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Constraints on long-term seismic hazard from an intact, vulnerable stalagmite for the surroundings of Ördöglik (Čertova diera) part of Domica cave, Slovakia

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ABSTRACT:

To verify seismic hazard maps by independent observations that serves long-term information should be necessary. It requires studying vulnerable dripstones, since they survived all earthquakes that have occurred over thousands of years, depending on the age of them.

Examination of an intact vulnerable stalagmite (IVSTM) in Ördöglik part of Domica cave (Slovakia) has been done. This IVSTM(4.5) is suitable for estimating the upper limit of horizontal ground acceleration (HGA) generated by prehistoric earthquakes. This research is the continuation of our previous examination of different IVSTMs in Baradla and Domica cave system, north-east Hungary.

The density, the Young's modulus and the tensile failure stress of the samples originating from broken speleothems have been measured in geo-mechanical laboratories, whereas the dimensions and natural frequency of the IVSTM(4.5) was determined by different types of in situ observations. The value of HGA resulting in failure and the natural frequency of the IVSTM(4.5) were assessed by theoretical calculations. The ages of the samples taken from a column next to the investigated IVSTM(4.5) at different heights have been determined by MC-ICPMS analysis. The measured ages fall between about 7.6 and 2.4 kyr. The critical horizontal ground acceleration (CHGA) values as a function of time going back into the past determined from the stalagmite that we investigated are presented. Our results show that all values of probabilistic seismic hazard maps, SHARE Map (Giardini et al. 2014) and PSHA Map (Tóth et al. 2006) at the location of Ördöglik part of Domica cave, are above the CHGA curve calculated by using the dimensions, geo-mechanical and elastic parameters of IVSTM(4.5), and the values of CHGA caves are lower than 0.056g (or 0.064g) since ~2.1 or ~2.4 kyr (0.056g and 0.064g was estimated by Szeidovitz et al. (2008) using another vulnerable stalagmite (IVSTM(5.1) located 4 km far from Ördöglik, in the Baradla cave.) All these means that the seismic hazard is **overestimated** at the territory of Ördöglik, Domica cave.

1. SEISMICITY IN HUNGARY AND AT THE SURROUNDING AREAS

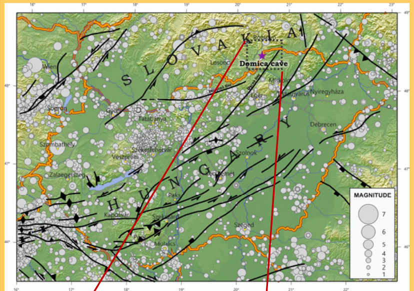

Fig. 1. Seismicity in Hungary and the location of the investigated cave, Domica and the active faults (Horváth et al. (2004) at the north-eastern part of Hungary) the original map was completed by Horváth et al. (2011)

Seismicity inside the Pannonian basin can be considered moderate compared to the peri-pheral areas. Construction of a reliable seismo-tectonic model for the territory proved to be a challenging task, due to the diffuse distribution of epicenters. The earth-quake activity and present day deformation is driven by the counter-clock-wise rotation and northward movement of the Adriatic micro-plate (Tóth et al. 2002).

In stable continental regions, like the Pannonian basin, far from the plate boundary faults, with low or moderate seismic activity the recurrence time of large earthquakes can be as long as 10,000 years (Scholz 1990), if any recurrence time exists (Calais et al. 2016). The seismic catalogues are short in geological time scale, therefore the estimation of seismic hazard is quite difficult for a longer period of time.

2. LOCATION OF THE CAVE AND THE STALAGMITE INVESTIGATED

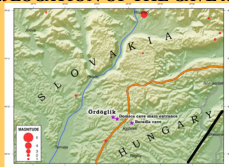

Fig. 2. Location of the investigated cave near the Slovak-Hungarian border, south-east Slovakia

Domica cave is situated in the south-eastern part of Slovakia right exactly at the Slovak-Hungarian border (Fig. 1, 2 and 3). In the Majko dome of the Ördöglik part of Domica cave stands a 451.5 cm tall, intact, slender, candle-stick shaped type and vulnerable stalagmite, IVSTM(4.5) (Fig. 4a and 5). Please see the detailed parameters of the IVSTM(4.5) in Table 1.!

The following questions were addressed:

What is the upper limit of the size of earthquakes occurring in the surroundings of the cave?

Equivalently: What is the largest ground motion (critical horizontal ground acceleration, CHGA) that this tall and vulnerable IVSTM(4.5) can survive currently and could survive in the past?

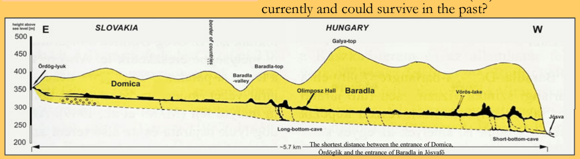

Fig. 3. Vertical profile of the Baradla-Domica cave system (Gruber & Gaál 2015)

Fig. 3 shows that Ördöglik part of Domica cave is located in ~40-50 m depth. That is shallower than the depth of Olimposz Hall in the Baradla cave. This means that the attenuation of seismic waves by the depth is not necessary to take into account in our results.

