal structures and lithological contacts (Schulmann et al., 2014). The eastern margin of the region is further disrupted by the large scale NNE–SSW trending Rödl–Blanice Fault System, which developed during late Variscan tectonic evolution and was subsequently reactivated during the Cretaceous and Miocene (Prachař, 2022).

230 **6.2. Structure from active seismic experiments**

The deep crustal structure of the Bohemian Massif has been investigated by several active seismic profiling (e.g., Tomek et al., 1997; Růžek et al., 2003, 2007; Hrubcová et al., 2005; Vavryčuk et al., 2004). These studies revealed higher P-wave velocities with lower vertical gradient in the Moldanubian crust, reflecting the dominance of crystalline rocks exposed at the surface. The Moho beneath this unit forms a sharp first-order discontinuity reaching maximum depths to 39 km (Hrubcová et al., 2005). This coincides with minimum surface heat flow values of $<50 \text{ mW m}^{-2}$ (Čermák, 1977), suggesting cold and
235 mechanically strong Moldanubian lithosphere (Babuška and Plomerová, 2000).

In contrast, the Teplá–Barrandian Unit is characterized by higher near-surface velocity gradients, consistent with its Palaeozoic volcano-sedimentary sequences. The Moho beneath this unit is shallower as documented along the refraction CEL09 profile
240 (Hrubcová et al., 2005, 2017). In addition, two middle crustal reflectors, characterized by modest velocity contrasts ($\sim 0.15\text{--}0.3 \text{ km s}^{-1}$), are identified along CEL09 at depths of $\sim 7\text{--}13 \text{ km}$ and $17\text{--}20 \text{ km}$ across much of the region.

7. Discussion

7.1. Geological control on macroseismic distribution

245 The 2024 and 2025 macroseismic observations provide insight into deep crustal structure of the Bohemian Massif. They are unevenly distributed around the epicentre, forming a trapezoidal pattern (Figs. 3,4). Their non-circular distribution is bounded by two major structures: the Teplá–Barrandian and Moldanubian contact in the west, expressed as a deep-seated lithological boundary, and the Rödl–Blanice Fault System in the east, expressed as a crustal-scale fault zone (Fig. 5). The enclosed area is dominated by intrusive felsic rocks, mainly granites and granodiorites of the Central Bohemian Plutonic Complex (CBPC),
250 and high-grade Moldanubian metamorphic rocks. Their low seismic attenuation may promote efficient wave propagation and possibly resonant effects.

West of CBPC, the density of macroseismic observations sharply decreases. This area corresponds to the Teplá–Barrandian Unit, dominated by early Palaeozoic sedimentary formations with steeply oriented, highly anisotropic deformation structures
255 near the contact (Fig. 5). This contrast suggests increased seismic attenuation within the Teplá–Barrandian Unit. The contrasting lithologies along this NW–SE-trending contact are also expressed in gravity and, particularly, in geomagnetic data, pointing to the deep character of this zone (Bucha and Blízkovský, 1994; Švancara et al., 2021).

To the east, attenuation coincides with the N–S-trending Rödl–Blanice Fault System, indicating a crustal-scale discontinuity.
260 The macroseismic pattern therefore delineates subvertical structures that are not clearly resolved by existing deep seismic surveys.

7.2. Population density and radiation effects

The epicentral region is sparsely and relatively evenly populated. However, and quite importantly, the main asymmetry in the
265 macroseismic observations cannot be explained by population density because the more densely populated area toward Pilsen region contains few or no macroseismic reports. Normalization by population density therefore enhances rather than removes the observed contrast.

The asymmetric distribution may partly reflect the seismic radiation pattern, particularly S-wave radiation toward the
270 southwest and northeast. However, the sharp termination of observations along two old tectonic structures, independently of population density, indicates a strong structural control on seismic-wave propagation.

Strong reflections from the Teplá–Barrandian–Moldanubian contact are unlikely. The earthquakes originated at depths of ~24 km, and ~25 km horizontally from the contact, whose subvertical geometry is unfavourable for reflecting substantial shear-
275 wave energy back toward the surface from such nearby sources.

