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Palynology and sediment data from the high alpine karst cave on Jungfraujoch, Switzerland

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Key words: High alpine karst, cave sediments, palynology, relative dating

ABSTRACT

Sedimentological and palynological data from a high alpine karst cave in Switzerland are presented. The non-layered, unsorted sediments seem to be mainly morainic, brought into the cave on Jungfraujoch by ice or short-distance water transport. The observed pollen assemblages comprise high numbers of deteriorated and indeterminable grains, in parts probably due to repeated wet-dry cycles occurring with the freezing and thawing of the sediments. These obviously distorted spectra are, in many respects, comparable with records from other karst caves; however, results from similar high alpine situations are not available. Palynostratigraphic correlations and dating of the sediments are problematic, but there are indications of a pre-late Pleistocene age for the accumulation. The cave on Jungfraujoch is inactive today; current conditions (permafrost) restrict cave-forming processes to occasional breakdown.

ZUSAMMENFASSUNG

Sedimentologische und palynologische Resultate aus der hochalpinen Karsthöhle auf dem Jungfraujoch werden vorgestellt. Die ungeschichteten, nicht sortierten Sedimente scheinen überwiegend von Moränen zu stammen; sie wurden von Eis oder – über kurze Distanz – Wasser in die Höhle transportiert. Die untersuchten Pollenspektren enthalten grosse Anteile von beschädigten oder verwitterten Palynomorphen. Dafür verantwortlich sind wahrscheinlich Nass-Trocken-Zyklen im Zusammenhang mit wiederholtem Auftauen und Gefrieren der Sedimente. Die offensichtlich veränderten, gestörten Spektren sind in mehreren Aspekten den Resultaten aus anderen Karsthöhlen ähnlich, jedoch fehlen Vergleichsmöglichkeiten aus hochalpinen Lagen. Palynostratigraphische Korrelationen oder Sedimentdatierungen sind kaum möglich; trotzdem konnten Hinweise für ein alt- bis mittelpleistozänes Alter der Akkumulation gefunden werden. Die Höhle auf dem Jungfraujoch ist heute inaktiv; aufgrund der herrschenden Verhältnisse (Permafrost) beschränkt sich die Höhlenbildung auf gelegentlichen Frostbruch.

Introduction

A karst cave was discovered in the high alpine permafrost zone of the central Alps on Jungfraujoch, during construction work above the railway station in 1983 (Keusen & Amiguet 1987). So far, sedimentological and palynological investigations of karst cave deposits have worldwide never been carried out in similar high alpine situations. The unique opportunity to study the cave sediments on Jungfraujoch has been taken to explore the potential and the limitations of the palynostratigraphic method in a rather extreme situation, and to obtain information about the age and history of the accumulation and of the cave. However, it is well known that palynological studies of cave sediments present more – and different – problems than the analyses of peat bogs and lake sediments; particularly concerning the mode of transport and the preservation conditions. Most scientists in the field of archaeological and karst palynology now seem to be aware of the mentioned problems, such as low pollen concentrations, differential destruction or selective preservation of palynomorphs (overrepresentation), and reworking of sediments (summarized e.g. in Turner 1985; Groner 1985). The careful application of the method in karst and cave studies has developed into a useful tool of palaeoecological research, as demonstrated e.g. in Spain by Carrión et al. (1999) and Navarro Camacho et al. (2000).

Situation, climate and geology

Jungfraujoch (3475 m a.s.l.), situated about 60 km south-east of Berne in the central Swiss Alps, and the Sphinx (3569 m) next to it form the connecting ridge between the peaks of Jungfrau (4158 m) and Mönch (4099 m). Jungfraujoch is within the permafrost zone, with monthly mean temperatures between -14.6°C (February) and -1°C (July), and an annual mean

