The Evolution of Waldheim Cave (BE, Switzerland)

M-J. F. Gilbert[1], Ph. Häuselmann[2], D. Fleitmann[3]

Abstract: Waldheim Cave is located in the Bernese Oberland, Switzerland. Its purely fracture-bound morphology suggests a formation solely by dripwater unsaturated with respect to calcite and the limestone underneath is therefore dissolved intensively and shafts formed (HAEUSELMANN, 2007). In order to gain insights into present-day hydrological and cave climate conditions, numerous physical (e.g. cave air temperature, drip rates) and chemical parameters (e.g. trace elements and stable isotopes in soil and drip waters) were monitored at a monthly resolution from January 2011 to March 2012.

Drip rates in Waldheim Cave respond within hours to a few days to rainfall events. However, the isotopic signatures ($\delta^{18}O$ and δD) of the dripwaters are fairly constant, suggesting that mixing and buffering effects take place within the soil zone and host rock. This residence time in the overlying calcite-containing sandstone is long enough for the water to apparently become saturated with respect to calcite before it enters the shaft. The onset of shaft formation has been calculated for different water quantities under the assumption of different dissolution capacities. Based on the incision history of the Aare Valley (HAEUSELMANN et al., 2007) and U-series dating of flowstone, cave formation has started between 670'000 and 500'000 years ago. For the monitored shaft, this would require the dissolution of 7.8 mg calcite per liter water and 25'000 liters per year on average.

The Study Site

Waldheim Cave is located on the municipality of Beatenberg north of Lake Thun at 1'020 m asl (Fig. 1). To locals, Waldheim Cave has already been known for a long time, but only at the end of the 90ties, a reliable plan and a description were completed (HAEUSELMANN, 2007).

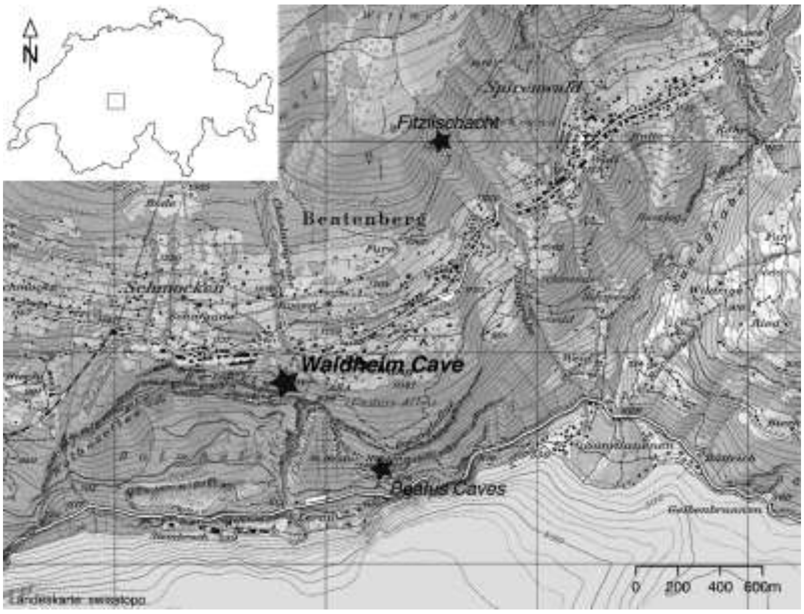

Fig. 1: Study location and two nearby caves.

Based on this work, it became evident that this cave is special in terms of its morphology, as it has neither phreatic conduits nor distinct vadose meandering canyons (HAEUSELMANN, 2007).

