

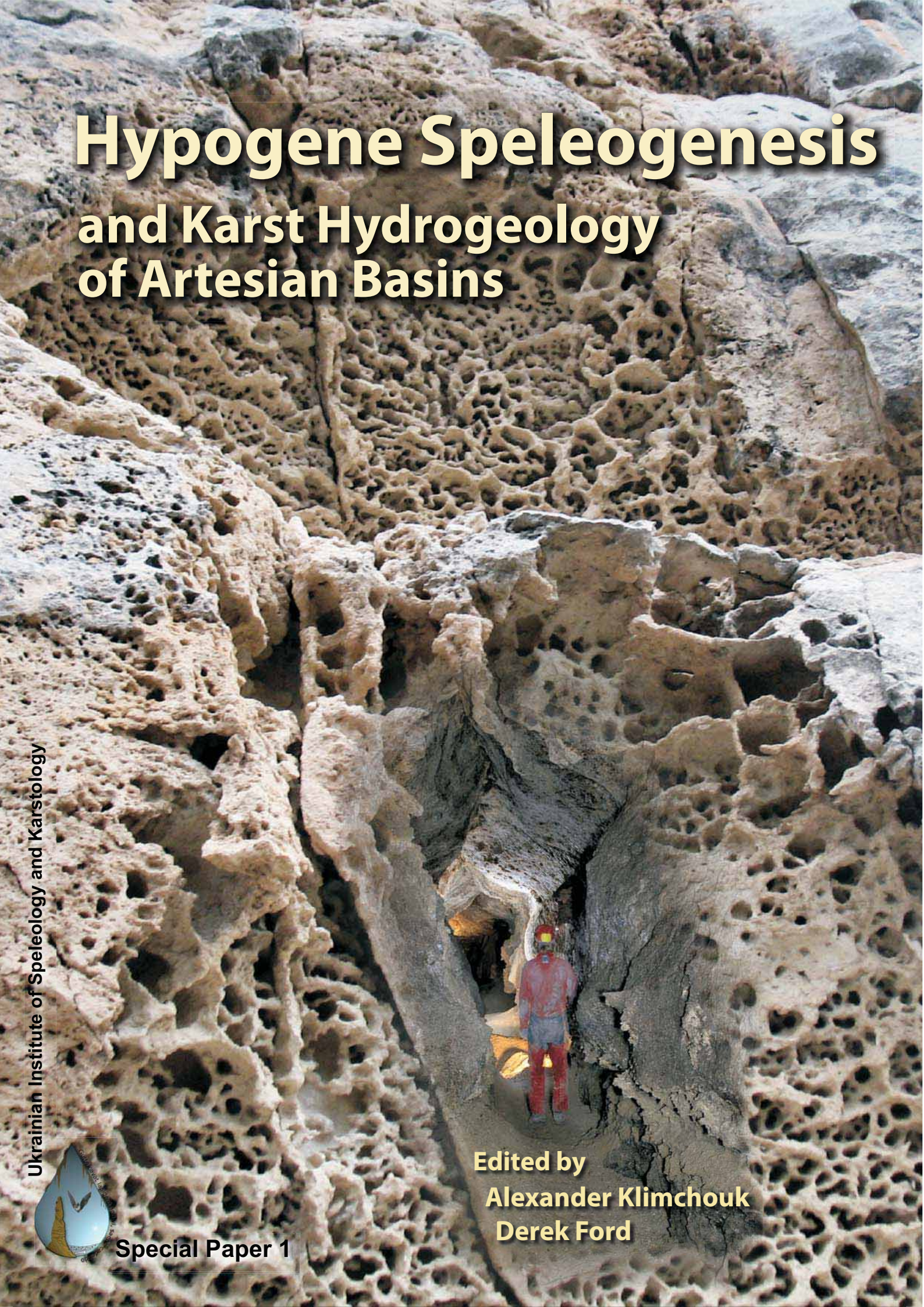
Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins

Ukrainian Institute of Speleology and Karstology



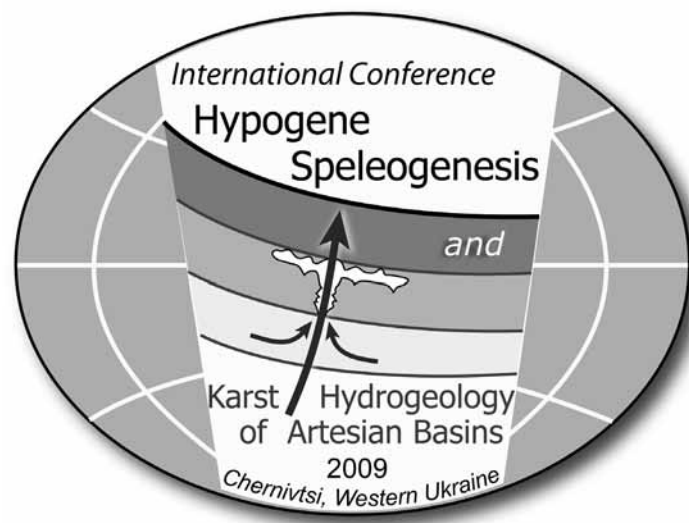
Special Paper 1

Edited by
Alexander Klimchouk
Derek Ford



Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins

Proceedings of the conference held May 13 through 17, 2009 in Chernivtsi, Ukraine



**Edited by
Alexander B. Klimchouk and Derek C. Ford**

**Ukrainian Institute of Speleology and Karstology
Special Paper 1**

**Simferopol
2009**

УДК 556
ББК 26.22
Г 505

Recommended citation for this volume:

Klimchouk, A.B. and Ford, D.C. (eds.). 2009. Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins. Ukrainian Institute of Speleology and Karstology, Special Paper 1, Simferopol, 280 pp.

ISBN 978-966-2178-38-8

The volume contains papers presented during the International Conference held May 13 through 17, 2009 in Chernivtsi, Ukraine.

