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PSEUDOKARST COMMISSION NEWSLETTER

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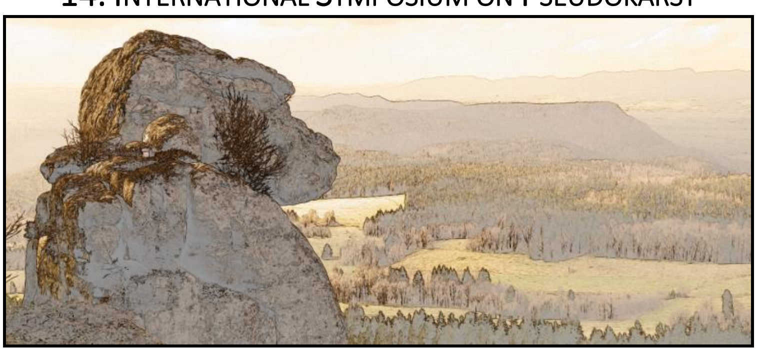
14. International Symposium on Pseudokarst



Kraków – Wien

FRONT COVER: Tham Meut Cave (481.5 m long), Ubon Ratchathani Province, Thailand (Photo L. Valenas).

BACK COVER: Kurza Stopka (Crow's Foot) Tor in the Błędne Skały rock labyrinth, Stołowe Mountains, Sudetes, Poland (Photo J. Urban).

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PREFACE / EDITORIAL NOTE

The "Pseudokarst Commission Newsletter" no. 30th (2022) was a special issue dedicated to the **International Year of Caves and Karst (2021-2022)**, as well as the **30th issue** and **25th anniversary** of the journal's edition. These reasons gave an accurate opportunity to propagate and disseminate the knowledge about non-karst caves that commonly occur around the globe. Although the current **31st issue of the "Pseudokarst Commission Newsletter"** is not assigned to such an occasion, it is not less significant and important, because it contains materials presented during the 14th International Symposium on Pseudokarst. This Symposium, after very long time, prolonged due to the pandemic situation and finally 8 years after the previous one, took place in the Stołowe (Table) Mountains and Broumov Highland (Poland and Czechia, respectively) – subregions of the Sudetes – in 24-27th May 2023. Therefore one key element of this issue is the report on this event, very briefly but comprehensively pointing out the most important elements and features of the Symposium, prepared by R. Pavuza. Important presentations at this symposium were therefore naturally descriptions of the state of research in the pseudokarst caves and other landforms that have developed in the very specific and impressive sandstone morphology of this area, as well as their value as geological heritage. In this context the most representative in the issue are both papers published by Jiři Kopecky describing cave explorations and scientific studies of root forms in caves of the Broumovská vrchovina Highland, the Czech part of the region. They are accurately supplemented by the description of the Broumovsko National Geopark, written by S. Stařik. The Polish part of the region – Stołowe Mountains – was comprehensively presented during the Symposium field sessions, but the scientific ideas expressed during these sessions can be found directly in the Symposium guidebook (see the Commission homepage http://www.pseudokarst.com/) or in the paper published slightly earlier in "Geomorphology" (Migoń et al. 2023). The problems of caves exploration and studies in the sandstone regions of the north-western part of Czechia (strictly: Kokořin region and Elbe Sandstones) are topics of two other papers presented by J. Adamovič and his collaborators.

Apart from these Central European speleological topics, several speeches during the Symposium concerned the exploration and genetical studies of caves occurring on the opposite side of the globe, which was partly possible due to the online participation of some lecturers. The papers relating these surveys are well represented in this issue of the "Newsletter". Among them are~~:~~ the comprehensive surveys (although comprising mainly explorations) of the caves in sandstones of Northeast Thailand written by L. Valenas, a review of non-karst caves genetical types of New Zealand's North Island, prepared by P. Crossley and G. Szentes, as well as an essay discussing the role of present-day extreme weather events in the morphological processes in sandstones of the Blue Mountains in New South Wales, Australia by J. Rowling. These papers, describing caves and other landforms developed in environmental and geological conditions completely differing from the central European ones, introduced quite new perspectives in the context of the Symposium in consideration of reasons and mechanisms of the speleogenesis in areas lacking classical karst rocks. Similar thoughts evoke the inclusion of two other papers, which were not presented during the Symposium, but we decided to include them into the "Newsletter" to broaden the perspective. These are: the description of very spectacular spacious and colorful sea caves of New South Wales in Australia prepared by G. K. Smith and a short supplementation of earlier reports on caves of remote volcanic islands in the middle of the Atlantic Ocean provided by R. Pavuza.

Very specific, but most probably good for sensing future trends in the perception of the geological heritage that obviously includes caves, is the proposal of the speleopark situated on the Atlantic coast of Galicia in Spain, submitted by M. Vaqueiro-Rodriguez.

The number of papers included into the no. 31st of the "Pseudokarst Commission Newsletter" is less than the number of the Symposium speeches and posters, which is a common situation, because usually not all authors want to publish their materials in the scientific-popular journals or they simply ran out of time. But – often extended – abstracts of all Symposium presentations are accessible on the Pseudokarst Commission homepage: http://www.pseudokarst.com/ .

At this point we want to encourage our members to have an occasional look at the homepage of "their" Pseudokarst Commission. There are several ways to contribute: updating data, adding photos and information about upcoming relevant events are just some of the possibilities!

Jan Urban,   Rudolf Pavuza

Migoń P., Duszyński F., Jancewicz K., Kotowska M., Porębna W. 2023. Surface-subsurface connectivity in the morphological evolution of sandstone-capped tabular hills – How much analogy to karst? Geomorphology 440: 22 pp, online: https://doi.org/10.1016/j.geomorph.2023.108884

PSEUDOKARST STUDIES IN THE BROUMOV AREA, CZECH REPUBLIC – SITUATION IN 2020

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1. Geology of the Broumovská vrchovina Highland

The Broumovská vrchovina Highland geologically represents the Czech part of the Intrasudetic Basin. The basin fill comprises sedimentary and volcanic rocks of Carboniferous, Permian, Triassic and Cretaceous ages, shaped into the form of a complex mid-altitude relief by geomorphic processes. About one-third of its area is covered by the Polická vrchovina Highland, composed of Upper Cretaceous sedimentary rocks, especially spiculitic marlstones and quartzose sandstones. Geological setting of the area was described by Tásler ed. (1979) and Čech and Gawlikowska (1999).

2. Geomorphological subdivision and definition of pseudokarst areas

The unit of Broumovská vrchovina Highland is subdivided into geomorphological subunits: 1) the Žacléřská vrchovina Highland (149 km^2) in the west, formed by Carboniferous and Permian sedimentary and volcanic rocks, 2) the Meziměstská vrchovina Highland (172 km^2) in the east, formed by Permian sedimentary and volcanic rocks and by Triassic sediments, and 3) by the Polická vrchovina Highland (224 km^2) in the middle, formed exclusively by Upper Cretaceous marine sediments (Fig. 1).

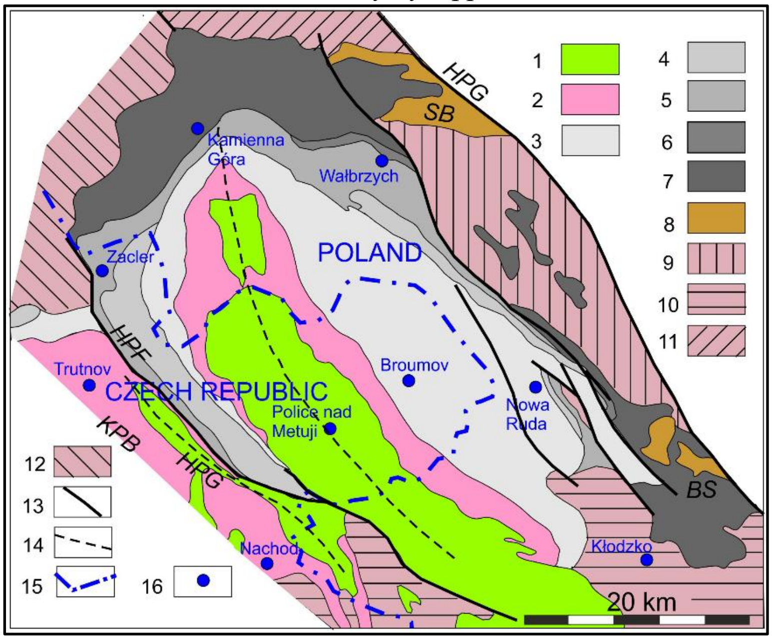

Fig. 1. Synoptic geological map of the Intrasudetic Basin (Tásler ed. 1979, adapted by J. Kopecký in 2013). Explanations: 1 – Upper Cretaceous, 2 – Saxonian, Thuringian and Lower Triassic (Trutnov, Bohuslavice and Bohdašín Fms.), 3 – Stephanian C, Autunian (Broumov and Chvaleč Fms.), 4 – Westphalian D, Stephanian A, B (Odolov Fm.), 5 – Namurian C, Westphalian A–C (Žacléř Fm. including Bialy Kamień Member in Poland), 6 – Namurian A (Walbrzych Mb.), 7 – Lower Carboniferous, 8 – Upper Devonian and Lower Tournaisian in the Świebodzice Basin, Silurian to Middle Devonian in the Bardo structure, 9 – Góry Sowie Crystalline Complex, 10 – Orlice-Kłodzko Dome (including magmatic rocks), 11 – weakly metamorphosed Lower Paleozoic of the Kaczawa Mts.; 12 – Krkonoše-Jizera Crystalline Complex; 13 – major fault; 14 – basin axis; 15 – state boundary, 16 – town; HPG – Hronov-Poříčí Graben; Hronov-Poříčí Fault – HPF, eastern part of the Krkonoše Piedmont Basin with the Trutnov-Náchod Depression – KPB, Outer Sudetic Fault – OSF, Świebodzice Basin – SB, Bardo Structure – BS.

The Polická vrchovina Highland, with a complex relief formed by quartzose sandstones and spiculitic marlstones, is particularly important for speleology. Cretaceous sediments 500–600 m thick were deformed into the shape of a brachysyncline due to the Alpine tectonic processes in the Neogene and Early Quaternary. This structure consists of many isolated blocks of different degrees of tectonic uplift and rotation. Major faults strike NW–SE (longitudinal faults) and NE–SW (transverse faults). The most important longitudinal faults of the Polická vrchovina Highland are the Police Fault and the Bělý Fault, the most important transverse structure is the Skály Fault. Such faults experienced a vertical displacement by 100 m or more. This tectonic setting set control on the subsequent geomorphic development including the drainage system of the area (Figs. 1 and 2).

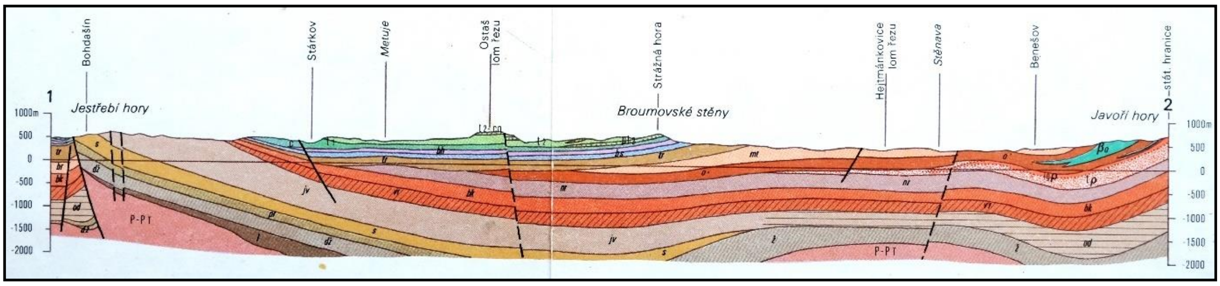

Fig. 2. A cross-section (principally of W-E direction) of the fill of the Czech part of the Intrasudetic Basin, covering the Žacléřská vrchovina Highland (left), the Polická vrchovina Highland (centre) and the Meziměstská vrchovina Highland (right) (after Tásler, Prouza eds. 1980). General explanations: pink colour – crystalline, mainly metamorphic basement; red (reddish), grey, brown and orange (also bluish-green) colours – Devonian, Carboniferous, Permian and Triassic sedimentary and volcanic rocks; dark and light green, yellowish green colours – Upper Cretaceous sandstones and marls.

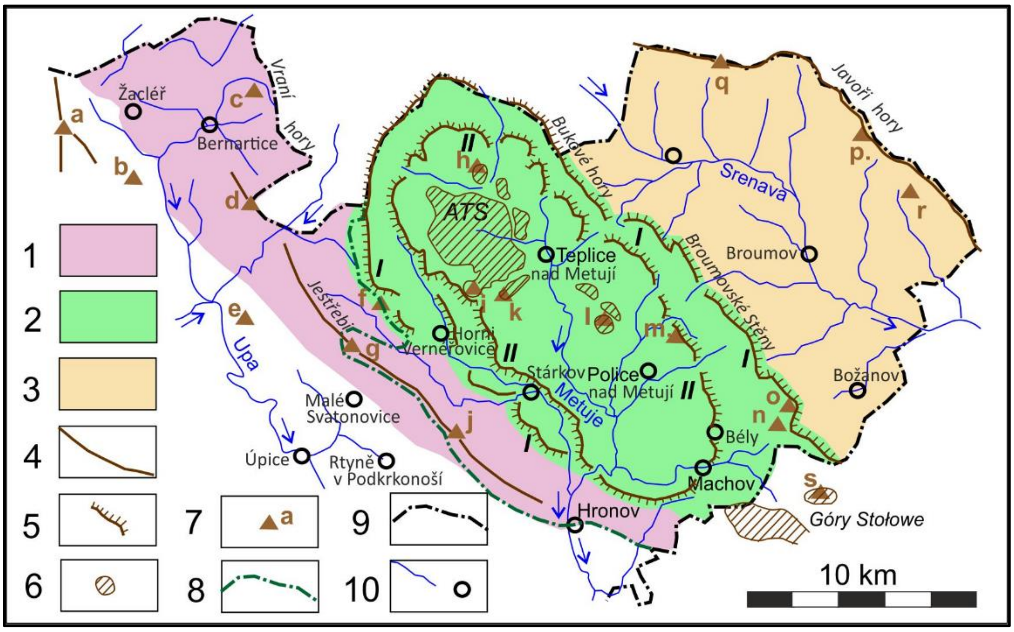

Fig. 3. Subdivision of the Broumovská vrchovina Highland into three geomorphological subunits (Tásler ed. 1979, adapted by J. Kopecký in 2013). Explanations: 1 – Žacléřská vrchovina Highland, 2 – Polická vrchovina Highland, 3 – Meziměstská vrchovina Highland, 4 – principal ridge, 5 – escarpment (cuestas) outer (I) and inner (II), 6 – structural plateau (Adršpašsko-teplícké skály – ATS), 7 – prominent elevations: a – Rýchory 1033 m, b – Hřebínek 633 m, c – Špičák 881 m, d – Janský 697 m, e – Čížkovy kameny 632 m, f – Hradiště (Rač) 710 m, g – Žaltman 739 m, h – Křížový vrch 567 m, i – Čáp 735 m, j – Švédský vrch 660 m, k – Skály 695 m, l – Ostaš 700 m, m – Klůček 614 m, n – Božanovský Špičák 773 m, o – Koruna 769 m, p – Bobří vrch 740 m, q – Ruprechtický Špičák 881 m, r – Rudný vrch 654 m, s –Szczeliniec Wielki 919 m), 8 – limit of the Broumovsko Protected Landscape Area, 9 – state boundary, 10 – town or village, stream or river.

The axis of the drainage pattern is now represented by the Metuje River and its tributaries Ledhujka, Židovka and Dřevíč, flowing to the Elbe River and the North Sea. The ridges of the outer cuestas form a divide between the North Sea and the Baltic Sea. The latter is the destination of waters draining the easterly-neighbouring Meziměstská vrchovina Highland. The combination of the basin-like shape of the Polická vrchovina Highland and the presence of impermeable rocks beneath the sandstones of the basin fill became the background for the presence of aquifers with significant resources of high-quality groundwaters. Erosional processes resulted in the formation of generally smooth landforms on marlstones, contrasting with rugged relief on more resistant sandstones, locally having the character of extensive rock cities. Orthogonally jointed sandstones are exposed to external agents, contributed by gravitational slope movements, rock disintegration and rockfall, piping and removal of weathering products. The height of outcrops in this rocky relief reaches 100 m or more.

The Polická vrchovina Highland is further subdivided into the following geomorphological districts: Polická stupňovina, Broumovské stěny and Stolové hory/Góry Stołowe (their Czech part) along the circumference, and the Police Basin and Adršpach-Teplice Cliffs in the middle. Separate geomorphological forms in the Police Basin are Mt. Ostaš, Mt. Hejda and the Kočičí skály Cliffs (Figs. 4, 5 and 6).

The geomorphology and geomorphological subdivision of the area were discussed by a number of authors starting from Demek ed. (1965), then Czudek (1972), Balatka et al. (1973) and repeatedly by Demek and Mackovčin eds. (2006, 2014). These studies, extended by the inclusion of subsurface pseudokarst phenomena (caves, abysses), were used as a basis for the subdivision of pseudokarst regions and subregions in this area (Fig. 4).

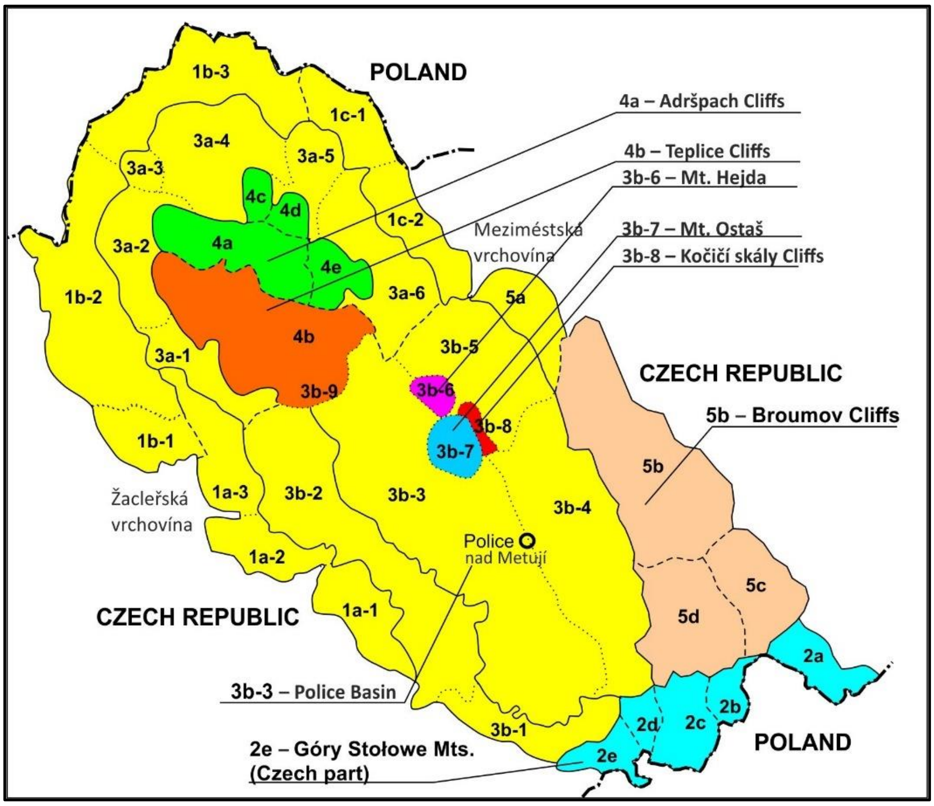

Fig. 4. Subdivision of pseudokarst terrains of the Polická vrchovina Highland into pseudokarst regions and subregions. Drawing by J. Kopecký in 2022. Geomorphological subdivision after Demek and Mackovčin eds. (2006) adapted by J. Kopecký in 2013. Different colours denote individual pseudokarst regions and subregions.

Fig. 5. A general view from the Teplice Cliffs towards the Broumov Cliffs and Góry Stołowe Mts. in the background (Photo O. Jenka).

Fig. 6. A general view of the Adršpach rock city (Photo O. Jenka).

Fig. 7. An aerial view of the surface relief of the sandstone plateau of the Teplice rock city (Photo L. Jenka).

3. Pseudokarst phenomenon: surface and subsurface

Since mid-1990s, the varied, almost bizarre shapes of sandstone cliffs have been attracting experts on the genesis, typology and classification of surface and subsurface phenomena in non-karstic rocks, generally referred to as pseudokarst (Kunský 1957; Panoš 1965; Vítek 1977; Balatka, Sládek 1984). The research was significantly contributed by speleology. Subdivision of landforms contributing to the pseudokarst relief is, as follows:

- macroforms: slot canyons, canyons, crevices, plateaus and ridges forming hydrological divides, rock pillars and rock towers
- mesoforms: caves, abysses and rock shelters (abris), dolines, rock perforations of various types (rock windows, arches, tunnels) and cliffs of tors type
- microforms: cavities and niches, honeycombs, karren and solution basins.

Relief of the Polická vrchovina Highland also projects into three forms of pseudokarst modelling (Figs. 4, 5, 6 and 7):

- zone weakly affected by erosion (flat or basinal surface covered with weathering products, only low outcrops),
- zone dissected by gorges and covered by outcrops of tors type – dominant in all areas of local pseudokarst surface
- zone of rock cities with prominent vertical diversification by deep canyons, gorges and crevices, with rocky ridges and individual rock pillars as much as 100 m tall, prominent and varied modelling of surface - especially in the Adršpach and Teplice Cliffs but also in parts of Mt. Hejda, Mt. Ostaš (Bludiště) and many parts of the Broumov Ciffs including the Czech part of the Góry Stołowe.

The second and third zones also include subsurface pseudokarst phenomena: caves and abysses.

The local geology and geomorphology of rock cities is highly favourable for the origin of subsurface pseudokarst phenomena, which have been reported since the beginning of pseudokarst studies here (Kunský 1950; Rubín, Skřivánek 1963; Vítek 1980; Kučera et al. 1981). A morphogenetic typology of pseudokarst and typology of pseudokarst caves have been proposed (Vítek 1980, 1981). Besides, all types of pseudokarst phenomena have been reported from the Broumov area sandstones (Table 1) (Vítek 1979). These studies became the starting point for subsequent speleological investigations in the sandstone rock cities in this area.

Table. 1. Typology of pseudokarst caves and their documentation indices (after Vítek 1979).

Locality type	**Index**
Fissure cave	01
Bedding-parallel cave	02
Shelter cave/cave niche (rock shelter)	03
Crevice cave	04
Talus cave (boulder cave)	05
Combined cave, e.g.	12 = fissure-bedding cave 45 = crevice-talus cave

4. Research, registry and documentation of pseudokarst caves – state in 2020

The speleological research of pseudokarst studies in the Broumov area was started by the Group of Karst Tourism of the Tourist Department of the Sporting Club Broumov in 1970s. This effort produced first data on the character of local sandstone pseudokarst, being guided by collaboration with the State Institute of Cultural and Natural Heritage in Prague (Dr. F. Skřivánek and Dr. J. Hromas), by the inspiring contacts with Czech and Slovak caving clubs and by several trips to the neighbouring karst and pseudokarst areas. Much information collected by this group could be later exploited by the first scientific description of pseudokarst in the Broumov area (Vítek 1979). In 1979, one year after the foundation of the Czech Speleological Society (CSS), this group transformed into a caving club of the CSS under the name 5-03 Broumov. The paper "Pseudokarst forms in sandstones of northeastern Bohemia" (in Czech language: Vítek 1979) became the starting material for later speleological activities, and its author Dr. J. Vítek became one of the collaborating experts.

Research, inventory and documentation of pseudokarst became the aim of the newly established caving club. The club received an exception from the conservational regulations in protected areas, being permitted to enter nature reserves. The focus on pseudokarst was exceptional: only a few caving clubs of the CSS were dealing with pseudokarst, mostly in combination with the study of karst or historical underground spaces. Specific was not only the pristine character of these terrains as for caving but also the interest of the nature-conservation authorities in the recording of all pseudokarst phenomena. Therefore, speleological activities were focused not only on the inventory and documentation of caves, but also their geo- and biogenic fillings, the study of meso- and microclimatic conditions in the subsurface and in climatically inverted parts of rock cities, and also the registry of important surface pseudokarst phenomena. The priority was the inventory of pseudokarst caves and abysses, which was conducted on a year-round basis in the following activities:

- basic speleological research in separate parts of the pseudokarst relief, recording not only subsurface localities (caves, abysses, rock shelters) but also prominent surface phenomena,
- documentation of subsurface sites and also selected surface parts of pseudokarst relief to obtain their geometry and dimensions (length, altitude difference),
- inventory, documentation and monitoring of mineral and biotic fillings of underground spaces, such as forms of cave mycorrhiza,
- study and monitoring of meso- and microclimate,
- study and documentation of anthropogenic effects in the pseudokarst relief (carvings, speleoarchaeology).

Besides the growing number of registered caves, the number of documented caves also started to rise in the last two decades (Table 2, Fig. 8). Only in the year 2020, the area of Kočičí skály received its complex geomorphological and speleological documentation, as the first of 8 speleological districts in the Broumov area (Jenka, Kopecký eds. 2020).

Table 2. Numbers of caves registered in the individual speleological districts in the Broumov area.

Pseudokarst district	**Numbers of caves registered***			
	1980	**2000**	**2010**	**2020**
01. Adršpach Cliffs	6	13	14	14
02. Teplice Cliffs	15	44	55*	56*
03. Mt. Ostaš	4	22	22	22
04. Kočičí skály Cliffs	2	14	20	21
05. Mt. Hejda	0	27	27	27
06. Broumov Cliffs	10	26	28	43
07. Góry Stołowe (Czech part)	0	1	1	1
08. Police Basin (marlstones)	0	1	1	1
Total	**37**	**148**	**168**	**185**

* *numbers registered by Caving Club 5-03 Broumov without registry at Caves Administration CR*

Cave documentation was also conducted in other pseudokarst areas, giving attention to large block accumulations on valley bottoms with complex cave systems hosting subterranean streams (Figs. 9 and 10). Documentation of such spaces had the character of a transverse cross-section of the Pod Luciferem Cave system (Kopecký ed. 2012) and Teplická Cave (Kopecký ed. 2016, 2017a). Documentation of surface pseudokarst forms and their series was also performed. Specific documentation was made at localities with root forms, the methodology of which was based on experience from the Broumov area (Kopecký 1999, Kopecký ed. 2021).

The Caving Club 5-03 Broumov was constantly informing the caving community about its activities and the current state of pseudokarst research. The First and the Second International Symposium on Pseudokarst were organized by this Club at Janovičky u Broumova already in 1982 and 1985 (Kopecký 1982, 1989). Information was also provided at other international or domestic symposia, conferences and workshops. Pseudokarst and speleology was the theme of a separate document substantiating the establishment of the Broumovsko Protected Landscape Area (PLA) (Jenka, Kopecký 1987). Many popular articles were published, especially in local newspapers.

Pseudokarst phenomena of the Broumov area as viewed by nature conservation at national level were first included in the publication on protected areas of the Hradec Králové Region (Kopecký 2000), the inventory of pseudokarst caves in this area was then included in their national review (Kopecký et al. 2009). A constant updating of the inventory is now conducted for the nature conservation authorities through the JESO (United Registry of Speleological Objects) kept with the Caves Administration of the Czech Republic, see Fig. 8.

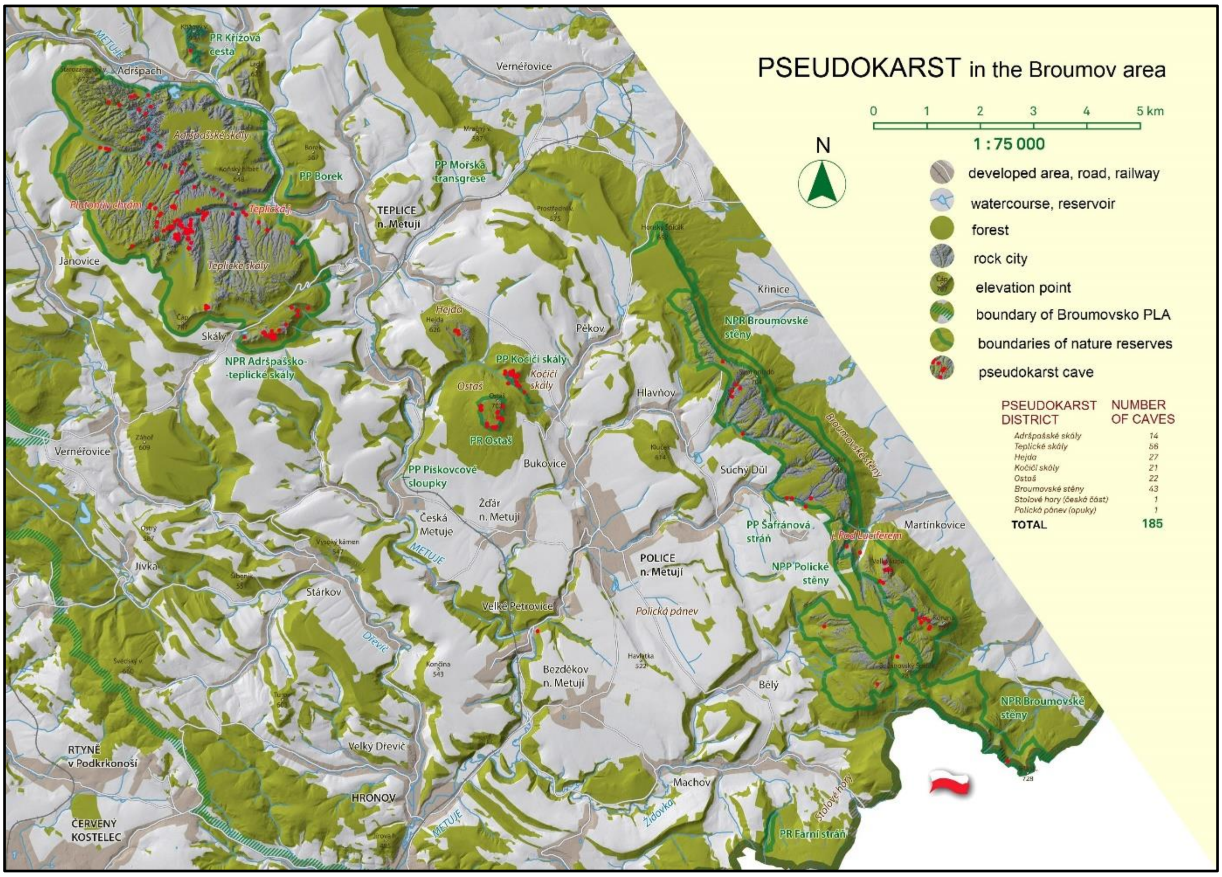

Fig. 8. A map showing the distribution of caves in sandstone pseudokarst terrains of the Polická vrchovina Highland; drawing by I. Balák in 2020 based on data from the JESO registry.

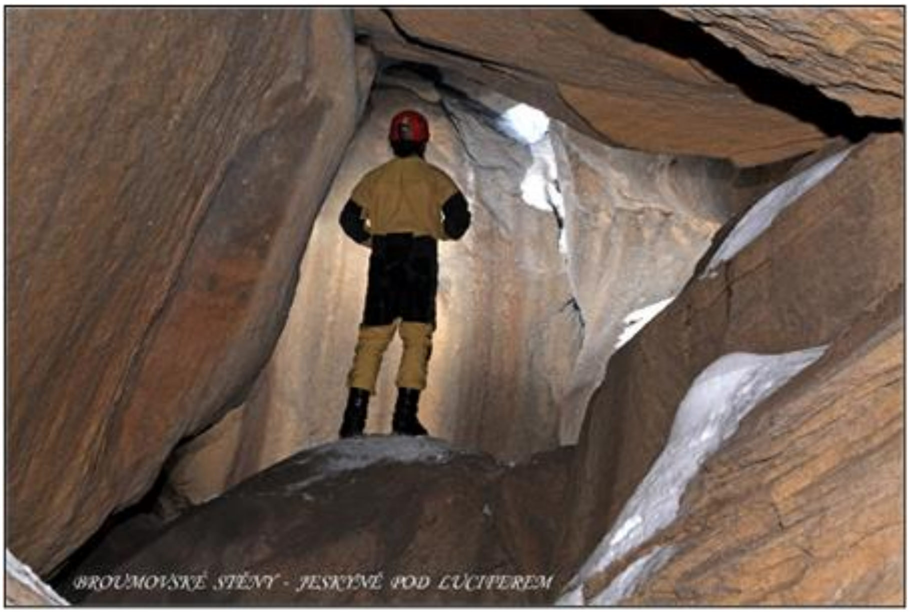

Fig. 9. A chamber limited by blocks from all sides in the Pod Luciferem Cave system (Photo O. Jenka).

Fig. 10. The new part of the boulder cave of Jelení propast in the Czech part of the Góry Stołowe Mts. (Photo J. Kopecký jr.).

5. Further studies and monitoring of the pseudokarst phenomenon

The exceptional variety of the rock environment and biota of the pseudokarst relief in the Broumov area, both on the surface and in the subsurface, resulted in a broad concept of speleological activities. Besides the research, inventory and documentation of caves, abysses and the most valuable elements of the surface relief, the activities of Caving Club 5-03 Broumov tackled many related issues. The number of sites with cave mycorrhiza became the target of specific research, soon becoming an independent biospeleological theme seriously studied by teams of experts in the Czech Republic and abroad (see the specific contribution in this volume). In this context, the occurrence of glacial relics among invertebrates was confirmed in the coldest parts of the rock cities. Cavers from this area also initiated, and contributed to the subsequent monitoring of invertebrate and small vertebrate fauna (Růžička, Kopecký 1998).