Geologically, the area belongs to the Cretaceous domain of the Helvetic Border Chain, detached from the Jurassic (HERB et al., 1978). The lowermost outcropping unit is the Kieselkalk (a siliceous limestone), which is then followed by the Drusberg-Member (a calcareous marl) and the Schrattenkalk-Formation (a pure limestone). All Upper Cretaceous units are missing and have either been eroded or were never deposited, as the area was above sea level at that time (BREITSCHMID, 1976). The Eocene Hohgant-Formation was deposited discordantly on top of the Schrattenkalk-Formation. At its base there is the 2 to 3 m thick Discus Layer (HAEUSELMANN, 2007), a sandy limestone with many discocyclins and nummulites (Jeannin, 1989), that was deposited on a biologically highly active inner shelf (BREITSCHMID, 1976). The following Hohgant-Sandstones show a variable carbonate content ranging from 10 to 60 % (JEANNIN, 1989; BREITSCHMID, 1976). This is due to fluctuations in the environmental conditions during deposition (BREITSCHMID, 1976). Tectonic movements during the alpine orogeny have tilted the entire stack, so that it is nowadays dipping towards the south-east. A rockfall older than the last glaciation formed the cliffs to the south (Herb et al., 1978). The entrances to Waldheim Cave are located at their top. Based on the dip of the geological units, HAEUSELMANN (2007) assumes that the water from Waldheim Cave reappears in the "Erosionsgänge" of the St. Beatus Caves.

[1] *SGH Bern / Institute of Geological Sciences, University of Bern, mjfgilbert@email.de*

[2] *SGH Bern / SISKA, La Chaux-de-Fonds*

[3] *Institute of Geological Sciences, Univ. of Bern*

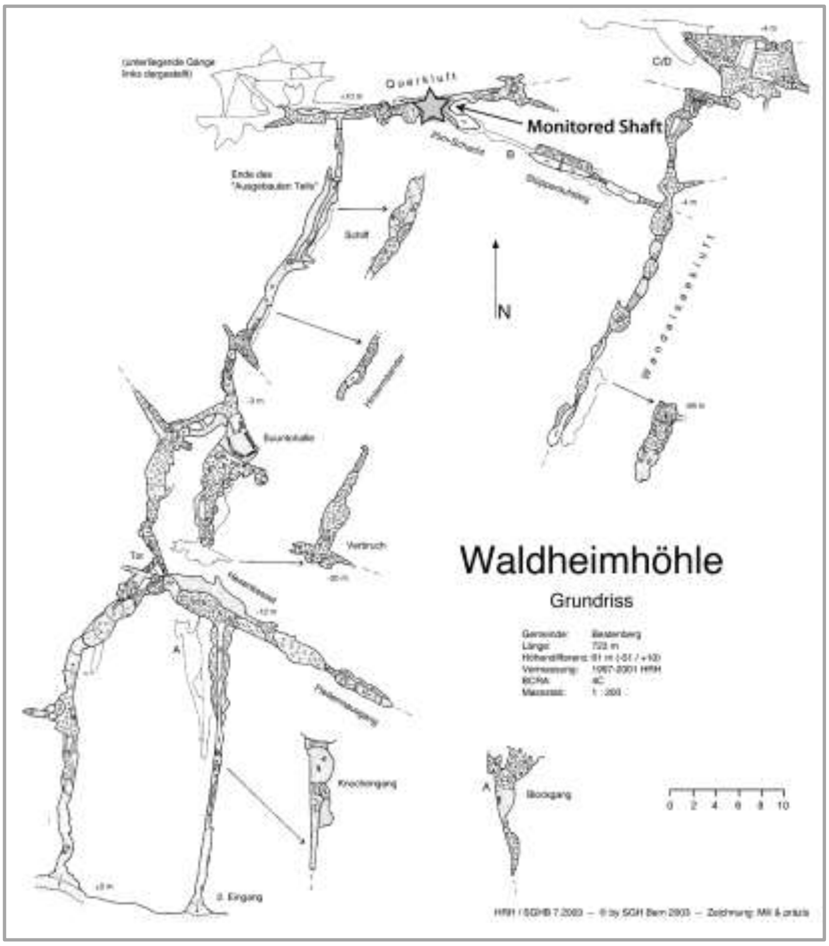

Fig. 2: Excerpt from the plan view of Waldheim Cave.

