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Verification of Hypocenter of Technogenic Karst-collapse Earthquake in Stebnyk (Western Part of Ukraine) on the Instrumental Data

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SUMMARY

The results of the verification of the hypocenter of the karst-collapse technogenic earthquake of 2017 in Stebnyk (Western Ukraine) using instrumental data are presented. The verification methodology is based on taking into account the inhomogeneities of the velocity structure of the earth's crust in the region and the corresponding kinematic corrections to the seismic wave hodographs used for hypocentering. The implementation of this methodology in relation to the specified karst-collapse technogenic earthquake in Stebnyk confirmed the localization of its source in the factual collapse zone and thereby unambiguously confirmed the karst-collapse technogenic nature of this earthquake. Based on the developed methodologies and results, kinematic corrections were also calculated for European seismic stations that participated in the express hypocentering of the specified earthquake; the use of these corrections provides an order of magnitude more accurate determination of the localization of the hypocenters of seismic events in the Stebnyk area using data from these seismic stations.

Keywords: Western Ukraine; Stebnyk; Karst-collapse technogenic earthquake; Hypocenter; Velocity structure of the earth's crust; kinematic corrections.

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Introduction

The area of the city of Stebnyk in the Ukrainian Precarpathians (see below, Fig. 1) in the territory of west of Ukraine was until recently aseismic. Modern seismic activity has been observed here since 2014 ((Carpathian..., 2026; Nazarevych et al., 2025a, 2025b). In 2014-2024, more than 40 small earthquakes with M=0.8-2.7 and shallow (H=0.1-6 km) foci depths were registered in the region. The strongest earthquake (with a magnitude of M=2.9), determined by our research as a karst-collapse technogenic (see below), occurred here in 2017 on the territory of the second mine of the Stebnyk MCE “Polymineral” as a result of a large-scale single-stage collapse of the roof of the mine workings (Nazarevych et al., 2025a, 2025b). Therefore, some of the local earthquakes are associated with technogenically provoked processes at the mine No. 2 of the Stebnyk MCE “Polymineral” (Rudko, Gaydin, 2019; Nazarevych et al., 2025b), and others with natural seismotectonic processes acting on the tectonic structures of the Precarpathian trough, the junction zone of the East European Craton with the Carpathian mountain folded system ((Nazarevych et al., 2025b) and others). The local seismicity of the trough is also partly technogenically provoked (earthquakes in oil and gas production areas ((Nazarevych et al., 2025b) and others).

Technogenic seismicity at the mine of the Stebnyk MCE “Polymineral” is associated with karst processes in the mine workings, which were activated during its wet conservation. These processes are described in detail by us (Nazarevych et al., 2025a, 2025b) and other researchers ((Khevpa et al., 2023; Rudko, Gaydin, 2019) and others). The main process is the destruction of pillars at different horizons of the mine workings due to the dissolution of salt-containing rocks in the process of flooding the mine, which leads to the collapse of the roof of the mine workings with the formation of depressions up to the surface. Such large-scale collapses occurred here in 2017, 2020 (Fig. 1, frame) and 2025, the first of which occurred on September 30, 2017 (at 00:46 local time / September 29, 2017 at 21:46 GMT) and caused an earthquake with a magnitude of M=2.9. This earthquake was initially classified as tectonic, since according to the results of instrumental express hypocentering using the regional seismological hodograph used for this territory, the localization of its focus was determined in the southwestern part of the city of Drohobych at a depth of 1.9 km (see below, Table 1, hypocentering variant B).