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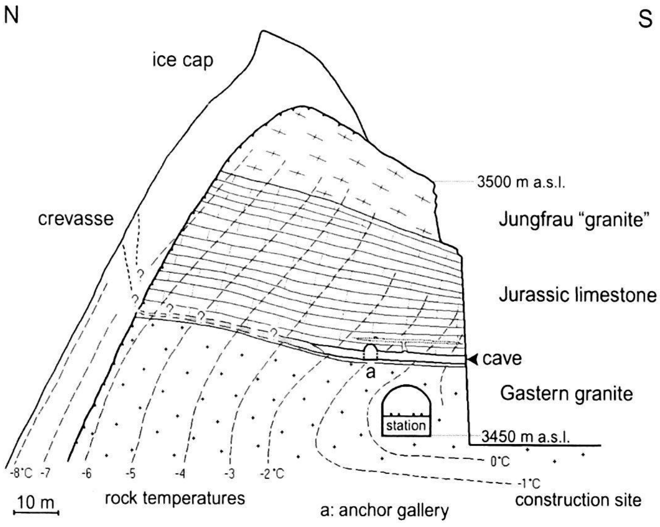

Fig. 1. Geological cross section of Jungfraujoch-Sphinx (after Keusen & Amiguet 1987). Karst cave with unknown extension to the north.

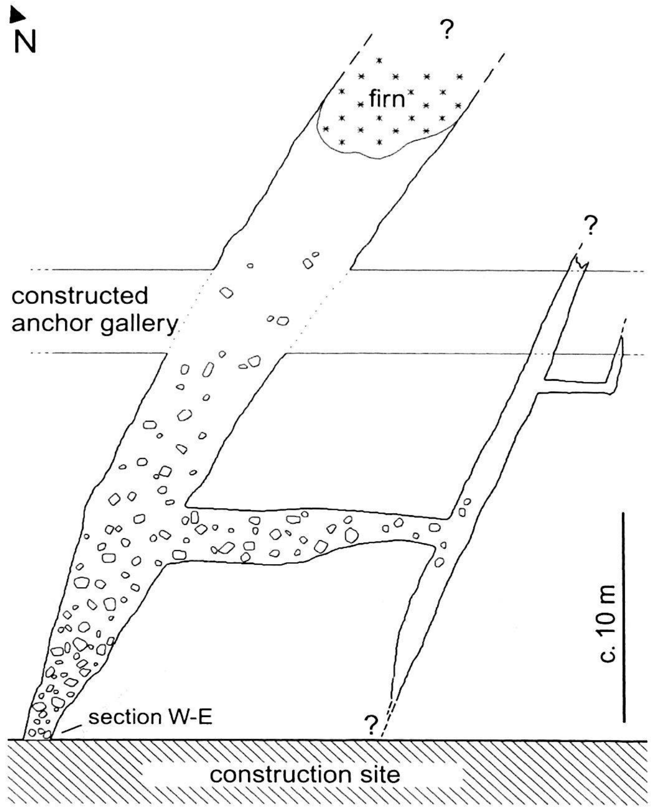

Fig. 2. Horizontal sketch-map of the cave passages (not to scale).

temperature of -8°C (Kirchhofer 1982). Precipitation averages over 3600 mm per year (Kirchhofer & Sevruk 1992). The cave on Jungfraujoch-Sphinx is the highest known in Switzerland (Wildberger & Preiswerk 1997), but several caves at altitudes above 3000 m a.s.l. were recently discovered in the Balmhorn region, about 25 km south-west of Jungfraujoch (Ducluzaux 1992). The karst system described here developed in metamorphic limestone of upper Jurassic age between Gastern granite of the Aar massif below and Jungfrau "granite" – mainly mica-rich gneiss and schist – of the Mesozoic Morcles-Doldenhorn nappe (Fig. 1; Keusen & Amiguet 1987). The limestone section is about 25 m thick; the grey rock is fine-grained and fractured and contains no organic-walled microfossils.

The cave and the cave sediments

The main passage of the cave follows the dip of the rock approximately from north to south in the basal part of the limestone (Fig. 1). The total length of the passages is estimated to be over 100 m with a volume of more than 400 m^3 (Keusen & Amiguet 1987); only recently, a part of the cave has been surveyed. An anchor gallery (to hold the anchors of the new building) has been constructed across the main passage (Fig. 2); north of this crossing the passage is blocked by ice and firn, the latter possibly entering from outside. A distinct draught has been noticed, but this may be due to the recently constructed openings. The almost rhomboidal pattern of the cave passages suggests that their formation began on joints and fractures within the limestone (Fig. 2). The main passage shows no traces of limestone solution, its cross section seems to be a result of breakdown. In contrast, the cross sections of the smaller passages in the east are more rounded and the walls' surfaces are almost smooth. The cave floor – especially in the southern part – is almost completely covered with angular limestone debris. Below, more finely grained, non-layered sediments with scattered blocks are found, with a total thickness exceeding 2.5 m (cross section, Fig. 3).