It is known that the underground in the area of Beatenberg is highly fractured (HAEUSELMANN, 2007). The Waldheim Cave clearly follows a series of such intersecting fractures, showing some disperse signs of meandering canyon formation in the entrance part as far as the "Schiff" (Fig. 2, HAEUSELMANN, 2007). However, some blind-ending shafts, several meters deep, pierce here and there this meander-like sub-horizontal gallery. Behind the "Schiff", the cave morphology is clearly dominated by such shafts, which are relatively narrow, but with depths of up to 25 m. They are connected to each other with smaller passages, and they clearly follow the interface of Schrattenkalk-Formation and the overlying Hohgant-Formation (Fig. 3). This reminds strongly of the shafts on the Dolny Vrch Plateau, Slovake Republic, described by BAROŇ (2002), except that the blind-ending shafts are not accessible from atop. Instead, they have grown together, forming a jigsaw of about 26 independent caverns (HAEUSELMANN, 2004).

Hypothesis

The sheer absence of morphological features indicating flowing water - either phreatic or vadose - only leaves dripwater as a possible source of corrosion. Even during present-day rainy periods when dripwater discharge into the cave is high, no waterfalls or watercourses occur.

These observations led HAEUSELMANN (2007) to the following hypothesis: *Water infiltrates into the soil and becomes enriched in CO_2. It then percolates through the Hohgant-Formation without being able to reach saturation with respect to calcite; therefore it intensively dissolves the limestone underneath. At 90 % calcite saturation, the dissolution rates of limestone are no more linear but drop substantially (DREYBRODT and KAUFMANN, 2007). This must be the case at the bottom of the shafts, as the outlets are only about fist-sized (Fig. 3). A further consequence is the assumption that the cave is substantially younger than the altitude may suggest, probably of Uppermost Quaternary age (<100'000 years).*

With this monitoring project, we aim at proving or disproving this hypothesis.

Methods

A dripwater monitoring project and age determination (U-series dating) of old flowstones were carried out between January 2011 and March 2012. Five drip sites, distributed vertically in one shaft, were sampled every two to three weeks on average. The water was then analysed for its chemical (major and trace elements) and isotopic ($\delta^{18}O$

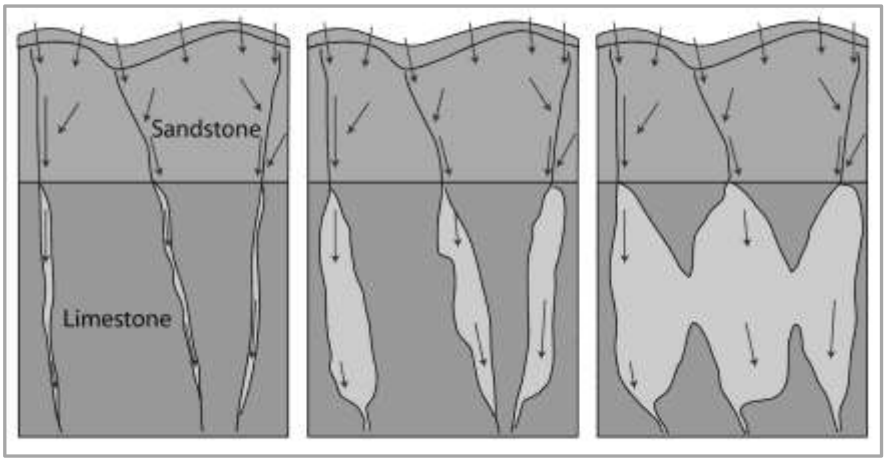

Fig. 3: Hypothesis of cave formation: Water undersaturated with respect to calcite percolates down to the limestone and forms the cavity (HAEUSELMANN, 2007).

and δD) composition using ion chromatography and mass spectrometry, respectively. In order to obtain some information about the initial chemical and isotopic composition of the water, several soil water samples were analysed. Beside temperature, relative humidity and CO_2 content of the air, the electrical conductivity and the pH of the water as well as dripwater discharge were measured.

