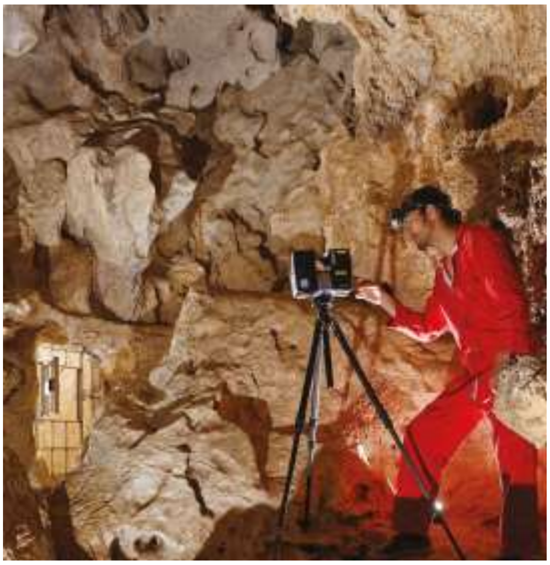
18ème congrès international de Spéléologie - 18th International Congress of Speleology

SCIENTIFIC CONFERENCE

Le Bourget-du-Lac – July 2022

PRE-PRINT 2021

SYMPOSIUM 09
Topography, Mapping, 3D, Documentation



La topographie des carrières souterraines de Citon-Cénac (Gironde)

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Résumé

La rive droite de la Garonne entre Langon et Bordeaux (Gironde, France) regorge de carrières souterraines dont la plupart sont abandonnées et incomplètement cartographiées. Ces carrières se caractérisent par un grand développement, une hauteur sous plafond assez faible et une exceptionnelle complexité. Une campagne de topographie systématique est en cours depuis 2016 dans divers réseaux : Citon-Cénac, 104 km ; Langoiran, 58 km ; Latresne, 30 km ; Tabanac, 13 km pour un total actuel de 210 km. Les relevés se font à l'aide d'un DistoX2 couplé à un terminal de type PDA ou Raspberry Pi. Le traitement des données est effectué avec l'aide de GHTopo (topographie spéléologique) et GHCaveDraw (dessin de plans de réseaux), développés par l'auteur. De nouvelles problématiques sont apparues et la grande taille des réseaux a nécessité d'importantes optimisations du code dans les logiciels de calcul. Un report sur carte des réseaux est fourni gracieusement aux organismes publics de gestion risques et patrimoine. Au-delà d'une simple topographie, un système de signalisation et de repérage à deux segments (sol + embarqué) a été développé. Il permet notamment de naviguer dans un réseau complexe en disposant d'un fil d'Ariane numérique calculé en temps réel (recherche du chemin de poids minimal entre deux stations).

Abstract

The topography of the underground quarries of Citon-Cénac (Gironde). The right bank of the Garonne between Langon and Bordeaux (Gironde, France) is full of underground quarries, most of which are abandoned and incompletely mapped. These quarries are characterized by a large development, low ceiling height and exceptional complexity. A systematic topography campaign has been underway since 2016 in various networks: Citon-Cénac, 104 km; Langoiran, 58 km; Latresne, 30 km; Tabanac, 13 km for a current total of 210 km. Surveys are carried out using a DistoX2 coupled with a PDA or Raspberry Pi type terminal. Data processing is carried out with the help of GHTopo (speleological topography) and GHCaveDraw (drawing of network plans), developed by the author. New problems have emerged, and the large size of the networks has required significant optimization of the code in the calculation software. A map report of the networks is provided free of charge to public risk and asset management organisations. Beyond a simple topography, a two-segment (ground + on-board) signaling and location system has been developed. In particular, it enables navigation in a complex network by means of a digital breadcrumb trail calculated in real time (search for the path of minimum weight between two stations).

1. Cadre géographique et présentation des réseaux

Les carrières souterraines de Citon-Cénac, à 15 km au sud-est de Bordeaux, forment un complexe de plus de 105 km de développement, toujours en cours d'exploration. Six niveaux de galeries ont été identifiés à ce jour, et au moins deux niveaux, figurant sur d'anciennes cartes, sont entièrement noyés.

L'exploitation s'est faite par la méthode des « chambres et piliers », avec une trame de 7,50 m et des piliers de 4 m de côté. Les blocs de pierre ont été découpés sur place avant évacuation. La hauteur sous plafond est relativement faible dans l'ensemble (1,50 m, avec quelques zones de plus de 3 m notamment dans les descenderies et inter-niveaux) ce qui rend la progression dans les réseaux assez pénibles. L'état des carrières est très variable, dans un contexte de roche encaissante à faible résistance mécanique. Certaines parties sont saines ou stabilisées (ce que montrent certains concrétionnements), d'autres sont complètement fracturées, avec effondrement du sol et/ou affaissement du plafond. Le massif encaissant est karstifié (présence de nombreuses cloches d'effondrement, conduits recoupés) et la stratigraphie indique la présence de plusieurs intercalations de couches d'argile, nécessitant le percement de galeries de liaison ou des changements de niveau. Par endroits, le concrétionnement est important (gours, excentriques, coulées de calcite) et peut renseigner sur la stabilité du secteur.

2. Le relevé sur le terrain

En spéléologie, les relevés sur le terrain sont basés sur la mesure d'une longueur, d'un azimut par rapport au Nord Magnétique et d'une inclinaison par rapport à l'horizontale. Ces trois données définissent une visée. Chaque visée est reliée à ses voisines via deux paramètres topologiques : un identifiant de début et de fin. Ces cinq valeurs permettent aux algorithmes de calcul d'assembler le réseau puis de calculer les coordonnées des points topo (stations). Plusieurs méthodes de notation existent mais nous avons choisi la méthodologie TOPOROBOT, basée sur un couple série / station, et qui a fait ses preuves depuis près de 50 ans. Une étiquette plastique dotée d'un marquage au feutre indélébile est disposée à chaque station. Ceci permet de se repérer dans le réseau à l'aide d'un plan ou d'une application spécifique (voir *infra*).

En carrière, nous utilisons un appareil électronique 'tout en un', appelé DistoX2, communiquant par Bluetooth avec un terminal de terrain (ici, un PDA doté du logiciel PocketTopo). Le logiciel intégré dans le terminal permet d'avoir un aperçu du plan en temps réel et d'y ajouter des croquis et des notes. En plus des visées de cheminement, nous effectuons de nombreuses visées rayonnantes, ce qui accroît la précision et la visibilité des volumes. L'identifiant unique de station permet de géoréférencer les notes et photos. Après la séance, les données sont transférées dans le logiciel de calcul pour traitement.

3. Le travail topographique en bureau

Nous utilisons le logiciel GHTopo pour le traitement des données topométriques : ce logiciel libre est le successeur de TOPOROBOT (abandonné depuis 2005) ; il est portable, léger et très puissant. Il est capable de traiter d'immenses réseaux (Shuanghedongqun, 305 km ; Réseau Trombe, 117 km ; Citon, 105 km). En topographie spéléologique, le problème principal à résoudre est la compensation des écarts de fermeture des bouclages dans un réseau. Tous les logiciels usuels (GHTopo, VisualTopo, etc ...) savent calculer un réseau de manière automatique depuis plus de 25 ans.

GHTopo utilise une méthode de calcul dans laquelle le réseau est assemblé automatiquement. Les écarts de fermeture des boucles sont corrigés par compensation matricielle en bloc : il est tenu compte de tous les chemins passant par un point pour calculer les coordonnées de ce point. Diverses optimisations dans les calculs matriciels permettent un traitement dans des temps raisonnables (environ 2 minutes pour un calcul complet) : l'étude des propriétés de certaines matrices a permis un passage d'une complexité en O(n**3) en O(n**2,2), qui a accéléré dans le cas de Citon II les temps de calcul d'un facteur 100 et plus ; le code parallélisable a été identifié, une structure de données minimisant l'empreinte mémoire (au détriment du temps de calcul cependant) a été développée.
Les données sont organisées sous la forme d'une base de données multi-tables gérée en mémoire centrale par le moteur de GHTopo ; elles sont sauvegardées sous forme d'un fichier unique (document) au format texte XTB (eXtended Toporobot Tab) ou au format GTX (GHTopo XML Format). Les résultats sont stockés dans une autre base de données mémoire, volatile celle-là, reconstruite lors du recalcul du réseau. Des outils de recherche et de débogage facilitent le travail de validation des données et la recherche d'erreurs.

L'interprétation des résultats

Après saisie et qualification des données, il est possible de visualiser le réseau en 3D, incluant éventuellement un modèle numérique de terrain, d'extraire des diagrammes d'orientation des galeries, de mettre en évidence l'étagement des réseaux et de produire des tableaux statistiques de synthèse.

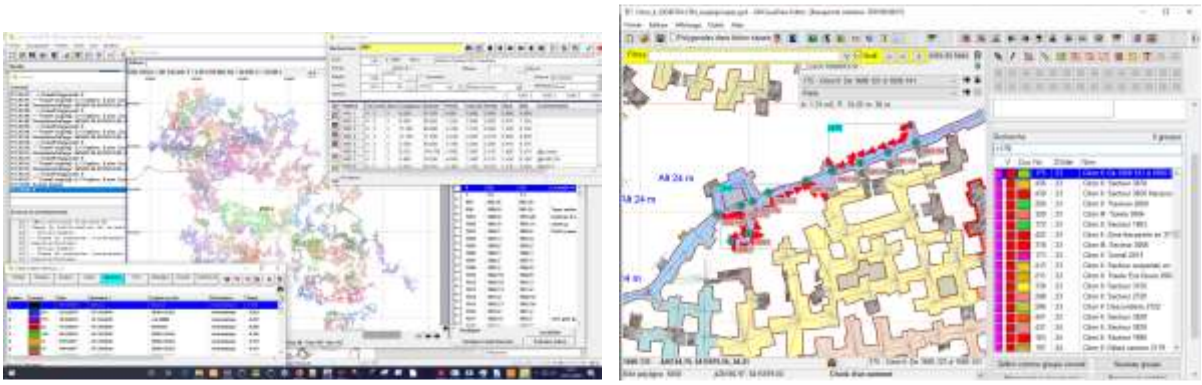

Figure 1 : Captures d'écran de deux étapes du travail (GHTopo et GHCave). Carrière Citon.

Le dessin topographique

La compensation des écarts de fermeture entraîne une déformation de la polygonale (cheminements). Comme une topographie spéléologique est évolutive, cette polygonale va être déformée au fil des jonctions, nouvelles entrées, découverte d'erreurs instrumentales, fautes de saisie, etc …). Nous utilisons GHCaveDraw, développé par l'auteur de GHTopo. Ce logiciel est léger, facile d'utilisation, très visuel (interface WYSIWYG). Son format de données est un langage de programmation. Dans GHCaveDraw, les objets graphiques (courbes, polygones, polylignes, textes, symboles), s'appuient sur des ensembles de sommets, lesquels sont en interne des tableaux d'enregistrements contenant :

• Un index (numérique ou littéral) pointant sur un grand tableau dont la première colonne contient ces index et les coordonnées de chaque station.
• Un décalage en x et y entre le sommet et sa station de rattachement.

Lorsque la polygonale est recalculée, le dessin s'adapte automatiquement. Cette polygonale peut d'ailleurs être

générée par un autre logiciel que GHTopo : Visual Topo, Therion, une feuille de calcul ou même un programme utilisateur.
Chaque objet graphique appartient à un groupe (même notion que le <g> du SVG), et chaque groupe comporte un polygone transparent (un scrap) qui est tracé avant tous ses autres objets. De plus, un groupe comporte un attribut d'altitude. La combinaison du scrap et de cet attribut permet de gérer automatiquement les superpositions de conduits, les groupes étant tracés du plus bas jusqu'au plus élevé.
Comme tout logiciel de dessin, GHCaveDraw possède un éditeur graphique doté de fonctions de création et d'édition.
Des systèmes de filtres permettent d'isoler des portions du réseau.
GHCaveDraw peut générer un atlas du réseau sous forme d'un dossier contenant des fichiers HTML. Un fichier principal affiche le plan général du réseau ; en cliquant sur ce plan, on accède aux pages de l'atlas qui sont d'autres fichiers HTML contenant un fragment du plan ainsi qu'une liste de groupes. Un clic sur la bordure de l'image permet de passer aux pages voisines.

4. Le système de signalisation-localisation

L'extrême complexité des réseaux de carrières, leur étendue et leur caractère uniforme imposent l'utilisation d'un système de repérage spécifique. Les fléchages, très souvent contradictoires, mis en place lors de l'exploitation puis lors des explorations successives rendent tout repérage impossible. Nous avons développé une méthodologie de signalisation à deux segments : un marquage sur le terrain associé à un terminal de terrain équipé d'un logiciel de localisation.
Le segment sol est ici très simple : il s'agit d'étiquettes numérotées (ex : 3683.43) disposées à demeure dans le réseau. Les axes principaux sont équipés d'étiquettes imputrescibles comportant les coordonnées de la station et la direction de l'entrée la plus proche.
Le segment embarqué est basé sur une importante fonctionnalité de GHTopo ajoutée récemment : le calcul et le tracé du plus court chemin entre deux stations (algorithme de Dijkstra). En renseignant le point de départ et celui d'arrivée, GHTopo surligne sur le plan du réseau le chemin de longueur minimale, et une feuille de route permet de suivre le parcours. Si on s'égare dans le réseau, on lit la première étiquette trouvée et on renseigne le point de départ : le chemin et sa feuille de route sont aussitôt recalculés.

Il est également possible de définir plusieurs itinéraires sauvegardables, et un distancier peut être calculé. Pour chaque itinéraire calculé, le nombre de stations et la longueur du parcours sont retournés. Le tracé est surligné sur le plan et une feuille de route détaillée est dressée.

Cette fonctionnalité est implémentée de deux manières dans le système embarqué :
• Un mode de travail spécifique de la version "terminal de terrain" de GHTopo
• Un fichier HTML - Javascript doté des mêmes fonctionnalités, entièrement autonome et généré par GHTopo (métaprogrammation). Ce fichier unique s'ouvre dans un navigateur Web (JavaScript activé), il implémente l'algorithme de recherche de chemin minimal et est parfaitement fonctionnel. Il peut être ainsi chargé dans une tablette.
Cet outil possède une fonction de recherche de station qui centre la carte sur la station trouvée, ainsi que des fonctions plus classiques de zoom et déplacement. La sélection d'une station dans la feuille de route (liste défilante) centre la carte dessus.

5. Perspectives d'évolution

La cartographie des carrières souterraines a très fortement accéléré le développement de GHTopo et GHCaveDraw. Avant ce projet, le dossier topographique le plus complexe traité par GHTopo était le complexe de Shuanghedongqun (135 km à l'époque), qui comportait seulement 1450 nœuds.
La topographie de Citon II a montré les limites de GHTopo en termes de temps de calcul (il variait avec le cube du nombre de nœuds). Une analyse du code et des propriétés des matrices utilisées ont révélé que ces matrices sont creuses et leurs termes non nuls sont proches de la diagonale, ce qui permet l'utilisation d'algorithmes plus performants et accélère considérablement les calculs.
Les essais en charge et le corpus de réseaux montrent que GHTopo se comporte très bien et se révèle stable. Le calcul du réseau de Citon I+II prend moins de 2 minutes et mobilise 550 Mo de RAM, ce qui est de nos jours très acceptable. Notons qu'il existe un modèle de stockage beaucoup moins gourmand (mais aussi bien plus long en temps de calcul), activable à la compilation, qui ne prend que 45 Mo pour le même réseau.
Le retour d'expérience de la part d'utilisateurs de GHTopo a considérablement amélioré l'ergonomie et les fonctionnalités, notamment grâce aux suggestions de l'équipe STEKA (Réseau Trombe) lors du premier confinement national de 2020. Des utilitaires de fusion puissants ont ainsi été développés.
Le code de calcul de GHTopo est partiellement multithreadé mais un important travail d'acquisition de connaissances en ce domaine reste à faire, les mécanismes internes étant difficiles à appréhender, tant du côté algorithmique que du langage de programmation. Ce travail a pour but de faire tourner le moteur de calcul de GHTopo sur un supercalculateur artisanal7 à base de Raspberry Pi.
Un atout de GHTopo, qui est d'ailleurs le seul logiciel de topographie spéléologique à proposer cette fonctionnalité, est le calcul de chemins minimaux entre deux stations. Ceci

a permis de mettre au point le système de signalisation et de localisation en carrière. En outre, la même fonctionnalité (y compris recherches et calculs de chemins) est disponible sur un livrable HTML / Javascript rédigé par GHTopo.
Le dossier le plus stressant pour GHTopo est actuellement le réseau de Shuanghedongqun (Chine), qui vient de dépasser les 305 kilomètres de développement. Si les 5 600 nœuds du complexe ne posent aucun problème, ses 31 200 stations font apparaître des lenteurs d'affichage qu'il faut résoudre. Et ce réseau, le plus important de Chine, a un potentiel estimé à 800 kilomètres.
Le logiciel de dessin GHCaveDraw se révèle stable, rapide et robuste malgré les 650 000 lignes de code en langage GHCaveDraw décrivant le réseau de Citon II. De nombreux développements, particulièrement en termes d'ergonomie, sont prévus.

Figure 2 : Outil de navigation développé dans le logiciel (ici possibilité d'indetifier différents parcours).

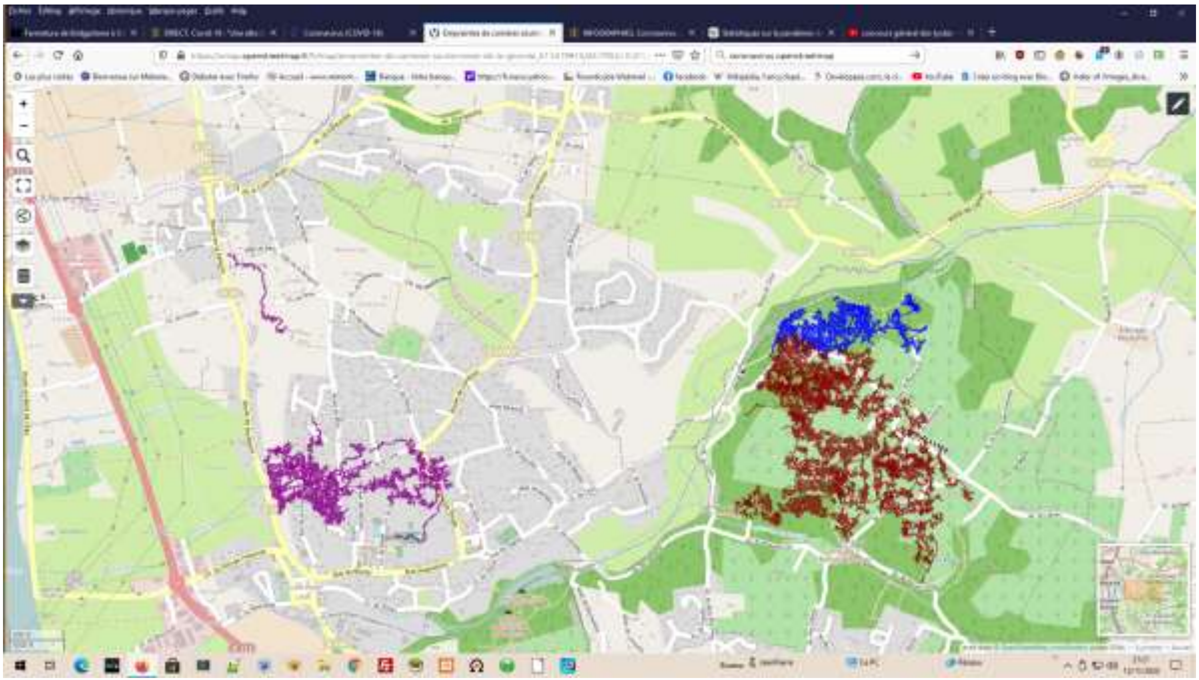

Figure 3 : Report des carrières topographiées sur une interface Web et sur un fond libre (ici open street map).

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Virtual caving libraries: toward a network of bibliographic information resources

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Abstract

Data collection and information sharing represent areas in which dramatic improvements and achievements appeared in the recent past, but the caving world looks troubled in coping with such a rapid progress. Recent international and national congresses were entitled to 'sharing data', 'sharing knowledge', and so on, but actual resources and tools appear underrated and underused. Italy holds the largest caving library in the world, in Bologna, and several caving archives with documents from the 19th century on, but such a huge amount of data is still little exploited, so as to provide useful information. The author, as a long-time computer science professional, explored the issue and developed some prototypes intended to establish links among bibliographic caving data in the Web, as a way to enhance the chance to get information from caving literature. As a proof-of-concept, some prototype personal virtual libraries were developed, about distinguished cavers of the past. An E.-A. Martel draft virtual library was developed, as a present to the 18th ICS. Further potential developments are discussed, together with links with world-wide caving archives and the KarstLinks project.

Résumé

Bibliothèques virtuelles de spéléologie : vers un réseau de ressources d'information bibliographique. L'ensemble de données et le partage d'informations représentent des domaines dans lesquels des améliorations et des réalisations spectaculaires sont apparues récemment, mais le monde de la spéléologie semble avoir du mal à faire face à un progrès aussi rapide. Les récents congrès internationaux et nationaux avaient le droit de « partager des données », de « partager des connaissances », etc., mais les ressources et outils réels semblent sous-estimés et sous-utilisés. L'Italie possède la plus grande bibliothèque de spéléologie du monde, à Bologne, et plusieurs archives de spéléologie avec des documents du XIX^e siècle, mais une telle quantité de données est encore peu exploitée, de manière à fournir des informations utiles. L'auteur, en tant que professionnel de l'informatique de longue date, a exploré la question et développé des prototypes destinés à établir des liens entre les données bibliographiques de spéléologie sur le Web, afin d'améliorer les chances d'obtenir des informations à partir de la littérature spéléologique. En guise de preuve de concept, des prototypes de bibliothèques virtuelles personnelles ont été développés, sur des spéléologues distingués du passé. Un projet de bibliothèque virtuelle de E.-A. Martel est présenté, un cadeau au 18^e ICS. D'autres développements potentiels sont discutés, ainsi que des liens avec les archives mondiales de spéléologie et le projet KarstLinks.

1. Introduction

Often in the past, caving research and dedication produced innovative results aimed at relieving part of the hard effort spent in underground exploration and documentation. Achievements in caving techniques and tools deserved application in areas outside of a cave: e.g. single rope technique, rappelling and abseiling devices, specific rescue tools and techniques, LED lighting equipment… Even the cave register is an extremely powerful tool, longed for by researchers in other fields.

In the field research, the digital revolution looks afar from the hard and muddy caving world; few digital technologies find some customisation in the caving world (e.g. new survey techniques and tools). However, dramatic recent achievements in paper books and journals digitalization and in full digital editing of new papers look under-exploited in the caving world. A fair number of historical caving books and journals were digitized and shared by librarian institutions (e.g. Spelunca 1895-1900 and 1907-1909) and most current caving magazines and journals are published and shared in a digital format. Most of these data are provided on the Web as public domain information; they sum up into a huge amount of cave-related information. They need to be organised, in order to improve the queries and enhance the chance to access the needed pieces of information.

2. Materials and methods

Digital caving bibliographic data are shared by several different providers. A first step toward caving information collection and organization is in the library catalogues. Speleoteca is the catalogue of 20 Italian caving libraries, first of all the Caving Documentation Centre "Franco Anelli" in Bologna (SIVELLI & FORTI, 2018). The catalogue collects more than 33,000 cave- and karst-related publications. 918 serials are registered, but most are related to non-

exclusively caving publications (e.g., mountain club magazines). More than one thousand bibliographic records are enhanced with the cover scan, and some of them with a link to the digital resource (e.g., the magazine *Speleologia*).
The Speleological abstracts (BBS; DERIAZ, 2018) is an extremely powerful tool to gain knowledge about specific caving disciplines, areas or keywords at a worldwide level. It is the result of a long-time collective work in analysing caving publications and categorising each single reference. The classification work started in 1969 but the present digital database spans from 1988 to 2014. The huge amount of 111,833 references is collected in the on-line search tool.
A full-fledged virtual library should provide both the links to the digital resources and search tools based on the underlying classification. Possibly, it should provide also full analytics. A couple of cave-related examples follow:

- the Karst Information Portal (KIP): a US-based open-access digital library, managed by the National Cave & Karst Research Institute, by the South Florida University and the New Mexico libraries, and by the Union Internationale de Spéléologie. The portal was established in 2006; in the near future, it plans to deploy a georeferenced query interface to the bibliographic database. Presently, the portal collects 7427 worldwide caving-related items.
- Commissione Grotte "Eugenio Boegan", Trieste: (MERLAK, 2018) an actual caving club virtual library, where all 64 issues of the Progressione magazine are shared, together with several issues of the Atti e Memorie journal and many books and excerpts produced by members of the Club, established in 1883.

Furthermore, the Union Internationale de Spéléologie shared digital copies of all International Congresses of Speleology proceedings. Up to 64 volumes are provided, summing up about 7.6 Gbytes.
The above-mentioned data show that a large number of cave-related books and papers are now freely available in the Web, but the task of searching and finding the relevant information is quite demanding. The author started collecting web links to cave related items in the Web and developing prototypes aimed at exploring ways to organize and share digital caving information.

3. Results

A prototype virtual library of caving references about the Lombardy region (Northern Italy) was developed (FERRARI 2013a; 2013b). It presently collects 5413 references to books, journal papers, newspapers; 2724 of them are freely available and public domain in the Web. The virtual library links each bibliographic reference to the mentioned caves, together with annotations about the mention type (e.g. description, photo, survey, archaeological notes, biological notes, etc.). A georeferenced map of caves is produced; each cave is linked to an automatically generated bibliographic listing enriched with links to the digital documents in the Web. The system proved a useful tool for research and on-field exploration too.

Cave-O-Zines
Cave-O-Zines means Caving Open-access magaZines. The Cave-O-Zines project aims at developing a collection of all the periodic caving resources (journals, magazines and newsletters) ever published in Italy, both in paper or just in digital format (FERRARI, 2018). Covers and index pages are provided where available. Links to the single digital resource are provided where available.
A query in Speleoteca provided the list of nearly all Italian caving serials. Very few additional entries came from direct search on the web or in actual libraries.
The Cave-O-Zines prototype is: virtual, that is the system is fully digital and web-based; distributed: the library resources are provided by several kinds of publishers, usually caving clubs or associations. The single resource is hosted in the provider web site. Data about each magazine were collected and organized, together with links to the Speleoteca and the OPAC/SBN records. A geographic positioning of the magazine is inferred from the address of the publishing organization (cave club, federation, …).

