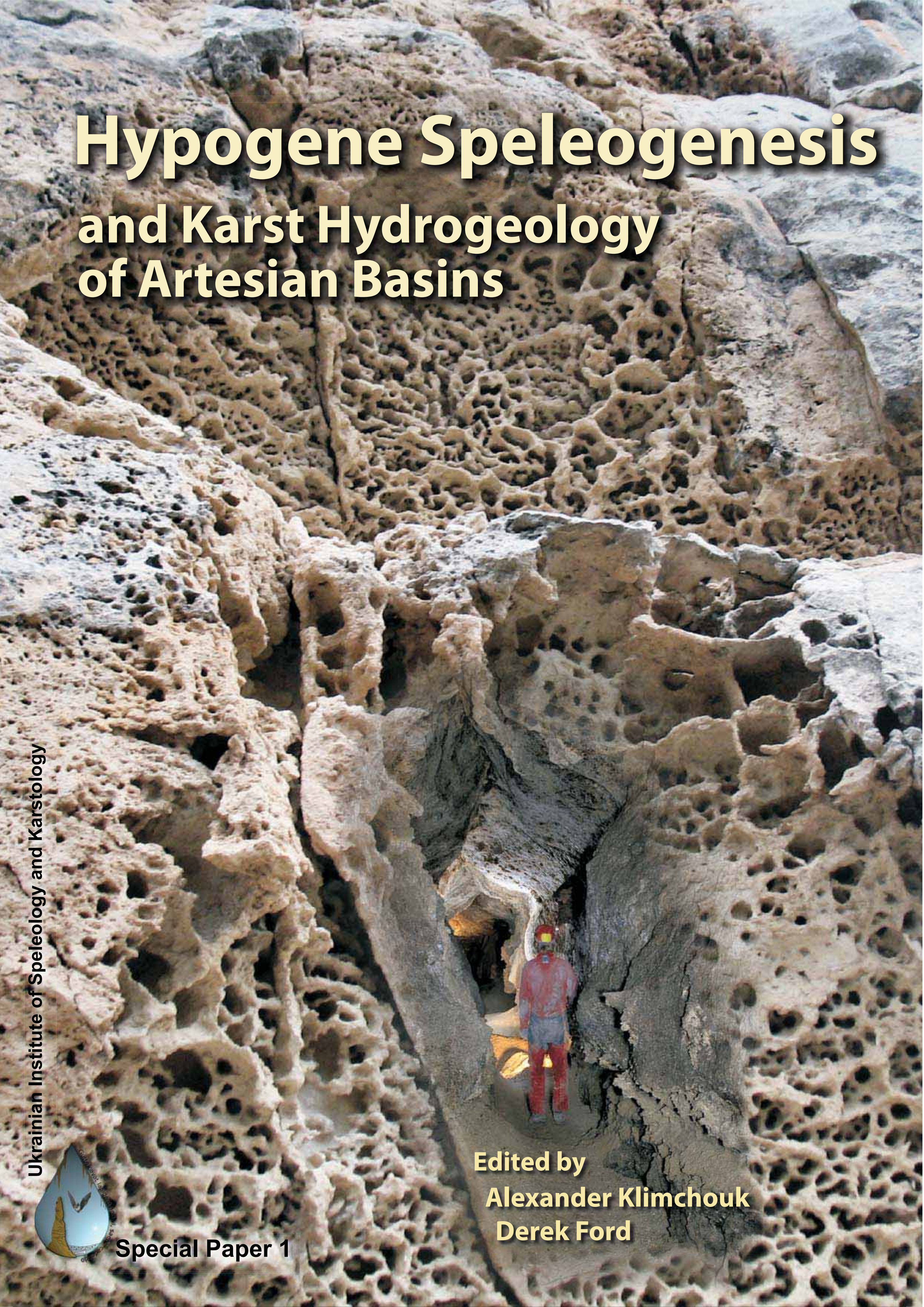
Hypogene Speleogenesis
and Karst Hydrogeology of Artesian Basins