The Caving Club 5-03 Broumov was also involved in geomonitoring in collaboration with Polish colleagues from the Agriculture Academy in Wrocław (currently: Wrocław University of Environmental and Life Sciences). Points of a small-scale geodetic network at Mt. Ostaš were chosen and fixed, much like those of the connective geodetical network Mt. Ostaš–Mt. Szczeliniec (Hejšovina). The Club also assisted at all measurement campaigns led by Polish geodesists and contributed to the maintenance of these networks (Krtička, Kopecký 1990). Collaboration with the Institute of Rock Structure and Mechanics of the Czech Academy of Sciences, started in 1985, resulted in the installation of 8 devices TM-71 within the OSTAŠ system, located at Mt. Ostaš, Kočičí skály Cliffs and Mt. Hejda. The Club members still conduct regular readings from the devices (on a monthly basis) including the necessary field maintenance (Kopecký 2005).

Caving Club 5-03 Broumov was involved in the registry of the most spectacular examples of ferruginization in sandstones and the study of the effects of iron cementation on the formation of bizarre small- and medium-scale landforms including the registry of secondary pisolite formation in caves (Kopecký 2002; Kopecký, Jenka, Adamovič 2002) and diverse forms of ice in the caves. Of great importance is also the basic monitoring of climate in the caves and in climatically inverted portions of the rock cities (Kopecký 1998), the most important of which is the completed recently monitoring in the Kočičí skály Cliffs (Kopecký ed. 2017b).

6. Conclusion

Speleological activities in the Broumov area, having an almost 50-years' history, proved that the local pseudokarst terrains, both surface and subsurface, belong among the most valuable of their kind. The achieved results in the study of a wide range of geological, geomorphological and biological phenomena permitted to conclude on the hierarchical arrangement of terms in pseudokarst studies:

- **sandstone phenomenon** is the set of living and inanimate components of the landscape associated with a specific type of pseudokarst relief;
- **sandstone relief** is a set of all landforms ranging from a mesa or a structural plateau to a honeycomb pit in size, i.e., a complex set of macro-, meso- and microforms developed in sandstone terrains;
- **sandstone pseudokarst** is a set of landforms notably similar to (or morphologically identical with) forms in limestone karst.

Pseudokarst terrains in the Broumov area continue to be highly promising for subsequent speleological activities, giving a chance for discoveries of new, unexpected underground spaces and their spectacular fillings. It can be estimated that the number of presently registered caves of 185 presents only about one-third of the total number. Great effort will be especially needed for the documentation of surface and subsurface localities of speleological interest. It can be surely stated that the Broumov area provides opportunities for the next several generations of active cavers.

References

Balatka B. et al. 1973. Regionální členění reliéfu ČSR. Sborník Československé společnosti zeměpisné, 78, Praha: 81-96.

Balatka B., Sládek J. 1984. Typizace reliéfu kvádrových pískovců České křídové tabule. Rozpravy Československé akademie věd, 94 (6), Praha, 80 pp.

Czudek T. 1972. Geomorfologické členění ČSR. Studia geographica, 23, Brno, 138 pp.

Čech S., Gawlikowska E. 1999. Góry Stołowe, mapa geologiczno-turystyczna. Adršpašsko-teplické skály, geologická mapa pro turisty. Państwowy Instytut Geologiczny, Český geologický ústav, Warszawa–Praha.

Demek J. (Ed.) 1965. Geomorfologie Českých zemí. Československá akademie věd, Praha, 336 pp.

Demek J., Mackovčin P. (Eds.) 2006. Zeměpisný lexikon ČR. Hory a nížiny. Agentura ochrany přírody a krajiny ČR, Brno, pp. 582.

Demek J., Mackovčin P. (Eds.) 2014. Zeměpisný lexikon ČR. Hory a nížiny. I– II. 2nd Ed. Mendelova zemědělská univerzita Brno, 595 pp. + maps.

Jenka O., Kopecký J. 1987. Speleologie v CHKO Broumovsko (Oborový dokument). Krajské středisko státní památkové péče a ochrany přírody Východočeského kraje v Pardubicích (manuscript). Archives of Broumovsko PLA, Broumov, and Czech Speleological Society, Prague.

Jenka O., Kopecký J. (Eds.) 2020. Kočičí skály a jejich pseudokrasový fenomén (manuscript: 22 pp, 28 appendices). Archive of the Czech Speleological Society, Prague.

Kopecký J. 1982. Pseudokrasové jeskyně v kvádrových pískovcích Broumovské vrchoviny. In: Sborník 1. sympozia o pseudokrasu v ČSSR, Česká speleologická společnost, Praha: 61-68.

Kopecký J. 1989. Stav a problematika výzkumu pseudokrasu v kvádrových pískovcích Broumovské vrchoviny. In: Sborník 2. sympozia o pseudokrasu, Knihovna České speleologické společnosti, 10, Praha: 127-133.

Kopecký J. 1998. Současný stav měření mikroklimatu v pseudokrasových terénech Broumovské vrchoviny. In: Pískovcový fenomén: klima, život, reliéf. Knihovna České speleologické společnosti, 32, Praha: 16-24.

Kopecký J. 1999. Dokumentace kořenových tvarů. In: Pseudokrasový sborník I., Knihovna České speleologické společnosti, 35, Praha: 61-68.

Kopecký J. 2000. Geologická, geomorfologická, klimatická, paleontologická a speleologická charakteristika – CHKO Broumovsko. In: Mackovčin P., Sedláček M. (eds.), Chráněná území ČR – díl V.: Královéhradecko AOPK ČR, Praha: 234-272.

Kopecký J. 2002. Proželeznění pískovců skalních oblastí Polické vrchoviny. In: Pseudokrasový sborník 2, Knihovna České speleologické společnosti, 27, Praha: 57-62.

Kopecký J. 2005. Geolaboratoř Ostaš. Broumovské noviny č.1/2005, 12-13.

Kopecký J. (Ed.) 2012. Jeskyně pod Luciferem (manuscript 9 pp., appendices). Archive of the Czech Speleological Society, Prague.

Kopecký J. (Ed.) 2016. Speleologická a geomorfologická dokumentace vyměřeného příčného profilu č. 2. „Propad“ přes blokovou akumulaci dna Vstupní rokle a systému Teplické jeskyně (manuscript: 10 pp, appendices). Archive of the Czech Speleological Society, Prague.

Kopecký J. (Ed.) 2017a. Teplická jeskyně – příčný profil č. 2 „Hlavní vchod“. (Příčný profil vedený napříč dnem Vstupní rokle a tzv. Hlavním vchodem do systému Teplické jeskyně) (manuscript: 10 pp, appendices). Archive of the Czech Speleological Society, Prague.

Kopecký J., (Ed.) 2017b. Mezo- a mikroklima jeskyní Kočičích skal (Jednorázové přeměření mezoklimatu ve skalním terénu Kočičích skal a mikroklimatu zdejších pseudokrasových jeskyní) (manuscript: 9 pp, appendices). Archive of the Czech Speleological Society, Prague.

Kopecký J. (Ed.) 2021. Metodika popisu a dokumentace kořenových struktur (manuscript: 8 pp, appendices). Archive of the Czech Speleological Society, Prague.

Kopecký J., Jenka O., Adamovič J. 2002. Broumovsko. In: Železivce české křídové pánve. Knihovna České speleologické společnosti, 38, Praha: 128-137.
Kopecký J., Mlejnek R., Ouhrabka V. 2009. Pseudokrasové jeskyně křídy vnitrosudetské deprese. In: Hromas J. (Ed.), Chráněná území ČR – díl XIV. Jeskyně. Agentura ochrany přírody a krajiny ČR, Praha: 341-352.
Krtička L., Kopecký J. 1990. Geodetická prostorová síť na Ostaši v Broumovské vrchovině. In: Sborník 4. sympozia o pseudokrasu, Podolánky (Beskydy). Knihovna České speleologické společnosti, 23, Praha: 54-60.
Kučera B., Hromas J., Skřivánek F. 1981. Jeskyně a propasti v Československu. Academia, Praha, 252 pp.
Kunský J. 1950. Kras a jeskyně. Přírodovědné nakladatelství, Praha, 200 pp.
Kunský J. 1957. Typy pseudokrasových tvarů v Československu. Československý kras 10: 108-125.
Panoš V. 1965. Problém krasovění nekarbonátových hornin. Časopis pro mineralogii a geologii 10: 105-109.
Rubín J., Skřivánek F. 1963. Československé jeskyně (Turistické zajímavosti ČSSR). Sportovní a turistické nakladatelství, Praha, 106 pp.
Růžička V., Kopecký J. 1998. Pavouci pseudokrasových jeskyní v severovýchodních Čechách. In: Pískovcový fenomén: klima, život a reliéf. Knihovna České speleologické společnosti, 32. Praha: 102-112.
Tásler R. (Ed.) 1979. Geologie české části vnitrosudetské pánve. Ústřední ústav geologický, Academia, Praha, 296 pp.
Tásler R., Prouza V. (Eds.) 1980. Přehledná geologická mapa broumovského výběžku 1:100 000. Ústřední ústav geologický, Praha.
Vítek J. 1977. Povrchové tvary v křídových pískovcích severovýchodních Čech. Památky a příroda 2, 7: 425-429.
Vítek J. 1979. Pseudokrasové tvary v kvádrových pískovcích severovýchodních Čech. Rozpravy Československé akademie věd 89, 4, Praha, 57 pp.
Vítek J. 1980. Typy pseudokrasových jeskyní v ČSR. Československý kras 30: 17-28.
Vítek J. 1981. Morfogenetická typizace pseudokrasu v Československu. Sborník Československé geografické společnosti 86, 3: 153-156.

GEOPARK BROUMOVSKO – THE LAND OF SANDSTONES

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The Broumovsko National Geopark, founded in 2011 and certified as National Geopark in 2018, is located in the northeastern Bohemia over the entire territory of the so-called Broumovský výběžek and the territory of the Žacléř region. Its territory is delineated according to the administrative division within the boundaries of the Broumovská vrchovina (Broumov Upland) region, which in fact corresponds to the Czech part of the Intra-Sudetic Basin geological unit. The total area of the Broumovsko Geopark is 570 km^2. More than 80 interpretive geosites are presented within this area (Fig. 1).

Fig. 1. Location of the Broumovsko Geopark.

The geological richness and geological history of the Broumovsko Geopark are interpreted in an engaging and comprehensible way for the general public, both on the website and on field trips and lectures. Emphasis is placed on an understanding of important natural and geological patterns in relation to contemporary everyday life. Geotourism attractions are linked to three genetically distinct geological areas and structures.

The southwestern part of the Broumovsko Geopark presents the oldest rocks in the region, Carboniferous sandstones and conglomerates with a number of coal-bearing assemblages of various thicknesses. They can be observed in the numerous rock outcrops forming often crags (Fig. 2), on the structurally (tectonically) condi-

Fig. 2. Crag formed of Carboniferous arkosic sandstones on the Jestřebí hory ridge (Photo S. Stařík).

tioned ridge of the Jestřebí hory mountains. The oldest local Carboniferous strata date back to approximately 315 Ma (Šimůnek, Libertin 2001). The more than 400-year-long history of coal mining in the region of northeastern Bohemia is linked to the Carboniferous outcrops here.

The northeastern part of the Broumovsko Geopark area comprises the distinctive Javoří hory mountains, built of volcanic and volcanoclastic rocks of basalt-andesite to rhyolite composition, alternating with various alluvial and lacustrine sediments of the Broumovská kotlina (Broumov basin (Fig. 3). Both volcanic and sedimentary rocks are of the Permian age, ranging approximately 295-275 Ma (Awdankiewicz et al. 2014; Awdankiewicz 2022).

Fig. 3. Permian sandstone cliff in Hynčice, Broumovská kotlina (Photo S. Stařík).

The substratum of the central part of the Broumovsko Geopark represents the geomorphologically distinct brachysynclinal structure of the Polická křídová pánev (Police Cretaceous Basin). The marginal units, formed by massive arkosic and glauconitic sandstones, are overlain in the central area by sandy marlstones and relicts of the youngest quartz sandstones that form rock cities (Fig. 4). All the mentioned marine sediments are of the Upper Cretaceous age, ranging 95-89 Ma. The development stage of the sandstone rock cities is supported by the extensive occurrence of pseudokarst phenomena, especially scree and fissure caves (Adamovič et al. 2020; Vítek 2016).

Fig. 4. Cretaceous quartz sandstones forming towers and arc in the Adršpach rock city (Photo S. Stařík).

In addition to the geomorphological and pseudokarst phenomena of sandstone rock cities, objects of professional interest in the Broumovsko Geopark are also fossils of an Upper Cretaceous marine fauna, specific Permian volcanic rocks and structures, fossils of Permian fauna and flora, as well as an exceptionally rich occurrence of Carboniferous plant fossils.

Geopark development activities are currently focused on thematic geoscience field excursions with a professional guidance, environmentally oriented educational programs for schools, cooperation with local municipalities in maintaining geosites and building geotourism infrastructure. Cooperation with other geoparks and important national and foreign geoscientific institutions are also successfully developed.

References

Adamovič J., Mikuláš R. Cílek V. 2010. Atlas pískovcových skalních měst České a Slovenské republiky. Academia, Praha, 460 pp.

Awdankiewicz M. 2022. Polyphase Permo-Carboniferous magmatism adjacent to the Intra-Sudetic Fault: constraints from U–Pb SHRIMP zircon study of felsic subvolcanic intrusions in the Intra-Sudetic Basin, SW Poland. International Journal of Earth Sciences 111: 2199-2224.

Awdankiewicz M., Awdankiewicz H., Rapprich V., Stárková M. 2014. A Permian andesitic tuff ring at Rozmital (the Intra-Sudetic Basin, Czech Republic) – evolution from explosive to effusive and high-level intrusive activity. Geological Quarterly58: 759-778.

Šimůnek Z., Libertin M. 2001. Palaeobotanical research near Žacléř in the quarries No.2, 3 and 4 (Carboniferous, Czech Republic). Geoscience Research Reports 34, 2001 (GRR for 2000): 48–49.

Vítek J. 2016. Adršpach-Teplice Rocks and Broumov Cliffs – large sandstone rock cities in the Central Europe. In: Pánek T., Hradecký J. (Eds.), Landscapes and Landforms of the Czech Republic. Springer, Cham 209-220.

STUDY AND DOCUMENTATION OF CAVE ROOT FORMS IN THE BROUMOV AREA, CZECH REPUBLIC

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1. Discoveries and early studies

Speleological research in the Broumov area officially started after the establishment of the 5-03 Broumov Caving Club of the Czech Speleological Society in late 1979, although the core of this group practiced caving-touristic activities in the 1970s already. Since 1980, the Broumov caving group has been engaged in research, inventory, documentation and study of underground pseudokarst phenomena as well as extraordinary surface landforms in all sandstone rock-cities of the Broumov Highland.

The first find of root phenomena in the Kořenka Cave in the Teplické skály Cliffs dates to 1979. The group of stalagmite-like forms demonstrably composed of a dense network of root fibres growing upwards – opposite to the direction of water dripping from the ceiling – was found remarkable by the cavers. This event raised interest in the understanding of the processes related to this as yet unknown form of filling of the local pseudokarst caves.

No previous record about this phenomenon was found in the Czech karsological literature. A note was, however, found in German literature: R. Winkelhöfer (1975) reported a similar root form from a sandstone cave on the Saxonian side of the Elbe Sandstones (Elbsandsteingebirge) and from one cave on the Czech side. Geomorphologist, Dr. Jan Vítek, when acquainted with the find in the Teplické skály Cliffs, found it analogous to a root form he previously reported from the Bohemian Paradise. These first facts became the basis for a description of "living" root stalagmites (connected with dripping water) from the Kořenka Cave (Kopecký 1983) and a "dead" specimen (without dripping water) from the Postojná Cave in the Bohemian Paradise (Vítek 1983). The Czech name of the phenomenon was based on a direct translation of the German term *Wurzelstalagmit* = root stalagmite, given in the very first German report.

Other root forms, individual or serial, were found in caves and rock shelters in the sandstone pseudokarst with the continued speleological research in the following years. Their occurrence was later reported from the Elbe Sandstones and the Lusatian Mountains but the highest numbers come from the Broumov area. Here, 15 sites with over 50 root forms were registered during the 1980s.

2. Scientific evaluation of the phenomenon of root forms

From the very beginning, the need of collaboration with experts was taken as a necessary precondition for the explanation of the existence of root forms. Fortunately, this was allowed by the enthusiasm of Assoc. Prof. Ing. Jan Jeník, then employed in the Botanical Institute of the Czechoslovak Academy of Sciences in Třeboň (later a professor at Charles University Prague), a geobotanist, ecologist and an expert in root systems. Already his first field trips with the Broumov cavers permitted to make basic conclusions. These were presented at the 2nd International Symposium on Pseudokarst held at Janovičky near Broumov in 1985 (Jeník, Kopecký 1985).

The most important findings were summarized by, e.g., Jeník (1998) and Kopecký (1998):

a) The root forms are pillow-shaped, conical or cylindrical in shape, up to more than 50 cm tall, resembling stalagmites or columns (Figs. 1 and 2). Some of the forms represent loaf-shaped or linear fillings of joints and notches. They consist of densely branched root masses of many coniferous or deciduous trees (mostly spruce and birch, respectively). They are formed due to the combined presence of many natural agents at places where water dripping from the roof of a cave or a rock shelter gets into contact with roots of a nearby tree in the bottom sediment. Root mass at this site experiences growth, dense branching and gradual piling in upward direction, against the gravity vector and towards the feeding water drip.

b) In combination with basidiomycetes, the root mass develops numerous paired organs – ectomycorrhizae. The mass is also augmented by dispersed quartz grains, transported into the root mass by dripping water. Dripping on the stalagmites must be of stable frequency and must last for many years (Fig. 3). When the drip is of low intensity only, low cupola-shaped individuals are formed, not exceeding 10–15 cm in height. In low spaces, the growth of the stalagmite may result in a contact of the root mass with the drip ledge on the roof and in a transformation of the stalagmite into a column. This form, however, continues to be fed with water, although its transfer from the roof is not visible any more. Root filling of notches and joints is fed by pore waters, in some cases also by overland or drip waters.

Fig. 1. Root stalagmites from the Horní sluj Cave at Hejda, the central stalagmite is 25 cm tall (Photo O. Jenka).

Fig. 2. A root column at the site of Saský převis with new roots adjoined to the ceiling (Photo O. Jenka).

c) Factors necessary for a proper growth of the root forms include appropriate temperature and darkness, or at least dim light, which allow reproduction of root tissues but inhibit the growth of epiphytic cyanobacteria and algae. Another important factor is the absence of larger herbivorous animals or parasites which would otherwise induce repeated damage to young, brittle roots.

d) The inventory of the identified, rather complex ecosystem of root forms also includes fungi and minor invertebrates – springtails, weevils, rove beetles, ants etc. They feed on young tips of root tissues and their ooze-like exudates. Their predators – especially spiders – are also present.

e) Formation of the root forms is probably also controlled by icing, which forms on their tops during winter months — often repeatedly, in connection with the occurrence of thaw and freeze days.

f) A local remodelling of the body of the stalagmite is common due to the formation of dripholes at the impact site of water drops, especially at higher heights and intensities of dripping water (Fig. 4). Occasionally, a subsequent destruction of the driphole rim may occur due to frost, severe draught or excessive drying of the mass in no-drip periods.

g) Dying of the root mass occurs upon the drip source termination (e.g., after the destruction of the drip ledge on the roof due to weathering), or upon the death of the parental tree or its branch connected with the root mass. Blackened root structure consisting of an undecomposed root peat then remains at the site for even several decades as a witness of once living organism.

Fig. 3. U Lokomotivy Cave in the Teplické skály Cliffs: Spongy matter pertaining to an unknown species fills the space between the apex of a root stalagmite and a drip ledge (Photo O. Jenka).

Fig. 4. A root stalagmite in the Pod balvanem I. Cave, Mt. Hejda – the apex of a root stalagmite with a driphole created by permanent water drip (Photo O. Jenka).

3. Monitoring of selected sites

The visits of Prof. Jeník to the sites of root forms in the Teplické skály Cliffs and Mt. Hejda in 1984 resulted in the need to obtain sufficient amount of data to explain the ecology of the root forms. Upon an agreement among speleologists, botanists and zoologists, the second stage of research was started. Three selected sites of different natural conditions and characters of the root forms were regularly monitored:

a) Kořenka Cave – Teplické skály Cliffs: this combined (crevice–talus) cave lies at a greater distance from the rim of the Ostruha structural plateau. It contains 7 root stalagmites of various sizes and growth activities. It also contains the largest root stalagmite in the Broumov area then documented, called The King.

b) Horní sluj Cave – Mt. Hejda: a small crevice cave near the rim of the sandstone structural plateau above the central gorge. It contains 6 root forms of various sizes (small to medium) and growth activities (Fig. 1).

c) Písečná Cave – Mt. Hejda: a talus cave with an extensive subhorizontal system on the bottom of the central gorge. It contains 5 root stalagmites of smaller size and lesser growth activity, of which a group of 4 stalagmites in the central dome was included in the monitoring programme.

Monitoring of these three sites was performed on a monthly basis, following the procedure postulated in cooperation with Prof. Jeník. The template form contained the list of recommended observations, activities and records:

- character of nature around the cave on the day of observation,
- notable physical and biological phenomena in the cave, including its microclimate,
- up-to-date description of the appearance and form of the root mass of each stalagmite, including the occurrence of fungi and biological coatings on the surface (their collection and conservation, if desired),
- description of the occurrence of small animals on the stalagmites (their collection and conservation, if desired),
- measurement of the rate, discharge, temperature and pH of dripping water for individual stalagmites,
- dripwater sampling for chemical analyses.

The selected cave localities were monitored according to this template between November 1984 and December 1987, i.e., for more than 3 years. Altogether 114 monitoring trips were made. Reports on these trips were regularly sent to Prof. Jeník to the Botanical Institute CSAV in Třeboň (102 pages of descriptions and data), together with dripwater samples (12) and plastic bottles with conserved samples of small animals (28), fungi or stalagmite coatings (17). Determinations of the animal samples were also provided by the Entomological Institute AS CR in České Budějovice (Kopecký ed. 1985–1987, parts I–IV).

After the suspected gnawing of root stalagmites by rodents in the Horní galerie Cave and after the find of tiny droppings on a root stalagmite body in the Horní sluj Cave (both at Mt. Hejda), exploratory sampling of small mammals was made at all three monitored sites. The traps at the Horní sluj site yielded 3 rodents belonging to the species of bank vole (*Clethrionomys glareolus*). It is, however, obvious that the effect of rodents on the overall modelling of the root forms is not a substantial one. One-off trapping did not prove the presumed occurrence of insectivores either.

The monitoring extended our knowledge of the root forms by many speleological, biological and microclimatic data. The occurrence of rare glacial relics among the invertebrate fauna of the caves and the coldest parts of rock cities in the Broumov area was also confirmed: spider *Bathyphantes eumenis*, mite *Rhagigia gelido* and many others (Růžička 1988). The results were presented at workshops (Jeník 1985), at the 3rd Symposium on Pseudokarst at Königstein (Jeník, Kopecký 1988) and the 4th Symposium on Pseudokarst in the Beskydy Mts. (Kopecký sr., Kopecký jr. 1990). An extensive summary was also provided to the governmental bodies for nature conservation (Kopecký ed. 1988).

The proven presence of invertebrate glacial relics was followed by detailed studies. "Expeditions" of arachnologists and other experts in invertebrate fauna lasting several days were undertaken in the rock cities of the Broumov area in cooperation with Caving Club 5-03 Broumov (Růžička 1998; Růžička, Kopecký 1998). Monitoring of invertebrates and small mammals led by zoologist, Dr. Petr Rybář, was also started at many surface and subsurface sites by the Regional Centre of State Cultural and Natural Heritage in Pardubice.

4. Documentation of root forms and sites of their occurrence

The basic research of the root forms necessitated documentation of their varied geometries. The template for this documentation was supposed to be compatible with the existing template for speleological documentation (Hromas, Weigel 1986) in terms of possible implementation of additional pseudokarst phenomena and botanical, zoological and other documentation. Such task had not been challenged yet, which made the Broumov speleologists choose their specific documentation procedure. This resulted in a contribution to the manual "Příručka mapování pseudokrasu (A Handbook on Pseudokarst Mapping)" by Demek et al. eds. (1990) with a template proposal for the documentation of root forms and their localities by J. Kopecký, to be tested in other areas in the Czech Republic or abroad. The template was promoted at the Czech Speleological Society (CSS) meetings (Kopecký 1999). Given the present situation that pseudokarst and karst sites with root forms are known from many countries within or outside Europe (Czech Republic, Germany, Austria, Poland, Slovakia, Hungary, Sweden and Republic of South Africa), it is appropriate to initiate an international study of the root forms.

The proposed template was tested in conditions of sandstone pseudokarst of the Broumovská vrchovina Highland. Documentation was made for individual localities (Figs. 5–8). Documentation of Cave No. 05 (Bivaková Cave) was also included in the first complex speleological study for a pseudokarst area of the Kočičí skály Cliffs in the Broumov area (Jenka, Kopecký eds. 2020). For a practical use in this area, the template was updated into a physical and electronic manual (Kopecký ed. 2021). However, it has to be tested in the course of a broad international discussion and particularly amended by proposals resulting from practical needs linked with specific (even exotic) regions. The proposed template should be taken as a challenge from the Broumov cavers for other domestic and international colleagues through the Commissions for Pseudokarst of the Czech Speleological Society (CSS) and the International Union of Speleology (UIS).

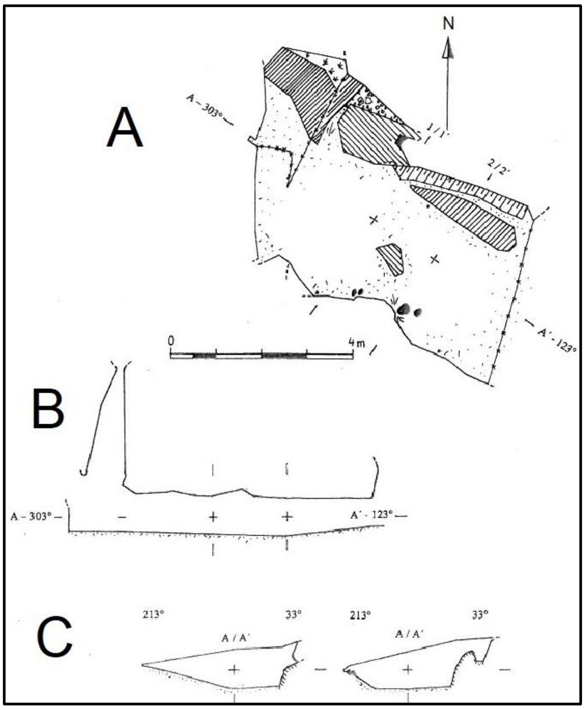

Fig. 5. A map of the Bivaková Cave, Kočičí skály Cliffs. A) A plan of the cave showing the longitudinal axis A–A′ (303°–123°) and locations of transverse profiles 1–1′ and 2–2′ (213°–33°). B) Longitudinal profile A–A′. C) Transverse profiles 1–1′ and 2–2′. The cave was surveyed by O. Jenka, J. Kopecký and J. Novotný (Caving Club 5-03 Broumov) on July 15, 2008. Drawing by J. Kopecký on April 6, 2017.

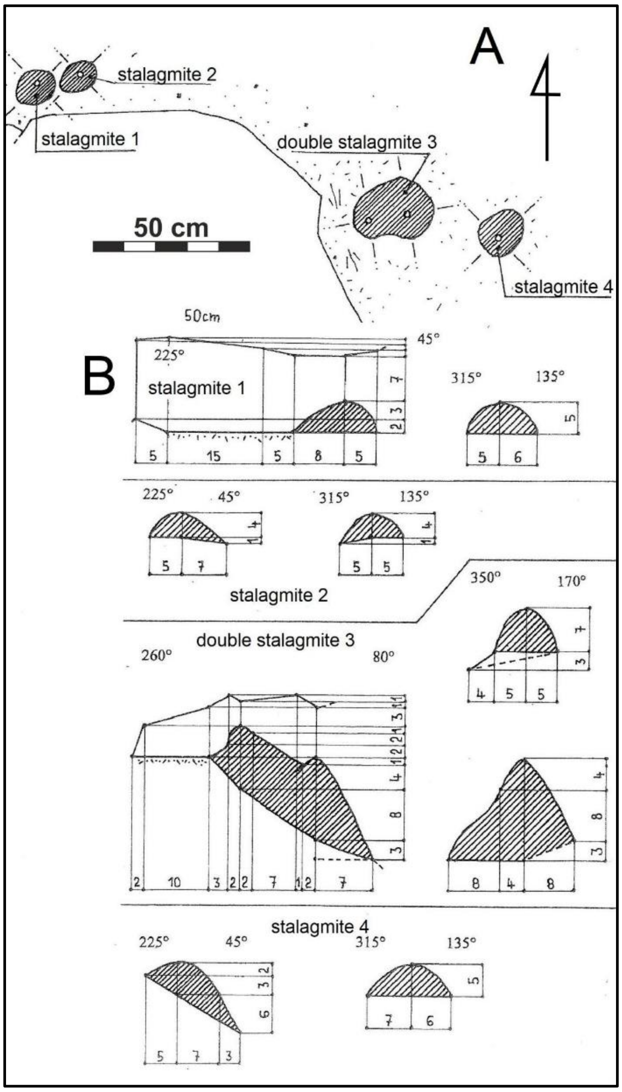

Fig. 6. Root stalagmites in the Bivaková Cave, Kočičí skály Cliffs. A) Location of the group of root stalagmites in the central part of the southwestern wall of the cave. B) Detailed documentation of individual root stalagmites showing their dimensions (in cm) and the spatial distributions of the root masses. Drawing by J. Kopecký, 2017.

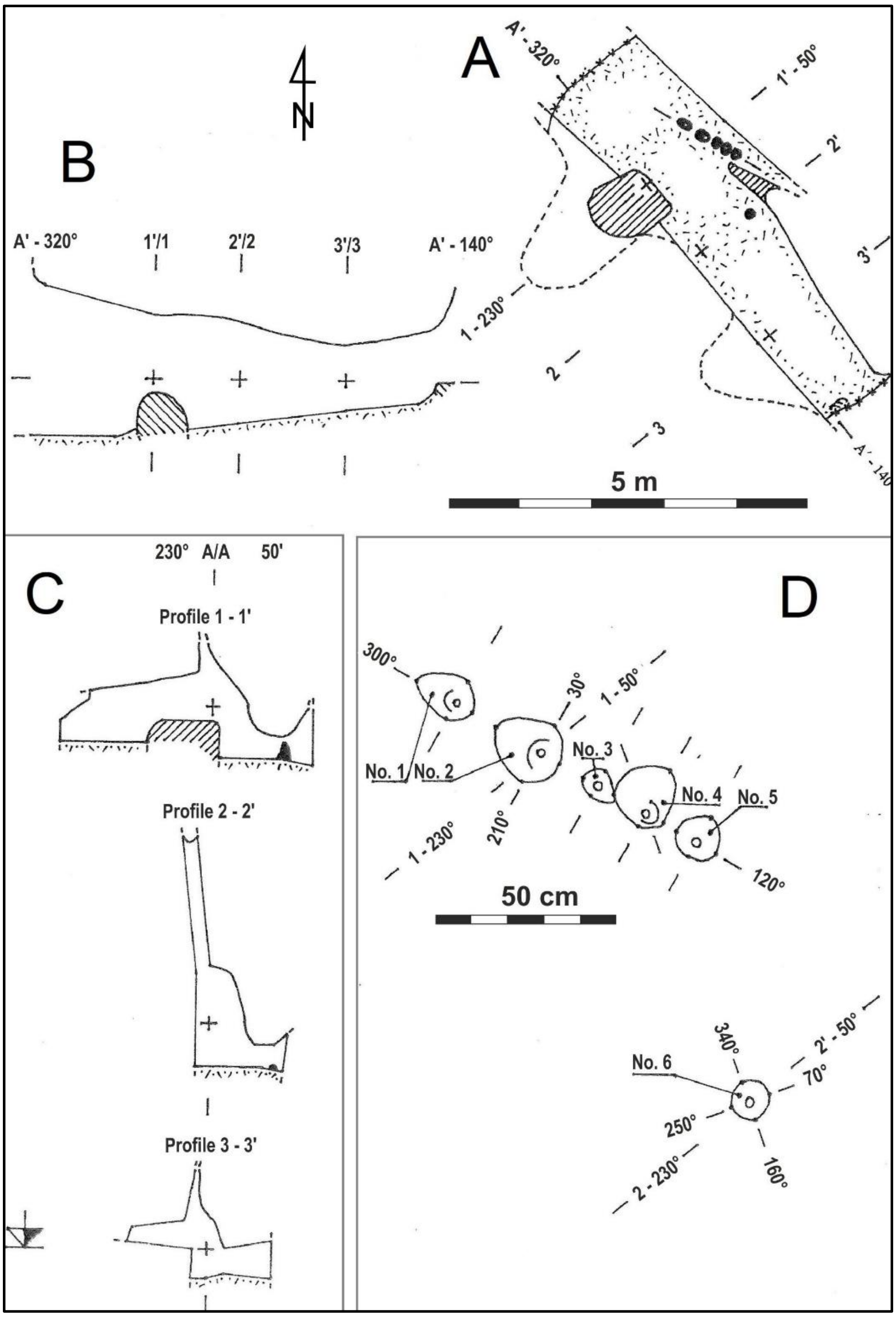

Fig. 7. A map of the Horní sluj Cave, Mt. Hejda area. A) A plan of the cave showing the longitudinal axis A–A′ (320°–140°) and locations of transverse profiles 1–1′, 2–2′ and 3–3′ (230°–50°). B) Longitudinal profile A–A′. C) Transverse profiles 1–1′, 2–2′ and 3–3′. D) Positions of the root stalagmites marked as No.1 – No. 6. Drawing by J. Kopecký (Caving Club 5-03 Broumov) in 2021 based on field sketches.

