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Underground fieldwork – A cultural and social history of cave cartography and surveying instruments in the 19th and at the beginning of the 20th century

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Abstract: At the turn of the 20th century, the practical examination of caves went through a radical change. Governmental organizations and private clubs were founded in an attempt to establish speleology as an independent academic subject. In contrast to earlier cave visitors, travelers began entering underground areas and attributing the names of “explorers” or “researchers” to themselves. Fieldwork—especially cave surveying and cartography—became common practice in speleology and such work provided important clues on speleogenesis, which was a controversial issue in the first half of the 20th century. Due to the fact that speleologists began separating themselves from ordinary cave visitors and tourists, tools and instruments for cave exploration and mapping, such as carbide lamps, ropes, compasses, clinometers, and drawing boards, became the emblems of speleology. Through historical discourse analysis, this paper examines whether this change in the status and practice of underground fieldwork had an effect on the self-perception of speleology and led to new forms of social cooperation and control between speleologists. Further questions address the manner in which the usage of new surveying instruments and the relevance of cave mapping modified the scientific research parameters and the cultural perceptions of the subterranean world. As a contribution to speleo-history, this approach opens a new perspective on the social and cultural dimensions of speleological fieldwork as well as the historical, scientific, and political dynamics in which they were involved. Sources for this research comprised historical scientific papers on cave mapping, textbooks, and archive materials from the Austrian National Library, the Natural History Museum in Vienna, and the Austrian Speleological Association.

Keywords: fieldwork; cartography; instruments; history; survey

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INTRODUCTION

Fieldwork or field research—especially cave cartography—is among the most fundamental and prestigious activities in speleology. In English, the existence of both terms, “speleology” and “caving,” underlines the role of cave surveying and fieldwork to distinguish between the scientific study of caves and the exploration of caves for recreational purposes. As a common practice, such work has a significant influence on the scientific self-perception of this research field and the professional identity of each cave explorer.

Historically, fieldwork arose in the 18th century, when empiric-based earth science was practiced by traveling to certain destinations (Wyse Jackson, 2007). While

earlier hypotheses on speleogenesis were formulated without the need of personal observation, later studies on speleology and cave contents were unthinkable without the experience and arduousness of personal travel. Like above ground travel, subterranean ventures also correspond to cultural practices. Similarly, such activities lead to exotic locations, require cultural exchanges with natives, and consist of phases (i.e., beginning, accomplishment, and return). Until recently, speleology and cave research remained as a “traveling” field of science. More than in other disciplines, fieldwork was responsible for the historical development of speleology and the formation of its own social group consciousness. Similar to geology, the first appearance of instructions in practical cave research and fieldwork was closely connected with the

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emergence of speleology as a scientific field of science (Vaccari, 2007; Klemun, 2012).

Even today, most speleologists would confirm that their discipline is, *per se*, fieldwork that involves scientific examination, survey, collection of finds, and further documentation of undiscovered caves. In contrast to its significance, limited studies have been published about the history of speleological fieldwork, and still less in English (Stummer, 1984; Neumann, 2000; Wookey, 2004; González-Ríos & Miret-Pérez, 2007). While papers and books on speleo-history mostly focus on plans, such as products of extensive fieldwork, photographs or specific tools like carbide lamps, the practice of fieldwork and its social, cultural, political, and scientific contexts are still a desiderate for historical examination. Recently, there has been increasing research on scientific objects, tools, and instruments, which was identified as a “practical turn” in the history of science (Soler et al., 2014). Further studies on expeditions and research travels as cultural and social ventures have also led to a deeper understanding of past and contemporary scientific practices (Schimanski & Spring, 2015). From the perspective of cultural studies, cave trips or subterranean expeditions can also be recognized as “laboratories” where social actors, institutions, instruments, objects, and practices collaborate and different methods of knowledge acquisition are carried out.

Since the turn of the 20th century, forms of cooperation between cave research teams have remained as examples of social practice, which was due to the complex interaction between instruments, a network of users, cultural influences, and scientific demands. In regard to the instruments themselves, while previous studies on scientific tools and instruments described them as devices for “the very practical purpose of making measurements and testing hypothesis by experiment,” recent articles emphasize the importance of tools and instruments as “mediators” between users and research objects during the process of knowledge acquisition (Price, 1980; Gooday, 2000; Meindel, 2008). In her article on the history of the geological hammer, Klemun (2011) pointed out that “an acceptance of an instrument in the scientific community, in practice and society correlates with the importance that is attributed to it not only by epistemic valence but in connection with a particular social status of its users and its cultural meaning.” In cave research, fieldwork was a constituent factor for the establishment of speleology as a scientific discipline and it corresponded to the implementation of measuring instruments and quantifying methods.

Although many cave plans were already drawn before the 18th century, one of the first maps (demonstrably based on a rudimentary cave survey) was made during the Age of Enlightenment by the imperial mathematician Joseph Anton Nagel (1748) in Slovenia (Fig. 1). Based on the usage of economical, easily manageable, and less accurate instruments that were suitable for the hazardous conditions of caves, the knowledge of surveying methods became a cause for the social distinction between non-skilled staff, such as guides or so-called “grotto workers” who were mobilized for mining operations in Slovenian caves, and well-respected speleologists (Pazze, 1893). After 1880, based on the earlier technique of triangulation by mine-surveyors, speleologists began establishing their own methods of cave surveying (Arnberger, 1966).

While the length of a cave was still primarily counted in hours (i.e., the time required to cross the cave), the first authors in the 19th century began calculating distances in the caves with units of length and they subsequently used the data as evidence of personal achievements. For instance, Adolf Schmidl—mostly known as the “father of modern speleology”—boasted about his examination and exploration of more than 15 kilometers of Slovenian cave passages in the yearbook of the Austrian Geological Survey (Schmidl, 1850; Shaw, 1978). He also criticized the practice of earlier travelers who considered the “length of time needed to cover a distance” as the “length of the way” (Schmidl, 1854).

As a critical contribution to the social and cultural history of speleology, the present paper examines whether this change in the status and practice of underground fieldwork had an effect on the self-perception of speleology and helped lead to new forms of social cooperation and control between speleologists. Through historical discourse analysis, this paper focuses on the evolution of cave research in Europe in the second half of the 19th century and the beginning of the 20th century. Sources for this

Fig. 1. Ground plan of the cave 'Postojnska jama' (Slovenia), drawn by Carlo Beduzzi (Nagel, 1748).

research consist of historical scientific papers on cave mapping, textbooks, and archive materials from the Austrian National Library, the Natural History Museum in Vienna, and the Austrian Speleological Association. Furthermore, the renewed self-image of travelers and explorers and their claims of being the first to enter unknown caves will be analyzed under the socio-political aspects of European imperialism. Finally, special attention is paid to the influence of speleological tools and measuring instruments on the new perception of underground fieldwork.