Methods

The freshly cut, non-layered, partly fine-grained deposits at the southern end of the cave were sampled at intervals of 0.2 to 0.6 m (Figs. 2, 3); 6 of the 7 samples weighing between 0.5 and 1.1 kg each. The block layer about 0.8 m above the bottom and the top block layer containing rocks up to 200 mm in length were not sampled. No. 7 represents the most recent layer, it was collected between the mentioned rocks of the cave floor and was much smaller (about 100 g). In the laboratory the samples were dried; the larger particles (>10 mm) were sorted out and used to describe the petrologic character. A part of each sediment sample was taken for pollen analysis, the main part was sieved to detect possible sorting.

Grain size analysis

Sediment samples between 200 and 400 g (no. 7 about 50 g) were wet-sieved, with mesh sizes of 10/2/1/0.5/0.25/0.125/0.063

mm. After drying and weighing, the sieved fractions were examined under the microscope (petrology; rounding of grains). Clay and silt (fraction <0.063 mm) were not investigated.

Pollen analysis

35 to 45 g of dry, mostly medium- to fine-grained sediment were used for pollen analysis. *Lycopodium* tablets were added for estimation of the pollen concentration. Sample processing included HCl-, KOH-, HF-treatment, gravity separation ($ZnBr_2$), sieving by hand (10 µm screen; squirt bottle) and acetolysis. The residues were mounted in glycerol-jelly.

Results

Sediment characteristics

The investigated samples are rather homogeneous mixtures of different grain sizes and of about the same grey-brown colour. This was observed at the exposed deposit as well as in the petrologic and granulometric analyses (Tab. 1). Gravel or other rounded particles were not found in the sediments. However, the edges of some of the coarser limestone and gneiss fragments were rounded (samples nos. 1–5). The coarse fraction (10-2 mm) comprises up to 50% of the dry weight of the samples; between 40 and 65% of the fraction <2 mm is sand. The grain size distributions are rather regular; there is no evidence of sorting or layering of the sediments. The percentages of the fine-grained fractions increase from bottom to top of the profile, the uppermost sample (no. 7) having the largest clay-silt fraction (<0.063 mm). The sandy fractions contain quartz, feldspar and large portions of mica, mainly weathered, rusty biotite. The non-calcareous rocks and fragments in the samples correspond with Jungfrau granite, the cap-rock (Fig. 1). Determinable plant or animal remains were not found.

Palynologic investigation

Pollen and spore grains in the samples are poorly preserved and non-deteriorated grains are rare (Fig. 4); moreover, morphological characters of the grains may be obscured by insoluble particles (Fig. 4 F). Many grains are crumpled or broken, but most conspicuous is the thinning of the pollen and spore walls (degradation; Fig. 4 E, I). The number of indeterminable palynomorphs is equal to or exceeds the number of identified grains (Tab. 2). The debris found in the samples consists of fine-grained, black, mostly angular particles of uncertain (organic?) origin. Absolute pollen frequencies are extremely low; they are highest in sample no. 7, which is more finely grained than the other samples. The concentrations are similar to those of other karst cave sediments, e.g. older Hölloch sediments (Groner 1985). In two samples no determinable pollen at all were found (nos. 5, 6). *Pinus* is the most frequent pollen type; *Alnus*, Poaceae, *Betula* and Pteridophyta (monolete and trilete spores) occur in 5 of the 7 samples (Tab. 2). Many taxa are