5. Conclusions

The root forms have been known for over 40 years. Their research in the first two decades developed from the primary discovery to their recognition as a specific, valuable biospeleological theme to be solved by both amateur and professional researchers. The next two decades, in the 21st century, were filled with the search for root forms in pseudokarst and karst terrains in global scale, but also with the formulation of the methods appropriate for their study and documentation.

It can be presumed that the issue of root forms will be further discussed in the coming years. This activity is beneficial for speleology as a whole but also for other disciplines. An international coordination of these activities can become one of the tasks for the Commission for Pseudokarst of the International Union of Speleology.

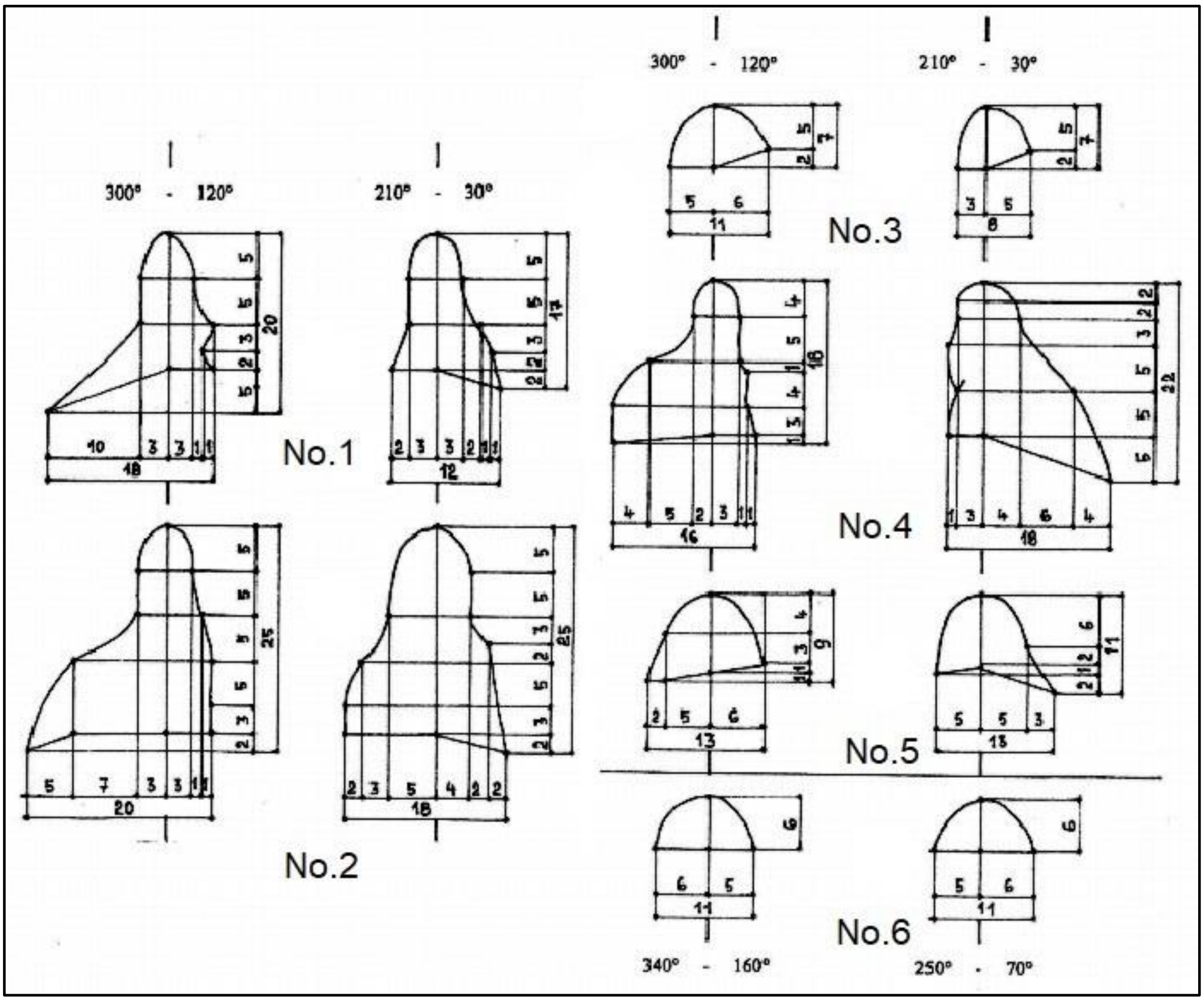

Fig. 8. Root stalagmites Nos. 1 – 6 in the Horní sluj Cave, Mt. Hejda area. Geometries of the stalagmites in longitudinal cross-sections (left columns) and transverse cross-sections (right column). Dimensions in centimetres. The survey was made by O. Jenka and J. Kopecký (Caving Club 5-03 Broumov) on January 7th, 1989. Drawing by J. Kopecký in 2021.

6. References

Demek J., Kopecký J., Kučera B., Wagner J. (Eds.) 1990. Příručka mapování pseudokrasu. Knihovna České speleologické společnosti, 20, Praha, 84 pp.

Hromas J., Weigel J. 1986. Základy speleologického mapování. Knihovna České speleologické společnosti, 8, Praha, 144 pp.

Jeník J. 1985. Stalagmitické kořání v jeskyních. Vesmír 64, 6: 357.

Jeník J. 1998. Kořenové útvary v pseudokrasových jeskyních. In: Cílek V., Kopecký J. (Eds.), Pískovcový fenomén: klima, život a reliéf. Knihovna České speleologické společnosti, 32, Praha: 61-68.

Jeník J., Kopecký J. 1985. Stav a problematika výzkumu pseudokrasu v kvádrových pískovcích Broumovské vrchoviny. In: Sborník 2. sympozia o pseudokrasu. Knihovna České speleologické společnosti 10, Praha: 127-133.

Jeník J., Kopecký J. 1988. Erforschung und Dokumentation der Wurzelstalagmiten. In: Proceedings of the 3rd Symposium on Pseudokarst, Königsten: 35.

Jenka O., Kopecký J., (Eds.) 2020. Kočičí skály a jejich pseudokrasový fenomén (manuscript: 90 pp., 28 appendices). Archive of the Czech Speleological Society, Prague.

Kopecký J. 1983. Kořenové stalagmity. Lidé a Země 32: 40-41.

Kopecký J. 1998. Výzkum kořenových stalagmitů. In: Cílek, V. and Kopecký, J. (Eds.), Pískovcový fenomén: klima, život a reliéf. Knihovna České speleologické společnosti, 32, Praha: 69-82.

Kopecký J. 1999. Dokumentace kořenových tvarů. Pseudokrasový sborník I., Knihovna České speleologické společnosti, 35, Praha: 61-68.

Kopecký J. sr., Kopecký J. jr. 1990. Kořenové tvary v pískovcových jeskyních – jejich výzkum, dokumentace a ochrana. In: Sborník 4. sympozia o pseudokrasu. Knihovna České speleologické společnosti, 23, Praha: 72-79.

Kopecký J. (Ed.) 1985-1987. Zpráva o výsledcích sledování vybraných lokalit kořenových stalagmitů – parts I, II, III and IV (manuscripts: 25, 25, 11 and 41 pp.). Archive of the Czech Speleological Society, Prague.

Kopecký J. (Ed.) 1988: Kořenové stalagmity a stalagnáty v pseudokrasových terénech Broumovské vrchoviny – jejich výzkum a ochrana (manuscript: 56 pp., appendices). Archives of the Broumovsko PLA, Broumov, and the Czech Speleological Society, Prague.

Kopecký J, (Ed.) 2021. Metodika popisu a dokumentace kořenových struktur (manuscript: 8 pp., 8 appendices). Archive of the Czech Speleological Society, Prague.

Růžička V. 1988. Problems of Bathyphantes eumenis and its occurrence in Czechoslovakia. Věstník Čs. spol. zoologické 52: 149-155.

Růžička V. 1998. Dosavadní výsledky arachnologického průzkumu pískovcových skalních měst. Pískovcový fenomén: klima, život a reliéf. Knihovna České speleologické společnosti, 32, Praha: 113-125.

Růžička V., Kopecký J. 1998. Pavouci pseudokrasových jeskyní v severovýchodních Čechách. Pískovcový fenomén: klima, život a reliéf. Knihovna České speleologické společnosti, 32, Praha: 102-112.

Vítek J. 1983. Kořenové stalagmity v pískovcových jeskyních. Živa 28, 3: 94.

Winkelhöfer R. 1975. Stalagmitenförmige Wurzelbildungen in Sandsteinhöhlen. Der Höhlenforscher 7, 2: 25-26.

TYPES OF CAVES IN THE KOKOŘIN AREA, CZECH REPUBLIC

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Deeply incised valleys and gorges around the Kokořín Castle near Mělník, north of Prague, represent an area of vast exposure of calcareous and quartzose sandstones of Turonian age (Upper Cretaceous, Jizera Formation). The sandstones are arranged into upwards-coarsening cycles (Adamovič 1994), the upper parts of which form cliff levels 20–30 m high, rocky ridges with isolated pillars and joint-controlled labyrinths. The deepest canyon-like valleys of the Pšovka and Liběchovka streams are lined by two to three superimposed cliff levels. All outcrops are formed by quartzose sandstones of the Jizera Formation. Faults strike mostly NNE–SSW or E–W and show a vertical displacement not exceeding 40 m. The Kokořín area falls within the Kokořínsko–Máchův kraj Protected Landscape Area (Fig. 1).

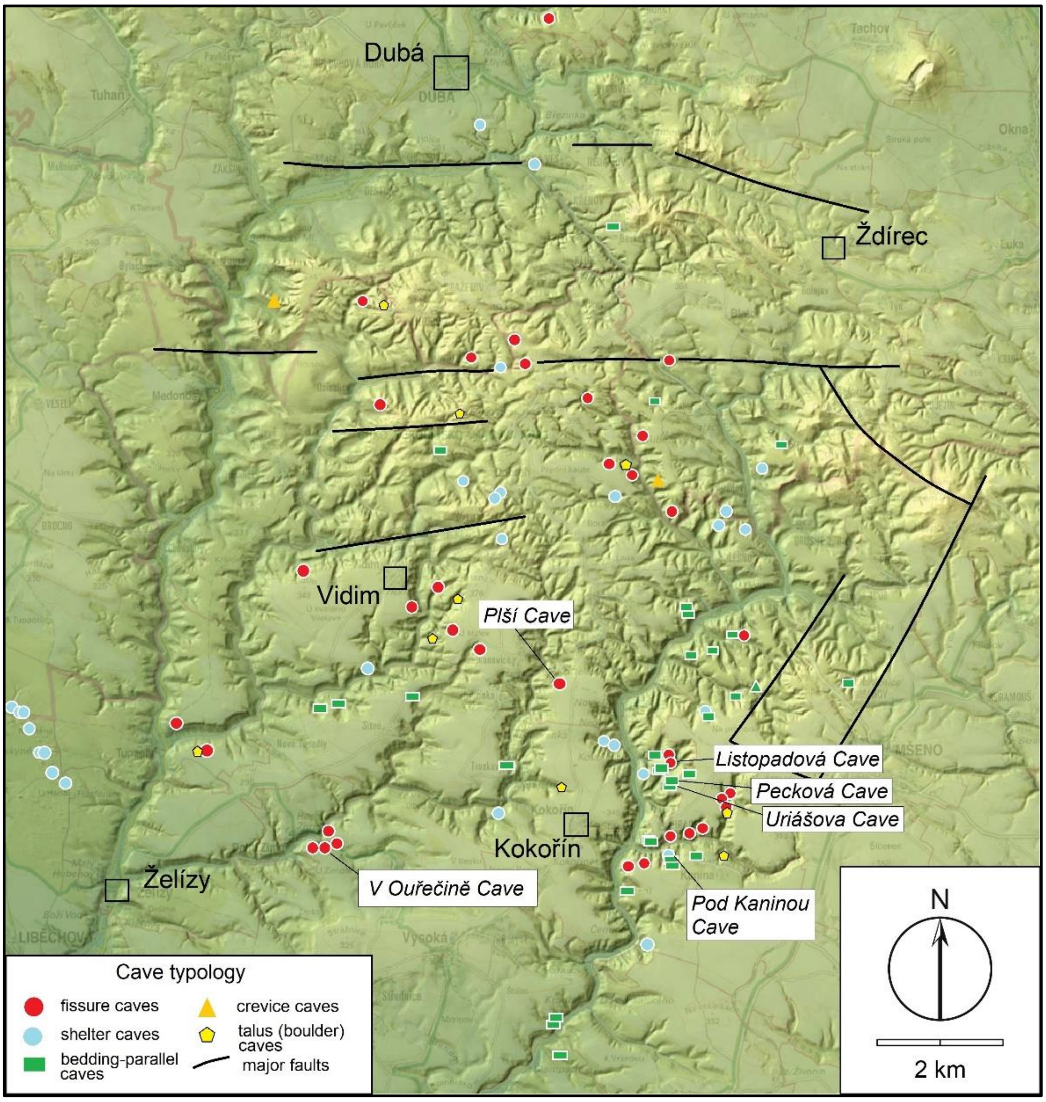
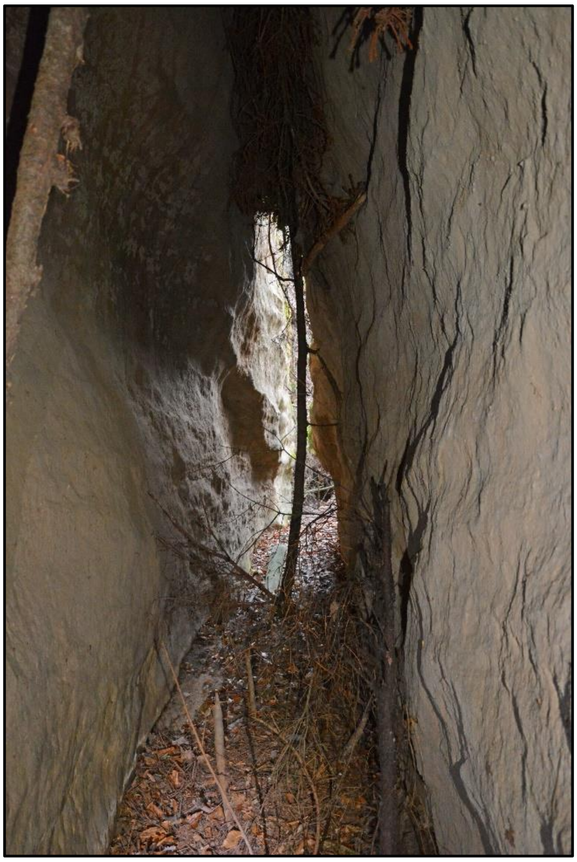


Fig. 1. A shaded-relief map of the Kokořín area with courses of major faults and indicated positions of caves of different types. Courses of faults adapted from Adamovič (2016). DMR after https://ags.cuzk.cz/av/ .

Kokořín is not a typical caving area, and its multiple caves have been mostly neglected due to their small dimensions. Moreover, there is no caving club actively operating in this area. The first exploratory works were conducted in the 1960s, concentrating mostly on artificially carved underground spaces like cellars, shelters or wells (e.g., Hromas, Hradecký 1966). Systematic studies of natural caves were initiated not earlier than in the 1980s by Václav Zimerman and Jiří Piller (Zimerman, Piller 2004). Although the reconnaissance of the Kokořín area has not been completed yet, 110 caves of various types are registered to date (Mertlík et al. 2009, Piller, Adamovič 2019). Most of the caves are less than 10 m in length, although some bedding-parallel caves or fissure caves exceed 30 m in total length. Strictly taken, almost all caves are combined caves or transitional caves between two types.



Fissure caves were formed by erosional widening of subvertical joints and usually display narrow triangular profiles, often several metres high. Their floors are covered with sand or talus of variable size, including boulders. A specific feature of the Kokořín area is the presence of ceilings formed by beds of resistant ferruginous sandstone. Examples of fissure caves are Dominův sklep, V Ouřečině and Sluj u Micky, fissure caves roofed by talus accumulations are Plší jeskyně, Faule Brücke (Pod Shnilým mostem) and the cave in the upper reach of the Štylec Gorge (Fig. 2).

Fig. 2. Fissure cave whose ceiling is formed by fallen boulders and soil. The upper reach of the Štylec Gorge near Šemanovice (Photo J. Adamovič).

Crevice caves are rare and of small size, restricted only to steep slopes with dynamic topography, favourable for gravitational sliding of blocks separated from the massif by basal undercutting or jointing.

Shelter caves are perhaps the most numerous. They have roughly isometric or even ellipsoidal shapes and vary between 3 and 10 m in length. Two processes are involved in their formation, usually occurring in a time succession. The first one is evacuation of sand within the limits of former carbonate concretions, later turned into loose sand due to cement dissolution (Adamovič et al. 2015). These cavities are typically ellipsoidal in shape. The second process is rapid weathering/removal of sandstone occupying stress shadows in the rock massif, thereby forming arcade-like cavities (Filippi et al. 2018). The latter process makes the cavities to coalesce and form larger spaces. Examples of shelter caves are the Pod Kaninou, Margareta, Zimermanka caves and the cave in a rocky step on the bottom of the Janošíkova rokle Gorge.

Bedding-parallel caves follow sedimentary strata prone to weathering and erosion. They mostly represent deep notches following major bedding planes or coalesced shelter caves. Total lengths of around 10 m are common, and some caves include relatively spacious halls. As examples, the following caves can be mentioned: Pecková (Fig. 3), Hlídky and Uriášova.

Talus caves, or boulder caves, are mostly restricted to areas where sandstone is hardened by near basaltic or phonolitic intrusions. In other areas, fallen sandstone blocks become relatively rapidly disintegrated, and no passable spaces among the blocks are formed. Boulders tend to accumulate on bottoms of narrow, dry gorges, and the caves are maximum 10 m long: Kočičina Gorge, Sitenský důl Valley, Planý důl Valley, and the gorges on the slopes of Mt Supí hora and Nedvězí hills.

The only secondary minerals registered in the caves are moonmilk coatings. They are found in fissure or shelter caves whose dripwaters pass through Pleistocene loess accumulations deposited on plateau tops. Many caves were adapted for shelter, refuge or temporary living in historical times, ranging from the Middle Ages to World War II.

Fig. 3. Arcades developed along a specific bedding plane tend to merge to form a bedding-parallel cave. Pecková Cave in the V kříži Gorge near Kokořín (Photo J. Adamovič).

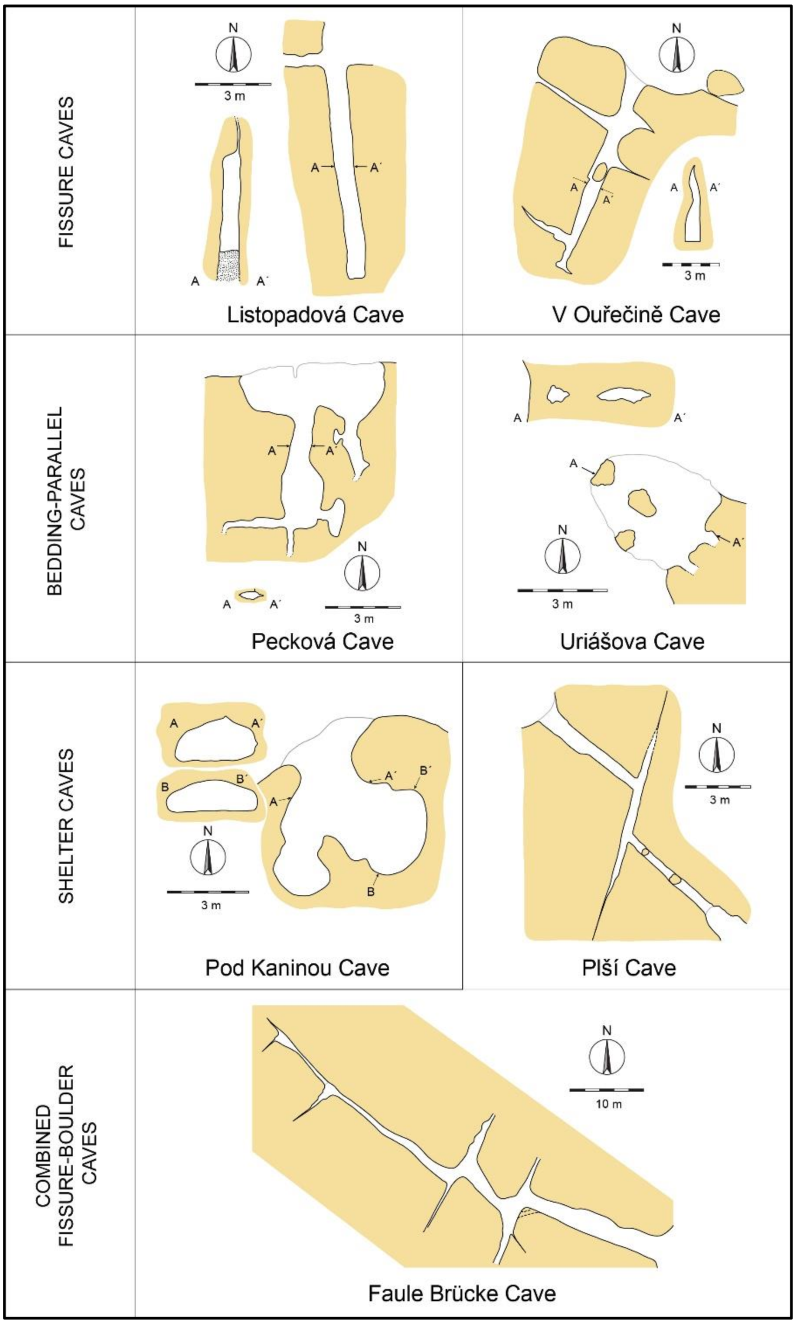


Fig. 4. Ground plans of selected caves of different types in the Kokořín area. After Piller and Adamovič (2019), the plan of the Pod Kaninou Cave adapted from V. Zimerman in Zimerman and Piller (2004). Cave typology follows Vítek (1983). For cave locations see Fig. 1.

Apart from the Kokořínský důl Valley, which has been thoroughly documented for caves by previous authors, there is still a prospect for discoveries of new caves in other parts of the Kokořín area. Especially the boulder accumulations have yet to be investigated for the presence of boulder caves at many sites. An interesting subject to be studied in the future is the age relation between the caves and the loess/colluvial accumulations on valley bottoms. No research has been made on cave speleothems or specific cave biota either. Caves in this area should be better reflected in the nature management plans prepared by the Protected Landscape Area administration.

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References

Adamovič J. 1994. Paleogeography of the Jizera Formation (Late Cretaceous sandstones), Kokořín area, central Bohemia. Sborník geologických věd, Geologie. Praha 46: 103-123.

Adamovič J. 2016. The Kokořín area: sandstone landforms controlled by hydrothermal ferruginization. In: Pánek T., Hradecký J. (Eds.), Landscapes and landforms of the Czech Republic, Springer: 153-164.

Adamovič J., Mikuláš R., Navrátil T. 2015. Spherical and ellipsoidal cavities in European sandstones: a product of sinking carbonate dissolution front. Zeitschrift für Geomorphologie 59, Suppl. 1: 123-149.

Filippi M., Bruthans J., Řihošek J., Slavík M., Adamovič J., Masin D. 2018. Arcades: products of stress-controlled and discontinuity-related weathering. Earth-Science Reviews 180: 159-184.

Hromas J., Hradecký P. 1966. Příloha ke zprávě o architektonicko-geologickém průzkumu na Kokoříně dne 25.-27. března 1966. Topografické zaměření a geologie místa. Unpublished material, MS Archive of the Czech Speleological Society, Prague.

Mertlík J., Ouhrabka V., Mikuláš R., Bílková D., Hromas J., Vítek J. 2009. Pseudokrasové jeskyně české křídové pánve. In: Hromas J. (ed.), Chráněná území ČR, svazek XIV. Jeskyně. Agentura ochrany přírody a krajiny ČR a EkoCentrum Brno. Praha: 283-304.

Piller J., Adamovič J. 2019. Kokořínsko. Jak mluví skály. Petr Prášil BARON. Hostivice, 156 pp.

Vítek J. 1983. Classification of pseudokarst forms in Czechoslovakia. Intern. Journal of Speleology 13: 1-18.

Zimerman V., Piller J. 2004. Kokořínsko - krásy a zajímavosti. Richard Kubeš. Mělník, 108 pp.
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NEWLY DESCRIBED Si-Al CORALLOIDS IN SANDSTONE CREVICE AND BOULDER CAVES OF THE ELBE RIVER CANYON (CZECH REPUBLIC)

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The Elbe River canyon in northern Czech Republic is a typical example of a sandstone area transected by a major river, often referred to as Elbsandsteingebirge or Elbe Sandstones (Rast 1959). The only speleothems previously reported from this area were calcite-dominated dendritic coralloids reported by Marwan (2000). Cave research conducted by Caving Club 4-03 of the Czech Speleological Society in the first decade of the 21st century revealed yet another type of speleothems: dark brown knobs maximum 10 mm in size, with smooth, shiny surfaces, arranged into lines along rock edges or covering small patches on steep walls. They were clearly deposited in subaerial conditions. Surprisingly, the cauliflower-shaped dendritic coralloids and the contrasting knob coralloids were often found in the same caves, close to each other, which suggested their different ages or their origin in highly varied cave environments. After prolonged sampling of the coralloids and dripwater in several caves, all types of speleothems were studied in thin sections and analyzed for the mineral phases present and their chemical composition. The results were published by Adamovič et al. (2022).

Knob coralloids were found to have a distinctly layered internal structure, with alternating silica- and kaolinite-dominated laminae. Microcrystalline silica clearly prevails over amorphous silica. Phosphate-rich laminae are also present, with taranakite, sasaite and vashegyite identified, being associated rather with kaolinite laminae than silica laminae. No microbial mediation of silica precipitation was observed. Cauliflower-shaped coralloids also contain silica-rich laminae but calcite is the dominant mineral. Gypsum crystals are found on the top, but pseudomorphs after gypsum are also present in deeper layers. Only modest microbial mediation of silica precipitation was observed in cauliflower-shaped coralloids.

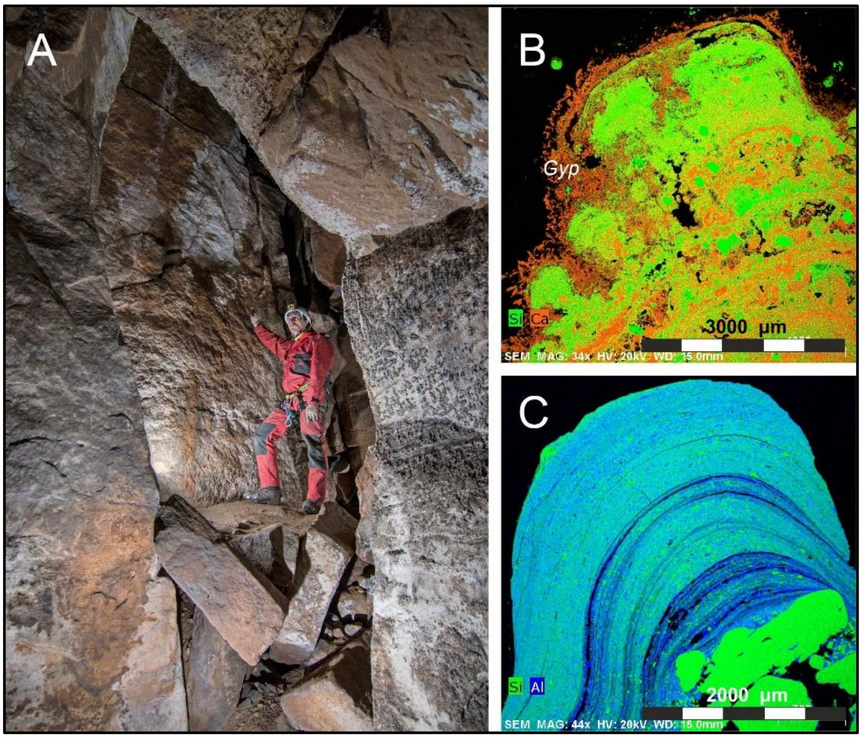

Fig. 1. A. The main shaft of the Loupežnická Cave with cauliflower-shaped coralloids covering the joint plane on the right. B. The distribution of Ca (calcite) and Si (quartz and opal) in a section of the apical part of a cauliflower-shaped coralloid. The top is covered with gypsum crystals (Gyp). Loupežnická Cave, SEM-EDS data. C. The distribution of Si (quartz and opal) and Al (kaolinite) in a section of a knob coralloid. Přesýpací svět Cave, SEM-EDS data (photo A by J. Kukla, photos B–C by N. Mészárosová).

Dripwaters of two types were encountered: (1) waters of a semi-neutral pH (6.1) with low Al concentrations, elevated Si concentrations but strongly elevated Ca, Mg and SO_4^{2-} concentrations compared to bulk or throughfall precipitation, compatible with the composition of cauliflower-shaped coralloids, and (2) acid waters (pH ~3.8) with strongly elevated Si and Al concentrations when compared to atmospheric waters. Although Si concentrations are not sufficient for direct opal precipitation under normal conditions, the presence of wind-guided forms of knob coralloids and their preferred formation along vertical shafts argues for their origin from pore waters similar to dripwaters (2) under the effect of draught, i.e., rapid evaporation.

While calcite-dominated cauliflower-shaped coralloids are spatially related to moonmilk coatings and are presumably still active, as suggested by gypsum crystals precipitation, silica- and kaolinite-dominated knob coralloids were probably deposited in pre-Holocene times (possibly in a warmer period in the Pleistocene) as suggested by their dark brown shiny surfaces rich in organic carbon and the lack of full chemical compatibility with the present dripwaters.

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References

Adamovič J., Kukla J., Filippi M., Skála R., Mészárosová N. 2022. Speleothems in sandstone crevice and boulder caves of the Elbe River Canyon, Czech Republic. Intern. Journal of Speleology 51, 2: 141-162.

Marwan N. 2000. Kalzit-Sinter in Sandsteinhöhlen des Elbsandsteingebirges. Die Höhle 51, 1: 19-20.

Rast H. 1959. Geologischer Führer durch das Elbsandsteingebirge. Bergakademie Freiberg, Freiberg, 224 pp.

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GEOMORPHOLOGY AND HYDROLOGY OF SILICEOUS KARST IN THE SANDSTONES OF NORTHEAST THAILAND

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1. Introduction

The northeastern part of Thailand is known as Isan (Fig. 1). The landscape of this region is relatively complex and diverse. The highest elevations are situated in its northwest extremity, where the highest peak reaches 1408 m a.s.l., and in its southeastern part, where the mountains reach a height of 1350 m. But such elevations are not typical for the Isan area which is mostly the horizontal plateau elevated 180-250 m a.s.l. However, within such a landscape some hills ranging up to 400 m a.s.l, and even mountain ranges up to 800 m a.s.l. occur.

Within the whole Isan area, where quartzitic sandstones are outcropping, one can find almost all classical karst landforms: swallow-holes, karst springs and karst microforms, especially kamenitza type. But the most spectacular are the underground forms – caves up to 1 km long (some with much greater exploration potential), and – last but not least – "mini-cenotes" filled with water even during the dry season. Such landforms developed in sandstones are described as sandstone karst (Charoenmitet al. 2020; Wilungkit, Jaimun 2022a; Valenas 2015a, b; 2023a, b).

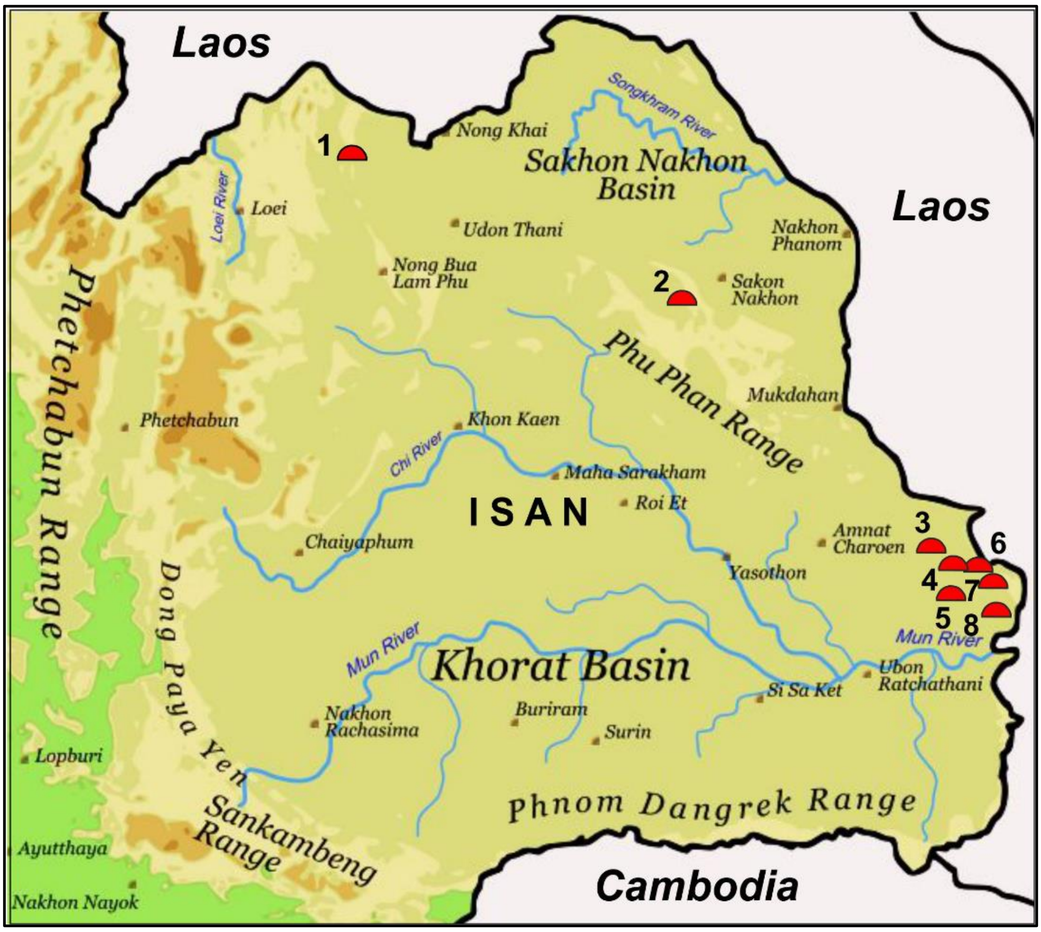


Fig. 1. Physical map of Northeast Thailand with location of caves: 1 – Tham Din Pieng, 2 – Seri Thai System, 3 – Tham Phu Phan No 1, 4 – Tham Phanon Di no 1 (Great Pit), 5 – Tham Nam Lot, 6 – Tham Ghia, 7 – Tham Meut, 8 – Tham Patihan.

