e-Research Reports
of Museum Burg Golling
Vol. 4 | 2022

MUSEUM BURG GOLLING
Das regionale WeltenMuseum

The Geisloch, a well preserved hypogene cave: statistical analysis of pronounced glacial speleothem damage and first U/Th dating of cave bear remains to older than 80 ka BP (Oberfellendorf, Franconian Alb, Germany)

Stephan Kempe[1], **Renate Fenzlein**[1] & **Hardy Schabdach**[2]

[1] TU-Darmstadt, Institut für Angewandte Geowissenschaften, Schnittspahnstraße 9, 64287 Darmstadt, Germany

[2] Ludwig-Tieck-Straße 22, 95460 Bad Berneck, Germany

✉ kempe@geo.tu-darmstadt.de

Geisloch | speleothem damage | cave ice | 3D-scanning | U/Th dating
Geisloch | Speläothem-Schäden | Höhleneis | 3D-Scannen | U/Th Datierung

Published: 06.09.2022

Citation: Kempe, S., Fenzlein, R. & Schabdach, H.(2022): The Geisloch, a well preserved hypogene cave: statistical analysis of pronounced glacial speleothem damage and first U/Th dating of cave bear remains to older than 80 ka BP. — e-Research Reports of Museum Burg Golling 4: 1-10.

Published by
Museum Burg Golling
Markt 1
5440 Golling a.d. Salzach
AUSTRIA
office@museumgolling.at
www.museumgolling.at

Abstract: The Geisloch (Goat-Cave) is a cave near Oberfellendorf in the northern Franconian Alb (Community Wiesenttal, State of Bavaria, Germany). It is accessible only for a controlled number of cave scientists and is therefore in excellent state of preservation. It contains a rich Pleistocene fauna, including remains of the cave bear. The cave has formed in Upper Jurassic (Malm) carbonates and is situated in a dolomitized reef. It consists of one large central hall with several irregular branching passages. This pattern is typical for most of the caves in the area, testifying to their hypogene origins. In 2014 we surveyed the main hall of the Geisloch with a FARO 120 3D-Scanner and evaluated 934 fragments of naturally damaged speleothems statistically. The kind of damage and the presence of cryo-calcites (dated to 29.4 ka BP) suggest that the damage was caused by the presence of cave ice in the Last Glacial Maximum (LGM). Furthermore, a sample from the floor crust was U/Th dated to 79.5 ka BP, correlating to MIS 5a and D-O event 21, the last warm period prior to the onset of the LGM. Most Pleistocene faunal remains are found below this crust and are therefore older.

Kurzfassung: Das Geisloch ist eine Höhle nahe Oberfellendorf in der nördlichen Fränkischen Alb (Kreis Wiesenttal, Bayern, Deutschland). Es ist nur für eine kleine Zahl Höhlenforscher zugänglich und daher in ausgezeichnetem Erhaltungszustand. Die Höhle enthält Knochen der pleistozänen Fauna, vor allem solche des Höhlenbären. Das Geisloch entwickelte sich in den dolomitisierten Riffen des oberen Jura (Malm). Die Höhle besteht aus einer großen Haupthalle und etlichen, irregulär verzweigten Gängen. Dieses Muster entspricht dem anderer Höhlen im Gebiet, das auf eine hypogene Entstehung verweist. Die Höhle wurde 2014 von uns mit einem FARO 120 Scanner vermessen und 934 Fragmente natürlich beschädigter Speläotheme anhand dieser Daten statistisch analysiert. Die Art der Schäden und das Vorkommen von Kryocalciten (datiert auf 29,4 ka BP) zeigen, dass es sich um Schäden durch Höhleneis während des letzten Hochglazials (LGM) handelt. Eine weitere Datierung der Bodenversinterung ergab ein U/Th Alter von 79,5 ka BP, das mit MIS 5a und dem D-O Ereignis 21 korreliert, der letzten warmen Phase vor dem Hochglazial. Die meisten Faunenreste liegen unter dieser Kruste und sind daher älter.

Introduction

Germany has a large variety of caves of different geological stratigraphy, different host rock composition, different origin, different age, different paleontological importance, different speleothem content and different preservation status (e.g., KEMPE & ROSENDAHL, 2008). One of the areas that attracted attention of romantic artists, bone-hunters for medical purposes and landscape gardeners early on in history, was the northern Franconian Alb were many caves are located in a relatively small area (**Fig. 1**). Among these caves is the Zoolithen Cave (HELLER, 1972), the type locality of the cave bear, *Ursus spelaeus*. One of the skulls from this cave served Johann Christian ROSENMÜLLER (1794) as holotype in establishing the first extinct mammal according to the rules of the binary Linnean System (e.g., ROSENDAHL & KEMPE, 2005) thereby making geological history (KEMPE et al., 2005). Part of the original Rosenmüller collections, possibly including the holotype, is now kept at the Museum für Naturkunde, Berlin (KEMPE & DÖPPES, 2009). These finds sparked the first foreign »British cave expedition« by the eminent early geologist and paleontologist, William Buckland, who visited several of the then-known caves in the area in search of traces and proof of the »deluge« (BUCKLAND, 1823; he, however, later recanted and accepted glaciation as cause of »diluvian« deposits).

The Geisloch

The caves of the northern Franconian Alb cluster in a rather small area. It is prominently structured by NW-SE (»hercynian«) and SW-NE (»variscan«) trending lineations as evident by the course of the incised river valley of the Wisent and its tributaries (**Fig. 1**). These lineations most likely mark faults associated with the center of the Malm Plateau which itself forms a shallow tectonic basin preserving Cretaceous sediments at its central depression (GOTTWALD, 1959; PETEREK, 2008). White pins (**Fig. 1**) mark caves evidently of hypogene origin. These are characterized by irregular ground plans composed of large halls, either isolated or connected by irregular passages, often of small size. This is the pattern also of the ground plan of the Geisloch (**Fig. 2**; sometimes spelled »Gaisloch«). The total length of the passages of the Geisloch adds up to 750 m (SCHABDACH, unpubl.). This irregular ground plan is specific for those caves that occur in dolomitized reef-areas, while those that occur in the lagoonal, banked facies often have maze-like ground plans following the local jointing. One of the best-known local examples is the Schönstein-Brunnstein Cave System (CRAMER, 1932/33). Morphologically, the cave lacks meandering passages and scallops (such as typical for the near-by Binghöhle; see KEMPE et al., 2022) that would indicate epigenic lateral and turbulent water movement; rather it is dominated by cupolas of various sizes

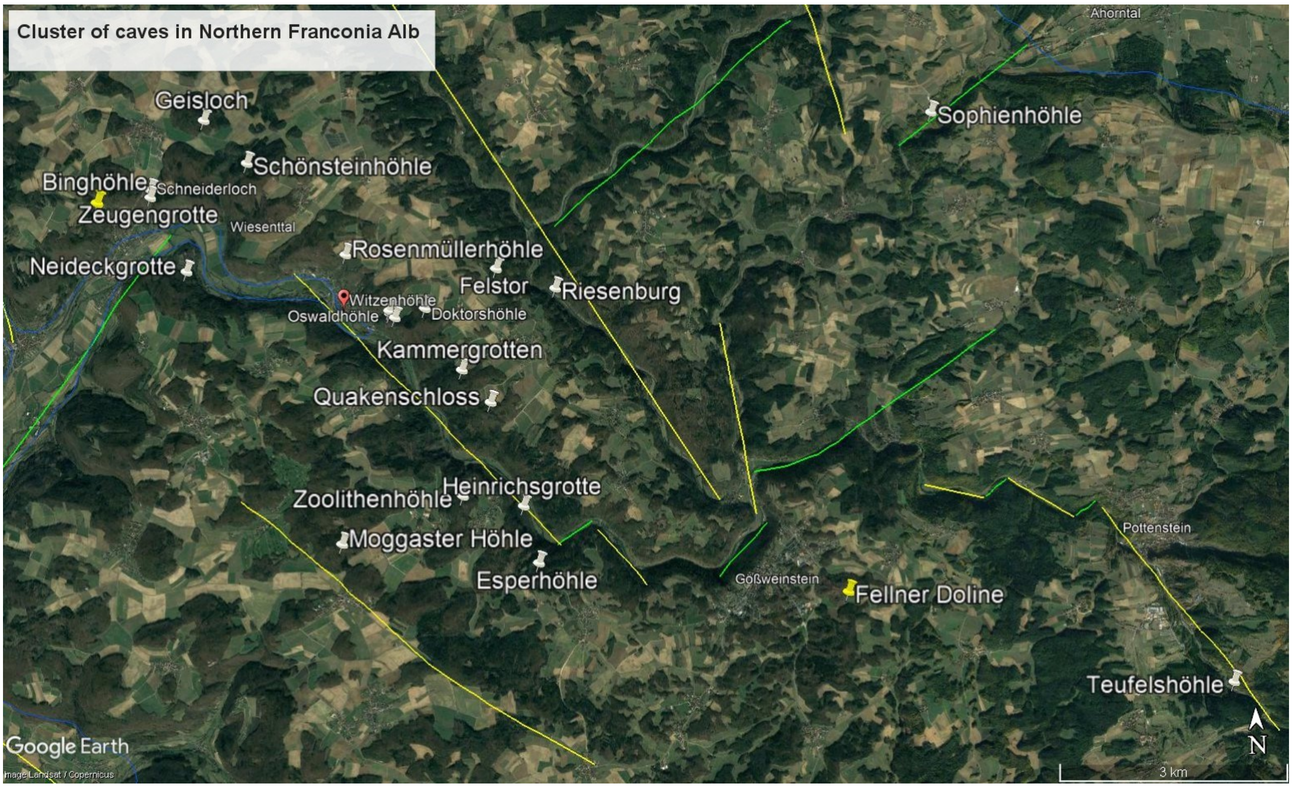

Fig. 1: The cluster of well-known caves in the northern Franconian Alb, Bavaria. Note the prominent photo-lineations suggesting tectonic fragmentation that may have served as paths for ascending deep groundwater. White pins: caves of hypogene origin; yellow pins: caves of epigene origin. Binghöhle, Sophienhöhle and Teufelshöhle are often-visited show caves. Some of the other caves are freely accessible. | **Abb. 1**: In der nördlichen Fränkischen Alb häufen sich einige der bekannteren Höhlen in Deutschland. Die in diesem Gebiet deutlichen Fotolineationen deuten auf eine starke tektonische Fragmentierung des Gebietes mit den entsprechenden Möglichkeiten für den Aufstieg von tieferem Grundwasser. Weiße Nadeln: Höhlen hypogenen Ursprungs; gelbe Nadeln: Höhlen epigenen Ursprungs. Binghöhle, Sophiehöhle und Teufelshöhle sind Schauhöhlen. Einige der anderen Höhlen sind frei zugänglich.

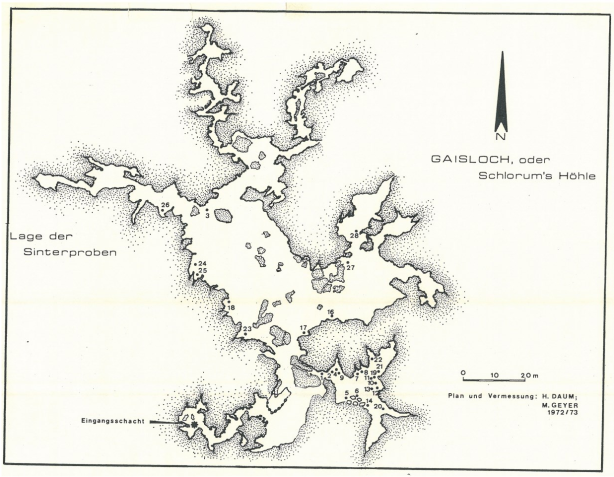

Fig. 2: Ground plan of the Geisloch; entrance at lower left. Map by H. Daum & M. Geyer. | **Abb. 2**: Karte des Geisloches, der Eingang befindet sich links unten. Karte von H. Daum & M. Geyer.

Fig. 3: View into the NE passage of the Geisloch where breakdown is absent. The primary morphology of the cave is characterized by cupolas and sloping wall facets. Photo: S. Kempe. | **Abb. 3**: Blick in die NE Passage des Geisloches. Hier gibt es keinen Versturz und die primäre Morphologie der Höhle mit Kuppeln und schrägen Facetten an den Wänden ist erhalten. Foto: S. Kempe.

and sloping side-walls, »facets« (**Fig. 3**). Both these features indicate that the cave was enlarged by slow convective dissolution (e.g., Kempe, 2008, 2014). The source of the »cave forming agent« (sensu Klimchouk, 2012) must have infiltrated the cave from below, i.e., hypogenically. At present, one can only speculate what this »agent« was. It could simply be hot water carrying CO_2 that — upon cooling near the surface — increased its aggressiveness; or dissolved gases such as hydrogen sulfide (H_2S) or methane (CH_4) that become oxidated by oxygen-carrying seepage water from above, mixed into the ground water body and producing CO_2 in situ in the reaction (Kempe et al., 2017). Such conditions may have existed during the upper Cretaceous prior to the regional uplift in Germany (Kley & Voigt, 2008). At the time water could have flown through the aquifers of the Keuper (Upper Triassic) sandstones eastward below the Jurassic rocks, where they were forced to ascend through the Liassic rocks. These contain pyrite that could be the source of acidic waters (**Fig. 4**). The Geisloch (**Fig. 5**) is famous for its well-preserved speleothems. Because of strict access limitation and documentation, it did not suffer human damage, such as has occurred in many of the other caves in the area that have been accessible freely for a long time. Nevertheless, the floor is littered with broken speleothem fragments. There has been much debate, as to what caused this speleogene facies of naturally broken speleothems. Interestingly, the »Gaisloch« served as the example for Moser & Geier (1979) to suggest earthquakes as the cause of this damage, following older suggestions (e.g. Becker, 1929; Schillat, 1965; and later Knolle, 1982). But even Hohenwart (1832a), who already considered earthquakes, suggested that those cannot explain certain observations such as the »broken pyramid« (compare Kempe & Henschel, 2004) in Postojnska jama by writing: *»Die allgemeine Meinung über die Veränderungen, die sich in derlei unterirdischen Höhlen ergeben, gehet dahin, dass durch Erderschütterungen die schwachen Gewölbe einstürzen, die losen Stämme von der Höhe herabfallen, und die in ihrer Basis nicht stark genug an der Decke befestigten Stalaktiten-Säulen herabgestürzt werden. Ein aufmerksamer Beobachter entdeckt dagegen viele Veränderungen, welche sich nach dieser allgemeinen Meinung* ***nicht*** *(enhancement by authors) erklären lassen*«. (Translation: »The common opinion about these alterations, which are given in such caves, is that weak vaults collapse, that loose stems fall from above, and that stalactite-columns that are not firmly affixed to base and ceiling are precipitated because of earthquakes. A careful observer, however, will notice that many alterations, **cannot** (enhancement by authors) be explained by this common opinion.«) Hohenwart thus correctly anticipated that there should be another process to explain the omnipresent speleothem damage in Postojnska jama and this is most likely cave ice and permafrost (e.g., Gili, 2004; Kempe, 1989, 2004; Kyrle, 1929; Pielsticker, 1998). The observation of leaning stalagmites, of stalagmites detached from their bases and offset, of stalactites resting on slopes that would not have had enough friction to hold them and other observations are explained best by glacial cave ice as a cause of their damage and location. The main phenomena that can be attributed to glacial cave ice damage are (**Fig. 6**):

— Missing ceiling formations of older generations.
— Sheared-off stalactites and draperies, deposited on top of floor speleothems.
— Broken and deposited stalagmites.
— Stalagmites sheared-off their base and moved but not toppled.
— Cracked compact stalagmites.
— Sheared-off stalagmites, leaning on the wall.
— Moraine-like piles of fragmented speleothems.
— Precariously placed ceiling formations.

In addition, calcite sands and crystal aggregates have been identified by isotopic studies (Zak et al., 2004) as being forced out of solution by freezing. These sands have also been identified as occurring in the Geisloch (Richter et al., 2021) as well as

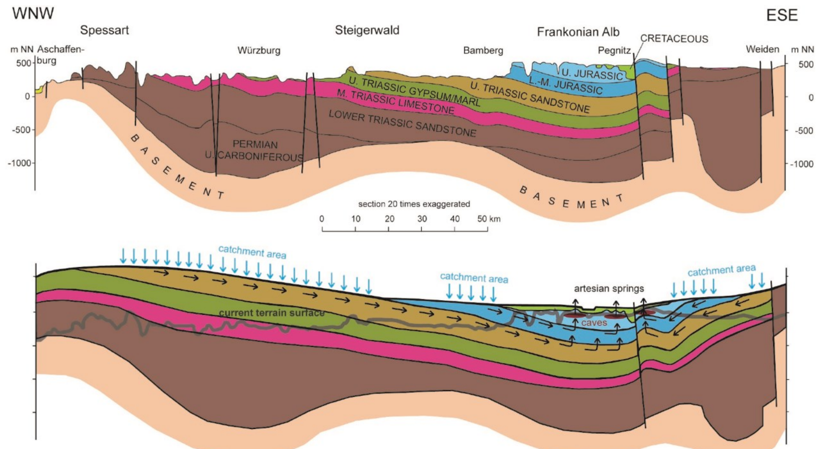

Fig. 4: Possible reconstruction (lower cross-section) of the hydrological situation prior to the Upper Cretaceous uplift when water could have infiltrated along the aquifers of the Keuper (Upper Triassic) sandstone (after GLASER in KEMPE et al., 2017). | **Abb. 4**: Eine mögliche Rekonstruktion (unterer Schnitt) der hydrologischen Situation vor der oberkretazischen Hebung als Keuper-Aquifere Wasser unter die Jura-Schichten der Alb liefern konnten (nach GLASER in KEMPE et al., 2017).

Kind of damage	Number	% of 934
Broken-off	906	97.00
Broken at both ends	181	19.38
New growth	23	2.46
Displacement on base	2	0.21
Tilted	4	0.43
Breakage of floor plate	1	0.11

Tab. 1: Kinds of damage seen on speleothem fragments. | **Tab. 1**: Art der Schäden der Speläothem-Fragmente.

in many other caves of Germany. They can be added as a separate 39th type (KEMPE, 2013) to the 38 families of speleothem types according to HILL & FORTI (1997).

Methods

Two approaches were chosen to further analyze the speleothem -content of the Geisloch for glacial cave ice impact: 1. mapping the cave for its sedimentary facies in detail (**Fig. 7**) 2. and 3D scanning of the central Hall with a FARO Laser Scanner Focus3D S 120 (**Fig. 8**). The FARO Scanner is a portable, lightweight, battery-powered instrument mounted on a tripod and is thus suitable to survey caves, as long as it is kept away from drip water (FARO Technologies Inc., 2011). The instrument uses an infrared laser of 905 nm (invisible to the eye) with a power of 20 mW and a beam divergence of 0.16 mrad (0.009°). Distance is measured by phase shift between two reflected pulses of different wavelength. Reflectance is measured by the strength of the returned signal, so that a picture in grayscale can be generated (the instrument could have generated a color picture, if ambient light had been available). A rotating mirror reflects the beam in full circle, while the instrument rotates 180°. Thus, a full sphere is scanned, except for a conical instrument shade of 60° towards the bottom.

The Faro Scanner is equipped with a barometric altimeter and a compass (magnetic declination at the site of Geisloch on 19.09.2014 was calculated to 2°38’53”E) so that each data point consists of the spherical coordinates (s, ϑ, ϕ), bearing, altitude and a reflectance code. The spherical coordinates are automatically transferred to cartesian coordinates (x, y, z). The coordinates of the first scan in a series is thus (0, 0, 0) or, in case of site Geisloch_000 (0, 0, 172.83 m above sea level). Each scan was recorded with ¼ of maximal resolution, i.e., recording 10,240 points per 360°, with 2 measurements per point and a resolution of 6.136 mm between points at a distance of 10 m. The total number of points per station amounted to 43.7 million (FENZLEIN, 2015). Further sites are linked to each other by the program SCENE also by Faro. To facilitate this, three to four non-reflecting reference balls of 15 cm diameter are placed between stations (compare Fig. 8). In total, 34 stations were needed, all (except Station 29 in the Knochenkammer) were used in the evaluation. Station 0 was placed at the entrance to the central hall in the south and then one station after the other was placed clockwise around the perimeter of the central hall and its south-eastern annex. The survey ended with the last station 33 about 4 m east of station 0, thus closing the survey.

Renate Fenzlein in her bachelor thesis (2015) used the grey-value pictures (**Fig. 8** bottom) and the coordinate system of the point cloud to assess and calculate the following information (for details of the geometric operations see her thesis and error assessment):

— kind of speleothem (stalactite or stalagmite)
— length of fragment
— coordinates of both ends of fragments
— diameter of thicker end of fragment
— slope and bearing of fragment
— kind of damage.

In total, 934 fragments of speleothems were thus recorded from the central hall of the Geisloch (**Tab. 1**). The choice, which fragment was measured was random, guided only by the availability and visibility of the fragment in question. Furthermore, a flowstone sample from the central hall (see **Fig. 7** for location) was recovered by Katja Huhn and U/Th dated (**Tab. 2**) by Jens Fohlmeister, Heidelberg, along with the samples from the Binghöhle (for methods see KEMPE et al., 2022).

Fig. 5: The central hall of the Geisloch features abundant speleothems, large conical and slender candle-stalagmites dominate while stalactites are small or absent. Hundreds of flowstone fragments litter the floor. Photos upper row: H. Schabdach, lower row: S. Kempe. | **Abb. 5**: Die Zentralhalle des Geislochs ist durch sehr reiches Tropfsteinvorkommen gekennzeichnet. Neben einigen großen Kegelstalagmiten dominieren viele Kerzenstalagmiten. Stalaktiten sind dagegen klein oder fehlen. Hunderte Fragmente von natürlich gefällten Stalagmiten und Stalaktiten bedecken den Boden. Fotos obere Reihe: H. Schabdach; untere Reihe: S. Kempe.

Results

The floor of the central hall of the Geisloch is covered by flowstone, while cryo-calcite sands and cave loam are the more pronounced facies in the side-passages (Richter et al., 2021). A few very large stalagmites dominate the central hall, but, by number, candle stalagmites are in the majority, both standing and damaged. In pouches and niches abundant mega-cryo-calcites are found.

Of the 934 fragments measured 50% were stalactites (up to 20 of these were soda-straws) and 49% stalagmites. 1 % were possibly fragments of columns. The kinds of damage are shown on **Tab. 1**.

A number of statistical analyses were run on the available data relating to resting directions. **Fig. 9** shows the distribution of resting direction of the measured fragments in twelve classes, each 30° wide. The distribution is rather even with two relative maxima (NE, 30-60° and NW 300-330°). These maxima (12.9% of stalagmites and 13.1% of stalactites) are not very prominent but they could suggest a difference in processes. Stalactites are ripped from the ceiling and, as the cave ice melts, could have sloped in one direction if the ice surface developed a slope during thawing. The stalagmites on the other may have been shifted by the melting ice according to the slope of the preexisting floor, thus producing a maximum in a different (but not opposite) direction. **Fig. 10** displays the distribution of inclination of the broken speleothem fragments. As can be expected, most of the fragments rest on rather level ground (56.5 % within -10° to +10°, with an overall arithmetic mean of -2.18° and a standard deviation of 16.26°). Stalactites seem to rest more with their tip pointing upward while stalagmites seem to rest more often with their tip downward. Again, this could support the hypothesis, that stalactites are sliding on the surface of the melting ice with their thicker ends downward, while stalagmites at the bottom of the ice mass could have been tipped over and slipped downward head-first.

One of the features possibly caused by shifting ice-bodies are stalagmites sheared-off their base and shifted by a few cm, without being toppled. A large example of this natural damage is found in the Geisloch (**Fig. 11**). Similar cases have been seen in other caves in Germany and in the Postojnska jama (Kempe, 2004: Fig. 15) and a further feature is called in German »Eishaftung« (ice-fixation), describing speleothem fragments that are attached to the wall in near-vertical position (**Fig. 12**).

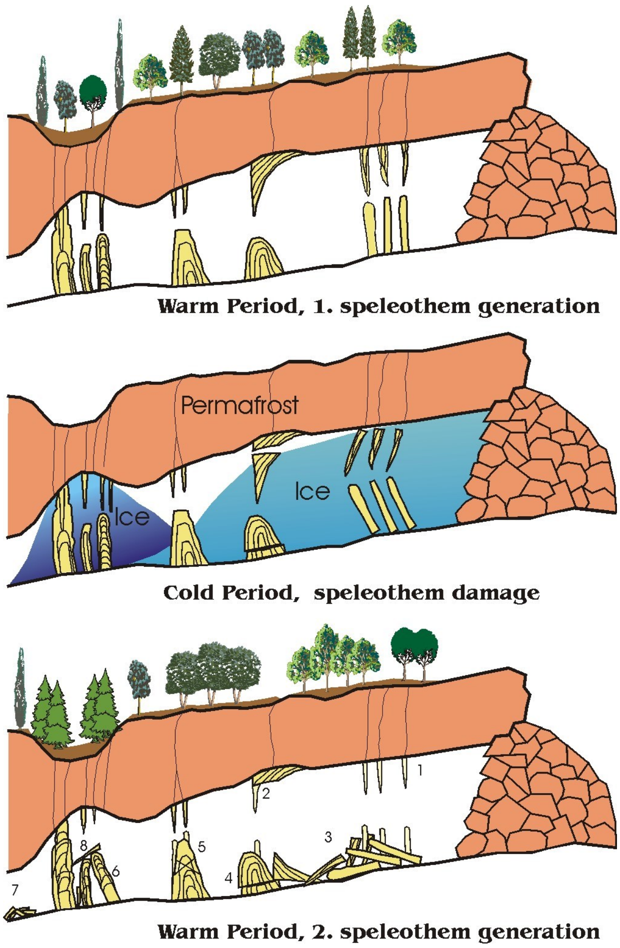

Fig. 6: Simplified sketch of speleothem damage caused by cave ice (for explanation see text; Kempe, 2004). | **Abb. 6**: Vereinfachte Skizze der Speleothem-Brüche durch Höhleneis (Erklärung siehe Text; Kempe, 2004).

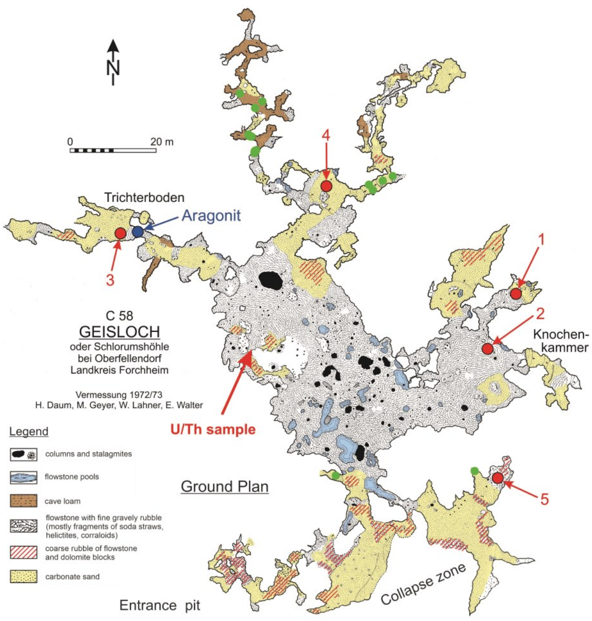

Fig. 7: Sedimentological map of Geisloch (Richter et al., 2021). 1-5: Sampling locations for the cryogenic cave carbonates. Green markings: »Bärenschliffe«. | **Abb. 7**: Sedimentologische Karte des Geislochs (Richter et al., 2021). 1-5: Probenpunkte für Kryocalcite. Grüne Markierungen: »Bärenschliffe«.

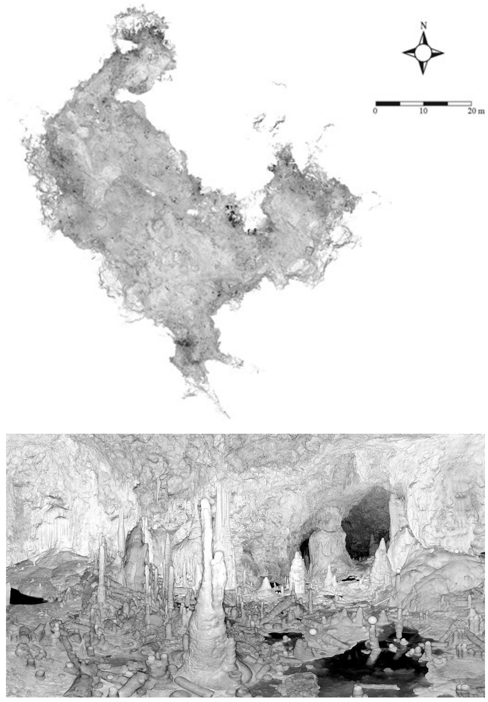

Fig. 8: Top: Ground plan of the scanned central area of Geisloch; bottom: Point-cloud view into the central hall featuring a large number of broken stalagmites; black areas are pools; white spheres are reference balls, 15 cm in diameter. | **Abb. 8**: Oben: Punktwolke des 3D-Models der Zentralhalle des Geislochs von oben gesehen; unten: Blick in die Punktwolke der Zentralhalle mit einer großen Zahl von fragmentierten Speläothemen; schwarze Flächen sind Wasserbecken; weiße Kugeln sind die 15 cm-großen Referenz-Kugeln der 3D Aufnahme.

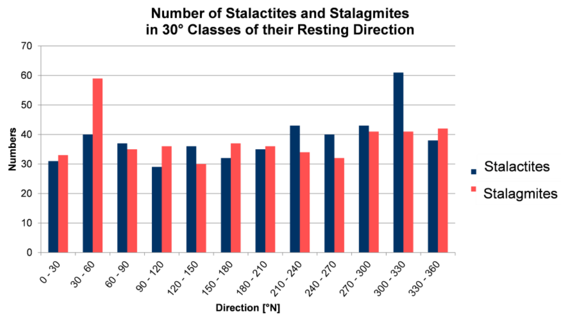

Fig. 9: Resting direction in twelve classes of broken stalactites and stalagmites (Fenzlein, 2015). | **Abb. 9**: Lage-Richtungen von fragmentierten Stalaktiten und Stalagmiten in zwölf Klassen (Fenzlein, 2015).

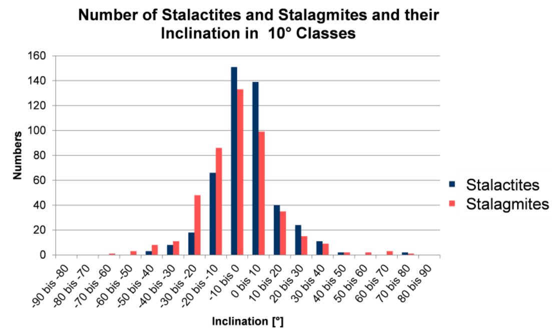

Fig. 10: Inclination of stalactites and stalagmite fragments in 18 classes of broken stalactites and stalagmites (Fenzlein, 2015). | **Abb. 10**: Lage-Neigung von fragmentierten Stalaktiten und Stalagmiten in 18 Klassen (Fenzlein, 2015).

Fig. 11: Point-cloud picture of a section of central hall of Geisloch. The upper section of the large stalagmite to the left is detached and has slipped a few cm (detail; photo: S. Kempe). Note four reference spheres (15 cm diameter), abundant stalagmite fragments on the floor and irregular dissolution cupolas on back wall. | **Abb. 11**: Punktwolken-Bild eines Abschnittes der Zentralhalle des Geislochs. Der obere Teil des großen Stalagmits an der linken Seite wurde abgeschert und um einige Zentimeter versetzt (Detail-Foto: S. Kempe). Beachte die vier Reference-Kugeln (Durchmesser 15 cm) und die zahlreichen, gefällten Stalagmiten sowie die Lösungskuppeln an der Rückwand der Halle.

Fig. 12: A small stalactite fixed to the wall in a near-vertical position in the Geisloch. Photo: H. Schabdach. | **Abb. 12**: Abgebrochener, kleiner Stalaktit, der in fast vertikaler Lage an der Wand im Geisloch haftet. Foto: H. Schabdach.

Discussion

Natural speleothem damage may have many causes (listed e.g. in Kempe, 2004), but massive damage to both stalactites and all sizes of stalagmites is hard to explain by anything but cave ice. Similarly, cryo-calcites add a strong argument as to the past presence of ice in caves in Central Europe (Zak et al., 2012). Also, »Eishaftungs«-speleothems are easily explained by ice processes, excluding the possibility of earthquakes as a cause (unless one invokes a hypothetical sediment fill, for which there is no evidence in the Geisloch). Germany is not a specifically earthquake-prone area, even though earthquakes occur. Several papers try to correlate certain earthquake events with speleo-

LabNr. Sample	238U (ng/g)	Error (abso.)	232Th (ng/g)	Error (abso.)	230Th/238U (act.ratio)	Error (abso.)	230Th/232Th (act.ratio)	Error (abso.)
6849, Geis 1	16,00	0,04	1,900	0,032	0,631	0,069	16,6	1,7

δ^{234}U corr. (‰)	Error 2σ (abso.) ‰	Age (uncorr.) (ka)	Error (ka)	Age (corr.) (ka)	Error (ka)	δ^{234}U (initial) (‰)	Error 2σ abso. (‰)
198,4	13,1	82,3	13,169	79,5	13,150	248,4	18,7

Tab. 2: Results of U/Th dating for sample Geis 1. | **Tab. 2**: Ergebnisse der U/Th Datierung der Probe Geis 1.

them damage (e.g., Postojnska jama and the earthquake of 1926; Šebela, 2010), but most can be easily explained by ice as a cause or are inconclusive. One of the main arguments for ice-damage is dating these.

As long as the damage is not clearly Holocene, earthquakes cannot be considered according to Ockham's razor, since older damage may have seen several periods of cave ice. In the case of the Geisloch, Richter et al. (2021) U/Th-dated the youngest cryo-calcite to 29.4 ka BP. Thus, cave ice formed in the cave shortly before the Last Glacial Maximum (LGM) and therefore we know that the cave has seen the presence of a widespread ice fill. Whether all observed damage is related to the LGM is an open research question. One will need to date overgrowth on broken stalagmites, to see if these were toppled in older glacial maxima or even by ice formed during cold stadials of Dansgaard-Oeschger cycles.

Fig. 13: Site of the U/Th sample Geis 1. It was taken from this crust that shows fracturing most likely due to frost during the LGM. Photo: H. Schabdach. | **Abb. 13**: Bodensinterplatte an der die U/Th Probe Geis 1 genommen wurde. Sie ist stark durch die Eiswirkung während des LGM fragmentiert. Foto: H. Schabdach.

Palaeontology

The Geisloch is also a paleontological site. Systematic excavations have not yet been conducted. Heller (1981) listed a number of species, among them *Ursus spelaeus*, *Panthera spelaea* and *Mammuthus primigenius*. According to him, bones were found both on and below flowstone layers. We now have the first U/Th date of the main flowstone layer from the central hall of the Geisloch (**Tab. 2**). The layer covers a loam that contains cave bear remains, including a skull (**Fig. 13**).

The layer was dated to 79.5 ± 13.15 ka BP, which is almost the same date as for the similarly looking, youngest flowstone layer in the Binghöhle (sample Bing 5, 80.0±1.8 ka BP, compare Kempe et al., 2022). Despite the young age, the standard deviation is quite large, due partly to a low U-concentration (16 ng/g), 5 to >10 times smaller than in the Binghöhle samples. Possibly dolomite has lost parts of the initial uranium during dolomitization. This new U/Th date puts the flowstone cover of the central hall into a warm Interstadial, i.e., MIS 5a, corresponding to Dansgaard-Oeschger Event No 21, the last longer-lasting warm Interstadial before the onset of the Last Glacial (Weichelian/ Würmian; compare Kempe et al., 2022, Fig. 20). The faunal remains below the flowstone layer therefore predate MIS 5a, possibly being contained in loamy deposits of the cold Interstadial MIS 5b, the first colder period initiating the cooling of Earth towards the Last Glacial.

The U/Th date match the fact that ^{14}C-dating of bones from the Geisloch failed so far due to low collagen content (pers. com. D. Döppes). One sample and a flowstone had ages older than the reach of the method. Many of the bones are included in a coarse matrix of stones, loam and flowstone, suggesting that they have

Fig. 14: Position of bones in the Geisloch within a very coarse matrix, possibly a mudflow. Photo: S. Kempe. | **Abb. 14**: Situation von Knochen im Geisloch innerhalb einer groben Matrix, möglicherweise eine Fließerde. Foto: S. Kempe.

Fig. 15: Example of an articulated setting of an upper and lower jaw of *U. spelaeus*. Photo: H. Schabdach. | **Abb. 15**: Beispiel für eine Einbettung mit zusammenhängendem Unter- und Oberkiefer eines *U. spelaeus*. Foto: H. Schabdach.

been transported in mudflows (**Fig. 14**) post-dating the age of the fauna. However, articulated bones (**Fig. 15**) and evidence of bears using the cave (**Fig. 16-17**) suggest that at least some of the *U. spelaeus* bones have been deposited in situ. It is also noteworthy that the Geisloch is the first site in the Franconian Alb where not only »Bärenschliffe« (wall patches polished by the fur of passing animals such as bears; for location compare **Fig. 7**) but also bear scratch marks have been recorded (Schabdach, 2021).

Fig. 16: Polished corner in Geisloch, attributed to passage of animals such as cave bears (a feature known as »Bärenschliff«). Photo: H. Schabdach. | **Abb. 16**: Eine Ecke im Geisloch, deren Politur auf das Vorbeischleifen von Höhlenbären zurückgeführt wird (in der Literatur als »Bärenschliff« bezeichnet). Foto: H. Schabdach.

Fig. 17: Claw scratches on the wall, attesting to the presence of cave bears in Geisloch. Photo: H. Schabdach. | **Abb. 17**: Kratzspuren von Bärenklauen an der Wand des Geislochs, die die Anwesenheit von Höhlenbären bezeugen. Foto: H. Schabdach.

Acknowledgements

Scanning of the Geisloch was by permit of owner H. Daum. It was performed by Ingo Bauer and Yasmin Rossmann (Inst. for Applied Geosciences, TU-Darmstadt). The U/Th sample was collected by Katja Huhn (Streitberg) and dated by Jens Fohlmeister (Inst. of Environmental Physics, University of Heidelberg), made possible by a grant of the Community Wiesenttal. Gregory Middleton, Tasmania, helped with English.

References

Becker, H. K. (1929): Höhle und Erdbeben. — Mitt. über Höhlen und Karstforschung, 1-4: 130-133.

Buckland, W. (1823): Reliquiae Diluvianae; or, observations of the organic remains contained in caves, fissures, and diluvial gravel, and on other geological phenomena, attesting the action of an universal deluge. — 2nd Ed., J. Murray, Albemarle-Street, 303 S., 27 Taf., London.

Cramer, H. (1932/33): Das Schönsteiner Höhlengebiet (Frank. Schweiz). — Speläol. Jb., 13/14:29-47.

FARO Technologies Inc. (2011): FARO® Laser Scanner Focus3D Manual.

Fenzlein, R. (2015): Statistische Auswertung der Sinterschäden im Geisloch bei Oberfellendorf (Oberfranken, Bayern). — Bachelor-Thesis, Inst. of Applied Geosciences, Techn. Univ. Darmstadt (unpubl.)-

Gilli, E. (2004): Glacial causes of damage and difficulties to use speleothems as palaeoseismic indicators. — Geodinamica Acta, 17/3: 229-240. DOI: 10.3166/ga.17.229-2.

Gottwald, H. (1959): Erläuterungen zur Geologischen Karte von Bayern 1:25000 Blatt Nr. 6133 Muggendorf. — Bayerisches Geologisches Landesamt.

Heller, F. (1972): Die Zoolithenhöhle bei Burggaillenreuth/Ofr., 200 Jahre wissenschaftliche Forschung, 1771-1971. — Erlanger Forschungen B5.

Heller, F. (1981): Paläontologisch-faunistische Untersuchungen. — Karst und Höhle 1980: 38-47.

Hill, C. & Forti, P. (1997): Cave Minerals of the World, 2nd. Ed. — Nat. Speleol. Soc., Huntsville, AL, 463 pp.

Hohenwart, F. Graf von (1830, 1832a, 1832b): Wegweiser für die Wanderer in der berühmten Adelsberger und Kronprinz Ferdinands-Grotte bey Adelsberg in Krain; als Erklärung der von Herrn Aloys Schaffenrath, k.k. Kreis-Ingenieur in Adelsberg, gezeichneten Ansichten dieser Grotte. — Wien, J.P. Sollinger, 3 Vol., 16 + 9 + 14 pp. and 21 copperplates (Reprint 1978: Šajn, S., ed.; Introduction: Habe, F. & Šlenc, J.: Postojnska jama; 1. ed., Postojnska jama THO; Postojna; 32 pp Introduction, folio).

Kempe, S. (1989): Sinterschäden: verursacht durch Permafrost oder Erdbeben? — Mitt. Verb. dt. Höhlen- u. Karstforsch. (Binder Festschrift) 35: 87-90.

Kempe, S. (2004): Natural speleothem damage in Postojnska jama, Slovenia, caused by glacial cave ice? A first assessment. — Acta Carsologica 33/1: 265-289.

KEMPE, S. (2008): Vom Urkanal zur unterirdischen Kathedrale, Höhlenformen und ihre Entstehung. In: KEMPE, S. & ROSENDAHL, W. (Eds.), Höhlen: verborgene Welten. — Wissenschaftliche Buchgesellschaft Darmstadt: 54-64.

KEMPE, S. (2013): Morphology of speleothems in primary (lava-) and secondary caves. In: SHRODER, J. & FRUMKIN, A. (Eds.), Treatise on Geomorphology. Academic Press, San Diego, CA. — Karst Geomorphology 6: 267-285.

KEMPE, S. (2014): How deep is hypogene? Gypsum caves in the South Harz. In: KLIMCHOUK, A., SASOWSKY, I.D., MYLROIE, J., ENGEL, S.A., & ENGEL, A.S. (Eds.): Hypogene Cave Morphologies, Karst Waters Inst. Spec. Publ., 18, Proc. San Salvador, Bahamas Feb. 2-7, 2014, 57-64.

KEMPE, S. & DÖPPES, D. (2009): Cave bear, cave lion and cave hyena skulls from the public collection at the Humboldt Museum in Berlin. — Acta Carsologica 38/2-3:253-264.

KEMPE, S. & HENSCHEL, H.-V. (2004): Alois Schaffenraths »zerbrochene Pyramide« (Postojnska jama), ein Zeuge glazialer Höhlenvereisung? — Mitt. Verb. dt. Höhlen- u. Karstforscher, 50(3): 76-81.

KEMPE, S. & ROSENDAHL, W. (2008): Höhlen: verborgene Welten. — Wissenschaftliche Buchgesellschaft Darmstadt, 168 pp.

KEMPE, S., ROSENDAHL, W. & DÖPPES, D. (2005): The making of the cave bear. Die wissenschaftliche Entdeckung des *Ursus spelaeus*. — Festschrift G. Rabeder Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., 14: 57-73.

KEMPE, S., BAUER, I. & GLASER, S. (2017): Hypogene caves in Germany, geological and geochemical background. In: KLIMCHOUK, A., PALMER, A. N., DE WALE, J., AULER, A. S., & AUDRA, P. (Eds): Hypogene Karst Regions and Caves of the World, Chapter 21, Springer International Publishing AG, Cham, Switzerland: 329-348.

KEMPE, S., WIESLER, S.V. & HUHN, K. (2022): The Binghöhle, an epigene cave of Pleistocene origin and its history revealed by U/Th dating (Streitberg, Franconian Alb, Bavaria, Germany). — e-Research Reports of Museum Burg Golling 3: 1-11.

KLEY, J. & VOIGT, T. (2008): Late Cretaceous intraplate thrusting in Central Europe, Effect of Africa-Europe convergence, not Alpine collision. — Geology, 36, 11, 839–842. DOI: 10.1130/G24930A.1.

KLIMCHOUK, A. B. (2012): Speleogenesis, hypogenic. In: WHITE, W. & CULVER, S.C. (Eds.): Encyclopedia of Caves, 2nd ed. Academic Press/Elsevier, Amsterdam: 748-765.

KNOLLE, F. (1982): Nachweis junger Erdbeben im Westharz durch Beobachtungen an Höhlensintern des Winterberges bei Bad Grund (TK 25:4127 Niedersachsen). — Karst und Höhle 1981: 35-47.

KYRLE, G. (1929): Frostsprengungen im Höhlensinter. — Speläol. Jb. 11/12: 134-136.

MOSER, M. & GEYER, M. (1979): Seismospeläologie: Erdbebenzerstörungen in Höhlen am Beispiel des Gaislochs bei Oberfellendorf (Oberfranken, Bayern). — Die Höhle, 30(4): 89-102.

PETEREK, A., (2008): Wie alt ist die Fränkische Schweiz? In: Riffe, Wüsten & Vulkane in Oberfranken. Was die Steine verraten… — Ausstellungskatalog des Fränkische Schweiz Museums 14: 8-25.

PIELSTICKER, K.-H. (1998): Die Große Sunderner Höhle, Sundern, Hochsauerlandkreis, BRD. Sinterbrüche und Umlagerungen, Eisdruck oder Erdbeben. — Mitt. Verb. dt. Höhlen- u. Karstforsch. 44(1): 4-11.

RICHTER, D., SCHABDACH, H., DREYER, R., SCHOLZ, D. & HUHN, K. (2021): Weichselzeitliche Kryocalcite und -aragonite im Geisloch bei Oberfellendorf, Fränkische Schweiz (C 58). — Der Fränkische Höhlenspiegel 64: 39-46.

ROSENDAHL, W. & KEMPE, S. (2005): *Ursus spelaeus* Rosenmüller 1794 and not Rosenmüller & Heinroth - Johann Christian Rosenmüller, his life and the *Ursus spelaeus*. In: Neue Forschungen zum Höhlenbären in Europa, 11. Intern. Höhlenbär-Symposium, 29.9.-2.10.2005. — Naturhistorische Gesellschaft Nürnberg e.V., Abh. Bd. 45: 191-198.

ROSENMÜLLER, J. C. (1794): Quaedam de ossibus fossilibus animalis cuiusdam, historiam eius et cognitionem accuratiorem illustrantia, dissertatio, quam d. 22. Octob. 1794 ad disputandum proposuit Ioannes Christ. Rosenmüller Heßberga-Francus, LL.AA.M. in Theatro anatomico Lipsiensi Prosector assumto socio Io. Chr. Aug. Heinroth Lips. Med. Stud. Cum tabula aenea. – 34 S., 1 Kupfertaf.; Leipzig.

SCHABDACH, H. (unpubl.) The Geisloch cave near Oberfellendorf (Germany, Oberfranken).

SCHABDACH, H. (2021): Faszinierende Lebensspuren an der Felswand. Bärenschliffe und Bärenkratzspuren im Geisloch bei Oberfellendorf (Landkreis Forchheim). — Naturwiss. Ges. Bayreuth, Berichtsband 29: 4-11.

SCHILLAT, B. (1965): Nachweis von Erdbeben in Höhlen. — Mitt. Verb. dt. Höhlen- und Karstforsch. 11: 100-107.

ŠEBELA, S. (2010): Effects of earthquakes in Postojna cave system. — Acta Carsologica. Ljubljana, Slovenija, 39(3): 597-604. doi: 10.3986/ac.v39i3.87.

ZAK, K., URBAN, J., CILEK, V. & HERCMAN, H. (2004): Cryogenic cave calcite from several Central European caves: age, carbon and oxygen isotopes and a genetic model. — Chem. Geol. 296: 119-136.

ZAK, K., RICHTER, D. K., FILIPPI, M., ZIVOR, R., DEININGER, M., MANGINI, M. & SCHOLZ, D. (2012): Coarsely crystalline cryogenic cave carbonate. A new archive to estimate the Last Glacial minimum permafrost depth in Central Europe. — Clim. Past 8: 1821-1837.