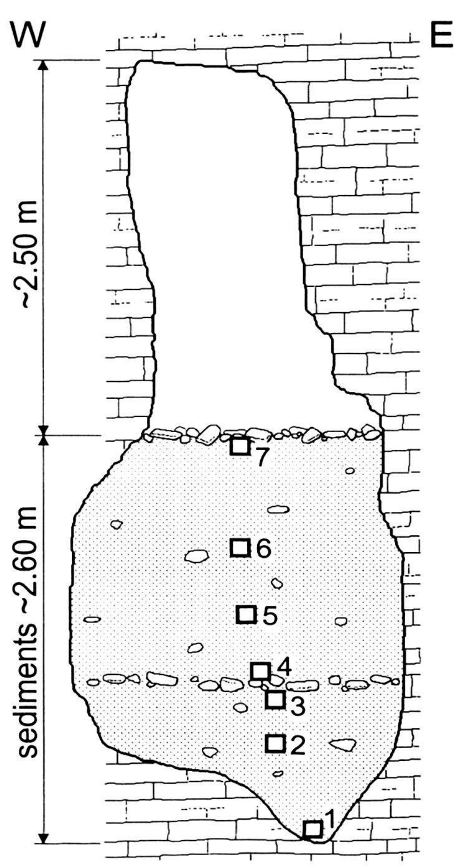

Fig. 3. Approximate vertical cross section W-E of cave main passage, southern end. Position of samples 1–7 (figure not to scale).

present as a single grain, like *Carya* (Fig. 4 G) found in sample no. 2. Several of the differently deteriorated triporate pollen forms probably also belong to the Juglandaceae (Fig. 4 D, H); their size and morphology do not correspond with the characteristics of similar triporate pollen (e.g. *Corylus*). The total numbers of identified pollen and spore types per sample are equal to or less than 14, and thus extremely low compared to the several dozens of taxa within Holocene peat spectra.

Discussion

Cave and sediments

The karst cave on Jungfraujoch may be called an ice-cave in the sense of Bögli (1980), although a substantial amount of the ice and firn possibly enters the cave from outside (Figs. 1, 2). A permanent crevasse in the ice cap must be due to the form of the rock surface below. It seems to be connected with the cave by rock fractures (Keusen, H.-R., Röthlisberger, H., pers. comm. 1988). The presently known cave passages are obviously only part of a larger, mostly inactive karst system; other un-

Tab. 1. Sediment characteristics of the Jungfraujoch cave deposit.

Sample No. Depth (m)	Clay + silt in % of total sample	Clay + silt in % of fraction <2 mm	Petrologic character	Remarks
Block layer			Limestone dominates	Blocks not sampled;
7 (0.02)	79.3	94.1		limestone: solution traces
6 (0.70)	61.3	61.3	Biotite gneiss and schists	–
5 (1.15)	55.9	56.0	Limestone dominates	Limestone: solution traces
4 (1.65)	53.8	59.4	Gneiss/schists equal to limestone	Limestone: solution traces
Block layer (1.75)	–	–	Biotite gneiss and schists dominate	– not sampled –
3 (1.85)	28.5	35.2	Biotite gneiss and schists dominate	–
2 (2.05)	39.8	47.6	Biotite gneiss and schists dominate	–
1 (2.55)	27.7	54.0	Biotite gneiss and schists	–

expected cavities posed serious problems when anchor holes were drilled (Keusen, H.-R., in litt. 1989). Comparing the dimensions of the cave with those of the limestone section on Jungfraujoch (Fig. 1), one can conclude that the drainage area must have been much larger when the cave was formed. The observed passage network as well as some roughly ellipsoid cross sections of the smaller passages indicate that this part of the cave mainly developed under phreatic (water-saturated) conditions (e.g. Bögli 1980). However, vadose or even phreatic cave formation is not possible under present conditions (altitude, climate, lack of drainage area) because flowing water – necessary for the solution of cave passages – does not occur (inactive cave). Today, daily and seasonal thawing and elevated pressure in the basal parts of the ice cap may produce some running water, which has been observed in the mentioned crevasse on the northern slope (Haeberli, W., pers. comm. 1988), but not in the cave. Evolution of the cave under current conditions is restricted to breakdown, obviously triggered by freeze-thaw cycles (frost breaking). Cave formation and evolution consequently occurred in warmer periods than today (see below).

A stratigraphic subdivision of the cave sediments is – apart from the two block layers – not possible (Tab. 1; Fig. 3). It may be argued that the lower block layer separates two accumulation periods, but no other indication supporting this hypothesis has been found. The limestone dominated top layer is the result of breakdown and presumably corresponds to the current conditions. The observed increasing percentages of the fine-grained fractions evidently reflect decreasing water flow velocities during the accumulation of the sediments. The gneissic components originate from the cap-rock, though a few particles possibly came from other, now eroded rocks of the cave's original drainage area. The absence of other sediment layers, the mixtures of different grain sizes and the lack of rounded components in the sediments suggest either short water transport distances or ice transport. Therefore, a large part of the cave deposit is most probably morainic or reworked morainic material.