Since the UIS congress in Olomouc (former Czechoslovakia) in 1973, according to the opinion of famous karstologist, professor Alfred Bögli, the term "sandstone karst" or "SiO_2/siliceous karst" has been internationally accepted. Since 2006, the Autor of this paper with a help of the Speleological Club "Z" explored and mapped 96 caves and potholes of a total length of almost 3 km in NE Thailand. A new research project concerning the study of siliceous/sandstone karst in the Isan region performed by the TU Bergakademie Freiberg, started in February 2023. Most of the large caves are situated in the eastern part of the Khorat Basin, in the Ubon Ratchathani province (Fig. 1).

2. Geological settings

Sandstones, conglomerates and clay shales of Triassic, Jurassic and Cretaceous age predominate among rocks of the Northeast Thailand plateaus. The substratum of the studied area is composed mainly of quartzitic sandstones, but also sandstones with calcareous cement. Magmatic rocks also appear in some places (Veeravinantanakul et al. 2018). The caves and potholes studied by us until 2006 and in 2023 developed in quartzitic sandstones of the Phu Kradung Formation of the Jurassic age (Veeravinantanakul et al. 2018; Nakchaiya et al. 2020). Red to yellow sesquioxide-rich, deeply weathered soils – Ferralsols, are predominant here. The entire Isan plateau is strongly tectonised (Doerr 2000a, b).

3. Karst geomorphology

Only in recent years a more coherent image of the karst in northeast Thailand has emerged. Apart from poljes (which have not yet been identified) the area of northeast Thailand includes all types of karst landforms: swallow holes (ponors), karst springs (some with high to very high outflow, Fig. 2), karren and karren fields (Fig. 3), caves, potholes (Fig. 4) (Vălenas 2016, 2020d, 2023a, b), except sinkholes, which are not characteristic elements of this landscape (Mouret C., Mouret L. 1994, Valenas 2023a, b). Caves are of two types, or represent a combination of these types. The smaller caves have a tectonic foundation, being developed along faults and diaclases. But even here the role of karstification is obvious as a determining factor in the widening of these faults and diaclases.

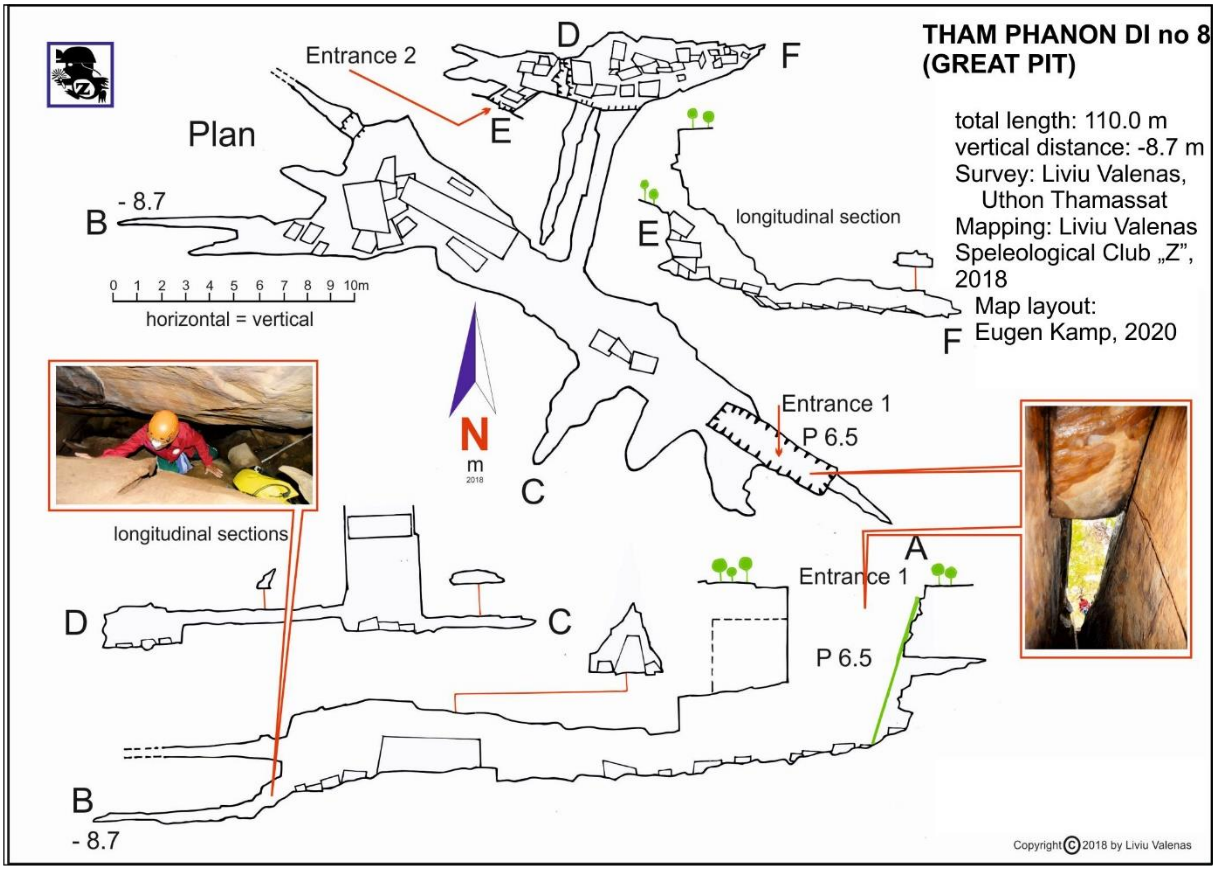
It should be mentioned that the entire area is subjected to a monsoon climate, with extremely high rainfalls in the May-October period. This is the determining factor in the formation of caves in northeast Thailand. Recent research has highlighted another important factor: the bio-corrosion created by the abundant, tropical and subtropical vegetation and especially by the bio-corrosion caused by extremely aggressive organic acids released by roots of trees and other plants, which perforate the cave ceilings (Mouret C. 2017; Valenas 2023a, b). The bio-corrosion created by bats is also considered, especially through guano deposits, but this does not appear to us to be a determining factor (Valenas 2023b).

Fig. 2. The karst spring of Tham Nam Lot cave, Ubon Ratchathani Province (Photo L. Valenas).

The large caves are almost all rectilinear, developed along bedding planes. Almost all caves are relatively horizontal with the biggest vertical range (VR) in the case of Tham Meut cave, reaching -30.3 m (Vălenas 2020e, 2023a, b). There are also typical potholes, almost all related to faults and diaclases. Tham Din Pieng cave (Dunkley 2011, Valenas 2023a, b) is characterized by specific morphology, comprising a continuous maze system (but focused on two underground streams), with many pillars

Fig. 3. Karren and karren fields in quartzitic sandstones of Ubon Ratchathani Province (Photos L. Valenas).

Fig. 4. Tham Phu Phanom Di no 8 cave (Great Pit), Ubon Ratchathani Province.



– a morphology similar to sandstone caves in Venezuela (Ellis 2017; Dunkley, Bolger 2017; Valenas 2023a, b). Such a shape is exclusively due to the fact that Tham Din Pieng cave develops in sandstones with calcareous cement (Figs. 5 and 6). Almost all large caves in quartzitic sandstones in northeast Thailand are caves developed on lithological contacts between different layers of sandstones, but also between sandstones, conglomerates and marls (Valenas 2023 a, b).

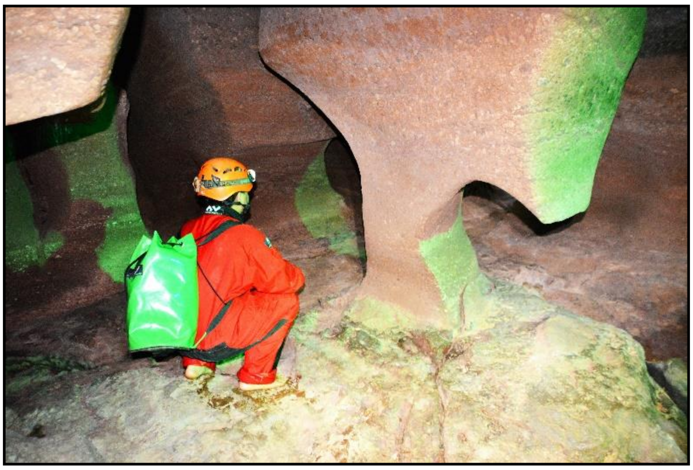


Fig. 5. Tham Din Pieng, a cave in sandstone with calcareous cement, Nong Khai Province (Photo L. Valenas)

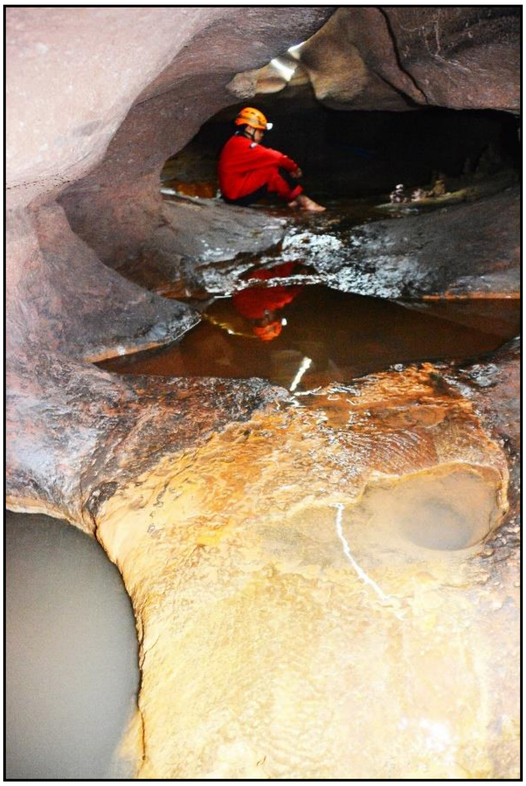


Fig. 6. The southern underground stream in Tham Din Pieng cave, Nong Khai Province (Photo L. Valenas)

The specific (and maybe unique) karst features in the quartzitic sandstones of northeast Thailand are also the so-called "mini-cenotes" (Fig. 7), perfectly vertical pits up to 5 m deep, occupied at their base by stagnant water in the dry season, whereas in the monsoon season they are completely flooded. They were formed by continuous corrosion due to the water accumulated in them, with a contribution of the bio-corrosion. They seem to be relatively recent landforms (Valenas 2020i, 2023a, b).

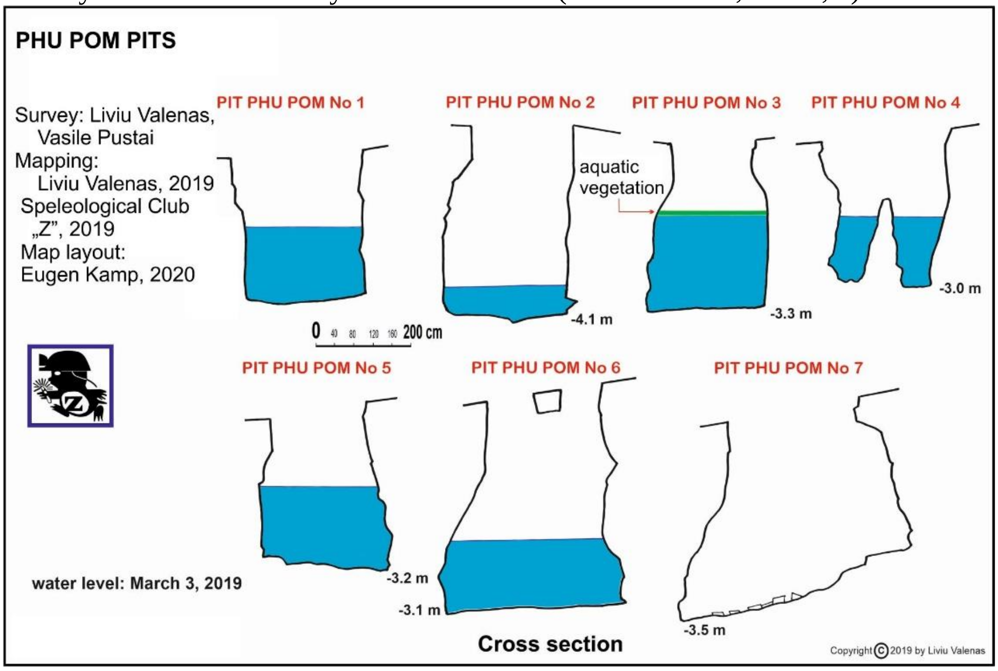


Fig. 7. Sections through "mini-cenotes" of the Phu Pom Mountains, Amnat Charoen Province

Regarding the length of the caves in northeastern Thailand, the only large caves precisely surveyed and mapped (by the author of this article) are the following ones: Seri Thai System (Fig. 8), of a length of 856.7 m (Valenas 2023a, b, 2024), Tham Meut, which is a practically rectilinear cave 481.5 m long (Fig. 9, see also the First Cover) (Vălenas 2020e, 2023a), Tham Phu Pom no 1 cave (Fig. 11) of a length of 283 m (Valenas, 2023a) and Tham Nam Lot cave (Fig. 11) 181 m long (Valenas et al. 2018; Valenas 2020g, 2023b). But there is also Tham Patihan cave (Mouret C., Mouret L. 1994;

Wilungkit, Jaimun 2022b), which may reach a length of 1 km, and especially Tham Din Pieng cave, which is a typical maze system probably up to 1 km long (Dunkley et al. 2017).

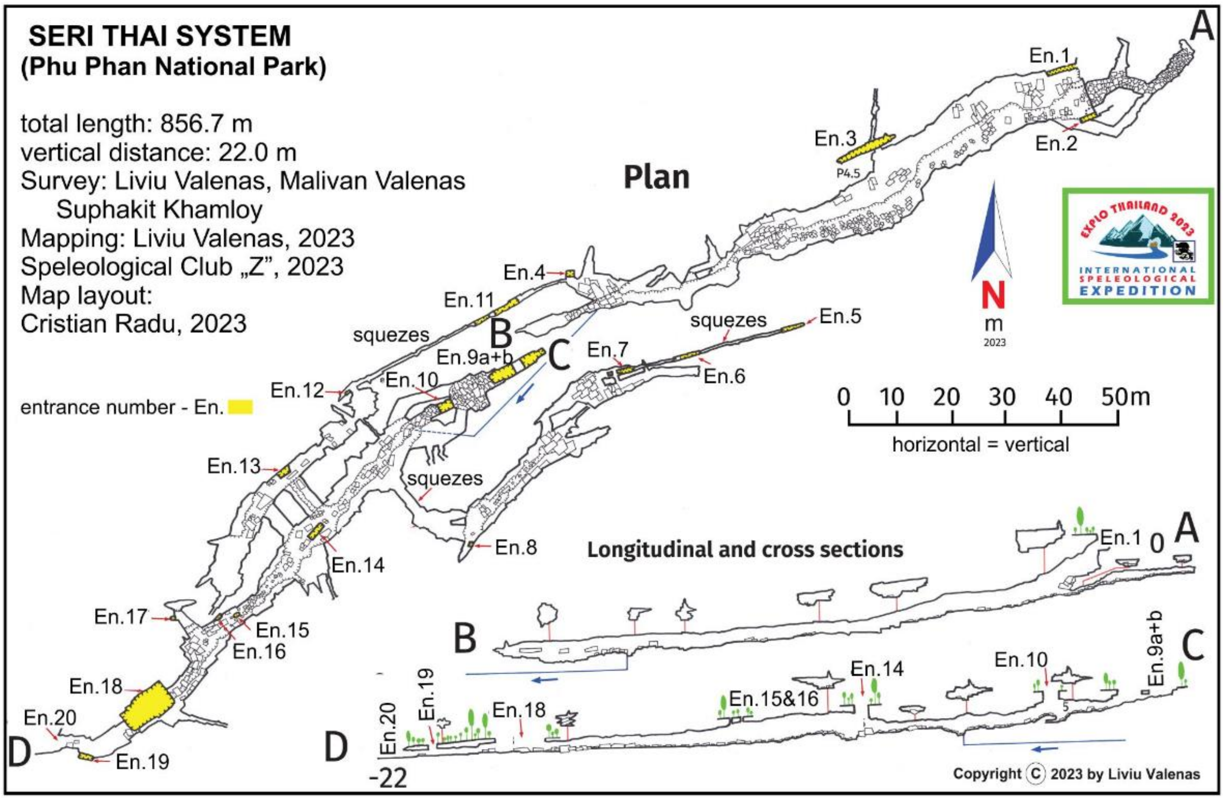


Fig. 8. Seri Thai System, the longest sandstone cave in Thailand, Sakon Nakhon Province.

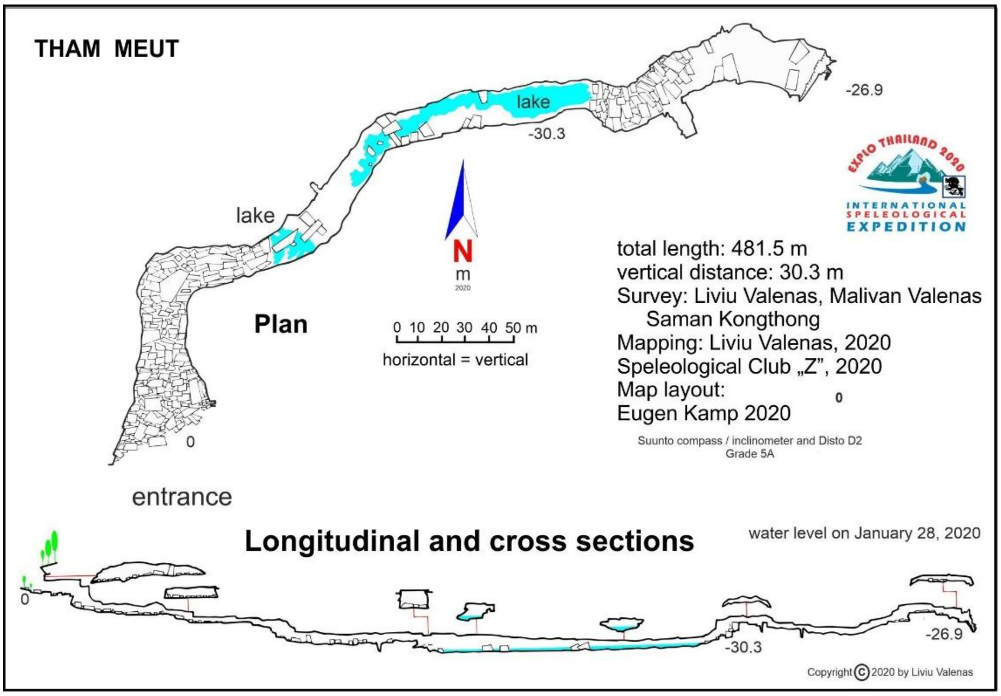


Fig. 9. Tham Meut cave, Ubon Ratchathani Province (see also First Cover).

Most caves are devoid of concretions or speleothem formations, except for those developed in sandstone with calcareous cement, in which speleothems are built of calcium carbonate. The concretions occasionally occur also in caves formed in quartzitic sandstones. Probably in the case of these concretions there are calcite veins within sandstones or marl inserts in them (Fig. 12).

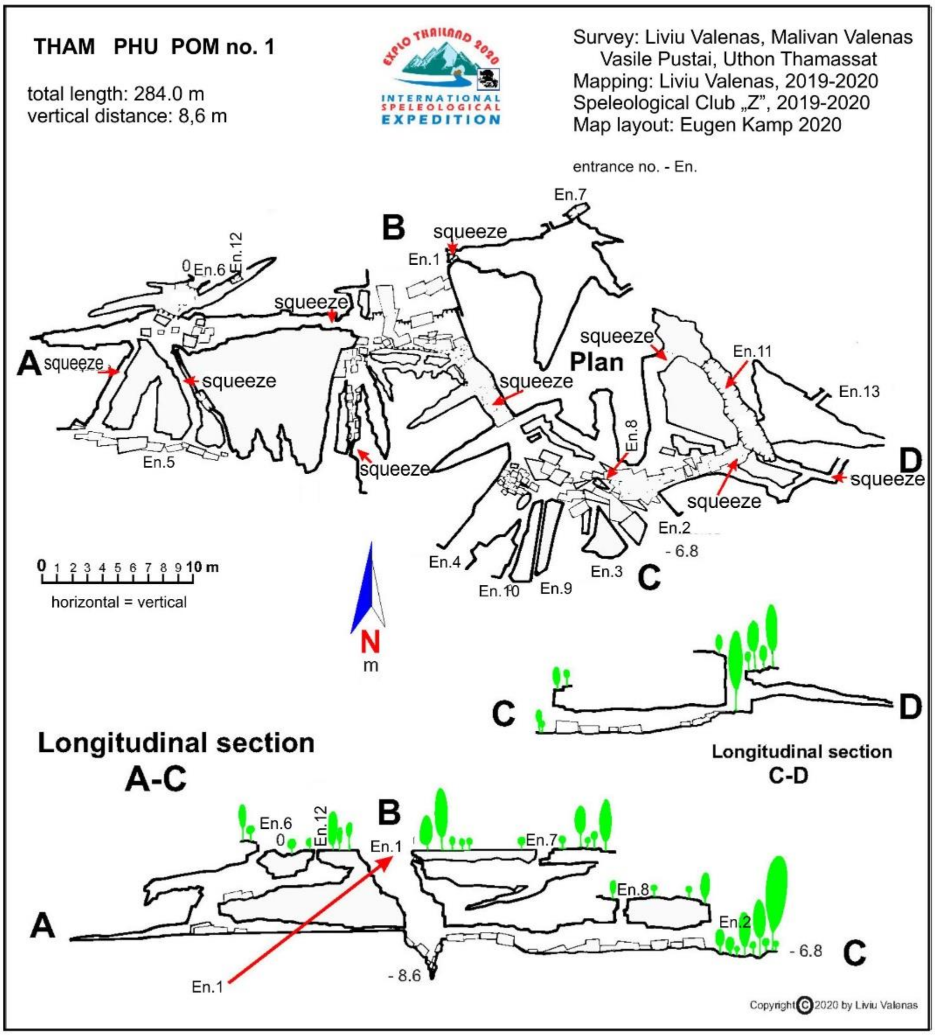


Fig. 10. Tham Phu Pom no. 1 cave, Amnat Charoen Province.

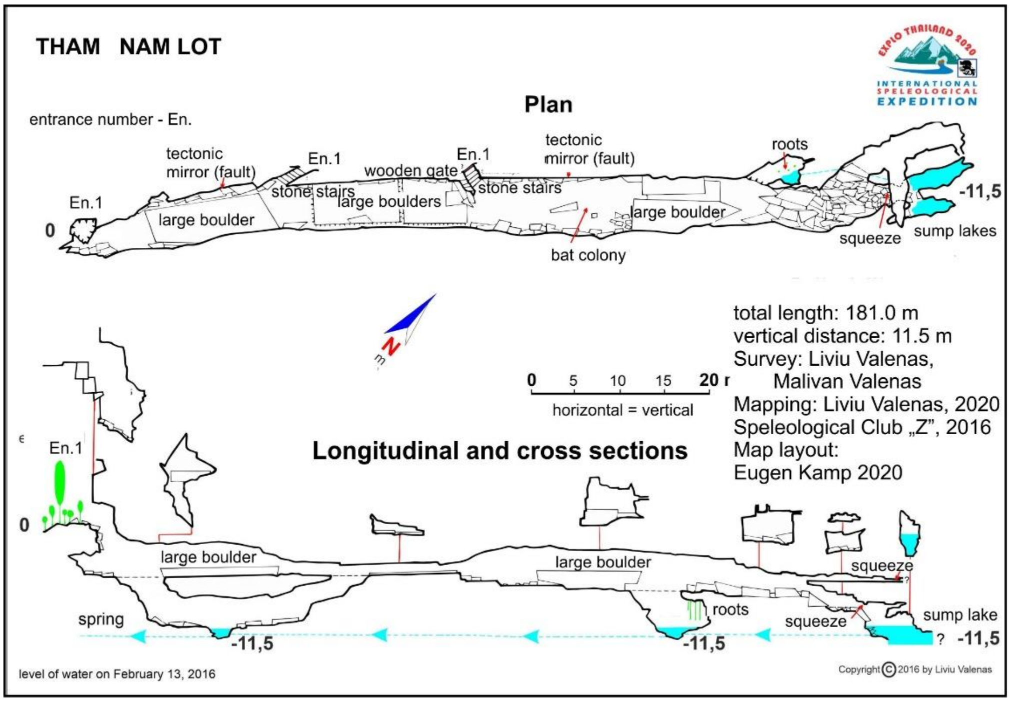


Fig. 11. Tham Nam Lot cave, Ubon Ratchathani Province.

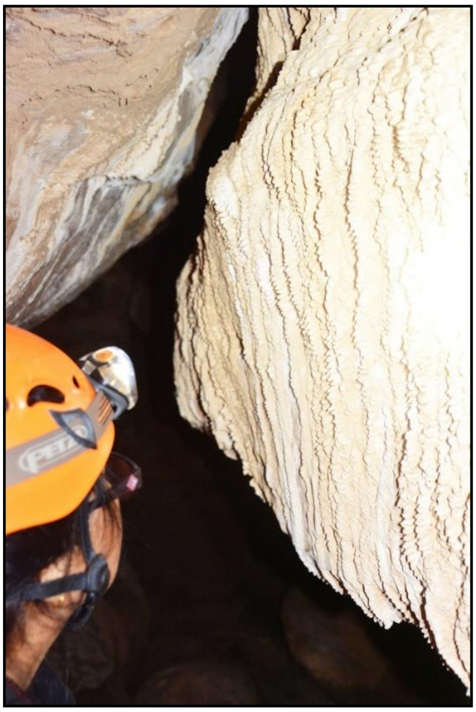


Fig. 12. Seri Thai System, carbonate flowstone, Sakon Nakhon Province (Photo L. Valenas).

4. Karst hydrogeology

Unfortunately, there is still a partial and deficient picture of the karst hydrogeology in northeast Thailand. The reason is that almost all speleological researchers were engaged in research and exploration exclusively in the dry season from December to May. However, certain conclusions can be drawn. Virtually all large caves are active in the monsoon season, but some are also active in the dry season. Tham Meut cave (Fig. 9 and First Cover) (Vălenas 2020e, Valenas 2023a, b) has extremely long-lasting lakes (at least 8 months) with flow in the dry season, whereas in the monsoon season it is completely flooded (Fig. 13). It is a “sinkhole cave” with a deep descent at the upper entrance. The discharge of water probably takes place directly into the Mekong River in an underground, strictly underwater spring. Tham Meut, Tham Patihan and Tham Gia are also typical “sinkhole caves” having their upper entrances at the ends of blind valleys. The flows in these caves are active at least 8 months a year, and the flow volume/speed in the valleys entering these caves is high, between 2 and 10 m³/s.

Tham Patihan, having two separate floors, is a unique cave among the caves in the quartzitic sandstones of northeastern Thailand, whose lower level, 126 m long, is completely flooded during the monsoon season (Mouret C., Mouret L. 1994, Wilungkit, Jaimun 2022b). The discharge of the underground river flowing within the Tham Patihan is probably in the surface valley, not far from the west end of this cave. Unfortunately, the Thai geologists from the Department of Natural Resources in Bangkok (DMR), which practically has an exclusive monopoly on the research of this cave, have not carried out any tracer test with fluorescein during the rainy season. The same applies the Tham Meut and Tham Din Pieng caves. At this last one, the spring is approximately 250 m apart from the terminal sump; there is also a tributary coming from a side swallow-hole (ponor) through inaccessible conduit (Ellis 2017).

In the case of the Tham Nam Lot cave (Figs. 11 and 14) (Vălenas 2016, 2020g, 2023a; Valenas et al. 2018) the swallow-hole (ponor) is located only 50 m from the spring of the underground stream within the cave, whereas the downstream spring is situated 45 m from the cave stream terminal siphon. The underground stream in this cave is 120 m long. Another interesting active cave is the Tham Ghia, developed almost linearly and 133 m long (Vălenas 2020h, 2023a). It is a natural tunnel, which is full of lakes without flow in the dry season and completely flooded during the monsoon season (Fig. 15). The downstream entrance gives rise to a large spring from which a stream emerges, which in the distance of 1 km flows directly into the Mekong.

Fig. 13. Tham Meut cave, the main gallery in the dry season, Ubon Ratchathani Province (Photo L. Valenas).

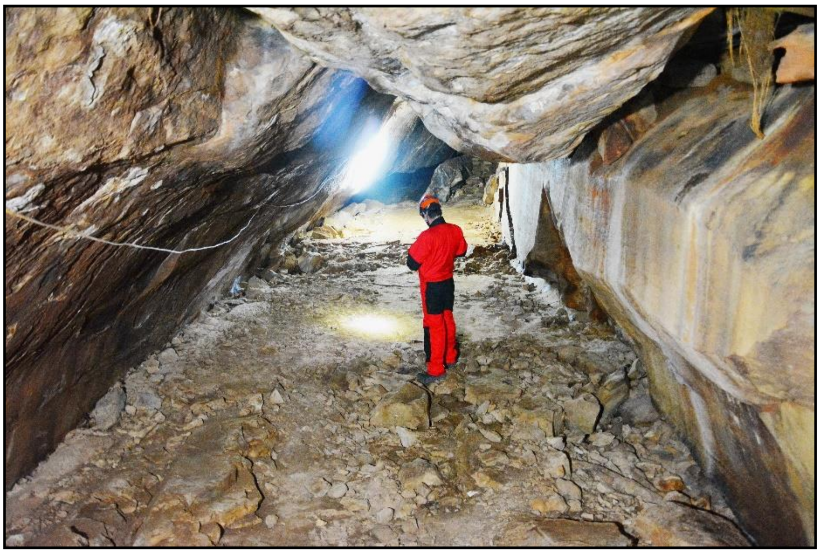


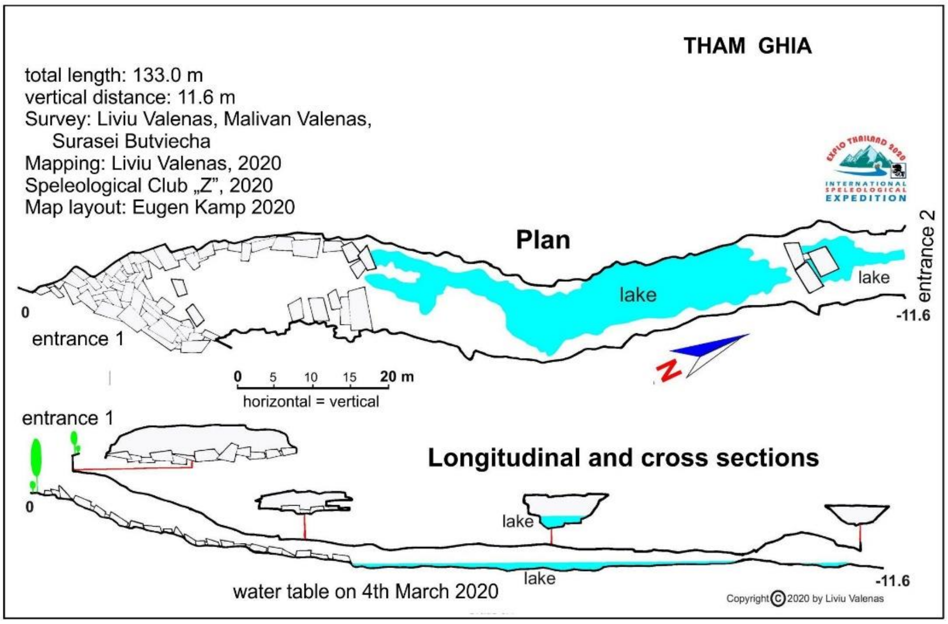
Fig. 14. Tham Nam Lot cave, Ubon Ratchathani Province. the tectonic mirror of the fault that generated the cave is visible (Photo L. Valenas).

Another interesting case is the Seri Thai System (Fig. 8), the longest sandstone cave in Thailand (Valenas 2023a, b). The system is composed of three parallel galleries developed along diaclases and faults. Within the middle branch, which is the longest, ranging a length of 300 m, an underground river flows. A swallow hole is situated several meters upslope of the cave entrance, while in its lower entrance a spring is active during 9 months a year. An impenetrable siphon divides the underground stream in the middle part of the conduit into two sections. The cave has one notable tributary conduit in the south-eastern part, with a length of 75 m (Fig. 8). Most likely, small tributary streams appear in the monsoon season. But no caver or hydrogeologist has studied the cave in the rainy season to see the exact hydrological situation of the system (Fig. 16).

We should also note 13 small caves (up to 39.7 m long) in the Phu Noy Mountain near Ban Kham Mae Mui village. These small cavities in the monsoon season represent the main catchment area of the karst spring located 1 km far from them, important for the area and people, because it feeds the stream that runs through the village (Valenas 2017, 2020g).

Our research, started in February 2023 and continued in the next study season, will explain several hydrogeological aspects. Chemical analysis of karst waters, marker (fluorescein) tests, etc. will be carried out in order to explain the intensity of silica dissolution as well as the hydrogeological system.

Fig. 15. Tham Ghia cave, Ubon Ratchathani Province



5. Geochemistry of karst waters

In the months of February and respectively March-April of 2023, 9 water samples were collected in the karst forms of quartzitic sandstones in the northeast of Thailand. Two samples were collected from underground streams in two caves, other two ones – from karst springs, Three samples were taken,

Fig. 16. Seri Thai System – the main gallery in the dry season, Sakon Nakhon Province (Photos L Valenas).