A second level of information is relevant to issues. For each publication, the list of published issues is collected, usually from Speleoteca. Where available, a link to the digital resource is added to each issue record.

Figure 1: Cave-O-Zines map of caving journals in Italy.

Geospatial information is used to generate a KML (Keyhole Markup Language) file, with a placemark to show the localization of each publication. The KML file can be loaded into Google Earth® or Google Maps® to generate a map (fig. 1) with the publication positions. A marker with a hanging bat is related to a no longer active publication, while a marker with a flying bat shows an active one. A click on a

placemark opens a box with essential data about the publication and a link to the publication web page.
The prototypical Cave-O-Zines system was developed and deployed on a private web server, so as to be demonstrated as need arises. Cave-O-Zines collects 328 Italian cave-related journals, magazines and newsletters, summing up 4213 issues, from 1899 on. New publications add an estimated 30 issues per year. 1817 issues are available as open access resources, which is 43 % of the whole issues ever published in Italy. This builds up a fairly large library, that is available to every interested researcher or explorer. The KML file can be loaded on a tablet or smartphone with Google Earth or Google Maps installed. Provided a mobile internet connection is present, the Cave-O-Zines virtual library can be navigated just in front of a cave entrance.
The magazine library is enhanced with pages about international, Italian and regional congresses.

Personal virtual libraries
A hint of a virtual library potential came from the late Giovanni Badino caving bibliography. Prof. Paolo Forti produced Badino's bibliography, thanks to a huge effort in perusing the Bologna Library books and magazines (FORTI, 2017). The caving-related papers summed up to 597 references. The author enhanced the bibliography with links to open-access papers: 447 references are available in the Web, that is 75 % of the total, mostly represented by papers on journals and magazines.
On the same rationale, several personal virtual libraries are under development, about renowned cavers of the past. Among them, the two pioneers of caving science and research in France and in Italy: É.-A. Martel and E. Boegan.

Figure 2: Top area of the E.-A. Martel virtual library.

The Martel virtual library is intended as a proof-of-concept, possibly to be carried on and improved by the Fédération Française de Spéléologie. The web page is partitioned in two sections. The top one shows the monographic works (fig. 2). Presently, eighteen books are displayed; thirteen of them (with light green background) are provided with a link to the digital resource. The bottom section lists the notes published into journals and magazines, in chronological order. The list is in-progress; presently it encompasses 149 references, 139 of them provided with link to the digital resource.

4. Discussions

The mentioned caving virtual library prototypes proved to be very useful in search, in new papers development and in exploration too. The Google Earth / Google Maps interface enables people, who are not confident with full-featured Geographic Information Systems, to get a dramatic insight into geographic information.
However, several improvement areas are left. Many enhancements are needed to improve the systems and the underlying data. The Cave-O-Zines system could be integrated with Speleoteca, so as to extend the catalogue of caving libraries to a comprehensive real/virtual library and a repository of paper and digital books and magazines.
A powerful improvement in the Cave-O-Zines system documentation and information power is in the development of a database of single papers. A full-fledged bibliographic reference system should at least be based on data about authors, titles and links to open access resources. It could be enhanced with information about caving clubs, caves and karst areas mentioned in the single paper. In this way, powerful searches could be run. Some journals and magazines published comprehensive indexes of the whole publication. The paper database could be established collecting and organizing these indexes.
A dramatic enhancement at world- or nation-wide level could foresee the following steps:

- the collective definition of a shared standard data model to manage caving bibliography data;
- the collection and digitalization of the published bibliographic catalogues and journal indexes.
- The integration with the powerful Bulletin Bibliographique Spéléologique data-base and with the Karst Information Portal.

5. Conclusions

Overall, the underlying challenges are: how to manage such a huge amount of information? How to profit from digital technologies so as to encourage cavers to read and write? A partial technological solution can come from the Linked data – Semantic web technologies (FAGNONI, 2018) which allow to process large amounts of open data in order to get the required information. The KarstLink project is aimed at organizing the machine-readable online sharing of data on cave and Karst environment. Preliminary data about Martel bibliography are already shared within the KarstLink infrastructure.

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The oldest “cave cadaster” of the World

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Abstract

Recently the Franco Anelli Speleological Documentation Centre in Bologna acquired the book *La Sicilia in prospettiva* printed in 1709 by the Jesuit Giovanni Andrea Massa. In this book all the known caves of Sicily - not only karst and volcanic, but also artificial - were described, supplying also the existing printed references on them. Later it was possible to identify most of the described caves thanks to the co-operation of the Speleological Register actually managed by the Sicilian Regional Speleological Federation. Presently the Massa’s book should be therefore considered the very first speleological “embryonic” cadaster of the world. Finally, this research allowed to unveil that during the XVI, XVII and XVIII Century, Sicily was also the world area in which the interest towards not only karst caves, but also volcanic and or artificial cavities, was present far before than in any other part of the occidental world.

Résumé

Le plus ancien inventaire spéléologique au monde. Le centre de Documentation spéléologique Franco Anelli de Bologne a récemment fait l’acquisition de *La Sicilia in prospettiva* du jésuite Giovanni Andrea Massa (1709). Y sont décrites toutes les grottes de Sicile, karstiques ou volcaniques, ainsi que les cavités artificielles. En s’appuyant sur l’inventaire régional actuel, il a été possible d’identifier la plupart de ces grottes, de telle sorte que le livre de Massa doit aujourd’hui être considéré comme le plus ancien embryon d’inventaire spéléologique au monde ; et la Sicile comme un des berceaux de la Spéléologie.

1. Introduction

Presently, quite all the National Speleological Societies in the world have an updated Cave Cadaster of their own Country.

Some of them started to be implemented only 50-70 years BP but many others are by far younger.

In Italy, the National Speleological Cadaster started in 1927 inside the Italian Institute of Speleology in Postojna (LA REDAZIONE, 1927).

Earlier some of the oldest Italian Caving Clubs (among them the most important were the “Commissione Grotte” of the “Società Alpina delle Giulie” in Trieste and the “Circolo Speleologico Idrologico Friuliano” in Udine) created local cadasters between the end of the XIX Century and the beginning of the XX Century (TAUCER, 1892; ANONIMO, 1907).

This fact is not surprising because that area of Italy was part of the “Classical Karst”.

But recently the Franco Anelli Speleological Documentation Centre in Bologna acquired *La Sicilia in prospettiva* printed by the Jesuit Giovanni Andrea Massa in 1709.

In this book all the caves of Sicily - not only karst and volcanic, but also artificial - known at that time were shortly described.

Thanks to the co-operation with the Sicilian Regional Speleological Federation, which actually manages the Sicilian Speleological Cadaster, it was then possible to identify many of the described cavities.

Presently the Massa’s book should be therefore considered the very first “embryonic cave cadaster”, of the World being printed over one and a half century before a true Caving Club will appear.

Finally, this research allowed to unveil that during the XVI, XVII and XVIII, Sicily was not only the single area of the World with a printed cave list but also the world area in which the interest towards not only karst caves, but also volcanic and or artificial cavities, was well present far before than in any other corner of the occidental world.


LA SICILIA
IN PROSPETTIVA.
PARTE PRIMA,
CIOE'
Il Mongibello, e gli altri Monti, Caverne, Promontorij, Liti, Porti, Seni, Golfi, Fiumi, e Torrenti della Sicilia
ESPOSTI IN VEDUTA
DA UN RELIGIOSO DELLA COMPAGNIA DI GIESU'.
DEDICATA ALL' ILLUSTRISSIMO
SENATO PALERMITANO
LI SIGNORI
DON ANTONINO LUCCHESE Duca della Gratia, de Principi di Campo franco, del Consig. di S.M. Gentilhuomo di sua Camera, Deputato, e Maestro Portulano del Regno, la seconda volta Pretore,
D. FILIPPO BOCCADIFUOCO, Quinta volta,
D. GIUSEPPE ANSALONE, E DE LA TORRE, Quarta volta,
D. PLACIDO GISULFO, Seconda volta,
D. GIO: FRANCESCO FERRERI,
D. GIO: DOMENICO ONETO,
D. GIOVANNI DE AOIZ, Secret. di S.M.
SENATORI.
IN PALERMO M.DCCIX.
Nella Stamparia di Francesco Cichè.
Con Licenza de' Superiori.

Figure 1: Title page of the Massa’s book (Anelli’s collection)

2. Caves described in the Massa's book

The Massa's book may be considered one of the first geographical monographies on Sicily, where all the remarkable morphologies of the Island are shortly reported. The main difference with respect to other similar books is represented by the fact that Massa decided to describe, as important geographical objects, the natural and artificial cavities.

The total number of described caves is a little bit more than 50 (among which 14 are limestone caves and 11 volcanic ones), while the reported artificial cavities are 14 (Fig. 2).

Cited volcanic caves

Pag.	Cave name	Locality	Actual name	Cadastral n.	References
18	Barracca vecchia	W-Etna			Brunelli & Scammacca, 1975
19	Grotta dell'Olmo	W-Etna			
19	Colletta	W-Etna	Collapsed (?)		Brunelli & Scammacca, 1975
19	Spelonca della Palomba	W-Etna	Grotta delle Palombe (?)	Si/CT 1047	
19	Antro di Monte Dolce		Riconco di Liricio	Si/CT 1192	
20	Grotta nuova	Serrapizzuta	Casa del Vescovo	Si/CT 1043	
20	Grotta della neve	Serrapizzuta	Buried by lava flow in 1766		Brunelli & Scammacca, 1975
20	Grotta dei Santi	Pedara	Destroyed in 1780		Brunelli & Scammacca, 1975
20	Grotta San Leo	Pedara			
20	Caverna Thalia	Paternò (CT)			
155	Grotta dell'Acqua	Etna	Destroyed in 1766		Brunelli & Scammacca, 1975
157	Grotta di Proserpina		Grotta di Santa Sofia		

Cited karst caves

Pag.	Cave name	Locality	Actual name	cadastral n.	References
129	Agiro	Agira (EN)	Grotta di S. Filippo		Eremos.eu
154	Grotta di S. Vito	Piana di Sopra – San Vito Lo Capo (TP)	Grotta della Zubbia	Si/TP 8059	Messana et al. 1994
157, 165	Grotta di Gazo o Jato	San Giuseppe Jato (PA)	Grotte di Pizzo Mirabella	Si/PA from 0260 to 0268	Messana et al. 1994
157, 212	Grotta del Gigante o Martogna	Erice (TP)	Grotta Martogna		
161	Grotta S. Sofia	Sortino (SR)	Eremo di S. Sofia "Arrassu"		
167	Lamia	Mineo (CT)	Grotta di Sant'Agrippina o di Drafone o della Làmia		
178	Grotta Santa Rosalia	Palermo	Grotta e Santuario di S. Rosalia	Si/PA 100	Messana et al. 1994
186	Grotta Santa Rosalia	S. Stefano di Quisquina (AG)	Grotta di Santa Rosalia	Si/AG 2062	Messana et al. 1994
191, 192	Antri di San Calogero e Cavernetta delle Pulzelle	Sciacca (AG)	Sistema delle grotte di Monte Kronio	Si/AG from 2014 to 2018	Messana et al. 1994

Cited artificial caves

Pag.	Name	Locality	Actual name	References
155	Grotta di Dionisio	Siracusa	Orecchio di Dionisio	
157	Grotta della Madonna di Santa Venera	Marsala	Grotta di Santa Venera - Madonna delle Grazie	
158	Grotta di San Calogero	Palermo	Cripta o antro di San Calogero	
158	Grotta di San Calogero	Naro (AG)	Cripta di San Calogero	Eremos.eu
159	Grotta di San Calogero	Brucoli (SR)	Grotta di San Calogero	
159	Grotta di San Filippo	Messina	Grotta e Monastero di San Filippo di Agira	Eremos.eu
159	Grotta di Santa Lucia	Noto	Basilica ipogea di Santa Lucia	Eremos.eu
160	Grotta (cripta) S. Maria	Marsala (TP)	S. Maria della Grotta	Eremos.eu
161, 162	Grotta della Sibilla	Marsala (TP)	Cripta di San Giovanni al Boeo o Grotta della Sibilla	Eremos.eu
161	Grotta di San Nicolò	Siracusa	San Nicolò ai Cordari	
161	Grotta Sant'Oliva	Palermo	Pozzo di Sant'Oliva	
163	Grotta Trocalitania	Caltabellotta (AG)	Grotta del Male o Grotta del Drago	
163	Grotta di S. Giovanni	Siracusa	Catacombe di San Giovanni	
198	Tajate	Siracusa	Latomie di Siracusa	

Fig. 2: Table with all the pages of Massa Book in which the volcanic, karst and artificial cavities are cited with their original names, the locality and their actual name and cadastral number (when known). Nowadays no data are available from the artificial cavities' cadastre, because of its deep restructuration.

Most of them were already cited, if not described, by previous authors. Thus, it is not easy to discriminate between those visited personally by Massa and those just reported on the basis of available bibliography.

Il was very hard to put in direct relation the cavities present in the Massa's book and those of the Official Cadaster of the Sicilian Speleological Federation (Messana & Panzica La Manna, 1994, WISH). In fact, some of them were destroyed by eruptions or other natural or human related events (BRUNELLI & SCAMMACCA, 1975), while it was practically impossible select the corresponding actual cavity for a few of them due to the scarcity of the Massa's description.

3. Sicily: not only the land of the first embryonic speleological cadaster

The important role played by Sicily in the History of Speleology is not restricted to the existence of the just outlined first cave cadaster.

In fact, a couple of decades ago, the "Franco Anelli" Speleological Documentation Centre found two very old maps, which were later recognized as the oldest cave map ever printed in the world (MANCINI & FORTI, 2009).

They were the plans of two caves, cited in the book of Massa as S. Rosalia on Pellegrino Mt near Palermo (p. 178) and S. Rosalia at S. Stefano di Quisquina in the Agrigento area (p. 186). They were firstly printed in 1651 (some 60 years before of the Massa's book) (Fig. 3 & 4) in "*Santa Rosalia Vergine Romita*" (CASCINI, 1651) by another Jesuit.

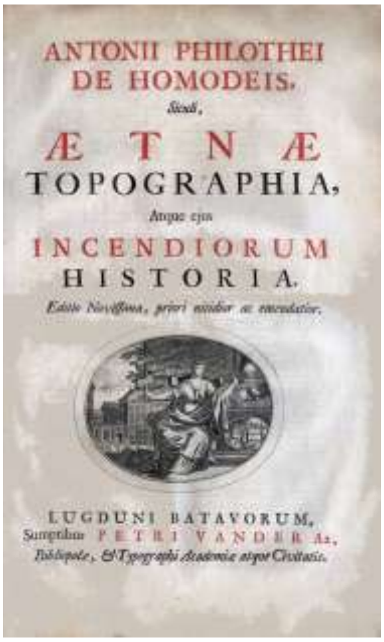
Figure 3: Copper engraving of the Santa Rosalia cave (and is plan) on Pellegrino Mt (Anelli's collection).

Therefore, these two maps are roughly 37 years older than that of Penn Park hole in England, former believed to be the oldest in the world (SHAW, 1992).

But another book, often cited by Massa, is fundamental for the History of Speleology and in particular for the Vulcanospeleology: *Aetnae Topographia*, printed in 1591 by Antonio Philodei de Homodeis.

In fact, in this book, beside citing some volcanic caves of Mt Etna, a very first genetic model for the evolution of the lava tubes was presented.

Figure 4: Copper engraving of the Santa Rosalia Cave at Quisquina (Anelli's Collection).



ANTONII PHILOTHEI
DE HOMODEIS,
Siculi,
ÆTNÆ
TOPOGRAPHIA,
Atque ejus
INCENDIORUM
HISTORIA.
Editio Novissima, priori nitidior ac emendatior.

LUGDUNI BATAVORUM,
Sumptibus PETRI VANDER Aa,
Bibliopolae, & Typographi Academiae atque Civitatis.

Figure 5: Title page of the book Etnae Tophographia *printed 1590 (Anelli's collection).*

It was suggested a mechanism very similar to that proposed for the karst caves, but only 75 years later, by KIRCHER (1665) based on the so called *Hydrophilaci*. Practically Philothei de Homodeis thought that a network of conduits, like the human wrists, connects the sea to the mouth of the volcano. When the sea water comes in contact with the fire deep underground, a powerful reaction is generated which causes the upwelling of vapour and lava, thus, giving rise eruptions and consequent to lava flows. In this theory lava tubes where nothing more than a survived portion of the original network of the Etna's wrists, while the presence of water and sometimes of different minerals within the caves is a direct consequence of direct connection with the sea.
In conclusion from 1590 and 1709 three true milestones in the History of Speleology were realized in Sicily.

4. Final remarks

Until now it was commonly thought that Speleology sprang up and developed mainly in the "Classical Karst", the region actually in between Austria, Slovenia and Italy.
This is surely true if we consider the activities performed by the first Speleological Associations, which gave rise to the pioneering explorations and studies during the whole XIX and the beginning of the XX Century. But in the previous Centuries random explorations and studies were performed in many other different European Countries and shortly reported in general books describing different geographical areas.

In the history of earth sciences and cave research, the central role played by Sicily, during the XVI, XVII and XVIII Century, in dealing with caves, volcanism, or artificial caves was already clear. But now the written document, shortly discussed in this paper, make even more evident this role: Sicily is the world area in which the interest towards natural and artificial cavities was present far before than in any other part of the occidental world: in fact, just there the first theory on the genesis of lava tubes was presented, the first cave maps drown and the first example of an "embryonic cave cadaster" realized.

Acknowledgments

We gratefully thank to Francesco Leone, responsible of the Sicilian Regional Speleological Federation cadastre, for the help given in identifying the cavities described in the Massa and Cascini's books and Pino Guidi for the news related to the first speleological cadastres of Friuli and Venezia Giulia. We thank also the Speleological Documentation Centre "Franco Anelli" for the possibility to consult all the documents fundamental for this research.

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CASCINI G. (1651) *Di S. Rosalia vergine palermitana libri tre*. Palermo, Cirilli, 400 p. https://eremos.eu/index.php/sicilia/

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WISH - *National portal of the Italian cave cadaster* http://speleo.it/catastogrotte/

Determining the depth of cave passages for the cave rescue

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Abstract

The Schachernhöhle was first researched and surveyed in the 1980s. It is frequently visited by cavers and by the cave rescue team. Hence, there is interest to know whether remote chambers of the Schachernhöhle (i.e. the 'Wasserfallhalle') could be reached directly from the surface. This is of special interest since the access to these chambers is challenging (i.e., narrow passages). There is interest in resolving the geometry of the cave as well as the type of cover (i.e., whether sediment or rock). To answer these questions, we conducted a survey of the Schachernhöhle using a DistoX and geophysical measurements (Electrical Resistivity Tomography, ERT). In particular ERT measurements were conducted along two profiles for intended depths of investigation of 40 m. Our result determines the depth of the Wasserfallhalle at 30 m, while the structure of the subsurface can be inferred from the resistivity images.

1. Introduction

The Schachernhöhle is a 1810 m long, mostly horizontal corrosive cave in Lower Austria (Austria). The research history dates back to the year 1941, where the first map was published by F. Waldner. In 1976 the research was restarted, initially to survey previously missing parts of the cave, but resulted in a new cave length of 465 m. During this resurvey two impassable passages were enlarged and large new corridors were discovered. The research was completed in 1978 and the cave had reached its current length (HARTMANN & ILMING, 1979). A ground plan (Fig. 1), but no vertical section was published.

The Schachernhöhle is developed in mostly horizontal layered Gutenstein limestone and holds several streams. The passages near the entrance are built by a narrow canyon, which has several extremely narrow passages ('Niphargusgang'). After the 'Schlammkompresse' the cave character changes and one enters mainly large-scaled passages and chambers ('Oberer Jupitergang'). A waterfall flows into a chamber ('Wasserfallhalle') at the end of 'Oberer Jupitergang'. During low discharge, climbing up the waterfall is possible and shortly after a siphon marks the end of the cave. Since the discovery of the new parts, the Schachernhöhle has been regularly visited for touristic and scientific purposes.

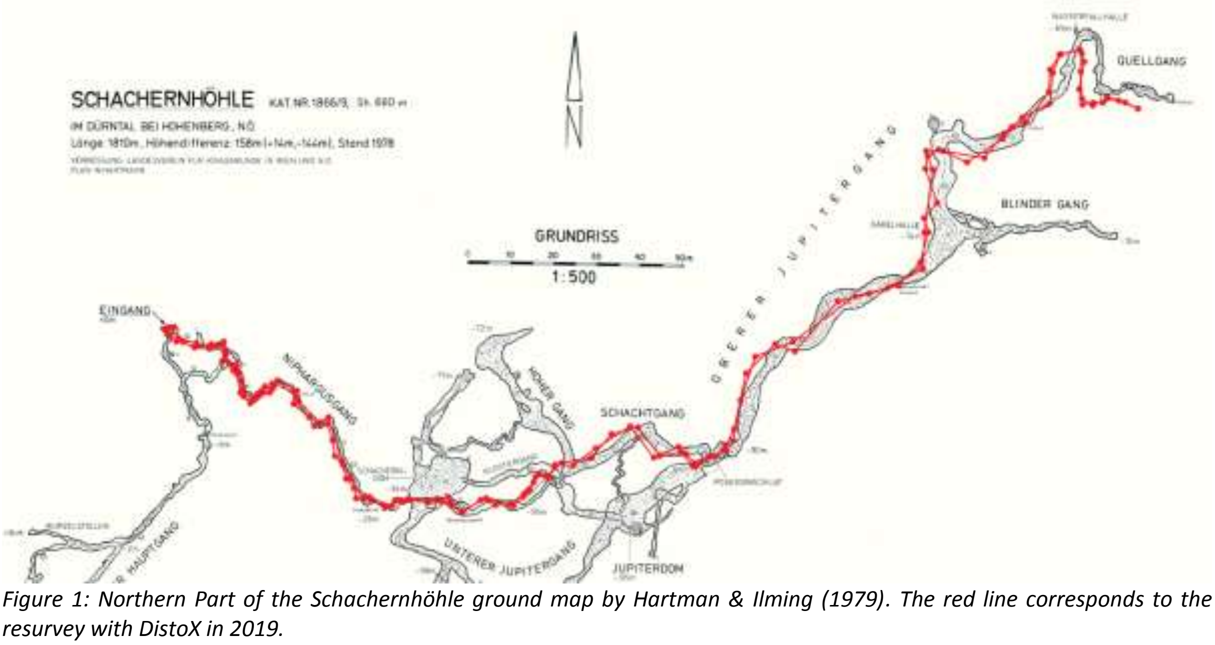

Figure 1: Northern Part of the Schachernhöhle ground map by Hartman & Ilming (1979). The red line corresponds to the resurvey with DistoX in 2019.

In 2018, the Austrian cave rescue started a project to create a cadastre of all large, often visited caves, to provide all necessary data in case of an accident.

For the Schachernhöhle, the rescue team concluded that it is probably impossible to pass the narrow passages near the entrance with a stretcher (e.g. Fig. 2). Hence the question arose, if it is possible to reach the 'Wasserfallhalle' directly from the surface. Therefore we used the following two different and complementary approaches to estimate the depth and structure of the rock and soil layers overlying the 'Wasserfallhalle':

1. **Geophysical measurements** offer the possibility to non-destructively gain information about the subsurface. ERT was used in this study, since it is a well-established method to indicate cavities as well as the border between soil and rock (e.g. KAUFMANN et *al*., 2015; FUNK et *al*., 2018).
2. **A survey with a DistoX**, where the path from the entrance to the 'Wasserfallhalle' (distance ≈ 500 m) was resurveyed (see red line in Fig. 1). In addition to the cave survey, the geophysical profiles and the connection between the cave and the profiles were also measured.

Figure 2: In the 'Niphargusgang'

2. Methods and measurements

Geophysical investigations are applied by using Electrical Resistivity Tomography (ERT), which is an electric direct current method and measures the voltage between electrodes. Therefore, metal rods (electrodes) are placed in the ground and through two of them current is injected and two others measure the resulting voltage. With multi-electrode instruments the voltage can be measured simultaneously at several electrodes, which enables an effective and time-saving recording of thousands of measurements. For the measurements presented here a Syscal device with 72 electrodes (Syscal Pro Switch 72, IRIS instruments) was used, which allows the use of up to 72 electrodes and is able to record up to ten voltage values simultaneously. By applying inversion algorithms, the quasi-continuous distribution of the resistivity in the subsurface is determined.

Cavities filled with air (electrical insulator) show high ($\rho > 100000$ Ωm) and water-filled cavities or soil quite low resistivity values ($\rho < 100$ Ωm). In between are the resistivity values of the surrounding limestone, which ranges between 100 and 10000 Ωm (KNÖDEL et *al*., 1997).

Beside the electrical properties of the subsurface materials, the spatial resolution of such measurements depends on the distance between the electrodes and the achievable depth of the total length of the profile. Since the old cave-survey suggests a depth of the 'Wasserfallhalle' of up to 30 m, we used two profiles (P1 and P2, Fig. 3), one with a distance of 3 m between the electrodes and one with 5 m, resulting in a total profile length of 213 m (P1) and 355 m (P2), respectively.

The theoretical depth of investigation can then be assumed to approximately 40 m for P1 and 70 m for P2. The spatial resolution can be expected with 0.75 m for P1 and 1.25 m for P2. Both profiles run from East to West and the Schachernhöhle is crossed in the middle of the profiles.

Figure 3: Overview of the surveys carried out: the resurvey of the Schachernhöhle is shown with orange and the geophysical profiles P1 with blue and P2 with green points. The survey connecting both measurements is shown with yellow points. Underlaid is an orthophoto of the region.

For the resurvey of the Schachernhöhle we used a DistoX. In order to enable higher accuracy and an estimation of the angle errors (in inclination and azimuth), the survey was carried out from the entrance to the 'Wasserfallhalle' and back again. The individual electrodes of profiles P1 and P2, as well as the connection between the cave entrance and the profiles were also measured with the same DistoX. Thus, it was possible to apply the angle errors also for the external surveys. According to REDOVNIKOVIĆ et *al*. (2014), the expected deviations in the distance (≈ 50 cm per 500 m) can therefore be estimated at 1.5-2 m.