FIELDWORK AS A SOCIAL PROCESS

From travelers to cave explorers

Sources regarding foreign travelers who visited the isolated karst regions and their subterranean areas in Europe date back to the 16th century. These individuals were not only scholars, but they were also merchants, artists, and nobles who yearned for romantic inspiration or pleasurable distraction, either of which could be satisfied by exploring underground caves. The motives of these travelers, however, were diverse. For example, some entered the caves to expand their knowledge and pursue research of the caves themselves, while others widened their collections of natural objects such as rare plants, insects, fossils, and minerals (Shaw, 2008).

After the turn of the 19th century, the number of subterranean travelers increased due to improvements in the transportation infrastructure that facilitated travel to the remote and economically underdeveloped karst regions. The sources of information—besides advice from fellow travelers or innkeepers—varied from early modern travelers' books that described natural wonders by provenance and topic to more descriptive handbooks that detailed specific caves. Beginning in the 1820s, the first widespread illustrated guidebooks, describing the best-known stalactite caves in Istria and Carniola, were published by urban travelers like Girolamo Agapito (1823), Franz Hohenwart (1830–32), and Adolf Schmidl (1853) in various languages such as Italian, German, French, and Slovene (Fig. 2).

In the Austrian Empire, a distinctive show cave management program (“Kgl. Grottenverwaltung”) was established in 1823 to reduce vandalism by travelers and harmonize the flourishing business of cave tours. The use of guides was essential, given the incapacity of most travelers to speak the language or local dialect of the karst regions, and they were imperative in terms of finding and exploring the caves. Recruited from the limited number of local inhabitants, the guides often provided the caving equipment and they were responsible for the lives of the visitors. Over time, some of the guides became regular employees of the show cave management team in order to deal with the increasing number of travelers who were interested in visiting these exotic underground attractions. Despite the availability of maps and detailed guidebooks, the locals still worked for individual travelers who were eager to visit the lesser-known caves, which were impossible to explore without the knowledge of the local population (Mattes, 2015).

Fig. 2. View on the highest point of the ‘Calvary Mount’ in the cave ‘Postojnska jama’ (Slovenia), drawn by Alois Schaffenrath in 1830 (Hohenwart, 1831).

For instance, in the 1880s, Édouard-Alfred Martel and Franz Kraus, founders of the Speleological Societies of France and Vienna, began their speleological research ventures as tourists in southern France and Carniola during their spare time. Both well-to-do gentlemen hired locals (with practical knowledge of karst landscapes and mountaineering) as guides and carriers of their extensive equipment and instruments. The guides were also instructed to reveal the entrances of the lesser-known caves, translate their instructions into the local languages, and handle the safety ropes. Consequently, the cave tours became a welcome source of income and an attraction for the local population. In his book, “Les Abîmes,” Martel described his interactions with the locals:

“Our equipment always attracted keen attention. When we had the misfortune to descend on a Sunday, whole villages would congregate around the entrance to the shaft and impede our activities. When we descended into the abyss, the old women would cross themselves and intone between recitations of the Lord’s Prayer: ‘Doubtless you may be able to climb down, worthy Gentlemen, but you’ll never come up again!’ Or alternately: ‘Madness has many forms!’ ... And the genial priests who offered us accommodation in the absence of guesthouses forced their blessings upon us” (Martel, 1894).

Stereotypical images of the unknown and mysterious underground, created by science fiction literature, such as Jules Verne’s “Journey to the Center of the Earth” (1864), and sensational media coverage encouraged public interest for underground exploration. From 1888 to 1913, Martel organized annual “campaigns” in more than 14 different countries during his summer vacations (Shaw, 1992).

In the second half of the 19th century, cave trips, which required more cooperation and division of labor between the participants, began to gradually differ from the simpler underground excursions of travelers in show caves. Fascinated by the thought of escaping from civilization, urban travelers entered caves searching for

their so-called “lost relationship” with nature. In other words, the tourists no longer felt that they were travelers or passive visitors. Instead, they began to consider themselves as “explorers” focused on a deeper perception of nature. Through new so-called “expeditions” and “campaigns,” signified by a high degree of hierarchy, organization, and pre-planning, these explorers faced more difficult conditions while traversing unknown caves, underground rivers, and deep shafts. Often dispatched from an institutionally developed center to a periphery, with the goal of researching, conducting measurements, making observations, and collecting objects, these expeditions (as a new social form of cave research) had a significant effect on the practice of speleological fieldwork. According to Martel (1894), “The usage of the precise instruments for cave surveying” and the reassessment of cave cartography as “one of the most important activities of cave explorers” should support the scientific claim of this comparatively young field of research.

Institutionalization of speleology

Speleology was eventually institutionalized in the form of competitive private clubs and governmental research organizations. From 1879 on, when the first speleological club was founded in Vienna, local caving societies as well as national speleological associations were developed geographically close to cavernous limestone regions in Graz, Trieste, Postojna, Udine, Paris, and Leeds. As a result of a broad popularization of science and technology at the end of the 19th century, new forms of community and scientific ideals were generated. Especially, the institutionalization of speleology manifested in the form of middle-class clubs interested in natural history. These new communities, which united scientists and members of the bourgeois elite, no longer centered on detailed knowledge, but they focused on Earth and life from a holistic perspective (Daum, 2002). This concept of cave study, bringing together different scientific and social fields of knowledge, can be still found in the organization of modern speleological societies in which scientists and academic cooperate in an interdisciplinary manner. In addition, the intention of the first speleological societies was to combine the scientific and recreational aspects of nature, which were two diverse roles maintained throughout the 19th century. Eventually, this goal was added to the statutes of several speleological clubs and societies (Shaw, 1992).

After the foundation of the “Société Spéléologique de France” (“Speleological Society of France”) in 1895 of which its members originated from diverse European countries, international cooperation increased (Schut, 2011). Nevertheless, up to 1945, speleology primarily remained an exclusive project carried out by members of the social elite who were influenced by nationalistic policies in political dependent territories. Even in the multinational atmosphere of the Austro-Hungarian monarchy, speleology remained as a project of the German-speaking portion of the population, by exploiting the efforts of Slovene, Czech, and Italian cave researchers.