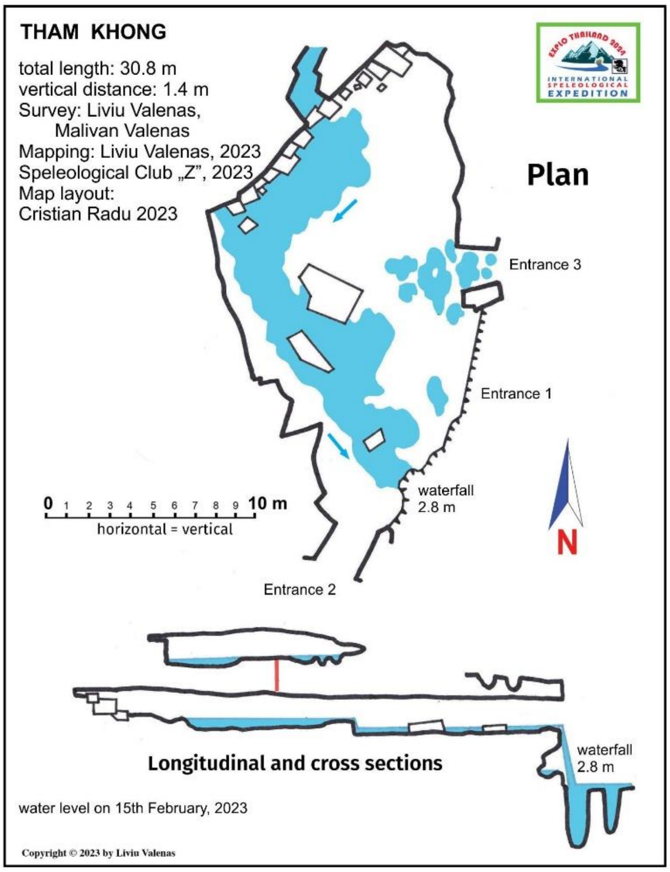
from "mini-cenotes" and two ones from surface streams. Chemical analyses were performed in the University of Freiberg, Germany. The final interpretation of the chemical values is still in progress but some conclusions can be drawn even now: the waters are acidic and very acidic, however still aggressive towards the quartzite sandstones. The samples collected from two "mini-cenotes" located a few meters from each other have different parameters, which supports the idea that they have nothing to do with ground water, they are fed only by a precipitation. Moreover, the values of chemical parameters of these waters from the "mini-cenotes" clearly demonstrate that the waters, even stagnant, are still aggressive towards the quartzitic sandstones, in which these "mini-cenotes" formed, a fact that explains their hourglass shapes (Fig. 17).

A clear exception among the samples is water from the main stream of Tham Din Pieng cave in the Nong Khai Province. The chemical values of this water are similar to the water in the limestone karst, characterised in particular by a high content of calcium carbonate. The reason of such a composition is the fact that the Tham Din Pieng cave develops in sandstone with calcareous cement. Until now, it is the only significant cave studied by us developed in this type of sandstone.

Fig. 17. "Mini-cenotes" near Phu Pom cave, Amnat Charoen Province (Photos L. Valenas).

6. Conclusions

The area covered by the sandstones in the Isan (northeast Thailand) is huge, over 150,000 km². After 1990 various speleologists from Europe, Australia, and others, spotted some larger caves in these sandstones, surveying them rather briefly (or not at all), and since 2000 they have abandoned this field of research, probably considering it uninteresting. Subsequently, since 2006 the author, supported by the Speleological Club "Z", has explored and surveyed 96 caves and potholes in detail, of the total length of galleries ranging almost 3 km of galleries (Vălenas 2020a, b, c, f, 2023a, b). The research has clearly showed that it is not a case of "pseudokarst", but a genuine karst, with all possible forms including sinkholes, springs (Figs. 18 and 19), karren, and underground networks of the total length up to 1 km. The primary "engine" of this karst is the dissolution of silica, the cement of the quartzitic sandstones exclusively under the conditions of the monsoon climate. Karst in quartzitic sandstones, the so-called siliceous karst, still raises many, many question marks.



Our research in the last four years has also led to another interesting finding: many of the large caves in Northeast Thailand are caves developed on lithological contacts between different layers of quartzitic sandstones, but also between sandstones and quartzitic conglomerates (Fig. 20).

The research, which must necessarily be multidisciplinary, is still practically at the beginning, because this karst was, unfairly, completely ignored until 20-30 years ago by karstologists and cavers.

Fig. 18. Tham Khong cave, Ubon Ratchathani Province.

Fig. 19. Tham Khong - an emergent cave, Ubon Ratchathani Province (Photo L. Valenas).

Fig. 20. Tham Phu Pom No 1 cave, Amnat Charoen Province – the cave developed along the contact between quartzitic sandstones and quartzitic conglomerates (Photo L. Valenas).

Appendix – Top Thailand sandstone caves, length (m) / VR (m)

1. Seri Thai System, Sakon Nakhon Province: 856.7 m /-22 m (Valenas /Speleological Club "Z", 2023) (Figs. 1, 8, 12 and 16)
2. Tham Din Phieng, Nong Khai Province: 694 m /-10 m (Department of Mineral Resources, Bangkok, 2021) (Figs. 1, 5 and 6)

3. Tham Patihan, Ubon Ratchathani Province: 660m /-27 m (Department of Mineral Resources, Bangkok, 2021) (Fig. 1)
4. Tham Meut, Ubon Ratchathani Province: 481.5 m /-30.3 m (Valenas /Speleological Club "Z", 2020) (Figs. 1, 9 and 13)
5. Air Raid Shelter Cave, Phitsanulok Province: 361 m / ? (Dunkley, Ellis & Bolger, 2017)
5. Tham Phu Pom No 1, Amnat Charoen Province: 284 m /-8,6 m (Valenas /Speleological Club "Z", 2019-2020) (Figs. 1, 10, 20)
6. Tham Nam Lot, Ubon Ratchathani Province: 181 m /-11.5 m (Valenas /Speleological Club "Z", 2016) (Figs. 1, 2, 11 and 14)
7. Tham Khang Khao, Phetchabun Province: 150 m / ? (Kositanon W. 2021. Phetchabun Geopark: paleosea to land and microplate margin wonders. Phetchabun Geopark, 61 pp.)
8. Tham Ghia, Ubon Ratchathani Province: 133 m /-11.6 m (Valenas /Speleological Club "Z", 2020) (Figs. 1 and 15)
10. Tham Cham Pha Tong, Sakon Nakhon Province: 120 m /? (unpublished data of Mouret and Leclerc, 1994)
11. Tham Phu Phanom Di no 8 (Great Pit), Ubon Ratchathani Province: 110 m /-8.7 m (Valenas /Speleological Club "Z", 2018) (Figs. 1, 4).

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References

Charoenmit, J., Thwai, S., Kaenthong, M. 2020. Survey and assessment of geological sites in Khon Kaen province, Academic Report No. Sor Kor 4 1/2563, Office of Mineral Resources Region 4, Department of Mineral Resources, 251 pp.

Doerr S.H. 2000a. Morphology and genesis of polygonal and karst-like weathering features developed in quartzitic sandstone, North-Central Thailand, British Geomorphological Research Group 40th Anniversary Conference, British Geomorphological Research Group, Sheffield.

Doerr S.H. 2000b. Morphology and genesis of some unusual weathering features developed in quartzitic sandstone, North-Central Thailand, Swansea Geographer 35: 1-8.

Dunkley J., R. 2011.Tham Din Phieng, Thailand: An unusual maze cave in sandstone, Proceedings of the 28th Biennial Conference of the Australian Speleological Federation, Chillagoe, http://st1.asflib.net/JNS/AUNat/ASF/ASF-ConfProc/ASF-28thConfMat-2011-Chillagoe/115-DinPhieng-2011.pdf

Dunkley J.R., Bolger T. 2017. An unusual maze cave in sandstone, NE Thailand – poster presentation at 17th International Congress of Speleology, Sydney, 23-29 July 2017.

Dunkley J.R., Ellis M., Bolger T. 2017. Unusual caves and karst-like features in sandstone and conglomerate in Thailand. Helictite 43: 15-31.

Ellis M. 2017. The caves of Thailand, vol. I, Eastern Thailand, Shepton Mallet, 312 pp.

Mouret C. 2017. Some fundamental features of speleogenesis in sandstone. 17th Intern. Congress of Speleology, Sydney, vol. 2: 174-179.

Mouret C., Mouret L. 1994. Prospection des karsts gréseux du nord-est de la Thaïlande (Isaan). Spelunca 55: 6-9.

Nakchaiya T. 2020. Geological and Speleological Surveys in Pha Cham Samphan Bok Geopark. Academic Report Sor Thor Khor 3 3/2563, Department of Mineral Resources, Bangkok, 79 pp.

Valenas L. 2015. Raport preliminar al expeditiei speologice internationale ISAN – 2015, Neodacii, Strasbourg, http/www. neodacii.com/content/raport-preliminar-al-expeditiei-speologice-internationale-ISAN-2015 .

Valenas L. 2016. Tham Nam Lot – a treia pestera ca marime din Thailanda in gresii cuartitice. Caietele Clubului de Speologie “Z”, serie noua, 1-2: 65-80.

Valenas L. 2017. Thailanda 2017. Caietele Clubului de Speologie “Z”, serie noua, 10.

Valenas L. 2020a. Report of the speleological expedition EXPLO THAILAND 2018. Cave Exploring 16, 1: 5-8.

Valenas L. 2020b. Report of the speleological expedition EXPLO THAILAND 2019. Cave Exploring 16, 1: 9-10.

Valenas L. 2020c. Report of the speleological expedition EXPLO THAILAND 2020. Cave Exploring 16, 1: 11-12.

Valenas L. 2020d. Speleological explorations in the North-East of Thailand. Cave Exploring 16, 1: 13-18.

Valenas L. 2020e. Tham Meut. Cave Exploring 16, 1: 29-36.

Valenas L. 2020f. Tham Phu Pom. Cave Exploring 16, 1: 37-42.
Valenas L. 2020g. Tham Nam Lot. Cave Exploring 16, 1: 43-46.
Valenas L. 2020h. Tham Ghia. Cave Exploring 16, 1: 47-50.
Valenas L. 2020i. Mini-cenotes of Phu Pom Mountain. Cave Exploring 16, 2: 55-60.
Vălenas L. 2023a. Geomorphology and hydrogeology of genuine karst in the quartzitic sandstones of northeast Thailand. In: Urban J., Jancewicz K. (Eds.), Abstracts, 14th International Symposium on Pseudokarst, Sudetes, Southwestern Poland, Karłów 24-27th May 2023. Inst. Geogr. and Regional Development, Univ. of Wrocław, Wrocław: 66-70.
Valenas L. 2023b. Silikatkarst in den quarzitischen Sandsteinen Nordost-Thailands. Mitteilungen des Verbandes der deutschen Höhlen- und Karstforscher, 3/2023: 76-83.
Valenas L. 2024. EXPLO THAILAND 2023. Thailand Rundschau, vol. 1: 4-6.
Valenas L., Valenas, M., Khamloy, S. 2018. Tham Nam Lot – a treia pestera ca marime din Thailanda in gresii cuartitice., Speomond, 19: 20-24.
Veeravinantanakul A., Kanjanapayont P., Sangsompong A., Hasebe N., Charusiri P. 2018. Structure of Phu Phan Range in the Khorat Plateau: its apatite fission track ages and geological syntheses. Bulletin of Earth Sciences of Thailand 9, 1: 8-16.
Wilungkit Y., Jaimun P. 2022a. Cave natural heritage sites in Khon Kaen Province, Academic Report No. Sor Thor Kor 2 1/2565 Office of Mineral Resources Region 2, Department of Mineral Resources, 187 pp.
Wilungkit Y., Jaimun P. 2022b. Guidelines for cave management for tourism in the Tham Patihan area, Na Pho Klang subdistrict, Khong Chiam district, Ubon Ratchathani province, Academic Report No. Sor Thor Kor 2 6/2565 Office of Mineral Resources Region 2, Department of Mineral Resources, 80 pp.
Wilungkit Y.; Jaimun P., Khamkhomkhet N., Mungkhun P. 2022. Cave natural heritage sites in Khon Kaen Province, Academic Report No. Sor Thor Kor 2 1/2565, Office of Mineral Resources Region 2, Department of Mineral Resources, 187 pp.

PSEUDOKARST CAVES IN NEW ZEALAND'S NORTH ISLAND ACCORDING TO THEIR DEVELOPMENT

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<u>Introduction</u>

The pseudokarst cave formation depends on the geological and geomorphological setting of the area. The physical and chemical influences create various caves, which developed by different forms of mass movements, the physical and chemical weathering in the volcanic and sedimentary rock formations of the North Island. In almost each individual cave it is possible to detect more than one cave forming factor, but to classify the cave into a genetical category it was necessary to define the main factor. The following main factors and genetical types of caves can be found in the North Island of New Zealand.

<u>Genetical types of pseudokarst caves in the North Island according to processes</u>

1. Mass movements

<u>1.1. Gravitational crevice caves</u>

Fractures are formed in the rock massifs by an equalization of the tension, extension and shearing stresses in these massifs that are caused mainly by a gravitational factor, namely gravity potential difference. The 430 m a.s.l. high Mount Manaia rises approximately 30 kilometres southeast of Whangarei city on the Whangarei Heads Peninsula (Fig. 1). The distinctive summit is crowned with five deeply eroded pinnacles. Near the summit opens an 85 m deep crevice cave, called Delph Fissure. The sizable fracture has been formed by the dislocation of the Miocene basalt lava masses.

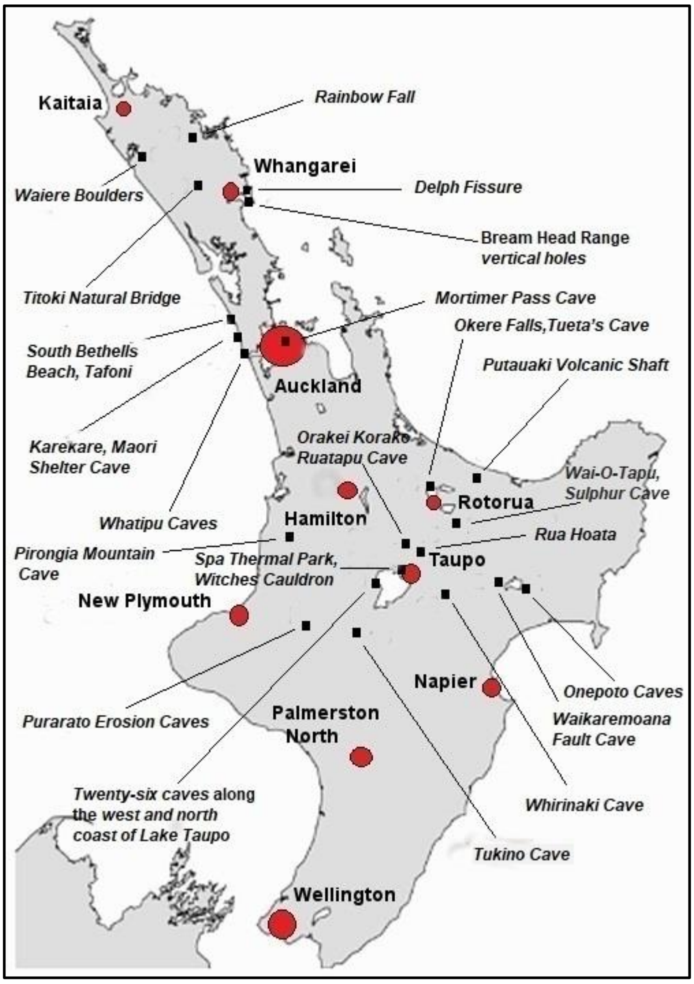

Fig. 1. Location of the caves mentioned and described in the paper.

The formation of the cave raised a set of genetical explanations, none of which appear to be fully plausible (Allen 1951). The hole is a large crack in the bedrock that is partially filled with rubble, but which extends several hundred meters in a roughly east-west direction. It narrows consistently from several meters wide at the top to less than 1 m wide at the level 75 m deep. The walls of the crack roughly match each other. It means that if the rubble were removed and the crack closed the both walls would fit together the same way. That eliminates the hypothesis that the sea has had recent influence and implies that the crack was once completely open and is progressively filling.

Near the northern shore of the Lake Waikaremoana at the State Highway 38 Waikaremoana Fault Cave opens (Fig. 1). The narrow crevice cave was formed in Middle Miocene bedded sandstone (Crossley 1995). The cave development was most likely related to the gravitational rock mass movement, which formed the lake, as well. The force of huge landslide that occurred 2200 years ago moved the compact rock masses and produced fractures (Fig. 2).

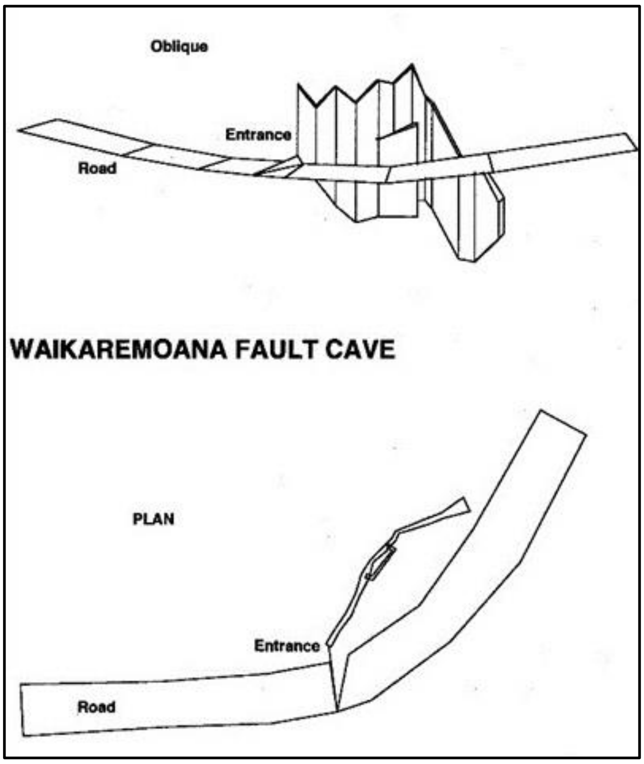

Fig. 2. Sketch of the Waikaremoana Fault Cave – oblique section and ground-plan (by P. Crossley).

The development of the Putauaki Volcanic Shaft in the Late Quaternary andesitic pyroclasts of Mount Edgecumbe (Fig. 1) may be associated with the Tarewara explosion in the year of 1886. The movement of the rock mass created a 13 m deep shaft and a 10x15 m cavity. The cave wall is composed of scoria and fine ash with occasional large lava boulders. The floor has silted up by basaltic dark grey ash from the Tarawera explosion (Ashley, Cody 1985*)*.

At the elevation of 850 m a.s.l. of the Mount Pirongia (Fig. 1) an 8 m deep vertical cave, Pirongia Mountain Cave opens near the boundary between Plio-Pleistocene basalt breccia and columnar lava. The cave has developed by the continuous sliding of the columnar lava on the basalt breccia surface. It consists of a single steeply dipping passage containing two small pitches, developed in hard, columnar-jointed basalt (De Lange 1989). The floor is covered by loose angular blocks and coarse gravel, derived from erosion of the underlying volcanic breccia.

1.2. Caves developed along bedding planes

Due to their situation the caves extend horizontally or nearly horizontally. The mass movement opens cavities among the bedding plains generally together with other cave forming forces, such as erosion or deflation. Two caves were formed along the bedding plains of the rugged mass of marine bedded pyroclastics of Miocene Manakau Breccia in the Whatipu Cliff (Fig. 1) among the abrasion caves. The Cave No. 1 (called also WP Cave) is located in the SE flank of the former shoreline near the swampy flat. It is a low 3 m long and 4 m wide rock shelter. The Cave No 3 (or WP 2 Cave) is a 4.5 m wide and 8 m long low and flat cavity. The permanently seeping water has widened both caves (Szentes 2007).

1.3. Atectonic Boulder Caves

Atectonic caves are those cavities which formed among the sliding boulders. On the convex slope moving boulders gradually move away from each other and holes formed among them. The occasionally occurring spreading force between the boulders favours the boulder caves development.

Near Horeke settlement at the end of Mc Donnel Road (Fig. 1) the Waiere Boulders, a valley filled with gigantic basalt blocks is situated. The boulders are relics of Miocene-Pliocene basalt lava flows and they are the best examples in New Zealand of the dissolution of basalt (protokarst) that has produced deep flutings and basins on their surfaces. There are large number of cavities formed among enormously large basalt blocks. They are from a few meters to several ten meters long, thus creating boulder caves. The development of this caves can be traced back to the continuous sliding of the rock masses and the consequent aggradation (Crossley, Szentes 2017). There are two significant caves along the Boulder Loop. The footpath goes through an unnamed cave of a length about 15 m (Fig. 3). The other cave is Dragon’s Cave, the longest cave of the boulder area. The length of the steep cave is nearly 40 m.

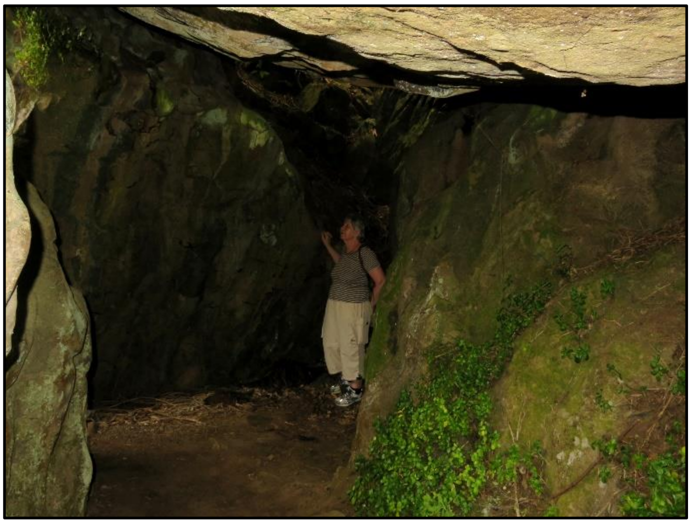

Fig. 3. Cave among the huge basalt blocks of the Waiere Boulders (Photo G. Szentes).

The Onepoto Caves Track is situated close to State Highway 38, approximately 10 km south of the Aniwaniwa Visitor Centre of Urewera National Park (Fig. 1). The track allows exploration of the various caves in the area. The Onepoto Caves were formed by the same upheaval that created Lake Waikaremoana 2200 years ago. The caves were formed by a huge landslide that occurred due to an earth-quake. Large blocks of Miocene sandstone broke into jigsaw-like pieces, some stacking on top of each other to form these caves (Crossley, Szentes 2017). The caves range from small cavities and rock shelters to deep recesses and tunnels up to 20 m long, some with multiple entrances. Some huge slabs of sandstone leaning over the massive blocks so much that they form leaning cavities (“pseudocaves”). Cave wĕta (endemic insects in New Zealand) can be found in these caves. They gather in the caves during the day and venture out at night to feed on plants. Onepoto Caves (called in local language also Te Ana-o-Tawa Caves) were well known to the Māori people of the Lake Waikaremoana area.

1.4. Breakdown caves, consequence caves

When a cavity ceiling loses its stability, it will collapse partly or completely. The original cavity will be filled with debris and in the upper part will develop a new hollow. The new cavity is a break up cave. In case of the natural breakup of a ceiling of an artificial hole (mine gallery, casemate etc.) due to the equalization of the potential rock stresses, the newly formed cavity is a consequence cave.

In the Whangarei Heads, towards the eastern extremity of the Bream Head Range (Fig. 1) some vertical holes 0.3 m to 0.6 m wide at the surface, but widening downwards, and of unknown, but very considerable depth, occur. They are formed in the andesite agglomerate in a narrow belt about 30 m long. About six such holes were seen by Allen (1951), but some others were closed by the owner of the area. They are situated at an elevation of several hundred meters above sea level, but not far from the shoreline and they seem to be related to the collapses at points of intersections of major joints along the abrasion caves at the sea level.

1.5. Movement of the plastic lava sheets

Mortimer Pass Cave in Auckland City (Fig. 1) is not a lava tube (Crossley 2014), but a cave in the basalt, formed during the hot lava stage due the slide of plastic lava sheets over another ones (Fig. 4).

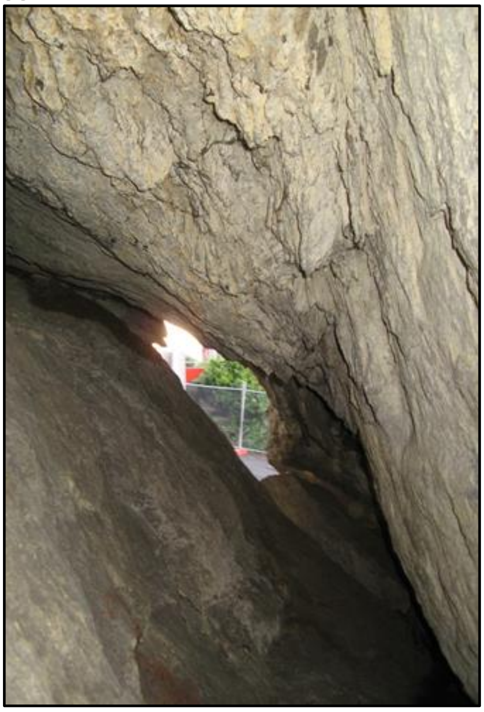

Fig. 4. Within the Mortimer Pass Cave one lava sheet slides over another (Photo P. Crossley).

2. Physical Weathering

2.1. Linear erosion

The linear erosion is effective along the water stream. A small tributary stream of the Waitomotomo River cuts the northern extremity of a basalt tongue. Above this stream, there is an impressive natural bridge formed in the olivine basalt, called Titoki Natural Bridge (Fig. 1). The natural bridge forms a broad arch 10-12 m wide over the stream. The basis of the arch is 4 m above the stream at its highest point (Heming 1979.). Titoki could represent the eroded remnants of small lava tubes, however, no signs of chilled zones, lava driblets, or any other morphological features associated with lava tubes can be found there. A stream could have flowed into the tube through a roof collapse and consequently, further erosion removed all traces of internal morphology of the tube. Erosion and opening of joints also seem to occur subsequently to the collapse. The present stage of the bridge can be considered as a pseudokarst cave originated due to the linear erosion (Fig. 5).

Fig. 5. The Titoki Natural Bridge (Photo P. Crossley).

Five kilometres far from the Pipiriki settlement upstream of the Whanganui River the Purarato Erosion Caves are situated (Fig. 1). Two small and one bigger caves were formed in the sequence of sandstone and siltstone interbeds (Hickson 1978). The caves developed by the erosion of the stream, which flowed through the fissures filled with loosened sandstone-siltstone rocks into the main river. The bigger cave comprises a maze system of passages developed in several levels. The passages are partly dry, partly wet and muddy with several pools and small waterfalls. The main passage terminated with a 13 m high waterfall. The length of the passages ranges approximately 100 m. The cave was reputably visited about 1855 by the Rev. Richard Taylor, who used a wooden ladder anchored in a Māori canoe to reach the top of the first waterfall.

The Whirinaki Cave locates in the Whirinaki Te Pua-a-Tāne Conservation Park (Fig. 1) along Whirinaki Track, between the Central Whirinaki Hut and the Upper Whirinaki Huts (Shaun 2009). The cave formed when the stream water eroded the Middle Quarternary pumice deposit creating one large cavern and a smaller one behind it. Inside one may find small creatures such as wētā (insects). Remnants of charcoal in the pumice are the products of the Taupo eruption nearly 2000 years ago, which destroyed local forest. The larger cave is a home to glowworms.

2.2. Lateral and turbulent erosion

The lateral erosion, as well as turbulent erosion produce rock shelters and niches in walls of gorges or beneath waterfalls. The erosion effect depends on the rock lithology, hardness of its fragments, the stream velocity and water volume, the angle of the application, etc.

There is a cave under the Rainbow Falls. The waterfall cascades over the edge of an eroded basalt lava flow on the Kerikeri River, 3 km upstream from the Old Stone Store in Kerikeri settlement (Fig. 1). The 27 m high waterfall has eroded the softer Miocene mudstone underlying the Pliocene basalt lava stream and formed a voluminous erosion cave (Crossley, Szentes 2017). The cave gradually lowers from the entrance and the moss-covered muddy floor is dotted with basalt blocks.

The Okere Falls mark the springs of the Kaituna river (Fig. 1). The falls are located 21 km from Rotorua on Trout Pool road from the Rotorua to Tauranga highway. Under the waterfalls, there is a 30 m long turbulent erosion cave, the Tueta's Cave (Fig. 6), developed in Middle Quaternary pumice and ignimbrite. Ten meters beyond the two entrances a Y-shaped passage has formed and there is a gap in the floor which leads to a much smaller lower level. The cave is named after one of the local Māori chiefs, Tueta, and was used by local women and children to hide during times of war (Turner 1974).

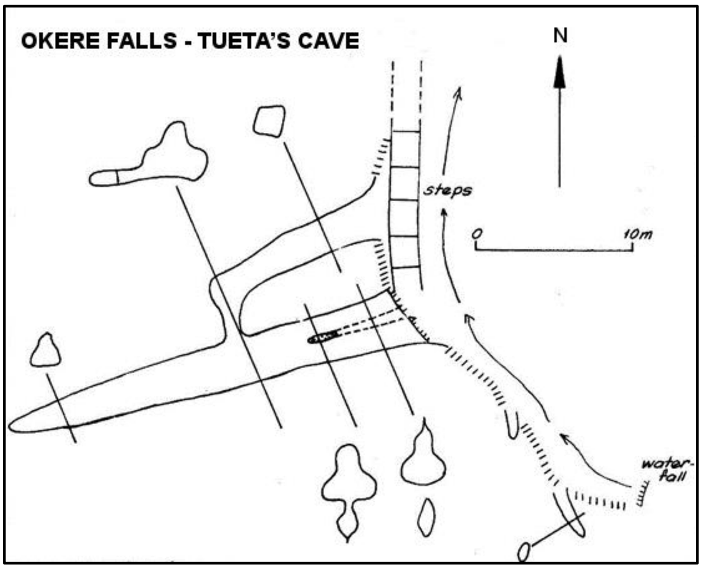

Fig. 6. Map of the Teuta's Cave (surveyed by P. Crossley).

The Rua Hoata shelter is a domed cave situated on the edge of the Waikato River on the eastern side below the Aratiatia Rapids (Fig. 1). The shelter is one of a few sites of ancient Māori rock drawings in the North Island on the Waikato River. The dimensions of the entrance are difficult to determine: it is approximately 8 m wide and 9 m high. The original floor level at the entrance has been covered with rock debris to a depth of about 4 m (Phillipps 1947). The cave is a deep recess in the pumice or fine-grained ash on the riverbank just above river level. The cave goes in for about 5-6 m and is about 6 m wide. It is known to have carvings over most of the ceiling. However only those at the entrance are obvious, and the remaining ones are in danger of flaking because the ash is quite soft and the cliff has been collapsing above them. *Rua Hoata* was a very large cave that was used as a place of refuge from invading Iwi (Māori tribe). It was flooded when the hydroelectric dam was built at Aratiatia.

2.3. Fragmentation

As a consequence of periodic alternations in the supply of heat and moisture, the rock surface and the surface of the mineral constituents change. The continuously affected surfaces separate themselves from the main rock body and tumble down. This process repeats on the newly formed rock surfaces and cavities repeatedly develop.

The upper and lower entrances of 15 m long Tukino Cave is situated just south of cascading Dimrill Stairs Waterfall (Fig. 1) in the Tongariro National Park (Climb National Route Database 2015). The cave is principally a narrow "crawl" passage at the base of the top cascade. The location and form of the cave suggest that the fragmentation, caused by the variation of freezing and melting water formed the cavity (Fig. 7).

Fig. 7. Entrances of Tukino Cave (Photo P. Crossley).

The Māori *Shelter Cave* is situated in the Waitakere Regional Park in the Eastern side of the Cave Rock in Karekare settlement (Fig. 1). It is composed of two cavities combined into large rock shelter (Fig. 8). The fragmentation of the Miocene agglomerate due to the temperature and humidity alteration as well as the erosion of the rainwater were the factors forming this cave (Szentes 2011).

2.4. Abrasion or wave erosion

There are numerous caves on the sea cliffs, although a tectonic uplift or sand and dune movement separate temporarily or continuously and finally these caves from the sea. From the genetical point of view they are abrasion sea caves (Crossley 1979), however they can obviously be considered as pseudokarst caves, as well.

Fig. 8. Māori Shelter Cave near the Karekare settlement (Photo G. Szentes).

The best example of the separation of the abrasion caves from the sea shore are the Whatipu Caves (Fig. 1), where a 1 km wide sand flat divides the caves from the sea. The sand flat and its mobile dunes have stabilized over the last 100 years and the caves have no more contact with the sea. Seven abrasion caves open at the same level along the cliff wall formed of the Manakau Breccia, which is composed of andesite lava, tuff and conglomerate as well as a mixture of gravels and sands left behind by the underwater lahars (Hayward 1976). The looser rock formation near the fault lines encouraged the abrasion effect. It's worth mentioning the 120 m long WP1 Cave, originally named Victor Cave, where the influence of the tectonic movement and the one-time abrasion can be observed equally. The WP5 Cave, originally called Whatipu Dance Hall Cave, has the largest and most spectacular entrance (Fig. 9). It is 18 m wide and 8 m high (Szentes 2007). A large abrasion chamber of a volume ranging approximately 3500 m^3) extends far beyond the entrance as the 3D model of the cave demonstrates (Fig. 10).

Fig. 9. Whatipu Dance Hall Cave entrance (Photo G. Szentes).