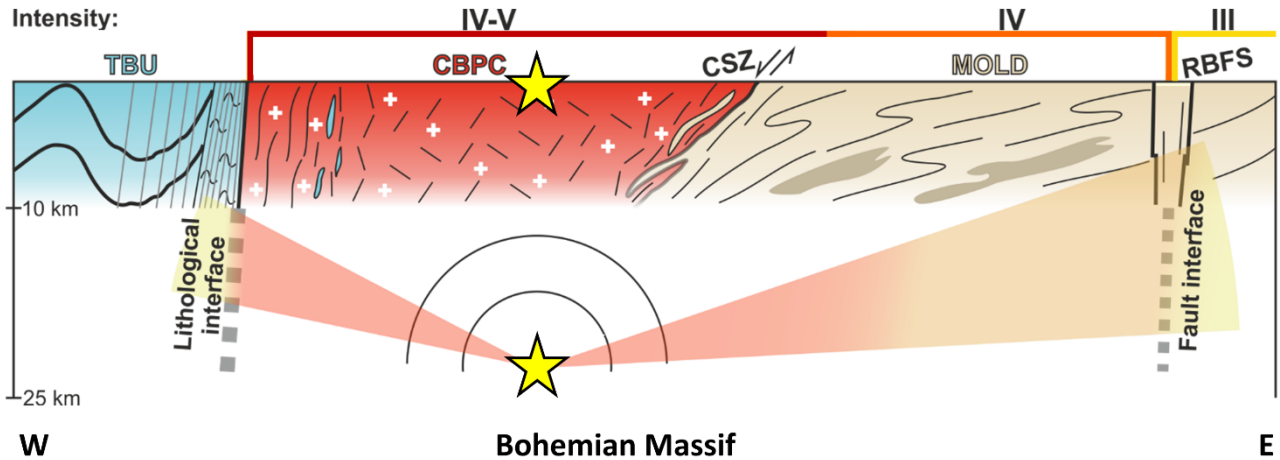


Figure 5. Schematic cross-section along a segment of the CEL09 profile (see Fig. 1) showing principal geological structures of the Bohemian Massif (modified after Deiller et al., 2021; Žák et al., 2014) with spatial distribution of 2024 macroseismic intensity (on top) of the Mirovice earthquakes (yellow stars). Note two interpreted subvertical, crustal scale tectonic boundaries affecting seismic-wave propagation and attenuation: the lithological contact between the Teplá-Barrandian (TBU) with the Moldanubian (Mold) in the west, and the deep Rödl-Blanice Fault System (RBFS) in the east. CBPC, Central Bohemian Plutonic Complex; CSZ, Červená Shear Zone.

Although smaller in magnitude, the 2025 earthquake (M_L 3.1) was reported more frequently than the 2024 event (M_L 3.5). Together with acoustic phenomena reported in approximately 90% of observations, this indicates efficient transmission of seismic energy from depth. It also suggests a relatively homogeneous crustal medium within the Moldanubian Domain, particularly the CBPC, facilitating both seismic-wave propagation and acoustic signals.

The attenuation observed within the Teplá-Barrandian Unit resembles regional patterns identified in deep seismic studies of the Bohemian Massif and Pannonian Basin (Beránek and Zátopek, 1981; Hrubcová et al., 2005, 2010). These studies showed efficient propagation through crystalline rocks of the Bohemian Massif and strong attenuation within sedimentary sequences of the Pannonian Basin.

7.3. Deep origin of Mirovice earthquakes

The Mirovice earthquakes are rare in the region and unusual because of their large focal depths of ~24 km within the Bohemian Massif. Their occurrence at such depths may reflect the low regional geothermal gradient (Čermák, 1977), which allows brittle failure to occur within the lower crust. Their hypocentres coincide with a reflective interface identified along the CEL09 seismic profile of the CELEBRATION 2000 experiment (Hrubcová et al., 2005), which passes close to the epicentral area

(Fig. 1). This interface may represent a structural or rheological discontinuity controlling earthquake nucleation. A persistent deep-seated source is further supported by the small 2012 earthquake, which originated in the same area.

7.4. Focal mechanisms and regional stress

The two earthquakes have nearly identical focal mechanisms, consistent with their similar waveforms recorded at the nearby ZVC station (Fig. 2b). Both indicate normal faulting on a NW–SE-striking plane (Fig. 2c; Table 1). The inferred stress regime is characterized by a vertical maximum principal stress, a NW–SE-oriented intermediate principal stress, and a minimum horizontal principal stress perpendicular to the fault strike. This geometry is consistent with normal faulting at lower-crustal depths, where lithostatic loading controls the vertical stress while the horizontal stresses retain the regional orientation. The regional stress field is influenced by far-field compression associated with Africa–Eurasia convergence with SHmax predominantly oriented NW–SE across central Europe (Müller et al., 1992; Heidbach et al., 2016).

8. Conclusions

The 2024 and 2025 Mirovice earthquakes provide valuable insight into the deep crustal structure of the Bohemian Massif and demonstrate the potential of crowdsourced macroseismic observations for investigating crustal structure. The analysis brings three major achievements.

- (1) Despite occurring in a region generally considered seismically non-active and characterized by relatively low population density, both earthquakes attracted significant public attention, resulting in a high number of completed questionnaires.
- (2) The uneven spatial pattern of macroseismic observations, which was not controlled by population density, proved highly informative and showed a clear correlation with major geological structures.
- (3) Both earthquakes occurred at unusually large depths, in the middle to lower crust below 24 km. They also showed very similar focal mechanisms and originated from nearly the same location, together with the small event in 2012. Their magnitudes, particularly M_L 3.5 for the 2024 event, are unexpected for a region generally considered seismically inactive.

The earthquakes occurred within the Moldanubian crystalline basement, inside the Central Bohemian Plutonic Complex (CBPC), slightly west of the deepest Moldanubian root and about 25 km east of its contact with the Teplá–Barrandian Unit. Their large focal depths, normal-faulting mechanisms, and efficient seismic-wave propagation are consistent with the low geothermal gradient and deep crystalline structure of the CBPC. The sharply delimited macroseismic observations outlines major crustal-scale boundaries: the deep Moldanubian – Teplá–Barrandian contact to the west and the Rödl–Blanice Fault System to the east. Together, these observations reveal deep, subvertical structures within the Bohemian Massif that are not easily resolved by conventional seismic investigations. The results demonstrate that major crustal-scale tectonic boundaries strongly influence seismic wave propagation and attenuation, and highlight the value of crowdsourced data for studying deep crustal processes in regions of sparse intraplate seismicity.

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Table 1: Focal mechanisms of the 2024 and 2025 Mirodice earthquakes

Earthquake	Strike 1	Dip 1	Rake 1	Strike 2	Dip 2	Rake 2
2024/03	169°	50°	-60°	307°	49°	-121°
2025/04	169°	67°	-55°	288°	42°	-144°

Author contributions

Conceptualization: PH; Data curation: PH, JV, AP, HKE, PS, and JZ; Formal analysis: PH, JV, AP, and PS; Funding acquisition: PH; Writing original draft and visualisation: PH and MM; Writing review and editing: PH, MM, JV, HKE, PS, and JZ.

340 **Competing interests**

We declare no potential conflicts of interest.

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Data availability

Macroseismic questionnaires related to this paper are in Czech and available at request from the authors.

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