Palynology

Important questions are how pollen and spores were deposited in the cave and whether they are contemporaneous with the accumulation. Today, there are only a few ways for such grains to enter the cave and the sediments: the only reasonable way is on or within ice, which brings wind-transported grains deposited on the ice cap into the cave. This process with relatively small amounts of pollen and spores in the ice (pollen counts e.g. in Bortenschlager 1967; Haeberli et al. 1983) could – together with the destruction of grains – be responsible for the extremely low pollen concentrations in the sediments. The pollen assemblage of the uppermost sediment layer might be influenced by such ice-transported grains. However, this explanation is not very probable for the entire deposit with irregularly scattered grains. The absence of seepage water under current and glacial conditions excludes any infiltration of ice- or wind-transported pollen grains into the lower parts of the sediments. Consequently, palynomorphs and inorganic sediment components accumulated together; the observed assemblages do not reflect the current environment.

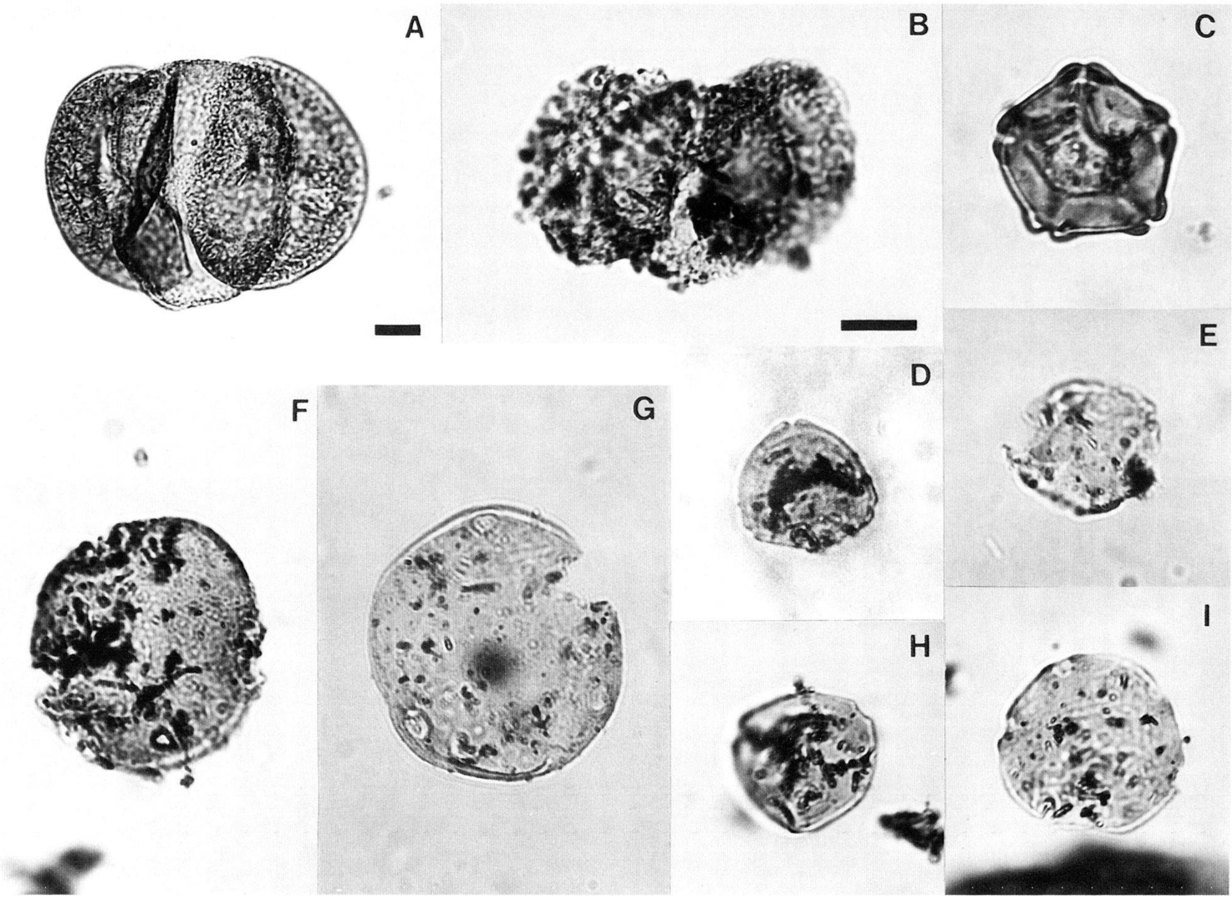

Fig. 4. Examples of pollen from Jungfraujoch cave sediments. (A–B) *Pinus*, sample no. 1; (C, E) *Alnus*, no. 7; (D) Triporate indet., no. 1; (F) *Tilia*, no. 7; (G) *Carya*, no. 2; (H) Triporate indet., no. 7; (I) *Ulmus*, no. 7. Scale = 10 µm; note different scale for A.

Well preserved pollen next to almost completely deteriorated grains (Fig. 4 A, B) and large numbers of indeterminable palynomorphs are the striking features of the investigated samples. Most of the identifiable pollen and spore types have a distinctive morphology, visible even in a poor state of preservation (Tab. 2; e.g. *Pinus, Alnus, Ulmus*, Fig. 4 A/B, C/E, I). Among the recorded types several forms are well known for their resistance to degradation. Pteridophyta spores, saccate grains of conifers (like *Pinus*), *Tilia* (Fig. 4 F) and Asteraceae pollen rank first in the resistance sequences presented by Morzadec-Kerfourn (1977), Vuorela (1977) and Havinga (1984). The preservation state of palynomorphs in sediments may be affected by several, usually combined factors, such as mechanical destruction, chemical and microbiological degradation. These factors cannot be estimated for the cave sediments on Jungfraujoch, but it may be assumed that under present conditions aeration of the