According to the results of our research ((Nazarevych et al., 2025a, 2025b) and others), this earthquake is unambiguously defined as a karst-collapse technogenic, caused by a large-scale sudden karst collapse of the rock massif up to the surface on the territory of the 2nd mine of the Stebnyk MCE “Polymineral”. Our interpretation of the nature of this seismic event is confirmed by all available data: the shock mechanism of the earthquake (positive polarities of P-wave arrivals at surrounding seismic stations); the localization of the earthquake focus in the collapse zone, obtained as a result of our refined hypocentering based on instrumental data (see below); localization of macroseismic (specific "shock" shaking of the ground), sound (impact sound and hum) and infrasonic ("shock" infrasonic wave) effects in the collapse zone (felt on the outskirts of the city of Stebnyk and the village of Solec close to the collapse) and the absence of registered macroseismic effects at this time anywhere else in this area; a break of a 35 kV high-voltage power line at this time, registered by Lvivoblenergo dispatchers (the poles of this power line collapsed into the collapse); coincidence of energy estimates of the seismic event according to instrumental seismological data and the karst collapse according to physical data (mass of collapsed rocks and height of their fall).

Method and Theory

As shown above, the problem of clarifying the hypocenter of earthquakes in the area of Stebnyk has become especially relevant in connection with study the nature of seismic event of September 30 (29), 2017 in this area. After all, while according to all other data (see above), this seismic event was indisputably associated with a karst collapse, the results of the previous hypocentering based on instrumental data controvert this, because the deviation of the hypocenter determined by instrumental data from the factual collapse was 4.94 km (see Table 1). The reasons for this discrepancy are the disregard the real significantly inhomogeneous depth-spatial velocity structure of the earth's crust in the subregion when conducting hypocentering based on the regional seismological hodograph. Because such hodograph corresponds to some averaged horizontally layered velocity model of the crust of the entire region and does not take into account the peculiarities of such structure for specific subregions and on the wave propagation paths from the focus of a specific earthquake to a specific seismic stations. And, as is known ((Structure..., 1978; Lithosphere..., 1987-1993; Zayats, 2013) and others), the earth's crust of western Ukraine is significantly heterogeneous in tectonic and velocity structure, there are structures of the Folded Carpathians with their low-velocity multi-layered thrusts and folds and deeply submerged basement structures, and structures of the Precarpathian trough with several-kilometer thicknesses of relatively low-velocity (3.2-3.6 km/s for P-waves) sedimentary rocks, and structures of the edge of the East European Platform with a significantly elevated (relative to the trough) basement with P-wave velocities of 4.6-5.2 km/s and more. It is obvious that such a complex velocity structure of the crust of the studied territory causes insufficient accuracy of the results of earthquake hypocentering when carried out using traditional methods. We have already encountered this before when conducting hypocentering of earthquakes in Ukrainian Transcarpathians, and to solve this problem, we developed and applied hypocentering methods using calculated hodographs of seismic waves ((Nazarevych et al., 2025a, 2025b) and others), obtained for velocity models of the earth's crust of the corresponding subregions, built according to the data of studies using the DSZ method on regional profiles (Structure..., 1978; Lithosphere..., 1987-1993; Zayats, 2013). To further clarification the hypocentering, kinematic corrections were determined for specific focus – seismic station wave propagation paths using such data, and additional refinement of the hypocentering of earthquakes was carried out using them.

Results

We also used the described approaches and methods to clarify the hypocenters of earthquakes in the Stebnyk area (Nazarevych et al., 2025a, 2025b), the results of their application are shown here on the example of verification of the hypocenter of the technogenic karst-collapse earthquake of September 30 (29), 2017 in Stebnyk (see Fig. 1 and Table 1), for which the actual coordinates and depth of the focus (karst collapse) are precisely known.

Table 1. *Coordinates of the focus of the 2017 technogenic karst-collapse earthquake in Stebnyk on the different hypocentering variants in comparison with the factual karst collapse data*

Hypo-centering variant	Latitude φ (ºN)	Longitude λ (ºE)	Depth H (km)	Time in the source t_0 (GMT)	Residuals (RMS) (km)	Devia-tion (km)	Notes
A	**49,2990 ±0.0009**	**23,5160 ±0.0014**	**0,10±0.015**	21.46.04.80	-	**-**	**Factual data**
B	49,34	23.49	1.9 ±0.5	21.46.08,4	2,6	4,94	Initial definition
C	49,3031 ±0.0030	23,5150 ±0.0055	0,15 ±0.07	21.46. 05,31	0,33	0,45	Refined definition
D	49,3008 ±0.0022	23,5141 ±0.0035	0,10 ±0.05	21.46.04,80	0,24	0,25	Refined definition +
EMSC	49,37	23,14	10	21.46.14.5	?	28	Initial definition EMSC