In the next step, all measured points were attached to the known coordinates of the cave entrance, using an UTM 33N grid, and corrected for the declination. These points were finally read into QGIS and underlaid with an orthophoto

(Fig. 3), in which the cave survey (orange points), both ERT profiles (P1 blue, P2 green points) and the connection points (yellow) between the cave's entrance and the geophysical profiles are shown.

The geophysical measurements were taken on October 24th and the resurvey of the Schachernhöhle was carried out on November 15, 2019. Before and during this time there was a very dry weather period which resulted in very low water levels in the cave. Thus it was possible to resurvey also the 'Quellgang' behind the waterfall in the 'Wasserfallhalle'.

3. Results

The results of the geophysical measurements are visualized to a depth of about 50 m in Figure 4. The upper graph shows the results for P1 and the lower graph for P2. In both cases only the areas of interest (where the cave is below) are shown. The reached depth of investigation was between 20 and 40 m for P1 and between 40 and 60 m for P2.

Both images show some spots of high resistivities (red) on the surface, which can be explained by a loose layer of gravel associated with the forest road on which parts of the profiles run along. Below follows a 10 to 20 m thick layer with low resistivity (blue), corresponding to well saturated soil and sediments. The transition zone between soil and bedrock (green) can be interpreted as well fractured limestone. Finally the border to the bedrock can be recognized by another clear change towards higher resistivity values (red). In both images, the boundary between soil and fractured limestone is marked with a grey line and between fractured limestone and the bedrock with a black line. The soil and fractured limestone layers above the black line can be interpreted to be part of an epikarst.

Both profiles cross the Schachernhöhle at two different points (see Fig. 3). Firstly, both profiles run above the 'Quellgang' (see Fig. 1), a narrow canyon behind the 'Wasserfallhalle'. The position of this first crossing is given by the higher and smaller grey points in Fig. 4. The second crossing is above the slightly larger passages, before reaching the 'Wasserfallhalle', symbolized by the deeper and larger grey points in Fig. 4. Both passages are not visible in the geophysical images, likely because the resolution of the ERT measurements is not sufficient to resolve small air-filled cavities in a large depth. The contrast in resistivity could be better if the 'Quellgang' had been filled with water, which was not the case during the measurements due to the dry weather period.

Hence, the position and size of both cave passages are shown according to the cave survey. The evaluation of the cave survey (entrance -> 'Wasserfallhalle' -> entrance) resulted in a closing error of about 60 cm, after correcting the angle errors, which were calculated to 0.56° in inclination and 0.22° in azimuth. The corresponding polygonal line is shown in Fig. 1 (red line) with the original cave map below, where the geometry of both corresponds quite well. Only the length of the passage between the entrance and the 'Wasserfallhalle' was overestimated by around 7 m in the original survey, most likely caused by the use of tape measures.

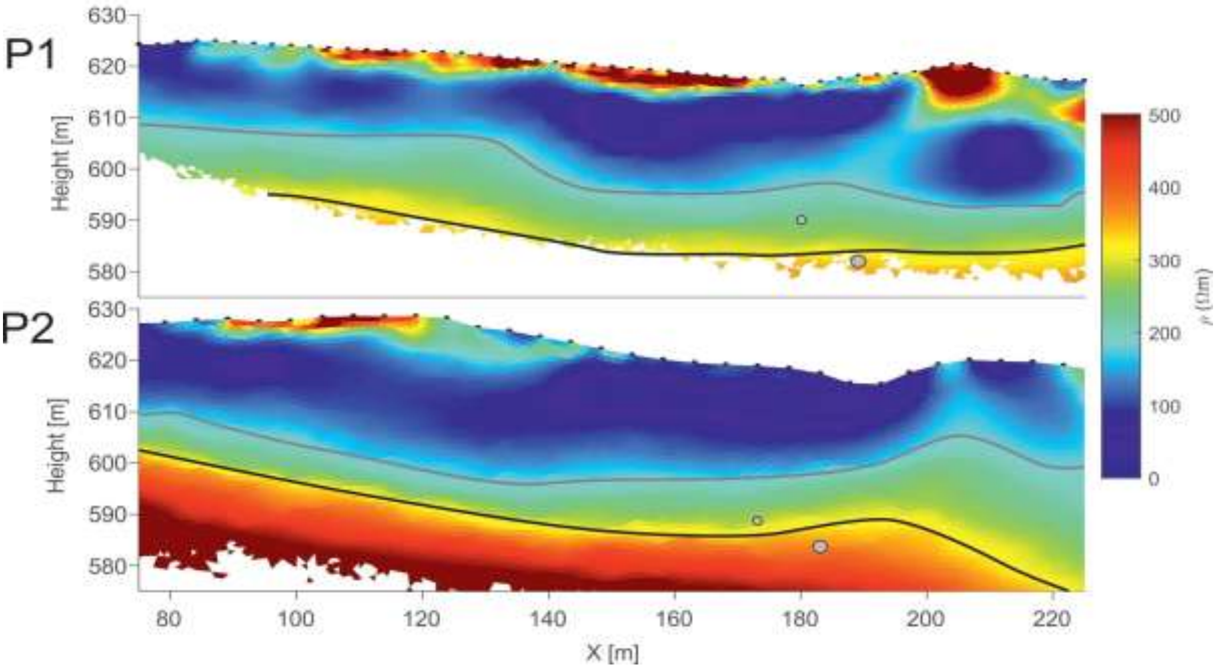

Figure 4: Results of the ERT measurements: upper graph for the profile P1 and lower graph for P2. The color code corresponds to the resistivity. The black line marks the border between rock and soil. The grey dots symbolize the position and size of the underlying cave passages according to the survey.

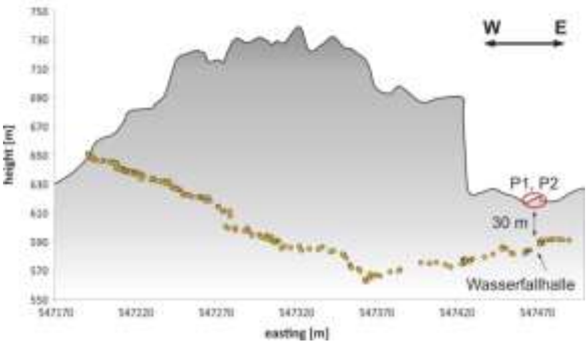

Figure 5: Profile of the Schachernhöhle (yellow points) and of the surface. The red ellipse marks the position of the ERT profiles.

To determine the distance between the 'Wasserfallhalle' and the surface we used the height from the geophysical profiles, obtained in the survey and a digital terrain model (DTM) for comparison and validation. The profiles of the study site (DTM) and of the cave survey (DistoX) are shown in Fig. 5.

The distance between the 'Wasserfallhalle' and the surface was then determined by using the cave survey and:

1. The heights of the survey of the geophysical profiles (DistoX) and
2. The heights of the DTM.

Both values correspond quite well and resulted in a depth of (30 ± 2) m. The narrow 'Quellgang' after the 'Wasserfallhalle' (Fig. 1) even extends a little closer to the surface. Here the calculated distance was (28 ± 2) m.

5. Summary and Conclusion

The aim of this investigation was to determine the depth of the 'Wasserfallhalle', a chamber in the Schachernhöhle, to clarify whether and with what effort direct access from the surface is possible. Thus, also the structure of the subsurface above the 'Wasserfallhalle' was of interest. To answer both questions we resurveyed the passage from the entrance to 'Wasserfallhalle' and carried out geophysical measurements.

There is a variety of geophysical methods sensitive to subsurface variations such as caves. However, in case of methods sensitive to electrical resistivity (ERT or a few electromagnetic methods), their resolution decreases with depth; thus, hindering an adequate delineation of small caves at a depth of a few tens of meters. Ground penetrating radar (GPR) may enhance the lateral resolution, but it is also limited at a few meters depth. Seismic methods are less dependent on the electrical resistivity of the ground, yet the resolution also decreases with depth and becoming more sensitive to variations in the lithology. ERT was used for the present study because it provides the best compromise between applicability in poorly accessible terrain, achievable depth and resolution.

The resurvey of the passage from the entrance to the 'Wasserfallhalle' resulted in a depth of approximately 30 m. The evaluation of the ERT measurements showed that the subsurface is composed of soil and sediments down to a depth of around 10 – 20 m, where above the 'Wasserfallhalle' the soil layer is more than 20 m deep. Below the soil layer there is another almost 10 m thick transition layer, which we interpret as fractured and saturated limestone. The upwards leading 'Quellgang' (Fig. 1) is partly developed in this fractured zone and probably easier to reach. Below, another border towards the bedrock with significantly larger resistivities (Fig. 4) can be seen.

The question of the cave rescue, whether the 'Wasserfallhalle' can be reached directly from the surface, can thus be answered as follows. In principle, it seems possible to dig a shaft to a depth of about 30 m, especially when taking into account that more than 20 m are just a soil layer. Hence, it would be possible to get to this depth with comparatively little effort. Just the last 5 to 10 m of an artificial entrance need to be built through solid rock. Nevertheless, the very time-consuming construction of a 30 m deep shaft only makes sense in very few situations.

Acknowledgments

We would like to thank Franziska Pezzei for the help with the recording of the geophysical data and Katharina Bürger and Markus Milchram for the assistance in resurveying the Schachernhöhle. Furthermore, we thank the Institute for Geodesy and Geoinformation from the TU Wien for the provision of the geophysical instruments and the Speleological Society of Vienna and Lower Austria for providing the surveying equipment and the cave map.

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Large scale test of ALS LiDAR data utilization for cave entrance detection: a case study from the UNESCO World Heritage Site - Plitvice Lakes National Park, Croatia

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Abstract
The fact that ALS LiDAR data analysis offers great potential in remote cave entrance detection is by now well known. Nevertheless, the literature on its large-scale use and ground-truth testing is still scarce. In this paper we present an ALS LiDAR data analysis workflow for semi-automatic remote detection of cave entrances based on the local relief model algorithm, applied and tested on LiDAR data covering the area of 380 km^2, encompassing the UNESCO World Heritage Site Plitvice Lakes National Park, Croatia, and its surroundings. With more than 230 ground verified locations so far and a large-scale systematic field reconnaissance still underway, this work represents the largest case study in the published literature to date.

1. Introduction

The potential use of Airborne Laser Scanning (ALS) LiDAR derived data for cave entrance detection or entrance location correction has been recognized for years (ČEKADA 2016, 2017; ČEKADA *et al*. 2017; GROZIĆ & KUKULJAN 2017; TIČAR J. & ČEKADA M. 2018, WEISHAMPEL *et al.* 2011), nevertheless, there are still very few examples of case studies aimed at locating unknown cave entrances and assessing the effectiveness of this approach compared to conventional field reconnaissance (GROZIĆ *et al.* 2017; MOYES & MONTGOMERY 2016, 2019). The aim of this study was not focused on morphometric properties of cave entrances derived from LiDAR data per se, but instead, on using LiDAR and field data to assess the limits of detectability through the implemented workflow of LiDAR data processing. By the widely accepted definition in Croatia, a cave is a subterranean cavity of natural origin that has more than 5 meters of length or depth where the ratio of entrance size/cave length or depth is smaller than 1 (SPELEOLOGIJA.HR 2020), and the same definition was adopted in this work. This study was conducted as part of the preparatory phase for the systematic cave exploration of the Plitvice Lakes National Park project.

Study area
The study area encompassed the UNESCO World Heritage Site Plitvice Lakes National Park, Croatia, and a 1 km surrounding buffer. The geological setting is composed of sedimentary deposits spanning from the least permeable dolomite deposits of Triassic age, more permeable limestones and dolomites of the Jurassic period to mostly limestone deposits of lower and upper Cretaceous (POLŠAK *et al*. 1976, 1978; VELIĆ *et al*. 1974), with the latter being especially prone to karstification. The landscape morphology is diverse, with dolines dominating atop the more soluble geological bedrock and the active canyon of the river Korana segregated by world-famous Plitvice Lakes where the less soluble dolomitic bedrock prevails. Elevation spans from 369 to 1279 m above mean sea level. The surface abounds with vegetation, dominated by mixed European beech – Silver Fir forests (BIOPORTAL 2020). The climate is temperate oceanic (Cfb) with an average of 110 -150 days with snow (ZANINOVIĆ 2008). The diverse terrain and abundant vegetation coverage make conventional field reconnaissance a difficult task during the vegetation period, and soon after, the snow makes field surveys more difficult, especially in more remote areas. The aforementioned characteristics and the fact that the Plitvice Lakes National Park was considered poorly explored from a speleological perspective made for an ideal study area for remote detection of cave entrances by analyzing ALS LiDAR data.

LiDAR data
LiDAR scanning of the area was conducted in 2014 in the beginning of the vegetation period and the dataset covered an area of 380 km^2, divided into 1631 0.25 km^2 tiles in LAS 1.2 format, encompassing the National Park with a 1 km buffer area. The calculated average point density of the complete area was 7.89 pt./m^2 and the scanning was done

with a system with five returns and a nominal scan angle of 31 degrees. No other information was available on data acquisition.

2. Materials and methods

The study consisted of two principal components: 1. LiDAR data processing and creation of the Cadastre of Potential Cave Entrances (Fig. 1); 2. Ground verification of potential cave entrances and traditional field reconnaissance in search of "non-LiDAR" cave entrances.

LiDAR data analyses and creation of the Cadastre of Potential cave entrances

Data manipulation and handling were done through a Python environment using standard tools for raster and vector spatial data processing (GDAL, Rasterio, Geopandas, ...) and those specialized for point-cloud processing (PDAL), combined with QGIS for visualization and minor manipulation of raster and vector data, as well as Displaz for point cloud visualization. The workflow can be separated into the following steps: **1.)** LiDAR data ground classification: since most ground filtering algorithms disregard crucial below-ground points as noise to some extent, a prerequisite for all subsequent steps is to reclassify ground with these "anomalous" points included, but again with ensuring good ground representation and a reasonable low-point cutoff to exclude real artifacts. A combination of Progressive Morphological Filter (ZHANG 2003), Simple Morphological Filter (PINGEL 2013) and finally Extended Local Minimum (CHEN 2012; a 50 m threshold was used in this work) algorithms proved most suitable for this task. **2.)** DEM creation and negative anomaly delineation; a 0.2 m horizontal-resolution digital elevation model (DEM) was created from reclassified point-cloud dataset on which a Local Relief Model (LRM) (HESSE 2010) algorithm was applied with a kernel size of 11 m. To preserve only negative local anomalies which might represent potential cave entrances, only cells with values of -2 m or less were kept in the raster, the rest were discarded. The remaining raster patches were then converted to polygons and dissolved where overlapping. The resulting multipolygon was used as a mask for cropping out reclassified ground point-clouds with a 30 m buffer in order to put potential cave entrances in context of the surrounding relief. **3.)** Ground truthing of a visually (manually) identified set of potential cave entrances (in this work 66) which are used as a benchmark dataset for testing and tuning parameters used in steps 1 and 2. **4.)** Identification and categorization of potential cave entrances; all clipped ground point-clouds were colored by LRM red gradient color ramp overlay for easier visualization and then manually checked and evaluated. Since the cave entrances were represented by point-cloud patches of variable quality, when identified, potential cave entrances were attributed with a low, medium or high probability label. The criteria for categorization were: 1. entrance size; 2. local point density; 3. position of the deepest recorded point relative to local ground level; and 4. the relation of the potential cave entrance to nearby terrain characteristics and discontinuities. The categorization process is semi-empirical, based on measurable morphometric characteristics as well as the observer's field experience, and is therefore somewhat subjective. The purpose of the categorization process was to 1.) help prioritize field explorations towards locations with a higher perceived probability of the presence of cave entrances; 2.) serve as a basis for finer result analyses, finding key limiting factors and detection limits. The high probability cave entrances were characterized by clear morphometric properties derived from high local point density where the cave entrance/depth < 1 and depth > 5 m criteria were almost certainly satisfied. Two types of potential cave entrances were classified as medium probability cave entrances. The first type were very large cave entrances where entrance size/measured depth ratio was close to 1 but the depth clearly exceeded the 5 m criteria, and the second were cave entrances which were located based on a larger cluster of points beneath the terrain data which would, if they are indeed attributed to a cave and not a scanning artifact, satisfy the entrance size/depth ratio and depth criteria. Low probability cave entrances were those where the basic morphometric criteria were clearly not met if evaluated based on the point cloud data alone and are usually characterized by low local point cloud density. Nevertheless, in these cases either a combination of small clusters of points beneath the local ground level or the surrounding terrain (poljes, dolines) indicated a potential presence of a cave entrance. All potential horizontal cave entrances were by default labeled as "low probability" since their identification was inferred by "shadows" in the point-cloud. The delineation of low probability cave entrances mostly relies on field experience of the researcher and can be considered as stretching the boundaries of detectability beyond the method's limitations.

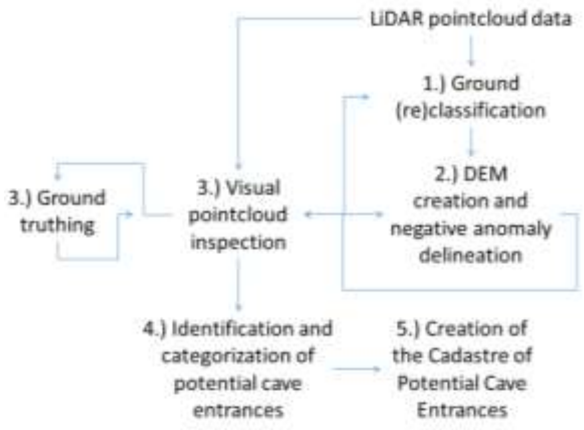

Figure 1: LiDAR data processing workflow

5.) Creation of the Cadastre of Potential Cave Entrances; once populated, the Cadastre consisted of a table holding data on Potential cave entrance ID number, x and y coordinates of the entrance expressed in EPSG:3765 and a probability label. Additionally, a 30 m buffer area clipping from the original point-cloud dataset was made for each potential cave entrance to serve as a 3D extension of the basic cadastre, and to help entrance recognition and verification in the field.

Ground truthing and result analyses

Ground truthing started in April 2020 and is still ongoing. Coordinates of potential cave entrances are being located in the field and the potential cave entrances are evaluated as either positives or false positive. Additionally, a systematic field reconnaissance of the entire area is being conducted in order to locate false negatives. These locations are recorded with GNSS measurements and added to the Cadastre database. A 30 m clipping from the original point-cloud of each false negative is evaluated as either indicated when there is an indication of a cave entrance present in the original point-cloud, or non-indicated. For those caves that underwent exploration, dimensions and type of entrance (vertical or horizontal) was recorded in the field. Additionally, local point density was calculated for the 30 m buffer area of each recorded cave entrance. These values were used for analysis only for cave entrances for which field data on cave entrance size and type were available for comparison.

3. Results

The implemented semi-automatic LiDAR processing workflow yielded 347 potential cave entrances with 14.1 % categorized as high, 16.7 % as medium and 69.2 % as low probability. Out of 347 potential cave entrances, so far 67.7 % (235 locations) were checked in the field with a 68.9 % overall success rate (162 confirmed cave entrances). 96.9 %, 93.2 % and 56.6 % success rate were recorded for high, medium and low probability potential cave entrances respectively. Systematic field reconnaissance so far resulted in locating 147 additional cave entrances not registered during LiDAR data analysis (false negatives), yielding a 52.4 % LiDAR analysis success rate compared to the total number of confirmed cave entrances (Fig. 2). 54 false negatives (36,7 %) were located in the subsequent point-cloud inspection while no indication of a cave entrance was found for the rest. Data on entrance size and type were available for 198 confirmed entrances: 127 non-LiDAR and 71 LiDAR derived. 29.8 % are horizontal cave entrances (n = 59), out of which 22,0 % (n = 13) were identified during LiDAR analysis. The smallest successfully identified cave entrance was 0.5 m^2 in size. The most obscure successfully identified cave entrance was described by only 0.96 theoretical points (calculated as entrance area*local point density) with the deepest measured point being 1.6 m below local ground level.

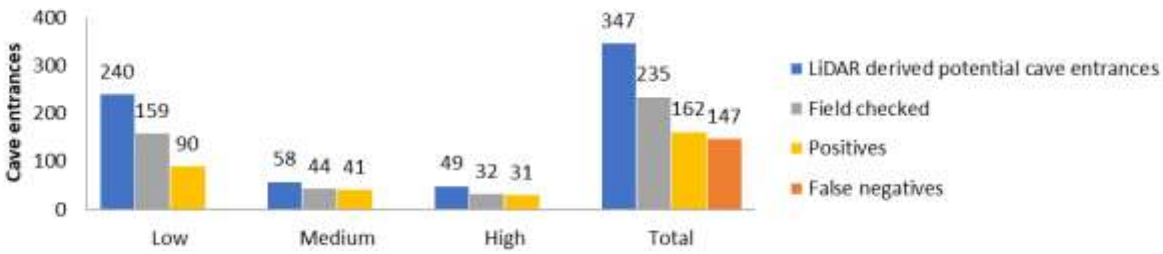

Figure 2: Plitvice lakes case study – current results

4. Discussion

The study area was characterized by a dominance of low probability cave entrances, i.e potential presence of narrow and shallow entrances in scarcely scanned areas. The difficulties of identifying these types of entrances are the major reason behind a considerable number of false positives as well as a relatively large number of false negatives. Although a large number of false negatives are cave entrances in no way indicated by the point-cloud data, the fact that 36,7 % of false negatives were somewhat indicated in the point cloud but not identified during analysis indicates that the identification algorithm could be further optimized. Point cloud ground density can greatly influence detectability, both during the automatic recognition stage as well as in the visual analysis part of the workflow. Scanning conducted outside of the vegetation period would surely provide better data. Recognizing horizontal entrances is problematic and highly dependable on point acquisition density as well as scanning tilt angle, with a higher tilt giving a better chance of horizontally penetrating beyond the cave entrance wall. Ground reclassification gave great overall results with the exception being horizontal entrances located in canyon topography where even very large entrances can be overseen due to cave entrance overhang being recognized as vegetation and eliminated from further analysis. Therefore, visual inspection of the original point-cloud of such locations is recommended for better results.

5. Conclusion

Utilizing ALS LiDAR data for cave entrance detection provides a great basis for systematic cave explorations. In only 1.5 years the UNESCO World Heritage Site - Plitvice Lakes National Park area has gone from speleologically poorly explored to one of the most systematically explored areas in Croatia and in a big part, due to LiDAR data analyses which yielded 162 new caves so far. Small and/or horizontal entrances as well as those located in very steep relief (e.g., canyons) remain a challenge for identification, but this research showed that a good success rate can be achieved even within the low probability cave entrance category, i.e., the entrances that clearly do not satisfy the morphological parameters when interpreted from point cloud data and therefore stretching the boundaries of detectability beyond the method's limitations. Cave exploration in the Plitvice Lakes area is still an ongoing process with 32,3 % of the LiDAR identified potential cave entrances yet to be verified.

Acknowledgments

We gratefully thank all the caving clubs and societies working on the systematic cave exploration of the Plitvice Lakes National Park project for sharing their field exploration data and the Plitvice Lakes National Park Management for financial support and cooperation.

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Atlas of caves of Russia

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Abstract

Atlas of caves of Russia is the first publication enlightening the occurrence and forms of the largest and the most interesting caves of the entire country. Compiled by a team of 100 authors, the 768 pages of large-format book are illustrated with 950 photographs. The bibliography contains about 1000 references. At the preparatory stage before compiling the Atlas, the open-access database and search engine "Caves" (https://speleoatlas.ru/) was developed and populated with data on five thousand caves of Russia and neighboring countries. It made it possible to effectively select the required caves and potential authors to describe them. Specifically for the Atlas, a new scheme of speleological zoning of the country was developed, based on the principles of the new global tectonics, as well as taking into account the distribution of karstiferous rocks. The entire presentation of the material was emplaced in accordance with this zoning. The very uneven speleological state of knowledge of the territory led to significant difficulty in presenting the data. The selection criteria for caves to be included in the atlas were their size (length and depth) and unique features. The Atlas was created with support of the Russian Geographical Society and Russian Union of Speleologists.

Résumé

L'Atlas des grottes de Russie. L'Atlas des grottes de Russie est la première publication éclairant l'occurrence et les formes des grottes les plus grandes et les plus intéressantes de tout le pays. Compilées par une équipe de 100 auteurs, les 768 pages du livre grand format sont illustrées de 950 photographies. La bibliographie contient environ 1000 références. Au stade préparatoire avant la compilation de l'Atlas, la base de données en libre accès et le moteur de recherche "Les grottes" (https://speleoatlas.ru/) ont été développés et remplis de données sur cinq mille grottes de Russie et des pays voisins. Il a permis de sélectionner efficacement les grottes requises et les auteurs potentiels pour les décrire. Spécifiquement pour l'Atlas, un nouveau schéma de zonage spéléologique du pays a été développé, basé sur les principes de la nouvelle tectonique mondiale, ainsi que sur la prise en compte de la distribution des roches karstifères. L'état spéléologique très inégal des connaissances du territoire a conduit à des difficultés importantes de présentation des données. Les critères de sélection des grottes à inclure dans l'atlas étaient leurs dimensions (longueur et profondeur) et leurs caractéristiques uniques. L'Atlas a été créé avec le soutien de la Société géographique russe et de l'Union russe des spéléologues.

1. Introduction

Since 2004, the Commission of Speleology and Karst Studies of the Moscow City Branch of the Russian Geographical Society has been working on the creation of an electronic cadastre of caves in post-Soviet countries. In 2017, the open-access informational database and search engine "Caves" was developed and populated with data on caves of Russia and neighboring countries. This project is designed to introduce everyone to the amazing world in the bowels of the earth. The use of the database facilitated the compilation and preparation of the Atlas of Caves of Russia. The Atlas begins with a General section covering the origin, classification of caves, and speleological zoning. It also touches upon issues of archaeology, paleontology, climate, hydrology, glaciology, biology, mineralogy of caves, as well as the history of their study and use by humans. The Atlas includes maps and descriptions of the largest caves in Russia with a length of more than 3 km or an amplitude of more than 250 m, as well as a number of smaller caves that are unique in their characteristics and significance. A list of all caves over 500 m in length and over 100 m in depth is provided. Descriptions are also given of four deepest caves of the World, all located in Abkhazia. Russian cavers have played a decisive role in the studies of three of them (Verevkina, Sarma and Snezhnaya), and in one (Krubera) - Ukrainian and Russian.