Results and Interpretations

The mean air temperature in Waldheim Cave is 8.46 °C (std. dev. 0.06), 8.38 °C (Feb. 2012) being the lowest and 8.64 °C (Sept. 2011) the highest measured value. As the monitoring sites are far from the entrance, the variations in air temperature indicate good ventilation. It is not quite clear where this air circulation originates, since the shaft is located well behind the junction of the two entrances (Fig. 4).

Compared to the cave air temperature, the dripwater temperature shows higher short-term variability (Fig. 4), whereas increasing water temperatures correlate with increasing drip rates and decreasing electrical conductivity. Each of these events marks the establishment of the hydraulic connection of infiltrating precipitation with the dripping sites. The delay between the onset of precipitation and the establishment of this hydraulic connection depends mainly on two factors: quantity of infiltrating water per time unit and saturation state of the percolation pathways to the dripping sites.

The precipitation event in mid June 2011 was intense and covered a large area. In terms of the onset of precipitation, the meteorological data from the MeteoSchweiz station at Interlaken (577 m asl) should, therefore, not differ significantly from conditions above Waldheim Cave (~1'040 m asl). As it follows another precipitation event few days earlier, the covering host rock and soils above the cave should still be close to saturation. A comparison of the two data sets suggests a time delay of about half a day (fig. 5).

On the other hand, there is rainfall at the beginning of December 2011 after more than a month of complete dryness. During this time, the two uppermost sampling sites fell dry, indicating a severe dehydration of the cover. Available data show a contemporaneous onset of several, low intensity precipitation events at Interlaken (MeteoSchweiz) and Beatenberg (ARA) (newly installed surface pluviometer) at the beginning of December. However, this water became noticeable in Waldheim Cave not before four and a half days later as one of the topmost sampling sites suddenly started to drip again.

The isotopic signals of seepage water reaching the cave after a hydraulic connection has been established does however not correspond to the seasonally-varying precipitation signals from Bern (IAEA, 2001): Lowest $\delta^{18}O$ values in precipitation are generally found during January but appear in the dripwater only in June. Also, the highest $\delta^{18}O$ values were measured in precipitation in August, they do not reach the cave before October. This delay in the maxima and minima of the isotopic signal is accompanied by smaller amplitude, mixing of waters from different precipitation events occurs during retention in the cover (Fig. 6).

Even though the cave is clearly fracture-bound, the retention time of the water in the cover indicates a significant portion of dispersed percolation and maybe even a perched reservoir in the sandstone. This is also indicated by the saturation state of the dripwater, as all samples show saturation with respect to calcite (The calculations were done with PHREEQ-C). The amount of calcite dissolved varies seasonally with values of about 120 mg/l in wintertime and 200 mg/l in summertime.

