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Estimation the upper limit of prehistoric peak ground acceleration using the parameters of intact stalagmite in Plavecka Priepast, PP2 Slovakia---Seismic Hazard of Vienna and Bratislava

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ABSTRACT: A specially shaped (high, slim and more or less cylindrical), vulnerable, intact stalagmite (STM) in Plavecka Priepast PP2 has been examined last year. This STM is suitable for estimating the upper limit for horizontal peak ground acceleration generated by paleoearthquake.

The method of our investigation is the same as before:

--- the density, Young's modulus and tensile failure stress of broken STM samples (lying at the same hall of PP2, as the investigated stalagmite) have been measured in mechanical laboratory;

--- the height and diameters of the intact STMs, as well as its natural frequency have been determined in situ;

--- theoretical calculations based on these measurements then produce the value of horizontal ground acceleration resulting in failure, as well as the theoretical natural frequency of the STM;

--- core samples were taken from a column dripstone standing in the same hall as the investigated stalagmite to obtain the age of the stalagmite, by Multi Collector – Inductively Coupled Plasma Mass Spectrometry analysis (MC-ICPMS).

This technique can yield important new constraints on seismic hazard, as geological structures close to Plavecka Priepast PP2 cave did not generate strong paleoearthquakes in the last few thousand years which would have produced horizontal ground acceleration larger than the upper acceleration threshold that we determine from the STM. These results have to be taken into account, when calculating the seismic potential of faults near to PP2 cave as well as in Vienna basin Markgrafneusiedler fault. A particular importance of this study results from the seismic hazard of two close-by capitals: Vienna and Bratislava.

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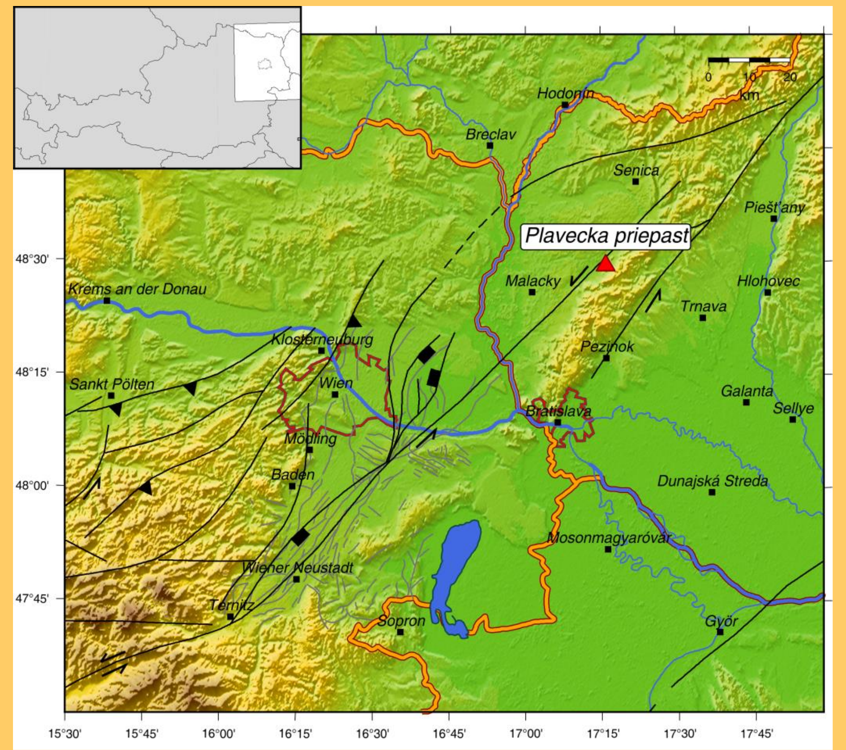
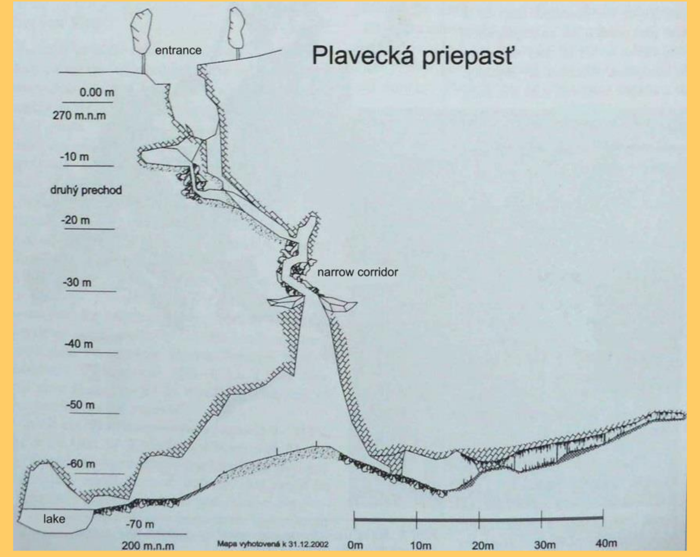
1. THE LOCATION OF PLAVECKA PRIEPAST PP2 CAVE IN THE LITTLE CARPATHIANS IN SLOVAKIA AND THE ACTIVE FAULTS