The Atlas was prepared in several stages: 1. Development of the principles of speleological zoning; 2. Speleological zoning of Russia; 3. Creation of a database of caves; 4. Selection of caves for the Atlas; 5. Direct work on the Atlas.

2. Principles of speleological zoning

Speleological exploration has led to the discovery of several thousand caves in Russia and new areas of their geographic distribution. Under these circumstances, zoning is an important tool in understanding the cave diversity of individual regions, which creates favorable conditions for the development of actions for their study, use and protection. Speleological zoning as a spatial matrix is the basis of cadastral registration of caves of different genesis. Extensive literature is devoted to the zoning of karst and caves of certain territories of Russia (VAKHRUSHEV, 2009;

GVOZDETSKY, 1972; GURKALO & MALKIN, 1998; DUBLYANSKY & DUBLYANSKAYA, 2008; LAVROV & ANDREYCHUK, 1993; MAKSIMOVICH, 1958; FILIPPOV, 1993; TSYKIN, 1990; CHIKISHEV, 1973, etc.). However, there are still a number of problems, the solution of which determines the spatial structure of the cave inventory system.

The problem of correlation between karstological and speleological zoning was posed long ago by MAKSIMOVICH (1958). Speleological zoning should not be considered as a variety of a special karstological zoning, but as a self-sufficient procedure, taking into account the distribution of not only karstogenic caves, but also cavities of other genesis, including anthropogenic. At the same time, the vast majority of natural caves are represented by karst cavities (about 90 %). Karstiferous rocks are present in most major tectonic structures in Russia and neighboring countries. Karstogenic, pseudokarst and artificial cavities are united by the main common criterion — these are objects of geological space developed in the Earth's crust. The peculiarity of karstological zoning is the discontinuity of the distribution of karstiferous rocks. The specificity of speleological zoning, on the contrary, is due to the continuity of the distribution of rocks in the Earth's crust.

When speleological zoning, it is necessary to take into account that speleogenesis occurs in the earth's crust but has cause-and-effect relationships with physiographic conditions. In this regard, at the highest levels of zoning, such as speleocountry and speleoprovince, the main criteria for their allocation are tectonic and morphostructural features of territories, and at the middle levels, such as speleoregion and speleodistrict, are morphostructural and physico-geographical.

Speleocountry is the largest unit of division of territories covering the continental platforms, or larger parts of the fold belts. The geostructure of the speleocountry, having its own tectonic regime, determines the history of its development and controls the distribution of igneous, metamorphic and sedimentary rocks, thereby determining the geological conditions of speleogenesis within its limits.

Speleoprovince is a part of the speleocountry corresponding to individual plates and shields of platforms or orogenic provinces of folded belts. These are, as a rule, large morphostructures of the 1st order with a uniform orientation and intensity of modern geodynamics, which affects the features of speleogenesis within them.

Speleoregion is a morphostructure of the 2nd order: a part of a platform, plate, shield (anteclise, syneclise, etc.) or a part of orogenic belt, connected by the unity of the geological and geomorphological structure, physiographic conditions (climate, hydrology, landscapes, etc.), which determine the corresponding type of relief and features of the caves located there.

Speleodistrict (the main unit of zoning) is a morphostructure of the 3rd order with a certain type of relief, hydrogeological and speleogenetic features of the caves. It is characterized by individual features of speleogenesis, which are determined by the corresponding types of karst and morphogenetic features of surface and underground karstic and non-karstic forms, hydrological and hydrogeological conditions of recharge, transit and discharge of karst groundwaters.

3. Speleological zoning of Russia

Speleocountries of Russia (fig. 1) cover separate continental platforms (East European, West Siberian, Central Siberian speleocountries) and large parts of folded belts (Crimea-Caucasus, Ural, Altay-Sayan, Baikal-Stanovoy, North-East Siberian, Far Eastern and Kuril-Kamchatka speleocountries). The only exception is the Arctic speleocountry, which is not distinguished according to the tectonic principle. It includes the subpolar islands and archipelagos of Russia. All of them have one thing in common: they are subject to constant glaciation, which is quite indifferent to the composition of the underlying rocks and tectonics. The enclosing rock of the caves is mainly the ice of glaciers. Caves there are also formed in the snowfields. A feature of the Kuril-Kamchatka speleocountry is a significant predominance of the number of volcanic caves over caves of other genetic types. In the zoning scheme of Russia, 11 speleocountries, 55 speleoprovinces, 101 speleoregions (fig. 2) and more than 150 speleodistricts have been delineated.

The completeness of speleological knowledge of Russia varies greatly from region to region. Along with the well-studied speleodistricts of Crimea, Western Caucasus, the Urals, Volga and Pinega river basins, Altay, Krasnoyarsk Krai and Khakassia, the Baikal region and Primorye, there are colossal territories that are practically white spots in speleological terms. These include, first of all, North-East Siberian speleocountry, extending from the submeridional segment of the Lena River to the Pacific Ocean, the southeastern parts of the Central Siberian speleocountry and the Tuva-West Sayan speleoprovinces and a number of others. All these lands are still waiting for their explorers.

4. The informational database and search engine "Caves"

At the preparatory stage before compiling the Atlas, the open-access informational database and search engine "Caves" (https://speleoatlas.ru/) was developed and populated with data on natural caves and abandoned artificial cavities of Russia. The work on the concept of this database began in November 2015. The database itself was launched by September 2016, and the filling with cadastral data began in October 2016. By June 2017, more than 3600 Russian caves were added to the electronic database.

To date, there are more than 5000 caves of Russia in the

Figure 1: Speleological zoning of Russia at the level of speleocountries.

system, and the database continuously being updated at present time.

The following information is entered in the database for each cave: cadastral number, name, length, depth, volume, description, research history, topography (plan, profile, sections), photos, transport accessibility, coordinates of the entrance, security status, presence of siphons (completely flooded passages), etc. Each underground cavity is tied to a specific administrative unit, as well as to an object of speleological zoning (speleocountry, speleoprovince, speleoregion, speleodistrict).

The search and sorting of caves are carried out both according to speleological zoning, and by administrative affiliation (including using interactive maps), as well as by morphometric characteristics (length, depth, volume). Working with the "Caves" database is carried out via the Internet. The main array of information stored in the database is in public domain. Some of the information is protected. The latter, in addition to the exact coordinates of cave entrances, includes some maps, photos, and documents related to individual unique and particularly vulnerable caves. Protected information is hidden for a user who does not have extended rights. The creation of the electronic cave database allowed us to effectively select the required caves for the Atlas and potential authors to describe them.

5. Selection of the objects for the Atlas

In the Atlas, in addition to large caves, smaller caves were also described for those speleoprovinces, speleoregions and speleodistricts where large caves were not found. An additional criterion for the selection of caves for the Atlas was their uniqueness. Thus, descriptions of caves developed in unusual rocks were prepared, such as carbonatites (Karbonatitovaya cave), calciphyres (Tonta cave), ankerites (Stary Zamok cave), ferrocalcite limestones (Kremenshetskaya cave), graphite marbles (graphite up to 20%) (Urungaiskaya Ledyanaya cave), serpentinites (Zhiloy grotto). The other caves were chosen because of famous anthropological discoveries in them (Denisova cave: Denisovan people; Okladnikov and Rudnichnaya (Chagyrskaya) caves: the most eastern finds of Neanderthals), important archaeological sites of the Paleolithic (Dyuktayskaya and Khayrgas caves in the Central Siberian speleocountry, Geographical Society cave in the Far Eastern speleocountry, Strashnaya cave in the Altay-Sayan speleocountry, Ignatievskaya cave in the Ural speleocountry), of the Mesolithic (Eleneva cave), the Neolithic and Early Iron Age (Aydashinskaya cave) in the Altay-Sayan speleocountry), rock paintings (Kapova (Shulgan-Tash) cave in the Ural speleocountry; Irkutskaya cave in the Baikal-Stanovoy speleocountry). Much attention is paid to caves rich in paleontological remains of vertebrates of various geological ages: Early-Middle Miocene (Aya cave, Baikal-Stanovoy speleocountry), the Early Pleistocene (Taurida cave, Mountain Crimea speleoprovince), Middle Pleistocene (Stary Zamok cave, Altay-Sayan speleocountry), Late Pleistocene (caves Malaya Nizhneudinskaya, Logovo Gieny, Bely Gorod, Altay-Sayan speleocountry; Kurtun-1 and Kaltsitovaya caves, Baikal-Stanovoy speleocountry; Bliznets and Medvezhyi Klyk caves, Far Eastern speleocountry) and Holocene (Sagan-Zaba-7 grotto, Baikal-Stanovoy speleocountry).

The Atlas contains a description of Bolshaya Baidinskaya cave in the Baikal-Stanovoy speleocountry, containing a relic of the oldest underground icing (aufeis) in Russia, which has a radiocarbon age of about 2740 years.

Speleocountries	Number of speleo-provinces	Number of speleoregions	Longest, deepest and some unique caves (meters)
East European	10	22	Kulogorskaya - Troya (17,650/23), Kungurskaya Ledyanaya (5,700/32), Ordinskaya (5100/50, underwater gypsum cave), Uzhla (100/-66)
Crimea-Caucasus	4	12	Krasnaya (24,430/253), Soldatskaya (2,100/−517), Krestik - Turist (14,758/633), Gorlo Barloga (3,140/−900)
Arctic	1	5	Prezidentskaya (500/32, glacier cave)
Ural	6	21	Kinderlinskaya (13,032/235), Divya (10,100/28), Sumgan-Kutuk (9,860/134), Shulgan-Tash (3,323/165, Paleolithic cave paintings)
West Siberian	3	—	Yamal crater (−50)
Central Siberian	12	6	Botovskaya (69,288/−40), Angarakanskaya (8,500/-57), Khudugunskaya (1,000/-12.5), Kurtuiskaya (820/−144)
Altay-Sayan	5	15	Bolshaya Oreshnaya (47,500/247), Yashchik Pandory (11000/195), Fantaziya (6,290/−311), Altayskaya (4400/240), Kyok-Tash (3,000/−308)
Baikal-Stanovoy	3	8	Okhotnich'ya (5,700/−77), Dolganskaya Yama (5,120/−130)
North-East Siberian	4	2	Onnyo (540/−55)
Kuril-Kamchatka	3	2	Tolbachinskaya (540/11), Marina (357/−44)
Far Eastern	4	8	Proshchalnaya (5,480/110), Olega Shadrina (550/−170)

Figure 2: Largest caves in different speleocountries of Russia.

6. Conclusion

The Atlas is a large summarization of the results of research into caves of Russia over the past 50 years. As in previous years, the main efforts of the cavers were focused on the exploration of the karstic caves. At the same time, an interest appeared in the glacier, gravitational, and volcanic cave research, which is reflected in the Atlas. Significant progress has been made in the underwater exploration of siphons and flooded caves. A detailed study of the archaeology, paleontology and mineralogy of caves, especially cryominerals, the research of the biodiversity of caves in the Ural, Alay-Sayan, Baikal-Stanovoy and Crimea-Caucasus speleocountries and the Kamchatka speleoprovince took place over the past decades.

Acknowledgments

We are sincerely grateful to the team of authors and the editorial board of the Atlas of Caves of Russia for their well-coordinated work. The Atlas and the electronic cave database and search engine "Caves" were created with grants from the Russian Geographical Society.

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UIS sub-commission Survey and mapping: 24 years of existence

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Abstract

The UIS workgroup on Survey and Mapping was founded at the famous UIS Congress in La Chaux-de-Fonds in 1997. Its basic aim was to unify and homogenize the cave mapping symbols. Once this project ended with a good and stable result (and an own homepage), other mapping issues were discussed. The communication informs about the working group that is now called "sub-commission", its members, its aims, and its results. The sub-commission still exists because there are still issues to be discussed, and it seems that the work does not end for the moment. All cavers are entitled to ask for actions, or for a specific topic, however the work is often at a slow pace, since many commission members (and its president) are more active caving than sitting in offices...

Résumé

La sous-commission de topographie et dessin de l'UIS : 24 ans d'existence. Le groupe de travail de topographie et dessin a été fondé lors du célèbre congrès UIS à La Chaux-de-Fonds en 1997. Son but était d'unir et homogénéiser les symboles utilisés dans la topographie souterraine. Lorsque ce projet a été achevé avec un résultat bon et durable (avec sa propre page web), on a continué à discuter d'autres points liés à la topographie. On vous présente ce groupe de travail, désormais appelé sous-commission, ses membres, ses buts, et ses résultats. La sous-commission existe encore parce qu'il y a et qu'il y aura toujours des points à discuter. Chaque spéléologue peut demander des renseignements qu'on traite un point spécifique. Toujours est-il que l'avancement est plutôt lent, car beaucoup de membres de la commission (y compris son président) se trouvent plus souvent sous terre que derrière leurs bureaux...

1. Prehistory of the sub-commission

At the Swiss National Congress of Speleology in Charmey (Fribourg) in 1991, a pre-congress activity called "International meeting of underground topography" was organized, with participants from France, Germany, Austria, Italy, England and Switzerland. The first task of that meeting was that all participants should map their portion of a passage in a cave in the Swiss Alps, and subsequently draw and present the results at the meeting. To general astonishment, the symbols for cave maps, which were thought to be uniformized, differed a lot between countries, but also between regions of a country. Therefore, the unanimous agreement was to review the mapping symbols. At the next International Meeting for underground topography, again at the Swiss National Congress in Breitenbach (Solothurn) in 1995, a tentative list of agreed symbols was worked out. This list was subsequently published in several publications as a proposal, and the results were discussed at the UIS Congress in La Chaux-de-Fonds in 1997. There, the working group "survey and mapping" within the UIS Informatics Commission was founded.

2. Structure and functioning of the sub-commission

There are quite few speleologists that draw cave maps. Of these, there are even fewer that want to be involved in standardizing symbols and other matter. Therefore, the sub-commission welcomes everyone that is interested in these topics and who can help.

However, the results of the sub-commission should be agreed on by different country representatives that vote for their respective country. Therefore, only one person per country has the right to vote on the results. The decision on the "culprit" is in the hands of the respective country.

The different points that were discussed, although always related to mapping and surveying, make that some persons are not always strongly interested. Therefore, the composition of the sub-commission may vary depending on the topic.

3. Work that has been done

Symbols for cave topography

The basic work for which the sub-commission was founded was the unification of a basic symbol set for cave topography. This work was finalized with a vote in 1999. Since then, the symbols can be seen and downloaded from a website made for that effect (address: see References).

In difference to former symbol lists, there are explanations that accompany the UIS symbol list. On one hand, they explain why the symbol was chosen with respect to another, and if there are alternative possibilities, they are also discussed. On the other hand, additional indications about the drawings are given. This way, the reasoning of the sub-commission is made transparent.

The UIS list is meant to be a standard uniform basis. It is always possible to add symbols that are specific to a given region or country. The main idea behind the symbol list is that the ubiquitous, "normal" symbols are the same internationally. In this way, national specific symbols are allowed, giving maximum flexibility for the cave mapper community.

Karst surface symbols

Already during the works for the cave symbols, it became clear that the surface symbols used on geomorphological maps were different in many places. So, in the years after the cave symbols, the karst surface symbols were discussed and finally agreed upon in 2006. Here, the karst commissions of the International Geographical Union (IGU) as well as the International Association of Hydrogeologists (IAH) were implicated in the works, although there was not much echo from their side.

The holy trinity!

During discussions with cave mappers worldwide, it became clear that in some cases, the mapping cavers are very motivated, but not aware what it needs to get durable cave documentation. In subhorizontal caves, they often draw maps, but not longitudinal sections, or in shafts, often the section is drawn, and the map is forgotten, or, in some cases, both are present, but the written description is missing.

Caves are three-dimensional objects. Therefore, in all cases and caves, both plan and longitudinal sections are 100 % needed. The written description finally is used to describe findings and interpretations that cannot be drawn on the map - a bat, for instance, in 1:500 is not drawable. Or fossil water levels are neither. And the access path to the entrance of the cave is best also described in a written description.

So, these three objects are the MUST of the cave documentation process and are compulsory. If they are present, the author(s) can be reasonably sure that their cave will not be remapped within some years in order to get missing information.

The last point, not belonging to the trinity, but also important, is the publication (or at least archiving) of the map. What use is it to work for years and decades, and some years afterwards, the cave has to be remapped because the data/maps are forgotten in a drawer, or burnt by a furious mother, or lost when moving house?

If you are interested in publishing the text that explains the holy trinity, let me know! It is available in many languages, and your language might still be missing?

Survey and mapping grades

Most probably, only the mapping cavers know what is behind the acronym "BCRA" on the maps, although more cavers know that this is the British Cave Research Association. As a matter of fact, the BCRA elaborated a grading system to assess the accuracy of a cave map. Although the BCRA grades were well elaborated, they were national, and other countries had their own and different grading system. So, the task was given to make an uniform UIS grading system, taking into account new developments as well as using to the largest possible extent, the existing grading systems. The first discussion on these points were held at the UIS Congress in Kerrville, in 2009. The elaboration was crowned by the final vote in 2012.

4. Work currently in progress, possible other projects

Symbols for artificial cavities

At the request of the Commission on artificial cavities, a collaboration began in 2013 in order to standardize symbols that are specific to artificial cavities. Here also, the idea is to create a symbol set that can be used as a basis for international understanding, that can be enlarged by national or regional other symbols specific to the region. The current aim is that the discussion should be closed around 2021 - with a vote of both commissions.

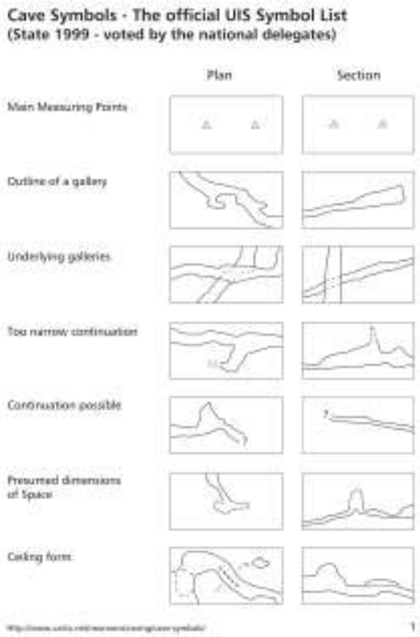
T-LIDAR cave scanning working group

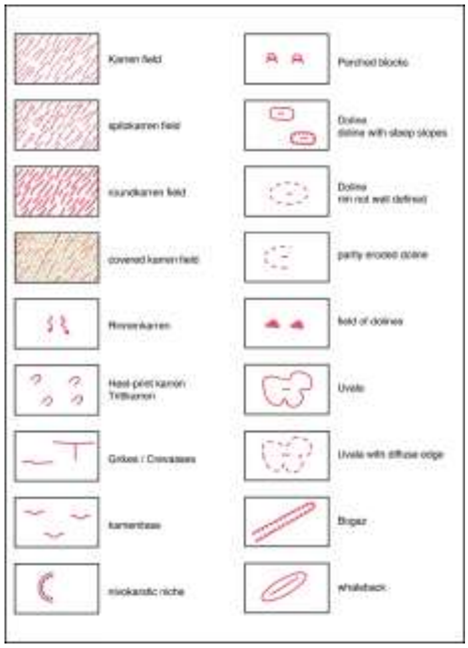
Under the lead of Don McFarlane, this working group, started in 2015, is interested in establishing consistent standards for the reporting of LIDAR data.

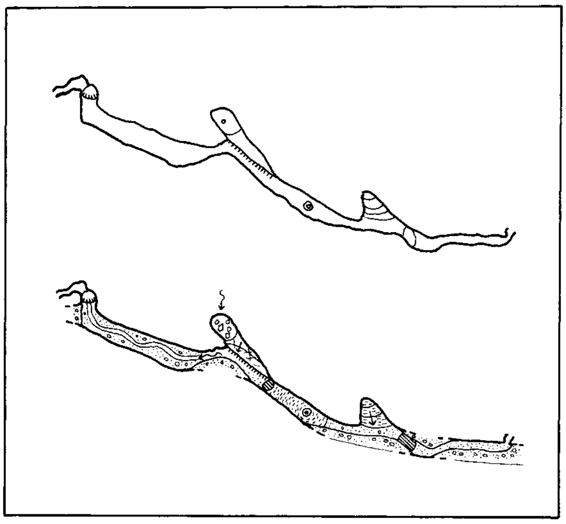
Possible future projects

Of course, there is a multitude of possible other projects. In the list here, those that had been proposed tentatively, are put forward. Do YOU know of another project that is worth discussing in the UIS sub-commission on survey and mapping? Please drop a line to me.

- How and where to safeguard cave maps and related information, such as mapping data?
- Several digital programs are used for drawing cave maps, but are their symbols concordant to the ones of UIS?







UIS Mapping Grades

Version 2: 14 Sep 2012

Survey and Mapping Working Group, UIS Informatics Commission
Edited by Philipp Häuselmann.

Introduction

At the 15th International Congress of Speleology in Kerrville (USA), the working group "topography and mapping" of the UIS Informatics Commission discussed the BCRA and ASF mapping grades, their use, limitations, and possible upgrades for international use within the UIS. The vast majority of the people present agreed that the use of a grading system in speleological mapping was needed in order to inform the map user of the expected accuracy of the map. After a lively discussion, it was seen that the current ASF standards quite closely match the expectations of the group and that they could be upgraded for UIS use. The following tables present the grades, the accuracy of details, additional information, and an explanation which helps to understand the meaning of the tables.

The present paper uses some brand names for easier understanding of the type of device. In no means, this is meant to be a support for these devices; it merely uses that name to describe the functioning principle.

Use

The agreed notation is "UISv1 4-2-BC" for a survey grade 4, map details 2, and additional qualification B and C. The version number (v1) has been added in order to retrace possible future revisions.
The present grades are not valid for underwater measurements, since the techniques, material, and difficulties may vary greatly. If an indication is to be given, it should read "Equivalent to UISv1 4-2-BC".
Ranges of UIS grades are not to be specified on the map. If the main passage of the cave is mapped by theodolite, and the lateral passages to grade 4, the grade to be indicated is the one that makes most sense to indicate the real accuracy of the given passages; most of the time, it will be the lower grade; if insignificant lateral portions (NOT the only connection of two high-quality maps!) of the cave are mapped in a lower grade, the higher grade may apply. Please keep in mind that those grades are to indicate precision and accuracy; and although grade 5 should be reached for a quality survey, it is not mandatory.
Especially for larger caves, details regarding on how the map was compiled should figure in the written description of the cave. There, also possible deviations from the general grade can be explained. Techniques to minimize loop-closure errors, measurement techniques and other additional detail can be given easily there.

Figure 1: Some pictures of the output of the UIS sub-commission on survey and mapping.

5. Countries/people actually present in the sub-commission

In the following, the presently active countries with their delegate are given. If you see that your country is not on the list, and you want to collaborate, you're cordially invited!

Argentina	G. Redonte
Australia	A. Warild
Austria	L. Plan
Brazil	F. Kok Geribello
Croatia	N. Bocic
France	B. Ournié
Germany	A. Wolf
Hungary	J. Moga
Italy	D. Pani
Japan	N. Ishikawa
Lebanon	G. Salem
Mexico	J.A. Montano Hirose
Netherlands	Y. Burgers
Russia	I. Lavrov
Serbia	J. Calic
Sweden	E. Agrell
Switzerland	Ph. Häuselmann
Turkey	N. Guner
UK	A. Atkinson
USA	P. Kambesis
Venezuela	R. Carreno

Acknowledgments

We gratefully thank all the active and past members of the group for their always constructive input and the friendly discussions on potentially heated topics. The group is another decent example that cavers form a large family.

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The evolution of the Speleological Abstracts (BBS/SA)

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Abstract

The Speleological Abstracts (SA), also known as BBS (Bulletin Bibliographique Spéléologique), is an annual review of the world's speleological literature, published by the Commission of Bibliography of the International Union of Speleology (UIS). It represents more than 38 years of bibliographic references from peer-reviewed and not peer-reviewed literature. The complete database currently contains 110,000 references. The UIS 2021 congress will be an important milestone in the already long history of the Speleological Abstracts (SA), as it gives the opportunity to draw new perspectives for the next decades. The SA was born during the 5th International Congress of Speleology in Stuttgart in 1969. It was solely based on a paper version until 1986, when the first computer-based records were compiled. With the ever-improving computer and Internet technology, the paper version gradually lost the battle versus digital. This literature database has been regularly evolving thanks to the contributors from each country since 1969, but today a new friendly to use online-tool is being developed on Grottocenter. It has been operational since the start of 2021.

We present the latest technological developments related to SA, its new organization and tools, all designed to allow easier involvement of the broad caving community, and at the same time to allow SA to be further an important tool at the service of cavers and science in general.

Résumé

L'évolution des Bulletins Bibliographiques Spéléologiques (BBS/SA). Le BBS est une revue annuelle de la littérature spéléologique mondiale, publiée par la Commission de bibliographie de l'Union internationale de spéléologie (UIS). Il représente plus de 38 ans de références bibliographiques à partir de publications évaluées et non évaluées par des pairs. La base de données complète contient actuellement 110 000 références. Le congrès UIS 2021 sera une étape importante dans la déjà longue histoire du BBS (Bulletin Bibliographique Spéléologique). Il donnera également l'occasion de dessiner de nouvelles perspectives pour les prochaines décennies. Le BBS est né lors du 5e Congrès international de spéléologie à Stuttgart en 1969. Il était uniquement basé sur une version papier jusqu'en 1986, date à laquelle les premiers enregistrements informatiques ont été réalisés. Avec des outils informatiques et liés à Internet en constante amélioration, la version papier a progressivement perdu la bataille contre le numérique. Cette base de données littéraire évolue régulièrement grâce aux contributeurs de chaque pays depuis 1969, mais aujourd'hui un nouvel outil en ligne convivial est en cours de développement sur Grottocenter. Il est opérationnel depuis le début 2021.

Nous présentons les derniers développements technologiques liés au BBS, sa nouvelle organisation et ses outils, tous conçus pour permettre une implication plus facile de la large communauté spéléologique et pour faire du BBS un outil important au service des spéléologues et de la science en général.

1. A 52 years-long history

Taking in consideration the long history of the Speleological Abstracts (also known as BBS), it may be important to remind shortly its history, which dates back to the initial work of the Swiss National Library in 1958.