Published by:
Ukrainian Institute of Speleology and Karstology,
4 Vernadsky Prospect, Simferopol 95007, Ukraine
<http://institute.speleoukraine.net>
institute@speleoukraine.net

Дизайн обкладинки: О.Б.Климчук
Cover design: A.B.Klimchouk
Оригінал-макет: О.Б.Климчук, А.М.Гребнев
Master copy: A.B.Klimchouk, A.N.Grebnev
Комп'ютерна верстка: А.М.Гребнев
Computer layout: A.N.Grebnev

Надруковано в типографії СПД Харітонов О.О., Сімферополь, АР Крим, Україна
Printed by SPD Kharitonov A.A., Simferopol, AR Crimea, Ukraine

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

©2009 by Ukrainian Institute of Speleology and Karstology (the book)
©2009 by authors (individual contributions)

ISBN 978-966-2178-38-8

Ukrainian Institute of Speleology and Karstology, Ukraine
Vernadsky Tavrichesky National University, Ukraine
Fed'kovich Chernivtsy National University, Ukraine
Institute of Geological Sciences, Ukraine
National Cave and Karst Research Institute, USA
Karst Water Institute, USA
Silesian University, Poland
Katowice Section of the Polish Geographic Society, Poland
Ukrainian Speleological Association, Ukraine

With support of:

Union International of Speleology (UIS),
UIS Commission on Karst Hydrogeology and Speleogenesis
International Geoscience Program 513
“Global Study of Karst Aquifers and Water Resources” (UNESCO)
International Year of Planet Earth (UNESCO-IUGS)

Patronage Committee

Bagrov N.V. – Rector of the Vernadsky Tavrichesky National University, corresponding member of the NASU
Gozhik P.F. – Director of the Institute of Geological Sciences of NASU, corresponding member of NASU
Mel'nichuk S.V. – Rector of the Fed'kovich Chernivtsi National University, corresponding member of NASU
Shelepnitsky I.O. – Head of the Chernivtsi Province Council
Shestopalov V.M. – Academician-Secretary of the Department of Earth Sciences of NASU, academician of NASU

Organizing Committee

Klimchouk A.B. – UISK, Ukraine – Chairman
Andrash V.V. – Ternopil' Speleo-Club "Podillya"
Andreychuk V.N. – University of Silesia, Poland – UISK, Ukraine
Apostoljuk V.A. – UISK – Ternopil' Speleo-Club "Podillya"
Koptchinsky A. – Vienna University, Austria
Rudenko V.P. – Fed'kovich Chernivtsy National University
Ridush B.T. – UISK - Fed'kovich Chernivtsy National University
Sokhatsky M.P. – UISK – Borshchiv Regional Museum
Vakhrushev B.A. – UISK – Vernadsky Tavrichesky National University
Zimel's J.L. – UISK – Ternopil' Speleo-Club "Podillya"

Scientific Committee

Shestopalov V. (NAS Ukraine) – Chairman
Audra Ph. (University of Nice, France)
Auler A. (Brazilian Institute for Karst and Caves, Brazil)
Andrejchuk V. (University of Silesia, Poland – UISK, Ukraine)
Dublyansky Yu. (Institut für Geologie und Paläontologie, Leopold-Franzens-Universität Innsbruck, Austria)
Ford D. (McMaster University, Canada)
Forti P. (University of Bologna, Italy)
Frumkin A. (Jerusalem University, Israel)
Kempe S. (University of Darmstadt, Germany)
Klimchouk A. (UISK, Ukraine)
Lowe D. (British Geological Survey, Nottingham, UK)
Osborne A. (University of Sidney, Australia)
Palmer A. (University of Oneonta, USA)
Veni G. (National Cave and Karst Research Institute, USA)
White W. (Pennsylvania State University)

CONTENTS

PRINCIPAL FEATURES OF HYPOGENE SPELEOGENESIS <i>Alexander Klimchouk</i>	7
HYPOGENE CAVE PATTERNS <i>Philippe Audra, Ludovic Mocochain, Jean-Yves Bigot, and Jean-Claude Nobécourt</i>	17
MORPHOLOGICAL INDICATORS OF SPELEOGENESIS: HYPOGENIC SPELEOGENS <i>Philippe Audra, Ludovic Mocochain, Jean-Yves Bigot, and Jean-Claude Nobécourt</i>	23
HYPOGENE CAVES IN DEFORMED (FOLD BELT) STRATA: OBSERVATIONS FROM EASTERN AUSTRALIA AND CENTRAL EUROPE <i>R.A.L. Osborne</i>	33
IDENTIFYING PALEO WATER-ROCK INTERACTION DURING HYDROTHERMAL KARSTIFICATION: A STABLE ISOTOPE APPROACH <i>Yuri Dublyansky and Christoph Spötl</i>	45
MICROORGANISMS AS SPELEOGENETIC AGENTS: GEOCHEMICAL DIVERSITY BUT GEOMICROBIAL UNITY <i>P.J.Boston, M.N. Spilde, D.E. Northup, M.D. Curry, L.A. Melim, and L. Rosales-Lagarde</i>	51
SIDERITE WEATHERING AS A REACTION CAUSING HYPOGENE SPELEOGENESIS: THE EXAMPLE OF THE IBERG/HARZ/GERMANY <i>Stephan Kempe</i>	59
SIMULATING THE DEVELOPMENT OF SOLUTION CONDUITS IN HYPOGENE SETTINGS <i>C. Rehr, S. Birk, and A. B. Klimchouk</i>	61
EVOLUTION OF CAVES IN POROUS LIMESTONE BY MIXING CORROSION: A MODEL APPROACH <i>Wolfgang Dreybrodt, Douchko Romanov, and Georg Kaufmann</i>	67
SPELEOGENESIS OF MEDITERRANEAN KARSTS: A MODELLING APPROACH BASED ON REALISTIC FRACTURE NETWORKS <i>Antoine Lafare, Hervé Jourde, Véronique Leonardí, Séverin Pistre, and Nathalie Dörfliger</i>	75
GIANT COLLAPSE STRUCTURES FORMED BY HYPOGENIC KARSTIFICATION: THE OBRUKS OF THE CENTRAL ANATOLIA, TURKEY <i>C. Serdar Bayari, N. Nur Ozyurt, and Emrah Pekkans</i>	83
ON THE ROLE OF HYPOGENE SPELEOGENESIS IN SHAPING THE COASTAL ENDOKARST OF SOUTHERN MALLORCA (WESTERN MEDITERRANEAN) <i>Joaquín Ginés, Angel Ginés, Joan J. Fornós, Antoni Merino and Francesc Gràcia</i>	91
HYPOGENE CAVES IN THE APENNINES (ITALY) <i>Sandro Galdenzi</i>	101
STEGBACHGRABEN, A MINERALIZED HYPOGENE CAVE IN THE GROSSARL VALLEY, AUSTRIA <i>Yuri Dublyansky, Christoph Spötl, and Christoph Steinbauer</i>	117
HYPOGENE CAVES IN AUSTRIA <i>Lukas Plan, Christoph Spötl, Rudolf Pavuza, Yuri Dublyansky</i>	121
KRAUSHÖHLE: THE FIRST SULPHURIC ACID CAVE IN THE EASTERN ALPS (STYRIA, AUSTRIA) <i>Lukas Plan, Jo De Waele, Philippe Audra, Antonio Rossi, and Christoph Spötl</i>	129
HYDROTHERMAL ORIGIN OF ZADLAŠKA JAMA, AN ANCIENT ALPINE CAVE IN THE JULIAN ALPS, SLOVENIA <i>Martin Knez and Tadej Slabe</i>	131
ACTIVE HYPOGENE SPELEOGENESIS AND THE GROUNDWATER SYSTEMS AROUND THE EDGES OF ANTICLINAL RIDGES <i>Amos Frumkin</i>	137
SEISMIC-SAG STRUCTURAL SYSTEMS IN TERTIARY CARBONATE ROCKS BENEATH SOUTHEASTERN FLORIDA, USA: EVIDENCE FOR HYPOGENIC SPELEOGENESIS? <i>Kevin J. Cunningham and Cameron Walker</i>	151
HYPOGENE SPELEOGENESIS IN THE PIEDMONT CRIMEA RANGE <i>A.B. Klimchouk, E.I. Tymokhina and G.N. Amelichev</i>	159