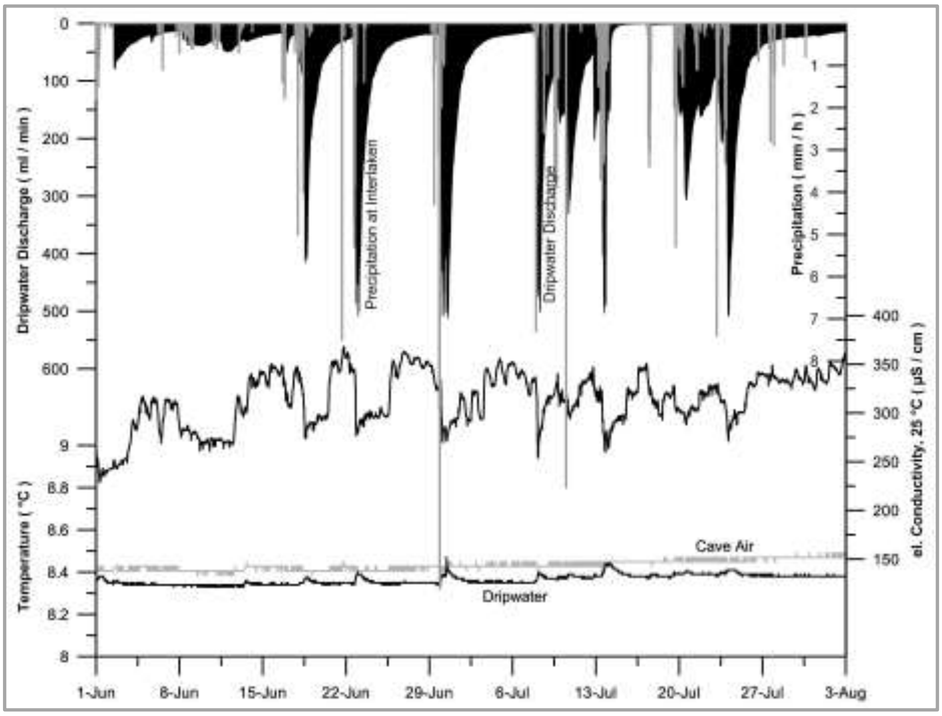

Fig. 4: Shortly after each precipitation event, the dripwater discharge in the cave increases together with the water temperature while the electrical conductivity decreases.

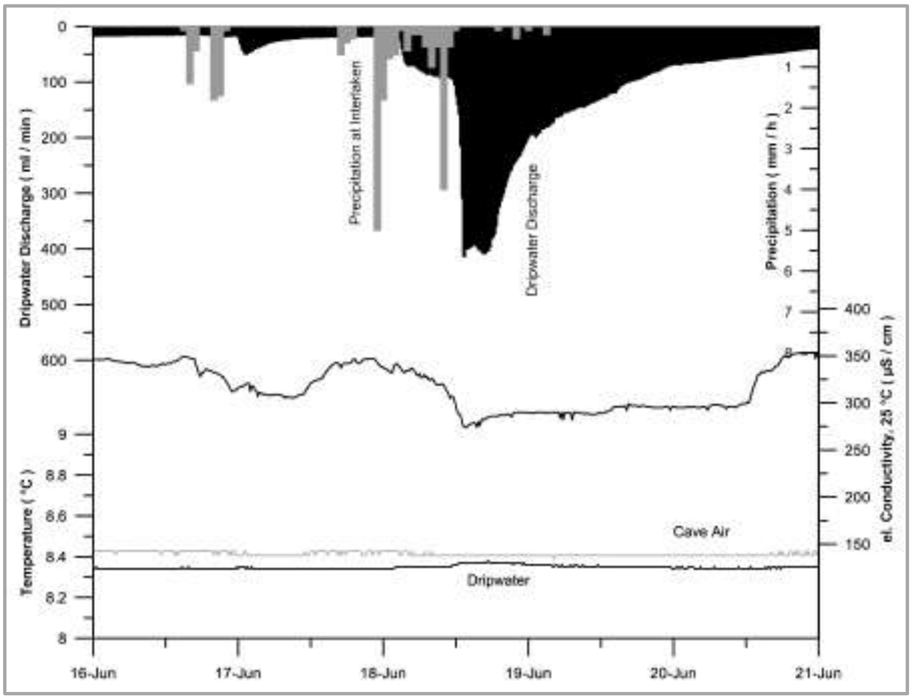

Fig. 5: The time delay between the onset of precipitation at Interlaken and the increase in dripwater discharge in the Waldheim Cave is about half a day.