The location of the investigated cave, Plavecka Priepast PP2 in the Little Carpathians in Slovakia, near to theVienna basin and the active faults
[grey faults Egger et al. (1999); black faults Horváth et al. (2004)]

Plavecka Priepast cave is situated in the Little Carpathians in Slovakia. This cave is close to two capitals: it is 70 km far from Vienna and 40 km from Bratislava. In this cave stands a 4.03 m tall, intact, slim cylindrically shape and vulnerable stalagmite (STM4.03m). In this study we try to find the answer to the question:
What is the upper limit the size of the earthquakes occuring at the surrounding of the cave? In other words:
What is the highest ground motion, that survives this tall and vulnerable STM (4.03m)?

2. THE CAVE AND THE INVESTIGATED STALAGMITE



Profile of Plavecka Priepast PP2 cave

STM(4.03m)

Plavecka Priepast cave is at shallow depth. The investigated stalagmite STM(4.03m) is about 55m below the surface. At this depth the seismic waves do not attenuate much compared with a surface location. [Lednicka et al. 2013]

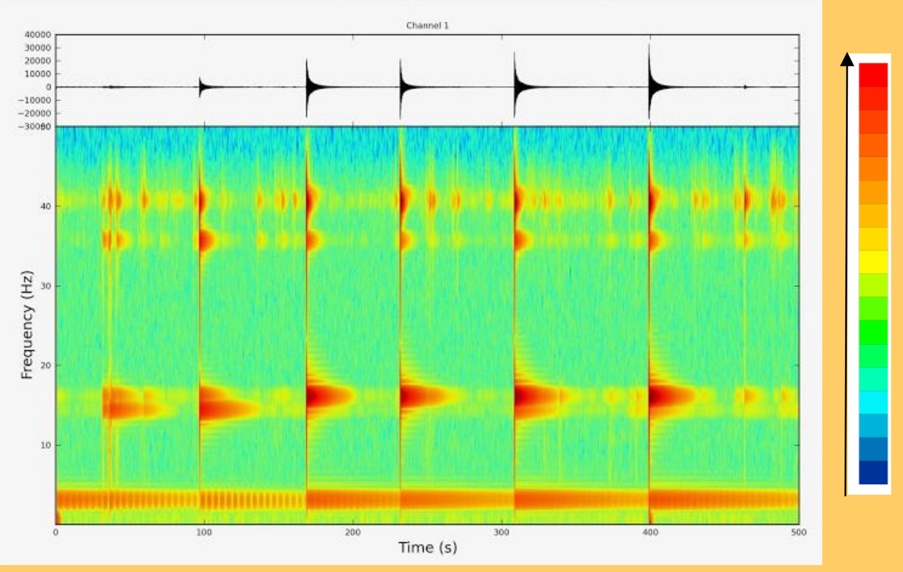
NAME	PLACE	HEIGHT (m)	DIAMETER (cm)	H/D	measured f_0 (Hz)	measured f_1 (Hz)	measured f_2 (Hz)	measured f_3 (Hz)
STM(4.03m)	Plavecka Priepast, PP2	4.03	average: 8.5 (11-6)	50	3	14.5; 16	36	41