STYLES OF HYPOGENE CAVE DEVELOPMENT IN ANCIENT CARBONATE AREAS OVERLYING NON-PERMEABLE ROCKS IN BRAZIL AND THE INFLUENCE OF COMPETING MECHANISMS AND LATER MODIFYING PROCESSES <i>Augusto S. Auler</i>	173
MORPHOLOGY AND GENESIS OF THE MAIN ORE BODY AT NANISIVIK ZINC/LEAD MINE, BAFFIN ISLAND, CANADA: AN OUTSTANDING EXAMPLE OF PARAGENETIC DISSOLUTION OF CARBONATE BEDROCKS WITH PENE-CONTEMPORANEOUS PRECIPITATION OF SULFIDES AND GANGUE MINERALS IN A HYPOGENE SETTING <i>Derek Ford</i>	181
THE INFLUENCE OF HYPOGENE AND EPIGENE SPELEOGENESIS IN THE EVOLUTION OF THE VAZANTE KARST MINAS GERAIS STATE, BRAZIL <i>Cristian Bittencourt, Augusto Sarreiro Auler, José Manoel dos Reis Neto, Vanio de Bessa and Marcus Vinícios Andrade Silva</i>	193
HYPOGENIC ASCENDING SPELEOGENESIS IN THE KRAKÓW-CZĘSTOCHOWA UPLAND (POLAND) – EVIDENCE IN CAVE MORPHOLOGY AND SURFACE RELIEF <i>Andrzej Tyc</i>	201
EVIDENCE FROM CERNA VALLEY CAVES (SW ROMANIA) FOR SULFURIC ACID SPELEOGENESIS: A MINERALOGICAL AND STABLE ISOTOPE STUDY <i>Bogdan P. Onac, Jonathan Sumrall, Jonathan Wynn, Tudor Tamas, Veronica Dărmiceanu and Cristina Cizmaş</i>	209
THE POSSIBILITY OF REVERSE FLOW PIRACY IN CAVES OF THE APPALACHIAN MOUNTAIN BELT <i>Ira D. Sasowsky</i>	211
KARSTOGENESIS AT THE PRUT RIVER VALLEY (WESTERN UKRAINE, PRUT AREA) <i>Viacheslav Andreychouk and Bogdan Ridush</i>	213
ZOLOUSHKA CAVE: HYPOGENE SPELEOGENESIS OR REVERSE WATER THROUGHFLOW? <i>V. Korzhyk</i>	221
EPIGENE AND HYPOGENE CAVES IN THE NEOGENE GYPSUM OF THE PONIDZIE AREA (NIECKA NIDZIAŃSKA REGION), POLAND <i>Jan Urban, Viacheslav Andreychouk, and Andrzej Kasza</i>	223
PETRALONA CAVE: MORPHOLOGICAL ANALYSIS AND A NEW PERSPECTIVE ON ITS SPELEOGENESIS <i>Georgios Lazaridis</i>	233
HYPOGENE SPELEOGENESIS IN MAINLAND NORWAY AND SVALBARD? <i>Stein-Erik Lauritzen</i>	241
VILLA LUZ PARK CAVES: SPELEOGENESIS BASED ON CURRENT STRATIGRAPHIC AND MORPHOLOGIC EVIDENCE <i>Laura Rosales-Lagarde, Penelope J. Boston, Andrew Campbell, and Mike Pullin</i>	245
HYPOGENE KARSTIFICATION IN SAUDI ARABIA (LAYLA LAKE SINKHOLES, AIN HEETH CAVE) <i>Stephan Kempe, Heiko Dirks, and Ingo Bauer</i>	247
HYPOGENE KARSTIFICATION IN JORDAN (BERGISH/AL-DAHER CAVE, UWAIYED CAVE, BEER AL-MALABEH SINKHOLE) <i>Stephan Kempe, Ahmad Al-Malabeh, and Horst-Volker Henschel</i>	253
ASSESSING THE RELIABILITY OF 2D RESISTIVITY IMAGING TO MAP A DEEP AQUIFER IN CARBONATE ROCKS IN THE IRAQI KURDISTAN REGION <i>Bakhtiar K. Aziz and Ezzaden N. Baban</i>	257
FEATURES OF GEOLOGICAL CONDITIONS OF THE ORDINSKAYA UNDERWATER CAVE, FORE-URALS, RUSSIA <i>Pavel Sivinskih</i>	267
ОСОБЕННОСТИ ГИПОГЕННОГО СПЕЛЕОГЕНЕЗА ГОРНО-СКЛАДЧАТОЙ ОБЛАСТИ ЗАПАДНОГО КАВКАЗА <i>Б.А.Вахрушев</i>	271
ГЛУБИННОЕ СТРОЕНИЕ ГИДРОГЕОСФЕРЫ: МОДЕЛЬ ВЕРТИКАЛЬНОЙ ЗОНАЛЬНОСТИ <i>В.Н. Катаев</i>	277
РОЛЬ КАРСТА В ФОРМИРОВАНИИ СОЛЕННЫХ ВОД И РАССОЛОВ ОЛЕНЁКСКОГО БАССЕЙНА <i>Александр Кононов, Сергей Алексеев, и Сергей Сухов</i>	287

HYPOGENE CAVE PATTERNS

Philippe Audra¹, Ludovic Mocochain², Jean-Yves Bigot³, and Jean-Claude Nobécourt⁴

¹ Polytech'Nice-Sophia, Engineering School of Nice - Sophia Antipolis University, 1645 route des Lucioles, 06410 BIOT, France, audra@unice.fr

² Aix-Marseille Université, CEREGE, Europôle de l'Arbois, BP 80, 13545 Aix-en-Provence, Cedex 4, France & Centre de Sédimentologie - Paléontologie «Géologie des systèmes carbonatés », 13331 Marseille, Cedex 03, France

^{3,4} French Association of Karstology, catherine.arnoux@club-internet.fr, jcnobecourt@free.fr

ABSTRACT

The hypogenic cave pattern reflects the speleogenetic processes involved. Processes vary according to the depth in the aquifer, involving mixing corrosion by convergent flux and with meteoric water, cooling, sulfur oxidation, carbon dioxide degassing, and condensation-corrosion. Cave patterns are: isolated geodes, 2D and 3D multistorey systems following joints and bedding planes, Giant phreatic shaft, Water table mazes, Isolated chambers, Upwardly dendritic spheres, Water table cave, 'Smoking' shafts.