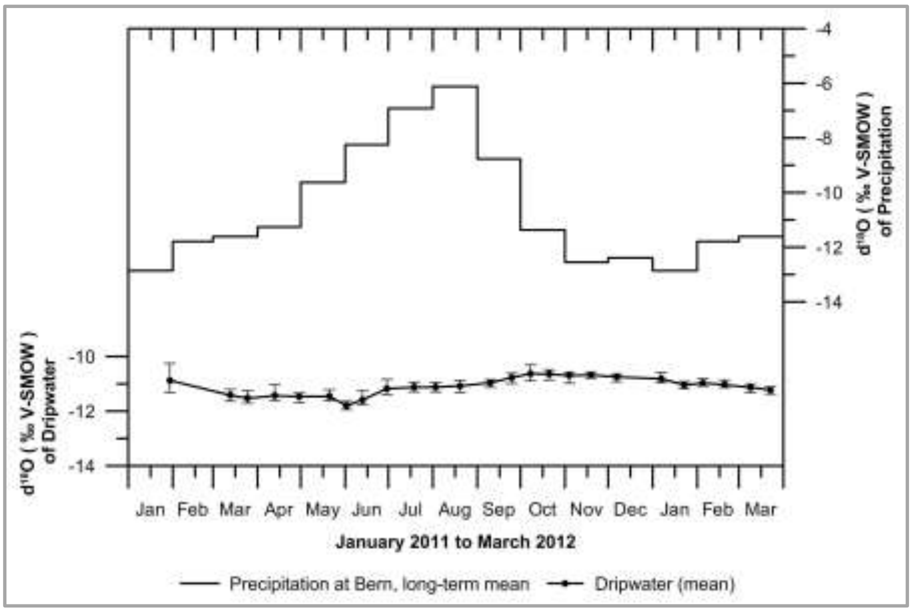

Fig. 6: The isotopic data from the dripwater indicates a retention time of several months as well as water mixing.

Reaction calculations based on the chemical composition of soil water are undertaken under the assumption of a soil pCO_2 10x higher than in the atmosphere, as biological activities produce CO_2. Under these conditions, each litre of soil water can dissolve about 156 mg of calcite, which corresponds to the average amount found in the dripwater. A volume of about 60 mm^3 calcite is therefore being dissolved in the host rock cover per litre percolation water. During the monitoring period, about 25'000 l of water (25 m^3) dripped down the shaft and carried a volume of 1.5 dm^3 of dissolved calcite.

The time needed to dissolve the volume of the shaft (~ 40 m^3) can be calculated for varying water quantities, assuming a certain dissolution capacity. As there is presently no such capacity, the calculations were performed for several amounts of calcite being dissolved (Fig. 7).