Exclusivity of the “first look”

Since the 1850s, scientists, urban travelers, and academic laymen began entering underground locations with the goal of being the so-called “first visitor.” This claim of being the first human to view, describe, and map an undiscovered area, was not only central for the distribution of meaning, but it also gave legitimization to such activity. However, the majority of the travelers or early explorers made no difference between undiscovered and well-known caves. In fact, due to the high number of competing groups, particularly in Slovenia, Austria, and Italy before World War I, several caves were “rediscovered,” surveyed, and renamed several times by rival groups who struggled for exclusivity of the “first look” (Mattes, 2013).

In many cases, the universal validity of science was used as a justification for inconsiderate investigations and discoveries of unique natural monuments, including explorations of caves that used explosives such as dynamite. Particularly during the 1920s and 1930s, members received clear authorizations concerning their proximity to these undiscovered areas. As expedition protocols concerning the division of labor demonstrate, speleological fieldwork is often based on extensive social practices that aim to limit and legitimate the privilege of the “first look”.

Due to the nationalist atmosphere at the time, cave exploration was often recognized as a political act, mainly practiced by supporters of right-wing politics and deliberately instrumentalized by nationalist propaganda before 1945. Thus, the exclusivity of the “first look,” which also included the privilege and ritual of naming, interpreting, and appropriating the underground locations, can be seen in the imperial context of occupation, acquisition, and consolidation of nation states at the turn of the 20th century.

Consequently, underprivileged groups, such as woodcutters, shepherds, poachers, hunters, and other locals (who possessed knowledge regarding cave entrances and whose economic or religious practices were connected to these underground locations) were excluded from the right to see a cave for the first time. For instance, in “Literaturanzeiger,” the first speleological periodical, Carl Fruwirth (1880) described his “discovery” of a locally known cave (“Annerlbauernloch”) in Styria (Austria): “This cave was only visited once by a group of hunters and woodcutters. Therefore and because of its namelessness, the cave was counted as undiscovered and it became the destination of my next excursion.” Subsequently, Fruwirth named the cave after his colleague Franz Kraus and mounted a plaque with his name at the entrance.

Although the success of a venture is normally based on a team’s effort, the exclusivity of the “first look” was limited to the urban leaders of the expeditions, who mostly consisted of members of the bourgeois elite in the United States, Australia and European countries like Austria-Hungary, England, France, Germany, Italy, and Spain. While locals or natives still took part in the underground campaigns as guides and carriers (“homes de manœuvre”), they were frequently left out of the expedition protocols and not rated as “sufficiently

fearless" (Martel, 1894). This view contradicted the fact that these unskilled locals were assigned to physically demanding or dangerous tasks during the expeditions, which, in some cases, even led to their deaths. For example, during the exploration of the caves "Škocjanske jame" (known as "Höhlen von St. Kanzian" at that time), these so-called "grotto workers" were recruited from local farmers to accompany the German-speaking explorers and build access paths to the undiscovered areas. According to some historical sources, several grotto workers laid down their tools and delayed the work progress due to the fatal accidents that occurred and the poor salaries offered by their employers (Gidl, 2007). A similar practice can also be noticed in Australia or Puerto Rico, where natives or slaves were deployed as cave guides or as explorers for tough and dangerous research goals. In the United States, African Americans like Stephan Bishop played a key role for the development of new cave routes and tourism (Thompson & Thompson, 2003).

CAVE SURVEYING

Surveying as a practice of governance

The socio-political concepts of topographical surveying date back to the 18th century, when measurements, units, and numbers became the "fundamental categories of the reality" and the basis for understanding the world (Behrisch, 2006). This historical discourse was linked to a new concept of space, which recognized a political area as an enclosed, homogeneous zone and enabled a quantitative compilation of its economic resources. Although maps, tables, and lists previously existed, new surveying methods, accurate plans, and enclosed measurements implicated a higher interpretative dominance due to their mathematical claims. As an instrument of standardization and systematization, such surveying methods not only disciplined the operators, but they also normalized the perception of the landscape. Under the aspect of economic exploitation and political domination, topographical surveying projects often went hand-in-hand with nation-building in Europe, America and overseas.

Similarly, the mapping of caves modified the human perception of underground areas, excluding images of body and gender, which were quite common in cave plans and pictures before the 19th century (Fig. 3A, 3B). While the practice of surveying became more homogeneous, the use of map designs and cave plans increased due to the rise in cave tourism and cost-effective improvements in printing techniques. In addition, during the first half of the 19th century, cave surveys were normally conducted based on the visits of sovereigns, members of the local government administration or miners who were authorized by state officials. In Spain, the cave "Coves d'Artà", surveyed in detail in 1862, was a must-see for travelers and naturalists, visiting the Mediterranean area and was described in several travel journals (Pagenstecher, 1867).

In many cases, the plans not only assisted visitors with route-finding, but they also identified the locations

Fig. 3. Caves pictured in anthropomorphic images. A) Detail of the longitudinal section of the cave "Demänovská ľadová jaskyňa" (Slovakia), drawn by Georg Buchholtz (Bél, 1723). B) Watercolour of the cave "Lurgrotte" (Austria) with the illustration of an anthropomorphic speleothem, drawn by Sebastian Rosenstingl (Nagel, 1747).

of bones, fossils, and speleothems. For instance, in his book "Reliquiae Diluvianae", William Buckland (1823) added fascinating longitudinal sections of bone caves, illustrated with digging or climbing staffage figures (Fig. 4). On the contrary, in the United States, the main cause for early cave surveying was the exploitation of saltpeter deposits, which was enforced at the beginning of the 19th century (Wookey, 2004).

During the era of imperialism and nationalism, cave surveying and topographical cartography became a "tool of imperial governance" and "means of control" used by the administration to "conquer and then engineer territorial space" (Seegel, 2012). Based on modernizing practices and Enlightenment discourse, visual control of underground topography often went hand-in-hand with its exploitation as a show cave, as an economic resource or as a scientific archive for natural history. Therefore, in Australia the government got involved in cave exploration, ensuring the appointment of caretakers and keepers, who acted as guide to visitors. While the exploration was mostly carried out by these caretakers, governmental surveyors and draftsmen, mainly of the Geological Survey, were assigned to examine caves scientifically and produced numerable cave plans and maps of cave areas (Shaw, 1992).