We see that taking into account the real velocity structure of the subregion's crust (Zayats, 2013) made it possible to reduce the deviation of the hypocenter determined by instrumental data from the factual one by an order of magnitude, from 4.94 to 0.5-0.25 km (see Fig. 1 and Table 1, variants of the refined hypocentering C and D, respectively, compared to the variant of the initial hypocentering B) (see Fig. 1, localization of the center of the depression (variant A) on the frame on Google satellite image (a point with two arrows pointing to it)). Based on the results of the refined hypocentering of the studied earthquake, we also calculated the corresponding kinematic corrections for this area for foreign seismic stations that were involved in the express hypocentering of this earthquake according to EMSC data (EMSC, 2017) (Table 2).

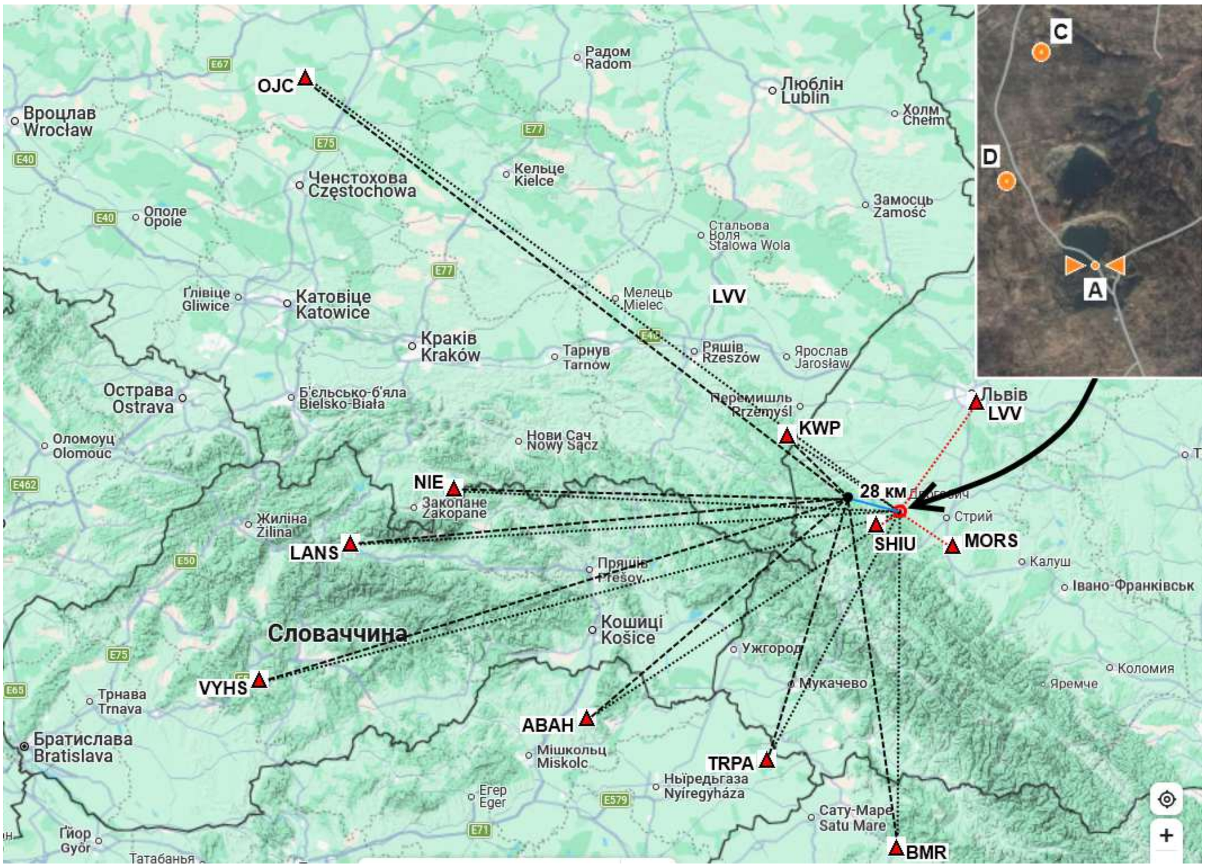

Figure 1. *Results of the initial and refined (taking into account the kinematic corrections presented in the Table 2) hypocentering of the 2017 karst-collapse earthquake in Stebnyk on the data of European seismic stations (EMSC, 2017) (explanations are in the text) in combination with the hypocentering on data from nearby Ukrainian seismic stations. Different variants of the hypocentering of the 2017 karst-collapse earthquake in Stebnyk on the data of Ukrainian seismic stations, are shown in more detail in the frame (in the background of Google satellite image of 2017 and 2020 Stebnyk collapses area (2022), explanation are in the text) (note: hypocenter by variant B (preliminary hypocentering on the seismological hodograph, see table 1) is located north-northwest far outside the frame)*

The use of these corrections (Table 2, columns 6, 9, 13) allows for these stations to refine the hypocentering of earthquakes in this area by an order of magnitude (see comparison of the results of the initial hypocentering of the earthquake of September 30 (29), 2017 according to EMSC data with the factual location of the collapse (Fig. 1 and Table 1)).

Table 2. *Results of the initial hypocentering of the 2017 technogenic karst-collapse earthquake in Stebnyk according to data from foreign seismic stations (EMSC, 2017) and kinematic corrections for them*