sediments (oxidation) and wet-dry cycles connected to freezing and thawing are more important for the degradation of palynomorphs than microorganisms (mites, fungi, bacteria). Increasing numbers of pollen damaged by repeated wet-dry cycles have been demonstrated e.g. by Campbell & Campbell (1994). The composition of the assemblages with many degraded grains resulting in large proportions of indeterminable forms and the low diversity and consistently low pollen concentrations indicate strongly altered (distorted) pollen spectra (e.g. Hall 1981). This kind of assemblage with overrepresentation of resistant grains is characteristic for many cave sediment analyses (Groner 1985, 1990). The recorded pollen spectra cannot be used for the reconstruction of past environments, and palynostratigraphic correlations should be applied only with great caution.

Cave and sediment history

Karst development and forming of a cave on Jungfraujoch are not possible under current conditions. The same is true for last glacial conditions: the karst was probably completely blocked and cave-forming processes must have been minimal. Therefore, it can be inferred that cave formation occurred before the last glaciation, at a lower altitude with corresponding higher

Tab. 2. Pollen counts: percentages and absolute number of grains (in brackets) in the sediment samples.

Sample No.	**1** % (absol.)	**2** (absol.)	**3** % (absol.)	**4** (absol.)	**5** –	**6** –	**7** % (absol.)
Pollen types							
Pinus	57.6 (80)	(10)	57.1 (52)	(3)			30.2 (55)
Picea	1.4 (2)		2.2 (2)	(2)			–
Abies	–		–				0.5 (1)
Indet. bisaccat.	6.5 (9)	(3)	8.8 (8)	(1)	(1) ?		4.4 (8)
Betula	5.0 (7)	(1)	5.5 (5)	(1)		(1) ?	5.5 (10)
Ulmus	1.4 (2)	(1)	1.1 (1)				11.5 (21)
Tilia	–		–				2.2 (4)
Other AP	0.7 (1) [Carpinus]	(1) [Carya]	1.1 (1) [Carpinus]	(1) [Fagus?]			–
Triporate indet.	1.4 (2)		–	(1)			15.4 (28)
Alnus	1.4 (2)	(1)	9.9 (9)	(4)			19.8 (36)
Ephedra	0.7 (1)		–				–
Poaceae	9.4 (13)	(3)	7.7 (7)	(2)			3.3 (6)
Chenopodiaceae	2.2 (3)		–				–
Asteraceae	2.9 (4)		–				–
Artemisia	–		–				0.5 (1)
Other NAP	5.8 (8)		3.3 (3)	(1)			2.2 (4)
Botrychium	0.7 (1)		1.1 (1)				–
Lycopodium	0.7 (1)		–				–
Selaginella	–	(1)	–	(1)			–
Polypodiaceae	0.7 (1)		2.2 (2)	(1)			4.4 (8)
Trilete Spores indet.	1.4 (2)	(1)	–				–
Pollen sum	100 (139)	(22)	100 (91)	(18)	–	–	100 (182)
Indeterminate	43.5 (107)	(37)	46.2 (78)	(44)	(7)	(13)	54.3 (216)
Pollen concentration	141 / g	35 / g	67 / g	51 / g	9 / g	10 / g	793 / g