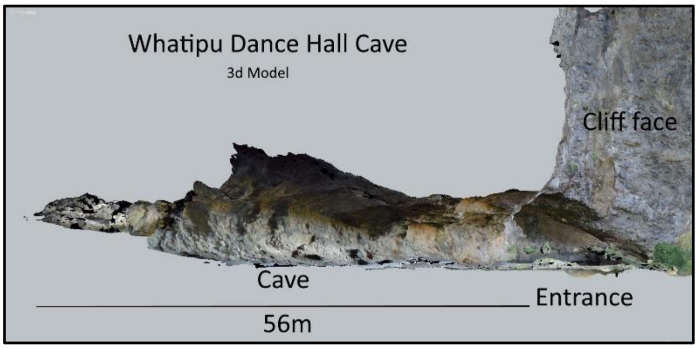

Fig. 10. 3D model of the Whatipu Dance Hall Cave (by P. Crossley).

Twenty-six caves have been listed in ignimbrite along the west and north coast of the Lake Taupo (Fig. 1). They were formed by the wave erosion of the lake at the loosened ignimbrite zones. The caves are important from the Māori heritage point of view.

3. Chemical weathering

The chemical weathering decomposes rocks in the presence of water. The weathering depends on the solution agent (inorganic acids, organic acids or lyes) and on the kind of the decomposition: hydration, hydrolysis, oxidation. In New Zealand the acidic solution effect can form caves in the geothermal fields.

Ruatapu Cave developed beneath a massif of hydrothermally altered Quaternary vitric tuff in the active Orakei Korako geothermal field (Fig. 1). The Orakei Korako thermal area is predominated by alkali-chloride alteration, and the cave hosts a steaming acid, a pool of sulphate solution and a series of efflorescences and other minerals precipitated due to the weathering of the surrounding tuff assisted by sulphuric acid. The cave length extends 45 m, with a vertical drop of 23 m, descending to a pool of clear, sulphate-rich, warm acidic water (Fig. 11) The water temperature varies between 43° and 48°C, the sulphate ion concentration is 450 mg/l and the pH ranges 3.0. Steam, accompanied by H_2S, rises from the pool and from a nearby fumaroles and joints in the ignimbrite, and condenses on wall surfaces within the cave (Cody 1978). Oxidation of H_2S to H_2SO_4 produces acid fluids which react with the surficial rocks to generate secondary minerals such as: kaolinite, opal-A, cristobalite, alunite, gypsum, melanterite, and thenardite (Rodgers et al. 2000).

Fig. 11. Ruatapu Cave in the Orakei Korako thermal area (Photo G. Szentes).

A boiling geothermal pool at the foot of a small cliff in the Spa Thermal Park (Fig. 1), Taupo, was known as the Witches Cauldron (Peter Wood 1994). The cauldron was described as a steam enshrouded clear hot pool and small cave emerging from the basis of a multi coloured wall that sparkled in the sunlight.

Wai-O-Tapu (in Māori language: sacred waters) is an active geothermal area at the southern end of Taupo Volcanic Zone (Fig. 1). Due to dramatic geothermal conditions beneath the ground surface, the area has many hot springs noted for their colourful appearance and the Sulphur Cave (Peter Wood 1994). The cave is a collapsed crater with mud pools at the bottom and multi-colored rock walls.

4. Tafoni/tafone

Tafoni are ellipsoidal, pan- to bowl-shaped natural rock cavities. These cavernous weathering features include tiny pits, softball-sized cavities, truck-sized caves, and nested and cellular honeycomb forms. Tafoni typically develop on inclined or vertical surfaces and occur in groups. During the evolution of the rock weathering pattern, new forms emerge including relatively shallow ellipsoidal hollows, cavities with angular wall intersections, and the remains of cave walls appearing that look like labyrinthine tendrils.

Examples of the tafoni can be found in the South Bethells Beach near the two sea caves (Fig. 1). The vertical wall of volcanic breccia is dotted with tafoni of various sizes like cavities (Fig. 12). The shape and size of the holes refer to the developing effect of fragmentation and downflowing rainwater.

Fig. 12. Tafoni like cavities in the South Bethells Beach (Photo G. Szentes).

References

Allen L.R. 1951. The geology of Whangarei Heads. Transactions of the Royal Society of New Zealand 79, 2, 307 pp.

Ashley D., Cody A.D. 1985. Putauaki Cave, Mt Edgecumbe, New Zealand Speleological Society Bulletin 7 (134): 427-429.

Climb NZ National Route Database 2015: Dimrill Stairs; https://climbnz.org.nz/routes/rock

Cody A. D. 1978. Ruatapu Cave, Orakei Korako. New Zealand Speleol. Soc. Bull. 6 (107): 184-187.

Crossley P. 1979. Sea Caves between Whatipu and Pararaha Stream, , New Zealand Speleological Society Bulletin 6, 109: 206.

Crossley P. 1995. The Waikaremoana Fault Cave (unpublished manuscript).

Crossley P. 2014. Inside Auckland lava caves, New Zealand Speleological Society Bulletin 11, 208: 215.

Crossley P., Szentes G. 2017. Study of pseudokarst caves in New Zealand. Pseudokarst Commission Newsletter 28: 11-15.

de Lange 1989. Pirongia Mountain Cave. , New Zealand Speleological Society Bulletin 8 (151).

Hayward B. W. 1976. Lower Miocene stratigraphy and structure of the Waitakere Ranges and the Waitakere Group, New Zealand Journal of Geology & Geophysics 19, 6: 871-895.

Heming R.F. 1979. Natural bridges in basalt lavas, Northland, New Zealand Journal Geology & Geophysics 22, 2: 239-243.

Hickson T. 1978. Purarato Caves. New Zealand Speleological Society Bulletin 6, 107: 162-164.

Peter Wood C.C. 1994. Aspects of the geology of Waimangu, Waiotapu, Waikite and Reporoa geothermal systems, Taupo Volcanic Zone, New Zealand Geothermic 23, 5–6: 401-421.

Phillips W. J. 1947. The Rua Hoata shelter, Waikato River. Journal of Polynesian Soc. 56, 4: 336-339.

Rodgers K.A., Hamlin K.A., Browne P.R.L. Campbell K.A., Martin R. 2000. The steam condensate mineralogy of Ruatapu Cave, Orakei Korako geothermal field, Taupo Volcanic Zone. New Zealand. Mineralogical Magazine 64, 1: 125-142.

Shaun B. 2009. Upper Wharíniki Hut. New Zealand Geographic 99.

Szentes G 2007. Relict abrasion caves in New Zealand, 9. Nature Conservation 63 (6): 69-76.

Szentes G. 2011. New study on the abrasion caves near Auckland (New Zealand). Pseudokarst Commission Newsletter 22: 6-9.

Turner J. 1974. Okere Falls – Hinemoa's Steps and Cave. , New Zealand Speleological Society Bulletin 5 (89): 27.

DEVELOPMENT OF CAVES AND CAVITIES RELATED TO EXTREME WEATHER EVENTS IN THE BLUE MOUNTAINS, NEW SOUTH WALES, AUSTRALIA

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Introduction

A sequence of extreme weather events: drought (2017-2019), bushfires (2019-2020), then floods (2020-2023) has allowed us to see iron minerals being deposited by temporary springs along a highway running through the Blue Mountains National Park, New South Wales, Australia. Usually these seeps were clear, and covered by vegetation, but recent weather extremes have made it easier to see a process of accelerated iron mineral deposition. Springs are depositing colourful bacterial iron flocculants (flocs), often with flowstone-like pattern (Fig. 1). Burnt areas allowed us to view some of the smaller sandstone caves which were previously hidden by vegetation.

This paper discusses some of the processes which may be operating within the quartz sandstone, leading to the attractive and unusual shapes, and how extreme weather led to the mobilisation and re-deposition of iron minerals.

Fig. 1. An example of a roadside spring in quartz sandstones of the Blue Mountains with bacterial iron flocculants (flocs) with flowstone patterns (Photo J. Rowling).

Location and setting

Mount Banks is a raised area (1049 m a.s.l.) of an undulating plateau of approximately 800–900 m altitude, located in the Blue Mountains National Park, 115 km west of Sydney, Australia (Fig. 2). The area is famed for its rugged scenery set in Triassic quartz sandstone, deeply dissected by creeks and sheer cliffs, 100 to 200 m high. Nearby, valleys are approximately 600 m altitude, developed in Permian marine mudstones. The bases of the cliffs are in Permian Illawarra Coal Measures, typically around 700 m altitude. Tourists enjoy the sculptural quality of ironstone bands and little caves in quartz sandstone

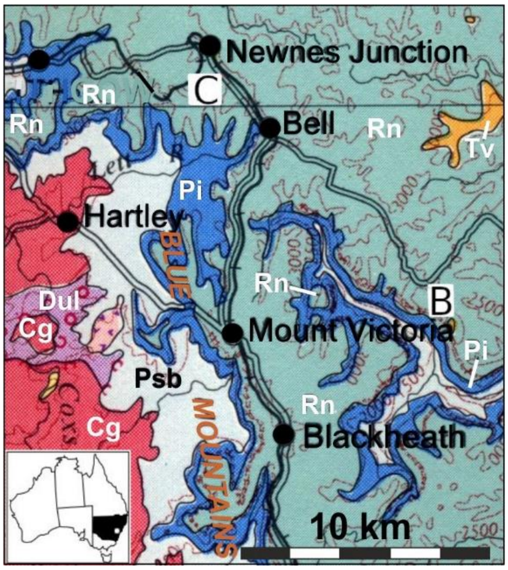

Fig. 2. Location of the study area and important sites mentioned in the paper. B – Mount Banks, C – Clarence. Geological units: Tv – Neogene (Miocene) basalt, Rn – Triassic Narrabeen Group sandstones. Pi – Permian Illawarra Coal Measures, Psb – Permian marine mudstones, Cg – Carboniferous granite and granodiorite, Dull – Devonian, Lambie Group, conglomerate, sandstone and shale. Contour heights are in feet. Width of view is approximately 20 km. Geological map base from Brunker and Rose (1967). Inset map of Australia is from Geosciences Australia.

(Fig. 3). The Blue Mountains National Park has abundant sclerophyll vegetation dominated by eucalypts. Transpiration keeps the water table low, especially during long droughts such as 2017-2019. It is this act of transpiration which releases eucalyptus oil into the air, making the Blue Mountains appear blue.

Fig. 3. Small sandstone caves under ironstone-capped bluff near Mount Banks (Photo J. Rowling).

Distinctive ironstone weathering patterns can be seen in exposed areas of the plateau which is mainly Banks Wall Sandstone at this study site. The most likely source of iron for the ironstone is the erosion of Neogene (Miocene) basalt cap on nearby Mt Banks (Pickett et al. 1997). The process of erosion allows iron oxyhydroxides to be re-worked by soil chemistry and biology, dissolving or precipitating iron oxyhydroxides downstream from the original source.

Specific phenomena and landforms

Springs

During a major bushfire of 2019-2020, a large area was burned, including much of the vegetation in the study area of Mt Banks to Clarence a little further west along the Bells Line of Road. After the fires, there were flooding rains. A "La Niña" wet weather event lasting from 2020-2023 brought significant rain and floods to the region. Without vegetation to draw down the water table, springs were seen in the area, coloured red-orange from apparent iron oxides. When active, springs could be seen on rounded rock faces below hanging swamps and on road cuttings as shown here near Clarence (Figs. 1 and 4). Gradually, vegetation returned naturally from a combination of epicormic buds and seed and the springs are now less obvious.

Fig. 4. Road cutting in quartz sandstone with iron spring at bottom, leached middle area and top reddish regolith near Clarence (Photo J. Rowling).

Swamps

Hanging swamps, as defined by Jacobs et al. (2014), occur on steep sites on the sandstone where groundwater rises due to a less permeable substrate. Generally they occur on the edges of the plateau and sides of steep hills such as Mount Banks. Other swamp types on the plateau include headwater swamps, which occur near catchment divides where topographic gradient is low (Jacobs et al. 2014). Both types are naturally acidic from organic acids, typically from peat. At the study sites, the Mount Banks swamps could be considered "hanging swamps" and the ones at Clarence, "headwater swamps". During the bushfires, parts of some swamps burned completely through the peat subsoil right down to the sandstone but others stayed wet. After flooding rain, water levels in the hanging swamps rose and flowed over the sandstone (Fig. 5).

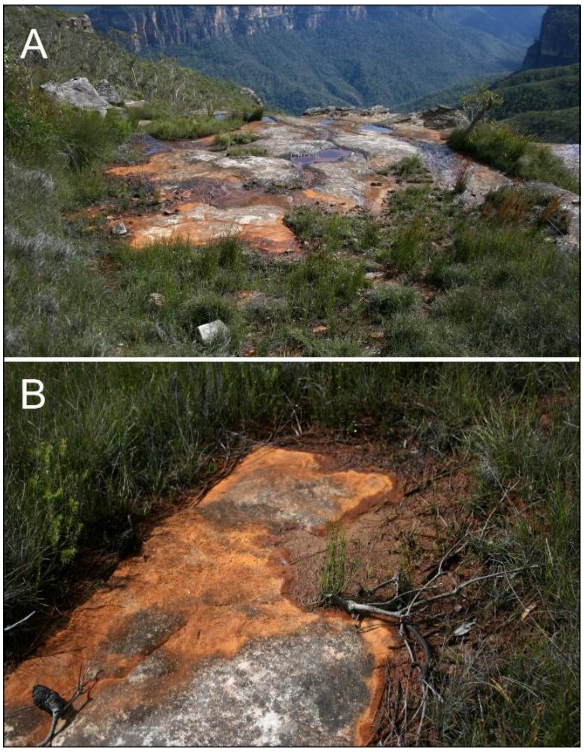

Fig. 5. Exposed sandstone on Mount Banks, with hanging swamp and iron deposit, with the Grose River valley forming a spectacular backdrop: A) general view; B) iron oxides and hydroxides deposited from overflowing swamp (Photo J. Rowling).

Exposed sandstone plateau

Apart from the swamps, the plateau has very thin soils, mainly composed of sand, quartz sandstone and ironstone clasts and a mat of interlocked roots of several plant species. The bushfires burned some of these mats, which subjected the soils to high temperatures close to the surface.

Near Mount Banks picnic area, it was possible to see some of the effects. After the fires and the first rains, the ash bed became a thick, foul-smelling black paste. This may have prevented some of the soil from being simply washed away, and was still present three years later. Reduced vegetation allowed us to see ironstone outcrops (Figs. 6 and 7).

Fig. 6. Sandstone outcrop with resistant ironstone banding, in swamp near Mount Banks (Dr. Mike Lake for scale) (Photo J. Rowling).

Fig. 7. Close view of soil and iron deposit in burned swamp area (Photo J. Rowling).

Heat on iron deposits

The delicate iron oxyhydroxide patterns in the sandstone (Fig. 8) are mainly goethite with some hematite on older surfaces. When subject to high temperatures, surface goethite can dehydrate to

ferric oxide (rust, Fig. 9). The temperatures required to do this are at least 500°C (Beuria et al., 2017) which can easily be achieved in bushfires. Possible there was also some small-scale iron reduction in low-oxygen situations.

Fig. 8. Typical iron banding in sandstone, Mount Banks road (Photo J. Rowling).

Fig. 9. Lichen was burned from this ironstone leaving a rusty appearance, Mount Banks road (Photo J. Rowling).

<u>Acid and microbes on wet iron oxide powder</u>

Rain washes iron oxides from their original position into cracks and swamps. Acid soil in the Blue Mountains can dissolve iron oxide particles. The process for converting ferric oxide to goethite is usually very slow, but there are a number of microorganisms which thrive in wet anoxic environments such as found in swamps, and these can convert the material from iron oxide to iron oxyhydroxide. Humic and fulvic acids also dissolve iron oxides. Other organisms operating in wet, oxygen-rich, near surface environments can further alter the hydrated iron products to goethite. Some of these products can be seen at swamp edges as an irridescent floating deposit on the water known as flocs (floculants). The material can also be lodged in rock joints forming dyke-like deposits and coatings on the sandstone as shown above a small cave (Fig. 10).

Fig. 10. Iron oxyhydroxide coating on sandstone below a swamp and above a small cave on Mount Banks (Photo J. Rowling).

<u>Groundwater mixing</u>

The quartz sandstone is generally porous, except where iron banding occurs. Rain falling on the plateau can be absorbed into the sandstone. This tends to be relatively neutral pH. On the other hand, water in the hanging swamps tends to be very acidic, often with low oxygen and can dissolve iron oxides. Where the two waters meet, there can be some mixing corrosion and delicate iron deposition following the mixing front within the sandstone, as seen above a small cave in cross-bedded sandstone (Fig. 11). The patterns formed by these mixing fronts can appear roughly circular, tubular, and repetitive as the groundwater levels change. In general, the patterns are formed valley-side as this is the general direction of groundwater flow.

Near the springs were small features similar to flowstone, comprised of sand grains and organic material as well as bacterial iron flocs at the air/water interface making irridescent patterns (Figs. 1 and 12). These bright colours usually occur close to the surface where there is plenty of oxygen. Deeper in the rock, the patterns are less distinct, most likely because a different bacterial species works in lower oxygen levels. The process can be seen in road cuttings where newly exposed rock has less colour than older exposed rock.

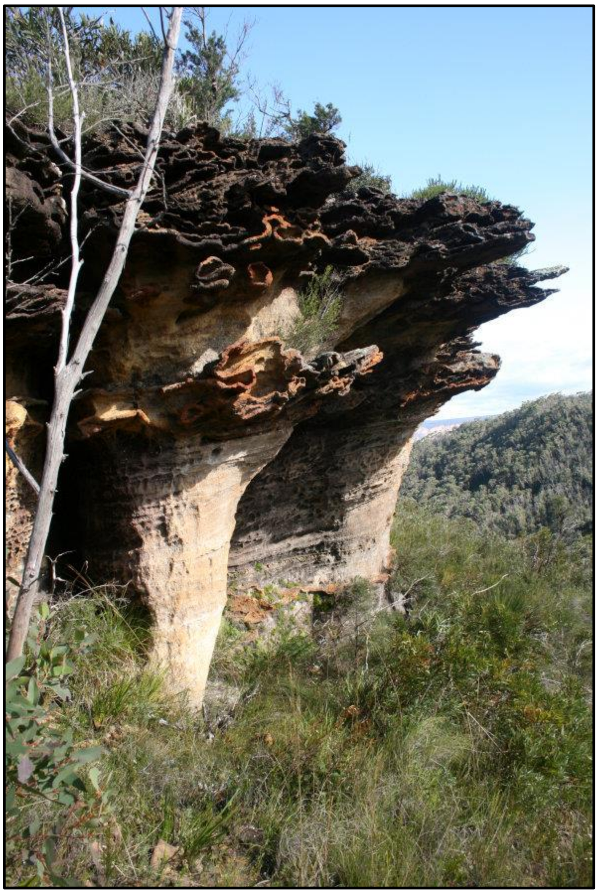

Fig. 11. Delicate ironstone banding forms the ceiling of a small cave in cross-bedded sandstone near Mount Banks (Photo J. Rowling).

Fig. 12. Iron flocs in swamp at Mount Banks; carnivorous plant is Drosera spatulata (Photo J. Rowling).

Formation of caves and flat ironstone layers

Within the sandstone, either impervious ironstone shapes or occasionally impervious shale layers redirect groundwater as springs. Generally the area just above the impervious layer is a softer sandstone where the grains are poorly cemented and frequently burrowed by insects. The quartz in the softer sandstone is only held together by a small amount of silica (probably common opal). This layer is more concave and where exposed in a road cutting or natural outcrop appears whiter than the rest of the sandstone.

Above the soft layer, one may see a layer of ironstone, caused by a mixing of acidic and neutral waters. The sequence can repeat in some areas, depending on groundwater sources. The iron-rich layer sometimes forms the ceiling of small sandstone caves (Figs. 13 and 14).

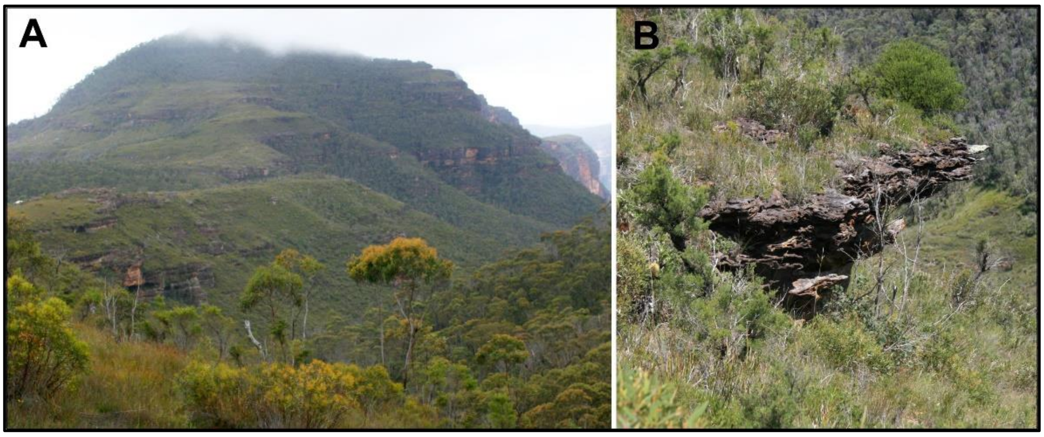

Fig. 13. A swamp edge forms the sandstone cavernous cliff near Mount Banks: A – distant, general view; B – irregular roof of a small cave and numerous smaller cavities (Photo J. Rowling).

Fig. 14. Sandstone outcrop with ironstone patterns, Mount Banks (Photo J. Rowling).

Relationship between iron springs and small caves in sandstone

The following is a suggested on-going sequence of weather and groundwater events leading to formation of iron springs and their relationship to small caves in quartz sandstone of the Banks Wall Sandstone in the Blue Mountains National Park:

1. The existing surface has ironstone patterns in the quartz sandstone (e.g. Figs. 6 and 14), where iron is derived from either weathered basalt or iron-rich minerals in the sandstone.
2. Severe bushfire removes vegetation and dehydrates some ironstone surfaces (e.g. Fig. 7, 8 and 9).
3. Rain washes iron oxides into joints and swamps.
4. A long period of unusually wet weather, coupled with lack of vegetation allows the water table to rise considerably.
5. Acidic and biochemical reactions dissolve iron compounds in the groundwater and re-deposit iron oxyhydroxides as flocs with small flowstone-like patterns on steeper surfaces as springs.
6. Mixing of fresh oxygenated (rain) and acidic (swamp) waters within the sandstone deposits iron oxyhydroxides at the mixing boundary, typically a curved layer (e.g. Figs. 11 and 15).
7. Removal of siliceous cement and iron oxyhydroxides from between quartz grains deep in the sandstone by mixing groundwaters results in a softer, more easily eroded sandstone as well as re--depositing silica and flocs lower down where groundwaters emerge.
8. Over time, iron oxyhydroxide flocs block the pores in the sandstone, forming impermeable layers of ironstone. Re-deposited silica may be responsible for case-hardening of sandstone surfaces.

Fig. 15. Tubular ironstone bands in sandstone above a small cave at Mount Banks, with water seepage (Photo J. Rowling).

The formation of these beautiful patterns is on-going as denudation exposes the iron banding. The sandstone caves are caused by leaching of quartz cement, initially by groundwater mixing to weaken the rock and later assisted by insect burrowing and tafoni weathering (Fig. 16). Some caves can be quite large (Fig. 17).

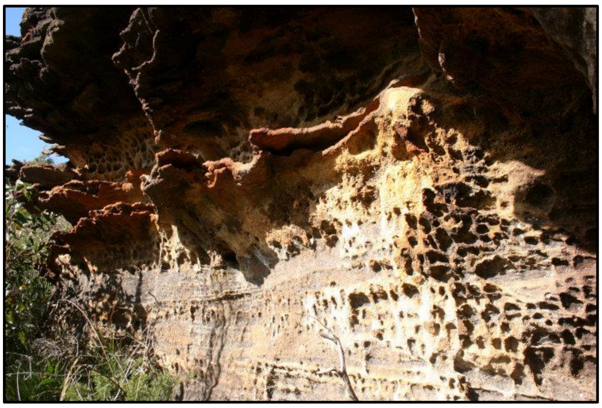

Fig. 16. Tafoni weathering in a small cave near Mount Banks (Photo J. Rowling).

Fig. 17. Jill Rowling looking for caves on Mount Banks (Photo M. Lake).

Conclusion

Quartz sandstone erosional features were studied at Mount Banks, in the Blue Mountains of New South Wales (Australia) after a series of extreme weather events (drought, fire and flood). The development of caves and cavities in Banks Wall Sandstone (Triassic, Narrabeen Group) is the result of a long period of exposure and denudation. Iron oxyhydroxides at the sites may be derived from either nearby basalt on Mount Banks, or from minerals originally deposited within the quartz sandstone. Variations in the erodability and porosity of the original quartz sandstone is most likely due to changes in its originally silicic cement due to mixed corrosion: groundwater flowing from hanging swamps and headwater swamps, meeting fresh, oxygenated rainwater. Impermeable, curved layers of ironstone exposed on the sandstone surface may be caused by silicic cement removal and substitution by bacterial iron flocs downstream of hanging swamps. These curved layers of iron oxyhydroxides filling the sandstone pores, may be slowly converted to other iron mineral forms (e.g. goethite) as oxygen permeates the rock during the denudation process, leaving shells of impermeable ironstone. The more permeable parts of the sandstone surface are more easily denuded, leaving small cavities and caves below impermeable ironstone.

Extreme weather events such as bushfires allows us to see some otherwise-hidden features such as small caves and accelerated alteration of surface iron deposits. Flooding rains after the fires allow the water table to rise considerably, which allows us to see groundwater changes, such as overflowing swamps and temporary springs depositing bacterial iron flocs onto the sandstone. Most likely springs redeposit silica lower in the landscape, causing local case-hardening of the sandstone surface.

References

Beuria P.C., Biswal S.K., Mishra B.K., Roy G.G. 2017. Study on kinetics of thermal decomposition of low LOI goethetic hematite iron ore. Intern. Journ. Mining Science and Technology 27: 1031-1036.

Brunker R.L., Rose G., 1967. Sydney Basin, New South Wales 1:500,000 geological sheet (special). V.C.N. Blight, Government Printer, New South Wales.

Pickett J.W., Alder J.D. 1997. Layers of time: the Blue Mountains and their geology. New South Wales Dep. Mineral Resources, Sydney, 34 pp.

Jacobs SKM, Young A., Eamus D. 2014. Temperate Highland Peat Swamps on Sandstone: ecological characteristics, sensitivities to change, and monitoring and reporting techniques. Commonwealth of Australia (commissioned report); https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwih3cLj0e6EAxWXcvEDHb7WAIQQFnoECBEQAQ&url=https%3A%2F%2Fwww.agriculture.gov.au%2Fsites%2Fdefault%2Ffiles%2Fdocuments%2Fpeat-swamp-ecological-characteristics.pdf&usg=AOvVaw1NxDYxXLvHE7Da_UN3HPev&opi=89978449

SEA CAVES SOUTH OF NEWCASTLE, NEW SOUTH WALES, AUSTRALIA

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Introduction

Sea caves in the rugged, conglomerate and quartz sandstone cliffs between Catherine Hill Bay and Frazer Beach, 35 km south of Newcastle, New South Wales (NSW), could arguably be among some of the most impressive in Australia (Smith 2022). They vary from just a few meters in length up to chambers 80 m long and 40 m wide and may have multiple entrances. Much of the above mentioned coastline is within the Munmorah State Conservation Area, managed by the NSW National Parks and Wildlife Service (Fig. 1).

Fig. 1. Location of the described sea caves.

The caves are mostly inaccessible at high tide and during high ocean swell, as waves crash into them with such ferocity as to be life threatening to anyone caught inside. However, when the tide is low and wave conditions permit, these caves can be explored in safety and admired for their beauty and awe inspiring size.

There are more than 16 major sea caves along this 3 km section of the coastline. Hence a 6 km return coastal walk at the right time can be a very rewarding experience.

Detailed in this article are seven of the major caves, which have specific points of interest. The article concludes with discussion of what constitutes a sea cave and how they can form.

Pink Cave (I6E-18)

This cave is located south of Catherine Hill Bay and is accessed from Mooney Beach by walking about 0.5 km across the relatively flat rock platform in a northerly direction until an obvious deep-water trench leads directly into the cave. A ledge of the platform with plenty of width to safely walk along, extends right into the cave beside the water filled trench (Fig. 2A). In recent times a couple of drownings have occurred at this cave, when freak waves washed people off the rock platform, so it is extremely important to only visit the cave in absolutely ideal conditions – very low tide and low sea swell. The cave is approximately 53 m long, 14 m wide and 6 m high. The full length and height of the trench inside the cave is covered in a vivid shade of bubble-gum pink coralline algae, a great deal of which is exposed at low tide (Fig. 2B). The high and persistent wave action in the cave's trench, is the ideal condition for the algae to thrive and cover the rocks with a hard calcareous deposit forming part of their structure. There are also a number of areas where off-white coloured calcium carbonate is being leached from the quartz sandstone and conglomerate rocks above to form small poorly developed speleothems in the form of flowstone, stalactites and stalagmites. Some are partly coated in green algae growing on the speleothem surface, while a few have an orange tint from iron oxide that has also leached from the conglomerate bedrock.

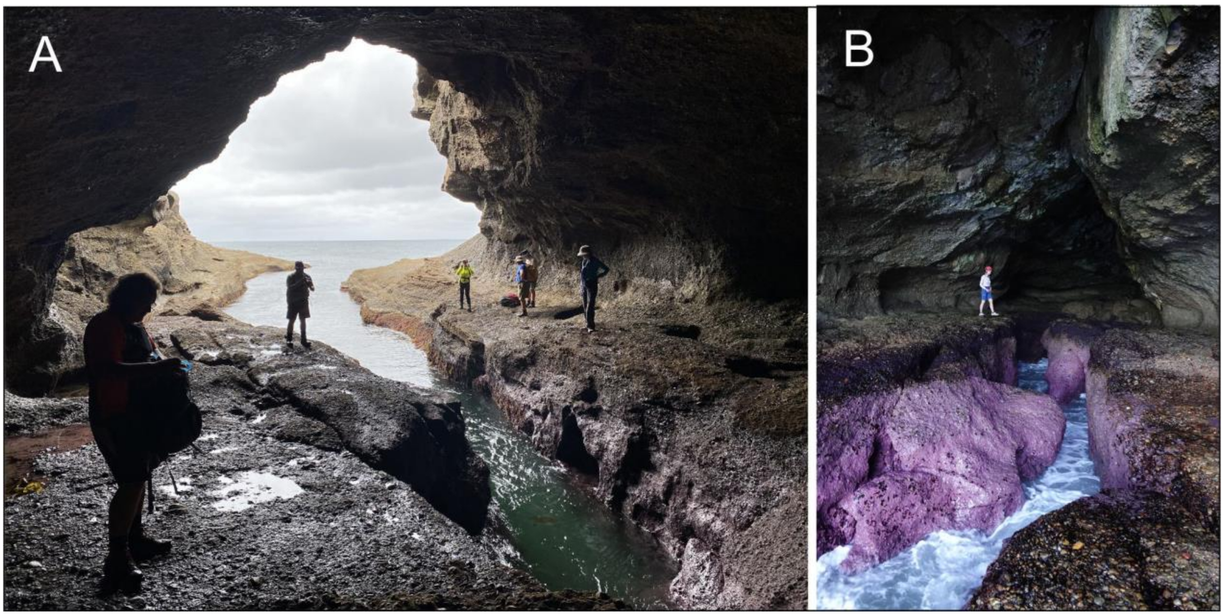

Fig. 2. Pink Cave in the headland near Catherine Hill Bay: A) the entrance; B) a bubble-gum pink calcite layer created by coralline algae, that coat the rocks (Photos Garry K. Smith)

Ghosties Beach Cave (I6E-29)

This cave is located about 1.8 km south of Pink Cave at the southern end of Ghosties Beach. It cannot be missed as the large slot entrance is obvious in the north facing cliff at the southern end of the beach (Fig. 3A). The cave has two entrances and has been created by erosion along joints in the sandstone cliffs. At low tide it is easy to walk through from one entrance to the other on a sand covered floor. The passage leading from the slot shaped entrance facing north, is approximately 37 m long, 2 m wide and 5 m high (Fig. 3B). At the end of this passage the cave opens up to a chamber measuring 12 m x 12 m, which is 5 m high with the east side opening to the other entrance facing sea

(Fig. 3C). While not a cave of large proportions, it is perfect for getting those magic photos looking out to sea or down the beach. The light cream colour of the sheer rock cliffs in the right light can be dazzling, you just have to wait for the right light. There are some pretty but small calcite speleothems in this cave if one takes the time to look carefully.

