

Speleothem-based chronology and environmental context of deposits from the Mishin Kamik Cave, NW Bulgaria – A contribution to the archaeological study of the Late Pleistocene human occupation in the Balkans

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ABSTRACT: The Balkan Peninsula represents one of the most important human pathways into and out of Europe during the Pleistocene. Mishin Kamik cave, located in the karst region of Western Stara Planina, has a rich faunal content and shows promising features indicating a human occupation site with the discovery of potential bone artefacts and an intriguing accumulation of bear skulls and bones. Petrographic study and U-series dating of a stalagmite and other calcite deposits in the cave provide an absolute chronological frame for the detrital infillings and their archaeological content and inform the environmental and climatic context of the cave evolution. Most detrital deposits in the cave were probably deposited before Marine Isotope Stage (MIS) 5 and the cave morphology and sedimentary deposits display current morphologies since ~135 ka. Consequently, the palaeontological and archaeological findings are older than ~135 ka. Calcite dated on and under the accumulation of bear skulls and bones suggests deposition during MIS 7. A first depositional contextualization of the bone accumulation does not allow us to discriminate between a natural or anthropogenic origin. The study emphasizes the added value of speleothem studies in archaeological sites and particularly in bringing a well-constrained chronological and environmental framework. Copyright © 2021 John Wiley & Sons, Ltd.

KEYWORDS: karst; Middle Palaeolithic; Neanderthal; MIS 6; speleothem

Introduction

The Balkan Peninsula is known as the 'Balkan' or 'Danubian' corridor (Spassov, 2016), one of the known routes for SE–NW human migrations and dispersal, besides the Eurasian steppes north of the Black Sea, the Anatolia–Balkans route and the route via the Aegean mainland and islands (Melars, 2006, 2011; Ivanova *et al.*, 2012; Spassov, 2016). In Bulgaria, more than 20 Palaeolithic sites are known, among which 12 cave sites are situated in the northern Stara Planina mountain range (Fig. 1) (Ivanova *et al.*, 2016). Mishin Kamik cave is well known to local 'treasure hunters' for its rich palaeontological content. An late Middle Pleistocene to Eemian age was attributed by Spassov *et al.* (2017) to the bulk sediments based on the species assemblages present. The cave gained interest for its human occupation potential after the discovery of potential bone artefacts and an intriguing accumulation of bear skulls and bones (Gurova *et al.*, 2015, 2016; Gurova and Ivanova, in press) [Supporting Information (SI) 1]. Mishin Kamik cave site is located a few kilometres to the west of known human occupation sites such as Kozarnika (Guadelli *et al.*, 2005; Sirakov *et al.*, 2010),

Temnata (Ginter *et al.*, 2011) and Bacho Kiro (Hublin *et al.*, 2020) and therefore provides an opportunity to fill chronological and spatial gaps regarding patterns of human occupation and dispersal along the Balkan route and its relationship to palaeoenvironmental conditions.

Caves and more specifically archaeological caves offer valuable geological archives, such as speleothems and detrital deposits. Speleothems or chemical cave deposits are now commonly used to recover environmental and climatic changes (Hendy and Wilson, 1968; Wang *et al.*, 2008; Barker *et al.*, 2011; Lechleitner *et al.*, 2018) and used to chronologically constrain other cave deposits (Quinif, 2006). Speleothem studies may also add valuable information for archaeological studies. For example, the study of speleothem breakage, displacement and use provided information on daily life and religious practices of ancient Mayan societies (Brady *et al.*, 1997) or palaeolithic communities (Lorblanchet, 1995, p. 184; Clottes *et al.*, 2005; Delannoy *et al.*, 2012). U-series dating of speleothems (Cheng *et al.*, 2009; Spötl and Böcher, 2012) offers chronological constraints to archaeological findings, by directly dating the speleothem manuports, i.e. natural material displaced by humans, as in Jaubert *et al.* (2016), or by indirectly providing chronological constraints for the cave deposits containing archaeological material, as in Gopher *et al.* (2010) or for human-related material

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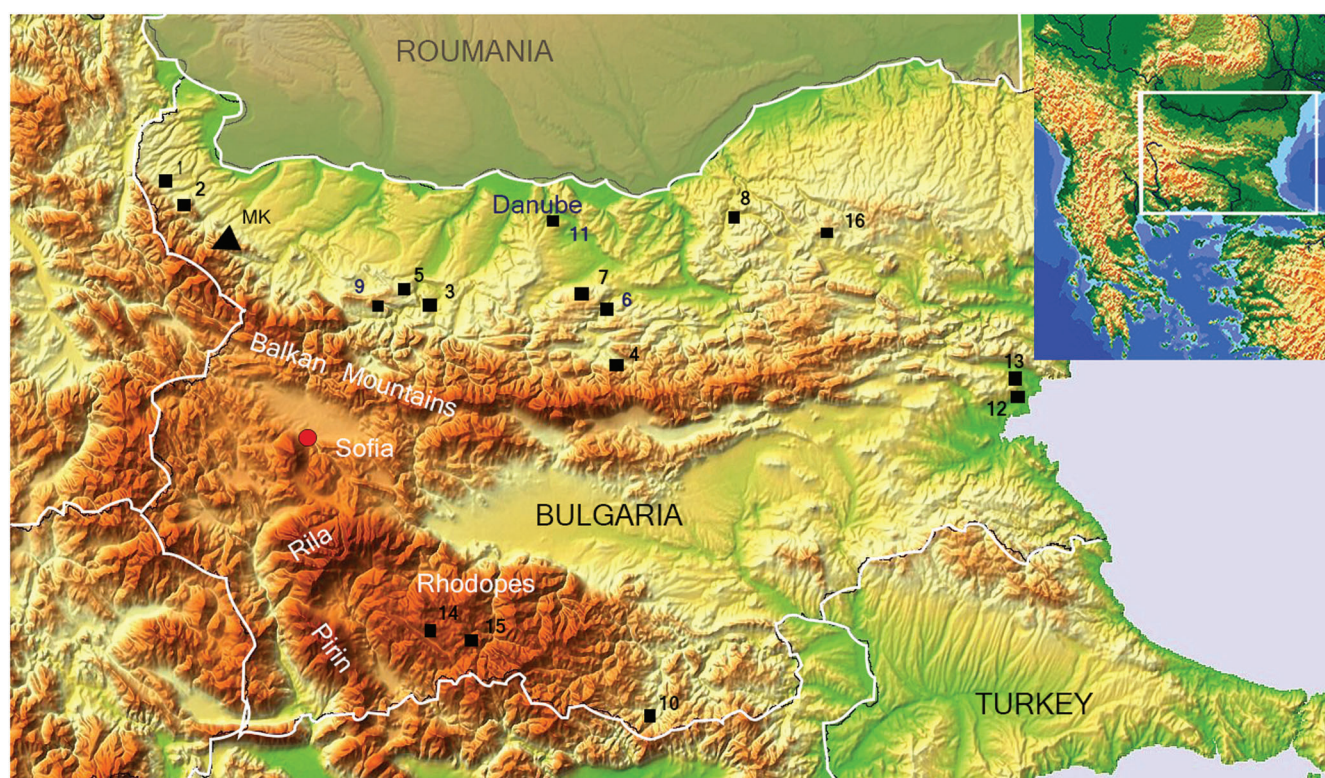


Figure 1. Orographic map of Bulgaria with localization of Middle Palaeolithic human occupation sites (modified from Ivanova *et al.*, 2016). MK: Mishin Kamik Cave. 1: Magura Cave. 2: Kozarnika Cave. 3: Temnata Dupka Cave. 4: Bacho Kiro Cave. 5: Samuiltsa II Cave. 6: Ochilata Cave. 7: Devetashkata Cave. 8: Pepelina Cave. 9: Svinskata Dupka Cave. 10: Benkovski (open air site). 11: Musselievo (open air site). 12: Dikilitash (open air site). 13: Beloslav (open air site). 14: Siroka Poljana and Kremenete (open air sites). 15: Kremakliev dol Valley (open air site). 16: Razgrad (open air site). [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/jqs.3364)]

covered by calcite as in Genty *et al.* (2004) and Walker *et al.* (2006).

Several speleothems are present in Mishin Kamik cave. The present study and U-series dating of a stalagmite and several flowstones provide a chronological and environmental framework for the detrital deposits and the archaeological findings in the cave. We discuss the consequences for the age of the archaeological material. The question of the deposition of the bear bones and skulls accumulation is raised in the context of the general cave environment, and related issues and perspectives are given to enrich the debate.

