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Ice Age geomorphological Ahorn Valley and Ailsbach River terrace evolution – and its importance for the cave use possibilities by cave bears, top predators (hyenas, wolves and lions) and humans (Neanderthals, Late Palaeolithics) in the Frankonian Karst

Case studies in the Sophie's Cave near Kirchahorn, Bavaria

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Abstract: The Sophie's Cave in Upper Franconia, Bavaria (South Germany) eroded into Upper Jurassic reef dolomite and is a perfect model including all three stages of cave development ranging from a 1. ponor cave, to 2. intermediate periodically flooded cave to 3. dry cave. The key position of the cave along the Ahorn Valley, a side valley of the larger Wiesent River Valley, allow a cave genesis and evolution reconstruction which started in the Pliocene. The main refill took place in the Quaternary with Middle to Late Pleistocene river terrace sediments, present as relict sediments. Seven valley genesis stages between Pliocene to final Late Pleistocene can be separated in elevations of 440 to 375 meters a.s.l. The lowering of the Ailsbach River in the Ahorn Valley is important to understand the accessibility of caves for Pleistocene animals and Palaeolithic humans in different valley positions and elevations during different times in Upper Franconia, and the natural erosive opening/closing of cave entrances towards drainage valleys. The Sophie's Cave was used first in the Middle Pleistocene in elevations of 420 m. a.s.l. over small entrances only by small carnivores such as martens and later in the Late Pleistocene (412 m a.s.l.) by cave bears mainly, which denned over generations leaving hereby rich Late Pleistocene bonebeds. Hyenas also used the cave entrances as dens, similar as wolves, but over shorter periods only. The Ice Age top predators and cave bears seem to have been in competition within the fluent geomorphological change or collapse of cave entrances especially along river valleys during the late Middle (Neanderthals) to Late Paleolithic (Aurignacians-Gravettians), which humans did not occupy the present Sophie's Cave entrance. Late Palaeolithics (Gravettians, indirectly dated by reindeer antler: 25.750±130 BP and mammoth pelvic fragment: 24.150 ±130 BP) used in the final Late Pleistocene a deeper part of dry cave only as sanctuary in form of a shamanic deposition of selected mainly shed male reindeer antlers (and possibly two mammoth pelvic remains). This human caused antler accumulation was finally scattered at the end of the Ice Age (Dryas to Alleröd) and was damaged by large dropping ceiling blocks and by dropping waters under the last and main speleothem genesis period. After the disappearance of cave bears and predators within the last maximum glaciation (= LGM), and after glaciers (or larger snow fields) might have have been present in some of the Upper Franconian Valleys, such as the Ahorn Valley, there was no sign of cave use by large mammals or humans. After the LGM, during the Dryas to Alleröd periods, not far in the Ahorn Valley at the Rennerfels rock shelter a settlement of similar Late Magdalénian/Epipalaeolithic age is known on the Ailsbach River terrace in elevation about 380 m a.s.l.

Eiszeitliche geomorphologische Ahorntal- und Ailsbach-Flussterrassen Entwicklung – und ihre Bedeutung für die Höhlennutzungs-Möglichkeiten durch Höhlenbären, Top-Prädatoren (Hyänen, Wölfe und Löwen) sowie Menschen (Neandertaler, und Spät-Paläolithikum) im Fränkischen Karst – Fallstudien in der Sophienhöhle bei Kirchahorn, Bayern

Kurzfassung: Die Sophienhöhle in Oberfranken, Bayern (Süddeutschland) erodierte in die massiven Ober-Jura Riff-Dolomite und ist eine perfektes Modell inklusive aller drei Höhlengenese-Stadien von 1. Ponor-Höhle, 2. Intermediate zeitweilig geflutete Höhle, 3. Trocken-Höhle. Die Schlüsselposition entlang des Ahorn-Tales, einem Seitental des größeren Wiesent-Flusstales, erlaubt eine genaue Höhlengenese und Verfüllungsrekonstruktion, die bereits im Pliozän begann. Die Hauptverfüllung mit Flussterrassen-Relikt-Sedimentserien fand im Mittel- bis Spät-Pleistozän statt. Sieben Höhlen-Genese und Verfüllungs-Stadien zwischen dem Pliozän und ausgehenden Spät-Pleistozän können in den Höhlenlagen zwischen 440 to 375 ü. N.N. unterschieden werden. Die Eintiefungsschritte des Ailsbachs im Ahorn-Tal sind wichtig für das Verständnis der Zugangsmöglichkeit der talnahen Höhlen für Eiszeittiere und paläolithische Menschen in verschiedenen Tälern von Oberfranken zu unterschiedlichen Zeiten, sowie den generellen Höhleneingangs-Öffnungen und -Schließungen während der Entwässerungs-Phasen in den Tälern. Die Sophienhöhle wurde erstmals im Mittel-Pleistozän in der Höhenlage der Terrasse auf 420 m ü N.N. über einen kleineren Eingang durch Kleinraubtiere wie Marder genutzt. Später, als die Terrasse auf 412 m ü N.N. abgesunken war kamen kleine erste Höhlenbären-Arten über einen neuen Eingang die im Früh-/Mittel bis Spät-Pleistozän die Höhle als Horst nutzten. Diese hinterließen reichhaltige Knochenlagen. Hyänen nutzten nur gelegentlich und kurzfristig den damaligen Höhleneingang, wie auch Wölfe. Die Eiszeit-Top-Prädatoren (Hyänen, Wölfe) und Höhlenbären scheinen im steten Konflikt im Kampf um die wieder und wieder zusammenbrechenden und sich verändernden Höhleneingänge entlang der Täler gewesen zu sein, besonders im Mittel-Paläolithikum (Neandertaler) oder Spät-Paläolithikum (Aurignacien-Gravettian). Keine dieser Menschengruppen nutzte die Sophienhöhle oder deren heutigen Eingang. Spät-Paläolithiker (Aurignacias/Gravettians, indirect datiert an Rentiergeweihen: 25.750±130 BP und einem Mammut-Beckenrest: 24.150 ±130 BP) nutzten am Ende des mittle-

ren Spät-Pleistozän einen tieferen Bereich der trockenen Höhle nur als rituellen Ort in Form einer schamischen Anreicherung von überwiegend selektierten männlichen Abwurfstangen (und möglicherweise zwei Mammut-Pelvisresten). Diese durch Menschen verursachte Geweihanreicherung wurde letztendlich am Ende der eiszeit (Dryas bis Alleröd) von herab fallenden Deckenblöcken und Tropfwasser der letzten Speleogenese-Periode auseinander gerissen und verfrachtet. Nachdem Höhlenbären und Top-Prädatoren (Hyänen, Löwen) im Hochglazial-Maximum (= LGM) in der Region verschwanden, als tentative Gletscher in einigen Tälern Oberfrankens vorhanden waren, wie im Ahorntal, erschienen Spät-Magdalénian/Epipaläolithikum-Rentierjägergruppen. Ein Jagdlager wurde aus diesern Epochen am Rennerfels-Abri unweit der Sophienhöhle in einer Höhenlage um 380 Metern auf der Ailsbach-Terrasse gefunden.

Keywords: *Bavaria, Ice Age, cave, Ahorn Valley, Alsbach River, terrace evolution, bears, humans, Neanderthals, Late Palaeolithics*

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1 Introduction

The Ahorn Valley in Upper Frankonia (Bavaria) connects to the Wiesent Valley (Fig. 1) and has the most dense cave amount in the Frankonian Alb karst whereas most of them are only small clefts or cavities (Schabdach 1998). The caves are eroded into the massif Upper Jurassic reef and lagoonal inter-reef dolomites and limestones (Meyer & Schmidt-Kaler 1992, Fig. 2). The large caves of the region are the König Ludwigs Cave with its large portal including a single large chamber (entrance 385 m a.s.l.). The 1833 discovered higher elevated and herein studied (entrance 411 m a.s.l., Fig. 1) Sophie's Cave (Holle 1833, Wagner 1833) is situated opposite. Other larger caves in higher elevations between 550 to 430 m a.s.l. have also Late Pleistocene Ice Age vertebrate content such as the Große Teufels Cave, Moggaster Cave, Zoolithen Cave; or Geisloch Cave.–Smaller and fewer cave bear remains containing caves are the Zahnloch Cave, Neideck Cave, Wunders Cave and Esper Cave (Diedrich 2012a, 2013a, Fig. 1).