Each year the Swiss National Library published in its "Bibliographia Scientiae Naturalis Helvetica" the chapter "Höhlenkunde / speleology", a compilation of Swiss literature related to caving. This work was carried out by Raymond Gigon (1929-1981), followed by Reno Bernasconi. In 1968 and 1969, two issues of the national speleological bibliography were published, called "Speleological Bibliographic Bulletin" (BBS).

Similar, Ray Mansfield as a contributor to the British Speleological Abstracts since 1964, decided to launch together with Tony Oldham the volumes "Current Titles in Speleology" (CTL) which presented each year, from 1969 to 1990, a synthesis of publications related to speleology in the English published literature.

In order to merge these initiatives, during the 5th International Congress of Speleology in Stuttgart (1969), the General Assembly of the International Union of Speleology (UIS) decided to create a Commission of Speleological Bibliography and elected Reno Bernasconi as its president.

The Speleological Bibliographic Bulletin / Speleological Abstract (BBS/SA) was then published every six months. The volumes 1 to 10 covered literature published from 1970 to 1974. Starting in 1975, collaborators included volunteer contributors, this considerably increased the number of documents and references included. In 1980, the French Caving Federation joined the project, followed in 1988 by the Società Speleologica Italiana, and in 1990 by the British Cave Research Association.

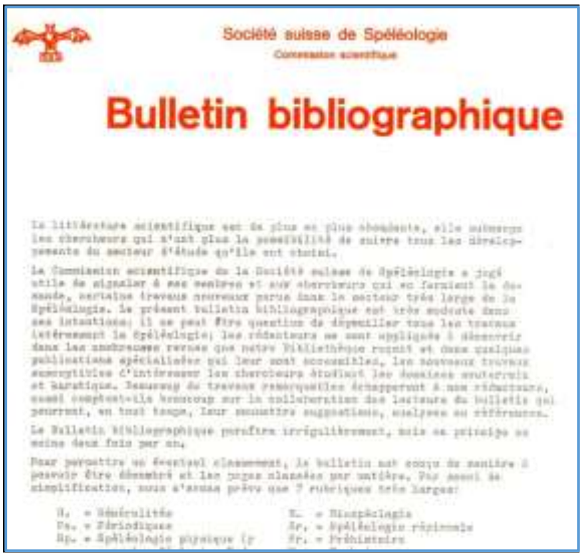
Société suisse de Spéléologie
Commission scientifique
Bulletin bibliographique

Figure 1: Extract from No. 1 of BBS Suisse

In 1980, the BBS was still produced on a typewriter, each analysis being the subject of an A6 file. For publication, the information was re-entered on an A3 format sheet.

In 1986, the BBS was edited directly on the computer, and it was from No. 30 (1991) onward that the BBS contributions were introduced by contributors directly in a data-file. The first CD was released in 1995.

Starting with 1998, as Patrick Deriaz took over the presidency of the UIS Bibliographical Commission, the development of digital tools took off.

The 30 contributors entered data directly using a Filemaker entry mask, summary of the cave-related literature was published in then sent the files to a national coordinator, who later sent the national files to the international coordinator. An annual paper format and then in CD forms, up to number 51/52 (2012/2013). Meanwhile, the SA/BBS database was directly available on the website of the Library of the Swiss Speleological Society.

Figure 2: BBS in 2019

2. The urge to evolve

The BBS has been using digital tools for many years and as expected, is aiming to follow the evolution and availability of new IT technologies. Two aspects play an essential part: the manipulation of digital data and new IT technologies.
The manipulation of digital data is now done, whenever possible, through a browser, so that it is no longer necessary to install any software or to update it, or to provide specific tools for users. Above all, data processing is directly accessible to all those who need it. Until present the file transfers from the BBS contributors to the national coordinator and then to the head of the UIS bibliographic commission led to many delays in the completion of the bibliographic analysis. Today, this is achieved in a matter of minutes.

On the other hand, the development of information technologies has seen the rise of new ways of working. Free software, standards for data exchange and collaborative work play a particularly important part in this, and the UIS Bibliographic Commission wants to integrate these concepts into the way it manages document-related information.

In 2018, BBS decided to start its collaboration with the Grottocenter application, a software developed by the Wikicaves association, which already partners with the UIS on issues related to data sharing. A new version of the software was under development, but in order to host the BBS, new developments were necessary. In 2019, the Swiss Speleological Society (SSS) funded a developer to provide access to the 110,000 BBS files, and in 2020, together with the French Federation of Speleology (FFS), funded the option of fully managing the BBS online.

Figure 3: Logo of the Wikicaves association

3. A new way of organization and visualization

Now the BBS is hosted at https://grottocenter.org. You can view it on any computer, phone or tablet with an interface in your own language.
If you want to contribute to the development of the app or create your own, just visit Project Github page at https://github.com/GrottoCenter/Grottocenter3. Taking part in the translation work is also very easy. If you want the app to be translated in a new language, the fastest way is to contact the Wikicaves association (https://fr.wikicaves.org/contact).

You can use the BBS search engine to look for the available literature by using different search criteria, which aim to assure the most suitable answers. An important note, a lot of the abstracts available do cover literature published in local and non-peer-review journals, literature otherwise difficult to find in other searching engines. The search result can be exported in csv format.

The information available for each document has been aligned with DCMI. DCMI is a standard way of describing documents. It is compatible with a large number of protocols and standards around the world. This work has been done in conjunction with the Karstlink project, also an UIS project, which is the subject of another article.

An important change has been made regarding the possibility of contributing to BBS. Previously, only authorized people could do it. Now, everyone can participate in the BBS. You only need to log on to the website.

The form where the input data is introduced has undergone significant work, in order to make it user-friendly, also to make input much easier through checks on the validity and consistency. Users may also complete a form for each journal article without having to re-enter the information related to this journal.

Although everyone can participate, it is important that the BBS continues to provide quality information. This is the reason why the online publication of the data will take place only after its validation by a coordinator, who has the possibility to correct the information if it is incomplete or contains errors.

This coordinator status can easily be given at demand by the BBS administrators, enabling the BBS team to be much more effective. For coordinators, a detailed file-interface is available, which will allow them to select the texts individually or as a group, with a larger number of selection criteria (region, date, subject, type of document). Also, it will give them the possibility to validate or reject the data by sending a comment to the data contributor.

All of these technical advances will make the BBS contributions more active and surely will increase its visibility on the global scale, which is its ultimate aim.

Figure 4: Search for BBS documents on Grottocenter

If we have access to all these features, it is also possible for search machines to use them. Do you want to be able to select data from the BBS and view them on your own site? It is enough just to use the APIs that are provided by us. The Grottocenter application is just an example of how these APIs can be used as you might do it yourselves.

Figure 5: Add a document

4. An ongoing project….

The BBS is fully functional now, but it is still possible to improve it with additional functions. Therefore, we took the opportunity to inform you about the current status of the BBS, and we are looking forward to your suggestions and comments.

For example, for now, the BBS makes it possible to present the metadata associated with documents, which can be linked with a document available on the internet. But these links are not always permanent, and some documents are not available online. This is why we are considering the addition of files while respecting copyrights.

Also, BBS data is available today via APIs in JSON format. Work is underway to ensure that they are also provided in JSON-LD format, as part of the specifications for making the semantic web for the BBS to be fully part of the Karstlink project. Many international caving libraries manage the documents on their own and are willing to participate in BBS without having to enter information twice: on their software and on the BBS application. This will be possible through the tools set up by Karstlink, but it will require the libraries to carry out some software developments. Another solution, with ongoing work, is to upload a csv file to Grottocenter which will allow all the document analyzes to be provided with a single click.

Finally, Grottocenter hosts the BBS, but also manages information on people, organizations, networks and, of course, on caves. Important developments are underway, which will allow to manage all of these different objects and to allow links to be created. These links between the documents, their authors, their publishers, the library where they can be consulted, the massif or the caves they are linked with, will give additional value to the BBS data.

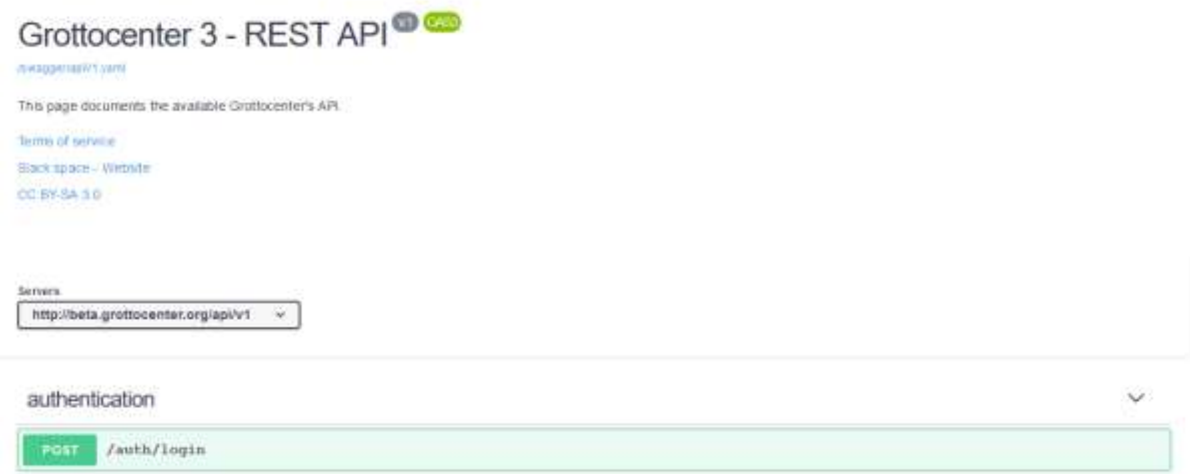

Figure 6: Use the Rest Api to access the datas

5. Conclusion

The UIS has some great ongoing projects, the BBS / SA is one of them, by allowing the community to contribute directly with as much information as possible regarding the literature published in the field of karstology. The tools have evolved, as have the methods. Each time, the BBS has been able to follow this evolution in order to offer the best service to users and ensure the sustainability of the information collected. Software with freely accessible code, freely downloadable and usable data, the possibility for everyone to contribute while ensuring quality control before publication, allows the BBS, still today, to be at the service of cavers and science at the same time.

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From 2D to 3D. From 3D to 2D. Towards a high-resolution representation of underground worlds

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Abstract

Over the past two decades, the representation of the underground worlds has evolved considerably. Certainly, the classic cave topography, in plan, longitudinal section and cross-section, remains the rule. But the arrival of the 3D has offered new ways of representing karstics networks, but also galleries or detailed objects (wall, stalagmite ...). The recent arrival of lasergrammetry and photogrammetry allows us to rethink, in depth, the underground images produced: we have gone from 2D to 3D. Yet we continue to visualize things in articles, books and computer screens. We project 3D views. We separate the galleries by floor. We separate the bottom and the ceiling, to offer 2D images, but now with high resolution and adapted to scientific issues. So, we go from 3D to 2D. This shows that 3D is not superior to 2D. It is only an additional option, a complementary means to study and visualize caves. Like all tools, it requires learning and appropriate use.

Résumé

De la 2D à la 3D. De la 3D à la 2D. Vers une représentation haute résolution des mondes souterrains. Depuis deux décennies environ, la représentation des mondes souterrains a considérablement évolué. Certes la topographie de grotte, classique, en plan, coupe et sections reste la règle. Mais l'arrivée de la 3D a offert de nouveaux modes de représentation à la fois des réseaux souterrains, mais aussi des galeries ou des objets de détail (paroi, stalagmite…). L'arrivée récente de la lasergrammétrie et de la photogrammétrie permet de repenser en profondeur les images produites sur les mondes souterrains : on est passé de la 2D à la 3D. Pourtant on continue à visualiser les choses dans des articles, sur des livres et sur des écrans d'ordinateur. On projette les vues 3D. On sépare les galeries par étage. On sépare le sol et le plafond, pour offrir des images 2D mais désormais à haute résolution et adaptées aux questions scientifiques. On passe ainsi de la 3D à la 2D. On montre ainsi que la 3D n'est pas supérieure à la 2D. Elle n'est qu'une option supplémentaire, un moyen complémentaire pour étudier et visualiser les grottes. Comme tous les outils, il nécessite apprentissage et usage adapté.

1. Introduction

For more than a century, speleologists have been producing cave topographies. Every time they are confronted to a major problem: representing an eminently 3D underground object in 2D (in plan). The 3D is expressed both at the network scale (sets of superimposed galleries), and the gallery scale (floor, walls and ceiling are to be represented on the same support). To solve this issue, they first sought to multiply the views: plans, cross-sections, and longitudinal section. They also sought to use perspective views or other 3D representation modes such as models (Fig. 1). Recently, the advent of computer technology and the development and popularization of lasergrammetry and photogrammetry have renewed the use of 3D methods in caves. Models are manipulated on computer screens and karst is visualised at different scales from different points of view. But ultimately, we come back to 2D views, angles of view on a screen or projections on a plane. In this note, we briefly analyse this passage from 2D to 3D and then from 3D to 2D, to finally show that 3D is just one more tool for the underground topographer.

2. From 2D to 3D

Topographical surveys in speleology are now fairly well codified (HÄUSELMANN, 2008, 2011). The underground gallery is divided into sections between two stations. Each station is characterised by four lengths (LRUD – Left Right Up Down). This type of approach (Fig. 2) is fairly common in most of the topography software currently in use (*TurboTopo, Toporobot, Visual Topo, DPTopo, GHTopo, CyberTopo, Topo Calc'R, Compass, Winkarst, Survex, CaveRender, Therion, Walls, Tunnel, Auriga, PocketTopo, TopoDroid, Cave3D, TopoDroid 3D sketching*…to name a few). On large networks, it is possible to propose very relevant representations of the passage organisation and then to analyse this 3D geometry for different purposes: speleogenetic phases, direction, relationship with tectonics, etc.

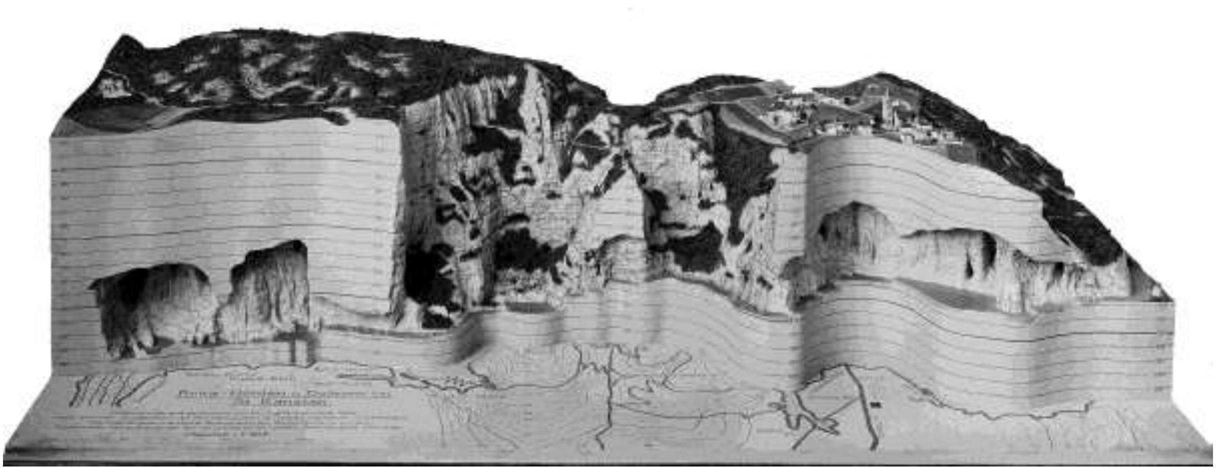

Figure 1: 3D model of Škocjanske jame (Slovenia), made in 1924 by Robert Oedl (1898-1978, student engineer at the University of Munich). The village of Škojan, the Mala and Velika sinkholes and the natural bridge can be recognized. Size: 167 cm x 71 cm x 50 cm, photo no. 2069 from the German Museum (Munich).

With this type of approach, it is already possible to switch from 2D to 3D while remaining at resolutions of the order of 10 m (average distance between two stations).
At a finer scale, that of galleries and walls, the arrival of lasergrammetry has made it possible to document shapes at metric to millimetric scales (OLUDARE IDREES et *al*., 2016; WALTERS, 2017). Terrestrial lidars are then used to acquire dense point clouds which are then consolidated by the sphere or best-fit method. Recently, portable mobile lidars have become even more timesaving. This approach, with better resolutions, is suitable for caves of reasonable dimensions or sections of galleries. It is then possible to analyse the wall morphologies (fig. 2). When the aim is to analyse even smaller elements (stalagmites, cave art), photogrammetry is often used. Based on image recognition (SIFT) and matching algorithms (SFM), this method makes it possible to generate dense clouds or meshes at very fine scales (fig. 2). Increasingly, the methods are not seen as opposed; on the contrary, they complement each other and are used at different scales.
When the cave survey is complete and coloured, it is sometimes referred as a digital clone. However, very few 3D cave survey projects actually achieve this rank of digital clone. We consider that this rank is achieved when the project meets at least three criteria: (1) completeness of the project (the entire cave is surveyed); (2) complete meshing without holes and triangles of the TIN model always ten times smaller than the average mesh size of the point cloud; (3) complete texturing (RGB colorimetry) of the model by texels (smallest element of a texture applied to a surface), themselves smaller than the triangles of the TIN model. All Not 3D models produced on caves are therefore clones. They are often limited to a portion of the cave and answer a specific question.

Object	Methods	Software (examples)	Resolution Accuracy	Image
Karstic massif, speleological network	Speleological topography (skeleton + gallery dimensions)	speleological software (Visual Topo, DPTopo, GHTopo, Compass, Therion…)	~ 10 m ~ 10 m	
Underground gallery, chamber, large volumes	Lasergrammetry (terrestrial lidar or mobile lidar). Photogrammetry available	Reverse Engineering software (3DReshaper, CloudCompare, Cyclone…)	~ 1 cm ~ 5 mm	
Wall, stalagmite, rock art	Photogrammetry (Photo acquisition high recovery rate). Lasergrammetry available	SIFT (Scale-invariant feature transform) & SFM (Structure From Motion), Agisoft Metashape	~ 1 mm ~ 0.5 mm	

Figure 2: Different 3D methodologies adapted to different scales of karst investigation and underground galleries. Speleological topography, lasergrammetry and photogrammetry complement each other according to the representation projects envisaged.

3. From 3D to 2D

However, the 3D model or digital clone is still a document that is usually viewed on a computer screen. In order to produce publishable and exchangeable images, it is necessary to project them. The selection of viewing angles and perspectives proposed for these 2D restitutions, made from 3D models, implies choices made by an operator who has mastered the handling of the model. Thus, the level of technicality required to produce these 3D images implies that a small community is the actor in the image production, while several people remain passive spectators, prisoners of choices made by the specialists. In some cases, however, the online publication of 3D models on free consultation platforms (e.g., https://sketchfab.com/3d-models) offers the possibility for the spectator to become once again an actor of the image production. He then chooses his or her own angles of view, zooms, lights and partially produces his or her own representations.

More generally, the 3D model is separated for the needs of a specific question. For example, if we wish to map elements present on the floor of the gallery, then the model of this gallery is cut in two parts and only the lower part is kept. This has been done, for example, in the Chauvet cave to carry out detailed mapping of the cave floor at a very fine scale (DELANNOY et *al*., 2020). In other cases, if the ceiling of the cave is of interest, the gallery is segmented and planar views of the 3D model, projected on an XY plane, are provided (fig. 3). These views allow the generation of dense images and offer the possibility of analysing particular morphologies in detail. These solutions make it possible to generate projected views. Here we go back from 3D to 2D. This is not a loss of quality, it is the continuation of a work whose objective is the production of high-resolution documents and of which 3D is only a step (JAILLET et *al*., 2014).

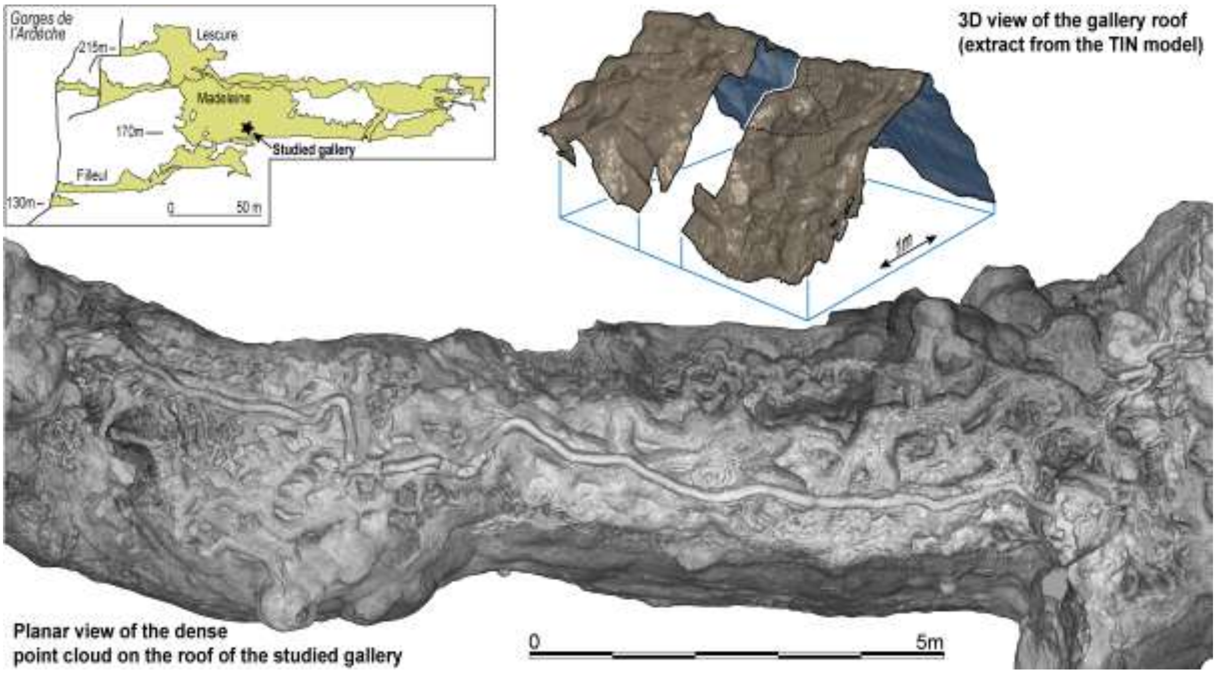

Figure 3: Extract from the 3D model of one of the galleries of the Grotte de la Madeleine (Ardèche). The ceiling alone is preserved and is projected on an XY plane. This view allows to visualize, from the top, the detailed morphologies of the gallery ceiling (anastomosing half-tube, cupolas), but not the other elements of the gallery, present on the floor.

4. Towards high resolution

Thus, 3D is not a goal in itself but a step in a cave documentation project. The acquisition obtained by lasergrammetry or photogrammetry makes it possible to obtain dense point clouds. These are segmented and cleaned in order to keep only the essential elements for a high-resolution topographic project. Figure 4 illustrates this. A conventional topographic survey is carried out over the same sector (right). It allows the wall and blocks to be mapped. In some cases, these blocks are actually measured, in others they are just drawn. On the same sector, a 3D lasergrammetric survey is carried out (left). Here, two dense point clouds can be acquired. The lower part of the cloud is kept and then rasterised to generate a DTM (2.5 D image = Digital Terrain Model with fixed mesh). Two raster grids are proposed, one at 5 mm, the other at 0.1 m. Elements are drawn from these raster grids (wall, blocks). In conventional topography, the ground survey and the cartography are carried out at the same time. In 3D surveying, the mapping is carried out on a computer after processing (raster grid). This example shows that there is no project of better quality than another. The 3D survey documents the entire cavity but does not produce a cavity map. This is done afterwards. Conventional topography can sometimes be less accurate. On the other hand it is more economical because it allows to take only the points necessary for the cartographic representation (here blocks and a wall). The "conventional" topographer can interpret the cave and its sediments better in terms of deposition or genesis.

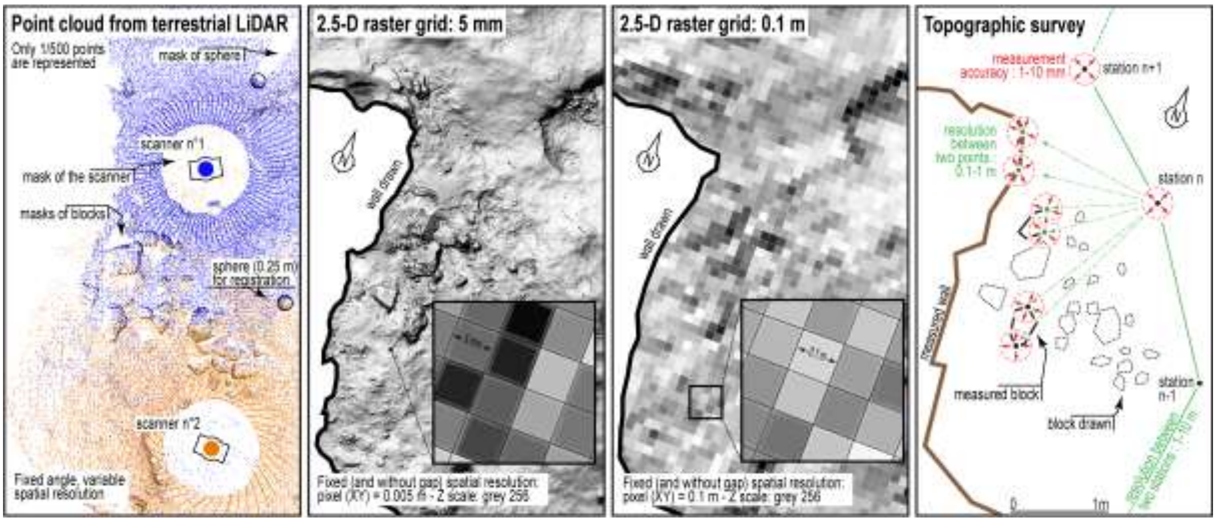

Figure 4: Discretization, segmentation and cartography of a cave (here, a section of the floor). In the field survey (right), discretization and segmentation were carried out simultaneously with a 10 cm-scale resolution. In the LiDAR survey (left), the dataset provided by oversampling was used to produce 2.5D and 3D images at density levels suited to the purpose of the survey. However, segmentation had to be carried out later, either on the basis of the field survey or from the 2.5D or 3D images (JAILLET et al. 2017).

5. Conclusions

We have tried here to show that 3D (3D of large networks, lasergrammetry and photogrammetry) is a remarkable tool for caves and karst representation. When used appropriately, this tool allows to propose high-resolution representations. But it is just one more tool. Just as a photograph allows to obtain a very dense image of a space (for example a gallery in a cave), it is indeed the analysis of this image (cartography, segmentation) that allows to separate the elements of this image and to identify the interesting elements (stalagmite for some, blocks for others). 3D thus appears as a new means of high-resolution representation. It does not replace topography, it complements it. The expected popularization of these tools towards the greatest number of people encourages the development of training courses adapted to their use.

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A high-resolution 3D model of the Chauvet cave entrance area (Ardeche, France): scree, scarp and related caves

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Abstract

The exceptional conservation of the Chauvet-Pont-d'Arc cave is linked to three successive collapses, the last of which definitively sealed the entrance to the cave 21,500 years ago. This closure is part of a wider morphogenic dynamic associating ancient karstification and gravitational activities that are still active. Understanding and monitoring the processes at work in the Chauvet-Pont-d'Arc cave (flow of the scree, evolution of the Pillar of Abraham), but also the current and past connections with the cavities associated with Chauvet (Grotte du Treuil, Grotte du Planchard) are essential to the knowledge of the current and past evolution of the site, but also for its management and conservation. The linking of these different geomorphological elements at the level of the entrance sectors had to pass through a high-resolution three-dimensional analysis. A high-resolution 3D model was made of the different geomorphological entities involved (collapse niche, wall, related cavities, the cave itself, etc.). It combines both underground and external elements and covers a space of 25 000 m^3 with about 600 scenes of scans, 400 million points, 50 million triangles for the grid areas. It constitutes an integrative reflection base for the study and management of the entrance sectors of the Chauvet-Pont-d'Arc cave.

Résumé

Un modèle 3D haute résolution de la zone d'entrée de la grotte Chauvet (Ardèche, France) : éboulis, escarpement et cavités connexes. La conservation exceptionnelle de la grotte Chauvet-Pont-d'Arc est liée à trois écroulements successifs ayant définitivement scellés l'entrée de la cavité il y a 21 500 ans pour le dernier. Cette fermeture s'inscrit dans une dynamique morphogénique plus large associant karstification ancienne et activités gravitaires toujours d'actualité. Ainsi la compréhension et le suivi des processus en œuvre au niveau de la grotte Chauvet-Pont-d'Arc (fluage de l'éboulis, évolution du Pilier d'Abraham), mais également des connexions actuelles et passées avec les cavités connexes à Chauvet (grotte du Treuil, grotte du Planchard) sont primordiaux pour enrichir la connaissance de l'évolution actuelle et passée du site mais aussi pour sa gestion et sa conservation. Ainsi la mise en relation de ces différents éléments géomorphologiques au niveau des secteurs d'entrée a dû passer par une analyse tridimensionnelle haute résolution. Un modèle 3D à très haute résolution a été réalisé sur les différentes entités géomorphologiques investies (niche d'écroulement, paroi, cavités connexes, grotte elle-même etc..). Il associe autant des éléments souterrains qu'extérieur et couvre un espace de près de 25 000 m^3 comprenant 600 scènes de scans, 400 millions de points, 50 millions de triangles pour les zones maillées. Il constitue une base de réflexion intégrative pour l'étude et la gestion des secteurs d'entrée de la grotte Chauvet-Pont-d'Arc

1. Introduction

The Chauvet-Pont-d'Arc cave, with its parietal paintings dating back 36,000 years, is located in the Ardèche gorges. Its exceptional state of preservation is associated with the successive collapses of the entrance, the last of which was dated at 21,500 years cal. B.P. (SADIER et al., 2012). About twenty topographical representations of the cave were made between 1994 and 2013 (JAILLET et al., 2020). However, the entrance sectors (Eboulis d'entrée, Atelier, Morel room), which are very poorly decorated, were underrepresented. In 2016 (Perazio / Chauvet cave conservation), it was possible to carry out a new 3D scan of the cave. It will be completed in 2020 for the external sectors (EDYTEM regional research project). The two galleries at the foot of the scarp, the Planchard cave, the Planchard sheepfold and the top of the escarpment were scanned with a short-range LiDAR (FARO Focus 3D). The objective is to analyse the evolution of the collapse cone (creep, translation of speleothems, DUBICH et al. 2022), the gravity morphodynamics (fissure network, exo- and endokarstic collapses, shifted speleothems, monitoring of the Pillar of Abraham) and the position of Chauvet in relation to related cavities (Treuil, Planchard, etc.). We present here the construction elements of this high-resolution 3D documentation.

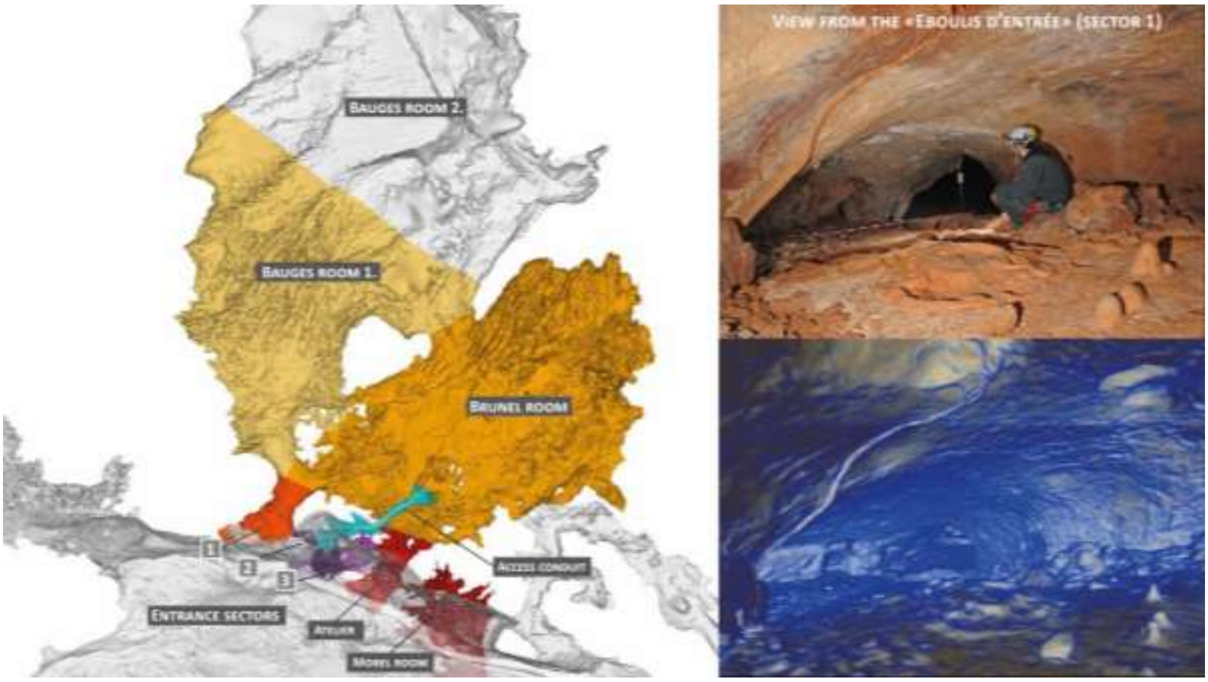

Figure 1: Left: view of the mesh sectors in the Chauvet-Pont-d'Arc cave. Right: comparison of the sector 1 (Eboulis d'entrée) with its mesh model.

2. 3D Acquisition and point cloud treatment

The 3D survey covers a volume of almost 25,000 m^3. The point cloud includes 823 scanner positions acquired in 2016 and 2020, representing more than 400 million points. The first set was assembled sphere-to-sphere in a common spatial reference frame facing north in Lambert 3 South, while the second set was connected to it by best-fit (BESL et al., 1992).

The different sectors inside the Chauvet-Pont-d'Arc cave have been separated to facilitate processing on the 3DReshaper software. The global cloud was divided into eight sets: Access Conduit, Eboulis d'entrée (palaeo-entrance), Atelier, Morel room, Brunel room, and Bauges room (in 2 parts). For understanding purposes in the text, the entrance area has been divided into three geomorphologically uniform zones. From west to east, these sectors have been numbered 1, 2, 3. Note the very high proportion of aberrant points in all of Chauvet cave - for example, "wedding veils": badly positioned points because they are tangential to the scanned objects (HAJRI et al., 2012) - particularly in narrow and/or highly calcited sectors. These sectors have been cut into metric to multi-metric parts according to the geometry of the volumes (flat ground, slope break, bench, vault counterpart) in order to facilitate their cleaning; based on several successive steps: 1) separation of the human installations, 2) separation of the speleothems, 3) combination of manual cleaning and automatic noise detection. These operations were carried out on the separated scales before they were reconnected in sections of gallery for meshing. The various facilities in the cave are extracted by hand: ladders, cables, walkways, rubber mats on the floor, doors, etc. These elements are grouped together in a single cloud that can be seen by superimposing the mesh model.

Figure 2: 3D survey in the Planchard cave (West of the Chauvet cave), with a Faro Focus 3D.

The speleothems are similarly separated before the elimination of the noisy points so as to avoid losing them in the operation. The distinction between the concretions and the noise is made by expertise, based on a criterion of point density: in the Z view, the speleothems are easily identified by high density circles. These selected elements can then be classified into three sets: (1) Fistula, (2) Concretions to Mesh (CtM), (3) Pillar to Mesh (PtM). This distinction was only made in areas in direct contact with the scree, where the mesh had to be precise enough to observe the translations of concretions. In the Brunel and Bauges rooms, the concretions were all merged into a single "Speleothem" cloud to facilitate the processing time. An initial cleaning is therefore carried out by hand and then completed by automatic noise detection (80% tolerance). In cases where the reading of the point cloud could have led to different interpretations due to too much background noise, a crossover between 3D data and 2D documents (photographs, geomorphological cartography) made it possible to correct the errors.

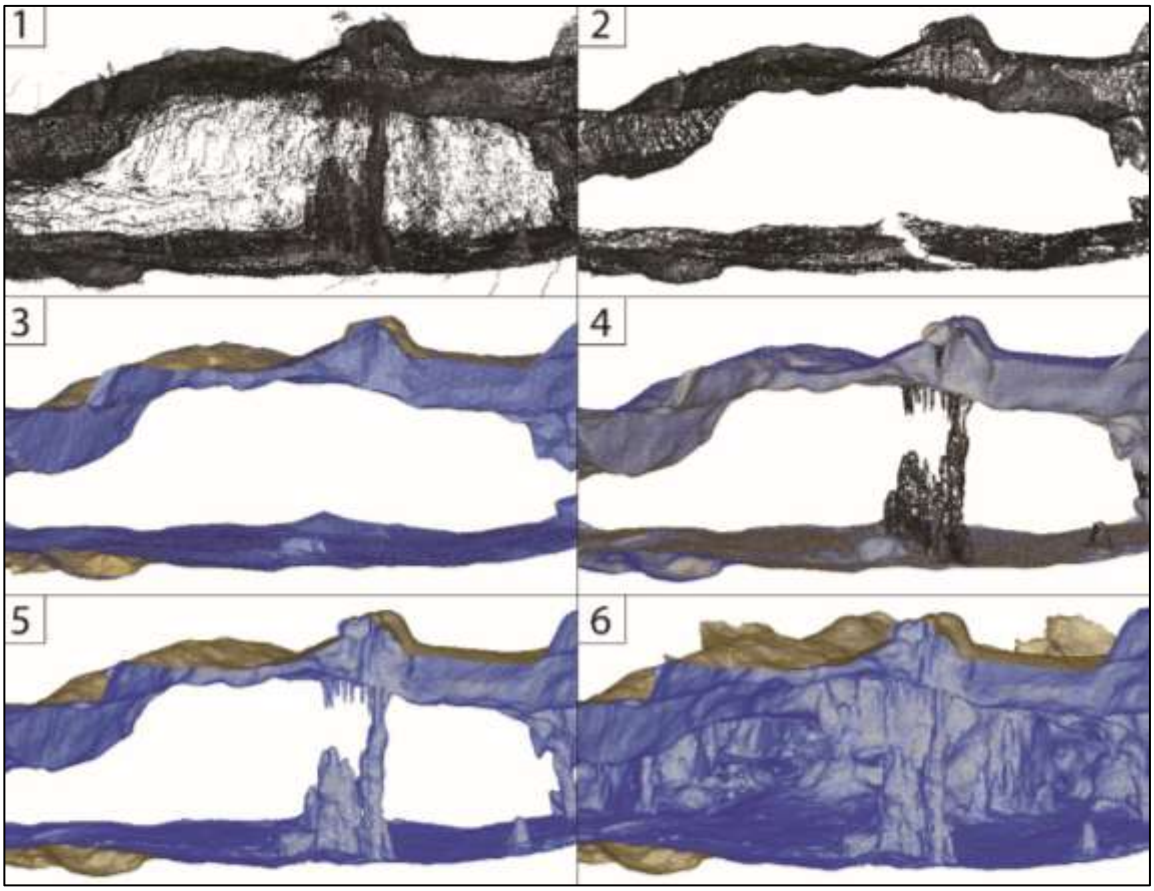

Figure 3: Steps for processing raw data: (1) Raw cloud, (2) Cleaned cloud, (3) Coarse mesh, (4) Refined mesh and raw speleothems, (5) Meshed speleothems connected to the mesh model, (6) Section connected to the general model

3. Mesh methodology

Once the scales have been cleaned, they are combined for meshing. It is first defined with a coarse resolution (of the order of 2 to 5 m) with uniformly spaced points (distance aberrant point to 1 m more than the maximum space between the points), to minimise the risk of outlier triangles and holes. Manual intervention is still necessary to plug these holes and obtain the right geometry of the volume. A refinement with uniformly spaced points is then applied at a finer resolution. After several successive refinements, the expected resolution is obtained: 0.03 m in the entrance sectors, 0.05 m in the sectors not in direct contact with the scree (Brunel, Bauges and Eboulis d'Entrée) and in the annex cavities (Treuil, Planchard, Planchard's sheepfold, Footbridge Conduits). Punctual smoothing of intensity 2 was applied to the whole cavity.

In the underground sectors in direct contact with the scree (Eboulis d'Entrée, Atelier, Morel room, Treuil, Planchard) the pillars (PtM) and concretions (CtM) were individually meshed. A refinement from the cloud, similar to the one of the general volume, is carried out on a cylinder to stick to the geometry of the element, until a resolution of 0.05 m is reached. The concretions are then incorporated into the meshed section of the volume. While individual modelling of the fistulas in the Chauvet entrance area (access gallery of Eboulis d'Entrée) was initially started (fistula creation by cylinders of similar width, length and orientation, then refined from the cloud), the time required to apply the method to the working area ended the test. The visualisation of the fistulae in a cloud of cleaned points over the general mesh already in itself makes it possible to visualise the speleothems and their distribution in space. Once the gallery section has been meshed with pillars and concretions, it is connected to the other sections in the same sector (junction and refinement from the cloud).

4. Discussion and conclusion

The assembly of the different objects in the same 3D model makes it possible to highlight the relationships between the meshed morphological entities. Connections or proximities can be identified, whether they are old or not. An upper karstic level (Treuil Cave, Eboulis d'Entrée, upper part of Planchard cave) is highlighted, which also seems to be developing at the top of the Brunel room. Although further geomorphological analyses remain to be carried out, this new representation already makes it possible to ask questions of a speleogenetic nature. Similarly, high-resolution modelling of the concretions at the collapse cone allows us to study the possible creep of the cone, highlighted by the presence of translated speleothems. Work in progress is thus based on the crossing of the 3D model and petrographic and morphological analyses of stalagmites present on the subterranean face of the collapse deposit in order to reconstruct the evolution of the collapse deposit (DUBICH et al., 2022).

In many ways, the entrance area of the Chauvet-Pont-d'Arc cave, at the crossroads of external influences (collapse, rockfall...) and internal processes (speleogenesis, creep...), deserved such a high-resolution 3D model. There is no doubt that it will be the support for future targeted research.

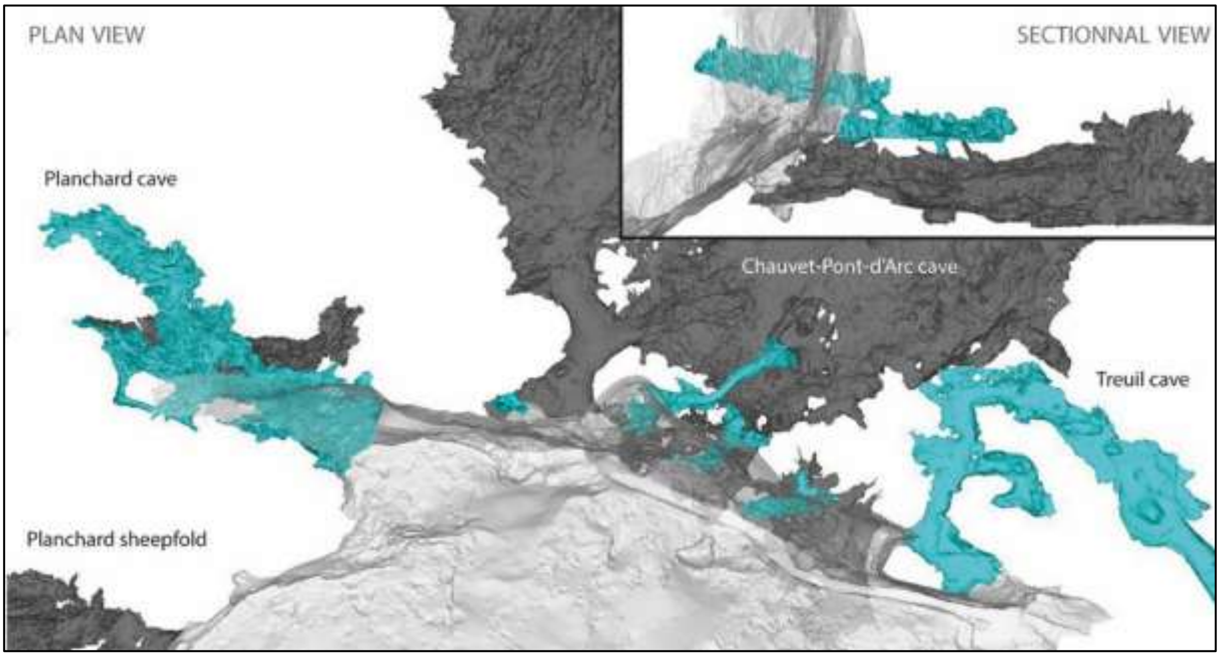

Figure 4: View of the general meshed model with highlighting of the upper karstogenic level (in blue) comprising from east to west: the Treuil cave, Scarp cavity 1, Scarp cavity 2, the Eboulis d'Entrée to the Chauvet-Pont-d'Arc cave and the upper level of the Planchard cave.

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KarstLink: organise the sharing of karst data

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Abstract

You've probably wondered how to find cave data? How to relate the caves to the documents which mention them? How to create links between the scientific observations, the measurements carried out and the caves in which these observations and measurements were carried out?
This is what the KarstLink project plans to offer you. The organization set up by the UIS has made it possible to mobilize skills in many countries and to advance this question, which was raised at the UIS Congress in Sydney in 2017. Using the tools of the semantic web, an ontology was developed. This common vocabulary makes it possible to share data without changing the structure of existing databases, thanks to tools that have been set up by various partner structures. The 2021 congress is an opportunity to check the progress of this project, to present a prototype for the interconnection of several databases, and to present the links with other subjects that mobilize people interested in the underground environment. We will also indicate the steps we want to take together in the forthcoming years.

Résumé

KarstLink : organiser le partage des données liées au karst. Vous vous êtes sans doute demandé comment trouver des données sur les cavités ? Comment relier les cavités aux documents qui les mentionnent ? Comment créer des liens entre les observations scientifiques, les mesures effectuées et les cavités dans lesquelles ces observations et mesures ont été réalisées ?
C'est ce que vous propose le projet KarstLink. L'organisation mise en place par l'UIS a permis de mobiliser des compétences dans de nombreux pays et de faire avancer cette problématique qui avait été évoquée au congrès UIS de Sydney en 2017. En utilisant les outils du web sémantique une ontologie a été élaborée. Ce vocabulaire commun rend possible le partage de données sans changer la structure des bases de données existantes, grâce à des outils qui ont été mis en place par différentes structures partenaires. Le congrès 2021 est l'occasion de faire le point sur l'avancement de ce projet, de présenter un prototype d'interconnexion de plusieurs bases de données, et de présenter les liens avec les autres sujets qui mobilisent les personnes intéressées par le milieu souterrain. Nous indiquerons également les étapes que nous voulons franchir ensemble dans les années à venir.

1. Motivation

Data sharing is a problem that has interested scientists for many years. Researchers working on questions related to karst are naturally concerned by this subject which is taking an increasingly central role in their daily work.

In the field of caving databases, the tools we have today are much dispersed; there are many tools built using different technologies, covering various territories, and even in the same territory different sources of information. We are talking here about cave databases, but also documentary databases, or bio-speleological databases, for example. Often, too, database developers find easier to incorporate all types of information into the same database, eventually duplicating data through different tools. This increases individual tool development efforts, but also the risk of incoherencies, and difficulties to maintain evolution of data through several tools. Solutions based on modular databases and linked data would be much better.
Beyond developing databases, their access by users is done through very diverse methods and formats, both for feeding data in the databases and for searching existing data through several different databases.
We think that users (both cavers and researchers) would be very interested in having compatible interfaces with several databases, and in sending complex requests to many different databases. It is therefore essential to develop tools that provide a link between the producers of information and those who wish to use it.

2. Sydney: already 4 years ago

Jason Boczar and George Veni, BOZCAR & VENI (2017) took part in the Sydney congress to present the Karst Information Portal. They presented the path that should be followed to use the tools of the Semantic Web and to organize the sharing of karst-related data on a very large scale.

In France, the FFS databases working group started debating about the World Wide Web Consortium (W3C) data exchange technologies more or less at the same time. Several other experiments appeared in publications (see the bibliography section below).

Discussions on the subject became more intense in 2019. After obtaining the support of the European Federation of Speleology and the French Federation of Speleology which participated in the promotion of KarstLink, the operations were launched on November 23, 2019 during a meeting of the FFS scientific commission in Courthézon.
A Sub-Commission was set up in January 2020 under the aegis of the UIS Informatics Commission both to support the discussion and to provide the technical infrastructure necessary to carry the project. It is managed by the authors of this article and thanks to Peter Matthews it has an evocative and sympathetic name: KarstLink.

We have decided to set ourselves the goal of offering, at the UIS 2021 congress, 4 years after that of Sydney, an infrastructure, tools and functional examples. This prototype should serve as a demonstration to attract other players, and a solid base to enrich the project.

3. The semantic web

The semantic web or web of data is a set of tools standardized by the W3C that allows data available on heterogeneous resources to be linked, without having to modify the technical infrastructure that makes this data available.

The foundation stone for organizing this information sharing is what is called an ontology. This is like a machine-readable dictionary defining the meaning of the terms of interest and also any relations to other terms. In order for the exchange to be possible, each of these elements is associated with a keyword, a definition that allows humans to fully understand the role that each of these keywords plays. Often ontologies are multilingual, allowing uniform access to data in different languages.
The second stone is a server that provides access to the ontology, either as a web page for us to read, or as a machine-readable file for servers that want to use the ontology directly.
The next step is to set up servers that are able to collect and deliver data that has been made available by reference to the KarstLink ontology. Everyone can naturally implement and provide a server, and a web portal, but it is essential that there is at least one.

Finally, the structures which have data to share must format them so that the exposed files are “translated” according to the rules set by KarstLink.
Figure 1 shows a simplified view of the KarstLink principles using semantic web concepts: at the toplevel, a database or a human, through a portal, will send requests to one or several KarstLink-enabled databases. These can be cave databases (in grey here), or document DBs (orange), biological DBs (green), etc.

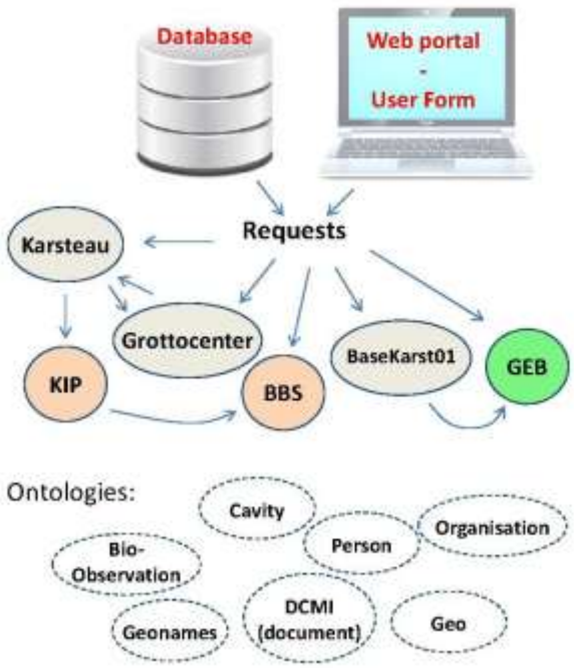

*Figure 1: **KarstLink: Our dream***

Both the requests, and the databases interfaces, will make use of Entities defined by ontologies, either ontologies from the KarstLink project (first line), or already existing ontologies (second line).

4. Project organization

There are three guidelines that we have set for building the ontology; they have served as a common thread since the launch of the project:

- All organizations wishing to provide data using KarstLink ontology must be able to find the concepts meeting their needs. It is for this reason that we have chosen to use entities that correspond to the most general concepts possible. Thus we propose an Under-ground Cavity object which must be able to describe a cavity whatever the definition that this cavity has for the group that wishes to share its work. It can be a rock shelter, a spring, a mega sinkhole or any kind of natural or artificial cave.

- It was also necessary to consider the organization of the data which is not always identical in all the databases. So often the data corresponding to the cavities is stored in a dedicated table, but there are also web services that rely on a data organization where the cavity and the entrance to the cavity are 2 different entities. The model that was built makes it possible to have these 2 types of data organization.

- It was also important to find the broadest possible consensus, for this we organized a major information campaign. Thanks to the network of contacts of the UIS, the FSE and the FFS, we were able to reach many of those who might be interested in KarstLink. A large number of other federations and structures then promoted KarstLink and we are very grateful for this very warm movement. A Wiki has made it possible to collectively build the ontology, to share resources. A mailing list has been set up by the UIS, it brings together more than fifty people who were able to participate in a vote organized from July 19 to 26, 2020 and which fixed the first elements that appear in the ontology. The choice was also made to rely whenever possible on already existing ontologies very widely used by other projects. For example DCMI (Dublin Core) was chosen for documents, Darwin Core for biospeleological observations, Geo for points and geographic coordinates, Geonames for geographic identities and Schema for postal addresses. The number of Classes and relations created specifically within the framework of KarstLink is therefore as limited as possible and corresponds, for the most part, to only the karst-related parts of our project.

Integrating into KarstLink all the elements allowing us to describe a cave, an underground river, a Paleolithic deposit, a colony of bats or a speleothem is a very long process. We have chosen to initially work only on the basic entities and to select only the essential elements for each of these entities. So we think we can meet the needs expressed by the greatest number of databases creators and the fact of working on a limited number of elements has given us the time to work in depth on the best solutions for this kernel. An ontology is a living object and KarstLink will necessarily expand later to allow new possibilities. This will be done in view of the needs or difficulties that will arise after a few months of actual use.

5. KarstLink at your service

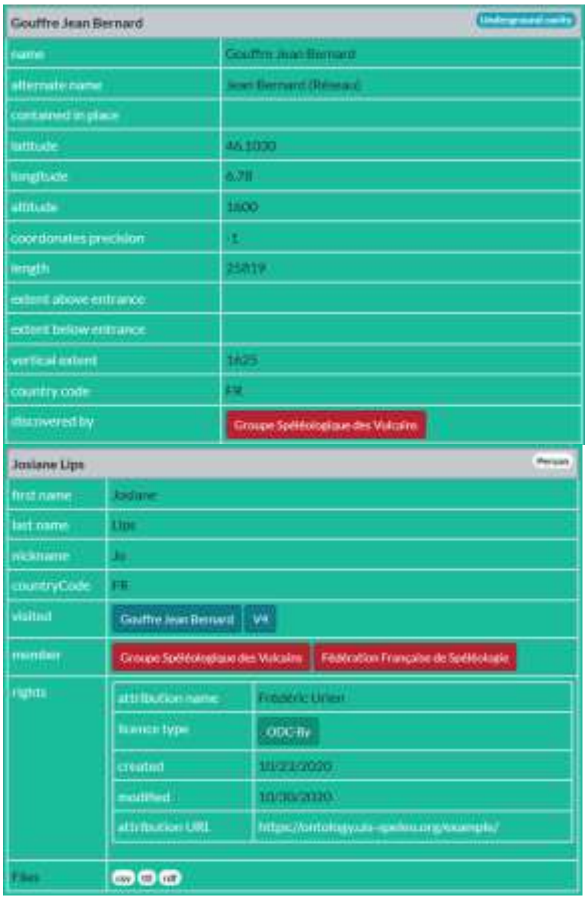

Figure 2: Exemple using the core KarstLink Ontology

The ontology directory at *https://ontology.uis-speleo.org* gives access to the ontology with an xhtml file for human beings, the server having been configured to refer to the ontology, which is described in a ttl (Turtle format) file when the request comes from a machine that expects this type of response.

We provide an example currently containing cave, organisation and person entities in various formats (html, csv, ttl, rdf, n3). It will be extended with all other entities approved by KarstLink, e.g., points, areas, documents or biological-observations.

In Figure 2, we show the example in a human readable form. It shows an excerpt of a cave entity (The Gouffre Jean-Bernard in the Alps) with some of its related data. In red or blue boxes, you can access related entities, e.g. here one of the Persons involved in the exploration, and the organization they belong to. All entities may include a “rights” object specifying the relevant license.

In order to collect the data and make it available to the community, a server has been set up by the Wikicaves association that publishes the site grottocenter.org. It is based on the Semantic-Forms software, developed by Jean Marc Vanel who was involved in the project and brought all his skills in the field of semantic web. This server will be searchable from the grottocenter.org site but it can also be searchable from any site using the APIs that we make available.

The precise list of available entities is evolving fast in this starting phase of the project, please refer to the KarstLink wiki if you are interested.

To date the APIs (Application Programming Interfaces) of grottocenter.org have been modified in order to respect the JSON-LD formalism, which is one of the formats of the semantic web.

5. Conclusion

In less than two years, thanks to the involvement of UIS, FSE, FFS, and many other structures, KarstLink was able to achieve its goal of being present at the 2021 UIS congress.

A large community showed interest and followed the progress of the work but the real involvement in the project was not as great as we had hoped. The difficulty that we had not measured by embarking on the adventure is that the concepts associated with the semantic web are far from being mastered by a very large majority of speleologists, or even database developers, even if they are present in a very large number of sites and more particularly those of the large institutions offering scientific resources. Clearly, we will need to implement one of our original goals that was to produce documentation, tools, on-line tutorials and a go-to enquiry/advice service to assist people to take advantage of our new facilities.

Beyond this understanding of general concepts, it will be necessary to form a larger group of computer scientists, of people with the technical skills to assemble new bricks and bring KarstLink to life, which has already made a very good start. The chosen organization and the tools put in place, in particular with freely accessible code on the Github platform, make it possible to ensure this development. Another aspect important to allowing full scientific use of shared data is that of data quality and reliability. Receivers of data need to know its provenance. We aim to follow the guidance of the World Data System of the International Science Council for this aspect of trusted data.

Beyond the UIS 2021 congress, we will have to unite new players, interface other databases with the project, but also extend our ontology and our capabilities to other related fields. Some already have existing databases, some are accessible with semantic web formats (sensors and measurements, meteorology, geology, etc.). Others are yet to be invented or specialized, but are of great interest to some of us, for example in the field of topographic databases, or specific data sensors and observations (temperature, pressure, flow rates, gas, etc.).

For most people KarstLink will become a practical and easy-to-use tool for providing or researching data, and that is the key.

Acknowledgments

We warmly thank the UIS for its support, both in terms of technical infrastructure, and for providing us with worldwide visibility and connections. We also thank all contributors and participants to the KarstLink mailinglist and wiki.

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KarstLink project page: http://uisic.uis-speleo.org/exchange/KarstLink/index-en.html
Version française: http://uisic.uis-speleo.org/exchange/KarstLink/index-fr.html
Wiki home page : http://uisic.uis-speleo.org/wiki/KarstLink/index.php
KarstLink ontology: http://ontology.uis-speleo.org

Radiolocalisation à la Grotte de Pâques

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Résumé

La Grotte de Pâques (St-Cézaire sur Siagne, 06) est longue, « profonde » et avec des passages étroits. Le CDS06 voulait positionner le siphon Goliath, situé à 2 km de l'entrée de la cavité, sous une forte épaisseur de calcaire. Les topographies avaient une précision insuffisante pour déterminer sa position cadastrale : nous avons étudié, avec le CIRKA, un repérage par radiobalisage. Ce balisage présentait des difficultés particulières : un grand recouvrement, la présence de générateurs de parasites très importants en surface; un terrain partiellement inaccessible et au relief difficile. En conséquence nous avons construit une balise spécifique : fréquence de 2927 Hz, bobine à air libre de grande dimension, support flottant pour une bonne horizontalité transportable dans 3 kits, (dans des conditions « un peu rudes »). Le balisage a duré 4 h, avec des récepteurs Brian Pease et standard, sans communication radio mais avec un calage temporel satisfaisant. La configuration du terrain a imposé un positionnement par calcul topographique. L'équipe du fond a refait une topographie précise de l'entrée du siphon. Les résultats ont été positifs : localisation à moins de 5 mètres de précision, à 250 m sous la surface.

Abstract

Radiolocation at the « Grotte de Pâques » Cave. The « Grotte de Pâques » Cave (St. Cézaire sur Siagne, 06, France) is long, "deep" and with narrow passages. The CDS06 (speleology association) wanted to position the Goliath siphon, 2 km from the entrance, and about 300 m deep. The topography had insufficient precision to determine its land registry: we studied, with the CIRKA (scientific and spelunking association), a radiolocation beacon. This radiolocation presented particular difficulties: a large overlay, the presence of very important parasite generators; partially inaccessible surface areas with difficult relief. As a result, we built a specific beacon: frequency of 2927 Hz, large open-air coil, floating support for a good horizontality transportable in 3 bags, (in slightly rough conditions). The radiolocation lasted 4 hours, with Brian Pease and standard receivers, without communication with the surface team but with satisfactory time coordination. The surface configuration imposed the positioning by topographical calculation. The underground team made a new precise survey of the sump entrance. The results were positive: location within 5 meters of accuracy, 250 m below the surface.

1. Objectifs

Le CDS06 et le CIRKA ont été sollicités par un syndicat intercommunal de gestion des eaux pour repérer en surface l'aplomb de l'entrée du siphon Goliath de la grotte de Pâques situé à une profondeur de l'ordre de 300 m. L'idée à long terme serait de pouvoir utiliser les eaux du siphon (grand volume) de manière ponctuelle, en fin de saison sèche, pour suppléer aux problèmes d'alimentation en eau du bassin de la Siagne. Des pompes au niveau du déversoir du siphon pourraient pomper cette eau et la déverser simplement en contrebas, l'acheminant par son trajet naturel à l'exutoire, où se situe le captage déjà en place. Dans une phase de test, le syndicat envisage d'acheminer les pompes par un forage vertical à l'aplomb de la plage du siphon, depuis la surface du plateau, estimé entre 200 et 300 m plus haut… Il faut bien sûr déterminer ce point en surface, et identifier son propriétaire.
Les topographies existantes ne sont pas suffisamment précises, le siphon étant à quelques 2 kms de l'entrée. Nous avons donc organisé cette opération de repérage électromagnétique, assez délicate vue la profondeur, mais aussi les conditions difficiles en surface.
Nous en profiterons pour refaire une topographie précise de la zone d'entrée du siphon, pour les besoins du syndicat.

Figure1 : Balise flottante

On utilisera une balise émettrice spécifiquement construite pour l'occasion, positionnée à l'entrée du siphon, et on déterminera son aplomb par triangulation, à partir des directions de la balise déterminées par écoute du signal avec des antennes extrêmement directives.

2. Contexte

La grotte de Pâques est une cavité majeure du système hydrologique drainant les plateaux de St-Cézaire et St-Vallier. Elle comporte environ 8 km de galeries, majoritairement horizontales, dont une partie derrière le siphon Goliath. La figure 1 montre le plan d'ensemble de la cavité : L'entrée (117-C) est à gauche, les galeries en rouge représentent la partie exondée accessible. Le siphon Goliath, au centre, est en bleu, les galeries en rouge sur la droite sont post-siphon. Le siphon mesure 800 m de long, avec un point bas à -60 m. L'exutoire principal du système est la grotte de la Foux (117-A). Son eau est captée, et constitue l'un des approvisionnements principaux du canal de la Siagne, et de la Ville de Cannes. Le projet serait, si les essais sont concluants, de prélever de l'eau dans le siphon en période de sécheresse en fin de saison, lorsque le débit résiduel est insuffisant, voire nul. Les précipitations d'hiver, très importantes à partir de fin octobre, devraient reconstituer les réserves, jusqu'à retrouver un débit naturel normal. Le cheminement depuis l'entrée naturelle est long de 2 km, et présente beaucoup de passages étroits. Le transport des pompes n'y est pas envisageable.

La topographie de la cavité, réalisée à la fin des années 1980, ne donne pas une précision suffisante pour permettre un forage. D'où l'idée de notre repérage électromagnétique. Cependant les conditions sont difficiles : épaisseur de calcaire au-dessus de la zone, terrain accidenté et végétation abondante, nombreuses sources de perturbations électriques. Ces conditions nous ont amenés à concevoir et construire un équipement spécifique.

Figure 1 : plan d'ensemble et zone de recherche.

3. Matériels et méthode de radio balisage

Émetteur 2929 Hz 60 W :

Il alimente une bobine de grande dimension de 2,6 m de diamètre assemblée sur place et flottante, en tube PVC, permettant un positionnement parfaitement horizontal sur le plan d'eau d'entrée du siphon (Fig. 1). Cet équipement a été construit spécialement pour pallier les difficultés spécifiques : le recouvrement important et la présence dans les zones d'écoute de nombreux générateurs de parasites électromagnétiques (lignes haute tension, secteur, téléphone). Des boitiers séparés contiennent l'électronique (en double) et les batteries.

Récepteurs :

Une antenne directive permet de capter le signal (principalement magnétique) et une électronique permet de l'entendre. On disposait de récepteurs avec ampli et filtre et d'un récepteur à quadrature de phase de technologie « Pease » PEASE (1997) moins sensible aux parasites, nécessaire pour l'écoute dans les zones perturbées. C'est pour pouvoir utiliser ce récepteur que l'on a utilisé la fréquence de 2929 Hz (au lieu de 827 Hz) ce qui a nécessité l'augmentation du diamètre de la bobine émettrice.

Figure 2 : le récepteur Pease

Triangulation :

Les principes et schémas utiles pour sa description sont disponibles dans la bibliographie. L'écoute doit se faire à une distance minimale de l'aplomb (pour avoir un signal suffisant et avoir des lignes de champ les plus horizontales possible). Compte tenu de cette distance (de l'ordre de 300 m), et du relief, on ne peut pas faire de repérage visuel pour la détermination du point de convergence des visées: la triangulation a été faites par calcul à partir des directions balise mesurées au DistoX et des coordonnées GPS des points d'écoute.

4. Réalisation sur le terrain

Sous terre :

L'acheminement de nos 5 kits de matériel et la mise en place de la balise ont été réalisés par une équipe de 4 spéléos. Une communication par système TPS était prévue, pour se synchroniser avec l'équipe de surface, mais un planning de secours était aussi prévu en cas d'échec du TPS « Nicola » (une tentative lors d'un exercice secours précédent avait montré que le contact n'était pas garanti).
Le transport et la mise en place de l'équipement (TPS et balise) aura pris 5 heures. Hélas pas de communication radio… Dès la mise en route de la balise nous réalisons que de très fortes interférences vont rendre l'usage du TPS impossible. Nous déplaçons celui-ci au maximum pour diminuer les interférences, mais rien n'y fera.
La balise en route, il ne reste qu'à attendre le temps prévu (4 heures), nous en profitons pour lever une topographie de détail de la zone, pour aider au futur forage. Retour en surface après 14 heures sous terre.

Figure 3 : retour

En surface :

Figure 4 : zone broussailleuse sans visibilité

En surface les écoutes, mesures etc. pour le repérage sont réalisées par l'équipe CIRKA. Le TPS est mis en place.
Le récepteur à quadrature de phase est utilisé dans les zones les plus parasitées, dans les autres le récepteur classique suffit.
En chaque point d'écoute on recherche l'extinction du signal (le signal est nul lorsque le flux magnétique est parallèle au plan de l'antenne) et on mesure l'azimut du plan de l'antenne.

Figure 5 : Zone escarpée et sans visibilité

Quelques points sont dégagés mais pour la plupart ils sont soit touffus (Fig. 4) soit escarpés (Fig. 5) et sans visibilité ce qui nécessite la méthode de triangulation retenue.
En pratique les points d'écoute (= points de visée), théoriquement répartis autour de la position supposée de la balise, ont été choisis en fonction de la possibilité d'accès aux terrains. Des points potentiellement intéressants n'ont pas pu être utilisés sur la route (ligne HT enterrée). Plus au sud les zones intéressantes étaient inaccessibles. La détermination de la profondeur n'est pas réalisée à partir des données de la balise, mais simplement estimée à postériori, à partir de la topographie et de la carte de surface.
Déroulement : à 14h début d'écoute de la balise. Pas de liaison TPS, nous nous conformons au timing prévu. Le signal balise est repéré à 14h30. Au bout de 10 mn il s'arrête puis réapparait après 10 mn env. On saura par la suite que c'était un arrêt volontaire suite à l'interférence avec le TPS de fond. L'émission se poursuit jusqu'à l'heure convenue. Un changement de batterie a été réalisé par l'équipe de fond au bout de 3h30 après arrêt automatique sur batterie faible. On réalise ainsi des mesures jusqu'à 18 h 15.

5. Détermination des coordonnées et résultats

Le principe est de calculer les points de convergences des directions balise 2 à 2 à partir des coordonnées GPS des points d'écoute et des azimuts mesurés pour la direction de la balise.
Les résultats de détermination sont visualisés sur la Fig 6 où, outre les points d'écoute, sont reportées pour l'exemple trois visées parmi les huit utilisées : elles indiquent la direction de la balise (étoile verte) depuis leurs points d'écoute. Le quadrillage bleu a un pas de 50 m.
Certaines visées sont moins précises que d'autres : celles en particulier où le signal est faible compte tenu de la position trop proche de l'aplomb de la balise (le signal est maximal à 150 m environ de la balise). Il n'a pas non plus été possible de répartir les points d'écoute tout autour de la balise. Ces limitations ont été apportées par les conditions d'accès aux terrains. Ces dégradations de mesure conduisent à ce que les points de convergence ne sont pas situés tous au même endroit. La dispersion des points de convergence indique la précision obtenue, elle inclue celle des coordonnées des points d'écoute (de +/- 3m). Huit points d'écoute ont pu être utilisés au final pour cette triangulation. Nous estimons la précision du positionnement en horizontal à 5 m, ce qui nous amène une correction de 40 m par rapport à la topographie.

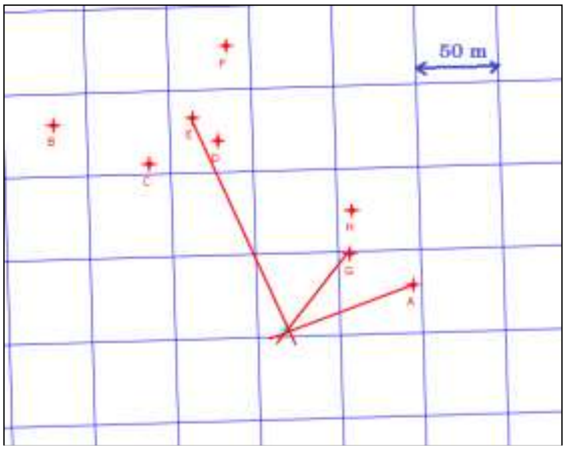

Figure 6 : points d'écoute et exemple de triangulation

Pour le calcul de l'altitude nous n'avons pas utilisé la méthode basée sur l'inclinaison du champ magnétique aux points d'écoute. Nous avons simplement utilisé l'attitude donnée par la carte IGN au point calculé, et l'altitude du lac du siphon donné par la topographie, soit 40 m au-dessus du niveau de la résurgence, ce qui est raisonnable, à 5 ou 10 m près.

6. Conclusion

Le choix des points d'écoute n'a pas toujours été optimale de par l'accessibilité limitée aux terrains et la présence de nombreux générateurs de parasites. L'utilisation d'un récepteur peu sensible à ces parasites et la mise en œuvre d'une balise de puissance adaptée ayant fonctionné sans problème ont toutefois permis d'obtenir des résultats tout à fait satisfaisants, pour une telle épaisseur de roche.
Le positionnement obtenu apporte une correction de 40 m par rapport au report topographique existant, avec une précision horizontale de 5 m. L'altitude estimée nous donne une épaisseur de calcaire de 254 m au-dessus de la surface du siphon. La galerie à cet emplacement fait 10 à 15 m de large, une opération de forage restera très délicate, les déviations en milieu calcaire fissuré peuvent être d'un ordre de grandeur supérieur à la précision de notre repérage.

Nul doute qu'une mesure électromagnétique lors du forage, en utilisant un émetteur en tête de forage, et un récepteur dans la cavité, ne pourraient aussi aider à en contrôler la position.
Cette opération a été une expérience très enrichissante de repérage à grande profondeur. Avec un grand bravo à l'équipe du CIRKA pour la construction « sur mesure » de la balise.
Coté liaison TPS, ce résultat négatif nous donne bon espoir de trouver un meilleur positionnement, définitivement très utile pour de futures actions dans cette zone, voire d'opérations de secours.

Remerciements

A tous les participants, Pascal, Michel, Eric, Xavier pour l'équipe de fond, Yves, Eric, Noah, Zoé, Pierre, Bernard, René pour l'équipe de surface.

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Strategies in cave mapping: an indicator of cavers' psychology

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Abstract
Cave mapping strategy during exploration can reflect cavers' psychology to a certain degree. Strategy may vary whether the exploration is on the long term or on a short one. When time is sufficiently available, strategy does not matter so much because exploration goals may be changed throughout time. If the exploration is time-limited, moreover if the cave is expected to be a long one, two main antagonistic behaviours can be depicted:

- A systematic mapping of all passages encountered from the entrance, leading to gradual expansion of cave mapping towards more distant areas. Such a surveyed canvass propagates in a similar way as a fungus. This approach is usually closer to a scientific interest for the cave, because detailed and systematic mapping has the preference, which is more compatible with observations.
- A preferential and even exclusive mapping of main passages, especially larger ones expected to lead far away. The mapping target is fast-track coverage over a longer distance and wider area. Side passages are neglected and left for following campaigns. This approach is closer to a race for the longest cave and the longest surveyed distance.

The paper explains possible motivations and psychological reasons leading to the choice of a given strategy and possible consequences, with generic examples.

Résumé
Stratégies choisies pour une topographie de grotte : un indicateur de la psychologie des explorateurs. La stratégie adoptée par les spéléologues pour lever une topographie au cours de l'exploration reflète d'une certaine façon leurs motivations et leur psychologie. En effet, un choix de stratégie est fait surtout en fonction des buts recherchés, et implicitement en fonction du temps considéré comme disponible. Si le temps est limité et surtout si la cavité a un gros potentiel, deux approches très différentes peuvent être constatées :

- Le levé topographique systématique de toutes les galeries rencontrées à partir de l'entrée, aussi bien les principales que les secondaires. Ainsi l'organisation fine du réseau apparaît de façon complète dès le début pour la partie topographiée et sa connaissance se propage peu à peu, à la façon d'un mycélium de champignon. Cette approche est habituellement mieux appropriée à l'étude scientifique de la grotte. La longueur topographiée n'est pas le but en soi, mais plutôt sa complétude.
- Une topographie préférentielle des grandes galeries, surtout celles qui sont espérées être de grande longueur. Le but recherché est de relever la plus grande longueur possible en un minimum de temps. Cette approche est plus proche de la « course au kilomètres » et les galeries secondaires sont laissées pour « plus tard ».

Cet article explique que ces approches différentes peuvent refléter des motivations et des attitudes psychologiques. Les exemples donnés sont génériques.

1. Introduction
More than half-a-century of cave exploration with personal mapping of some 150 km of passages enabled the author to observe a variety of cave mapping strategies used by a number of cavers, especially when exploring newly discovered cave systems. "Newly discovered" means by speleologists, though local people may have been aware of the cave existence and may have penetrated inside over some distance (up to a few kilometres).

The ways selected for cave mapping and speleologists' behaviour over the following years are often linked. Our observations are based on past events, but they are presented here after in a generic manner.
Different cases of cave networks shall be considered, as not all caves show the same pattern, obviously.

2. Examples of cave networks
Large-sized passages
First, let us consider the generic example of a complex cave system (Fig. 1), with two known entrances (A and B) and a network of galleries of contrasted heights and widths. We assume, for simplification, that passages of different sizes show their average section at the connection (Fig. 2, left): it simply means that a second-rank passage cannot be mistaken for a first-rank and that a third-rank can be mistaken with neither a second-rank nor a first-rank passage. A sharper contrast of the passages dimensions at the connection enhances the visual perception of first,

second and third rank passages. The concept of first-rank passage could, in some cases, be replaced by a succession of connected windy passages or by passages with flowing water, to a certain degree. Such features may replace dimensions criteria in the definition of a first-rank passage or succession of passages. Second and third ranks could be defined by dimensions or else. In this paper, we shall keep dimensions as the main factor of passages ranking.

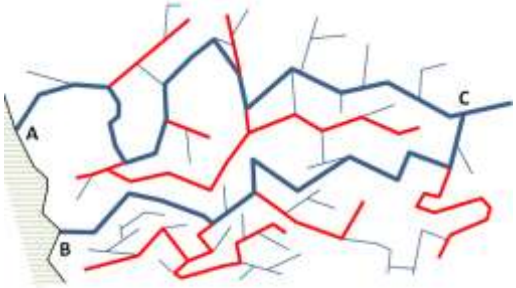

Figure 1: a theoretical cave network with three passage sizes: large, medium and narrow. It also has two entrances, to the left. Let's assume for instance a 2 km straight distance from the left to the right of the picture. No scale.

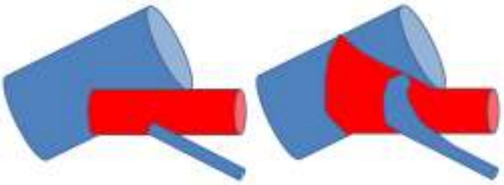

Figure 2: Left, no change of passage size at junctions. Right, funnel-like connection: possibility of no immediate perception of real passage size. No scale.

Maze areas

Maze areas are relatively common in caves and may have to be crossed through during progression. Their mapping requires special care, especially when the mesh is of short dimension. For instance, we encountered a maze with a mesh of 10 to 15 metres: it means that every 10 to 15 metres, three to four new passages were starting. In this case, after several junctions, mapping just becomes a "nightmare". It is necessary to place numbers on paper cards and to adopt a methodical way of mapping. This becomes even trickier in tree-dimensional mazes.

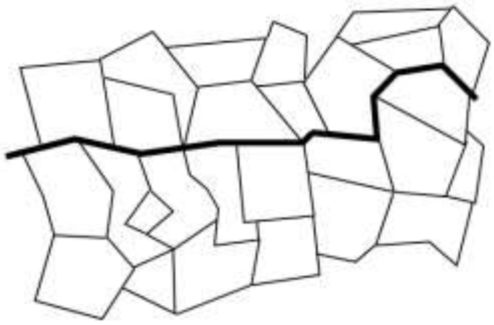

Figure 3: generic 2D maze area on either side of a main passage. We could also consider the same maze with no main passage. In this case, an alignment of passages might, for instance, be considered as a reference passage for mapping.

3. Mapping strategies

Our experience has shown two main strategies typical of persons' goals. Theoretically, everyone in a team is supposed to contribute to the same work and publish results in cooperation with other team members. In practice, this has proved to be not always true. For instance, some people want to publish alone or do not want to publish at all, leaving this to others. On one hand, a good way is to publish all together, at least for the main contributors; other persons can possibly be named in a well visible list of "other" contributors. In a few cases, people who want to publish alone simply discard other names. On the other hand, work made alone can be signed by its author but acknowledgements are recommended.

Cave mapping usually requires three persons: the mapper who writes measurements (especially lengths, azimuths and slope angles…), draws the cave shape and takes note of all necessary information on morphology, sediments, speleothems, etc.; the measurer, who takes measurements and transmits them to the mapper; a helper (or several), who holds the end of a length-measuring instrument or holds a target for laser measurements. Ideally, the helper is also looking for hidden features, such as small passage entrances or else. In practice, the drawer may also be the measurer, but it is difficult to have no helper.

"Long distance mapping" strategy (LDMS)

In this LDM Strategy, the mapper is usually the survey director (literally the one who directs it) and it is not rare that he also acts as being the measurer. Two or three persons are commonly with him. He chooses to ignore side passages, because his goal is to achieve a survey as long as possible. If we look at his cave sketch, information is relatively limited: side passages are usually indicated with a question mark or sometimes not mentioned, slopes are merely indicated and lower lateral extensions of the main passage are nicely represented by a dashed line and question marks, despite they may lead easily to large spaces. We even heard of a case where the mapper followed a talweg passage in a chamber without seeing the really gigantic void along it on one side.

The mapper does expect to map side passages only in the future. Sometimes, he prefers that time-consuming secondary passages are mapped by other people rather than himself, though he may claim for their results, as being the mapper of the longest part.

In maze areas, only the most obvious passage is surveyed, at least at the beginning. The mapper rushes along what he thinks is the most important direction, but the hazard exists of getting lost on the way back. In addition, nothing is known on most of the cave space.

"Systematic mapping" strategy or "propagative mapping" strategy (PMS)

In this strategy, every passage is surveyed as soon as it is encountered, whatever its rank. This brings several benefits.
First, safety: when we explore caves in distant areas of distant countries with neither a rescue team nor many cavers around, it is of paramount importance.
Second, the cave characteristics in passages of all ranks are known since the beginning and their evolution throughout space can be better characterised.

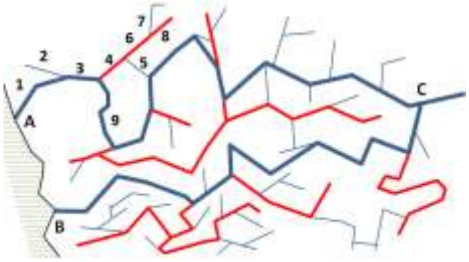

Figure 4: Example of order of surveyed cave segments.

Obviously, at some stages, decision has to be made. For instance, after mapping segment 5 of Figure 4, the next one could be in the main gallery (but it is still unknown whether it is the same passage as at segment 3). When we select segment 6 as it is done on Figure 4, the idea is to complete an area of smaller passages, though this completion is not always certain in advance. If at the end of segment 5, we had chosen to follow the larger passage, then we would have turned right, i.e., in the direction of the cave entrance, with hope of closing a loop. Turning left would not have respected the mapping principle.
The actual survey is therefore a compromise, but the idea remains to complete an area before going further away.
Third, as this kind of work is time-consuming, because surveying smaller passages takes longer time, it makes it worth collecting information on the cave (rock nature, dip, nature of sediments, paleoflow indicators, etc.) that will be extremely useful for a good understanding of speleogenesis and so help in discovering otherwise difficult to spot parts of the cave.

"Brick-wall mapping" strategy (BWMS)

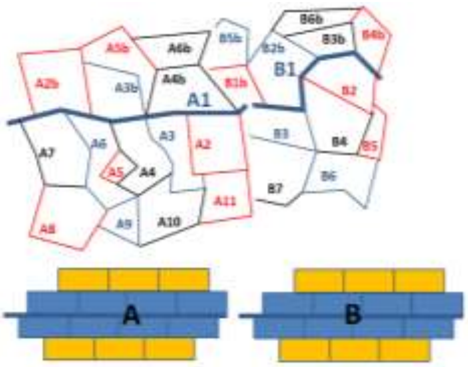

Figure 5: "Brick wall" mapping strategy.

BWMS is very useful where cave passages are organised in a complex way, moreover if all passages show more or less the same size. Nevertheless, if one larger passage exists, it can be used as a reference, as on Figures 3 and 5. We have mentioned above that an alignment of passages could be a similar reference.
In BWMS, the idea remains similar to this of PMS: to complete cave areas, before going further away. In this case, we map first the main passage, but only on a limited distance that depends on the number of side passages encountered. Once this distance is surveyed, we shall close successively adjacent loops. For this, we shall start from the end of the already surveyed part and close successively a first row of loops: A2, A3, A4… (Fig. 5). After that, we restart from the last loop of the first row and shall close loops of a second row: A8, A9, A10… until we reach A2. Then, a third row will be surveyed if necessary.
Once one side of the reference passage is completed, then the other side is surveyed using the same principle and, when it is complete (segment A6b of Fig. 5), then we start the same process with a further segment, B1, of the reference passage. Loops are closed in the same way, on one side of B1 and after on the other side.
It such a way, the cave pattern is well known between the mapped segment and the cave entrance. It is a safe way.
More complex cases may be encountered. In Figure 6 case, while mapping the two sides of main passage (A), another main passage (A'1) has been discovered. Not including it immediately into the loops would bring the disadvantage of leaving some unclosed loops, such as Loop A9. Therefore, it is better to include it, as in the case of Figure 6.

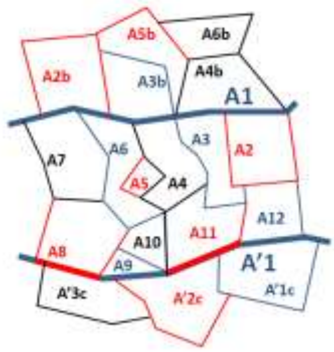

Figure 6: maze between two main passages, the second (A'1) being discovered while mapping away from the first one (A1).

After closing Loop A12, whether continuing the mapping on the opposite side of main passage A'1 or at the end of passage A1 may be a matter of appreciation but, as in PMS, the rule remains to complete areas as much as possible before starting new ones and preferably the nearer to cave entrance.
The BWM Strategy can also be adapted if necessary, by closing half-ring-shaped concentric zones of loops, starting from a point instead of a passage. It is also a strategy which can be classified among PMS, as can BWMS.

Hybrid strategies

In a cave, we may have to adapt strategy to the case we have to face. For instance, if we follow a 30 to 50 m wide main passage, we may, in a first step, neglect 1 to 5 m wide lateral passages, due to high contrast but we shall survey them in a second step.

In a complex cave system, we probably shall have to combine pure PMS and BWMS.
However, the idea remains to know the cave well, starting from its entrance, rather than going quickly as far as possible and cumulate more kilometres and less survey accuracy.

If exploration and mapping could be planned over several years, it might be important to organise surveys in a global way. However, we never know in advance what the cave length or circumstances will be. Operating with several mappers could be a possibility, but it needs precise co-ordination.

4. Psychological aspects

Considering that genuine cave exploration (i.e., of galleries previously unknown by cavers) is in any case motivated by a will of discovery, of adventure, of sport for a number of persons, of science for some others, of fame (not for everybody), the strategy of mapping is likely to be different.

Long distance mapping strategy (LDMS)

Persons looking for fame, sport, wild adventure or emotions (emotional people often find great excitation in finding virgin passages, a fashionable behaviour) tend to prefer LDM Strategy. Consequently, they tend to perform fast-track mapping, with smoothened angles, approximate drawing, but often accurate path measurements. The cave map is more a record, a proof of reached length than a document for cave studies.
Another kind of persons performing LDMS are people who are wishing to publish the cave alone, often without telling it in advance to other participants. Such persons often want to attach their name to long caves. When they publish, their name is alone in authors' list. Companions are cited in a small part of their paper, and not always. [It is a common feeling that persons identify with long caves, deep shafts, etc., especially when this is expected to bring fame. Fortunately, such persons seem to be not very numerous]. Therefore, they collect themselves as many data as possible, because they do not want to have to ask other participants for something, so they can publish the cave on a stand-alone basis. They usually survey and take photographs at the same time, even collect insects, take note of every quickly seen spectacular feature, sometimes hide to observe some features not seen by the others, who are not told of. Nevertheless, they do not hesitate to ask for all data possibly detained by other participants and may be arrogant to obtain that. If, for some reason, they are not the mapper, they tend to show less interest in cave exploration and may even disturb the surveying action. They pay little interest for the team work and spend their time in looking for future prospects.

Propagative mapping strategy (PMS)

Adepts of PMS are less emotional and do not necessarily feel big emotion when moving into virgin passages. To them, knowledge of the cave is more important than personal emotions. Scientists are more prone to belong to this category, because emotions are assumed to be unwelcome in reasoning and writing scientific publications. They are more used to team work and to add companions' names among publication co-authors. So, they rely upon other team members who make additional observations and measurements and bring their own experience, which is a real strength. The trouble arises when persons of the other type are with them and behave in a not co-operative way.

5. Discussion et conclusion

The two behaviours above described may show variations. First, obviously, not everybody's mind fits the end terms of LDMS vs PMS. Transitional behaviors exist, due to present persons, group effect, and so on. Second, not all caves are prone to constant mapping strategies. For instance, if the main passage shows no branching, obviously there is no other possibility than mapping it up to the end. Also, short caves do not arise much interest from LDS practisers. The two main behaviours presented in this paper mainly apply to caves expected to be long, even very long. Some persons use LDMS in order to show that they have already mapped longer distances than others or that they penetrated further into the cave. In the case shown on Figure 1, a person practicing LDMS will reach faster Point C than another one practicing PMS. This may prove a source of conflict in the future. The former may try to claim to be more legitimate to conduct further explorations, which is, of course not necessarily the case, especially if the cave was discovered by someone else.

The manners of a person practicing LDMS are often an indication that he/ she wants to publish alone. When the list of publications of such a person is examined with some detail, it may be easy to find previous publications of long caves with his name only. Practisers of propagative mapping strategy (PMS) show no protective enough behaviour, as large parts of the cave are not yet covered by mapping and so are still virgin, meanwhile they are prepared to share work with other team members, for instance, to take photographs, collect biomaterial, make a variety of measurements (e.g., temperature) and else. Obviously, such persons are prepared to share authorship with other persons. Different strategies of cave mapping exist, consciously or not in mapper's mind. This paper, based upon a very long experience acquired over many years in many places, was aimed at showing mainly end types. However, it was also shown that planned mapping may be applied to complex areas, such as mazes where it helps in leaving no passage unmapped. Moreover, it brings more safety in remote areas.

Acknowledgments

The author warmly thanks all his many friends for their time, efforts, contributions and good mood and with whom he could accomplish so much in speleology.

The Electronic FieldBook: an innovative tool for underground field science operations

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Abstract

CAVES (Cooperative Adventure for Valuing and Exercising Human Behaviour and Performance Skills) is a human behavioural and performance training programme that has astronauts explore and perform science in natural cave systems, as these environments present similar challenges to those imposed by space exploration. One of the innovative technologies developed for the campaign is the Electronic FieldBook (EFB), an information system designed to support scientific documentation in extreme environments and data exchange with surface. The EFB allows users to aggregate, save and share contextual information about their surrounding environment, such as hypogeal surveys, the creation and geo-referencing of scientific data and experiments (associated to the survey), or field notes. The EFB also supports integration with external instruments, such as microscopes, sensor boxes for measuring environmental values, or surveying instruments. The system can be operated through portable devices (e.g., tablets) to allow users in the field to store exploration sessions. Synchronisation with the other users and surface control centres is possible through wired or wireless relays. In the latter case, a series of wireless mesh repeaters can be used to provide connectivity and real-time communication between the cave, the surface and any other points reached by the distributed network.

1. Introduction

Future human missions to the Moon and Mars will involve sorties to the planetary body's surface called Extra-Vehicular Activities (EVA), focused on scientific exploration. Much like during the Apollo missions (GODDARD *et al.*, 1965), astronauts participating in these EVAs, will investigate scientifically interesting areas, gather a variety of information, including pictures, videos, audio recordings, scientific data and will collect samples, very similarly to what speleologists do while exploring and documenting new caves. Planetary explorers will very likely be supported by a host of new technologies for managing operations and data collection. The storage and distribution method employed to share this data with scientists and agency mission control personnel is vitally important for enabling timely and useful feedback to be provided to the astronauts from specialists on Earth, for example when selecting the best samples for return (HODGES & SCHMITT, 2011). To prepare astronauts for these future planetary science exploration activities, specific training campaigns have been developed by space agencies, like the European Space Agency (ESA) CAVES and PANGAEA courses, to enhance field science, exploration and teamwork experience (BESSONE *et al*. 2013). In this context, the Electronic FieldBook (EFB) was developed as key supporting tool for the ESA CAVES 2019 campaign, which offers a structured and contextualised data collection infrastructure (TURCHI *et al.* 2021). A key part of CAVES is its documentation and science programme. For this, the EFB has developed into a promising system not only for supporting ESA's field training programmes, but also for speleological exploration and research. In this abstract we describe how the EFB has been used during CAVES and we discuss possible uses in speleological expeditions.

2. The Electronic FieldBook use in CAVES training

Traditionally, in speleological exploration campaigns, data is separately captured through a multitude of devices and stored locally. Rarely it is integrated into an overall data collection and distribution system. Surveys, photographs, science points, experiments, samples, specific environmental data are collected on the way and need to be re-organized at the end of the expedition. Having a system that allows the organization of all data collected in real time would be crucial for documenting cave systems, especially during expeditions with limited time and complex logistics.

The Electronic FieldBook (EFB) is a deployable system being developed to meet the needs of astronaut field training, but its functionalities could have direct applications in speleological exploration. The EFB is designed to support field operations, scientific data gathering and direct interaction with remotely located specialists and science support teams through automatic data transmission. The system provides a structured way to collect data during underground activities, where astronaut/speleologists can use a number of sensors and loggers, collect data and/or samples, and take notes, contextually linking all to a timestamp and cave survey points (Fig. 1).

Figure 1: The crew in expedition using the EFB tablet for geo-referencing experiments (Credits: ESA – V. Crobu).

In the frame of ESA CAVES training, the system has been designed to provide real time data and situation awareness to the following primary entities:

- A "Field Segment" (Astronauts/Speleologists), who require a portable tool to retrieve reference geological and survey information, document locations, sites, samples, collect notes and drawings, capture scientific data from analytical tools and communicate with other users during the exploration.
- "Support Centres" (scientists and "mission" support teams out of the cave), who require an overview of the scientific data/samples collected by the team in order to provide relevant and informed scientific or operational advice.

The current version of EFB is developed for laptops and tablets, and provides the following functionalities (Figs 2 and 3):

- Pinpoint of sampling sites on the maps, with retrieval of associated reference and real time information
- Collection and storage of experiments associated to science sites, containing relevant geological/scientific information and data analysis
- Simultaneous crew data acquisition in multiple devices
- Interface with wireless external scientific instruments like microscopes, analytical tools or sensors for environmental monitoring
- Interface with wireless external tools for cave mapping, with automatic download of stations points and rendering in the 2D and 3D maps

The types of information that can be retrieved, collected and exchanged includes, but is not limited to: point clouds, rendered surveys, rich text, photos, audio, videos, reference files, support databases. One of the main functionalities of the EFB is the automatic data flow amongst any element. The system is designed to cope with loss of connection and/or extended offline sessions, ensuring data availability from local database-replicas. The EFB uses a dedicated wireless mesh network to ensure the replication of data across multiple nodes, allowing two distant nodes to share a database without direct connection, and relying on a series of inter-nodes to transfer replicated data.

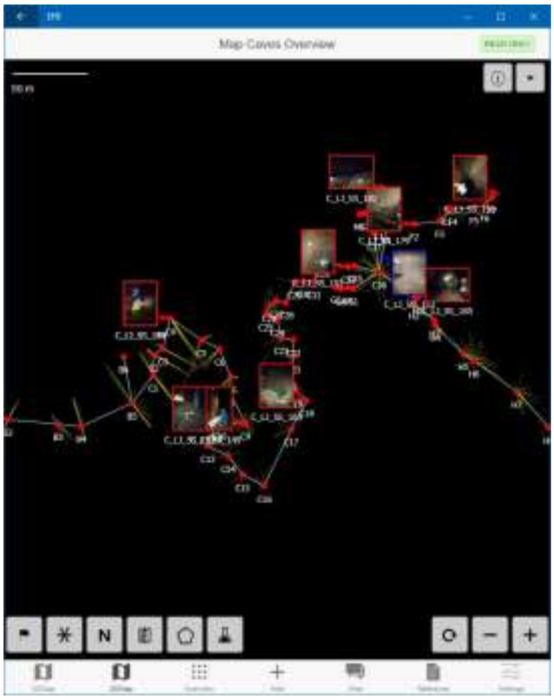

Figure 2: Using the EFB, both field and ground teams can maintain situational awareness over a traverse, each sampling site and experiment can be displayed as pinpoints in 2D (above) and 3D viewers.

The system comes as a fully integrated package including:

- Portable, lightweight, waterproof devices with long battery lives
- Wireless mesh data transmission and disruption tolerant data communication between each system node (different teams in the same cave)
- Data forwarding for long range applications, by use of specific antennas or consolidation nodes
- Data acquisition from every point on the deployed network (e.g., communication with sensors left in key positions)

During CAVES, localization of the science activities carried out during explorations is one of the key aspects providing situational awareness and scientific relevance both to the team of explorers and to the scientists on the surface.

Integration of external devices includes an EFB Environmental sensors, a Microscope, and survey tools such as Leica Disto 8 and Megaplot's CaveSniper from the Polish Speleological Foundation. The first one is a multi-purpose sensor box capable of providing wireless readings over Temperature, Relative Humidity, Pressure, CO_2, O_2, Virtual Organic Compounds, Particulate Matter, Air quality, and providing access to a wireless portable microscope for fauna and soil experiments. The second one is a system formed by a laser ranging distance meter and a tool provided with an internal compass and accelerometer for a quick cave surveying-mapping. The external instruments are constantly connected to the EFB Tablets, enabling them access to real time data acquisition and on the fly assessments. The EFB runtime can fetch, process and generate the updated profile of the explored portion of the cave at a glance, integrating a 2D cave viewer and a 3D cave explorer, as aid for users' selforientation. This is needed for the geotagging of the various entities coordinated by the system, such as crew members, interesting sites, sampling sites, samples, experiments, com infrastructure repeaters. Survey data can be exported in different formats (txt, plt) allowing the interface with other survey software (Therion, Compass, C-Survey). Loop closures have to be implemented in these software and cannot be calculated in the EFB. Also, a drawing tool is not provided in the EFB at the moment but could be implemented in the future.

Cave communications infrastructure consists of a cave-to-surface interlink, achieved through the positioning of a number of EFB Mesh wireless repeaters interconnecting the underground campsite to a surface high bandwidth re-transmitter, providing access to cave data from a remote-control room. For the CAVES 2019 campaign, EFB repeaters were deployed in strategic points of the cave, providing a wireless mesh backhaul throughout a portion of the cave from the surface to the main campsite (Fig. 4). Access points exposed an accessible Wi-Fi network at predefined intervals, for instrumentation and monitoring. A special 'mobile' access node (which included also an embedded camera-microphone) was carried in a backpack, allowing to interface with the network in any position covered by the backhaul inside the cave, and communicate with the outside in case of coordination or remote supervision. A use of specific antenna types for specific nodes locations, together with the calibration of their transmission power, resulted in a very stable network, capable of reaching the camp-site at around 900 meters from the surface, and capable to cross a shaft of 200 meters of depth with a single wireless link. Planning took into account various cable losses, antenna gains, free space loss, moisture and shape of the various cave tunnels, and estimated the front-end sensitivity of each receiver, in order to ensure an acceptable link margin whilst staying below the 100mW EIRP of the EU regulation in each radio.

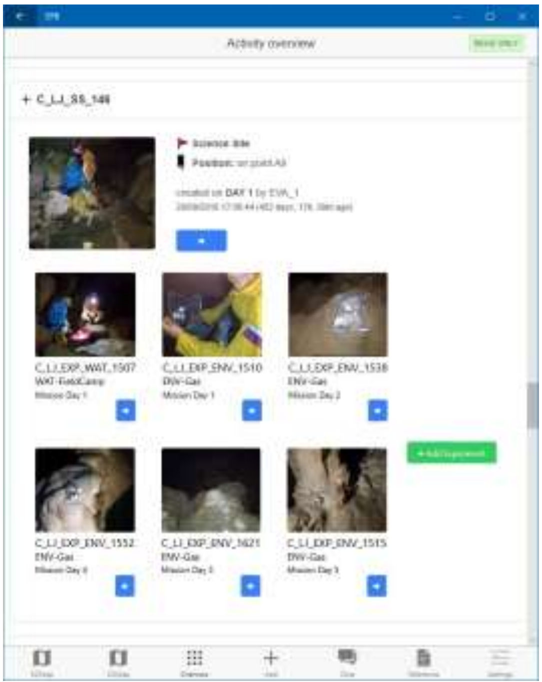

Figure 3: The Overview section of the EFB: science sites, containing experiments, are displayed in a time-based list.

3. Results

Within the ESA CAVES campaigns, which involve astronauts in exploration of underground systems for days, the EFB ensures local cooperative science activities (in real time within astronauts in exploration) and an automatic data forward to the surface-team. The system architecture allows to hold data locally and wait for a connection to synchronize. Scientific data, cave surveys, media, chat, and video logs are exchanged in morning and evening connection windows from the cave base camp to the surface.

According to feedback received from astronauts, speleologists, scientists and engineers, the system outperformed by providing a high level of situational awareness to the support team on the surface about daily progress in exploration and scientific data collected throughout the day. The system provided a safe and low latency local communication for devices and sensors during the scouting, and an asynchronous information exchange from camp-site. The associated EFB environmental sensor box reduced the documentation time in science sites, by directly interfacing to the tablets. In addition to allowing the surface team to keep track of the expedition, both cave and surface team were able to successfully exchange structured-enriched information automatically whenever in the range of the communication network. The surface team could therefore provide remote assistance for data enhancement and aggregation throughout the expedition.

During the 2019 campaign it was possible to initiate live and high-quality video-calls even from the farthest point of the network grid. From our tests we found the mesh network's data rate reflects the real scenario for a chain of a number of consecutive nodes, where (because of the exponential degradation of the throughput across the daisy chain due to retransmissions) the actual throughput after the 7th node is about 10% of the initial one, resulting in our case in a throughput of 0.8 Mbps. We believe the proposed architecture can help field campaigns and speleological expeditions in remote locations where internet/satellite connectivity is not always possible, and where the exploration would benefit of a prolonged stand-alone collaborative science tool (e.g., synching amongst users' tablets) that is capable of auto batch upload to surface teams whenever required (e.g., return to base camp). The system could also allow to geo-localize cave entrances and integrate caves surveys, scientific information (samples, environmental parameters) and photo among multiple teams exploring multiple caves/branches by automatically synchronising data once team return at a common camp. The system could be further developed to include different cave systems, also with application to cave registers

collecting not only survey and entrance photo documentation but also environmental parameters, bio-speleological surveys, geological information, etc.
The system has a large potential to be used as an aid in navigation, since the 3D surveys can be imported into the EFB at any time during an expedition, and if data is returned to the surface on a regular basis, it could offer a valid aid in keeping track of the progress of the expedition, as well as providing a valid tool for rescue organisations on getting a more precise reference information. The project is looking to add additional functionalities in the future, especially aiming at improving the potential use for extending communication and easing navigation.

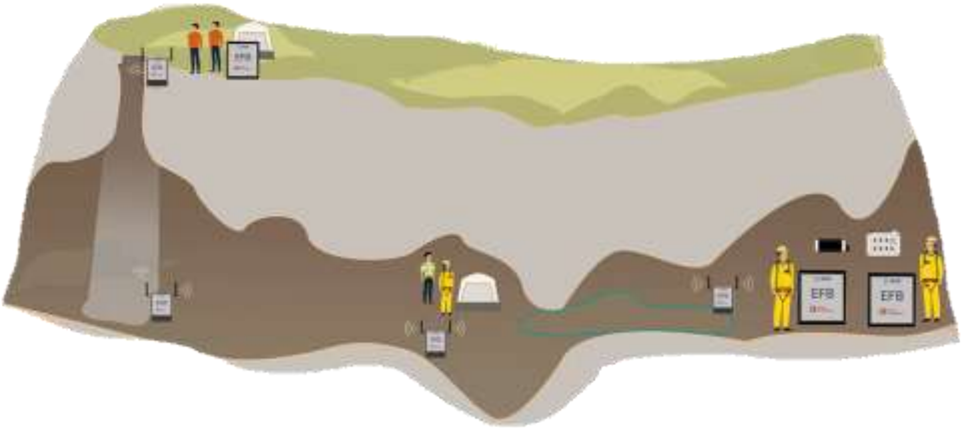

Figure 4: The network used in CAVES 2019. A number of wireless repeaters could enable access to internet, and EFB data exchange between the field and ground teams. The crew could also rely on local connectivity to synchronize data whenever not reachable from the extended wireless network and keep running sampling activities with the help of external sensors or mapping devices.

4. Conclusion

The European Space Agency has developed CAVES: a course that prepares international astronauts as safe and effective teams during spaceflight. To enhance the quality of the course and the analogies with future missions to planetary surfaces, ESA developed the EFB: an information system that allows structured gathering, exchange and contextual visualization of documentation and scientific data between astronauts/speleologists and surface teams, providing a high level of situational awareness and allowing remote scientific and logistic assistance. The same collaborative science architecture provided by the EFB could represent a powerful tool for cooperative science and documentation during speleological expeditions.

Acknowledgments

We gratefully thank the whole ESA European Astronaut Centre (EAC) CAVES & PANGAEA team and the people that supported authors during the field and test campaigns. We would also like to acknowledge the trainees who have worked on the Electronic FieldBook project and scientists who contributed to definition of requirements and to development of key hardware & software features. Additionally, we would like to the institutions that allowed us to access the CAVES field sites for the EFB operations and tests: the Ministry of Environment in Slovenia and the Škocjan Park.

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