Fig. 4. Section of Goat's Hole (also: Paviland Cave) in Wales, mapped by T. Webster after a sketch of W. Buckland (1823).

Rethinking human activity in caves from the perspective of cultural studies, the acquisition of underground space can be realized through the installation of paths and the usage of caves for residential, economic, and cultic purposes. Additionally, cave surveying, further methods of documentation, and the specific act of naming underground locations can also be recognized as immaterial forms of acquisition. As a key part of cave surveying and mapping practices, naming was an essential form of representation through which subsequent travelers and explorers could recognize parts of the cave and its features (Grusin, 2004). However, naming was also essential for the popularity of cave research and the public image of speleology circulating in society. Appellations, such as “Grotta di Morte,” expressed the hazards of such exploration and names like “Abisso Bertarelli” (known today as “Grotta della Marna,” “Abisso di Raspo,” and “Zenkanja Jama”) were given to commemorate historic persons or the explorers themselves. For example, the naming in the show cave “Coves del Drac” in Mallorca is mainly related to explorations in 1896 by Martel, whose research stood under the patronage of the Archduke Ludwig-Salvator from Austria and Tuscany. Figure 5 shows Martel's cave plan of “Coves del Drac”, whose chambers were dedicated to his aristocratic sponsors. In the 20th century, the great pool of the cave was named after Martel to honor its first explorer (Ginés & Ginés, 1992). Especially in Slovenia, cave naming was a political act that represented the social dominance of the German- or Italian-speaking portions of the population. In the nationalist and imperialist contexts at the turn of the 20th century, this was extremely significant. The Austrian speleologist Hans Reisner described cave cartography as a method for taking possession of an underground

area as follows: “The survey of a cave is a basic requirement: for the construction of a show cave, for the exploitation of underground resources and all scientific research” (Reisner, 1921).

Since the details of surveying techniques are rare before 1900, it is impossible to reconstruct them properly. While books on caves and underground attractions published before 1850 (Rosenmüller & Tilesius von Tilenau, 1799, 1805; Lang, 1801; Ritter, 1801, 1803) normally made no difference between artificial and natural caves, mine surveyors and their techniques (especially triangulation) were recognized as most suitable for cave surveying. Well-known cave explorers of the 19th century, such as Anton Lindner, Adolf Schmidl, and Franz Kraus, were all accompanied by miners who realized the plans and were recommended by their employers to other speleologists (Mattes, 2015). Corresponding to the institutionalization of speleology in private clubs and scientific societies, these “cavers” began developing individual surveying techniques mainly based on the use of specific measuring instruments.

In some cases, one's own methodology was more suitable for the specific topography of caves, which was easier to learn than the traditional art of mine-surveying. Such an approach also became a symbol for the scientific autonomy of speleology. For example, William Boyd Dawkins, a Professor of Geology in Manchester, described that cave surveying consists of marking points and measuring legs, which indicate the length, inclination, and angle between two points (Dawkins, 1874). While the usage of a compass for cave surveying was quite common, aneroids or plumbing tools were sometimes utilized instead of clinometers to indicate the altitude of a cave passage.

Fig. 5. Ground plan and vertical section of the cave “Coves del Drac” (Mallorca), drawn by Martel in 1896 (Museo de la Espeleología, Granada, Spain).

In 1894, Martel described the usage of a notebook with an attached compass for cave surveying. After having aligned the small compass with the lamp of his assistant, Martel read off the data, recorded it, and drew the corresponding line, which he subsequently used as the basis for the draft of the remaining cave. The distance was normally measured with a marked rope or by pacing, and the inclination was primarily estimated. For bold slopes, Martel specified an inclination between 33 and 35 degrees (Martel, 1894; Wookey, 2004).

Coinciding with the institutionalization of speleology in private clubs and scientific societies at the turn of the 20th century, the influence of government administration on cave surveying began to decline. Collected in private or club owned cave cadastres, surveying data was handled as a treasure and its limited utilization went in conjunction with demands for financial compensation. For instance, in 1923, the general assembly of the German (and Austrian) Speleological Association (*"Hauptverband Deutscher Höhlenforscher"*) discussed the establishment of a central cave cadastre:

Wolf [President, Berlin]: "One of the most important tasks of the German Speleological Association is to free speleology from the breath of being a servant of science and to accomplish the equality of speleology with other fields of science. We have to bethink ourselves of our treasures. Scientific results of our fieldwork will be only delivered for money or equivalent value".
Bock [Graz]: "The utilization of our cadastre should be only allowed in case of receiving financial compensation. No money, no speleology".
Angermayer [Salzburg]: "Exclusively, the establishment of an own cave cadastre legitimates the foundation the German Speleological Association" (Hauptverband Deutscher Höhlenforscher, 1923).

Surveying as a practice of social distinction

According to this renewed significance of cave surveying and mapping, speleological fieldwork became a location of social distinction. The introduction of various standardized, more abstract plans and more accurate methods of surveying encrypted cave maps and created difficulties for untrained cavers and third parties. For Robert Oedl, a speleologist and cave cartographer in the 1920s, the learning of cave surveying methods "is a long way paved with thorns and requires a great deal of patience" (Oedl, 1922a). In addition to longer and more hazardous expeditions, cave trips became complex social ventures with a high degree of disciplinary action, instruction, and hierarchy. For instance, the instructions for an expedition into the "Geldloch" in Lower Austria—at that time, the deepest cave on world—pointed out that "all participants have to commit themselves to follow all the directions of the leader and the relevant section commander" (Mühlhofer, 1923). Similarly, in his book, "Höhlenkunde," Rudolf Willner indicated the following:

"A division of labor according to the tasks, skills and knowledge of each participant

is indispensable. ... For the continuance of discipline, which is absolutely necessary, it is required that each participant subordinates himself entirely under the expedition leader. He is of course an experienced speleologist"
Willner (1917a).

In other words, speleological fieldwork and cave surveying is based on a strict division of labor. For example, at least three or four cavers as a specialized group had to work together and a "precisely defined task" was assigned to every member. According to the number of available surveyors and assistants, the following functions had to be filled: instrument reader, note keeper/cartographer, lamp and measurement tape holder, and survey station marker. The function of the cartographer, normally occupied by a leading geologist or a caver trained in geoscience, was generally the only one with the privilege of interpreting and naming the underground location (Willner, 1917b). Photos of contemporary cave surveying groups, shown in Figs. 6A and 6B, demonstrate cave surveying as a social process with a clear division of labor. Moreover, the arrangement of the pictured surveyors in Fig. 6A, according to their assigned tasks, illustrates their different levels of social prestige. According to earlier portrayals of geologists and mineralogists, this photo also expresses the new relevance of surveying and mapping, how speleology should be practiced, and depicts the instruments as a "part of the [explorers'] body" or "extension of [their] hands" (Klemun, 2011).