2a. LOCATION OF THE STALAGMITE INVESTIGATED, IVSTM(4.5)

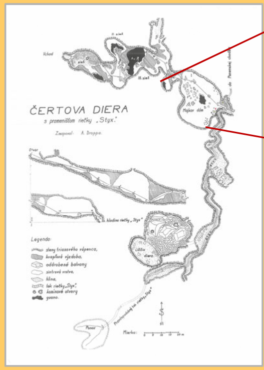

Fig. 4. Map of Ördöglik part of Domica cave (front and side view), map was prepared by A. Droppa in 1950

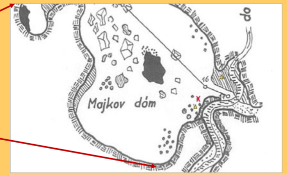

Fig. 4a. Location of IVSTM(4.5) in Majko dome, Ördöglik, Domica cave (red cross) and the location of the stalagmites used for dating (yellow triangle No.1)

Fig. 5. IVSTM(4.5) in Majko dome, Ördöglik, Domica cave (red cross in Fig. 4a)

3. THE DRIPSTONE COLUMN USED FOR AGE DATING

Since the investigated stalagmite (IVSTM(4.5)) is too slender to take core samples from it, therefore a dripstone column (fixed to the ground at the base and to celling at the top) was used for age dating. This column is located in Majko dome, Ördöglik, and can be seen on Fig. 4a (No.1, the yellow triangle) and in Fig. 6.

We took core samples from this column at different part of them, and determined the age of the core samples by MC-ICPMS method in laboratory. The height of the investigated, vulnerable, slender stalagmite (IVSTM(4.5)) as a function of time going back into the past was calculated by the results of age dating (green function in Fig. 8).

Fig. 6. Column No.1 (yellow triangle)on Fig. 3a

Fig. 7. 5.1 m tall intact and vulnerable stalagmite in Baradla cave, Olimposz Hall (IVSTM (5.1))

4. DETERMINING THE UPPER LIMIT OF CHGA

The method of our investigation has been presented in Gribovszki et al. (2017):

– the natural frequency and geometrical dimension of IVSTM(4.5) were determined by in-situ non-destructive measurements (Table 1.);

– the density (ρ), the dynamic Young's modulus and the tensile failure stress (σ_u) of broken stalagmite samples have been measured in mechanical laboratories;

– the value of horizontal ground acceleration (a_g) resulting in failure of IVSTM(4.5) were assessed by theoretical calculations in the static case (Eq. 1). Resonance (dynamic amplification) was not taking into account (Cadorin et al. 2001);

$$a_g = \frac{D\sigma_u}{4\rho H^2} \quad \text{(Eq. 1)}$$

– age dating of core samples drilled from columns No.1 were assessed by MC-ICPMS method.

Height H [cm]	Diameter D [cm]	H/D	Measured f_0, f_1, f_2 [Hz] (by LF-24)	Calculated a_g (CHGA) [m/s²]
451.5 CODE: IVSTM (4.5)	average: 5.5 ± 0.5	82	2.1; (10.2; 10.6); (25; 26.5)	0.25 (present time)

Table 1. Parameters of the investigated stalagmite IVSTM(4.5), Fig. 5 in Ördöglik part of Domica cave

The critical horizontal ground acceleration (CHGA, blue curve) provided by the height of IVSTM(4.5) as a function of time going back into the past was calculated by Eq. 1 (Fig. 8).

By the calculation of CHGA curve in Fig. 8 the attenuation of seismic waves by depth from the surface to the cave wasn't took into account in case of Ördöglik, since the situation is the same as in case of Baradla cave, Olimposz Hall (Szeidovitz et al. 2008): both place (Ördöglik and Olimposz) is situated only about 40-50 m below the surface (Fig. 3 and Fig. 4, side view). *(The situation was different in case of Detrekői cave, Plavecka priepast (Gribovszki et al. 2017).)*

Real in situ measurements would be necessary to reveal the real value of the attenuation!

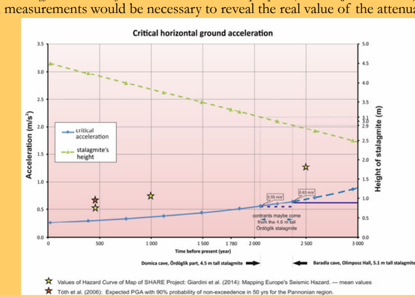

Fig. 8. Critical horizontal ground acceleration (CHGA, upper limit) depending on the height of stalagmite (IVSTM(4.5)) calculated by the growth rate of column No.1

5. CONCLUSION

Fig. 8 shows that all values of probabilistic seismic hazard maps, SHARE Map (Giardini et al. 2014) and PSHA Map (Tóth et al. 2006) (yellow and red stars) at the location of Ördöglik part of Domica cave, are above the CHGA curve calculated by the dimensions and geo-mechanical and elastic parameters of IVSTM(4.5) (blue curve), and by the dating of the No.1 column. Therefore we can concluded that the seismic hazard is **overestimated** at the territory of Ördöglik, Domica cave.

Comparison of CHGA values calculated by using IVSTM(5.1) or IVSTM(4.5)

The values of this CHGA curve (Fig. 8) is lower than 0.55 m/s² (or 0.63) since ~2.1 or 2.4 kyr. (0.55 or 0.63 m/s²). These values were estimated by Szeidovitz et al. (2008) using IVSTM(5.1) (Fig. 7) 4 km far from Ördöglik, in the Baradla cave, Olimposz Hall.)

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