№ з/п	Station code	t_p (s)	*Δt_p (s)	Δt_p (s)	**K(t_p)**	*Δ (km)	Δ (km)	**K(Δ)**	σΔ(s) (km)	*V_p (km/s)	V_p (km/s)	**K(V_p)**
1	2	3	4	5	6	7	8	9	10	11	12	13
1	KWP	46:20,7	6,2	15,9	**2,56**	42,8	69,3	**1,62**	26,5	6,90	4,36	**0,63**
2	TRPA	46:35,5	21,0	30,7	**1,46**	147,6	150,2	**1,02**	2,6	7,03	4,89	**0,70**
3	ABAH	46:42,7	28,2	37,9	**1,34**	185,2	201,9	**1,09**	16,7	6,57	5,33	**0,81**
4	BMR	46:43,4	28,9	38,6	**1,34**	190,8	180,3	**0,94**	-10,5	6,60	4,67	**0,71**
5	NIE	46:49,6	35,1	44,8	**1,28**	205,9	232,9	**1,13**	27	5,87	5,20	**0,89**
6	OJC	47:01,6	47,1	56,8	**1,21**	356,5	382,8	**1,07**	26,3	7,57	6,74	**0,89**
7	VYHS	47:02,2	47,7	57,4	**1,20**	329,5	353,1	**1,07**	23,6	6,91	6,15	**0,89**
8	LANS	47:08,0	53,5	63,2	**1,18**	267,9	294,0	**1,10**	26,1	5,01	4,65	**0,93**

The results of such refinement for the studied 2017 karst-collapse earthquake in Stebnyk are graphically presented in Fig. 1, which shows the localization of the epicenter of this seismic event, determined according to the data of the initial EMSC hypocentering (EMSC, 2017) (black dot and dashed lines from European seismic stations to it) and the factual localization of the earthquake focus – the karst collapse (red circle with a black dot in the center and dotted lines from European seismic stations to it), such refined localization is obtained using the proposed corrections, the distance (blue line in Fig. 2) between the previously determined localization of the focus and the refined (factual collapse) is 28 km (see also Table 1).

Conclusions

Summing up, we can state that the results of the refined hypocentering of the earthquake of September 30 (29), 2017 in Stebnyk, obtained from the data of Ukrainian seismic stations and the developed methods, unambiguously confirmed its technogenic karst-collapse nature. The presented results, as well as data on the nature and characteristics of this earthquake, clearly show that the most accurate hypocentering of the registered seismic events is extremely important for the correct interpretation of their nature and features.

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