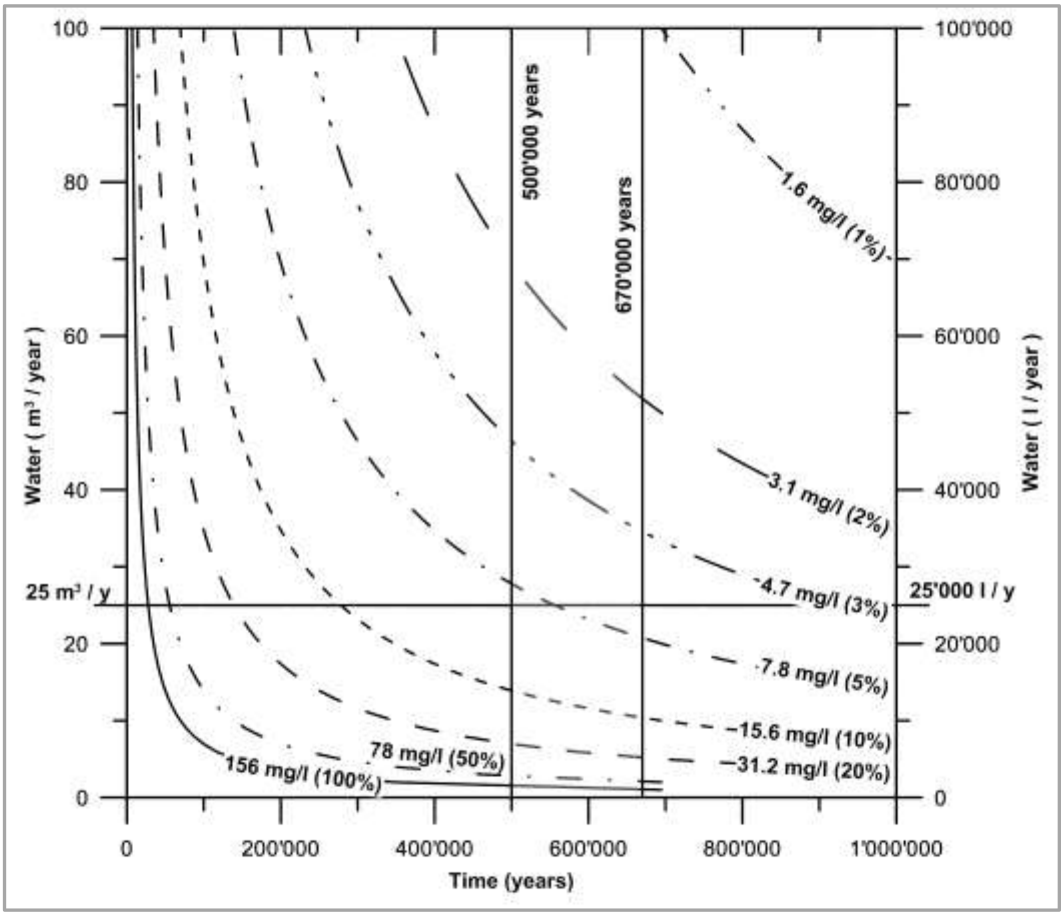

Fig. 7: This graph plots the water quantity needed to form the monitored shaft against time. Each curve was calculated for another amount of calcite dissolved per litre. Onset of cave genesis is thought to have been in the grey-shaded interval.

Depending on the quantity of calcite dissolved per litre of percolation water, any time range could theoretically be possible. However, there are some age constraints. U-series dating from the collected flowstone was not possible, as the age limit of the method (500'000 years) was exceeded and a cavity must already have existed. Considering the cave morphology, which is assumed as entirely vadose (HAEUSELMANN, 2007), initiation of cave formation must have occurred after the floor of the Aare Valley had reached the altitude of the cave. According to HAEUSELMANN et al. (2007), this could have been 670'000 years ago at the earliest.

These calculations give a rough idea of the development scenario: Varying saturation states, different quantities of calcite being dissolved in the shaft and changing amounts of water due to variable climatic conditions have certainly affected the system. Nevertheless, it can be stated that the scenario is possible without the need of extreme conditions.

Conclusion

Currently, the dripwater in Waldheim Cave is saturated with respect to calcite. This must have been different during other periods, making cave genesis possible within somewhat more than 500'000 years. Given a decent amount of percolation water (25'000 to 50'000), only few milligrams of calcite need to be dissolved per litre. The hypothesis from HAEUSELMANN (2007), even though plausible, could neither be proved nor disproved.

A change in climate could be one reason for more favourable saturation states. However, similar studies performed in caves located in different climatic settings (AUDRA & PALMER, 2011; PRELOVŠEK, 2009) do not point towards a distinct condition. Present-day climate is rather warm, and due to vegetation and soil CO_2, speleogenesis should be enhanced in warm climate (AUDRA et al., 2007 and references therein). Considering the geomorphological setting at the tear-off edge of a rockfall and the findings of BAROŇ (2002), Waldheim Cave might have been inaccessible during formation. As a consequence, the cave had been badly ventilated. CO_2 levels must have been higher but since inaccessible caves are not traps for vegetative debris, only running water can bring in CO_2. In case of water saturation with respect to calcite, even elevated CO_2 levels cannot trigger calcite dissolution and undersaturated waters would dissolve the host rock in any case. This possibility for the formation of Waldheim Cave, although untested, does therefore not seem very plausible. Closed or not, the question as to when caves really form is thus unresolved yet.

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