The development of caves by hypogene processes (i.e. "hypogenic speleogenesis") corresponds to the formation of caves by water that recharges the soluble formation from below, driven by hydrostatic pressure or other sources of energy, independent of recharge from the overlying or immediately adjacent surface" (FORD, 2006). Hypogenic caves - often referred to as "thermal caves" - were often considered as an "exotic" side of the "normal" (i.e. meteoric) caves. Palmer (1991) estimated that about 10% caves have hypogenic origin. Recent studies (overview in KLIMCHOUK, 2007) have emphasized the specific hydrogeological background and shown that hypogenic caves are much more common than previously thought. The extreme diversity of settings (carbonic, sulfuric, thermal, cold, deep phreatic, shallow phreatic, vadose...) in different geological or geomorphological contexts produces a puzzling impression: each hypogenic cave seems to be unique, with few characteristics in common with the other hypogenic caves in terms of their patterns.

METHODS

A data base of more than 350 hypogenic caves was compiled from the literature, comparing geological structure, hydrology, morphology of caves at different scales (wall features, passages morphology, and cave pattern), mineralogy, deposits... Field study of the most representative hypogenic caves, combined with the information in the literature, show that the apparent dissimilarity in shape can be overcome. Taking into account the diverse settings (hydrologic, geologic) and the speleogenetic processes, we obtain a conceptual model of a cave pattern, integrating all kinds of hypogenic caves (Figure 1) (AUDRA, 2007). Patterns are subdivided into two main types: deep phreatic systems generally developed in a confined aquifer by transverse speleogenesis (*sensu* KLIMCHOUK, 2000), and cave systems developed above the water table, where condensation-corrosion plays a paramount role.

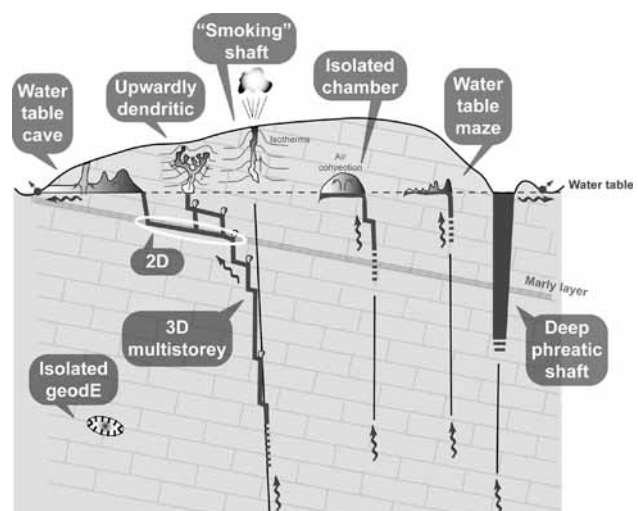


Figure 1. Conceptual model of the hypogenic cave patterns, according to the geological structure, the groundwater recharge, and the speleogenetic processes.

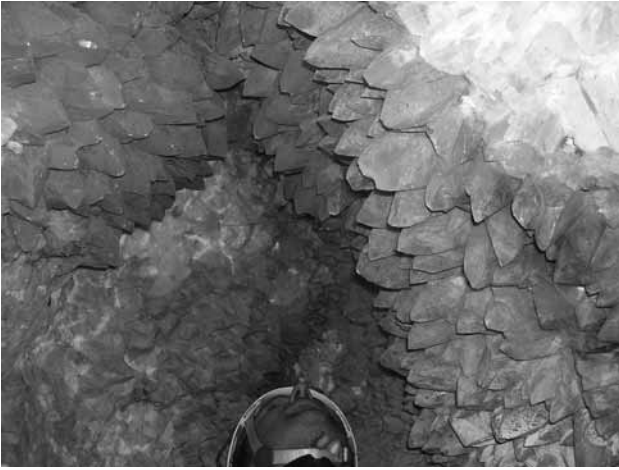


Figure 2. Geode lined with calcite spar, crystallized as sharp rhombohedrons. Cave in Ardèche, France (photo. P. Deconinck)

1. HYPOGENIC CAVE PATTERN IN PHREATIC CONDITION

Isolated geodes

At depth, mixing allows complex dissolution and deposition processes. Isolated voids are created and large crystals (calcite, gypsum...) may be deposited in them (from slightly saturated water), together with diverse other minerals, mainly metallic sulfides (Figures 2 and 3).

3D multi-storey maze cave

The rising hypogenic flow uses joints and bedding planes alternatively, producing a 3D maze cave in a staircase pattern. Generally, the cave displays a main trunk where hypogenic flow was rising, surrounded by 3D mazes, smaller in size (Figure 4). In the Monte Cucco Cave system (Italy), the sulfuric water was rising toward the top of an anticline, where an impervious cover was breached, allowing discharge of the karst aquifer (Figure 5). Contiguous vertical passages correspond to discrete

hypogenic trunks, inclined galleries follow dip, horizontal passages and some cave entrances record past base level positions (GALDENZI AND MENICETTI, 1995). In the Black Hills (South Dakota), Jewel and Wind Caves range among the largest maze caves of the world (Figure 6). Their genesis is complex, involving several early phases (PALMER, 2006), however the pattern resulting from the main speleogenetic phase is simply a dense network of enlarged discontinuities, similar to the previous examples.

2D maze caves

If an aquitard is present, the cave develops below this impervious ceiling as a 2D maze cave (Figure 7). The passages are horizontal or inclined in accordance with the dip. The Denis Paris system in the central part of the Paris Basin is horizontal. In Monte Cucco, the Faggeto Tondo develops below the inclined marly cover (cave indicated as no. 2 in Figure 5). The 2D maze cave is a subtype of 3D maze cave; some parts of 3D mazes locally develop as 2D mazes, when a less permeable stratum is present.

Deep phreatic shafts

In active tectonic areas, the combination of rising warm water, with CO_2 and H_2S outgassing concentrates speleogenetic processes along major fault lines, producing the deepest phreatic shafts of the world: Pozzo del Merro, Italy (-392 m); El Zacaton, Mexico (-329 m); Hranica propast, Czech republic (-267 m).