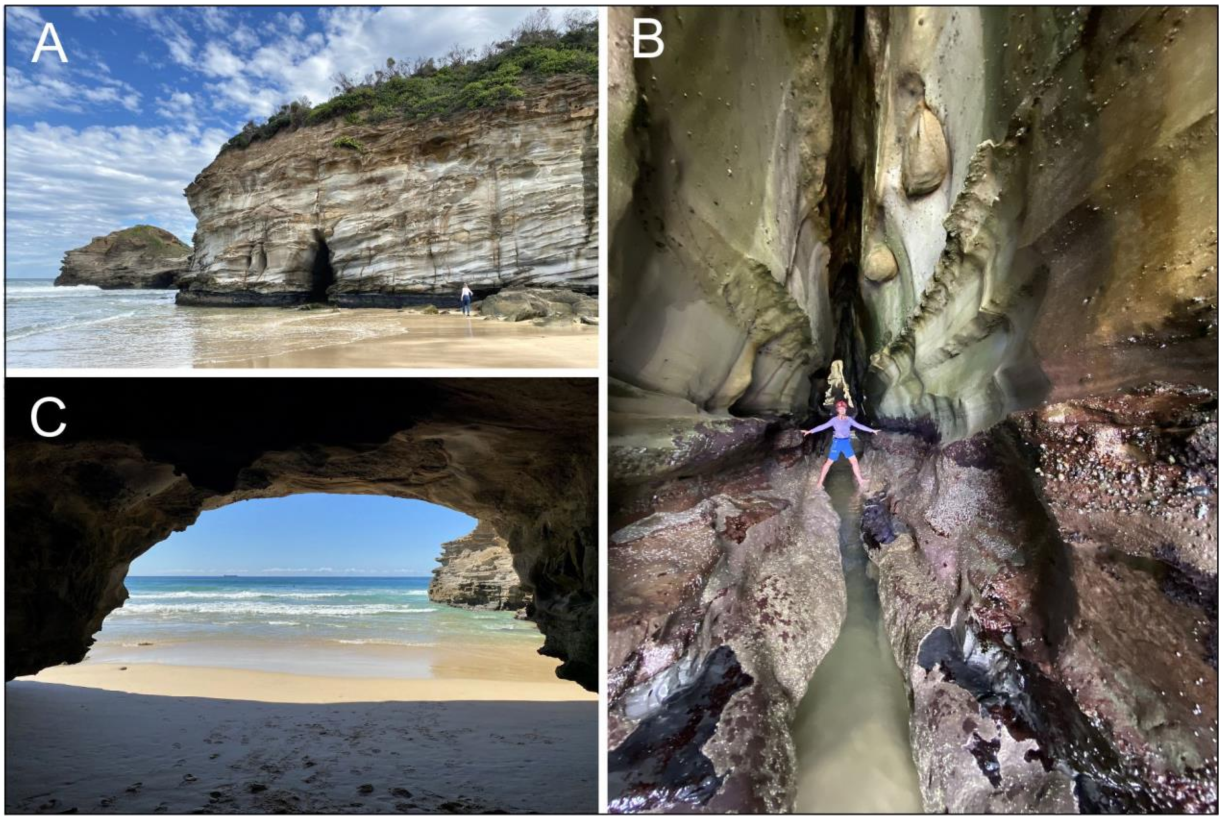

Fig. 3. Ghosties Beach Cave: A) north facing entrance; B) passage; C) – looking out the easterly facing sea entrance (Photos Garry K. Smith)

Ghosties No 1. South Cave

No name or number appears to have been previously allocated to this cave, so I have called this cave Ghosties No.1 South, because it is just 30 m SE of the Ghosties Beach Cave (16E-29). Even at low tide this cave has small waves entering several meters into it. The floor is mostly covered in beach sand. The cave is 27 m long with an entrance measuring 7 m wide and 4 m high, tapering to less than 1 m at the very end. The actual length is possibly another 10 m more as sand build-up at the rear (observed during surveying) appeared to be blocking entry to a chamber noted during a visit several years earlier. There were a number of calcite speleothems in this now inaccessible chamber. This is a beautiful cave to take photos from, to silhouette people against the backdrop of ocean and beach (Fig. 4).

Fig. 4. Ghosties No 1. South Cave (Photo Garry K. Smith).

Ghosties No. 2 South Cave

I have called this cave Ghosties No. 2 South, as it has no gazetted number and is the second small cave, about 70 m south of Ghosties Beach Cave (I6E-29). The cave is accessed by climbing over the small rocky headland. It is above the high tide level but in bad weather it would get the occasional wave breaking over the rock platform and into the cave. The cave measures 20 m wide, 12 m deep and 2.8 m to 1.2 m high. At the back of the cave are several areas of well-formed calcium carbonate speleothems: shawls, flowstone and small stalagmites (Fig. 5).

Fig. 5. Ghosties No. 2 South Cave – calcite flowstone and shawls; note the green algae growing on surfaces exposed to the small amount of light reaching the back of cave (Photo Garry K. Smith).

Timber Beach Cave (I6E-33)

The next major cave to the south is the Timber Beach Cave located at the base of a cliff on the south side of a 40 m long beach of the same name. It is just 130 m south of Ghosties No. 2 South Cave. The cave has been created along several parallel and intersecting joints that have been eroded away to such an extent that in some places only pillars of bedrock remain to support the cave roof at the seaward extremity (Fig. 6A, B and C). The first two chambers are almost identical in size measuring approximately 32 m long, 17 m wide and 4 m tapering to 1 m high, which it could be argued are two separate caves connected by an overhang. These two chambers can be entered at mid to low tide. A much larger chamber can be accessed via a narrow passage by wading in knee deep water at a very low tide and low swell. This passage leads into a huge chamber measuring 80 m long, 40 m wide and more than 6 m high (above low water level) (Fig. 7). The surveyed cave length exceeds 300 m of passage including the large chamber, an extraordinary size for a sea cave. There are five entrances from the ocean into the large chamber, but only one is accessible by wading. This passage leads to an exposed rock platform (at low tide) covering half the area of the large chamber. Waves enter through the other four less protected deep-water ocean entrances. The sound of crashing waves is amplified in the cave, a reminder to keep an eye out for dangerous freak waves.

Some parts of this cave are coated with the bright pink calcite deposited by coralline algae and there are a few locations where calcium carbonate has leached from the sandstone above and deposited as small speleothems. Overall this is an amazing cave that is difficult to capture in a photo because of its size.

Although not commonly known, some people have visited the large chamber of this cave when conditions permit. The full extent of the cave does not appear to have been known at the time of compiling the 1985 Australian Karst Index (Matthews 1985).

Fig. 6. Timber Beach Cave: A and B) Looking out of the second chamber (from top of map – Fig. 7) toward the sea. C) Panorama view inside the large chamber, note the size of person dressing in red, standing half way across chamber - centre of image (Photos Garry K. Smith).

Canyon Sea Cave (I6E-34)

The cave is located 280 m south of Timber Beach. It consists of a large partly water filled passage of approximately 37 m in length, plus a 40 m x 17 m wide tunnel which goes right through a rocky headland (Fig. 8A and B). The tunnel has approximately 2 m to 5 m of air gap along its length at low tide. A water filled canyon (approximately 5 m deep) in the rock shelf leads to one entrance and the other entrance facing north at right angles to the prevailing ocean waves. The canyon funnels the ocean waves into the cave. It is an amazing cave for a diver or just a swim through, if one can time entry with low swell conditions. Even if you are not a diver then just looking into this cave from either entrance is awesome.

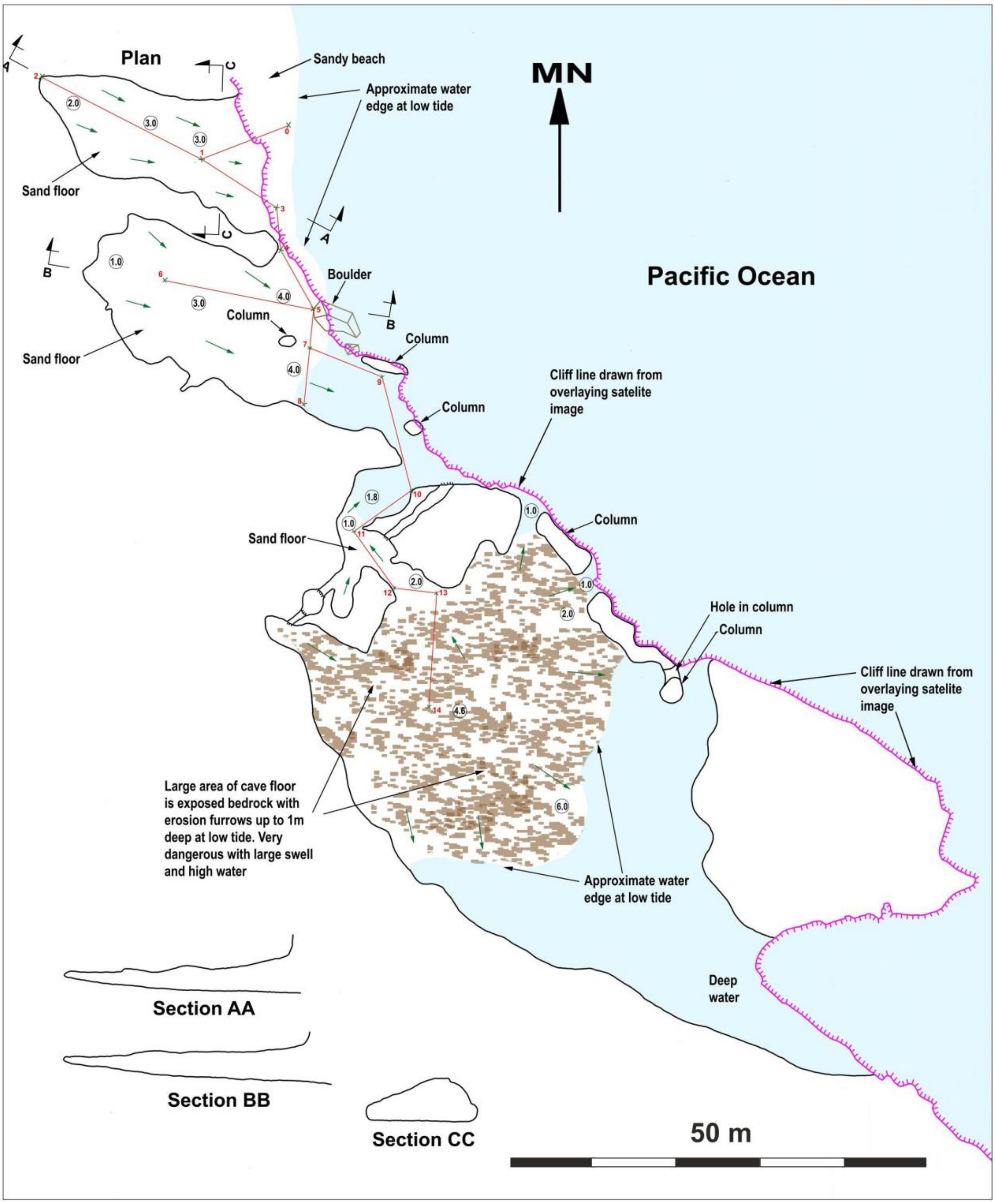

Fig. 7. Map of Timber Beach Cave illustrating interrelations between marine/sea processes/activity and cave shape and floor; surveyed and drawn by Garry K. Smith, 2021.

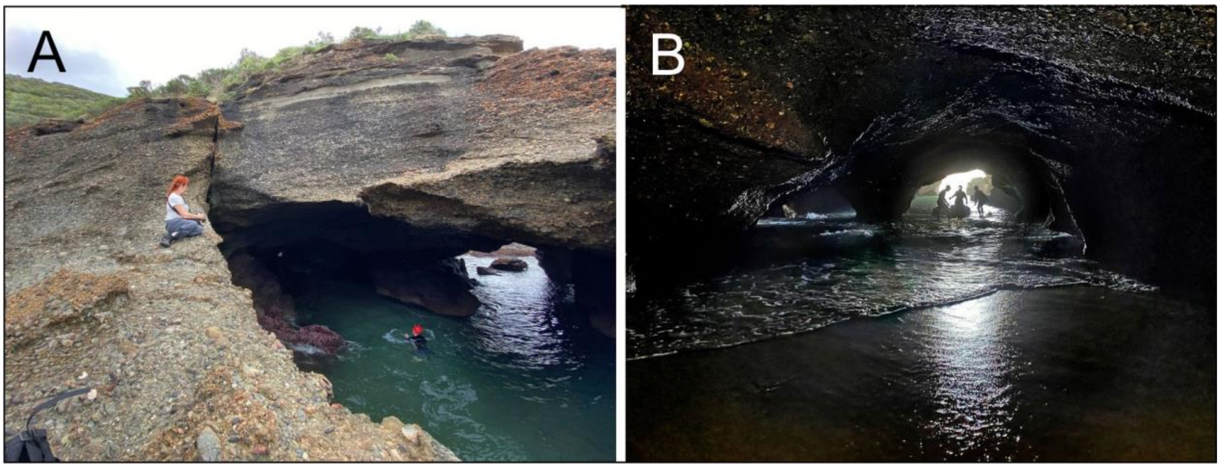

Fig. 8. Canyon Sea Cave: A) Cathi watches as Phil swims past the passage through headland and on toward the back of the cave. Speck of light deep inside cave is from small second passage through headland; B) View from the back of Canyon Sea Cave looking toward the sea; the day light on the left is coming through the second small passage which also connects to other side of headland (Photos Garry K. Smith).

Snapper Point Sea Cave (I6E-40)

This cave can be accessed by walking to the southern end of Snapper Point and then around the rock platform back toward the north till you are looking directly at the cave in the base of a cliff. A deep-water inlet funnels waves into this cave, which can only be entered during absolute perfect conditions, however one must still do some swimming (Fig. 9A and B). The cave can be extremely dangerous and lives have been lost in this vicinity when fishermen have been washed off rocks by freak waves. The cave is basically one large chamber which is 62 m long, 64 m wide and 15 m high (18 m wide at the entrance). The waves crash onto the sand and pebble beach just inside the entrance. One can see most of this cave from the safety of an elevated rock platform at low tide and low swell. Hence there is little need to actually put oneself in danger by swimming into the cave and then upon exiting, undertaking the risky act of trying to scramble back on the rock platform between waves.

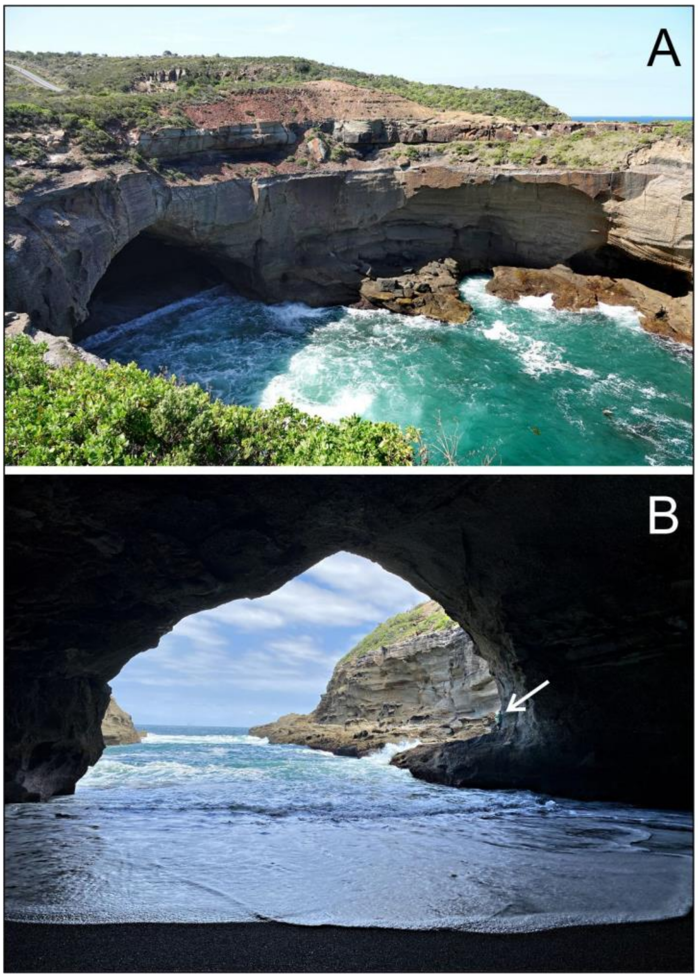

Fig. 9. Snapper Point Sea Cave (A and B) – note the size of people (pointed by an arrow) (Photos Garry K. Smith).

What are sea caves and how do they form?

Sea caves are sometimes referred to as ‘littoral’ caves. This term relates to the shore of a lake, sea or ocean. In coastal environments, the littoral zone may extend well above the high water mark, which is rarely inundated, to shoreline areas that are permanently submerged.

Generally speaking, sea or littoral caves in sedimentary rocks are created by mechanical erosion along joints or bedding-planes or contact zones between layers of relative weakness, where the waves attack the rock to create the caves. Whereas, in metamorphic or igneous rock, the weakness is typically a dyke, fault or major joint.

Sea caves can also form in carbonate rocks (e.g. limestone, dolomite), such as a few reported along sea cliffs in Victoria, which have been created by wave action at or near the water line. However, higher up the cliffs there are multi-process caves that were initially created by dissolution and later modified by wave action. True sea caves should not be confused with dissolutional caves exposed by retreating cliff-lines and later modified by subsequent wave action (Bunnell 2006).

Sea cave development is initially driven by direct wave action and salt erosion of rock along zones of weakness. As a cave becomes larger, rock is removed at a greater rate by rock particles carried by the turbulent water plus the tremendous force of air and water compression in the confined space. (Webb et al. 2003, Kiernan 1979, Bunnell 2006, K&GU 2010/2011; Smith 2022). The cave roofs can at times collapse and create blow-holes.

References

Bunnell D. 2006. Littoral Caves. In: Gunn J. (Ed.), Encyclopedia of caves and karst science. Frizroy Dearborn, Taylor and Francis Group. New York-London: 1050-1054.

K&GU 2010/2011. Sea caves. Sandstone Arches and Caves. In: Guide to New South Wales karst and caves. Karst and Geodiversity Unit, Office of Environment and Heritage, NSW Government. 36-37.

Kiernan K. 1979, Sea caves and morphological karst on the Tasmanian Coastline. SCS Southern Caver, The Southern Caving Society (now Southern Tasmanian Caverneers) 11, 2: 2-23.

Matthews P.G. 1985. Australian Karst Index. Australian Speleological Federation Inc.

Smith G.K. 2022. Sea caves south of Newcastle, NSW. Caves Australia 220: 11-15.

Webb J.A., Grimes K.G. Osborne A. 2003. Black Holes: Caves in the Australian Landscape. In Finlayson B.L, Hamilton-Smith E. (Eds), Beneath the surface: a natural history of Australian caves. Univ. New South Wales Press Ltd, Sydney: 1-52.

SUPPLEMENTAL DATA TO "CAVES OF ASCENSION AND ST. HELENA" AND A BRIEF INFORMATION ON CAVES OF TRISTAN DA CUNHA ISLAND

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Introduction

In the "Newsletter of the Pseudokarst Commission of the UIS" we presented a brief introduction to caves of two of the British Islands in the South Atlantic, namely Ascension Island and St. Helena (Pavuza, Cech 2014, 2019). Some additions are presented here as we visited Ascension Island again in 2015 after our first overview, otherwise we report on a cave on St. Helena Island perceived from a distance that we omitted from the initial report. Initial speleological information - derived exclusively from Internet data – about the incredibly remote island of Tristan de Cunha rounds off this supplement.

Ascension Island

Ascension Island lies some 80 km west of the Mid-Atlantic Ridge as a volcanic island, with the last eruption dating back 600 years ago. The diversity of volcanic rocks – from basalts to trachytes and rhyolites to pyroclasts – results in a variety of different cave types. A total of around 25 caves have been documented so far, but there could be many more, especially along the 40 km long coastline.

Bird Cave

The cave is well known to the temporary inhabitants (technicians and tourists - there is no indigenous population) of the island, as the existence of a geocache clearly indicates. Its name however derives from nesting birds in the past. It is a classical lava tube abruptly ending some 10-15 m behind the entrance. The morphology of the neighbouring outsides indicate that this tunnel was considerably longer but collapsed (Fig. 1). A some 80 m long tunnel fragment of the original cave has been preserved. Solidified lava stalactites on the cave ceiling give the cave a unique character (Fig. 2).

Fig. 1. Present-day entrance to Bird Cave with remnants of the original cave in the foreground (Photo R. Pavuza).

Fig. 2. Lava dripstones at the ceiling of Bird Cave (Photo R Pavuza).

Northeast Bay Sea Cave

This so far undocumented cave is situated at the north end of the Northeast Bay Beach in a prominent protruding mafic lava ridge. Entering via a 2 m vertical entrance, one encounters a 25 m long low passage of the present-day cave, which originally was a lava tube that was entirely filled with layers of red-layered volcanic ash, part of which has been removed by the sea at high tide (Fig. 3). However, the time frame of its formation remains open.

Fig. 3. Gallery in Northeast Bay Sea Cave (Photo R. Pavuza).

Coconut Bay Sea Cave

This cave in mafic lava, which is maybe reached only at rare very calm water situations, only at first site represents an abrasion cave as we know such caves worldwide in all types of rocks. In fact it is the remnant of a classical lava tube that was only opened by the sea. Otherwise, it would be peculiar that the sea force is more effective on the lava than on the adjacent softer pyroclastic layers (Fig. 4). Its length is about 60 m with a considerable height up to 11 m (Fig. 5). Inside there is a “fine group of stalactites from the roof, about a third of the way in” (Ashmole 2000, p.189).

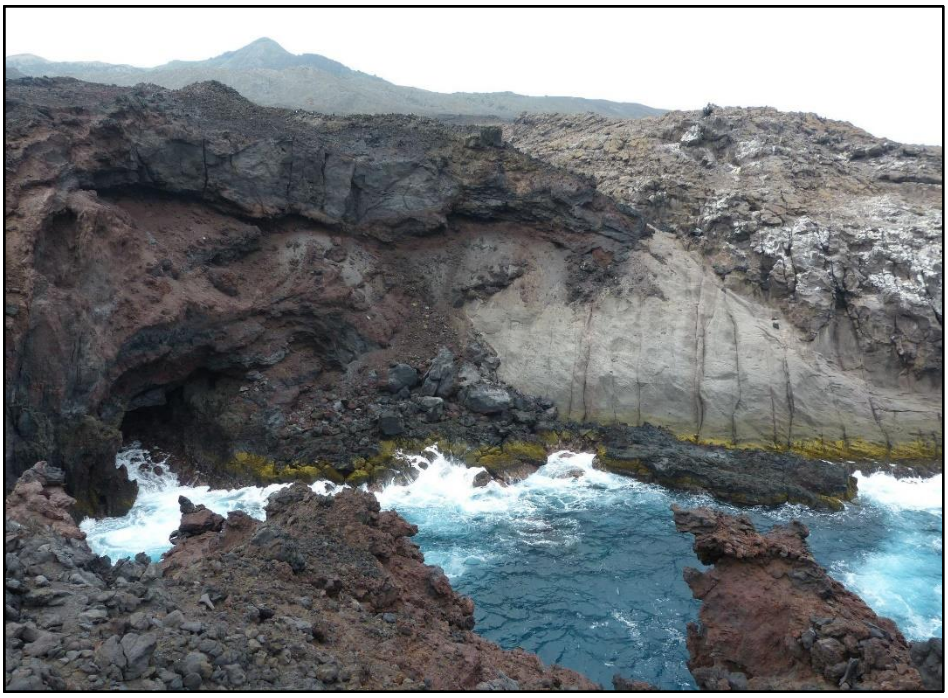

Fig. 4. Surroundings of the entrance to Coconut Bay Sea Cave (Photo R. Pavuza)

Fig. 5. Closeup of the entrance and continuation of Coconut Bay Sea Cave (Photo R. Pavuza)

In a local guidebook (MacFall et al. 2015), describing walks on the island, a cave not far from the Goat Hole Walk in the NE part of the island is mentioned. Referring to the actual inhabitants of the caves, we named it <u>Fairy Tern Caves,</u> but understandably we did not approach it (so as not to disturb the birds). The same guide refers to <u>White Cave</u> (a small shelter in trachyte) along Wolves Bluff Walk at the western slopes of Green Mountain.

At Mc Arthur's point on the western shore of the island, not far from the airport, we encountered an active sea cave in a mafic lava flow (calling it <u>Mc Arthur's Point Sea Cave</u> obviously) with an estimated length of 20 m. It may be entered through shafts at very low tides.

Finally, Dampier's Drip, a heavily reworked natural shelter, which was one of the few water supplies for the island's first visitors, even featured on a stamp (Fig.6)

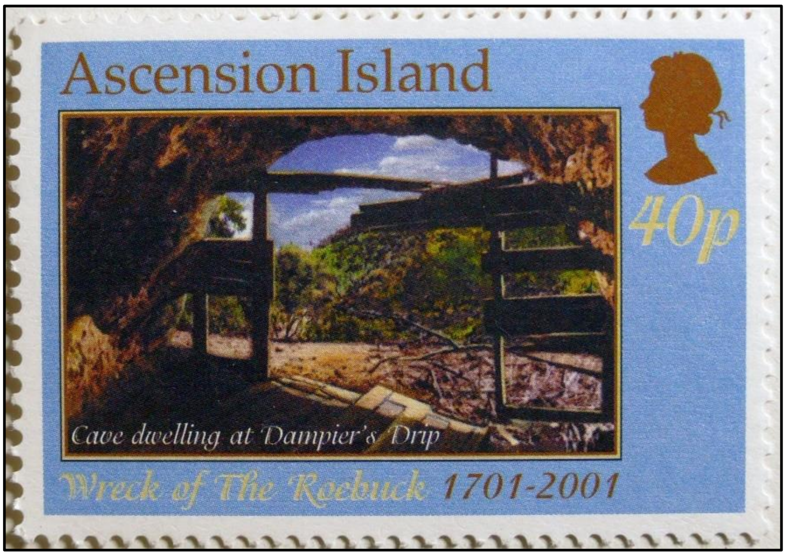

Fig. 6. Official stamp, showing Dampier's Drip on Ascension Island, a reworked natural shelter.

St. Helena Island

St. Helena Island lies some 400 km east of the Mid-Atlantic Ridge and is therefore geologically older than Ascension Island. The last eruption took place 7 million years and, hence, its geomorphology is much more dominated by intensive erosion landforms. As a consequence classic lava tubes and other primary volcanic caves are not abundant. In 2019 we documented 17 caves, but – just like on Ascension Island – there are probably many more caves, especially on the coasts.

In addition to the caves described 2019 a secondary volcanic cave has to be added. It can be seen clearly from High Hill at the western tip of the island and may be named Old Woman's Valley Cave (Fig. 7), referring to the local name for the area behind and below. From the distance it seems that due to the apparent "dipping" of the weathered phonolitic rocks gravitational mass movement is responsible for the formation of this cave (or just huge shelter) whose extension is unknown to us so far. Obviously, there are more caves to discover in this area, which is not easily accessible.

Fig. 7. Distant view of the entrance of Old Woman's Valley Cave (Photo R. Pavuza)

Tristan de Cunha Island

This tiny island is the third and southernmost of the politically fully undisputed British islands in the South Atlantic 2400 km SW of St. Helena Island. It is a small (200 km^2) volcanic island, which can be reached only by boat, which takes six days for the 2800 km journey from Cape Town. The island is home to only a handful (approx. 250) of inhabitants. The smaller islands in its surroundings are uninhabited.

Its highest summit – Queen Mary's Peak (2060 m a.s.l.) is an active stratovolcano, whose most recent devastating eruption was in 1961. The island itself is said to be about 3 million years old – younger than the last eruption on the St. Helena Island.

Most of the caves so far described are sea caves, but for example Devils Hole, situated about 300-400 m above sea level, is a classic lava tube up to 50 m long, which is reportedly used intensively by petrels during the breeding season (instructive photographs see: www.tristandc.com/news-2018-01-25-Devils-Hole.php). Another primary lava cave is the 37 m deep vent Hill-with-an-hole-in-it, situated on the southern plateau, also several hundreds of meters above sea level. There are likely to be many more caves of this type around the volcano. Cave Point refers to a group of sea caves that have been cut into the volcanic rock at the southern tip of the island by the sea and are sometimes used as shelter caves. In their vicinity we also find descriptive place names such as Archway Cave and Cave Gulch Hill".

On Tristan's smaller sister islands, such as Nightingale Island, Gough Island, Inaccessible Island, there are also brief references to sea caves such as Ned's Cave and Cave Rock.

All information about caves on Tristan comes from an internet search carried out on 19.02.2024. There is no classic cave directory available, yet.

References

Ashmole P.M. 2000. St. Helena and Ascension Island – a natural history. A. Nelson, Shropshire, England, 475 pp.

MacFall N., Machattie A., Avery D. 2015. Ascension Island Walking Guide: Letterbox Walks, 34 Letterbox Walks and 8 National Park Walks. Ascension Heritage Society,104 pp.

Pavuza R., Cech P. 2014. Caves of Ascension Island – an introduction. Pseudokarst Commission Newsletter 24: 11-16.

Pavuza R., Cech P. 2019. Remarks on caves of St. Helena (South Atlantic Ocean). Pseudokarst Com. Newsletter 19: 28-39.

DEVELOPING THE „SPELEOPARK OF A MARIÑA SHIRE“ – CAVES AND CONVERGENT FORMS WITHIN LIMESTONES, QUARTZITES AND GRANITES IN NORTH LUGO (GALICIA, SPAIN)

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Introduction

Geodiversity refers to the number and variety of geological elements present in a region: rocks and sediments of the substrate, their geometry, structure and composition, minerals, fossils, relief forms and the processes that give rise to each of them; aquifers and water resources, etc. And among this diversity we include the caves.

Many people associate the concept of a “cave” exclusively with karst. But they ignore that this term characterizes a form, but it does not determine the composition of the host rocks in which it is located, nor the genetic process that gives rise to the cave formation (Stone 1953; Charles, Courbon 1997).

In 2020, the eve of the International Year of Caves and Karst promoted by UIS, the Galician Federation of Speleology initiated a project aimed at the dissemination and promotion of caves and karst as a global phenomena, taking advantage of the natural and speleological resources located in the shire of A Mariña Central (municipalities of Burela, Alfoz, Foz and Mondoñedo), where on a length of just 30 km one can visit caves developed in limestones, quartzites, granites and various schists. This accumulation of natural curiosities allows us to carry out activities aimed at showing different types of landscapes (karst, parakarst, pseudokarst, consequence caves), the plurality of geodynamic processes involved, and a great variety of surface and underground microforms. Our idea is to use and promote all these elements, because together they give rise to a rich and diverse cave heritage, a sample of our geodiversity, our geomorphodiversity and an irreplaceable part of our geological heritage.

One concept: “Convergent Forms”

Certain forms produced both on the surface and in the subsurface are similar in their geometry and immediately recognizable despite developing in rocks of a very varied lithology (Eraso, Pulina, 1994, pp. 13-17, 67-72). Also it should be noted that the similarity in a shape and colour does not necessarily mean that the formation process was the same. This is what we call “convergent forms” (Fig. 1). We use this concept to build the script and the routes of the speleopark.

Fig. 1. Stalactites are convergent forms: similar morphologies different compositions and not necessarily identical processes or conditions (pH, temperature, etc.) to grow. A) Fe/Mn stalactites in Silvarosa Mines (Viveiro, province of Lugo); B) pigotite stalactites in Furna da Laghoa (Baiona, province of Pontevedra); C) calcite stalactites in La Cripta Cave (Folgoso do Courel, province of Lugo); D) calcite/azurite stalactites in Cova do Rei Cintolo Cave (Mondoñedo, province of Lugo) (Photo M. Vaqueiro, 2014-2023).

One idea: speleopark

A Speleopark: What is it for us?

Speleopark is a territory with well-defined margins, which includes a number of representative sites related to caves and karst systems, that not only represent typical geological and paleontological heritage, but also those of archaeological, ecological, historical and cultural features and values. Moreover, they together allow the public to discover the fact that there are caves in various rock types and of various origins, illustrating the different phenomena related to caves and discovering and appreciating the value of the underground natural heritage.

For whom and for what?

We consider different types of visitor profiles

- Educational visits: students and school-oriented activities for the promotion, discovery and learning about the underground natural environment.
- Speleological scientific tourism: participants whose objective is to recognize the geodiversity, biodiversity and cultural heritage related to these spaces.
- Research visit: scientific, planned activities (projects) in order to increase the knowledge and understanding of the caves located within the speleopark; also basic or preliminary cave activities like the exploration and mapping, geolocation and inventory of underground geoheritage sites.
- Free recreational visits: activities related to caving as a sport or for plain recreation purpose.

One place: Shire of the A Mariña Central (North Lugo)

The Speleopark area

The "Speleopark of A Mariña" (Fig. 2) is a relatively small area (335 km²) located in the northern part of Lugo province, which encloses caves and geomorphosites (geomorphologic heritage sites – Table 1) in the municipalities of Burela, Alfoz, Foz and Mondoñedo. The sites of the speleopark (Fig. 3) are located relatively close to each other. Moving between extreme sites takes less than 1 hour by car.

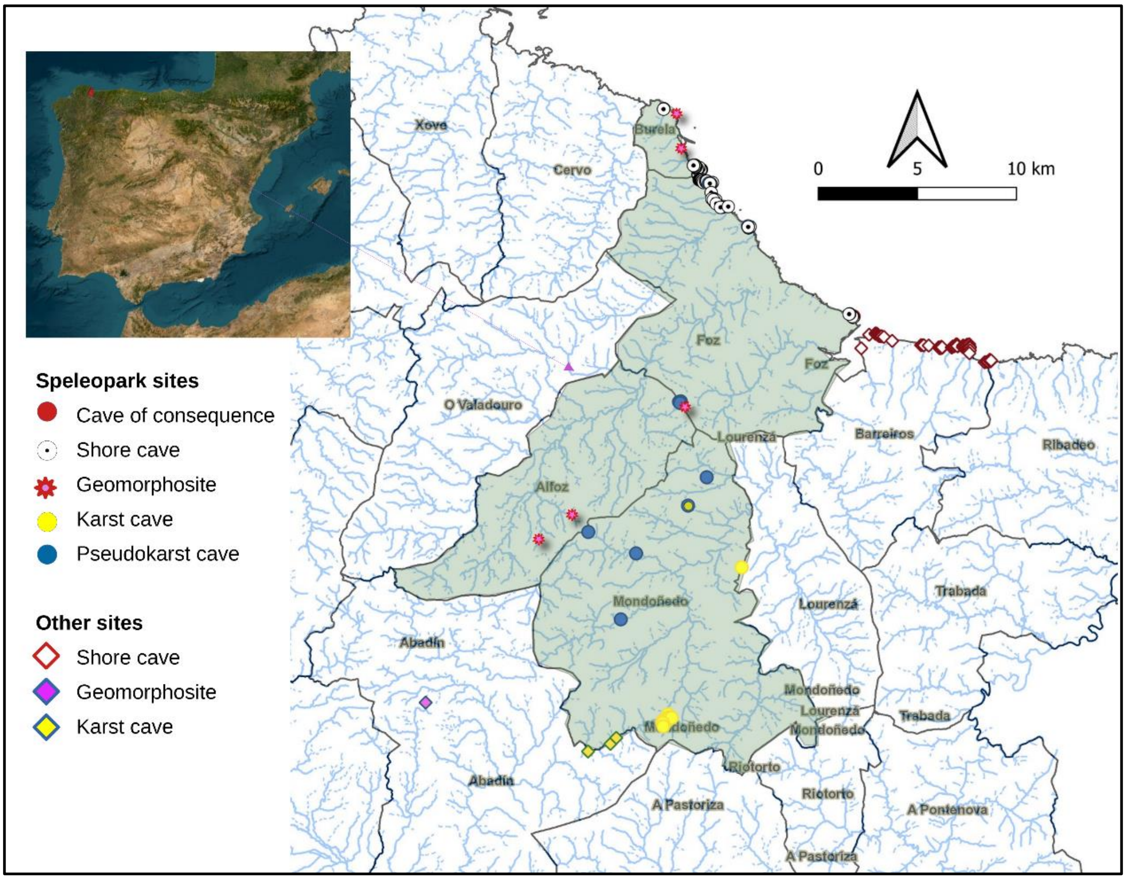

Fig. 2. General map of the sites inventoried in the "Speleopark of A Mariña" and its surroundings.