temperatures and sufficient quantities of water. The evolution of the karst system is obviously connected with warmer periods, such as lower Quaternary interglacials or the Tertiary. The uplift of the Alps subsequent to the main Alpine orogeny was considerable, especially in the Pleistocene (Trümpy 1980). Presently, the uplift rate is between 0.5 and 1.5 mm per year (Labhart 1992). In the Pliocene the Alps were probably eroded to a chain of hills (Trümpy 1980). It can be assumed that Jungfraujoch then was at least 1000–2000 m (probably more) lower than today: estimates with the mentioned uplift rates (0.67 – 2 million yr) show that karst development and cave formation must have started in the upper Pliocene or lower Pleistocene as a consequence of the intensifying Alpine uplift. During the following period of increasing altitude and continuing tectonic processes, the original drainage area of the cave was almost completely eroded.

Not much information is available to trace the history of the accumulation in the cave, and comparable studies do not exist. The *Carya* pollen type found in the lower part of the deposit is an indication of a warmer climate. *Carya* and other Juglandaceae such as *Engelhardtia* or *Platycarya* (with triporate pollen grains) are known as a part of the Tertiary flora of Central Europe; these taxa disappeared during cold periods of the early and middle Pleistocene (Mai 1995). However, pollen flora and cave sediments cannot be attributed to the upper Tertiary or the lower Quaternary, irrespective of whether the assemblages are altered or not. Neogene intermediary elements like *Carya*-Juglandaceae and other expected Tertiary taxa (Hantke 1978; Mai 1995) are much too rare. The grains in question were probably reworked from older sediments and are not contemporaneous with the rest of the pollen assemblage. This supports the above interpretation of the cave deposit, since reworking of sediments and their palynomorph assemblages by advancing or melting glaciers is a well known phenomenon (e.g. Streel & Bless 1980). The source of the Neogene elements cannot be traced, as the corresponding sediments were completely removed. The determination of the cave sediments' age turns out to be rather speculative due to the lack of other indications and the mentioned restricted use of palynostratigraphic arguments. Nevertheless, it seems reasonable that the sediments accumulated in the pre-late Pleistocene; some Tertiary taxa were still common elements of the flora and it is more probable that pollen reached the cave or sediments within the drainage area during this time. Finally, it may be assumed that geomorphological processes in the older Pleistocene period were more effective (erosion, accumulation, redeposition of sediments) when the Jungfraujoch region was considerably lower.

Conclusions

The geographic situation and the results of the present study strongly suggest that the karst cave was formed during warmer climatic periods at lower altitudes during the upper Pliocene or the lower Pleistocene. Sediment transport and accumulation occurred later in similarly water-rich – possibly early or late glacial – periods. The use of the palynostratigraphic method is rather limited because the pollen spectra represent mixtures of various origin, affected by degradation and differential destruction of the grains. Consequently, an exact dating of the cave sediments on Jungfraujoch with palynostratigraphic correlations is impossible. The presence of a few Neogene and early Pleistocene, probably reworked elements in the cave deposits does not prove a Pliocene or preglacial age, but it suggests a lower – rather than upper – Pleistocene accumulation. The mentioned lack of corresponding investigations excludes a comparison or a wider interpretation of the results. Therefore, more studies in similar situations are necessary, preferably dealing with clearly stratified sediments and more favourable conditions for the preservation of palynomorphs.

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