Already Neischl (1904) remarked first, that sediments in caves along Upper Frankonian river valleys are important for the landscape and glacial dewatering system reconstruction. First identifications of river terraces and their possible elevations discussed Spöcker (1952) for the Frankonian Pegnitz Valley, but with a coarse model only, whereas "problems of the valley genesis and dating" were reviewed by Habbe (1989).–Again, only karst evolution models were presented, especially for the earlier Cretaceous to Tertiary periods (Groiss et al. 1998). A new discussion about river terraces in the valleys of Upper Frankonia appeared with the new sedimentological research of the Zoolithen Cave along the Wiesent Valley, where 140 meters above today's river elevation the entrance must have been flooded postglacially, dated by cave bear tooth morphology and stratigraphy (Diedrich 2011, 2013a).

In this study, the Sophie's Cave in the Ahorn Valley is presented, which allows a detailed picture of the valley and cave genesis starting in the Early Pleistocene as a model for the Upper Frankonian geomorphological change, especially with details of river terraces and elevations for the late Middle Pleistocene to final late Pleistocene.

The Upper Frankonian Karst, which formed mainly into the massif Upper Jurassic dolomites and partly also in limestones, can be reconstructed in its geomorphological change between the Plio- and Pleistocene (latter in high resolution). The only data available are cave relict river terrace sequences, which were found on entrance areas of valley-cut caves. Here it is presented for a case study area of the Ahorn Valley between south of the village Kirchahorn and the Rabenstein Castle, especially in the larger Sophie's Cave of Upper Frankonia (Fig. 4).

Their three main sedimentary series are correlated and dated partly with megafauna remains, whereas repeating floods of the cave and resedimentation destroyed parts of older layers (Figs. 3–4). The Sophie's Cave with autochthonous cave genesis and allochthonous river terrace infills allows the reconstruction of the lowering of one of the Frankonian rivers in the Ahorn Valley starting 5 Mio years ago. The Sophie's Cave is furthermore a perfect model for Frankonian caves in dolomites with three main development stages from a 1. ponor, to 2. transitional and finally 3. dry cave, which much more details can be found in Diedrich (2012a-b).

2 Material and methods

From January to July of 2011 a first interdisciplinary cave survey of the Sophie's Cave allowed the genesis, refill (see sections Fig. 3) and use by animals and humans to be reconstructed (Fig. 4). The methodologies followed general cave genesis and morphology analyses (Bretz 1942, Jennings 1985), cave sedimentology (Dogwiler & Wicks 2004, Sasowsky & Mylroie 2007, White 2007) but also river terrace analyses (Kaiser 1961). Finally the recent chronostratigraphy for the Plio-Pleistocene of Gibbard & Cohen (2009) was used. Sections all over the Sophie's Cave in different positions and elevations were analysed in grain sizes, sediment structures and fossil contents (including reworked Jurassic fossils). Palaeomagnetic studies are still in progress. First and only relative dating was possible following "fluvial river terrace sequence stratigraphy" (Bridgland et al. 2004), and the "evolution of cave bear and especially tooth morphology" (Rabeder 1999, Stiller et al. 2010), but also the "cave megafauna bone assemblages" and "taphonomy" in Late Pleistocene mountainous regions in general (e.g. Diedrich 2011, 2012b, 2012a) and its change, which support the climatic interpretations.

The cave was explored geologically, palaeontologically, and archaeologically in January-August 2011. The historically opened sections at different parts of the cave system were prepared and studied being now accessible and protected for further studies and popular scientific presentations within the show cave. New Middle Pleistocene marten tracks were left in-situ, such as a new excavated large bonebed field in the Reindeer Hall, and a small bonebed field in the Bear's Passage. The Late Pleistocene megafauna remains, mainly cave

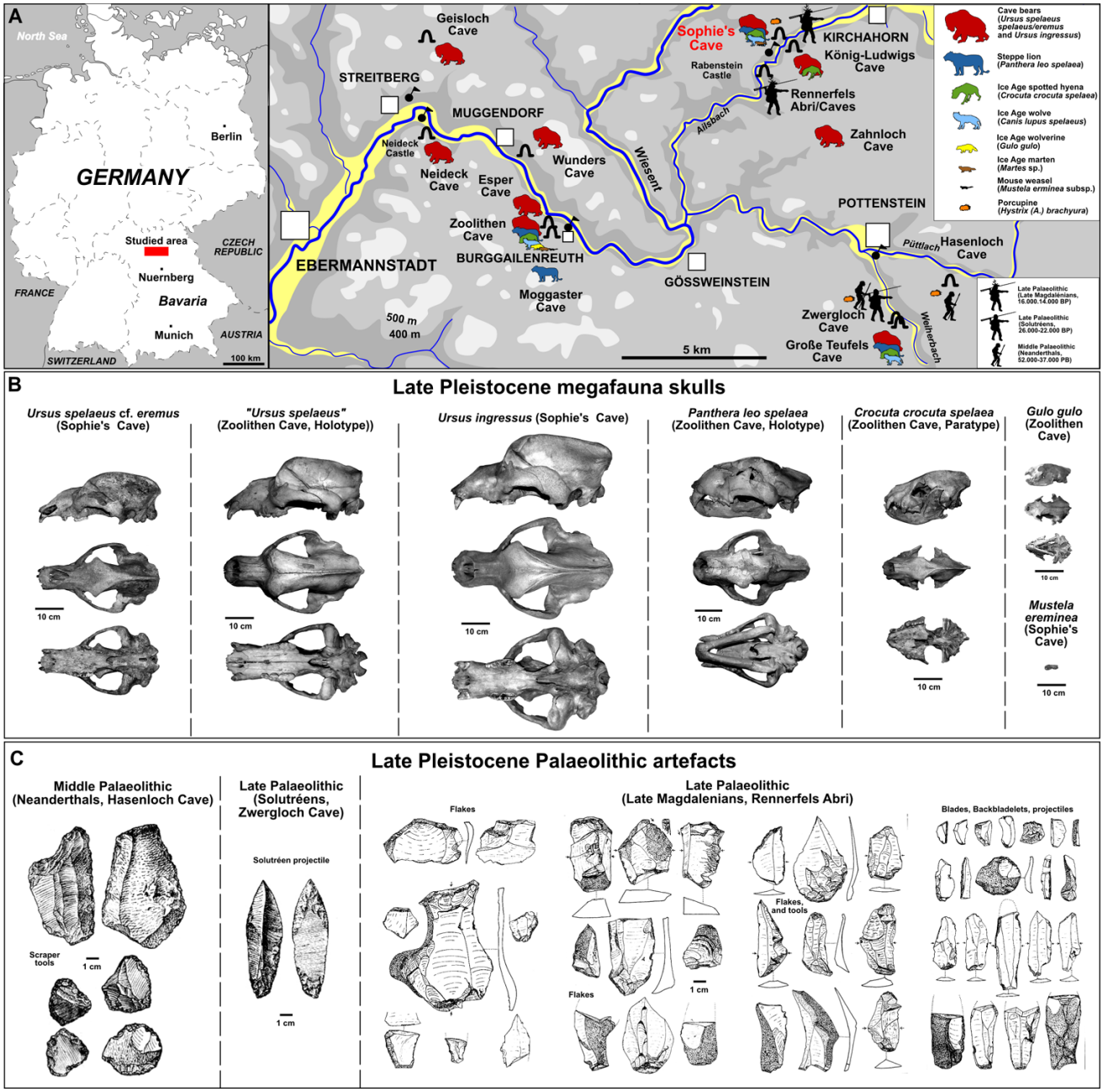

Fig. 1: A. Late Pleistocene cave bear, hyena, wolf, marten and weasel den cave sites and caves/valleys used by humans in the Middle (Neanderthals) and final Late Palaeolithic (Late Magdalénians/Epipalaeolithics). B. Selected Late Pleistocene Ice Age animal skulls (composed from Diedrich 2011, 2012a). C. Composed stone artifacts from the Hasenloch Cave (Middle Palaeolithic) and Rennerfels rock shelter (Late Magdalenian/ Epipalaeolithic) sites (selected from Gumpert 1981).

Abb. 1: A. Spätpleistozäne Höhlenbären-, Hyänen-, Wolf-, Marder- und Mauswiesel-Höhlen-Horste und Nutzung der Höhlen/Täler durch Mittel-Paläolithiker (Neandertaler) und spätem Spät-Paläolithikum (Spät-Magdalénian/Epipalaeolithikum). B. Ausgewählte spätpleistozäne Eiszeittier-Schädel (zusammengestellt aus Diedrich 2011, 2012a). C. Zussammengestellte Steinartefakte von der Hasenloch-Höhle (Mittel-Paläolithikum) und Rennerfels-Abri (Spät-Magdalénian/Epipaläolithikum) (zusammengestellt aus Gumpert 1981).

bear bones (about 98%), which were dumped historically in two areas of the Bear's Passage and the Bear's Catacombs (more then 1,600), were cleaned, inventoried and studied during this project and are housed now in the museum of the Rabenstein Castle which belongs to the cave (www.burg-rabenstein.de). Additionally the so far incorrectly composed "cave bear skeleton" was demounted and analysed. A new small cave bear species skeleton was compiled including all small bones which is presented since 2011 in a show case in the cave lying with the isolated bones in "hibernation bed position".

Finally two C14 datings were made on a reindeer antler and mammoth pelvic (both found both below last speleothem layer in the centre of the Reindeer Hall) by the Beta Analytic Laboratory, Florida, USA (www.radiocarbon.com).

3 Results and discussion

A. Pliocene-Early Pleistocene: Below a Pliocene plateau phreatic waters caused the main cave genesis in underground water level period (ponor cave stage, Fig. 5A). The first sediments were deposited fluvial by the underground

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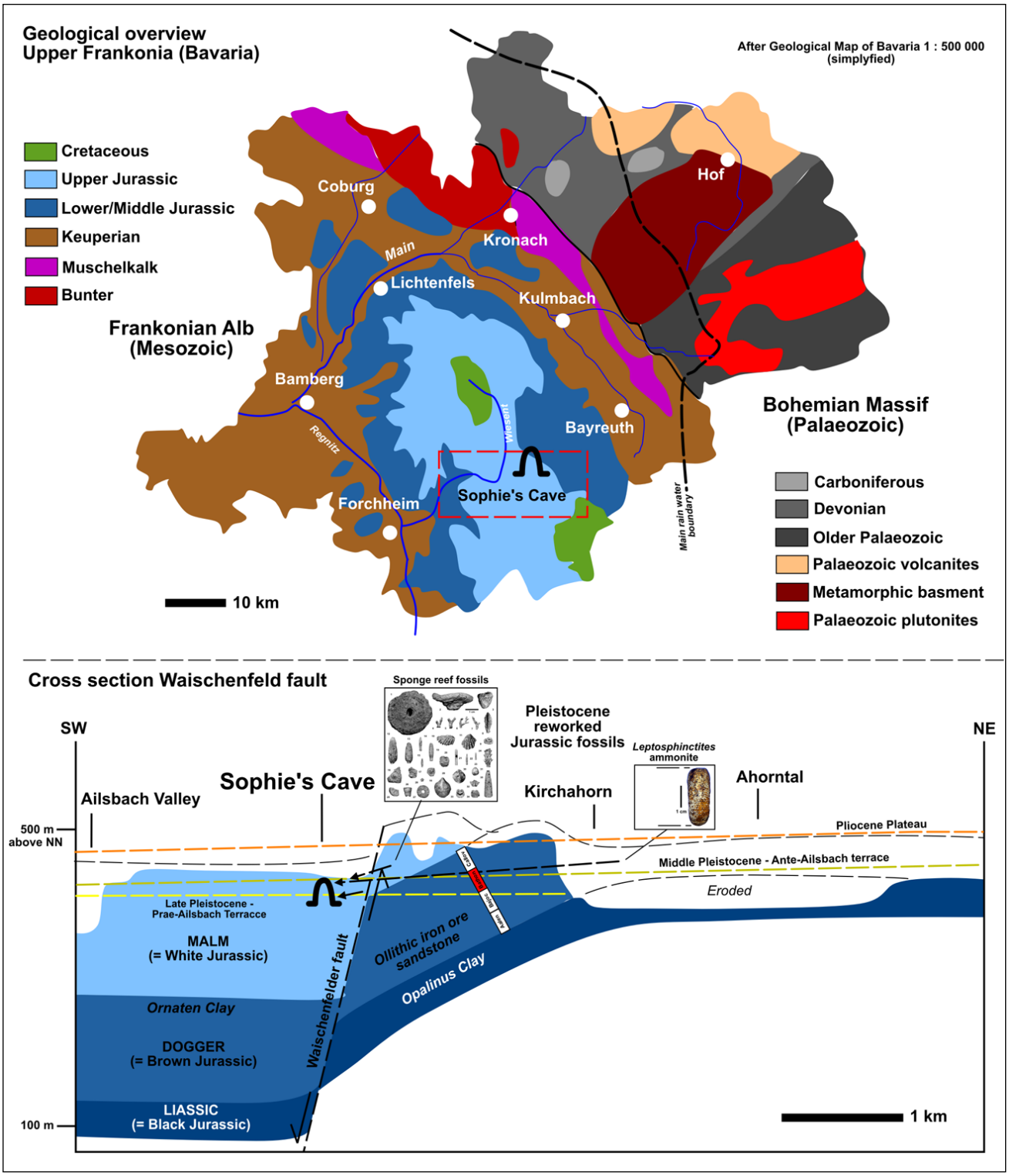
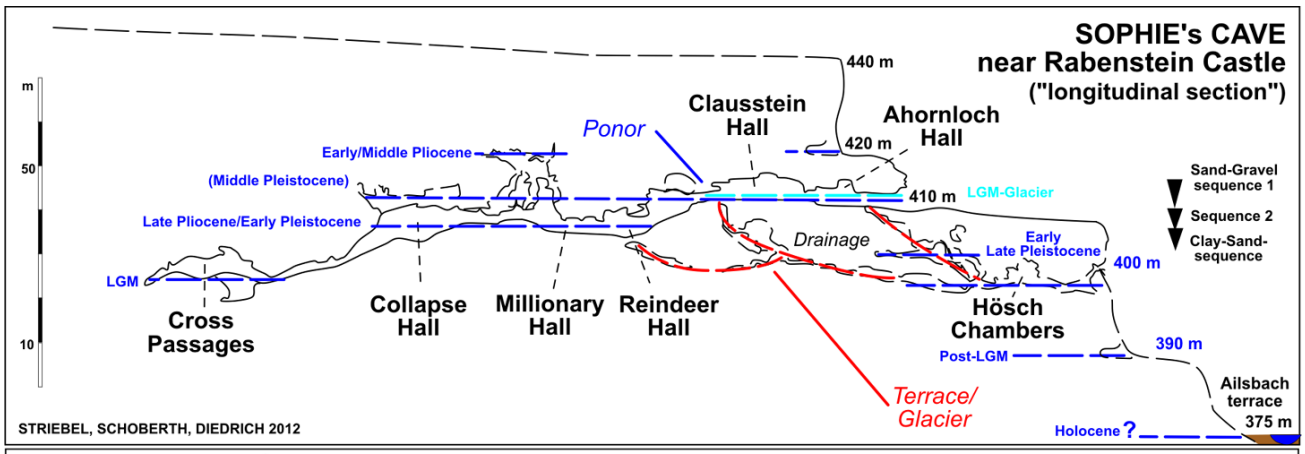


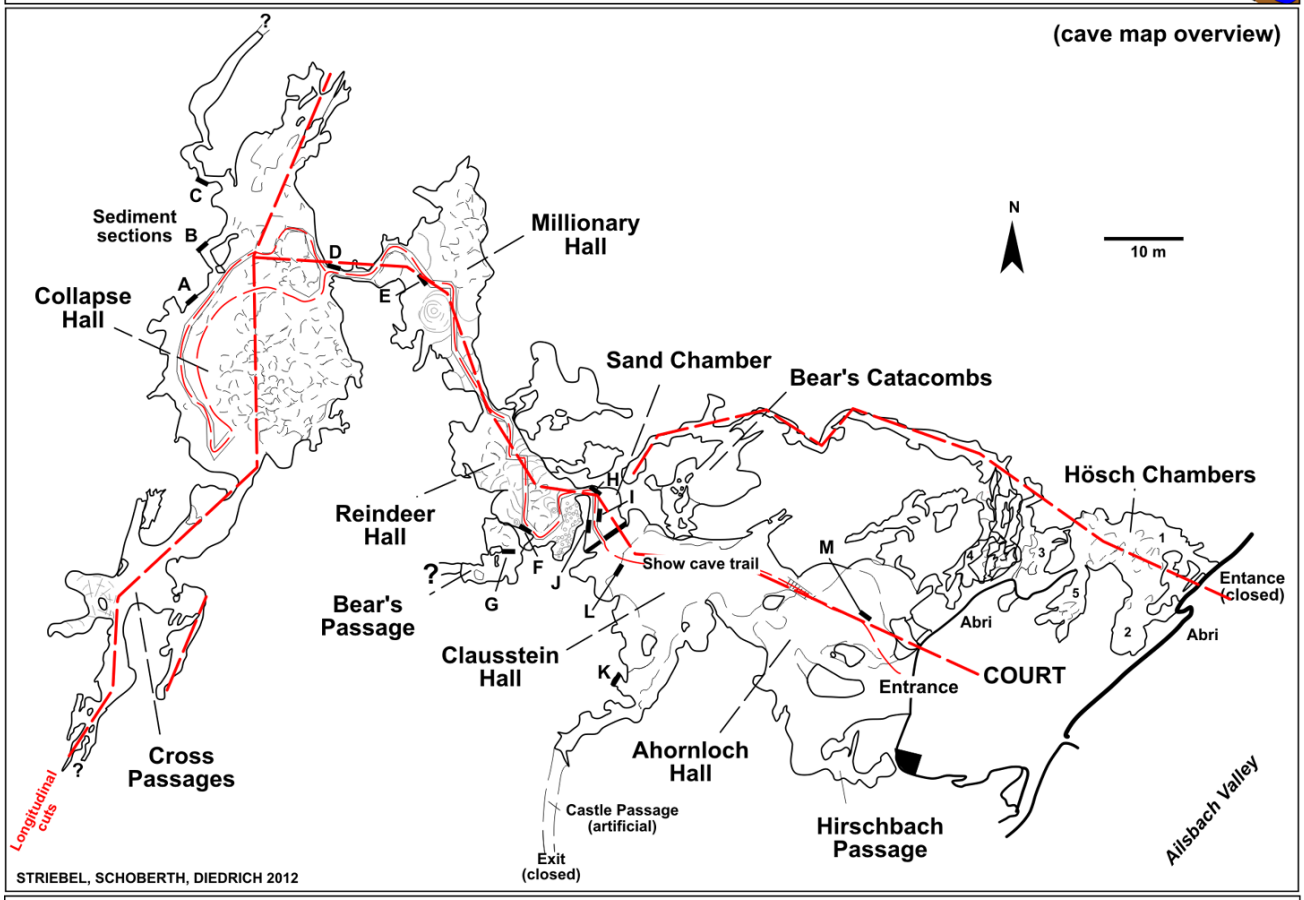
Fig. 2: Geological overview of Upper Franconia and cross section along the Kirchahorn Depression and Ahorn Valley and fault, and former elevations of the river terraces. The fossils found in the Pleistocene sediments of the Sophie's Cave are from the surrounding Brown and White Jurassic, whereas quartz pebbles are from nearby Lower Cretaceous sandstones (geology modified and simplified after Meyer & Schmidt-Kaler 1992 and Geological Map of Bavaria 1 : 500.000).

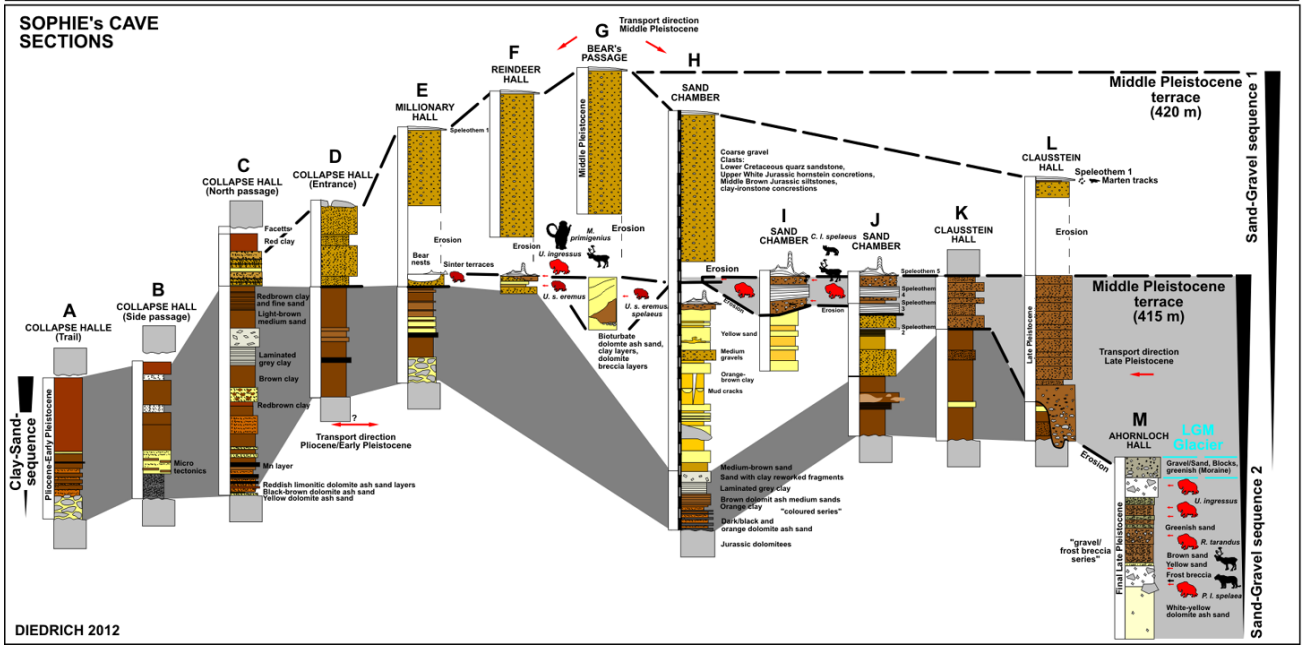
Abb. 2: Geologische Übersicht von Oberfranken und Querschnitt entlang der Kirchahorn-Depression und Ahorntal-Störung sowie ehemaligen Flussterrassen-Höhlenlagen. Die Fossilien aus den Pleistozän-Sedimenten der Sophienhöhle stammen aus den umgebenden Braun- und Weißjura-Schichten, wobei Quarz-Kiesel von wenig weiter entfernten Unter-Kreide-Sandsteinen aus der Umgebung herrühren (Geologie verändert umgezeichnet nach Meyer & Schmidt-Kaler 1992 und Geologische Karte von Bayern 1 : 500.000).

river in the Plio-Early Pleistocene consisting of „coloured series" of about 1–4 meters thickness: black manganese, red iron (minerals are used for palaeomagnetic anlyses) and orange limonite clays, silts and yellow dolomite ash sand layers (Fig. 4). Within the Early Pleistocene, the upper wide extended initial river valley must have developed in elevations starting below 450 m a.s.l. (with unclear depth of erosion at end of Early Pleistocene) but terrace sediments were impossible at that time to have been washed into the not opened Sophie's Cave branches. The cave was cut by the Ante-Ailsbach River not before the Middle Pleistocene.

B. Middle Pleistocene: During the further valley genesis







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(continuing wide valley morphology) and river terrace deepening of the Ante-Ailsbach River, parts of the cave fell dry time by time, others (valley close related parts) were flooded and filled (transitional cave stage, Fig. 5B). The oldest Ante-Ailsbach River terrace (elevation about 420 m a.s.l) left a first larger sedimentary fluvial sequence („yellow series", Fig. 4) of up to 8 meters thick limonitic, yellow clay/sand (high flood deposits) which end in some meters thick massive coarse gravel layer (terrace maximum high). The water did clearly not went too deep into the cave system (preserved bonebeds and cave bear nests in the Millionary Hall). The water did not produce a classical underground river system again, most probably due to vadose changed cave morphology and vertical shafts. Waters clearly disappeared vertically in the Reindeer Hall, and the Clausstein-Halls, which have larger vertical shafts to lower elevated systems, in which most probably the water was drained (Fig. 3). Those Middle Pleistocene gravels which maximum thickness in the Reindeer Hall contain Middle/Upper Jurassic non-dolimitic rock pebbles (even Middle Jurassic ammonites: *Leptosphinctites* – Fig. 2, and many metasomatic silicatic replaced and calcitic reef fossils) but also up to 1 cm small well-rounded clear quartz pebbles, which latter were transported twice and originate from surrounding eroded Lower Cretaceous fluvial deposits. The sediments were washed over an open vertical/diagonal shaft above the Clausstein Hall into the cave, and filled up nearly half of the Reindeer Hall and most of the Millionary Hall and were finally covered in some areas by a first undated speleothem layer (first speleothem genesis period, Fig. 3, compared to other Frankonian Caves: cf. Nordhoff 2005). Below this, in the Clausstein Hall, marten tracks on originally mud-cracked clay surfaces (preserved now as hyporeliefs below speleothem layer) (Fig. 5B) indicate the first use as a marten den of the Clausstein Hall cave part at least.

C. Early Late Pleistocene: The terrace lowered only few meters to an elevation of about 415 a.s.l. (Fig. 5C). In the early-middle Late Pleistocene only small cave bears used the cave over a new opened entrance (not today's entrance) even deep for hibernation purposes to protect against carnivore predators (lions, hyenas, and wolves). Many bite damaged and cracked cave bear bones, and scavenged disarticulated carcasses were found deep in the cave (Millionary Hall, Reindeer Hall and Bear's Passage). Wolf (*Canis lupus spelaeus*) and small weasel (*Mustela erminea*) remains were also found there. Porcupines (*Hystrix (A.) brachyura*) are indirectly proven by two chewed (typical 4-5 mm wide rodent bite marks) cave bear cub humeri. Many wolf excrements were found in the Bear's Passage mainly, and few also in the Reindeer Hall and Millionary Hall in which coprolites partly digested cave bear bones are cemented.

D. Middle Late Pleistocene: In the middle Late Pleistocene a first slight ceiling collapse and new speleogenesis (second speleothem genesis) changed the cave morphology few which resulted the blocking of the Bear's Passage to the Reindeer Hall and in general to the deeper hibernation areas. Further 5 meters the river terrace lowered deeper (410 m a.s.l.) (Fig. 3, 5D) possibly during a warmer period (third speleothem genesis period), which finally opened the today's valley-sided large portal entrance, but closed the former one. The youngest Pre-Ailsbach River terrace started with another coarsening up terrace sequence and started to grow again indicating increasing valley terraces (?glaciers) (Fig. 4). This time, quarz-rich sands (brown to greenish colored, warmer period) do not contain clay layers and are intercalated with frost brekzia layers (colder period). Large cave bear remains of *U. ingressus* date all those layers of the anterior cave area into the final Middle Late Pleistocene (32.000–24.000 BP, cf. Münzel et al. 2011; Fig. 4), where large cave bear types used the today's entrance and side chambers over many generations (rich bonebeds, and many cub remains). Ice Age spotted hyenas and wolves used this cave part periodically as a den, and scavenged on the bears too. Finally climatic cold interstadial indicators are arctic fox remains from the anterior cave area (Ahornloch Hall).

E. Final middle Late Pleistocene (Late Palaeolithic Gravettian, around 25.000 BP): The terraces seem to have been eroded fluvial (or ?by glaciers); the ponor cave was the Hösch Chambers elevation, whereas the deposits in the Clausstein Hall increased about 2 meters in a short time of a cold period (Fig. 5E). This is the time, when Gravettian humans used the Reindeer Hall as sanctuary place only (see cave use by humans), and large *U. ingressus* cave bears the anterior cave parts.

F. Last Glacial Maximum (= LGM, around 19.000 BP): Floods of melting large snow field (e.g. large depression area in soft Middle Jurassic sediments around Kirchahorn) or ?glacier surfaces washed in events the side moraine/kames material (unsorted sediments with local dolomitic non-well rounded blocks in the uppermost layers into the Ahornloch Hall (see glauconitic till: Figs. 3-4) and the large cave bear *U. ingressus* bones downwards into the Bear's Catacombs and other side branches (Fig. 5E), which bones are in "non-stratified" dolomite gravel layers (semi-rounded pebbles) and are in non-rounded well conditions. The some meters higher elevated gravels in the Clausstein Hall, which replaced the bone layers, and contain itself only very few bone remains. Those sediments seem to represent LGM side moraine/kames reworked gravels, when the ?terrace increased on elevation of about 410 a.s.l. (if not transported from glacier surface waters).

G. Final Late Pleistocene – Meiendorf, Alleröd to early Holocene: When the snow field (or ?Valley glacier) was melting post LGM lowering from 412 m a.s.l. to the ground (?ground moraine) the former river terrace eroded from an unknown level to 385 m a.s.l. (or even deeper, Fig. 5F). Again braided rivers and its coarse gravels must have formed the steep margins of the narrow valley morphology, where no terrace sediments were left on the wall margins before (?due to the glaciers); which lateral moraine sediments (till) mainly

Fig. 3: Correlation of the sections in the Sophie's Cave, and dating of the two river terrace sequences using mainly cave bear species/subspecies (cave map according to Schoberth et al. 1997, and longitudinal cuts composed by Dr. T. Striebel).

Abb. 3: Korrelationen der Profile in der Sophienhöhle und Datierung der beiden Flussterrassen-Sequenzen mit Hilfe der unterschiedlichen Höhlenbären-Arten/Unterarten (Höhlenplangrundlage nach Schoberth et al. 1997, Längsschnitte zusammengestellt von Dr. T. Striebel).

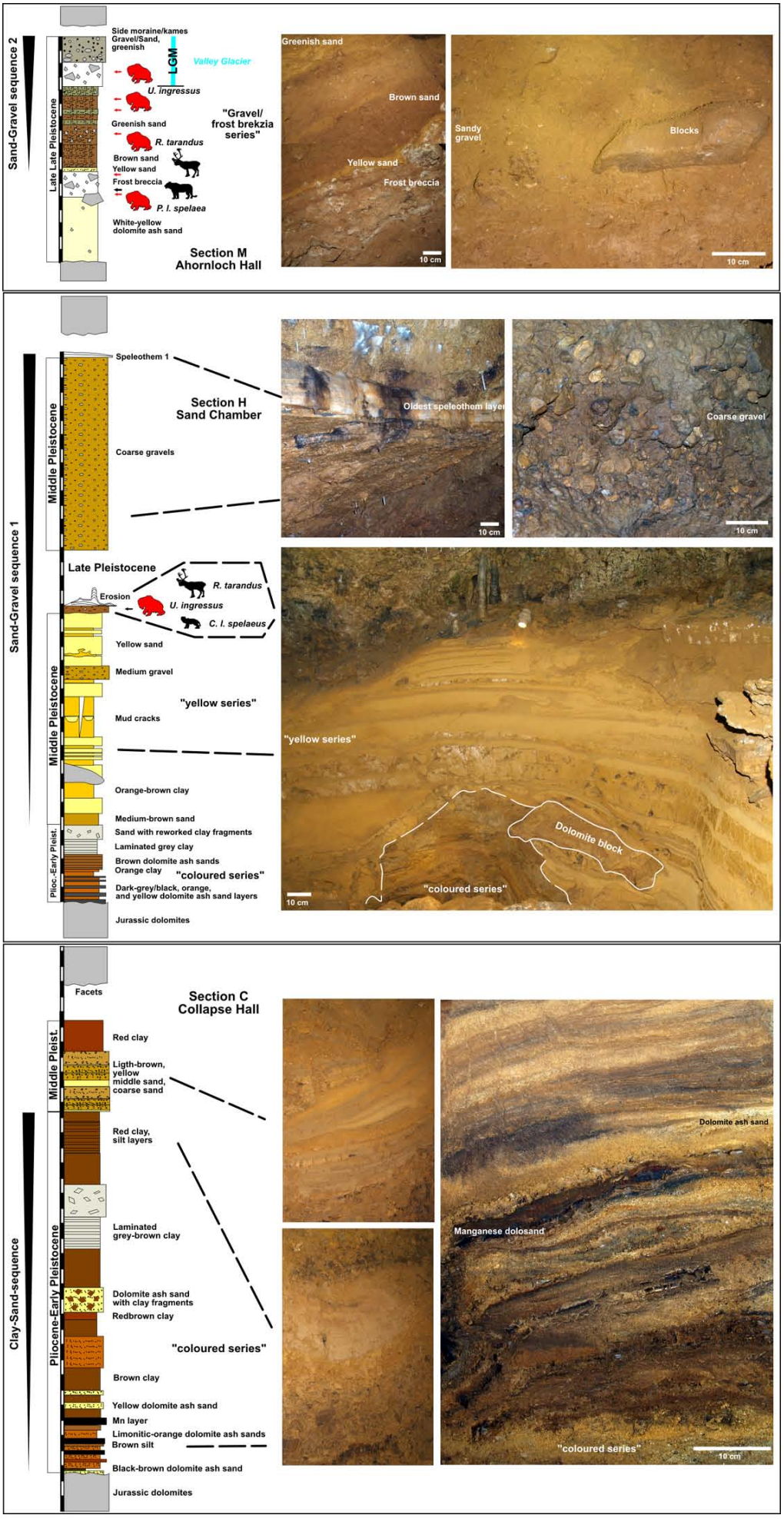

Fig. 4: Sophie's Cave main sedimentary series types and composed generalized Pliocene to Late Pleistocene section.