Given that many caves were explored by competing groups and surveying data made such areas quantifiable and comparable to one another by length, depth, and volume, cave surveying and cave plans became exclusive proof for an explorer's personal achievement. Subsequently, surveying began to be recognized as the main legitimization for underground expeditions and it attached "great importance to their research [of the speleologists]" (Martel, 1894). The first speleological periodicals began mentioning the length or depth of the explored caves, not only to place them in order according to their scale, but also to compare the findings of competing speleologists or research groups. Given that many speleologists used unquantifiable terms like "most beautiful" to describe their explorations, and the specific topography of caves made it difficult to compare them to above ground phenomena, the length and depth of an explored area became the main source of information that supported a speleologist's claim and reputation.

Surveying as a practice of science

Finally, the adoption of cartographic and geodetic methods for cave mapping can be considered as a constitutive element in the establishment of speleology as a scientific field (Kyrle, 1923). After measuring charts concerning speleological questions first appeared in the book "Zur Höhlenkunde des Karstes" (1854) by Adolf Schmidl, the scientific importance of cave surveying was emphasized around 1900. Furthermore, a written report by Édouard-Alfred Martel to the Congress of Scientific Societies in Paris (Congrès des Sociétés savantes, à la Sorbonne),

Fig. 6. A) Representative photo of a surveying group, (from left to right) Johann Reger, Major August Neischl, Johann Deinlein, Franconia (Germany) around 1903. (Brand, 1935) B) A surveying group of speleologists inside the cave "Frauenmauerhöhle" in Styria (Austria), photo by Gustave Abel about 1930 (Archive of the Department for Karst and Cave Studies of the Natural History Museum in Vienna).

published as a small book in 1892, can be recognized as the first manual or textbook on cave surveying and mapping. While Martel and subsequent authors of textbooks on speleological cartography underlined the central function of plans for the solution of scientific questions, cave surveying was gradually attributed as a significant "scientific method" (Kyrle, 1931). Much like the characteristics regarding the scientific virtues of surveyors, such as precision, objectivity, and self-control, fieldwork and cave maps became an important legitimization for the scientific value of speleology.

MEASURING INSTRUMENTS

Influence on the self-image of speleologists

The appearance of the first instructions in speleological fieldwork was significantly linked to the development of new methods in cave mapping and the use of measuring instruments as symbols of territorial control, acquisition, and scientific knowledge. In his book, "Cave Hunting," William Boyd Dawkins wrote:

"The instruments which [we] found the most valuable in cave hunting, apart from the tools of

a workman, are as follows: 1. A hammer (...). 2. A chisel (...). 3. A prismatic compass. 4. A thermometer for taking the temperatures of the air and water. 5. An aneroid. 6. A steel measuring tape. 7. Abney's patent level which is used for laying down datum lines for plans, as well as for taking the dips and angles. In making a plan, we have found it useful to mark the datum line by a stout string or wire and to measure from it as the work proceeds, indicating on the sides and floor of the cave the points of measurement with paint or wooden pegs" (Dawkins, 1874).

For Dawkins, "Cave Hunting" covers the practical work of exploring an underground cave scientifically. More specifically, this includes collecting prehistoric remains, fossils, new species, plants, minerals or finding clues for the geology or hydrography of a cavernous landscape. By using instruments for cave surveying, as described above, the results of his cave hunting trips were saved and described in a scientific manner. While measuring tools formed the basis for the cultural appropriation and scientific categorization of caves, exploration of previously boundless depths of vertical caves with the use of a compass, measuring tape, and drawing board also made the explorer's psyche as well as his dreams and fears, controllable.

Along with lamps, candles, and ropes, measuring instruments, such as compasses, aneroids, measuring tapes, plumbing tools, and thermometers, turned out to be the most important equipment in cave exploration. In addition, their correct handling and further development gained a central role in the practice of speleological fieldwork. More than simple tools or measuring devices, distinctive instruments for cave exploration and subsequent mapping (e.g., carbide lights or rope ladders) became the emblems of speleology, which were shown on club logos, badges, and representative photos (Neischl, 1904). Fig. 6A illustrates the prestigious and community-generating function of measuring instruments for the self-image of speleologists.

By using these specific instruments, a new concept of underground fieldwork was formed, which replaced the individual perception of explorers with the objectivity of standardized methods. The look of an admiring traveler of the 18th and 19th centuries gradually changed into a competitive, demanding perception of nature. Moreover, the results of the cave surveys were regarded as "prey for brave explorers" (Hoenig, 1914) and proof regarding the examination of underground caves, which were shared with those on the surface.

According to the differentiation and increase of tools and instruments for cave surveying, the terminology of these travelers changed. The new scientific self-consciousness of speleology led to a modification of the formerly common expressions of "step out a cave" (Valvasor, 1689), "stride across a cave" (Rosenmüller, 1805), and "delve into a cave" (Wankel, 1868). Instead, by focusing only on the observer and not nature as an object, the explorers began using stronger expressions such as "explore" and "survey a cave" (Martel, 1894).

The new linkage between speleologists and their instruments, described above, also required the surveyors and their assistants to undergo special training and instruction. This led to increased disciplinary action within the survey group and identification of speleologists with their instruments. The precision of the instrument was also habitualized by the surveyor and it became an ideal for the accuracy required to adjust the instruments and read off the data. In addition, the instruments' claim to objectivity was taken over by speleologists and transformed into a scientific virtue of the surveyors and a symbol for the objectivity of speleology in general. This not only influenced cooperation and communication within the survey groups, but it also became manifest in the selection of suitable staff for expeditions. From that point on, the surveyor and his assistants had to interact like instruments, collecting data in a continuous production flow. As Ludwig Teißl indicated in his textbook on cave surveying and speleological instruments: "Only persistent, considerate and thoughtful working can guide you quickly to the goal" (Teißl, 1925b).

Invention of new cave surveying instruments

Especially, the search for appropriate instruments used in cave surveying was an essential and consistent part of speleological fieldwork in the first half of the 20th century (Lüdemann, 1926-27). Due to their size, weight, and vulnerability, the survey instruments of miners were not deemed suitable for use in caves. After World War I, several new instruments were developed, tested in practice, and eventually modified. Simultaneously, numerous instructions for cave surveying were published in speleological journals (Oedl, 1923) and since various types of caves existed (e.g., shafts or narrow passages, and ice or water caves), each speleological club or society favored a specific method of traverse surveying and certain types of instruments such as geological, Bézard or miner's compasses as well as levels, clinometers, and telemeters.

In Figs. 7A and 7B, two measuring instruments are shown, which were constructed by German speleologists in the 1920s. The first one is the "Speläometer" by Richard Spöcker in which a spool of measuring tape (made of silk) is fixed onto a tripod. Due to the integrated compass and the graduated arc, the surveyor was able to determine the vertical and horizontal angle as well as the distance between the instrument and the end of the traverse line. The second instrument is the "Polygometer" by Helmuth Cramer, which consisted of a vertical angle with a pendulum and a compass. In this case, the surveyor had to hang the instrument on a tightened measuring tape between point A and B of the traverse line and read off the vertical and horizontal angle. The "Speläometer" and the "Polygometer" included three advantages: 1) their construction was robust and immune to the muddy, wet, and icy conditions in the caves; 2) the instruments could be easily used by both scientific layman and professional surveyors; and 3) only two persons were required to complete an accurate survey.

Fig. 7. Invention of new cave surveying instruments, "Sektion Heimatforschung der naturhistorischen Gesellschaft Nürnberg" (Germany) about 1920. A) "Speläometer" constructed by Richard Spöcker. B) "Polygometer" constructed by Helmuth Cramer (Teißl, 1925b).

CAVE PLANS AND OBJECTIVITY

Maps as sources for scientific hypotheses

While ground plans and longitudinal sections of caves were already drawn in the 17th and 18th centuries, members of the "Société Belge de Géologie" pioneered the use of schematic cross-sections of caves in order to explain their theories on karst hydrology and speleogenesis. In 1894, Édouard Francois Dupont (1893-94) asserted that the formation of caves was due to an acidic solution formed by a reaction between water and carbon dioxide. He also pointed out that this can occur either in the groundwater zone or higher. His recognition of a phreatic solution was an extremely controversial issue in the first half of the 20th century. In arguing that many cave passages were entirely formed by this solution, he also included

representative cross-sections of caves in his scientific publications (Fig. 8A).

A similar theory was published several years afterward by Jonathan Barnes and William Holroyd (1896) of the "Manchester Geological Society." The series of pictures, which they added to one of their scientific papers, also included typical cross-sections of the caves (Fig. 8B) and schematic sketches that indicated the direction of the solution. As shown on Fig. 8C, cartographers began adding cross-sections of caves to their maps. From that point on, especially in regard to the large cave systems in France, Italy, Austria-Hungary, and Germany, the plans were used to reveal clues on speleogenesis and instructions for speleology began to emphasize the relevance of maps as sources for geological and hydrological problems. In addition, cave plans were discussed in articles on karst geomorphology and they were used as an argument during the controversy on karst hydrography between Alfred Grund (1903), Albrecht Penck (1904), and Friedrich Katzer (1909) at the beginning of the 20th century (Martel, 1909; Bock, 1913).

Search for standardized cave symbols

Another unsolved problem was that there were no consistent symbols for cave surveying. In the area of the Austro-Hungarian Empire, the issue was primarily initiated by economic problems. During World War I, the cave commission of the Austro-Hungarian government decided to exploit the phosphoric deposits in caves as organic fertilizers for agriculture (Willner, 1917b). As speleologists and soldiers explored, registered, and drew maps of more than 1,500 caves in the following years, the lack of standardized plans and symbols became an obvious problem since an accurate evaluation of a cave was necessary before any industrial exploitation could be conducted.

Emil Racoviță and René Jeannel (1918) were the first to attempt to introduce internationally valid symbols for cave plans. However, their failure was caused by the enforced nationalization of speleology in the interwar period. Similar attempts were made by the German Speleological Association, which established a commission for the standardization of plan symbols in 1921. Four years later, the Viennese cartographer Ludwig Teiřl (1925b) published a comprehensive handbook on cave surveying and mapping (including a proposal for cave plan symbols) that took account of contemporary cave plans and imitated the symbols of Austro-Hungarian ordnance maps used during World War I (Fig. 9). Nevertheless, many cave cartographers still used their own symbols until the 1960s, when the International Union of Speleology took up Teiřl's plan symbols and accepted a modified proposal made by the geographer Max H. Fink (Audétat & Trimmel, 1966, Trimmel, 1968).

Photography and the truth claim of speleology

With the common usage of photography in cave exploration, the truth claim of speleology experienced a profound modification. Although the history of underground and flash photography began in the

Fig. 8. Cross-sections of caves in geological publications, about 1900. A) Schematic cross-section illustrating phreatic and vadose solution by Édouard François Dupont, 1894 (Willems, 1893-94). B) Series of cross-sections by Jonathan Barnes and William F. Holroyd illustrating the formation of passages by solution (Barnes et al., 1896). C) Ground plan and cross-sections of the cave "Sophien-Höhle" in Franconia (Germany), drawn by August Neischl and Johann Reger in 1902 (Neischl, 1904).

1860s, the broad usage of this comparatively new media for documented claims of cave expeditions cannot be found before World War I. Previously serving as advertising media for show caves or as illustrations of cave trips, photographs were subsequently regarded as an instrument of scientific observation (Asal, 1922a). While cave plans still varied from cartographer to cartographer, the automatic technique of photography

In 1922, the well-known German Alpine photographer Alfred Asal also asserted that speleology requires, above all, “accurate reproductions regarding the morphology of a cave” (Asal, 1922b; Lehmann, 1922).

different plans of the “Gassel-Tropfsteinhöhle” cave in Upper Austria. The maps were drawn in the course of several extensive cave expeditions between 1922 and 1930 by Willibald Hochegger (1922), Richard Spöcker (1927), and Hermann Bock (1930). Being experienced speleologists and cartographers themselves, they did not have enough confidence in the work of their precursors. Thus, the decision was made to map the cave once more. On the one hand, this compilation illustrates certain discrepancies between the used symbols; while on the other hand, the difference in the accuracy of the three cave surveys contravenes the contemporary discourses of accuracy and objectivity in speleology. While Martel (1892) still noticed that cave plans “necessitate highest simplification” and they “can never be more than very sketchy”, the scientific revaluation of photography had a significant influence on cave maps.

“A practiced draftsman will always have the advantage over photographers, that he can

From that point on, instructions for cave surveys began to emphasize the accuracy and exactness of a plan. In this regard, each survey should map a cave as exactly as a photograph would and it should be realized without the subjectivity of the observer. As speleologist Robert Oedl wrote in 1922: “An exploration of a cave without a very accurate description is worthless and this can only be done by a cave plan, which pictures everything. Only on the basis of the most accurate cave plan, scientific questions can be solved” (Oedl, 1922b). For his PhD thesis, Oedl used stereophotogrammetric methods to survey “Škocjanske jame” in Slovenia. His detailed measurements made it possible to construct a 3-dimensional model of the cave in the scale of 1:500, which has substantial similarities to 3-dimensional models of mountains, presented in alpine museums after World War I (Fig. 11) (Shaw, 2010).

Despite adverse environmental conditions, speleologists began to utilize also different types of theodolites to survey a cave (Cramer, 1924; Teiřl, 1925a). First efforts began in England (Ingleborough Cave) and the United States (Mammoth Cave) around

1830 and were carried by mine surveyors (Fig. 12). Further successful attempts to utilize theodolites for cave mapping represent the survey of the Jenolan Caves (Australia) lead by Oliver Trickett and the survey of “Škocjanske jame” (Slovenia) by Anton Hanke (Fig. 13). In these cases, tourism also played a part and inspired the mapping of caves with theodolites. However, the broad use of these more accurate instruments for cave surveying did not occur until after World War I (Cramer, 1926).

An example of a theodolite used for cave surveying is shown in Fig. 14. Constructed by Robert Fuess in Berlin, this theodolite was used to survey the “Eisriesenwelt” cave in the 1920s, which was, at 20 kilometers in length, the world’s longest cave. Although theodolites provided more accurate results than previous surveying instruments, precision was sometimes difficult to obtain due to the environmental conditions of the underground caves and their specific topography. Nevertheless, on the measuring charts, the surveyors began to measure the length of a traverse line not only in meters, but also in centimeters and even millimeters. However, plans of the same cave still

Fig. 11. Model of “Škocjanske jame” (Slovenia), made by R. Oedl in 1924. While the model was destroyed during World War II, this photo was taken by G. Abel (Salzburg) around 1930 (Archive of the Department for Karst and Cave Studies of the Natural History Museum in Vienna).

Fig. 12. Ground plan and sections of Mammoth Cave (Kentucky), drawn by Edmund Lee in 1835. It seems quite possible that Lee also used theodolites for his survey (Library of Congress Geography and Map Division Washington, D.C.).

Fig. 13. Ground plan and vertical section of "Škocjanske jame" (Slovenia), drawn by A. Hanke in 1888 (Archive of the Department for Karst and Cave Studies of the Natural History Museum in Vienna).

varied from cartographer to cartographer, since most of the surveying process (especially the drawings of the cave walls) still depended on the observer. In this sense, the illusion of objectivity and accuracy in cave cartography became an essential part of the scientific claim of speleology.

CONCLUSION

Moreover, the institutionalization of speleology in private societies and scientific institutes went hand-in-hand with new social forms of cooperation and methods of acquisition. In contrast to previous times, cave surveying and the exclusivity of the "first look" became significant parts of the scientific claim of speleology and the most distinguishing features between ordinary cave visitors and explorers. In sum,

representation of the exclusivity of the "first look", cave plans symbolized a scientific and individual entitlement to interpretation and can be recognized not only as a representation of a specific space, but also as a space of representation, where contemporary discourses on knowledge and science were debated. The accuracy and objectivity of the surveying instruments became an ideal for the teamwork and self-discipline necessary for handling the instruments and technical equipment, especially during the exploration of deep shafts. According to the acceptance of photography as a legitimate medium for scientific description, the objectivity and accuracy of cave plans were emphasized, which often stood in contrast with the practice of speleological fieldwork.

Finally, as symbols for social distinction, the usage of surveying instruments and cave plans was mostly limited to the expedition leaders. Due to the fact that speleologists began distinguishing themselves from ordinary cave visitors and tourists, instruments for cave mapping (e.g., compasses, clinometers, drawing boards) and caving tools, such as carbide lamps and ropes, became the emblems for speleology. Rather than individual perception and qualitative reports, objective data and quantifying methods became more significant in speleology. Special details like the length, total depth, and vertical range of a cave were used as the scales that provided evidence of such discoveries and increased the social prestige of an explorer. Furthermore, the introduction of standardized plan symbols and more accurate methods of surveying required surveyors and their assistants to undergo training to read and interpret the cave maps. Based on the aforementioned investigation, although many improvements have occurred in the surveying and mapping of

Fig. 10. Forschungstheodolit von R. Fuess.

Fig. 14. Exploration theodolite used for the survey of the cave "Eisriesenwelt" near Salzburg (Austria). The theodolite was constructed by R. Fuess, Berlin-Steglitz (Germany), around 1910 (Oedl, 1922a).

underground caves as well as the instruments used for such activities, present-day speleology is still based on a variety of specific practices that were formalized at the turn of the 20th century.

Until today, mapping and surveying are still two of the most important activities of speleologists. Even though the use of electronic surveying devices like the DistoX and “paperless” tools for documentation have significantly changed the cave surveying methods, it does not reduce the need of carefulness and accurate plans. Today’s instructions for cave surveying emphasize the necessity to combine a ground plan, longitudinal section and cross-sections of a cave with verbal descriptions and photos in order to give a general idea of a cave’s dimension and content (Häuselmann, 1999, 2007). The recent set of international standardized cave mapping symbols was defined in 1999 (updated in 2008) by the Survey and Mapping Working Group of the UIS’ Informatics Commission, which is engaged in various issues to cave/karst survey and mapping (UIS, 2015).

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REFERENCES

- Agapito G., 1823 – *Le Grotte di Adlersberg, di S. Canciano, di Corniale e di S. Servolo (...)*. Anton Strauss, Wien, 204 p.
- Arnberger E., 1966 – *Handbuch der thematischen Kartografie*. Deuticke, Wien, 554 p.
- Asal A., 1922a – *Photographische Aufnahmen in Höhlen*. In: M. Rohrer (Ed.), *Die Höhle in Sport, Wissenschaft und Kunst*. Verlag der Alpenfreund, München, p. 36-38.
- Asal A., 1922b – *Lichtbildaufnahmen, ausführlicher Bericht über die Ergebnisse der Höhlenexpedition der Akademie der Wissenschaften in Wien, 1921*. Speläologisches Jahrbuch, **3**: 31-33.
- Audétat M. & Trimmel H., 1966 – *Signes conventionnels à l’usage des spéléologues*. Stalactite, **16 (3)**: 71-125.
- Barnes J. & Holroyd W.F., 1896 – *The mountain limestone caverns of Tray Cliff Hill, Castleton, Derbyshire, with some of their contained Minerals*. Transactions of the Manchester Geological Society, **24 (10)**: 215-252.
- Behrisch L. (Ed.), 2006 – *Vermessen, Zählen, Berechnen des Raumes im 18. Jahrhundert*. Campus, Frankfurt a. Main, New York, 181 p.
- Bél M., 1723 – *Hungariae antiquae novae Prodrum, cum Specimine, quomodo in singulis operis partibus elaborandis, versari constituerit*. Monath, Nürnberg, 204 p.
- Bock H., 1913 – *Der Karst und seine Gewässer*. Mitteilungen für Höhlenkunde, Karstmelioration und Urgeschichte, **7 (3)**: 1-23.
- Brand, H. (Ed.), 1935 – *400 Jahre Höhlenforschung in der Bayrischen Ostmark*. Verkehrsamt der Gauleitung Bayrische Ostmark, Bayreuth, 61 p.
- Buckland, W., 1823 – *Reliquiae Diluvianae, or, observations on the organic remains contained in caves, fissures and diluvial gravel and on other geological phenomena, attesting the action of an universal deluge*. John Murray, London, 303 p.
- Cramer H., 1924 – *Bericht über Sektion Heimatforschung der naturhistorischen Gesellschaft Nürnberg*. Mitteilungen über Höhlen- und Karstforschung, **2**: 29-32.
- Cramer H., 1926 – *Bericht Nürnberg*. Mitteilungen über Höhlen- und Karstforschung, **4**: 56-57.
- Daum A.W., 2002 – *Wissenschaftspopularisierung im 19. Jahrhundert. Bürgerliche Kultur, naturwissenschaftliche Bildung und die deutsche Öffentlichkeit 1848-1914*. Oldenbourg, München, 632 p.
- Dawkins W.B., 1874 – *Cave hunting. Researches on the evidence of caves respecting the early inhabitants of Europe*. Macmillan & Co., London, 455 p.
- Dupont É.F., 1893-94 – *Les phénomènes généraux des cavernes en terrains calcaireux et la circulation souterraine des eaux dans la région Han-Rochefort*. Bulletin de la Société belge de Géologie, de Paléontologie et d’Hydrologie, **7**: 190-297.
- Fruwirth C., 1880 – *Kraushöhle ober den Kläfferbrunnen bei Gschöder (Steiermark)*. Literatur-Anzeiger, **5**: 2-4.
- Gidl A., 2007 – *Alpenverein. Die Städter entdecken die Alpen*. Böhlau, Wien, Köln, 445 p.
- Ginés A. & Ginés J., 1992 – *Las Caves del Drac (Manacor, Mallorca). Apuntes históricos y espeleogenéticos*. Endins, **17-18**: 5-20.
- González-Rios M.J. & Miret-Pérez F., 2007 – *La cartografía de cavidades españolas de los siglos XVIII y XIX*. Boletín del Museo Andaluz de la Espeleología, **16**: 7-28.
- Gooday G.J., 2000 – *Instrument as embodied theory*. In: Hessenbruch A. (Ed.), *Readers guide to the history of science*. Fitzroy Dearborn, New York, p. 376-378.
- Grund A., 1903 – *Die Karsthydrographie, Studien aus Westbosnien*. Geographische Abhandlungen, **7 (3)**: 101-301.
- Grusin R., 2004 – *Culture, technology, and the creation of America’s National Parks*. Cambridge University Press, Cambridge, New York, 214 p.
- Hartwig G., 1863 – *Die Unterwelt mit ihren Schätzen und Wundern, eine Darstellung für Gebildete aller Stände*. Kreidel, Wiesbaden, 474 p.
- Häuselmann P., 1999 – *UIS-Höhlsignaturen: Definitive Liste*. Stalactite, **49 (2)**: 110-113.
- Häuselmann P., 2007 – *Nachhaltige Vermessung und Kartierung von Höhlen*. Die Höhle, **58**: 90-98.
- Hauptverband Deutscher Höhlenforscher, 1923 – *Gener-al-versammlung 1923*. Mitteilungen des Hauptverbands Deutscher Höhlenforscher, **2-3**: 13-27.
- Hoening T., 1914 – *Die Höhlenforschung in den Alpen*. Mitteilungen des Deutschen und Österreichischen Alpenvereins, **40 (6)**: 86-88.
- Hohenwart F., 1830-1832 – *Wegweiser für die Wanderer in der berühmten Adelsberger und Kaiser Ferdinands-Grotte, bei Adelsberg in Krain*. Kleinmayr, Ljubljana, 82 p.
- Jeannel R. & Racoviță E.G., 1918 – *Enumération des grottes visitées 1913-1917*. Biospéologica **39**. Archives de zoologie expérimentale et générale, **57 (3)**: 203-470.

- Katz F., 1909 – *Karst und Karsthydrographie*. Kajan, Sarajevo, 94 p.
- Klemun M., 2011 – *The geologist's hammer. 'fossil' tool, equipment, instrument and/or badge?* Centaurus, **53** (2): 86-101.
<http://dx.doi.org/10.1111/j.1600-0498.2011.00220.x>
- Klemun M., 2012 – *Verwaltete Wissenschaft: Instruktionen und Forschungsreisen*. In: Hipfinger A., Löffler J. & Niederkorn J. (Eds.), *Ordnung durch Tinte und Feder? Genese und Wirkung von Instruktionen im zeitlichen Längsschnitt vom Mittelalter bis zum 20. Jahrhundert*. Böhlau & Oldenbourg 2012. Wien, München, p. 391-412.
- Knebel W., 1906 – *Höhlenkunde mit Berücksichtigung der Karstphänomene*. Friedrich Vieweg & Sohn, Braunschweig, 222 p.
- Kraus F., 1894 – *Höhlenkunde–Wege und Zweck der Erforschung unterirdischer Räume*. Carl Gerold's Sohn, Wien, 308 p.
- Kyrle G., 1923 – *Grundriss der Theoretischen Speläologie*. Österreichische Staatsdruckerei, Wien, 353 p.
- Kyrle G., 1931 – *Die Entwicklung der Höhlenkunde in Österreich*. