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DETAILED MORPHOLOGIC ANALYSIS OF PALAEOTRAUN GALLERY USING A TERRESTRIAL LASER SCAN (DACHSTEIN-MAMMUTHÖHLE, UPPER AUSTRIA)

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Having a length of currently 67 km the Dachstein-Mammuthöhle is one of the major cave systems in the Northern Calcareous Alps. The genesis of its partly huge galleries has been discussed controversially almost since its discovery ca. 100 years ago. Special focus was always given to a 200 m long gallery named Paläotraun. To study the morphology of this more than 10 m high tunnel in detail a terrestrial laser scan was performed. The method proved to be successful and confirmed that the Paläotraun is a paragenetic channel.

1. Introduction

Dachstein-Mammuthöhle cave is the fourth longest cave in the Eastern Alps and in Austria. Currently it has a length of 67 km and a vertical range of 1.2 km (Pfarr et al. 2012). A very small portion of the cave is developed as a show cave. It includes a huge 200 m long gallery with up to 100 m² cross sectional area that was named *Paläotraun* (Fig. 1).

Since the discovery of the cave at the beginning of the 20th century, its speleogenesis has been discussed controversially. Hermann Bock proposed his *Höhlenflusstheorie* (*cave river hypothesis*), well-known in the German-speaking area, stating that an enormous underground river with a discharge of 1,500 to 3,000 m³/s that had its catchment area in the Austro-Alpine Crystalline crossed the Northern Calcareous Alps in the Tertiary (Bock et al. 1913). The showpiece of his model was the *Paläotraun*, the origin of which was mainly attributed to mechanical erosion by the palaeo Traun River. His hypothesis formed the core of a long-standing and ongoing scientific dispute among speleologists and other scientists in Austria about the origin of the Dachstein-Mammuthöhle in general and the "Paläotraun" in particular (for details see Plan and Herrmann 2010 and Trimmel 2012).

Other theories were for example that the Paläotraun formed mainly by seepage water and collapse (e.g., Trimmel 1949) or is purely of tectonic origin (e.g., Arnberger 1953). Already in 1961 Bauer concluded from the flow direction deduced from scallops that Paläotraun is a rising phreatic channel and that the floor was covered by a growing pile of sediments and the ceiling only could evolve upward. Detailed morphological mapping and the application of modern speleogenetic models could confirm the paragenetic origin proposed by Bauer (Plan and Xaver 2010).

However, with conventional methods in the up to 15 m high *Paläotraun* morphometric measurements were restricted to the lower 2 m. Therefore a high resolution terrestrial laser scan (TLS) was conducted to enable detailed morphologic studies over the whole cross section.

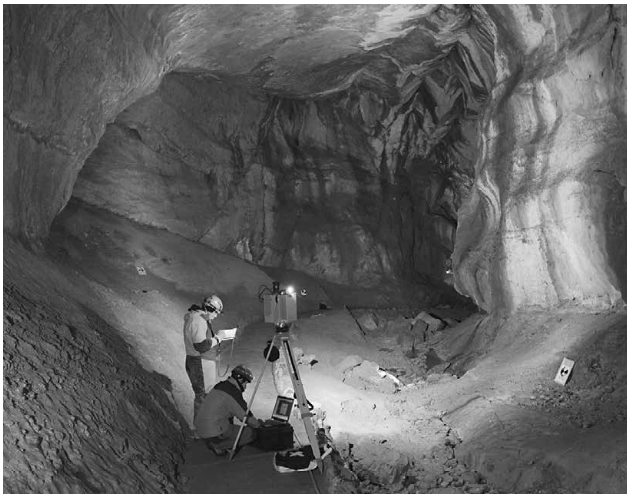

Figure 1. Performing the terrestrial laser scan in Paläotraun.

2. Geography and geology

The Dachstein-Mammuthöhle is located at the northern margin of the Dachstein plateau (Dachstein-Summit: 2,995 m a.s.l.) reaching below the local summit of Krippenstein (being 2,108 m a.s.l.). Up today 21 entrances are known to the polygenetic cave system that consists of (1a) epiphreatic horizontal galleries with up to 100 m² cross sectional area, (1b) inclined mazes that are controlled by bedding planes and (1c) (epi?)phreatic pits with up to 90 m depth. Younger vadose parts are (2a) series of canyons and complex canyon systems that reach up to 200 m height and (2b) vadose pits of up to 100 m depth.

The entire cave developed in well bedded Upper Triassic limestone (partly dolomitic) of the Dachstein Formation and generally the strata dip with 20 to 40° to the northeast.

The geometry of the cave and several small-scale features (e.g., scallops, karren, ceiling meanders), which date back to the early history of the cave formation, allow the following interpretation: old phreatic parts (galleries, mazes, and some pits) developed under epiphreatic conditions during flood events, followed by younger, vadose canyon-shaft-systems. Scallops and sedimentary structures indicate a general westward flow direction.

Sediments played an important role during the formation of the profiles, i.e. the profiles expanded upward (paragenesis) because the floor of the galleries was sealed by sediments, and only part of the cross section, as it can be seen today after removal of these sediments, was occupied by water (Plan and Xaver 2010).

3. Methods

The laser scanning measurements in Paläotraun took place on May 7th, 2011. The instrument used for this purpose was a Z+F Imager 5006i phase-shift scanner, capable of recording 3D point clouds in distances from 0.4 m to 79 m. The scanner's field of view is 360° horizontally and 310° vertically (for details see: Zoller+Fröhlich 2012). Paläotraun was scanned from 14 positions; four of them in the scan mode "super high" (angular resolution of 0.018° which corresponds to a point spacing of 3 mm in a distance of 10 m) for a detailed recording of the scallops. Two scans were done in the "high" mode (resolution: 0.036° and 6 mm@10 m, resp.) and 8 scans in "middle" mode (resolution: 0.072° and 13 mm @10 m, resp.), resulting in an overall 3D point cloud of approx. 860 million points. The single 3D point clouds were accompanied by panoramic images acquired with an integrated camera on the scanner platform, enabling a better visual interpretation of the data and the derivation of a textured 3D model of Paläotraun.