2. HYPOGENIC CAVE PATTERNS ALONG OR ABOVE THE WATER TABLE

Upwardly dendritic caves

Above thermal water, condensation occurs at the ceiling which is cooler. CO_2 and H_2S outgassing enhance aggressiveness. By condensation-corrosion, cupolas develop upward as a dendritic pattern of stacked spheres (AUDRA *et al.* 2007). The development of two neighboring spheres will be divergent, toward the greatest potential heat transfer, because the rock in between the two spheres has

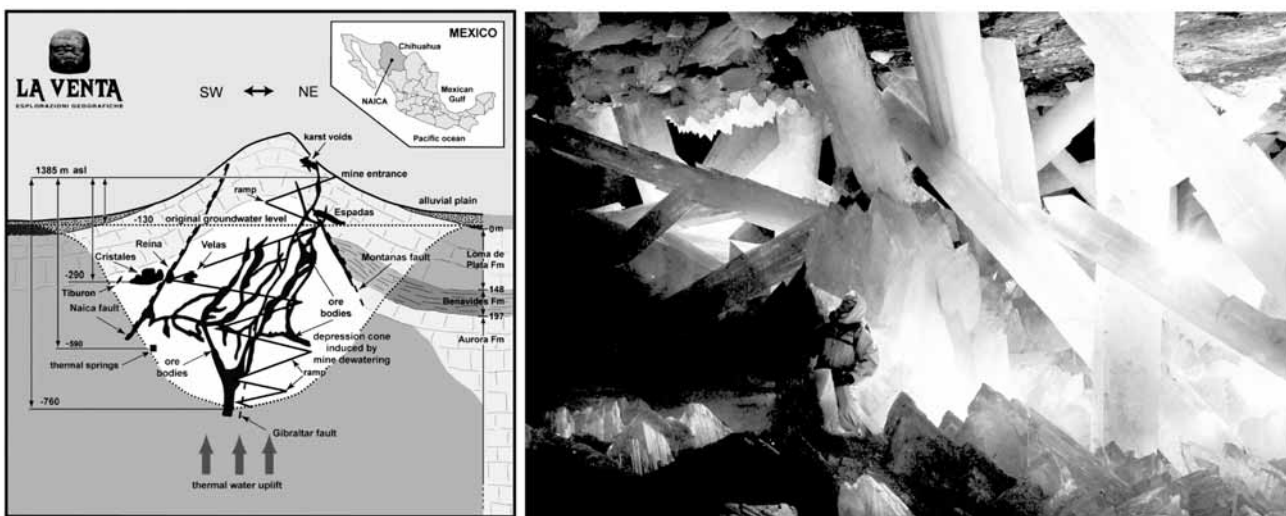


Figure 3. Cueva de los Cristales (Chihuahua, Mexico) was intersected and drained by the Naica mine (BERNABEI *et al.*, 2007). The gypsum swords in this cave are the largest crystals known in the world (photo. R. Tedeschi arkif Speleoresearch & Films and La Venta Exploring team)

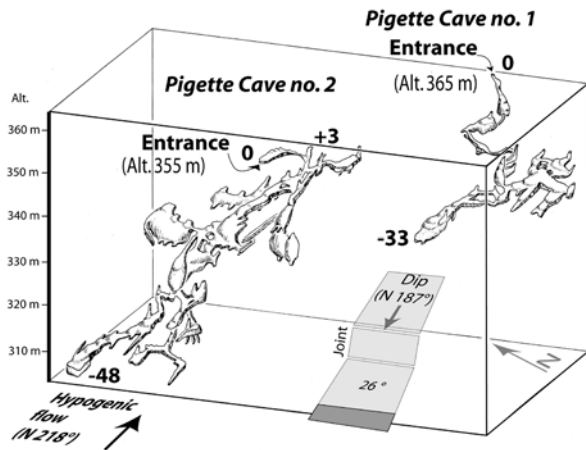


Figure 4. Perspective view of the Pigette Caves (France), a 3D multistorey maze cave originating in the phreatic zone by hypogenic upwelling, following structural weaknesses (inclined dip and vertical joints) (sketch by J.-Y. Bigot)

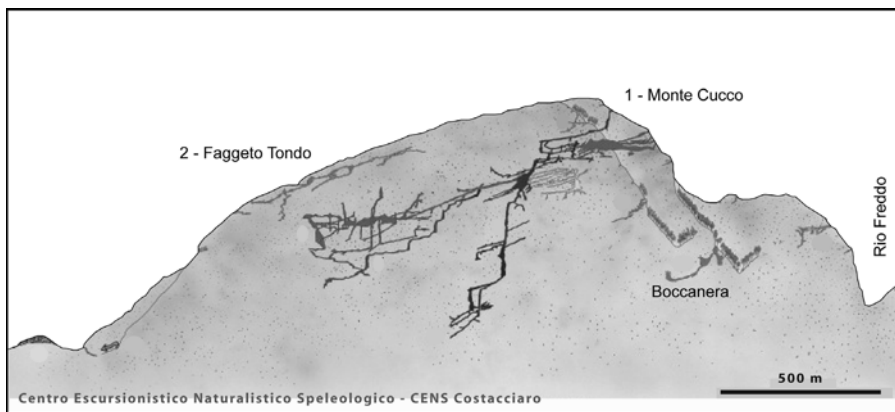


Figure 5. Monte Cucco System (Italy), probably the deepest known hypogenic cave system of the world (- 923 m / 31 km), with large shafts of several hundred meters of depth and ramps inclined along the dip of the anticline (CAIROLI *et al.*, 1991)

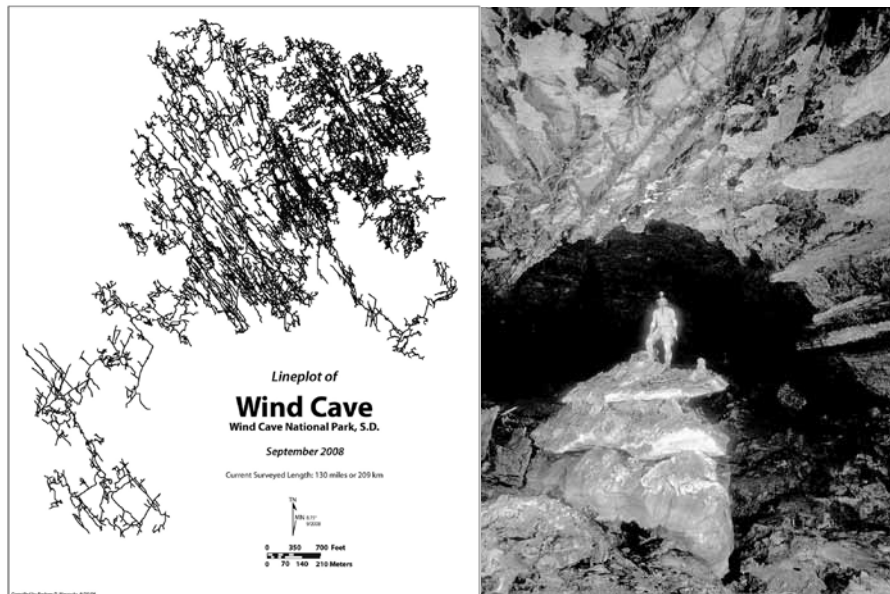


Figure 6. Wind Cave (USA), 209 km of passages in a 3D maze cave (map compiled by R. Horrocks; photo. A. Palmer).

less transfer potential and remains warm (SZUNYOGH 1990), giving the bush-like structure, as found in the Sátorköpuszta Cave, Hungary (Figure 9).

Isolated chambers

When strong degassing occurs, upwardly dendritic spheres enlarge and join together, eventually producing large isolated chambers (Figure 9; AUDRA *et al.*, 2002). Taking into account moderate thermal gradient and $p\text{CO}_2$, modeling has shown that such volumes can develop in a rather short time span, about 10 000 years (LISMONDE, 2003). From occurrences in Israel, FRUMKIN AND FISCHHENDLER (2005) assign the origin of isolated chambers to phreatic convections.

Water table sulfuric cave

Above the water table, sulfuric vapors and thermal convection cells produce strong condensation-corrosion and replacement gypsum crusts (EGEMEIER, 1981). The main drain develops headwards from springs (Figure 11). Due to the sulfuric corrosion the long profile displays only a

tiny gradient (Figure 12). Minor changes in base level cause the flow to migrate laterally, making incipient mazes (Figure 12) (AUDRA, 2007). Condensation domes develop upward and may breach the surface (Figure 11). The most illustrative water table sulfuric caves are Cueva de Villa Luz (Mexico), Chat Cave (France), Kane Caves (USA). In case of major base level lowering, successive horizontal cave levels develop: Frasassi Cave (Italy).

«Smoking» shafts in the vadose zone

Above thermal aquifers, the rock is significantly heated by the geothermal gradient. In winter the atmosphere of open shafts is unstable: cold air sinks into the shaft, expelling its warm air and creating condensation, giving the impression that the shaft is smoking. The air flow follows ceiling channels where condensation-corrosion focuses. Eventually, it produces condensation ceiling cupolas and channels, which can lead to misinterpreting them as phreatic in origin (Vapeur Shaft, France; Nasser Schacht, Austria; Fumarollas and Vapor Shafts, Spain). The origin of the shaft is generally a mechanical fracture (Figure 13); the hypogenic role through thermal gradient is indirect and limited to the etching of the wall features.

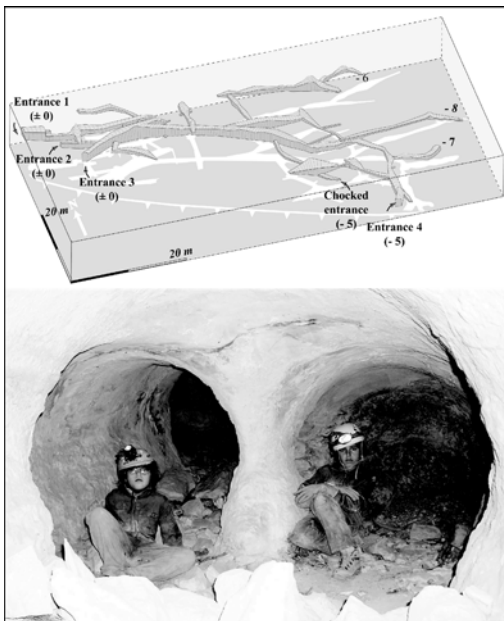


Figure 7. A sub-type of the 3D maze, the 2D maze confined under an inclined impervious roof. Grotte de Saint-Sébastien (France). The dip is towards the SE, water used to well up towards the left (sketch Ph. Audra, photo. J.-Y. Bigot)

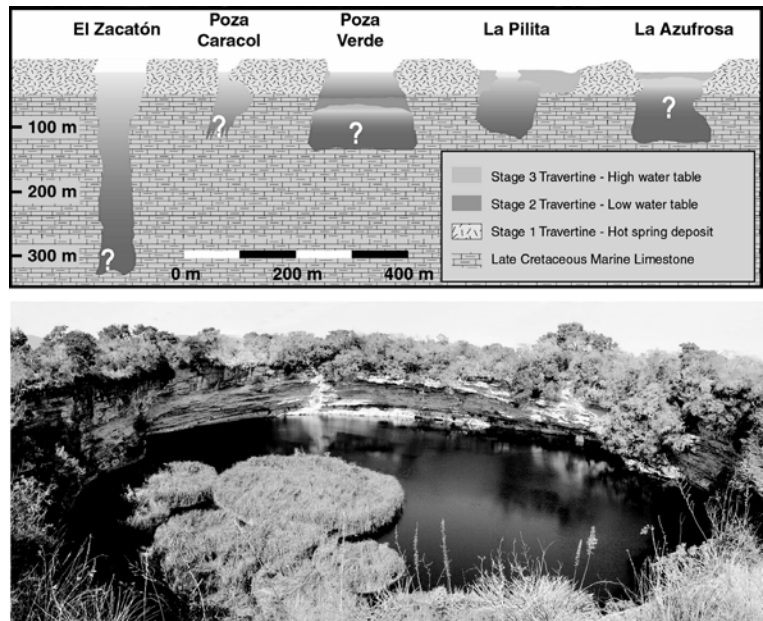


Figure 8. Deep phreatic shafts. Zacatón shaft is one of the numerous windows in the karst aquifer of the Tamaulipas area (Mexico), reaching a depth of 329 m (Photo A. Palmer). Investigation showed nearby volcanoes were the source of H₂S. Microbial activity based on sulfur oxidation is present (GARY AND SHARP 2006)

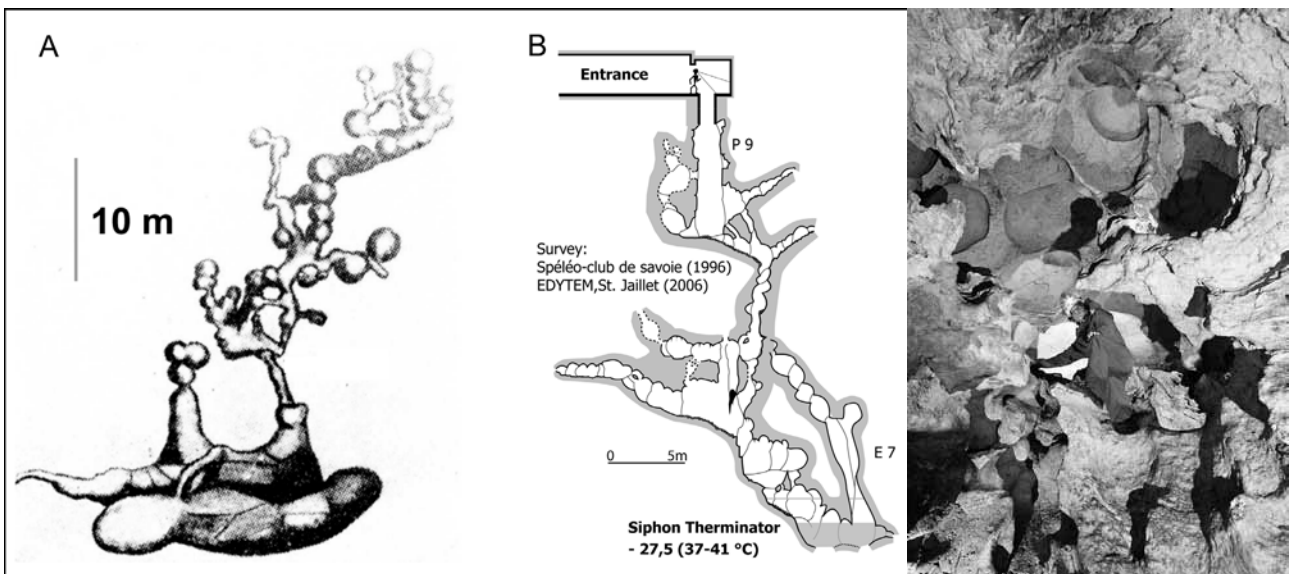


Figure 9. Upwardly dendritic caves. Left: Sátkörö-pusztá Cave, Hungary, has been used to represent thermal speleogenesis. Upwardly dendritic spheres develop above a basal chamber (survey in FORD AND WILLIAMS 1989). Center: Chevalley shaft, France (AUDRA *et al.*, 2007). Right: stacked up spheres in Serpents Cave, France, which is close to Chevalley (photo. S. Jaillot)

CONCLUSIONS

The diversity of hypogenic caves is now placed in a global model, explaining all of the kinds of patterns encountered, stressing their dependence on geological structure, groundwater recharge, and the particular speleogenetic processes at work. In addition to hypogenic

caves developed at depth by mixing corrosion and rising flow, some hypogenic caves develop in the atmosphere at -or above- the water table, mainly by condensation-corrosion, due to the combination of thermal convection, sulfuric and carbonic corrosion.

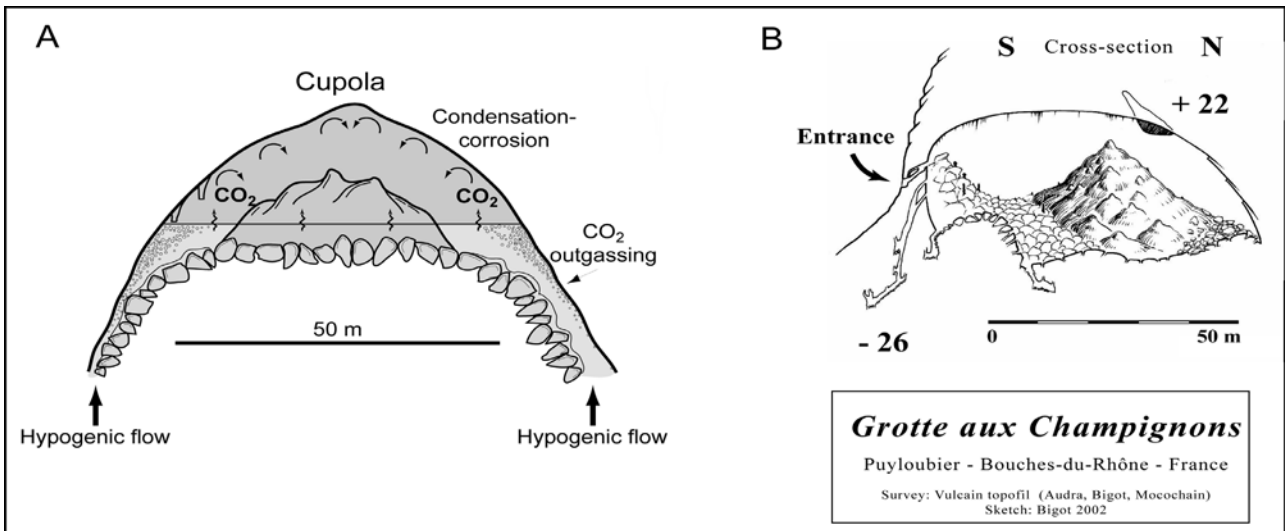


Figure 10. Isolated chambers. Thermal hypogenic flow degasses at shallow depth, thermal convection with CO₂ (or H₂S) gas enhances strong condensation-corrosion and the development of large isolated chambers. They tend toward a hemispherical shape. Simultaneously, a massive calcite deposit occurs in the lake, oversaturated after CO₂ degassing; Champignons, France (sketches J.-Y. Bigot)

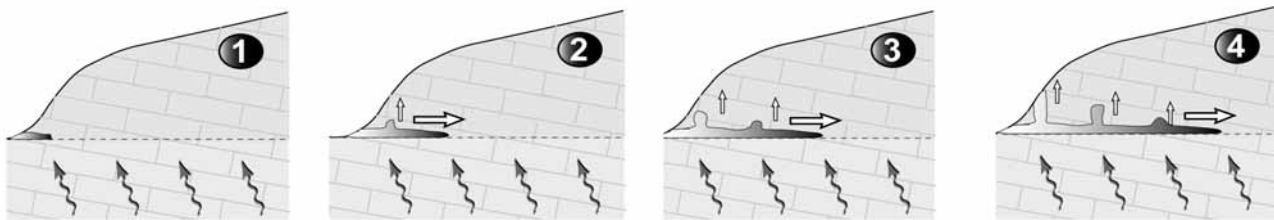


Figure 11. Water table Sulfuric cave. Headwards evolution by condensation-corrosion along the water table, supplied with major sulfuric upwelling along a fracture. Simultaneously, thermal water heats the air to induce convection, condensation-corrosion occurs, bells and chimneys develop, some finally break through to the surface. The white arrows indicate the direction of cave development (inspired from Cueva de Villa Luz, Mexico)