Location and cave context

Mishin Kamik Cave is located in the western part of the Stara Planina (Balkans) Mountains on the northern foothills. The cave ($43^{\circ}27'N$, $22^{\circ}53'E$) opens at 463 m asl and ~30 m above a small tributary of the Ogosta river, a tributary of the Danube, in Upper Jurassic to Lower Cretaceous bioconstructed and micritic limestones (Angelov *et al.*, 1995). The cave is approximately 300 m long (Fig. 2). A porch 4 m wide and 2 m high gives access to the main gallery with a first low passage followed by a ~20-m-long gallery of 3×3 m leading to a first room that is ~8 m wide and 4–5 m high. The cave floor consists of detrital material that is mostly covered by a calcite flowstone, up to ~15–25 cm thick in the first room. In the back of the room, a narrow (~1 m) but high (~4–5 m) corridor marks an end to the 'main gallery' and leads to a second room and the further expansion of the cave. The floor of the second room is covered by a similar calcite flowstone in continuation with the flowstone of the first room, resulting in one extended flowstone. The archaeological findings were made between 2013 and 2017 when four trenches were excavated in the gallery and in the first

room, triggered by the rich bone material found in the cave by locals (Fig. 2) and under the auspices of the National Institute of Archaeology and Museum and of the Bulgarian Academy of Sciences (NIAM-BAS). [The excavations were directed by Ivanova (2013) and Gurova (2014–2017).] Trench 4, close to the entrance, revealed polished bones, a remarkable layer of large stone fragments of unknown origin and an upside-down hollow stalagmite, located on one of the large stones alongside the cave wall. The stalagmite is relatively porous, indicating alteration and is clearly not *in situ*. Trench 1 in the first room revealed animal bones with potential cutmarks and the strange accumulation of bear skulls (S1 File) (Gurova *et al.*, 2015, 2016). Trench 1 was completely covered by the ~30-cm-thick flowstone extending over the first and second rooms. Trenches 2 and 4 were both covered by the same ~3-cm-thick flowstone as a result of the horizontal expansion of a nearby stalagmite. The results of the five archaeological campaigns were regularly published in the series of the NIAM-BAS. Trenches 2 and 3 revealed respectively no material of interest or animal bones. Detailed study of some aspects of the archaeological research and of specific finds is ongoing. An overview can be found in Gurova and Ivanova (in press). Several speleothems, i.e. stalagmites, stalactites and draperies, are observed in the cave, but most of them are damaged. A stalagmite, part of the flowstone covering the floor, was retrieved in this second room, at ~60 m from the entrance. Additionally, seven flowstones covering the trenches and present at different levels in trench 1 (Fig. 2) were sampled for U-series dating.

Materials and methods

Sampling of the geological material was granted by the Bulgarian Academy of Sciences. A total of 33 carbonate

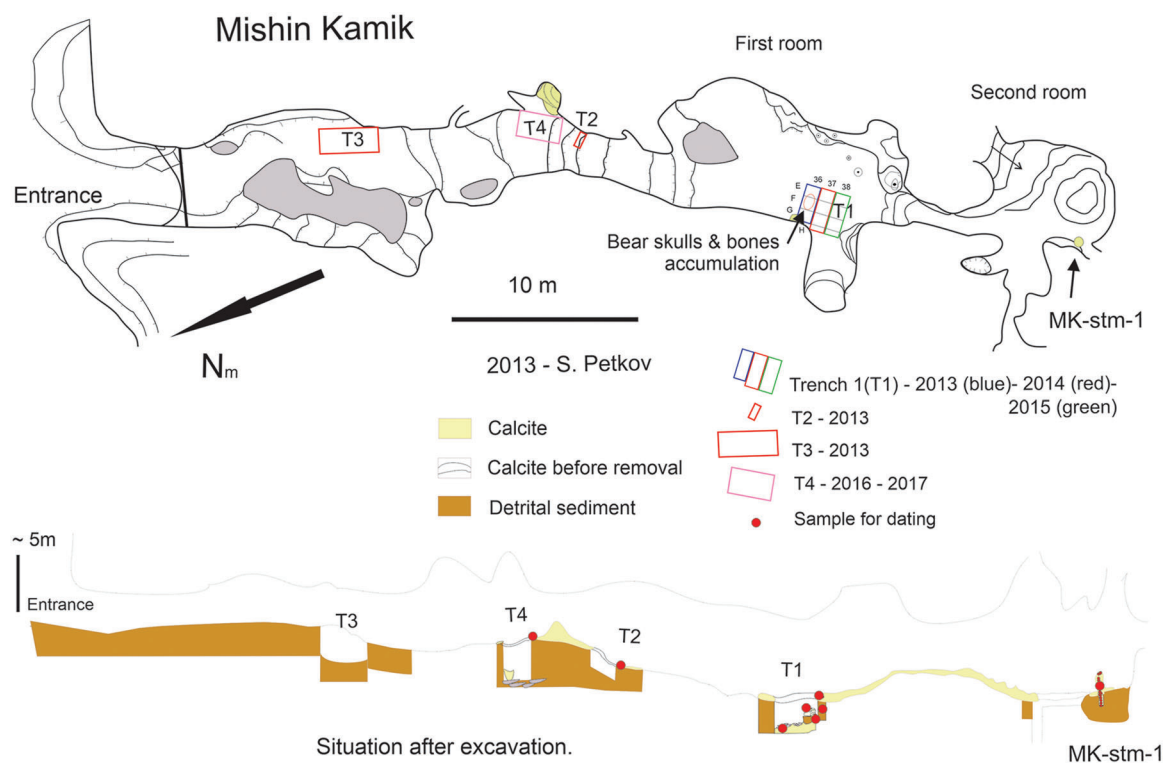


Figure 2. Map of Mishin Kamik Cave, Bulgaria. Map and indicative profile of the cave with indication of the trenches for archaeological analysis and the year of their study. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/jqs.3364)]

Table 1. Location and description of samples taken for uranium–thorium dating in Mishin Kamik Cave, Bulgaria.

Sample	Location	Description
MK 1–8 and 10–23.	Subsamples from the MK-stm1 stalagmite located in the second room at 54 m from the entrance.	Calcite stalagmite. The upper 66 cm was sampled on top of and underneath today's cave floor.
SV65	Subsample of the upper part of a clay-rich calcite flowstone, embedding the skulls in trench 1 (6MK/E36) at 38 m from the entrance.	Calcite flowstone with a detrital, probably clay-rich and porous, altered base which evolves towards a more compact calcite on top.
SV66	Subsample of the upper part of MK-PL-1, calcite flowstone covering trench 1 at 38 m from the entrance.	MK-PL-1 is a powdery (altered?) calcite flowstone. The subsample is taken in a harder sublayer of the flowstone.
SV153	Subsample of the middle part of MK-PL-1.	Powdery calcite from MK-PL-1
SV152	Subsample of the basal part of MK-PL-1.	Same as above
SV154	Subsample of the basal part of MK-PL-1.	Same as above
MK9	Subsample of MK-PL-3, a porous (altered) clay-rich flowstone located at 33 cm depth in trench 1 at 38 m from the entrance. MK-PL-3 was sampled ~1 m away from the skull location.	~8-cm-thick irregular calcite The calcite is a crystalline, relatively porous calcite showing partial dissolution. The flowstone corresponds to the one in which the bear skulls and yellow clay were embedded and was therefore deposited after the deposition of the skulls.
SV147	Second subsample of the MK-PL-3 flowstone taken at ~2 cm from the MK9 subsample.	Same as above
MK-S2-T2	At 22 m from the entrance. Subsample from flowstone MK-PL-2 covering trench 2.	An ~1.5-cm crystalline calcite flowstone layer covering trench 2 and connected to a relatively massive stalagmite on the side of the trench.
MK-S1-T4	At 19 m from the entrance. Subsample from flowstone MK-PL-4 covering trench 4.	An ~1.5-cm crystalline calcite flowstone layer covering trench 2 at the other side of the massive stalagmite described above. An ~4 cm detrital deposit covers the flowstone.
SV78	Subsample of MK-PL-20 from the lower part of the calcite flowstone fragment underlying the skulls in T1 at 38 m from the entrance	An ~5-cm-thick clay-rich crystalline calcite flowstone fragment on which the calcite skulls are positioned.
SV79	Subsample of MK-PL-20 from the upper part of the calcite flowstone fragment underlying the skulls at 38 m from the entrance	Same as above
MK11	Subsample of MK-PL-7, a flowstone with rim stone (basins) structures, located at ~20 cm under the skulls at ~60 cm in trench 1.	Yellow rim-stone calcite showing complex depositional structures.
SV77	Second subsample of MK-PL-7, taken ~3 cm away from MK11.	Same as above.

samples from seven different carbonate flowstones and from one stalagmite were U-series dated (Table 1). Selected flowstones included (i) the flowstone covering trenches 2 and 4 – both trenches are covered by the same ~3-cm-thick flowstone result from the horizontal expansion of a nearby stalagmite; (ii) the flowstone covering trench 1 (first room) – this ~30-cm-thick flowstone extends over the first and second rooms; and (iii) flowstones present at several depths in trench 1.