For the calculation of this 3D model, the point clouds of the single scans were first approximately aligned relative to each other using coded targets (as visible in Fig. 1, lower right corner). For a precise alignment, also referred to as "co-registration", the point clouds underwent a special filtering, and the calculation was done automatically using an ICP (iterative closest point) algorithm (cf. Nothegger and Dorninger 2009). After the co-registration, the overall point cloud was filtered again with special emphasis on keeping small features while removing redundant information in locally planar areas where a high point density is not needed. The resulting model is a three-dimensional triangulation of this filtered point cloud (Roncat et al, 2011).

Using the software package GoCAD and ArcGIS the structures were analysed and morphometric measurements on scallops were performed. A movie of a virtual flight through the gallery along defined points was rendered using the software Pointools (Fig. 2).

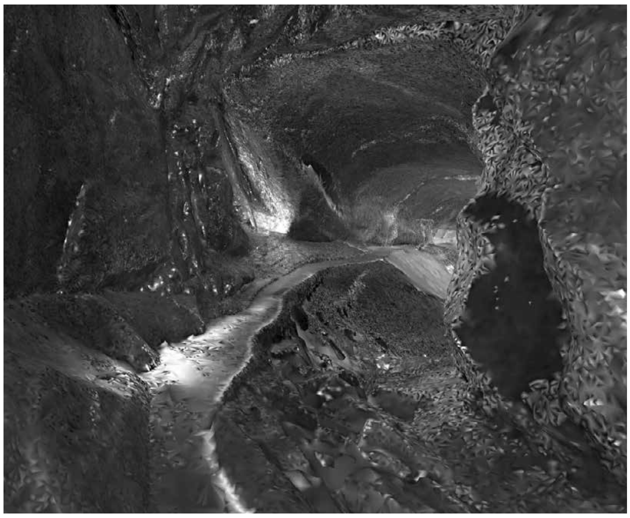

Figure 2. Screenshot of the flight through the Paläotraun.

5. Results and Conclusions

The conducted study showed that a TLS is a powerful tool to investigate the morphology of large cave passages in detail. However a high – higher than expected – resolution is necessary if very small scale features like cm-sized scallops shall be investigated.

The Laser Scan shows many morphologic details of the cave walls and the ceiling including: faults, bedding planes, scallops, paragenetic dissolution ramps, and paragenetic ceiling cannels.

In general the hypothesis that Paläotraun is a huge paragenetic Channel proposed by Bauer (1961) and in more detail by Plan and Xaver (2010) could be confirmed.

Indicators for a paragenetic origin of the main portion of the profile are paragenetic dissolution ramps and ceiling channels that developed above a single bedding plane at the basis of the profile. It is the only spelaeogenetically relevant bedding plan as it shows small tubes and anastomoses, which is not the case for other bedding planes that are visible in upper parts of the profile. Further, the average length of groups of scallops differs with the height of the profile which can only be interpreted by a paragenetic origin: At different sediment fill levels different flow velocities have caused these differences (Fig. 3).

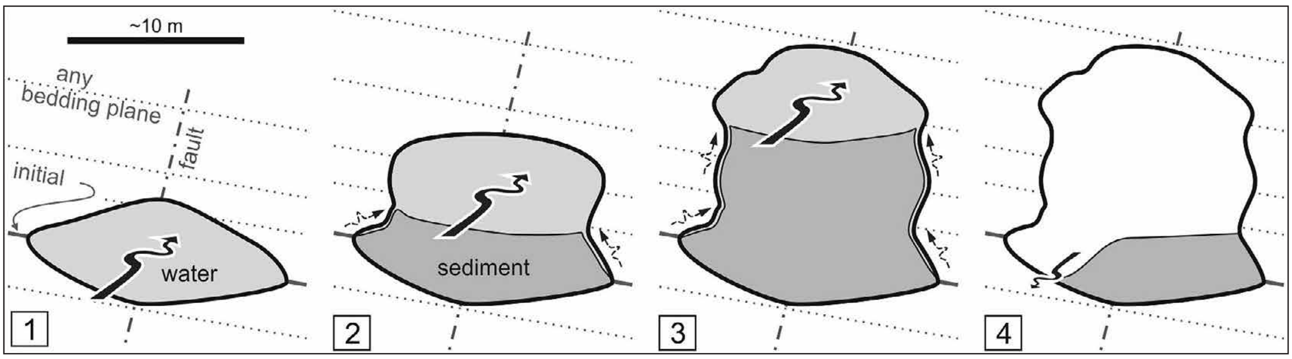

Figure 3. Schematic evolution of the paragenetic profile of Paläotraun gallery: (1) at the junction of a bedding plane and a fault an (epi)phreatic elliptical profile develops. (2) Sediments at the floor enable only an upward evolution of the profile. Water rinsing between the sediment and the cave wall forms paragenetic ceiling channels at the overhanging parts. Further bedding planes play no role for the development of the profile. (3) Further upward development of the profile above a growing pile of sediments. (4) Erosion of the sediment – most probably by vadose waters – exposes the whole profile as it is visible today.

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Michael Behm and Agelika Xaver helped in the field. The management of the Dachstein show caves enabled access to the cave and provided the infrastructure (electricity, powerful spotlights) for the scan. The Austrian Spelaeologic Association covered the costs for accommodation at Schnöbergalpe for the time of the fieldwork.

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