Table 1. Results of non-destructive in-situ examinations of stalagmite: dimensions and measured natural frequencies

3. NON-DESTRUCTIVE IN-SITU EXAMINATIONS OF STALAGMITES

Considering that in situ measurements of slim and tall stalagmite had to be done non-destructively, we confined ourselves only to determine the **dimensions** and **natural frequencies** of them. In case of STM slim enough resonance effect can occur [Lacave et al. 2000].

In order to measure the natural frequency, horizontal LF-24 geophones were fastened on the stalagmites, and they were excited by small amplitude forced vibration obtained by a gentle hit.



The oscillation and Power Spectral Density of STM(4.03m) along the recorded signal of the excited stalagmite

It can be seen on Table 1, that the two lowest natural frequencies of STMs are below 20Hz, this means that they fall into the frequency range of nearby earthquakes.
If the natural frequency of stalagmite is below 20Hz then **resonance can occur**. Our theoretical calculations (equations by using cantilever beam theory) did not take into consideration the phenomenon of resonance, which means that in reality the STMs would break at a lower value of horizontal acceleration than the computed ones.

4. MECHANICAL PROPERTIES OF STALAGMITES DETERMINED BY LABORATORY MEASUREMENTS

Mechanical laboratory measurements were performed on some samples originating from STMs, which was found lying broken on the ground in Plavecka Priepast PP2 cave. Tensile failure stress (σ_u) was measured by pure tensile test, while dynamic Young-modulus (E) was determined by using ultrasonic velocity propagation values. The measurements were done on wet and on dry samples as well. The tensile failure stress results show very low values compared with our previous results from caves in the Carpathian Basin.

	density, ρ [kg/m³]	Ultrasonic, Vp [km/s]	dynamic Young-modulus, E [GPa]	tensile failure stress, σ_u, [MPa]
Plavecka Priepast PP2, dry samples	1941	4.09	32.469	0.51
Plavecka Priepast PP2, wet samples	2136	4.28	39.128	0.17

Table 2. Results of mechanical laboratory measurements

5. OSCILLATION OF STALAGMITES BY THEORETICAL CALCULATIONS

The natural frequency of a stalagmite

$$f_0 = \frac{1}{\pi}\sqrt{\frac{3ED^2}{16\rho H^4}}$$

The horizontal ground acceleration resulting in failure of a stalagmite

$$a_g = \frac{r\sigma_u}{2\rho H^2}$$

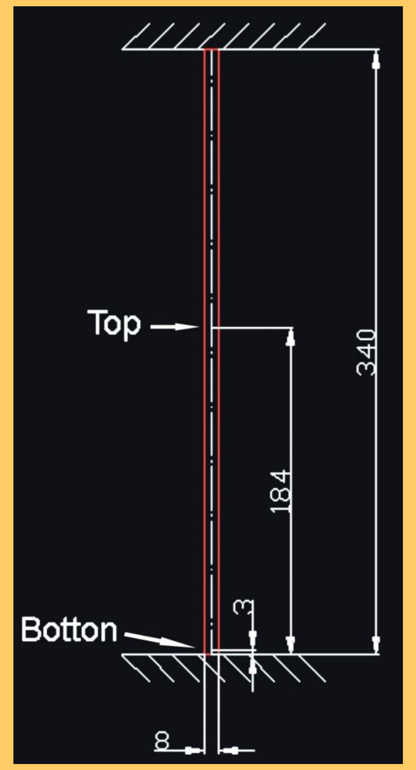
D: diameter
r: radius
measured at the horizontal section of the cylindrical shaped stalagmite,
H: height of the stalagmite, ρ: density of the stalagmite, E: dynamic Young-modulus,
σ_u: tensile failure stress of the stalagmite