Edited by
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Ukrainian Institute of Speleology and Karstology

Special Paper 1

Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins

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Front cover: Tafoni on a limestone escarpment in the Crimea Piedmont (background) and a passage in Slavka Cave, Western Ukraine (inset). Photos and collage by A.Klimchouk

Back cover: Hypogenic morphology in gypsum caves of the Western Ukraine. Photos and collage by A.Klimchouk

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CONTENTS

HYPOGENE CAVES IN AUSTRIA

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ABSTRACT

Among the ca. 14,000 registered caves of Austria few have been attributed to hypogene speleogenesis. This paper provides an overview of hypogene caves in Austria. A few dozen examples are known around the Vienna Basin. Some of these caves, such as Eisensteinhöhle and Nasser Schacht, display a thermally anomalous microclimate and are associated with thermal springs. Other caves are inactive, but their morphology and deposits are suggestive of a hypogene origin. Preliminary morphologic observations suggest sulfuric speleogenesis for Stephanshöhle near Bad Deutsch Altenburg. In the Northern Calcareous Alps, which host the majority of caves of Austria, only very few have previously been identified as hypogene (e.g., Märchenhöhle, Wasserhöhle), but the number of such caves is likely to increase in the near future. Also, "normal" (epigenetic) cave systems sometimes show morphological evidence suggestive of a hypogene origin, but conclusive proof is lacking. The only Austrian cave where a sulfuric acid speleogenesis is well documented is Kraushöhle. In marbles of the Central Alps lukewarm and thermal springs are present and cavities of likely hypogene origin were encountered during tunnel construction near Lend. In a nearby cave, Entrische Kirche, isotopic evidence of marble alteration by warm paleowaters was recently identified. Extensive calcite deposits are also known from nearby Stegbachgraben, and ongoing isotopic and fluid-inclusion studies strongly suggest hypogene water-rock interaction at lukewarm (<40°C) temperatures there. A few caves in the Southern Calcareous Alps also show morphological evidence of a hypogene origin (e.g. Kozakhöhle), which is U/Th-dated to older than ca. 144,000 years. CO_2-rich springs discharge nearby.

INTRODUCTION

About 22 % (Kralik, 2001) of the Austrian territory is underlain by karstifiable rocks, and approximately 14,000 caves have been registered up to now. Even though there are several thermal karst springs (Zötl and Goldbrunner, 1993) and a few active hydrothermal caves, Austrian researchers did not pay much attention to the topic of hypogene speleogenesis until recently. A first, concise inventory of hypogene caves in Austria was reported by Pavuza and Plan (2005). Since then, interest in this topic has increased and ca. 70 Austrian caves – or at least parts of them – are now regarded as hypogene in origin. This paper provides an up-to-date overview of hypogene speleogenesis in this country.

Distribution of hypogene caves

The Alps cover about two thirds of Austria and host the country's most important cave systems. Three main geological units constitute the Austrian Alps, stretching in an east-west direction: the carbonate-dominated Northern Calcareous Alps, the Central Alps of crystalline rocks including some marble beds, and the Southern Calcareous Alps, which are again dominated by limestones. The Austrian Alps are surrounded by sedimentary basins including the Molasse Basin in the North, and the Vienna Basin in the East at the transition to the Carpathians. An overview is given in Figure 1.

Margins of the Vienna Basin

Most hypogene caves presently known in Austria are restricted to the margins of the southern Vienna Basin (Pavuza and Plan, 2008), a Miocene pull-apart structure hosting up to 6 km of sedimentary fill. Several thermal karst springs are known from this area. According to the hydrogeological model of Wessely (1983) for the western margin of the basin, confirmed by hydrocarbon exploration drilling, water infiltrating into the adjacent mountains of the Northern Calcareous Alps descends along basin-marginal faults, migrates towards the center of the basin, and then ascends along a major fault. Impermeable Tertiary sediments force this water to flow back toward the margins of the basin where it emerges as warm springs aligned along minor faults. Prominent natural springs which accommodate spas are Baden (31°C), Bad Vöslau (22°C), and Bad Fischau (~20°C).