A stalagmite (MK-stm-1) was sampled in 2014 in the second room (Figs. 3 and 4), at ~15 m from T1 in the first room (Fig. 2). The stalagmite seemed to grow on and be part of the extended calcite flowstone covering the cave floor continuously from the first room (and covering T1) and second room (Fig. 5). Once sampled down to floor level, a basal part of the stalagmite was located under the calcite floor buried by the underlying sediments, and was also retrieved in part. The total retrieved MK-stm-1 stalagmite sample is 66 cm long. It was halved along the growth axis and its surface polished with different grain sizes of silica carbide paper. Petrographic information was obtained using a binocular microscope with a magnification of 20× to 60×. Twenty subsamples were taken for U–Th dating. Each subsample of 200–400 mg of speleothem calcite was taken using a 0.8-mm tungsten carbide dental drill and analysed with a Thermo-Scientific Neptune-Plus multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) at the Isotope Laboratory at Xi'an Jiaotong University. Uncertainties in uranium and thorium isotopic data were calculated offline at the 2σ level, including corrections for blanks, multiplier dark noise, abundance sensitivity and contents of the same nuclides in spike solution. Ages were corrected assuming an initial $^{230}\text{Th}/^{232}\text{Th}$ atomic ratio of $4.4 \pm 2.2 \times 10^{-6}$. The age is given in years before 1950 CE.

For additional information about the U-series methodology, we refer to Edwards and Chen (1987); Shen *et al.* (2012) and Cheng *et al.* (2013).

Raman spectroscopy performed at the Royal Belgian Institute of Natural Sciences in Brussels was applied to confirm the calcite composition of the samples. Additionally, a black layer in one of the calcite layers covering the skulls (6MK/E36) was analysed for its composition. We used a Bruker Senterra BX31 confocal Raman microscope. Excitation on all samples was carried out with a 785-nm laser (~5 mW at the sample surface). Raman spectra were usually acquired at two resolutions: 1–3 cm^{-1} between 60 and 1200 cm^{-1} , and 9–18 cm^{-1} between 100 and 3720 cm^{-1} .

The sedimentological and petrographical study of a single stalagmite in this study helps to date the environmental information. The chronological information is complemented by the ages of several flowstones framing detrital deposits in the cave. One of the flowstones is physically linked to the speleothem. The cave information is compared to global and regional environmental and climatic information, available from the literature, which strengthen part of the information retrieved from the stalagmite. The stalagmite in turn provides a precise chronology.

Results

The 66-cm-long MK-stm-1 calcite stalagmite is composed of white-yellow to dark-brown calcite. Its longitudinal profile displays several important sedimentary changes (Fig. 3). The basal part (lower 25 cm, 66–41 cm from top) is a ~5.5 cm candle-shaped stalagmite, composed of regularly deposited, white-yellow, fine-layered columnar calcite. At the upper part

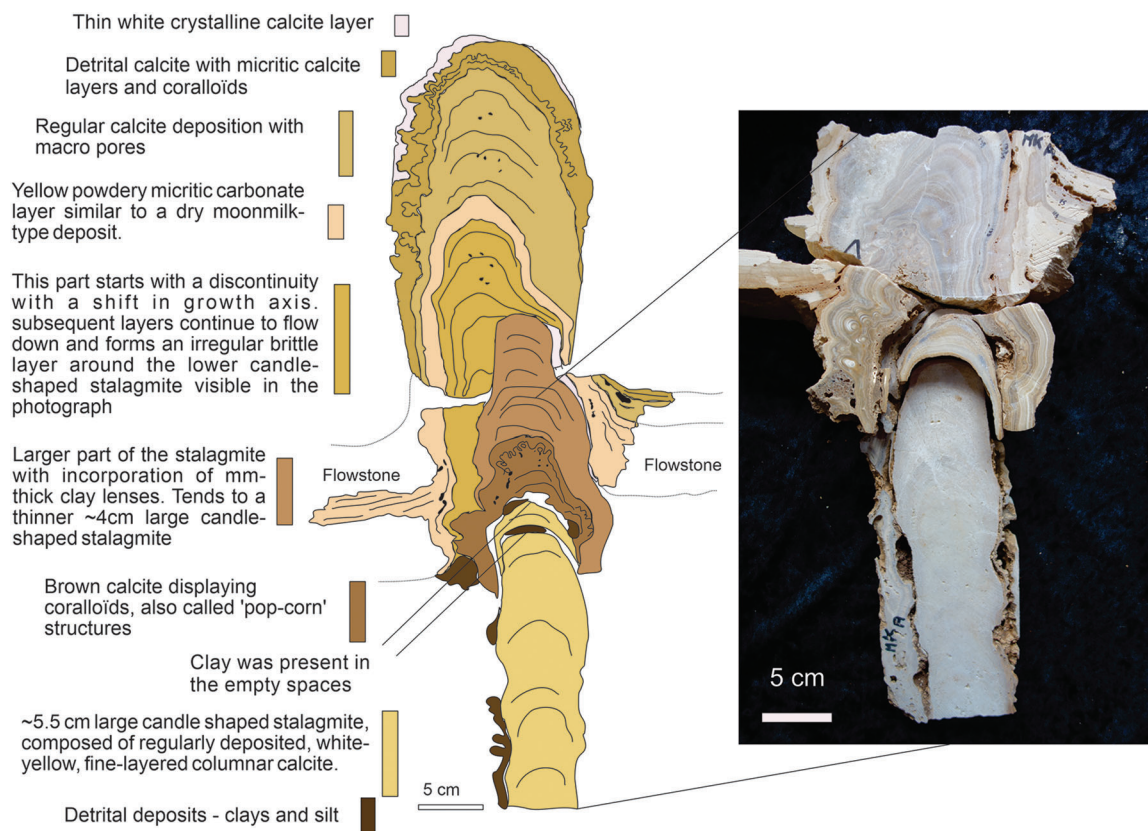


Figure 3. Longitudinal profile of the MK-stm-1 stalagmite, Mishin Kamik Cave, Bulgaria. Left and middle: description of the different sedimentary units recognized in the speleothem. Right: image of the lower part of the stalagmite with its brittle calcite 'lace', deposited with incorporation of detrital sediments around the candle-shaped stalagmite. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/terms-and-conditions)]

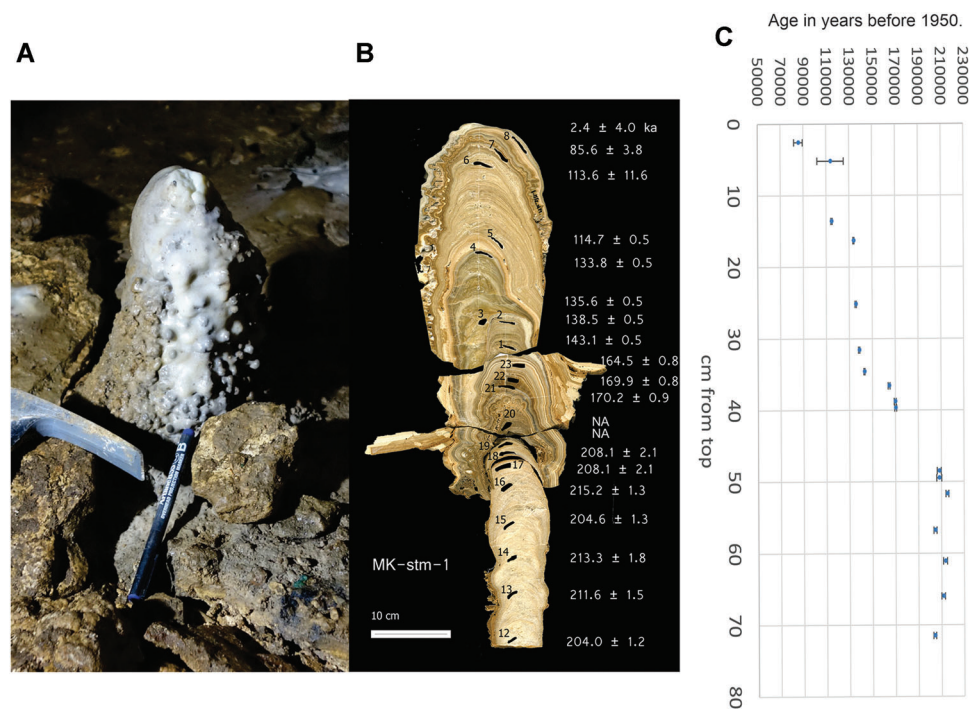


Figure 4. The MK-stm-1 stalagmite from Mishin Kamik Cave, Bulgaria. A. *In situ* in Mishin Kamik cave (Bulgaria). B. Longitudinal profile of the upper 66 cm of the stalagmite that could be retrieved from the cave and the U-series dating results. C. Uranium–thorium ages against distance from the top. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