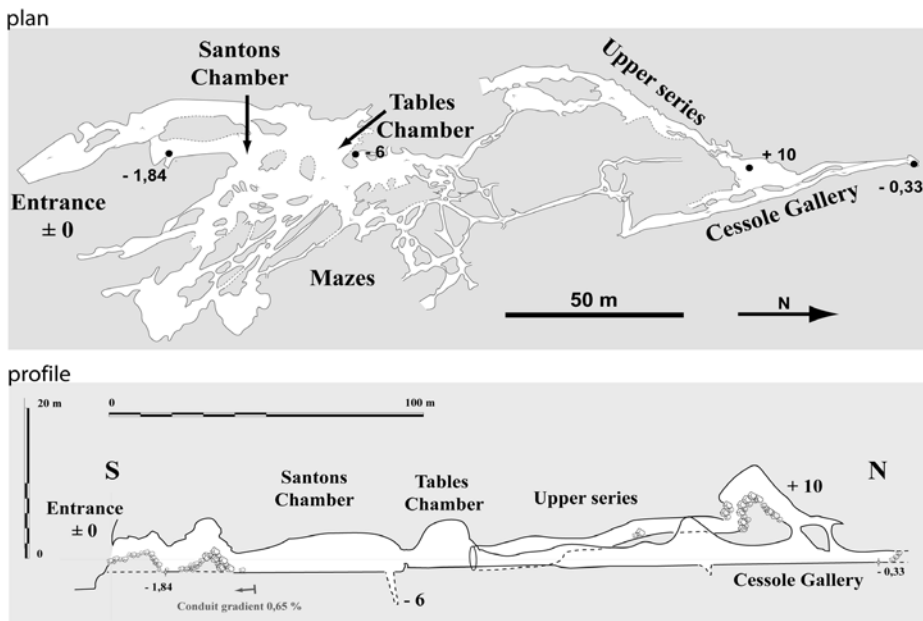


Figure 12. Chat Cave, France. The long profile with a very low gradient (0.7%) results from the sulfuric acidic water flow (plan from M. ROUSSEAU, profile Ph. Audra)

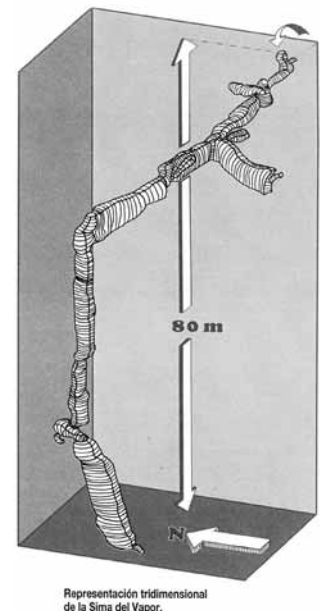


Figure 13. Sima del Vapor, Spain. The temperature of the air at bottom is 41 °C, giving rise to convective airflow in winter, with a condensation plume outside (survey Cuatro Picos, Cartagena)

REFERENCES

- Audra P. 2007. Karst et spéléogénèse épigènes, hypogènes, recherches appliquées et valorisation, 278 p. Habilitation Thesis, Nice.
- Audra P., Bigot J.-Y. and Mocochain L. 2002. Hypogenic caves in Provence (France). Specific features and sediments. *Acta Carsologica*, **3**, 33-50.
- Audra P., Hobléa F., Bigot J.-Y. and Nobécourt J.-Cl. 2007. The role of condensation-corrosion in thermal speleogenesis. Study of a hypogenic sulfidic cave in Aix-les-Bains. *Acta Carsologica*, **2**, 185-194.
- Bernabei T., Forti P. and Villasuro R. 2007. Sails: a new gypsum speleothem from Naica, Chihuahua, Mexico. *International Journal of Speleology*, **36:1**, 23-30.
- Cairolì E., Corsini M., Junker K., Leoni C., Galli M., Menichetti M., Rondoni R., Salvatori F., Gambaro C., Gigante M. and Magnini M. 1991. Massiccio del Monte Cucco - Guida naturalistica ed escursionistica, 151 p. Centro Nazionale di Speleologia, Costacciaro.
- Ford D. C. and Williams P. 1989. Karst geomorphology and hydrology. 601 p. Chapman & Hall, London
- Egemeier S. J. 1981. Cavern development by thermal waters. *NSS Bulletin*, **43:2**, 31-51. National Speleological Society, Huntsville.
- Ford D.C. 2006. Karst geomorphology, caves and cave deposits: A review of North American contributions during the past half century. In: *Perspectives on Karst Geomorphology, Hydrology and Geochemistry*, Harmon R.S. and Wicks C.W. (Eds.), GSA Special Paper, vol. **404**, Boulder, Colorado, 1-14.
- Frumkin A. and Fischhendler I. 2005. Morphometry and distribution of isolated caves as a guide for phreatic and confined paleohydrological conditions. *Geomorphology*, **67:3-4**, 457-471. Elsevier
- Galdenzi, S. and Menichetti, M. 1995. Occurrence of hypogenic caves in a karst region: examples from central Italy. - *Environmental Geology*, **26**, 39 – 47; Berlin, Heidelberg, New York (Springer).
- Gary M.O. and Sharp J.M. Jr. 2006. Volcanogenic Karstification of Sistema Zacatón. *Geological Society of America Special Paper*, vol. **404**, p. 79-89
- Klimchouk A. B. 2000. Speleogenesis under deep-seated and confined settings. In: *Speleogenesis. Evolution of karst aquifers*, Klimchouk, A., Ford, D.C., Palmer, A.N., and Dreybrodt, W., (Eds.), National Speleological Society, Huntsville, p. 244-260.
- Klimchouk A. 2007. Hypogene speleogenesis. Hydrogeological and morphogenetic perspective. NCKRI Special Paper Series, vol. 1, 77 p. National Cave and Karst Research Institute, Carlsbad, 106 p.
- Lismonde B. 2003. Limestone wall retreat in a ceiling cupola controlled by hydrothermal degassing with wall condensation. *Speleogenesis and Evolution of Karst Aquifers*, **1/4**, 3 p.
- Palmer, A.N. 1991 Origin and morphology of limestone caves. *Geological Society of America Bulletin*, **103**, 1-21.
- Palmer A. N. 2006. Cave geology. 454 p. Cave Books, Dayton
- Szunyogh G. 1990. Theoretical investigation of the development of spheroidal niches of thermal water origin – Second approximation.- *Proceedings of the 10th International Congress of Speleology, Budapest 1989*, III, 766-768, Hungarian Speleological Society, Budapest.