The most prominent hypogene cave is *Eisensteinhöhle* (cave inventory no. 1864/1) near Bad Fischau. It is a show

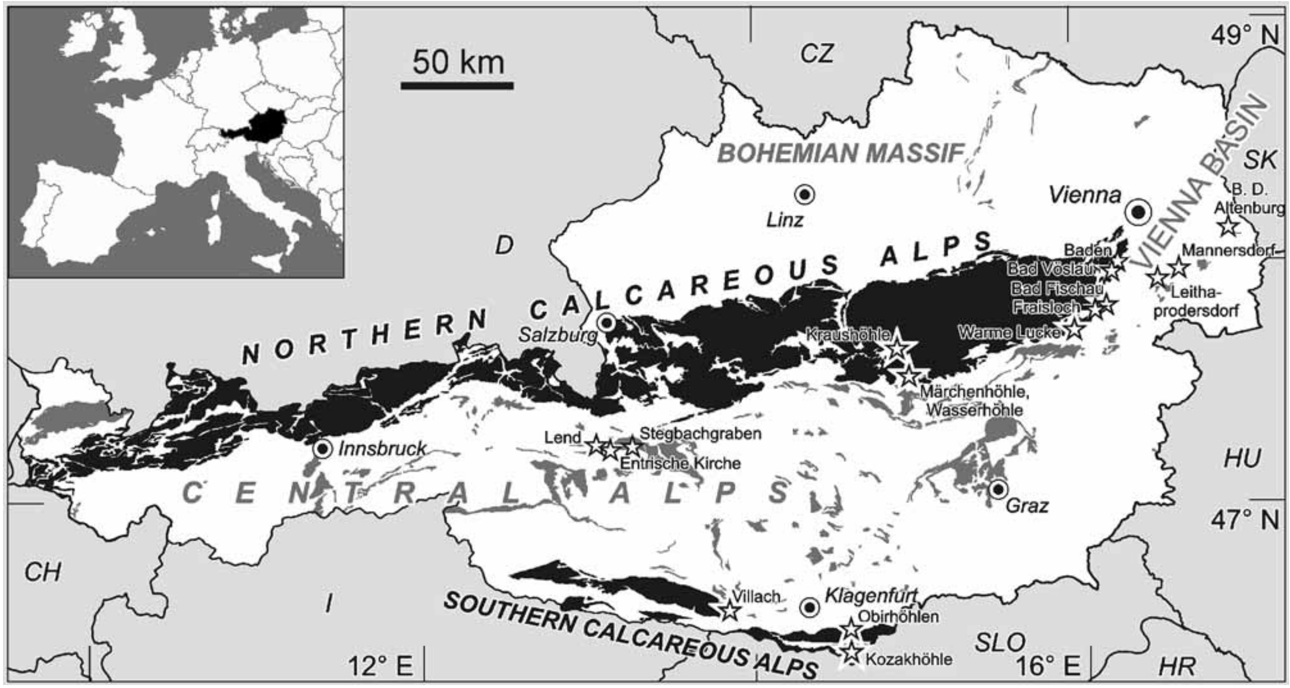

Figure 1. Distribution of hydrothermal caves (or areas with several objects) indicated by stars. Background: karst rocks in Austria (after Schubert, 2003). The Northern and Southern Calcareous Alps are shown in black; karstic rocks of other geological units in grey.