Table 1. Number of sites per municipality included in the last update (December 2022) of the resources inventory of the "Speleopark of A Mariña".

Municipality	**Caves**	**Geo- and geomorphosites**
Burela	23	1
Foz	43	3
Alfoz	2	2
Mondoñedo	24	0

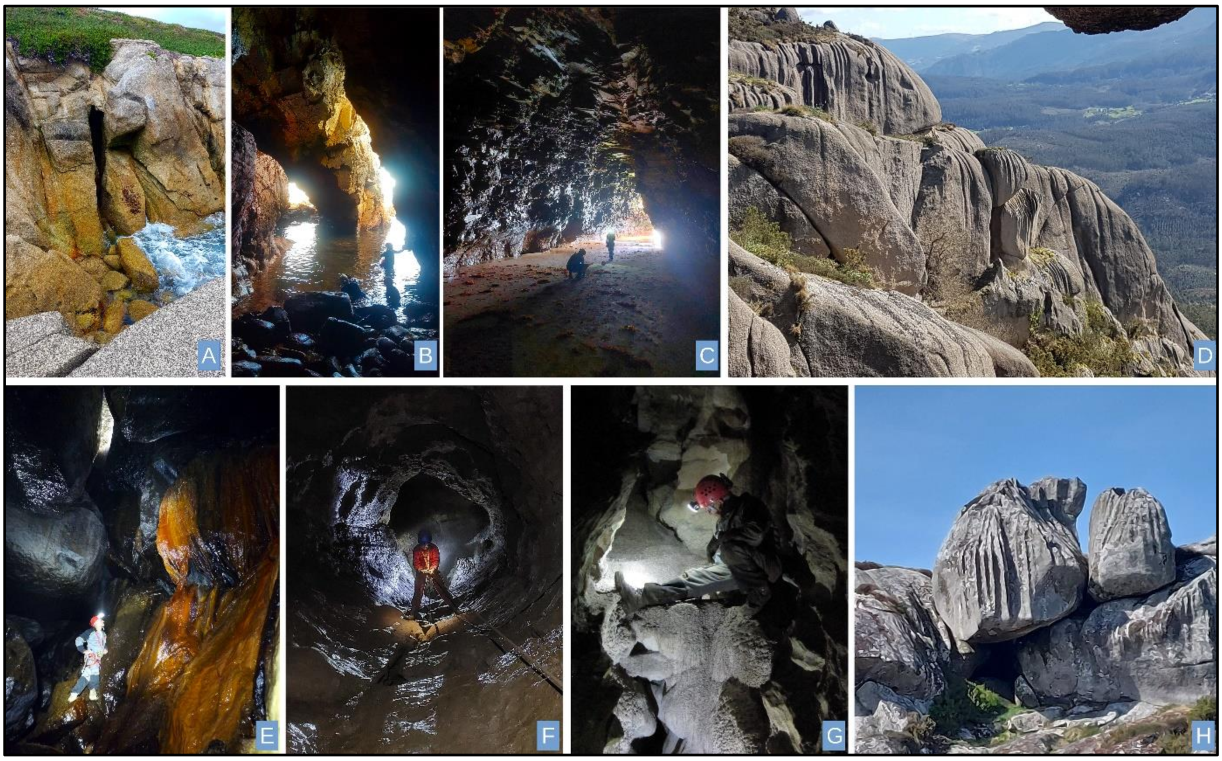

Fig. 3. Visual synthesis of speleopark sites: A) Cave on the coast developed in granite (Burela council); B) Cave on the coast developed in quartzites (Burela council); C) Cave on the coast developed in quartzite (Foz council); D) Cave of blocks and rills on granites (A Frouseira, Foz council); E) Pigotite speleothems from the roofed canyon of O Tronceda granite cave system (Mondoñedo council); F) Among the karst cavities, Cova do Rei Cintolo Cave stands out, which is the largest cave in Galicia (Mondoñedo council); G) Cova dos Arcos cave preserve one of the most representative bear (Ursus sp.) scratches in the Speleopark (Mondoñedo council); H) Caves in blocks and rills on granites (Castromaior, Abadín council) (Photo M. Vaqueiro 2016-2023).

Geological settings

The northern zone of the "Speleopark of A Mariña" is characterized by the quartzites of the Lower Cambrian, set between Hercynian two-mica granites from the west, and granodiorites from the east (Martínez-Alvarez et al. 1975). The central zone is characterized by Hercynian granite rocks (granodiorites), and by quartzites, limestones, as well as other calcareous rocks representing the lower Cambrian (Arce-Duarte et al. 1976). The eastern zone is characterized by the quartzites and slates of the Lower Ordovician, that crown the Cambrian series of the first two zones.

How we will do it?

The protection of our caves and underground heritage is fundamental. And that is why it seemed advisable to develop the process following the three phases proposed by Cigna and Forti (2013):

- PHASE I – Resource inventory and assessment: In this phase all the possible sites, and all the potential points of interest for visitors (geomorphological, geological sites and viewpoints, biospeleothems, speleothems and cave minerals; biologic inhabitants; paleontological and archaeological remains, etc.) should be recorded. And also all the potential hazards/risks (boulders sliding or breakdowns, floods, or other problems limiting the access to the site or cave) must be clearly defined and studied for each site. This study should also take into account the specificity of the site/cave area and access problems.

- PHASE II – Organization of geosites and their features and values: Sites and caves are grouped taking into account the scientific history we want to tell. A preliminary plan for each feature and related to them itineraries that integrate different sites must be considered. Finally, the detailed plan of routes along the territory including visits to cavities is constructed.
- PHASE III – Implementation, that must include: monitoring and impact monitoring; promoting the cave research in the area; updating of sites and features inventories and guides.

How do we do it? Phase Ia – Feature/resource inventory

Our inventory concerns geosites, geomorphosites and their specific types as caves and includes their geoposition, topography and values, as well as assessment of features in terms of their accessibility, fragility, representativeness, scenic value, critical factors and existing damage. To solve it, we adapt the concept of Visitor Impact Mapping (Bodenhamer 2006) which involves pinpointing damages on detailed maps and also any fragile undamaged resources which are recorded in detail and quantified. So, our proposal (Fig. 4) uses georeferenced digital models of caves in which impacts caused by human visitation, values/resources connected with biodiversity, geomorphodiversity, and cultural heritage (in accordance with the law in force in Galicia: archaeological, paleontological or archaeo-paleontological) are data added to the survey stations in existing digital cave models. And even, if necessary, auxiliary survey stations are created to pinpoint new features or damages.

Survey Station

Cave	Survey station	Location	Local geometry
Cave ID	Label ID	EPSG code	Distance to entrance
	Parent ID	UTM East	Left
		UTM North	Right
		UTM Elevation	Up
			Down

Related information (by group of resource) [simplified]

Geodiversity	Biodiversity	Archaeological Heritage	Palaentological Heritage	Impact	Environment
Process	Phylum	Group	Phylum	Group	Group
Type	Class	Type	Class	Type	Not used
Related mineral	Family/Order	Dating	Family/Order	Grade	Source
Element	Species	Element	Species	Element	Not use
Detail	Detail	Detail	Detail	Detail	Parameter
Observation notes	Observation notes	Observation notes	Observation notes	Observation notes	Value
Date	Date	Date	Date	Date	Date

Fig. 4. Structure of the records in the georeferenced digital model of a cave. From this model we can obtain a completely referenced cave geometry (main and auxiliary topographic stations, polyhedra that define a cavity segment, etc.). And we can associate structured data with each georeferenced point in the model. In our case we include data on geodiversity, biodiversity, cultural heritage (archaeological, archaeo-paleontological and paleontological remains), impact and environmental variables (temperature, isotopic data, natural radiation, etc.).

In the georeferenced digital model all its elements are consequently referenced to the topographic/geographic system. So, we build the geo-registration databases (directly derived from digital models) which provide extremely detailed locations and information about mineral formations (damaged and undamaged), bone deposits, archaeological remains, floor surface damages, human impacts and so on. Our Visitor Impact Mappings are dynamic maps updated from new digital models and their related database (Figs. 5 and 6). Our project uses QGIS as geographic information system.

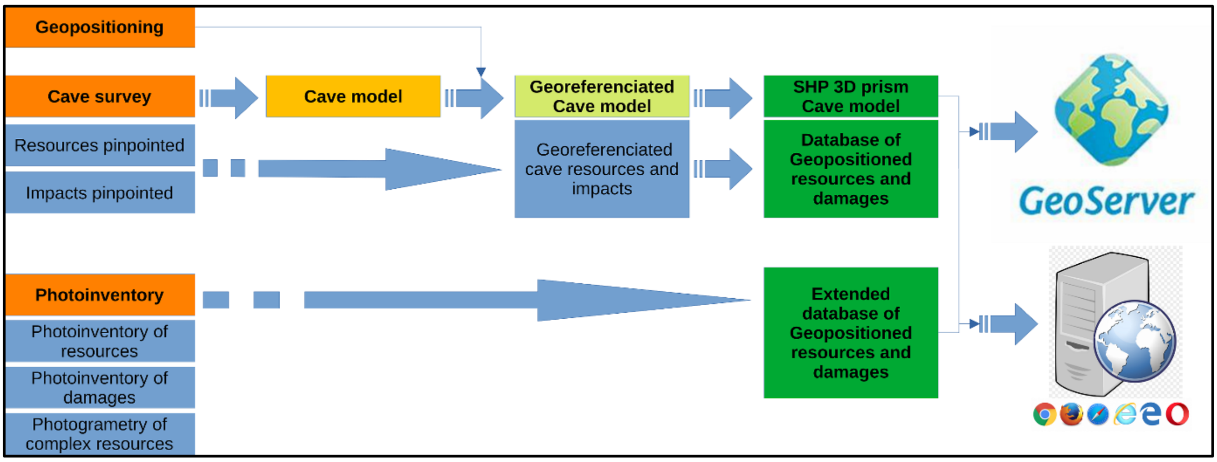

Fig. 5. General scheme that we followed to group the field information (georeference, cave heritage, existing impacts and graphic material) into georeferenced and related information of the cave digital model.

Database and digital models may be complemented with a photoinventory. As indicated by Hildreth-Werker and Werker (2006), it is much like a picture inventory: It is an organized, labelled and, in our case, georeferenced collection of pictures and 3D photogrammetry records of the evaluated features and resources of a cave or a Speleopark site (Fig. 7).

<u>How do we do it? Phase Ib – Feature/resource assessment</u>

The selection of the best sites to construct the itineraries in the Speleopark does not depend solely on their scenic values or greater diversity of features. Other criteria, such as accessibility, fragility, existing or potential impact, as well as accident risks and rescue difficulty also have their importance and should be taken into account. To carry out the selection of better sites for our itineraries, we developed a methodology based on the application of multicriteria techniques that are commonly used in evaluation processes when there are different criteria, with different priorities to determine a set of best candidates (Ariel Sarache et al. 2004) (Fig. 8).

An important issue to solve by the experts, is determining the prevalence of one criterion over another. We use a modified Fuller's Triangle, a criterion-criterion matrix applied to calculate the final weighting of the criteria, where priorities are established for each pair of criteria ($M_{ij} = 1$ means that the criterion "i" is more important than criterion "j").

<u>How do we do it? Phase II – Organization of the geosites and use of their features/values</u>

Until now we are working in four routes aimed at telling different (but interrelated) scientific stories. We have assigned to each itinerary the relevant sites that allow us to see the phenomenon throughout the entire territory:

- Route 01 – Convergent forms: From the granites of Foz-Mondoñedo to the limestones of Abadín; pseudokarren, caves and underground rivers, speleothems and biospeleothems.
- Route 02 – Geology-Day 2023: Water dissolves the granites of A Mariña; evolution of granites that intruded the limestones of the speleopark.
- Route 03 – Convergent forms: From the granites of Burela to the quartzites of Foz; uplift of a coast, advances and retreats of the sea, caves on the coast, speleothems and biospeleothems.
- Route 04 – "In any landscape, on any type of rock": caves in quartzites, granites and limestones between Foz and Mondoñedo; relationship between cave and rock structure.

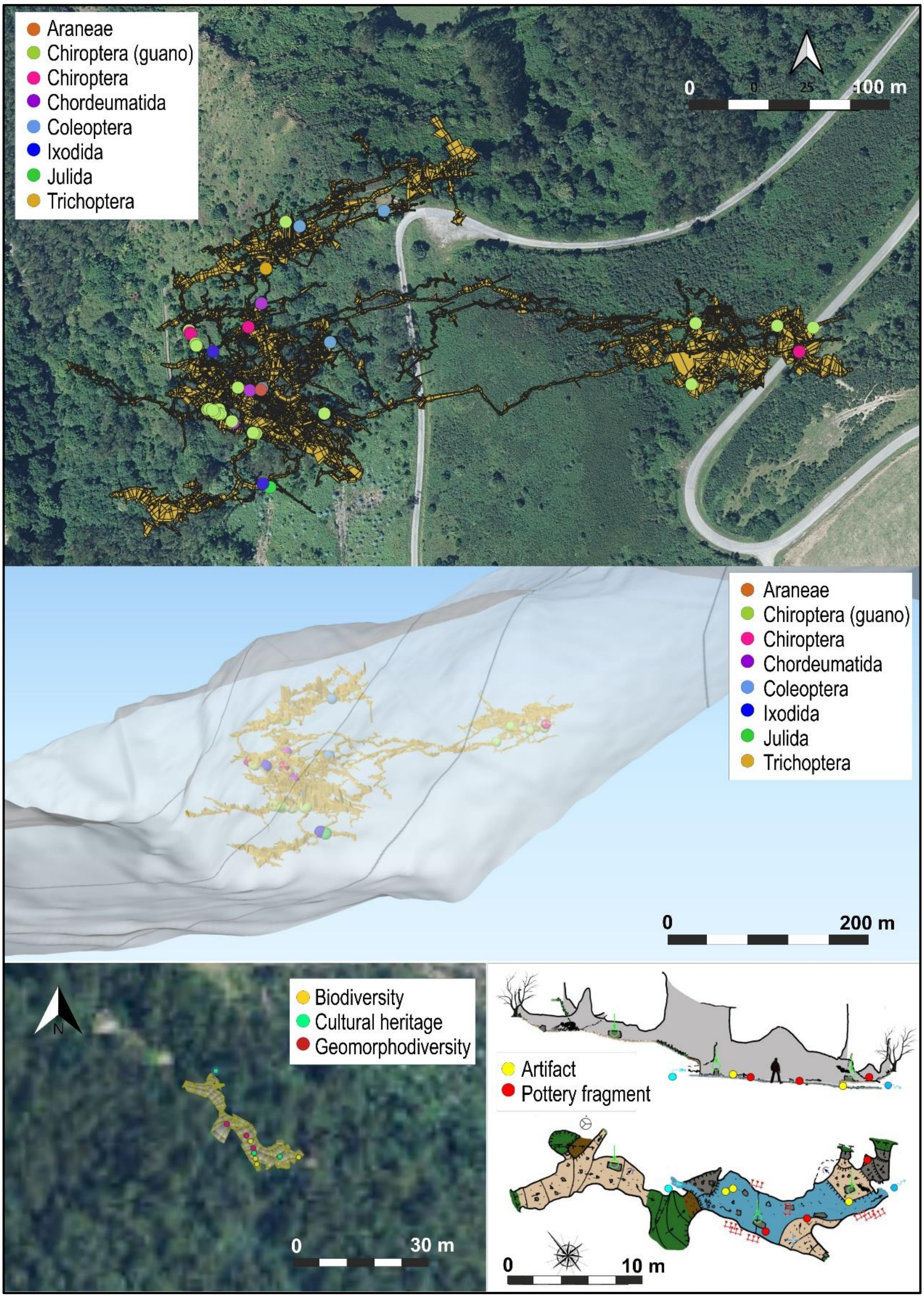

Fig. 6. The inclusion of structured information in the georeferenced models allows us to generate collections of maps. In upper part of the figure: digital model of Cova do Rei Cintolo Cave (in limestone) on which we activate layers related to biodiversity. Center: 3D model of Cova do Rei Cintolo Cave on which we activate layer related to biodiversity. Lower part: model of a small granite cave with an underground river, Abrigos da Ameixoada, in which resources are grouped by asking the query "which underground heritage groups are present?". The detailed information on which the queries will be made, although loaded into the database, is also reflected in conventional cartographic detailed information (as in conventional topography) or grouped information.

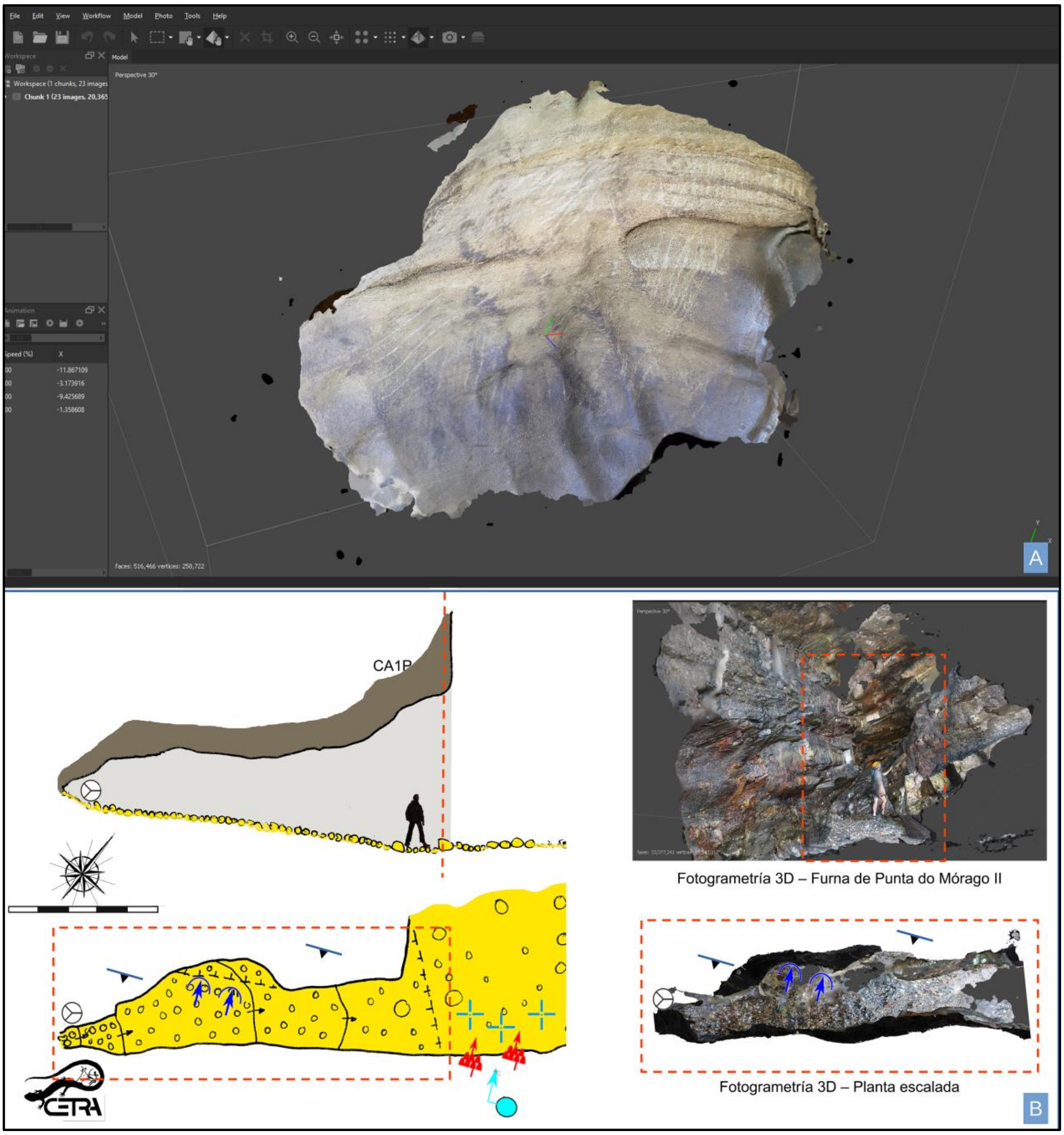

Fig. 7. The examples of 3D photogrammetry added to the graphic documentation of the Speleopark, either of singular elements, or of complete cavities. The advantage of photogrammetry is that we have a high-definition virtual model of an element or cave, that makes accessible (virtually) the most sensitive features and values to all audiences. A) Photogrammetry of a cave wall with bear scratches; B) Photogrammetry of a cave in quartzite on the coast of the A Mariña shire – the figure compares photogrammetry results and topography.

How do we do it? Phase III – Implementation: Where we are?

We still have a long way to go, but in 2021 we presented the first inventory of values and resources, and the main touristic route in the speleopark. Recently an inventory update has been presented, including the results of 3 camps focussed on the exploration and mapping of newly discovered caves in granites and quartzites in the area. At the same time – from 2020 to 2023 – we organized and carried out promotional/educative activities in the area, some aimed at university students (using granite and limestone caves as classrooms), others in the form of summer camps aimed at teenagers living in the area. And also courses focused on training speleologists for the campaigns of digital modeling of the caves.

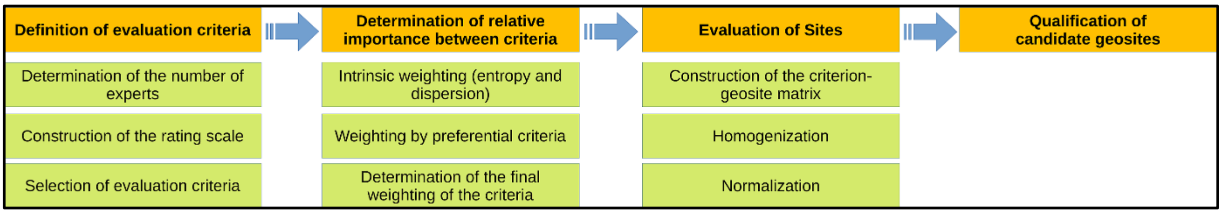

Fig. 8. Qualification of candidates (sites and geosites) using multicriteria techniques; figure adapted from Ariel Sarache et al. (2004).

One of the main events in 2023 was the celebration of "Geolodia 2023" in the "Speleopark of A Mariña". The "Geolodia" (Geology-Day) is an initiative promoted by the Geological Society of Spain in which on the same day, one geological field trip (guided by geologists) in each Spanish province is held, free and open to all audiences. The greatest difficulty is to achieve progress in the involvement of land managers and authorities in such events.

For 2024, new trips with university students are already scheduled, as well as educational and discovery visits of the Speleopark with schoolchildren. We also hope that between 2024-2025 the first field guidebook of the Speleopark will be published.

<u>Who promotes the Speleopark?</u>
The project is an initiative of the Rural Development Group of A Mariña Shire (G.D.R. Terras de Miranda) and the Galician Federation of Speleology. Also the municipalities of Burela, Foz, Alfoz and Mondoñedo participate and collaborate in this project.

Discussion

Our project aims to value and protect the caves heritage with a global vision, because it is a fact that caves exist in all types of rock, and also that underground landscapes are the reflection of a wide variety of processes that have taken place over time, leaving their traces in the cavity. We are fortunate that in the shire of A Mariña there are examples of many types of caves in a relatively small area. This allows us to disseminate caving in all its facets, in addition to promoting the protection of all these spaces. We must not forget that promotion and protection go hand in hand: "*The more we know, the more we can preserve and protect*". And one way to educate is by bringing the caves to all kinds of audiences. However, whether the project is feasible in the long term, depends on the involvement of those responsible in the municipalities. Both for their necessary support to the project, and for the need to move forward in a responsible and sustainable way.

References

Arce-Duarte J.M., Fernández-Tomás J., Monteserín-López V. 1976. Hoja 24 (08-04) Mondoñedo. Mapa Geológico de España E1:50 000. Servicio de Publicaciones del Ministerio de Industria. Madrid.

Ariel-Sarache W., Hoyos-Montoya C., Burban J.C. 2004. Procedimiento para la evaluación de proveedores mediante técnicas multicriterio. Scienta et Technica Año X, 24: 219-224.

Bodenhamer H. 2006. Visitor impact mapping in caves. In: Hildreth-Werker V., Werker J.C. (Eds.) Cave conservation and restoration. Nat. Speleol. Soc, New Mexico: 193-292.

Chabert C., Courbon J. 1997. Atlas Des Cavités Non Calcaires Du Monde. Au Pré De Madame Carle, Paris, 109 pp.

Cigna A.A., Forti P. 2013. Caves: the most important geotouristic feature in the world. Campinas, SeTur/SBE. Tourism and Karst Areas 6(1): 9–26.

Eraso A., Pulina M. 1994. Cuevas en hielo y ríos bajo los glaciares. McGraw Hill/Interamericana de España, S.A. Madrid, 280 pp.

Hildreth-Werker V., Werker J.C. (Eds.) 2006. Cave conservation and restoration. Nat. Speleol. Soc, New Mexico, pp. 600.

Martínez-Alvarez J.A., Torres-Alonso M., Gutiérrez-Claverol M. 1975. Hoja 9 (08-03) Foz. Mapa Geológico de España E1:50 000. Servicio de Publicaciones del Ministerio de Industria. Madrid.

Stone R.W. 1953. Description of Pennsylvania's Undeveloped Caves. National Speleological Society Bulletin 15: 51-137.

14th INTERNATIONAL SYMPOSIUM ON PSEUDOKARST IN THE STOŁOWE MOUNTAINS, SUDETES, POLAND, 24th-27th MAY 2023

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According to the tradition the international pseudokarst symposia were held each two or three years since the 1990s. But after a comparatively long break starting from the 13th Symposium in Kuncice pod Ondrejnikem (Czech Republic) in 2015, the UIS Pseudokarst Commission had – additionally – to deal with two postponements in 2020 and 2021 due to the Covid pandemic. Moreover, in present-day world, which is progressively predominated by online meetings, personal participation in symposia is obviously losing its appeal. The long interval was bridged somewhat by the International Year of Caves and Karst (IYCK) 2021/22, where many members of the Commission contributed to an impressive worldwide overview of pseudokarst phenomena in the Pseudokarst Commission Newsletter No. 30.

We have to thank our Polish colleagues – and especially the local speleologists and scientists from Wrocław – that the 14th symposium was able to take place in the Stołowe (Table) Mountains, Sudetes, the significant mountain range in south-western Poland. The event was extremely well organized in the Centre of Training and Education of the Stołowe Mountains National Park in Karłów between 24-27th May 2023 with two post-symposium excursions.

The symposium was attended by 38 people from 10 countries, several of whom took part online. On May 24th and 25th (before noon), there were a total of 27 papers planned and most of them were actually held directly by authors, a few were shown by organisers using authors' presentations (Fig. 1). Furthermore a series of posters were presented. Nevertheless, all planned presentations were included in a pre-published 82-page booklet with extended summaries (it can be downloaded from the Commission's homepage). Summarizing the presented papers once again demonstrated the great variability of the term "pseudokarst", which was also the subject of intense terminological debates.

Fig. 1. Scientific sessions of the 14th International Symposium on Pseudokarst, Stołowe Mts, Poland, 24-25th May, 2023 (Photo J. Urban).

Following the lectures, there were excursions in the immediate vicinity over the course of the next day and a half, i.e. on Friday, May 25th afternoon and Saturday, May 26th. The afternoon excursion on May 25th led to Mt Szczeliniec Wielki, a mesa-like table mountain (Fig. 2) covered with a tremendous labyrinthic "rock city" built of Cretaceous very thick-bedded sandstone (Fig. 3) with several caves – the longest extending for some 230 m. Removal of sand in the depth of the jointed rock masses is a crucial study perspective performed here and was discussed intensively on the spot. Among others it came out – at least for the author of this report – that the dissolution kinetics of silica is much less understood than that of limestone. This is maybe an attractive aspect for future coordinated research by members of the pseudokarst community.

Fig. 2. Mesa-like table mountain of Mt Szczeliniec Wielki visible from the Centre of Training and Education of the Stołowe Mountains National Park in Karłów (Photo J. Urban).

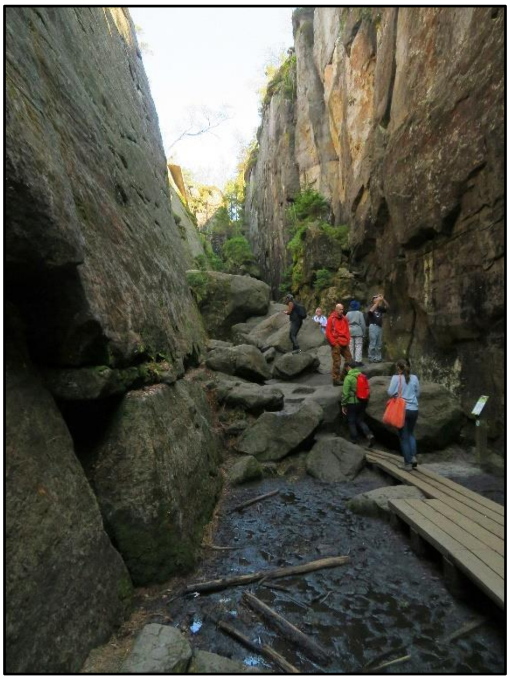

Fig. 3. Participants of the Symposium in the Piekiełko (Little Hell) crevice – one of the element of the rock city within the Mt Szczeliniec Wielki plateau (Photo J. Urban).

In the morning of the following day we went to the Białe Skały crag group and Mt Narożnik mountain range where we encountered needle-like remnants of the highly disintegrated margin of the plateau, consisting of Upper Turonian quartz-arenites. Further along the cliff Kacper's Cave was visited and the scientific investigations performed here were discussed with great interest. After visiting the Skały Puchacza (an old quarry) and some good viewing points we reached Skalna Czaszka where a peculiar sandstone formation resembles a somewhat spooky skull (Fig. 4).

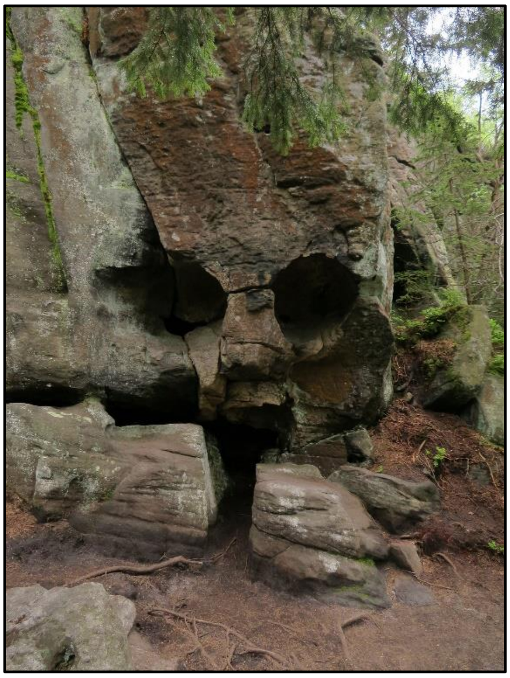

Fig. 4. Skalna Czaszka (Rock Skull) crag in Mt Narożnik Range (Photo J. Urban).

The Skalniak Plateau with the Błędne Skały rock labyrinth was our destination in the afternoon of the second day of the excursion. Its traverse (on an area of 400x200 m) was almost more confusing than that of Mt Szczeliniec Wielki, visited the day before. It is clearly oriented on a system of faults – but of three different directions, thus making the orientation in between occasionally somewhat tricky ... (Fig. 5 and Back Cover). Investigations concerning its genesis are still ongoing, but the subsurface dissolution of silica may be one of the important factors here too.

On Saturday 27th, two post-symposium excursions with a partial focus on speleology led to the famous Broumov area (Broumovsko National Geopark) in the Czech Republic (a detailed guide can be found on the homepage of the Commission, too).

Fig. 5. Symposium participants in the Błędne Skały rock labyrinth (Photo R. Pavuza).

On the first evening of the Symposium the assembly of the Pseudokarst Commission of the UIS took place with 10 participants on the spot and two via internet (online). After the report of the president about the past 8 years since the last, 13th Symposium, there was a broad discussion about the future of the Commission, future goals, the "Newsletter" and the next symposium. As any attempt for a "rejuventation" of the longtime-board of the Commission turned out to be unsuccessful, the current board (Jan Urban – president, Rudolf Pavuza – vice-president and Hartmut Simmert – secretary) was – or more precisely: had to be – re-elected, but two new and fortunately younger members were included: Kacper Jancewicz (Poland) as secondary secretary and Jan Lenart (Czech Republic) as executive member.

There were also discussions about the future of the "Newsletter" (which has already changed much in the past) – there might come up additionally something like an internet "blog" which would enable a faster information among the community about new results, methods etc. than in the yearly newsletter, but there was no consensus or final decision about that. Concerning the next symposium the idea came up to combine it with the national speleological meeting of the Czech Speleological Society in 2026 but other upcoming ideas might be considered, too.