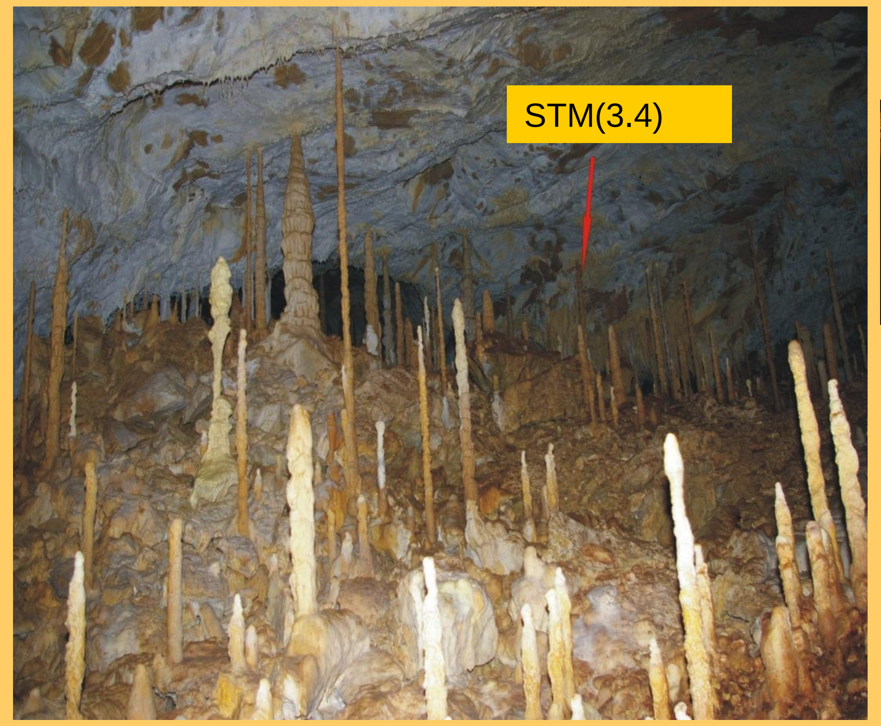
Cadorin et al. 2001

NAME	PLACE	HEIGHT (m)	DIAMETER (cm)	H/D	measured f_0 (Hz)	theoretical f_0 (Hz)	a_g (m/s²)
STM(4m) wet	Plavecka Priepast PP2	3	average: 8.5 (11-6)	47	3	5.2	0.18
STM(4m) dry	Plavecka Priepast PP2	3	average: 8.5 (11-6)	47	3	5.0	0.58

Table 3. Table 1. completed with natural frequency and horizontal ground acceleration resulting in failure obtained by theoretical calculations

6. SAMPLING AND AGE DETERMINATION





We took core samples from STM(3.4) standing column at Plavecka Priepast PP2 at two different heights (at 1.8m and at the bottom) to determine its age and rate of growing. The core samples were measured at the Institute of Geology, University of Innsbruck by MC-ICPMS method.

The results show that the bottom of STM(3.4) is about 10.5 kyears old, while at 1.8m it is about 5 kyears old. The mean growing velocity is about 1mm/3years, which shows much faster growing rate than it was previously determined by us in Baradla or Domica caves in Slovakia as well. By this data we can assume, that:
STM(4.03m) was ~3m tall ≈ 2.5 kyears ago.

Summary:

-Intact (vulnerable) stalagmites can provide important constraints on seismic hazard.

- Based on this preliminary study, the stalagmites in Plavecka Priepast would have collapsed, if a strong earthquake had happened in the last several thousand years.