Figure 2. Condensation corrosion channel in Eisensteinhöhle. Note the distribution of popcorn speleothems. Photo: P. Audra.

cave where visitors can climb down ladders to a lukewarm spring 73 m below the entrance. The temperature of the ephemeral spring is up to 15.5°C, whereas the mean outside air temperature is only 9.1°C. This 2.3 km-long and rather convoluted cave developed along a N-S-trending fault dipping 60° to the East. The host rock is a polymict Miocene carbonate breccia. Some parts of the cave, e.g. the *Turm* and *Alter Eingang,* display cupola morphologies, while others are characterized by breakdown possibly related to active tectonic movements. Additional hypogene morphological features are condensation-corrosion channels on ceiling surfaces without speleothems, while the surrounding ceiling is overgrown by popcorn (Figure 2). The cave is decorated by abundant popcorn and coralloids as well as calcite and aragonite frostwork. A preliminary mineralogical investigation also identified huntite. Small amounts of periclase and quartz, and possibly pinakiolite are present as well, but it is not yet clear if they are secondary precipitates or corrosive residuum. Calcite dripstones and flowstones are rare. Radon and CO_2 are elevated, reaching 6500 Bq/m3 and 5300 ppmv, respectively.

The spring of Bad Fischau-Brunn emerges at the foot of the hill below the *Eisensteinhöhle* and is used as a spa although the temperature is only about 20°C. *Fischerhöhle* (1864/5) and *Badstollenspalte* (1864/66) are located upstream of the spring along with two smaller caves which were encountered during construction of an air-raid shelter (*Südliche-* and *Nördliche Luftschutzhöhle* (1864/25 and /67)). These caves developed in Upper Miocene carbonate conglomerates and show small cupolas and popcorn deposits.

At least ten more caves are known from this region whose morphologies – including cupolas – suggest a hypogene origin, but no thermal anomalies have been reported. The most important caves, *Fraisloch* (1864/6) and *Emmerberghöhle* (1864/3), consist of complexly arranged, near-vertical tube passages interconnected with hemispherical enlargements.

Warme Lucke (1861/22), located in the southeastern part of the Vienna Basin near Gösing, is a 62 m-long cave

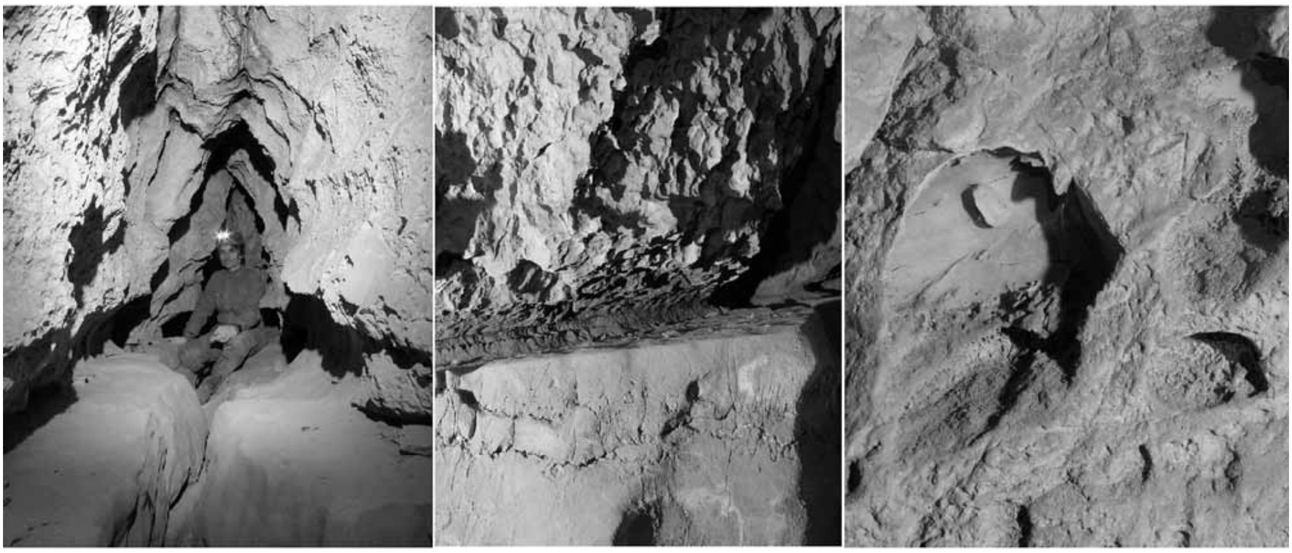

Figure 3. Morphology of Stephanshöhle. Left: Gallery cross section: Feeder fissure and corrosion table below water table notch. The wall above the notch is sculpted by pockets; Middle: detail of notch. Note the smooth wall below and the rough surface above the notch (width of picture: 50 cm); Right: gypsum replacement pockets (width of picture: 10 cm). Photos: L. Plan.

with predominant breakdown morphology. During the winter the cave exhales air that is 4.5 °C warmer than the mean annual outside temperature. At *Nebellöcher* (1911/36; near Gainfarn) cave air 3.5°C warmer than the outside air ascends along inaccessible karstified fissures. Radon shows elevated values in both caves.

The origin of the *Brunnenhöhle* (1911/8), a cave 131 m long near Bad Vöslau-Gainfarn with an artificial entrance only (Mais, Pavuza and Traindl, 1985), may be related to former thermal waters as suggested by hydrogeochemical data. The temperature of modern cave water, however, is only slightly higher than the mean outside air temperature (11°C versus 9.5°). Two stalagmites provide minimum ages of cave formation: alpha counting U/Th (Pavuza, 1988) yielded 124,000 years which agrees well with a basal TIMS U/Th age (Spötl and Mangini, unpubl. data) of 128.700 years.

Three thermal sulfur-bearing spas are located at the eastern margin of the Vienna Basin. Two of them, Bad Deutsch Altenburg (24°C) and Mannersdorf (22°C), are associated with hypogene caves, whereas no caves are currently known at Leithaprodersdorf (23°C).

Preliminary new investigations suggest that eight caves close to the thermal sulfur spring of Bad Deutsch Altenburg are of hypogene origin, and the morphology of one of them, *Stephanshöhle* (2921/30; length 121 m), indicates sulfuric acid speleogenesis. Several paleo-water table notches are present in this cave within a vertical distance of 13 m and the gallery cross section at the lowest one reveals several features diagnostic of the former presence of sulfuric acid (Figure 3). The walls below the notch consist of a corrosion table and a fissure that may have acted as a thermo-sulfuric discharge slot. This part is very smooth, in contrast to the walls above which are sculptured by features that are interpreted as gypsum replacement pockets. These pockets are abundant and even intersecting directly above the notch, but are significantly less abundant with increasing distance from the notch. In its uppermost part the cave displays euhedral calcite spar section that is mostly corroded. No traces of gypsum or other minerals typical of sulfuric speleogenesis have been found in *Stephanshöhle* yet. The cave is probably very young because the deepest point lies only a few meters above the present water level of the Danube River. Other nearby caves are located at higher elevation and show similar features but no replacement pockets. All caves mostly lack cupolas, which is in contrast to the nearby caves described below.

An extensive cave system near Bad Deutsch Altenburg (*Höhlen im Steinbruch Hollitzer*, 2921/18) was discovered by quarrying and largely destroyed. The cumulative length of this cave, which developed in weakly metamorphosed Middle Triassic limestone and dolomite, was several hundred meters with a depth of more than 100 m. Most of this system was completely filled by Pliocene to Miocene sediments. Observations of the few remaining fragments suggest that these passages are at least partly of hypogene origin. This cave system is also known for its abundance of Early Pleistocene mammal bones (Mais and Rabeder, 1984).

Güntherhöhle (2921/2), with a length of 206 m, is currently the largest cave of hypogene origin in the area. The cave air temperature is 4°C above the mean annual outside temperature, but it is not yet clear if this is due to a geothermal anomaly or to the fact that the cave interior is higher than the entrance. The cave contains several spherical chambers and cupolas (Figure 4), and the oxygen isotope values of -15 to -7 ‰ VPDB in a calcitic flowstone may suggest a thermal influence. The morphologic features of the adjacent *Zwergelloch* (2921/12) and of five smaller nearby caves also suggest a hypogene origin.