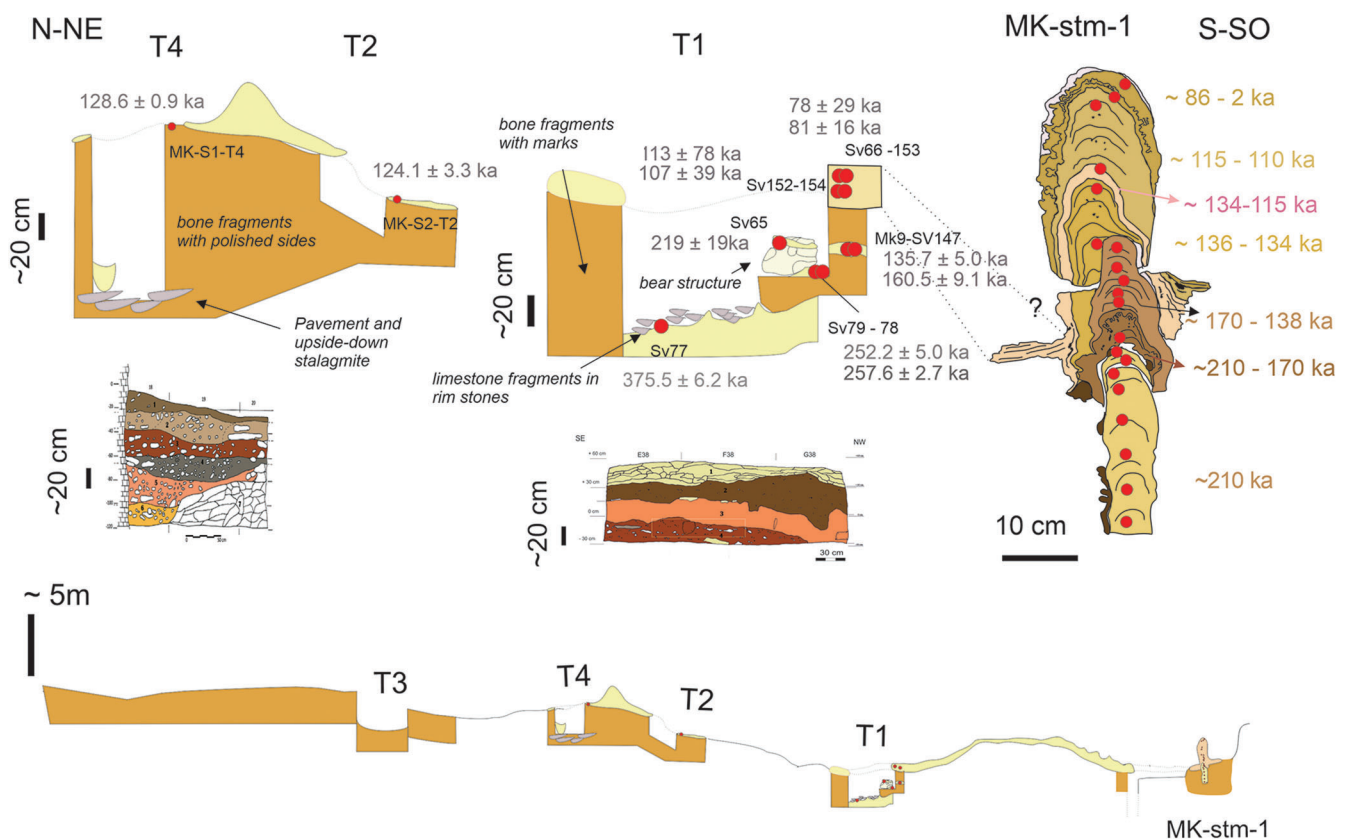


Figure 5. Cave deposits in Mishin Kamik cave, Bulgaria. Overview of the chronology of the cave deposits and archaeological findings, based on U-series dating of speleothems. The trenches are positioned on a vertical profile of the cave. The archaeological finds are indicated in italic. Dated samples are indicated as red dots and sample numbers refer to Table 2. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

of the candle-shaped stalagmite, a layer of ~ 0.5 cm clay interrupts the growth, which continues above the clay over ~ 2 cm followed by a second ~ 0.8 cm clay layer at 39 cm from top. Above these interruptions, more detrital brown calcite

displaying coralloids, also called ‘popcorn’ structures (Hill and Forti, 1997), is deposited. Between 39 and 36 cm from the top, the stalagmite is wider and displays incorporation of millimetre-thick clay lenses. Above this detrital part, the

stalagmite tends to return to a ~4-cm candle shape, but at 24 cm from the top, a discontinuity with a shift in growth axis of ~2.5 cm is found. The subsequent stalagmite diameter increases to ~8 cm. Some of the layers continue down the stalagmite and are dispersed in the underlying detrital sediments, forming a calcite 'lace' around the basal candle-shaped stalagmite (Fig. 3). Most of the stalagmite is made of crystalline columnar calcite (Frisia, 2015). At 16 cm from the top, a first, ~1-cm-thick, yellow powdery (as it leaves a yellow powder after touching) carbonate layer comparable to a dry moonmilk-type calcite is deposited over the entire stalagmite and further spreads horizontally in a ~5- to 10-cm-thick flowstone, i.e. the flowstone covering the second and first rooms. After a thin detrital layer, the upper part of the stalagmite displays more regular calcite deposition with macro pores up to 1 cm long. In the upper 3 cm more clay-rich layers are deposited, alternating with popcorn structures and a second yellowish powdery calcite layer is deposited over the stalagmite and spreads further on the flowstone covering the surrounding sediments. The calcite flowstone is similar to the one covering T1 ~15 m away in the previous room (Fig. 2).

The stalagmite was dated to between ~210 ka (lower end of the sampled stalagmite) and ~80 ka with a potential recent layer (~2 ka) on top of the stalagmite. Dating results are shown in Fig. 4 and Table 2. The basal candle-shaped stalagmite, dated to ~215–204 ka, displays some ages that are not in stratigraphic order. Two datings provided impossible ages probably due to opening of the system with respect to uranium, i.e. permitting migration of uranium resulting in too old (loss of U) or too young (accumulation of U) ages, as suggested by the high uranium content of one of the samples. These ages are underlined in Table 2. The upper recent date of 2.4 ± 4.0 ka should also be taken with caution because of the high detrital content, i.e. $^{230}\text{Th}/^{232}\text{Th}$ values less than ~100, although this recent age is consistent with the stratigraphic order and recent deposition of the white crystalline texture of the upper calcite layers (Geyh, 2008). The ages of 170 ka and younger are in good stratigraphic order, suggesting more reliable ages than the older part, in agreement with a generally decreased risk of chemical opening for younger calcite.

The thin flowstones covering the detrital infillings of T2 and T4 both originate from the same broad stalagmite on the side of the gallery and are therefore two sides of the same flowstone (Fig. 5). Their ages are 124.1 ± 3.3 and 128.6 ± 0.9 ka, respectively, and display only a slightly different age when considering the uncertainties. Their crystalline calcite is different from the powdery micritic texture of the flowstone covering T1 in the first room and the floor around the MK-stm1 stalagmite in the second room. The $^{230}\text{Th}/^{232}\text{Th}$ results for the calcite layers inside trench 1 indicate an overall detrital-rich calcite and the ages should be used with caution. Only the ages confirmed by multiple dates are considered reliable. In the T1 profile, the upper calcite layers display ages between 78 ± 29 and 113 ± 78 ka. The calcite layer from the middle of the profile, i.e. MK-PL-3, is dated to between 160.5 ± 9.1 and 135.7 ± 5.0 ka, the middle calcite layers under and above the skulls, respectively between 257.6 ± 2.7 and 219.5 ± 18.5 ka, and the underlying calcite water-pool rims are dated to around 375 ka. Although the age seems reliable, only one date is available for the rims and should therefore be confirmed by additional dates (Fig. 5; Table 2).

Raman results (S2 File) demonstrated that all phases of the stalagmite as well as the different flowstones, including the powdery layers, were composed of calcite. It additionally also demonstrated that the black crusts present in the sediments are mostly manganese mineralizations.

Discussion

Environmental and climatic information inferred from the MK-stm-1 speleothem

Speleothem deposition is known to depend on (i) CaCO_3 saturation of the water, (ii) temperature and (iii) water supply rate (Dreybrodt, 1988; Baker *et al.*, 1998). Rainfall and temperature have an important influence on stalagmite growth rate, through their direct influence on soil biological activity and consequently on CO_2 production, driving the carbonate dissolution and precipitation processes (Dreybrodt, 1999; Genty *et al.*, 2003). Therefore, increased speleothem growth rates and larger speleothem diameters are related to increased water availability and/or higher carbonate saturation of the water linked to increased CO_2 production and thus an active soil under favourable climatic conditions. Consequently, increased speleothem growth and diameter generally indicate warmer and more humid conditions in northern temperate regions. It is also known that caves underwent phases of detrital infilling during glacial periods, at least when water was running at the surface and not during the coldest phases (Atkinson *et al.*, 1978; Baker *et al.*, 1993; Quinif, 2006). Increased incorporation of detrital material into the calcite therefore indicates increased erosion at the surface often related to a decrease in vegetation that would maintain the detrital particles and delay the arrival of recharge water into the cave. Instead, important flooding of the cave with muddy water (mudflows) or larger debris (debris flow) (Ek and Quinif, 1988) may be registered in the 'dirty' particle-rich layers of speleothems.

The MK-STM-1 stalagmite (Figs. 3 and 4) grew during several periods with different climatic and environmental conditions. Although caution is required while retrieving information based on a single speleothem, some of the specific speleothem periods can be chronologically connected to the sedimentary evolution of the cave based on dating of the flowstones. The precise chronology of the speleothems allows reliable correlation with larger regional climatic conditions and allows us to place the archaeological and palaeontological findings in a chronological and palaeoenvironmental context.

1. The basal candle-shaped stalagmite, dated to ~210 ka, displays ages that are not in stratigraphic order, suggesting an opening of the chemical system with respect to uranium. However, overall, we can consider deposition of the candle-shaped stalagmite to between 210 and 208.1 ± 2.1 ka, the latter age based on two reliable similar ages. The candle-shaped stalagmite indicates rather stable conditions, favourable for speleothem deposition. As a comparison, candle-shaped stalagmites seem to be a major type deposited during the Holocene in Belgium (Quinif, 1990, 2006). This stable period in MK-stm-1 corresponds to Isotope stage 7c (Fig. 6), known in Europe as a period of intense forest development (cf. López-García *et al.*, 2014, and references herein) and of high sea level (Dutton *et al.*, 2009). During this period the ice-sheet volume was comparable to that of today (Lambeck *et al.*, 2006).
2. The subsequent deposition of clay layers and calcite with high detrital content as also indicated by the low $^{230}\text{Th}/^{232}\text{Th}$ clearly indicates a deterioration of climatic conditions as explained above. This deterioration between ~210 and ~170 ka corresponds to the demise of MIS 7 associated with a general sea-level drop around 185 ka (cf. Antonioli *et al.*, 2004; Waelbroeck *et al.*, 2008) and with generally less favourable climate conditions (Roucoux *et al.*, 2006). The observed

Table 2. U-series dating results for the Mishin Kamik cave speleothems, Bulgaria.

Sample no. (cm from top)	^{238}U (p.p.b.)	^{232}Th (p.p.t.)	$^{230}\text{Th}/^{232}\text{Th}$ (at. % $\times 10^{-6}$)	δ^{234} U (measured)	$^{230}\text{Th}/^{238}\text{U}$ (activity)	^{230}Th age (a) (uncorrected)	$\delta^{234}\text{U}_{\text{initial}}$ (corrected)	^{230}Th age (a BP) (corrected)
MK-stm-1 stalagmite								
MK-1 (34.6)	316 ± 0	5367 ± 107	1011 ± 20	358.6 ± 1.3	1.0413 ± 0.0013	143 446 ± 451	537 ± 2	143 059 ± 504
MK-2 (31.6)	236 ± 0	4773 ± 96	818 ± 16	332.7 ± 1.4	1.0020 ± 0.0013	138 951 ± 460	492 ± 2	138 492 ± 537
MK-3 (25.2)	222 ± 0	629 ± 13	5643 ± 114	309.9 ± 1.6	0.9703 ± 0.0015	135 668 ± 520	454 ± 2	135 547 ± 521
MK-4 (16.3)	215 ± 0	2386 ± 48	1453 ± 29	328.0 ± 1.3	0.9790 ± 0.0014	134 041 ± 448	478 ± 2	133 758 ± 473
MK-5 (13.6)	70 ± 0	994 ± 20	1035 ± 21	317.7 ± 1.6	0.8895 ± 0.0018	115 017 ± 472	439 ± 2	114 666 ± 512
MK-6 (5.2)	57 ± 2	1301 ± 26	663 ± 13	349.9 ± 57.1	0.9095 ± 0.0352	114 156 ± 11635	482 ± 80	113 646 ± 11571
MK-7 (2.6)	124 ± 0	33 145 ± 664	50 ± 1	392.7 ± 1.5	0.8146 ± 0.0016	90 950 ± 305	500 ± 6	85 573 ± 3783
MK-8 (0.5)	86 ± 0	22 910 ± 459	6 ± 0	398.4 ± 1.3	0.1006 ± 0.0010	8113 ± 82	401 ± 5	2375 ± 4029
MK-12 (71.5)	114 ± 0	3811 ± 76	547 ± 11	254.1 ± 1.4	1.1141 ± 0.0016	204 751 ± 1075	452 ± 3	204 011 ± 1170
MK-13 (66.0)	138 ± 0	9119 ± 183	283 ± 6	260.9 ± 1.5	1.1375 ± 0.0017	212 939 ± 1226	474 ± 3	211 558 ± 1527
MK-14 (61.1)	99 ± 0	6431 ± 129	289 ± 6	260.3 ± 1.9	1.1401 ± 0.0020	214 669 ± 1520	475 ± 4	213 312 ± 1757
MK-15 (56.8)	119 ± 0	6281 ± 126	351 ± 7	265.9 ± 1.4	1.1285 ± 0.0016	205 713 ± 1062	474 ± 3	204 596 ± 1288
MK-16 (51.7)	112 ± 0	3059 ± 61	698 ± 14	272.2 ± 1.4	1.1551 ± 0.0018	215 805 ± 1226	500 ± 3	215 209 ± 1276
MK-17 (49.5)	113 ± 0	14 698 ± 294	146 ± 3	278.0 ± 1.4	1.1514 ± 0.0018	210 711 ± 1170	500 ± 4	208 096 ± 2137
MK-18 (48.5)	129 ± 0	10 364 ± 208	235 ± 5	277.3 ± 1.8	1.1487 ± 0.0019	209 770 ± 1368	499 ± 4	208 129 ± 1749
MK-19 (47.0)	165 ± 0	822 288 ± 16482	4 ± 0	278.8 ± 1.8	1.2331 ± 0.0098	259 868 ± 7471	330 ± 251	59 562 $\pm 3. \text{E} + 24$
MK-20 (43.7)	476 ± 5	748 827 ± 16535	4 ± 0	64.5 ± 6.9	0.3887 ± 0.0051	49 295 ± 918	64 ± 10	-5216 ± 42999
MK-21 (39.7)	162 ± 0	2478 ± 50	1139 ± 23	279.9 ± 1.7	1.0582 ± 0.0017	170 599 ± 837	453 ± 3	170 226 ± 862
MK-22 (38.8)	139 ± 0	4702 ± 94	538 ± 11	331.9 ± 1.6	1.1079 ± 0.0014	170 570 ± 702	536 ± 3	169 860 ± 833
MK-23 (36.6)	205 ± 0	3215 ± 64	1061 ± 21	246.7 ± 1.5	1.0109 ± 0.0017	164 910 ± 775	393 ± 2	164 516 ± 807
MK-PL1: calcite flowstone (FS) covering trench 1								
MK-10	448 ± 3	474 086 ± 9821	4 ± 0	153.7 ± 5.4	0.2669 ± 0.0026	28 519 ± 352	153 ± 11	-1965 ± 22335
SV66 (upper)	51 ± 0	78 407 ± 1569	9 ± 0	298.5 ± 1.9	0.8775 ± 0.0036	115 536 ± 867	372 ± 30	77 619 ± 28773
SV153 (middle)	58 ± 0	54 850 ± 1103	14 ± 0	303.0 ± 2.8	0.8167 ± 0.0037	102 099 ± 832	380 ± 17	80 075 ± 15963
SV152 (base)	85 ± 0	227 686 ± 4574	7 ± 0	271.4 ± 2.3	1.1001 ± 0.0067	190 207 ± 3041	374 ± 78	113 329 ± 78127
SV154 (base)	105 ± 0	191 864 ± 3887	9 ± 0	247.6 ± 3.5	0.9853 ± 0.0058	155 890 ± 2187	335 ± 37	107 127 ± 38718
MK-PL-3: calcite crust in the sediments at - 33 cm in trench 1 at ~1 m distance of the skulls								
MK-9	210 ± 0	73 287 ± 1468	48 ± 1	336.1 ± 1.4	1.0193 ± 0.0018	142 753 ± 585	493 ± 7	135 678 ± 5014
SV147	141 ± 1	81 993 ± 1677	30 ± 1	285.8 ± 3.5	1.0701 ± 0.0062	172 840 ± 2562	450 ± 13	160 460 ± 9092
6MK/E36: calcite crust at the upper level of the skulls, at ~20 cm in T1								
SV65	236.6 ± 0.3	252 272 ± 5056	17.3 ± 0.3	198.1 ± 1.8	1.1197 ± 0.0029	244 744 ± 2611	368 ± 20	219 522 ± 18520
MK-PL-20: calcite crust underneath the skulls and bones, at ~30 cm in T1, top (SV79) and bottom (SV78)								
SV79	178.7 ± 0.2	52 255 ± 1046	63 ± 1	175.6 ± 1.6	1.1113 ± 0.0015	258 651 ± 2064	358 ± 6	252 147 ± 4966
SV78	296.4 ± 0.4	28 472 ± 571	186 ± 4	152.6 ± 1.7	1.0858 ± 0.0016	259 849 ± 2315	316 ± 4	257 639 ± 2728
MK-PL-7: calcite subsample from the gour-like structures under the skulls at - 60 cm in trench 1								
MK-11	645 ± 3	4 ± 1	34 678 ± 6506	94.9 ± 4.1	0.0117 ± 0.0002	1172 ± 19	95 ± 4	1107 ± 19
SV77	135.1 ± 0.1	12 779 ± 256	204 ± 4	152.0 ± 1.7	1.1682 ± 0.0013	377 452 ± 6195	439 ± 9	375 455 ± 6242
MK-PL-14: calcite flowstone covering trench 4, at ~2 cm in trench 4								
MK-S1-T4	119 ± 0	6451 ± 129	295 ± 6	338.8 ± 1.4	0.9703 ± 0.0013	129 722 ± 419	487 ± 2	128 588 ± 861
MK-PL-T2: flowstone covering T2 at-2 cm in trench 2								
MK-S2-T2	77 ± 0	18 159 ± 364	70 ± 1	372.4 ± 2.0	0.9934 ± 0.0018	128 779 ± 559	529 ± 6	124 143 ± 3285

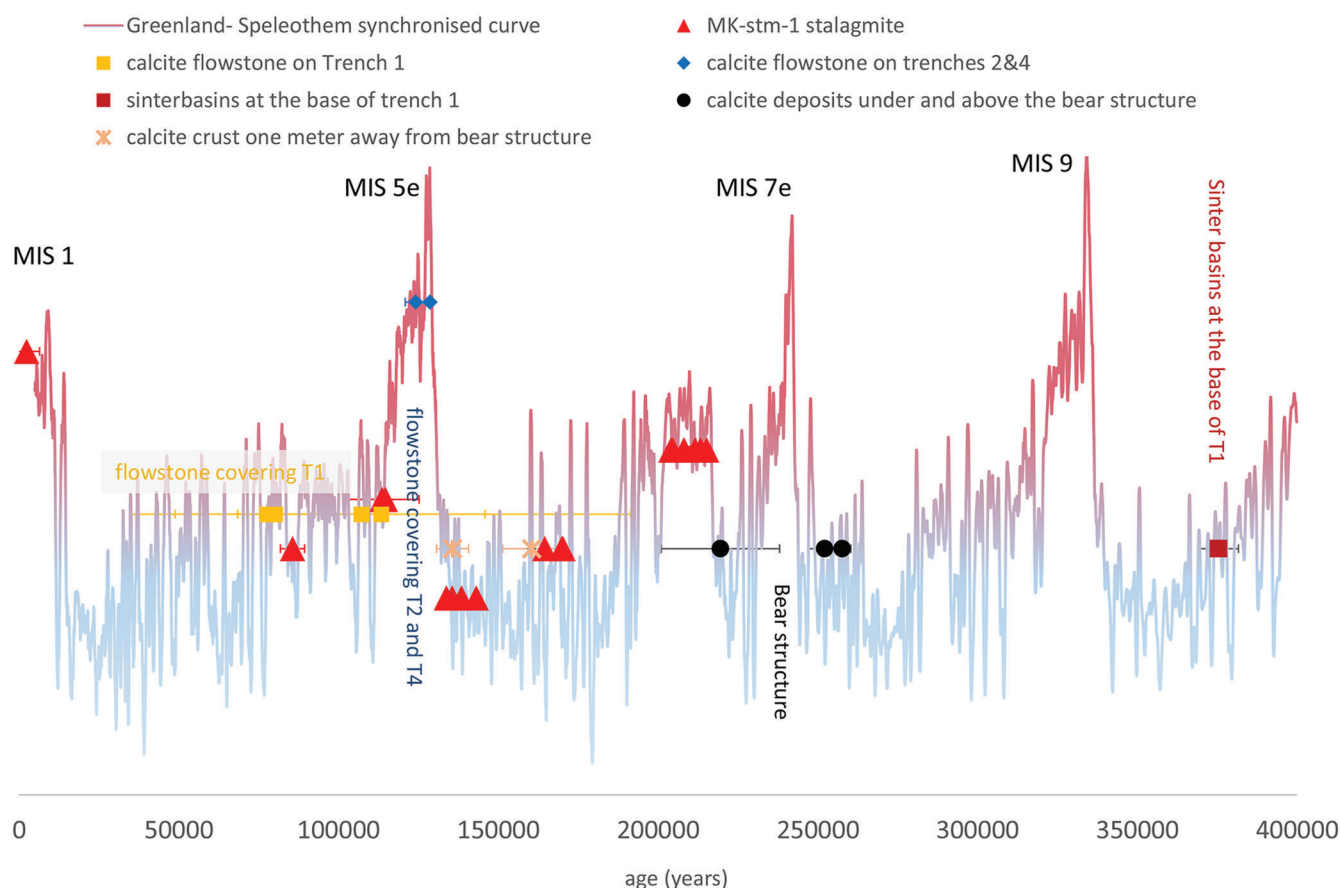


Figure 6. Palaeoclimatic context of Mishin Kamik cave, Bulgaria. Chronology of the cave deposits, based on U-series dating results and positioned against the Greenland speleothem synchronised palaeoclimatic curve by Barker *et al.* (2011) with a relative y-axis. Only the x-axis has sense for dating results. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/jqs.3364)]

coralloid calcite is associated with increased airflow, evaporation and condensation processes resulting in higher calcite saturations (Hill and Forti, 1997, pp. 59–60; Vanghi *et al.*, 2017), in agreement with a smaller stalagmite diameter, indicating lower water availability or decreased carbonate saturation (Dreybrodt, 1999). The succession of detrital layers and coralloid calcite therefore suggests a climatically unstable period with successive mudflows and floods, followed by drier conditions towards ~170 ka.

- From ~170 ka onward, a more regular larger stalagmite indicates more favourable conditions, although not reaching full interglacial conditions as indicated by the rather high detrital (clay) content. Contrasted layering may indicate periodic growth, suggesting that unstable conditions still prevailed. The important reduction in growth rate and diameter between 164.5 ± 0.8 and 143 ± 0.5 ka suggests drier conditions or decreasing carbonate saturation related to reduced soil activity and low CO_2 production. This deterioration is partly contemporaneous with the Drenthe maximum, the 5-kyr-long coldest phase of the Saalian glaciation occurring at 155 ka (Lambeck *et al.*, 2006) and coinciding with the largest extension of northern glaciers (Colleoni *et al.*, 2009). Our observations also agree with the appearance of permafrost features in central Germany at 144 ± 13 ka, while no permafrost features are observed at 173 ± 16 and 160 ± 13 ka (Lauer and Weiss, 2018). The Warthe ice sheet extension (between 143 and 140 ka), however, does not seem to have greatly impacted the cave site, and speleothem growth between 143 ± 0.5 and 138.5 ± 0.5 ka did not display any visible discontinuity that could indicate a growth hiatus. The calcite layers deposited between ~170 and ~138-ka can

be followed down the stalagmite and form a detrital calcitic lace around the underlying MIS 7 candle-shaped stalagmite, indicating that surrounding sediments were partially washed away and consolidated by calcite. In contrast, the layers deposited after 135.6 ± 0.5 ka completely cover detrital sediments up to the middle of the stalagmite, showing that the surroundings of the stalagmite were filled by detrital sediments at least up to this level between 138.5 ± 0.5 and 135.6 ± 0.5 ka. A rapid infilling of the cave, suggesting a particularly wet climate or massive ice melt, may have pushed the stalagmite, resulting in the observed shift in growth axis between 138.5 ± 0.5 and 135.6 ± 0.5 ka. This ultimate infilling of the cave can therefore be connected to the first global deglacial phases, characterized by greenhouse gas increases (Govin *et al.*, 2015). The successive detrital episodes roughly correspond to MIS 6. This indicates that this mountain region did not experience continuous permafrost conditions during the Penultimate Glacial Period but that conditions permitted the deposition of speleothems at least around ~170–160 and ~143–138 ka, both ages corresponding to higher global sea-level stands (Waelbroeck *et al.*, 2008) and general warming episodes during MIS 6 in Western Europe (Barker *et al.*, 2011; Wainer *et al.*, 2011; Lefort *et al.*, 2019) (Fig. 6).

- Speleothem deposition continued between 135.6 ± 0.5 and 133.8 ± 0.5 ka, suggesting increasing warming and soil activity above the cave. The onset of warming seems to occur some ~3–5 kyr earlier than in southwestern Europe and coincides with the second global deglacial episode related to massive iceberg discharges between 135 and 129 ka (Govin *et al.*, 2015). The Eemian Interglacial (roughly ~130–120 ka) was not favourable for speleothem growth,

suggesting either dryness or too acidic waters caused by increased soil activity, although no important dissolution features are observed in the speleothem. Instead, a white powdery calcite layer was deposited (followed by a detrital phase or event) between 133.8 ± 0.5 and 114.7 ± 0.5 ka in the stalagmite and spread further around the stalagmite. The powdery aspect may be due to a micritic texture related to moonmilk deposits (Frisia, 2015) or to an alteration of the columnar calcite. A similar ~10–30-cm-thick layer of powdery detrital calcite is found on the floor of the MK-stm-1 room as well as in the T1 room where it covers the sedimentary profile. The stalagmite indicates that the powdery calcite was deposited during the Last Interglacial (LIG), or during the first climate deteriorations of the LIG demise, starting at ~117 ka as indicated by West-European stalagmites (Meyer *et al.*, 2008; Moseley *et al.*, 2015; Vansteenberghe *et al.*, 2016) and lake sediments (Sirocko *et al.*, 2007).

5. From at least 114.7 ± 0.5 ka onward, and up to 113.6 ± 11.6 ka, calcite deposition seems relatively regular. However, the important uncertainty of the upper date of 113.6 ka hampers estimation of the growth period. The larger stalagmite diameter, the relatively thick calcite layers and the thickness of the regular deposition of calcite suggest relatively favourable conditions for speleothem deposition after 114.7 ± 0.5 ka, in agreement with observations in western Europe, indicating important speleothem deposition after MIS 5e (Quinif, 1990; Vansteenberghe *et al.*, 2016).
6. At ~100 ka, conditions favourable for stalagmite deposition came to an end with deposition of only ~1 cm of additional calcite deposited to the present. The occurrence of popcorn structures and a second powdery calcite layer after 85.6 ± 3.8 ka suggests a drying of the cave. This second powdery carbonate layer covers the surroundings of the speleothem on top of the previous similar layer deposited between 133.8 ± 0.5 and 114.7 ± 0.5 ka. The similarity of the layers suggests deposition of both layers under similar conditions.

A comparison of the speleothem-based evolution of MIS 7 to MIS 5 with what is known from the surrounding loess sequences (Danube Valley, Antoine *et al.*, 2019; Balescu *et al.*, 2020) and Lake Ohrid deposits (between Greece and Albania, Francke *et al.*, 2016; Sadori *et al.*, 2016) reveals striking similarities. For example, the deposition of a regular candle-shaped stalagmite during MIS 7, but an absence of deposition during MIS 5, interpreted as probably drier conditions, agrees with generally drier interglacial periods after MIS 7 (Sadori *et al.*, 2016), aridification during interglacial periods (Balescu *et al.*, 2020) and more evaporites in Lake Ohrid during MIS 5 than during MIS 7 (Francke *et al.*, 2016). A dry MIS 5e, as suggested by the MK stalagmite, adds to the hypothesis of Antoine *et al.* (2019) that the Ogosta River, of which Mishin Kamik Valley is a tributary, had a steppe vegetation during MIS 6 and had no vegetation during MIS 5, explaining the changes in grain size of the Harletz loess deposits (Antoine *et al.*, 2019). Sinopoli *et al.* (2019) suggested more changing conditions between 129 and 112 ka which are not expressed by the MK-stm1 speleothem. The stepwise change from MIS 7 to MIS 6 shown by the stalagmite is supported by the cyclical evolution with short climatic oscillations in the loess deposits and significant lake level fluctuations (Francke *et al.*, 2016). The evolution to drier conditions with the observed increase in aeolian dynamics roughly dated to 170–160 ka in the Harletz loess and interpreted as enhanced cold and dryness (Sadori *et al.*, 2016) is registered in the speleothem, which dates the change more precisely to between 164 and 143 ka.

The speleothem also suggests slightly better conditions after 143 ka, enabling more rapid speleothem growth until 134 ka. The important difference between MIS 6, which is still well represented, and MIS 4–3, mostly absent in the MK stalagmite, does not correspond to any observed difference in other regional deposits and should therefore be confirmed by surrounding speleothem deposits.

Speleothem-based chronological attribution of the other deposits in Mishin Kamik cave

Several sedimentary structures in the stalagmite can be associated with other deposits of the surrounding cave environment. The two powdery micritic calcite layers in the stalagmite continue laterally as a flowstone covering the second room. The large flowstone also extends to and covers the first room and T1 (Fig. 5). We hypothesize that the two powdery layers and the large flowstone were deposited simultaneously during two phases. The MK-PL-1 flowstone, covering T1, displays the same powdery micritic aspect and has a high detrital content. The ages should be taken with great caution. However, with the exception of one unrealistic age possibly due to opening of the system as indicated by the inconsistent uranium content, the ages of 107 ± 39 and 113 ± 78 ka for the lower part of the flowstone, and the ages of 78 ± 29 and 81 ± 16 ka for the middle/upper part of the flowstone, although with high uncertainties, are convergent and in stratigraphic order between the lower and upper parts of the flowstone. We can reasonably hypothesize that the MK-PL-1 flowstone is younger than ~130 ka, and the ages of the flowstone itself and those of underlying flowstones and probably older than 50–70 ka. These ages are in agreement (within uncertainties) with the ages of between 133.8 ± 0.5 and 114.7 ± 0.5 ka and after (younger than) 85.6 ± 3.8 ka for both similar powdery micritic calcite layers in the stalagmite, which are laterally connected to the large flowstone covering the floor in the second and first room with T1. The combined ages of the flowstone and the stalagmite therefore suggest that they could have been deposited simultaneously. Moreover, the ages suggest that the sedimentary infilling under the flowstone occurred at least before 50–70 ka (minimum age of the flowstone) and probably before 114.7 ± 0.5 ka (minimum age of the first powdery layer in the stalagmite). The flowstones covering T2 and T4 are dated to 124.1 ± 3.3 and 128.6 ± 0.9 ka, respectively, indicating that the sedimentary infilling here occurred before 128.6 ± 0.9 ka. Since both places are only ~15 m away from T1, in a unique gallery, we can reasonably hypothesize that the cave infilling in the gallery took place at least before 128.6 ± 0.9 ka.

The age of detrital infilling of the cave agrees with the successive detrital infillings retrieved from the stalagmite that registered at least two important phases between 208.1 ± 2.1 and 170.2 ± 0.9 ka, an important final infilling between 138.5 ± 0.5 and 135.6 ± 0.5 ka, and smaller detrital phases in the upper part of the stalagmite.

These results mean that today's floor topography in the cave was set at the latest most probably before 128.6 ± 0.9 ka (T2), and even probably between 138.5 ± 0.5 and 135.6 ± 0.5 ka (MK-stm-1), i.e. during the MIS 6–5 Glacial–Interglacial transition (TII). We can conclude that the cave gallery, overall, was roughly similar during and after MIS 5e to what it is today. However, we argue that the flowstones covering T2 and T4 and the one covering T1 were not deposited simultaneously. The flowstones covering T2 and T4, both extensions of the same stalagmite, differ by <3 kyr in age. The limited calcite deposition of the ~2-cm-thick flowstone is best explained by relatively slow dripping and agrees with a reduced growth or

hiatus in calcite deposition observed in the MK-stm-1 stalagmite and in agreement with a dry MIS 5e as discussed above. Although the age of T2 and T4 flowstones ($\sim 125.1 \pm 2.1$ ka) is consistent (within age uncertainties) with the age of the basal part of T1 flowstone (113 ± 78 ka), the question arises as to whether these flowstones are contemporaneous since the T1 flowstone has a completely different texture from the flowstone covering T2 and T4. The T1 texture more closely resembles the powdery calcite layers of the stalagmite MK-stm-1. The age of the oldest one, between ~ 134 and ~ 115 ka, suggests its deposition either just before, during or after the LIG, which saw the deposition of crystalline calcite on T2 and T4.

A lower limit of 375.5 ± 6.2 ka (MIS 11; Lauer and Weiss, 2018; International Commission of Stratigraphy, 2016) for the sedimentary infillings is given by the basal calcite sinter basins in T1 (Fig. 5, S1 File). As only one age is available, although with low uncertainty, confirmation by additional dating is preferable.

The position of the bear skulls inside T1 and the successive levels and ages of the calcite layers indicate detrital sedimentation before and after the deposition of the skulls, which are dated to between ~ 258 – 252 ka ± 5 ka (age of the underlying calcite pieces) and $\sim 220 \pm 20$ ka (age of the calcite covering the skulls). The ages are in stratigraphic order, although with high uncertainties and give confidence to the dating results of these samples. By contrast, the ages of ~ 135 and ~ 160 ka of the calcite deposit MK-PL-3 (subsamples MK9 and SV147) located ~ 1 m away are not in agreement with the flowstones framing the skulls and appear to be younger. Since the MK-PL-3 calcite layer is difficult to position relative to the skulls, it is difficult to conclude on their mutual stratigraphic position, but it gives an additional rough indication of a MIS 6–5 age of the surrounding sediments. The calcite under and above the skulls consists of flowstone pieces under the skulls that may be not in place, while the upper calcite flowstone embeds the upper part of the skulls and was therefore clearly deposited in place. The ages of the upper flowstone (between 240 and 200 ka) suggest the existence of a more stable period, i.e. without detrital infilling, at the time or after deposition of the skulls, in agreement with interglacial conditions of the Penultimate Interglacial Period ($\sim$ MIS 7e) and in agreement with the deposition of the candle-shaped stalagmite in MK-stm-1, dated to around 210 ka, although with uncertainties of the order of several thousand years. The calcite deposits give chronological constraints for the skulls but also for the sediments deposited above and below the skulls. Overall, we can conclude that sediment infillings occurred at least in two or three steps. The first infilling occurred between ~ 375 ka (basal sinter basins) and ~ 258 ka (flowstone under the skulls; MIS 11–9) or ~ 220 ka (MIS 11–7) if the underlying flowstone pieces are not in place. A second infilling occurred between ~ 220 ka (flowstone above the skulls, in place) and ~ 110 ka (flowstone covering T1), probably before ~ 128 ka (T4) and maybe even, as suggested by the stalagmite, in at least two steps, between ~ 208 and ~ 170 ka (MIS 6) and between 138.5 ± 0.5 and 135.6 ± 0.5 ka (end of MIS6 to start of TII).

Consequences for the age of the archaeological findings and further perspectives

Study of the Mishin Kamik stalagmite and dating of the stalagmite and several calcite crusts in the archaeological trenches suggest that all archaeological findings are older than ~ 110 ka (upper crust in T1), probably older than ~ 124 ka (upper crust in T2 and T4) and even older than ~ 135 ka (last

infilling dated in the stalagmite). For the findings in T2 and T4 (potential bone tools, potential pavement, upside-down stalagmite) no other chronological constraint could be made, which excludes a clear statement on a contemporaneous deposition or not with the accumulation of bear skulls and the other archaeological finds (bones, limestones pavement and upside-down stalagmite). For the accumulation of bear skulls in T1, the underlying calcite flowstone pieces indicate an age of ~ 255 ka. Since these pieces may be not 'in place', they could have been deposited together with the bear skulls at a later stage. However, the upper calcite flowstone embedded the upper part of the skulls and indicates an age of at least 219.5 ± 18.5 ka, suggesting a period during which the skulls were free of detrital material at least on their upper half. It also indicates that cave bears were present inside the cave already during MIS 7, an age slightly older than the Late Middle Pleistocene age (MIS 6–5) attributed to the bears, based on the study of the bulk faunal remnants (Spasov *et al.*, 2017). The authors attributed the bears to the same age as the covering sediments. Our study indicates that sediment infilling occurred in different steps. The fauna may therefore represent a relative long period of deposition of successive, partially reworked sediments and characterizing different climates and environments, suggesting a mosaic landscape of forests and open areas as stated by the authors.

The intriguing accumulation of bear skulls found during the archaeological excavations opened a debate on its natural or anthropogenic origin given their relatively 'structured' position together with long bones and yellow clay (SI 1; Gurova and Ivanova, in press). During the period of interest (MIS 7–5), Early Neanderthals were the only known human species living in Europe (Hublin, 2009). An anthropogenic origin for the accumulation of bear skulls dated to before ~ 220 ka would challenge the chronology of first symbolic behaviour and relaunch the so-called 'bear cult' debate formulated in the early 20th century by Bächler (Bächler, 1940; Maringer, 1960) and heavily refuted in the 1950s and 1960s (Koby, 1953; Leroi-Gourhan, 1965). Today, symbolism related to bears is easily accepted for the Upper Palaeolithic (Philippe *et al.*, 2001; Germonpré and Hamalainen, 2007; Dutkiewicz *et al.*, 2018), when anatomically modern humans were present in Europe, but is strongly debated for the Middle Palaeolithic (cf. Lascu *et al.*, 1994; Wunn, 2001; Otte, 2006–2007, 2019; Cavanhié, 2009; Cârciumaru *et al.*, 2015), although regular new evidence for symbolic behaviour among Middle Palaeolithic humans (Burdikiewicz, 2014) has been published (d'Errico *et al.*, 2009; Finlayson *et al.*, 2019).

However, our study revealed no indication for any anthropogenic intervention, but neither is there a straightforward explanation for a natural deposition of the bear skull accumulation. Detailed and direct reconstruction of the depositional history of the bear skull accumulation (S1 File) is difficult since the skulls, bones and surrounding sediments were taken out of the cave directly after their discovery for preservation and further study. We can therefore only reasonably present the following points.

- The bones and skulls of the bears were found disarticulated, excluding an *in situ* death, without post-mortem transportation.
- There is no nearby pit that can explain a bone accumulation by gravity fall-down from an opening in the ceiling of the cave, i.e. sinkhole or 'aven' type (Arsuaga *et al.*, 1991; Auler *et al.*, 2006).
- The general position of the skulls in the middle of the gallery and the absence of any gully structure beneath the skulls give no indication for deposition by water flow.

- The accumulation of bear skulls occurs separate from other bone-rich sediments uncovered in excavation squares E-G 37–38 (Fig. 2) and, according to Spassov *et al.* (2017), both the bear skull accumulation and other bones suggest a different conservation state, implying a different depositional history.
- Debris flow or mud flows often fill caves with poorly sorted material (Bertran and Texier, 1999; Mazza and Ventra, 2011) and may be responsible for the accumulation of the bear bones and skulls in a thick layer of mixed, partly reworked, material (clay, calcite flowstone pieces), which may include remobilized bones and skulls.
- Accumulation of bones by bears or other carnivores is regularly invoked to explain remarkable bone structures.

The contextual information available today is insufficient to conclude on the depositional process for the bear skull accumulation and more detailed study is needed on the bone and skull taphonomy, surrounding sedimentary structures, grain size, microstratigraphy, etc., to better define the depositional environment and processes of the cave sediments, including the bear skull accumulation and other palaeontological material.

Conclusions

Speleothems from Mishin Kamik cave (Bulgaria) provide information on the climatic and environmental evolution of the cave, which can be linked to a broader regional framework. It enables us to place the retrieved information, cave sedimentary units and archaeological findings, e.g. several bone fragments with cutmarks or polished ends and a surprising accumulation of bear skulls, in a well-constrained chronological context. The speleothems demonstrate that overall stable temperate conditions prevailed during the end of MIS 7 up to 208.1 ± 2.1 ka. Successive floods in the cave indicate characteristic unstable conditions for MIS 6 between ~208 and ~136 ka. Episodes with improved climate conditions occurred between ~170 and ~164 ka and between ~143 and ~138 ka. Cold and dry conditions are inferred from the stalagmite during the penultimate glacial maximum (~155–150 ka) with a decreased and/or hiatus in speleothem growth until ~143 ka. After a slow retrun of better (mild and humid) conditions up to ~138 ka, a final detrital infilling of the cave between 138 ± 0.5 and 135.5 ± 0.5 ka resulted in the cave configuration much like today. Relatively dry conditions are suggested during the LIG (roughly MIS 5e) optimum, in agreement with information from regional studies on loess sequences and the Ohrid Lake sediments, although the MK-stm1 stalagmite seems to more closely follow the more arid loess areas during MIS 5e. By contrast, enhanced stalagmite deposition suggests more humid conditions during the demise of the LIG, indicating relatively mild conditions after ~115 ka. Deposition of a powdery, probably moonmilk-type flowstone around ~110 and ~75 ka seals the sedimentary record in the cave. The chronological context retrieved from the speleothems revealed an age of between ~250 and ~220 ka (MIS 7) for the bear skull accumulation. The current contextual information does not allow us to conclude on the depositional process responsible for the accumulation of bear skulls and bones, an important issue in the controversial Neanderthal bear-symbolism debate. However, the study provides a clarified chronological framework for the cave infillings and better constrains the palaeontological and archaeological finds. The important scientific potential of the cave and the chronological context indicate the added value of further multidisciplinary investigation of the cave site. The study

demonstrates the important contribution of a detailed speleothem study for archaeological, environmental and sedimentary investigations in cave sites.

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Supporting information

Additional supporting information can be found in the online version of this article. This article includes online-only Supplemental Data.

S1 File. Detailed description of the bear skull accumulation and adjacent calcified bones, schematic sedimentary profile and description of trench 1, Mishin Kamik cave, Bulgaria.

S2 File. Raman analyses of Mishin Kamik samples.

Abbreviations. LIG, Last Interglacial; MIS, marine isotope stage.

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