Abb. 4: Hauptsedimentär-Serientypen der Sophienhöhle und zusammengestelltes generalisiertes Pliozän-Spät-Pleistozän-Profil

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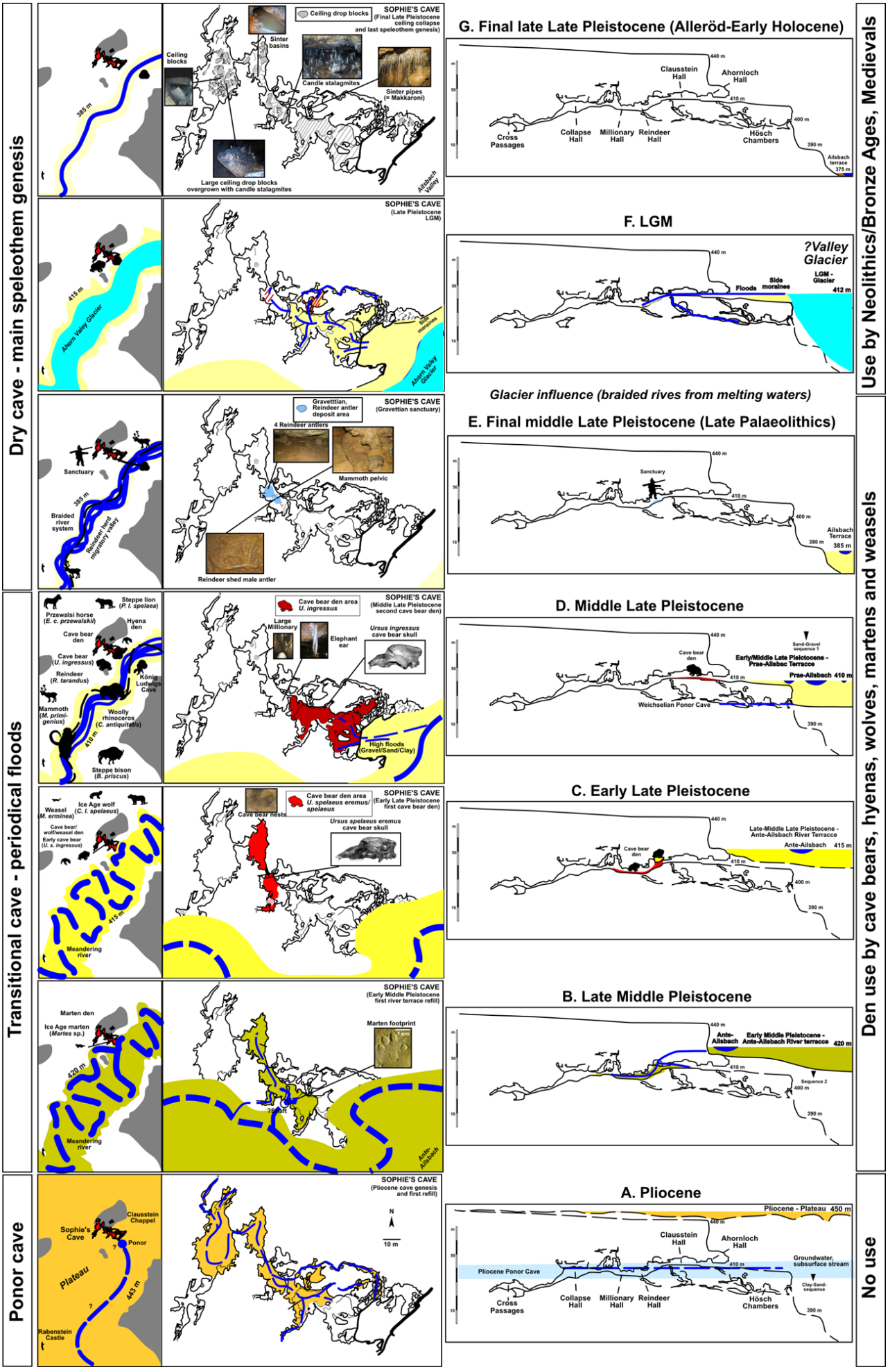
were left only in caves or cavities, such as found in the upper layers of the Sophie's Cave (Fig. 4). In the cave changing conditions caused massive event-ceiling collapse changed the cave morphology drastically, which blocks are mainly in the chambers covering their floors (Fig. 5F). Their age can be dated indirectly by two facts, first the reindeer antler remains partly are "below" those dropped blocks, whereas the last speleothem layer and candle stalagmites grew all over those large blocks, which are comparable in age to absolute dated candle stalagmites from other Frankonian caves (Nordhoff 2005: dated around 10.513 and 10.227 cal. a B.P.). During this again humid interglacial period the terrace still lowered some meters (today 375 m a.s.l., Fig. 5G) under more humid climates, that also caused the fourth and final speleothem genesis (continuing into the Holocene). Most of the speleothems such as typical "candle stalagmites" also developed on the large ceiling drop-blocks. At this ending Ice Age time, finally the access to the Reindeer Hall over the Sand Chamber was closed by a speleothem layer (that was opened again in 1833 when the cave was "discovered" twice – first by Gravettians).

The Ahorn Valley terrace stages and dating

The 550 meters elevated Moggaster Cave of Upper Frankonia was refilled with sediments during the Early to Middle Palaeogene (Palaeocen-Eocene: Groiss 2000). The 455 meters elevated Zoolithen Cave (close to the Moggaster Cave, Fig. 1) was refilled very few with sediments (clay layers) not before the Neogene (most probably Miocene: Diedrich 2013a). The Sophie's Cave in elevation of 410 meters must have been eroded and refilled correlating the cave level elevations only (south few higher as in the north, see Fig. 1) in younger Tertiary times, which Pliocene age is expected, not being confirmed by fauna or absolute dating. Typical first refills not only in the Sophie's Cave are the dolomite ash sands (yellow or dark-manganese or reddish-limonite layers = coloured series, Fig. 4), products of dolomite weathering (cf. Burger 1989). Whereas the Zoolithen Cave repesents a cave system in elevation between 460–430 meters in about three different levels (Diedrich 2013a) with early to maximum middle Middle Pleistocene refill, and finally latest Late Pleistocene flood event and terrace infill with medium to coarse dolomite gravels, the Sophie's Cave is more north and in lower elevation of 415–385 meters and has mainly a Middle to Late Pleistocene terrace refill (Figs. 4–5). The Ahorn Valley was eroded between the Pliocene and late Middle Pleistocene between 450–420 meters (Fig. 5). In the upper first 10 meters, the valley was wide, and started about 440 meters to become narrower. In the late Middle Pleistocene, the Ante-Ailsbach was already one third deep eroded of the today's Ahorn Valley elevation (375 m) on 420 meters. Possibly in this stage and first speleothem genesis time that covered the first terrace sedimentary sequence in the Sophie's Cave correlates more or less with the first speleothem genesis in the Zoolithen Cave (cf. Diedrich 2013a). There are few speleothem data available from the Franconian Alb caves, which can be used for correlations of the Sophie's Cave speleothem ages preliminary. Oldest speleothem data delivered the Zoolithen Cave 342.050 ± a 71.400 BP (Middle Pleistocene, Holsteinian interglacial, MIS 9) with its largest and oldest speleothems (Kempe et al. 2002). Those speleothems in the Zoolithen Cave developed on an elevation of about 445–435 meters in some parts of the cave system only (Diedrich 2013a). At Hunas Cave ruin the first and older speleothem is represented by a dated flowstone sample (HU-i) bearing a single age of 270.593 ± 24379 BP (Middle Pleistocene, Middle Saalian, MIS 7, Nordhoff 2005). The younger Hunas Cave ruin stalagmite has been dated between 79.373 ± 8237 and 76.872 ± 9686 BP (Late Pleistocene, MIS 5d) during the warm interstadial around 79 ka BP (Nordhoff 2005). This seems to be the time period, where the larger older speleothems (Large and Small Millionary) of the Sophie's Cave also started to grow. The Mühlbach Cave candle stalagmite reveal some analogy to the candle stalagmites of the Sophie's Cave including the transitions from the post-LGM (Boelling/Alleroed Interstadial and Younger Dryas cold phase) to the Early Holocene between 10.513 and and 10.227 BP (Nordhoff 2005). During the early/middle Late Pleistocene small cave bears (*Ursus spelaeus eremus/spelaeus*) date an unknown river terrace elevation at that time below 410 meters, and indicate dry cave conditions (no more flooded). The final Late Pleistocene and LGM has at least two deposit levels or series in the cave on elevations of 410 and 412 meters, dated by *Ursus ingressus* cave bear teeth which appeared in general in central Europe between 32.000-24.000 BP (Stiller et al. 2010). The Pre-Ailsbach River terrace grew first slowly and finally postglacially after the LGM at least two meters. The post-LGM replacement of bonebeds in the Sophie's Cave is similar to the replacements of bone layers in the Zoolithen Cave or Große Teufels Cave, which is also dated into the post-LGM (Diedrich 2013a). Although so far there is no geomorphological and for hard rock areas (here those are soft sedimentary rocks) typical evidence of a (valley) glaciation in the Franconian Alb during the LGM a minor glaciation of some elevated valleys in the study area could be a matter of debate. In this case sedimentary remnants of the glaciers have been eroded or remained undetected so far in the valleys but may have been preserved in caves (see Fig. 5 F and Diedrich 2013b). After 19.000 BP, the terraces must have eroded (probably even by ?glaciers) in some Frankonian valleys (Wiesent Valley, Ahorn Valley) whereas massive melting waters (which originate from larger snow fields or ?glaciers) replaced the "bonebed layers" of the anterior cave areas and mixed them with non-rounded and reworked tilt material. A questionable glaciation in 500 a.s.l. elevations and valley glacier development would have had massive impact of the Palaeolithic settlement of Upper Frankonia, because the natural quick landscape change explain the absence of Late Palaeolithics such as Late Solutréeans to Middle Magdalénians (= around LGM time). This is similar as recently described for the Harz Mountain Range and its caves in northern Germany (Diedrich 2013b).

Finally, there is the discussion about the extreme high elevation of the Zoolithen Cave gravel relicts of LGM times times compared to the today's Wiesent elevation (140 meters deeper), which dolomite gravels are found also in other caves around Muggendorf in elevations between 455-435 meters (Diedrich 2013a) which can be explained at the moment only by the presence of large snow fields in depressions or ?glaciers (ice caps or filled depressions) at least on the highest Frankonian areas and branching valleys (over 500 a.s.l.), especially around Muggendorf (Diedrich 2013a). The directions of the postglacial drainage (or LGM-valley gla-



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ciers) reconstructions is still vague and a first model (Diedrich 2013a) under further study. This theme has to be discussed much further (e.g. at Große Teufels Cave), but much more cave relict sediments have to be studied and interdisciplinary cave research in Upper Franconia are of need. However, those LGM sediments in the Zoolithen Cave or Sophie's Cave such as Große Teufels Cave seem to be reworked moraine tilt sediments (including glauconite or loess sands). Glaciers would have been over 80 meters thick in the Muggendorf Wiesent Valley region (after present estimations of the Zoolithen Cave sediments: Diedrich 2013a), but only 30–40 meters in the Ahorn Valley near the Sophie's Cave. Glacial signs outside caves in lowlands or glacier valleys (e.g. moraines, drumlins, ice scratch marks on dolomite rocks) would not have survived outside the caves, because dolomites weathered quickly (to dolomite ash sands), also the post-LGM fluvial valley erosion was that rapid caused by climatic changes in the Meiendorf-Younger Dryas stadials/interstadials and must have destroyed those typical glacial signs within the valleys. Possibly relicts and signs are present, but have not been described or identified yet. This is different in "hard rock" middle high mountain regions of central Europe such as the Krkonoše Mountains (CZ, Pl: Engel et al. 2010), the Bohemian Forest Mountains (Mentlík et al. 2010), or northern German Harz Mountain Range (Diedrich 2013b), where all typical glacial structures and deposit types are still preserved in several valleys or also only as relic sediments in caves (cf. Diedrich 2013b). At least the deep valleys would fit to a glacier landscape. The early Postglacial was the main "hazard time" in Upper Frankonia, when caves collapsed due to climate changes in the Bölling/Alleröd times (see last speleothem genesis phases of Frankonian Alb in Nordhoff 2005) when the valley formed quickly (?and glaciers melt rapidly).

Cave use by mammals

Ice Age mammals were able to use the Sophie's Cave when it was cut during the valley genesis not before the late Middle Pleistocene.

Middle Pleistocene: After the first river terrace material was washed into the cave, when it fell dry before the first speleothem generation grew, martens used a part of the cave (Clausstein Hall) as den (only track records, Fig. 5B).

Early-Middle Late Pleistocene: The further erosion opened an entrance to the Bear's Passage which was used in the early and middle Late Pleistocene by small cave bear subspecies mainly with still primitive cave bear dentition and enamel morphology (P4 are three-coned, dated after methods of Rabeder 1999), which went deep into the cave for hibernation. About nine cave bear nests are still preserved in the Millionary Hall (Diedrich 2012a). Also weasels (*Mustela erminea*) used the same cave area as a den (also Zoolithen Cave, Diedrich 2013a), whereas porcupines (*Hystrix* (*Atherurus*) *brachyura*) went into the cave via the former entrance (into Bear's Passage) for bone chewing (possibly also short den use there). In Upper Frankonia such Ice Age porcupines are not only indirectly proven in the Sophie's Cave (Diedrich 2012a), those were already found in the Hasenloch Cave, and the Fuchsloch Cave in the Franconian Alb with original bones, and additionally with typical rodent-chewed bones (Ranke 1879, Nehring 1891, Brunner 1954, Heller 1955). Also lions must have penetrated the cave for bear hunting (especially cubs) similar as demonstrated not only for the Zoolithen Cave (Diedrich 2011, 2012a). Lion remains are not directly present yet of the Sophie's Cave from the early-middle late Pleistocene, but from the final Late Pleistocene (Diedrich 2013a). Wolves also consumed the bear carcasses in the Sophie's Cave similar as documented for the Zoolithen Cave (Diedrich 2011, 2012b, 2013a), especially in the Bear's Passage somehow during the middle Late Pleistocene, when there was a block (large dropped ceiling block) between the Bear's Passage and the Reindeer Hall, a time where cave bears had to hibernate at the end of the Bear's Passage way too close to the entrance. There the bones show strongest carnivore damage caused by of all four, lions, hyenas, wolves and porcupines (Diedrich 2011, 2012a-b, 2013a).

Latest Middle Late Pleistocene: In this time, the largest cave bears species *Ursus ingressus* replaced the smaller and older cave bear subspecies (*U. spelaeus eremus/spelaeus*; cf. cave bear evolution and dating: Rabeder 1999, Stiller et al. 2010) which used the new opened today's entrance and anterior Sophie's Cave areas (Ahornloch, and Clausstein Halls, or Sand Chamber). A hyena den was present (early *U. ingressus* time) not only at the opposite König-Ludwigs Cave (Fig. 1), which pioneer work there started with the beginning of the "hyena den cave research" by Buckland (1823). He worked against Esper's (1774) biblical flood theories, explaining at least "non-cave bear bone assemblages in caves" to be of Ice Age hyena origin. Hyenas imported also in the Sophie's Cave few mammoth steppe animal prey remains (*Mammuthus primigenius*, *Coelodonta antiquitatis*, *Equus caballus przewalskii*, *Rangifer tarandus,* even *Panthera leo spelaea* juvenile remains, Diedrich 2014) into the short-term used den. Also similar few mammoth steppe prey was imported into the large hyena den of the Zoolithen Cave entrance, which is typical in boreal forest mountainous regions, and explains the "cave bear scavenging and hunt specialization" in those habitats (Diedrich 2011, 2013a).

LGM: Already before the last glaciation maximum in the final Late Pleistocene cave bears (last large species) and top predators (steppe lions, Ice Age spotted hyenas, Ice Age wolves) disappeared/became extinct with most species of the "mammoth steppe megafauna" from northern Germany and also from Upper Franconia (e.g. Diedrich 2013a).

Neanderthal camp sites

Dense populations of hyena clans, wolf packs and cave bear families in Upper Frankonia might have been a good reason, why Middle Palaeolothic (Neanderthals) humans did not oc-

Fig. 5: Sophie's Cave genesis during the Pliocene to final late Pleistocene, river terrace relicts and cave use by animals (marten, hyena, wolf, cave bear dens) and by humans (Late Palaeolithic, Gravettian).

Abb. 5: Genese der Sophienhöhle während des Pliozäns bis zum ausgehenden Spät-Pleistozän, Flussterrassen-relikte und Höhlennutzung durch Höhlenbären und andere Tieren (Marder-, Hyänen-, Wolfs-, Höhlenbären-Horste) und durch Menschen (Spät-Paläolithikum, Grevettian).

cupy the large portal cave entrance of the Sophie's Cave or other caves nearby (similar at e.g. Zoolithen Cave or Große Teufels Cave). The killing of cave bears by Neanderthals is not proven yet in Europe, and the only site where a camp site was possibly present is the Hasenloch cavity near Pottenstein.

Cave use by Gravettians-Solutréens (middle Late Palaeolithic)

In the final middle Late Pleistocene Gravettians used the Reindeer Hall only for shamanic purposes. They left there a "reindeer antler depot", similar as reported for the Magdalénian culture layers of the Oeger Cave (Sauerland Karst, Westphalia: Bleicher 1993), or at the unclear dated Westeregeln open air site (Diedrich 2012c). The origin of the Sophie's Cave antler accumulation will be discussed with comparisons of other caves in Northern Germany (Sauerland Karst) in future in more detail to be of human origin. The antlers (estimated about 100 using the new documented finds and historically mentioned ones in Sternberg 1835) are nearly all "shed male antlers", and are clearly not of "carnivore - hyena, wolf" selective origin (Diedrich 2012a-b, 2014). Additionally, those are found only limited in the Reindeer Hall, close to the "Elephant Ear" and "Bee Basket" speleothems (map in Diedrich 2014). After comparisons to other caves (Zoolithen Cave, Mühlbach Cave), the speleothems Elephant Ear and Bee Basket have not existed that large within the Late Palaeolithic Gravettian period (compared to dated ones in Mühlbach Cave: Nordhoff 2005). The only large reindeer antlers, of which one shed male antler was dated C14 to 25.750±130 BP, were found in a "sanctuary hall", the Reindeer Hall of the Sophie's Cave. A different shamanic use is found in the Mäander Cave, which is also in Upper Frankonia. There only engravings on speleothems (abstract feminine symbols) were left by Late Magdalénians (Bosinski 2011). The absence of artifacts at both shamanic used cave sites in the caves is not unusual and also typical at sites with "cave paintings and engravings" of SW-France (e.g. Lumley et al. 1984). At both Upper Franconian cave sites, the Late Palaeolithic ritual places are deeper in the caves, where "camp site rubbish" is anyway not expected.

Cave use by Late Magdalénians/Epipalaeolithics (final Late Palaeolithic)

Late Magdalénians had a settlement rock shelter site very close to the Sophie's Cave situated close to the Neumühle (between Kirchahorn and Oberailsfeld) at the historically discovered and excavated Rennerfels rock shelter which includes some cavities (Gumpert 1931). There, the Late Paleolithic (deeper layer, "Madeleine" = herein Late Magdalénian VI) and Early Mesolithic (upper layer, "Tardenoisian" = herein: Epipalaeolithic and not Mesolithic) material was excavated (Gumpert 1981) being housed at the Museum in Tüchersfeld. The Late Palaeolithic artefacts can be identified herein as belonging to the today's so-called Late Magdalénian VI and Epipalaeolithic based on two typical projectiles figured by Gumpert (1981). This hunting camp rock shelter site in nearly today's river terrace elevation includes a fire place and artifacts and less bones (Gumpert 1981).

The König-Ludwigs Cave (opposite to the Sophie's Cave) would have been a perfect Late Magdalénian/Epipalaeolithic settlement or hunting camp cave site, too. It was also accessible for the humans at that time (14.000–12.000 BP) after (terrace elevation was below the entrance, Fig. 5F). It is known there, the archaeological layers have been removed already during the 19th century (Sommer 2006) and were moved in front of the cave (still dumped there), similar as at the Sophie's Cave entrance area, where also the upper layers of the first halls have been scooped in front of the cave (or Ahornloch Hall branching areas). The final Late Paleolithic reindeer hunter groups (Late Magdalénians/Epipalaeolithics) were possibly present at further rock shelters similar to the Rennerfels (Gumpert 1981) and not in the caves. At that time entrances were already collapsed or closed by speleothems (e.g. Sophie's Cave) or were not used (no art in caves anymore) as known from other cave-rich regions of Europe). The rock shelter cavities instead were used along the Upper Franconian valleys, because seasonally reindeer herd migration took place and allowed the hunt on those. It seems that the absence of further archaeological sites of those cultures is only a lack of research knowledge and cave history damage or non prosecutions of rock shelters. This is demonstrated at the Sophie's Cave and Mäander Cave with their presence of at least shamanic sanctuaries. Their camp sites along the river valleys (on the plateau margins or caves) must be prospected systematically in future. A further Epipalaeolithic site was described also not far in Upper Frankonia at the site Plankenfels (Schönweiss & Sticht 1968).

Conclusions

The Sophie's Cave can be used as a model for the cave evolution from a ponor cave, to transitional cave with floods and refills of river terrace and glacial (?valley glacier) sediments, which became a dry cave that collapsed and built finally its main speleothems at the end of the Ice Age and during the Holocene. Animals started to use the cave as a den within the Middle Pleistocene (marten den). In the Late Pleistocene mainly small cave bear subspecies (*Ursus spelaeus eremus/spelaeus*) denned in the cave, but those had to change the entrances and areas of denning due to lowering of the river terraces, and collapse of the older entrance (transitional cave stage). Those were hunted by lions and scavenged by hyenas and wolves also deeper in the cave. This is the reason why several of their hibernation nests (9) are still preserved in the deepest reachable part, the Millionary Hall. The closing of the Bear's Passage did not allow bears to hibernate there furthermore. Later, at the late Middle Pleistocene (32.000–24.000 BP) new larger *Ursus ingressus* cave bears appeared, which were able to use the new opened today's entrance. *U. ingressus* populations inhabited several caves along the Wiesent and branching valleys, and also still hyenas, wolves and lions which all disappeared already before the LGM (= before 19.000 BP). Hyenas and wolves also denned periodically in the Sophie's Cave entrance area. At this time of final Middle Late Pleistocene Late Palaeolithic Gravettians left a reindeer antler accumulation within the Reindeer Hall of the Sophie's cave. This depot counts more then 100 mainly shed antlers, which are all or dominated male antlers of which one was C14 dated with 25.750±130 BP. Possibly to this shamanic antler/bone deposition also two mammoth pelvis remains belong to, one being dated with an C14 age of 24.150

±130 BP. With few increase of the terrace, and tentative presence of a LGM valley glacier, all their bones were washed post-LGM into deeper and side-branched Sophie's Cave areas, mainly into the Bear's Catacombs. Possible glaciation models with larger snow fields (or ? small glaciers) of the Upper Franconian region could explain both, the absence of humans around the LGM (22.000–16.000 BP: Late Solutréens to Middle Magdalenians), and the strong and deep erosion of the river valleys, and even extremely high elevated young river terraces, such as tilt or glauconite sand relict sediments in valley sided caves. The massive erosion of the steep valleys must have happened directly post–LGM and may tentatively also be explained by smaller glaciation forms in which form however remains unclear with first models being under construction. First new human appearance in this study area are the Late Magdalénians within the end of the Ice Age when the climate allowed the resettlement of the middle high mountainous region. Whereas in the Ahorn Valley at the Rennerfels rock shelter a camp site is known of those Late Magdalénians/Epipalaeolithics. Whereas in the Mäander Cave feminine engravings are present (Magdalénian), in the Sophie's Cave an antler depot was left (Gravettian) – both indicating a shamanic use of medium-deep cave areas within the Upper Frankonian cave-rich region. Late Magdalénians/Epipalaeolithics reindeer hunter groups found the valley already deeply eroded similar as today, which were used by reindeer herds for seasonal migrations to the boreal forests. Epipalaeolithics have left at least one (or two) camp sites (Plankenfels, Rennerfels) in the Upper Frankonian region, with the end of the Ice Age.

The valley and cave genesis of the Upper Frankonian river valleys started mainly in the Pliocene when the region was still a plateau. Most of the caves evolved within the Pliocene to early Pleistocene in the "ground water level" (ponor caves) due to climatic changes which caused the erosion of the plateau – the time of the beginning of the landscape change. Caves in different elevations were then opened time by time by rivers along the valleys. Those were partly refilled and contain different elevated river terrace relict sediments between 450 to 375 meters a.s.l. The natural weathering and erosion such as river terrace lowering changed the accessibility of caves (for humans and animals) of the Upper Frankonian valleys. Some entrances were blocked by collapses, other were closed by terrace sediments or even speleothem layers. In general, caves in the study area above 410 meters a.s.l. contain Late Pleistocene to Middle Pleistocene megafauna remains. Below 410 meters, caves have only final Late Pleistocene (Late Magdalenian to Epipalaelithics) human settlement or shamanic sites, or even Holocene Early Mesolithic (Rennerfels rock shelter) and younger epoch sites. In the Hasenloch Cave near Pottenstein Neanderthals used a smaller cave (also porcupines there) also in higher elevation as camp site, which was at the branching Püttlach Valley of another strongly frequented cave bear, wolf and hyena den cave, the Große Teufels Cave in the branching Weiherbach Valley. Also at this den site no human artifacts are known. At the time of the Neanderthals, the river valleys were about half to two-third deep eroded, as today and much less in its geomorphology relief. It seems, the larger cave systems where large mammal bone amounts were found, Neanderthals were unable to occupy due to dangerous competitions with denning cave bears and hyena clans or dwelling wolves and lions.

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