Nasser Schacht (2911/21) is an active thermal cave located close to Mannersdorf. The cave was opened during quarry works in 1965, is 260 m long, and developed in very low-grade metamorphic Lower Triassic dolostones and Miocene limestones in the upper part. The temperature of the cave air as well as of the water in a pool near its deepest point 35 m below the entrance is 15.5 °C (Plan *et al.*, 2006). Some parts of the cave are controlled by a

Figure 4. Two huge cupolas in Güntherhöhle (upward view; person for scale). Photo: L. Plan.

vertical fault while others are in the sub-horizontal contact between the two lithologies. Several large cupolas, round tubes and condensation-corrosion channels similar to those in *Eisensteinhöhle* are present in this cave. Cave walls are soft and porous due to the presence of a several centimeter-thick alteration layer. Coralloids and popcorn as well as various mineral efflorescences including calcite, dolomite, aragonite, huntite, hydromagnesite, and epsomite were found in this cave (Plan *et al.*, 2006). The rather shallow (35 m) character of the cave results in a temperature gradient of 19°C/100 m. As in *Eisensteinhöhle*, Rn and CO_2 concentrations are elevated, reaching up to 5800 Bq/m³ and 2600 ppmv, respectively. The chemical composition of modern water in the cave, however, indicates seepage, quite distinct from the waters of the nearby thermal spring. The stable isotopic composition of popcorn deviates slightly from that of speleothems in epigenic caves from this area, suggesting a weak thermal influence.

Another 20 caves were opened (and partly destroyed) in surrounding quarries and displayed some indications of hypogene speleogenesis (morphology and speleothems); their temperatures do not significantly exceed the outside air temperature.

Northern Calcareous Alps

The Northern Calcareous Alps are a 20 to 40 km-wide mountain range mainly comprised of Triassic carbonate rocks with a total thickness reaching several kilometers. The basal units are evaporites (Upper Permian) and siliciclastic rocks (Upper Permian and Lower Triassic), followed by thick carbonates (Middle and Upper Triassic). Jurassic, Cretaceous and Paleogene sediments have limited thickness and areal extent. The Northern Calcareous Alps are famous for their impressive karst massifs including *Dachstein, Tennengebirge,* and *Totes Gebirge* that host extensive cave systems up to 130 km in length and up to 1.6 km in vertical extent.

Kraushöhle (1741/1) near Gams was the first known cave in the Eastern Alps whose development is related to sulfuric acid. This unique cave is discussed in detail in a separate paper (Plan *et al.*, this volume). 15 km southeast of *Kraushöhle*, close to the southern margin of the Northern Calcareous Alps, two caves are known: *Märchenhöhle* (1742/17, 135 m-long) and *Wasserhöhle* (1742/21; 619 m-long). Both caves host inverted cone-shaped chambers (Figure 5 and 6) a few meters in diameter and with flat roofs, as well as peculiar cup-shaped corrosion features on inclined walls (Figure 7). *Märchenhöhle* is rich in calcite speleothems. Besides normal flowstone and dripstones, an older abundant mammillary crust (cave clouds, Figure 5) up to 40 cm thick is present. The crust presumably formed in pools of moderately thermal water and rests on partly bleached limestone. Stable isotope data, however, suggest only partial alteration of the limestone. A preliminary U/Th date indicates that these cave clouds are older than 400,000 years. A rather old age for *Märchenhöhle* is consistent with its high elevation (ca. 1500 m a.s.l., 900 m above the present base level), as well as the abundance of breakdown. *Wasserhöhle* shows similar morphological features to the adjacent *Märchenhöhle*, but lacks cave cloud deposits.

Within two caves of the Northern Calcareous Alps features have been detected that indicate a hypogene origin for some parts of these predominantly epigenetic caves: chambers in *Hoyoshöhle* (1852/5, length: 135 m) and *Hirschgrubenhöhle* (1744/450, length: 4.2 km) display cupola-like features with flat roofs and cup-shaped hollows (Figure 8). In both cases they are associated with ore-crusts.

Central Alps

In the Central Alps of Austria, carbonate rocks are present as marbles intercalated with schists and gneisses, as carbonate-bearing schists, and as low-grade

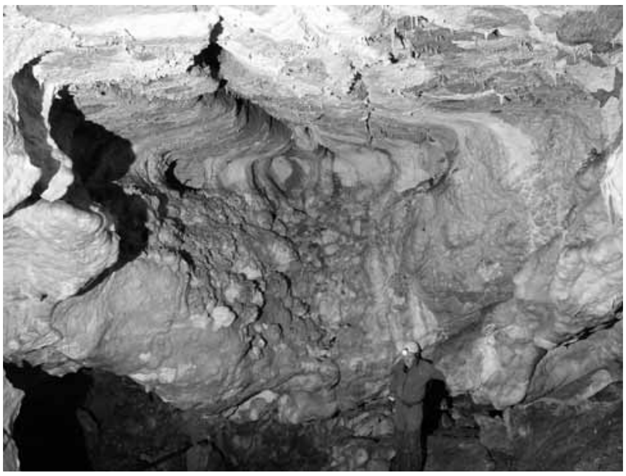

Figure 5. Cone-shaped chamber in Märchenhöhle. The mammillary crust occurs only below the notch (person for scale). Photo: L. Plan.

Figure 6. Cone shaped chamber in Wasserhöhle (upward view with wide angle lens). Photo: D. Sulzbacher.

metamorphic limestones and dolomites on top of the crystalline basement. Because of the greater altitude many known cave systems in the Central Alps are presently located near glaciers. Examples include the areas near Kitzsteinhorn (Kaprun Valley, Salzburg), and near the Hintertux Glacier (Tux Valley, Tyrol; Spötl *et al.*, 2004). Most of these caves are thought to be of epigenetic origin, but a few sites revealed evidence of a hypogene origin.

A hydroelectric power plant tunnel in the Salzach valley near Lend was flooded by warm water which was circulating in karst channels up to several meters in diameter (Horninger, 1959). The host rock is a Jurassic marble with near-vertical dip due to intensive tectonic deformation along a major strike-slip fault.

A dry karst chamber encountered in this tunnel showed evidence of wall-rock bleaching, half a meter thick, and contained several cm-long euhedral calcite crystals (Horninger, 1956, 1958). A recent study found compelling stable isotope evidence of similar wallrock alteration in *Entrische Kirche* (2595/2), a nearby large and surprisingly deep cave (Spötl *et al.*, 2009). This cave shows no thermal anomaly today and the age of the hypogene phase was dated to older than 240,000 years based on U/Th dates of an overlying flowstone. Even more abundant evidence of past hypogene fluid-rock interaction is present in a fossil cave at *Stegbachgraben*. The walls of this cave are lined with a coarsely crystalline calcite crust locally exceeding 1 m in thickness and exhibiting up to 3 major depositional episodes. Precipitation occurred from warm (less than ca. 40 ºC), low-salinity water at significant depth (fluid inclusion data – Spötl *et al.*, 2009; Dublyansky *et al.*, this volume). At the deepest part of a nearby gorge lukewarm springs emerge from the same marbles, which indicate the presence of a deep-seated hydrological regime even today.

Southern Calcareous Alps

This geological unit comprises non-metamorphic to very low-grade metamorphic limestones of the Carnic Alps and the Karawanken Mountains. Caves are much less abundant in these mountain ranges compared to the Northern Calcareous Alps. Locally, however, large caves are present, such as in the area north of Eisenkappel (Obir, Carinthia). The origin of the *Obirhöhlen* (3925/7 to /9) remains elusive, but two lines of evidence suggest that a hypogene origin should be considered: (1) the hydrochemistry of springs down below in the Vellach valley indicates the influx of deep-seated carbon dioxide (Poltnig and Strobl, 1996), and (2) there are no natural entrances to this extensive cave system, which was discovered during mining operations. CO_2-rich springs are even more abundant south of Eisenkappel (Zötl and Goldbrunner, 1993) and are related to the occurrence of magmatic rocks brought to the surface along the Periadriatic Lineament. *Kozakhöhle* (3931/29) is a rather small cave whose speleogenesis was apparently associated with such aggressive waters. This cave exhibits funnel-shaped chambers, pendants and other features diagnostic of a hypogene origin. The cave also hosts abundant aragonite deposits overlain by calcite stalagmites. U/Th data constrain the maximum age of these deposits to 144,000 years (Spötl *et al.*, 2007).

Near the town of Villach some of the numerous caves of Dobratsch Mountain are associated with an active hydrothermal regime and thus maybe of hypogene origin, but no detailed studies have been conducted so far. Examples include *Hungerbachhöhle* (3742/1), *Mistloch* (3742/79) and *Thermenhöhle* (3742/109).

Figure 7. Cup-shaped corrosion features in Märchenhöhle (glove for scale). Photo: L. Plan.

CONCLUSIONS AND OUTLOOK

Modern research on hypogene caves in Austria has barely started yet. Several caves have been attributed to this type of origin and the majority of them are linked to lukewarm thermal springs. Only two examples of caves formed by sulfuric acid – a well documented case (*Kraushöhle*) and a new possibility awaiting further study (*Stephanshöhle*) – are known to date. Most caves identified as hypogene are quite close to the present-day base level and are therefore presumably young, most likely Pleistocene in age. The probability of preserving pre-Pleistocene hypogene caves in a mountainous setting such as the Austrian Alps is low and modification by later invasion of epigene waters or even obliteration by erosion and/or neotectonics is likely. Only two exceptions have been identified so far, *Märchenhöhle* and *Wasserhöhle,* and these caves are presumably as old as the major epigene caves systems of the Northern Calcareous Alps, whose origin dates back to the Oligocene – Frisch *et al.*, (2002).

A new research project on hypogene caves in Austria is planned to start in the summer of 2009, looking specifically at caves whose origin is associated with lukewarm and thermal, partly CO_2-rich waters. This study will combine field work and state-of-the-art analytical techniques to constrain the mode of origin and timing of these caves and to establish geochemical tools to reliably identify hypogene water-rock interactions. In addition, research on Austria's interesting sulfuric acid caves continues and will be expanded in the near future.

Figure 8. Cup-shaped corrosion features in Hirschgrubenhöhle (film box for scale). Photo: L. Plan.

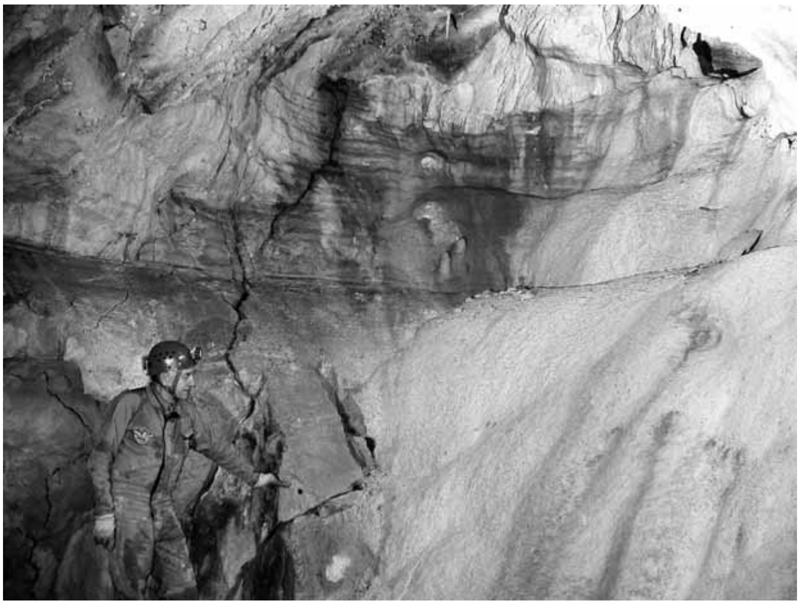

Figure 9. Funnel-shaped chamber in Kozakhöhle showing paleo-water table marks. Note later tectonic fractures (behind caver) and flowstone (right part of picture). Photo: C. Spötl.

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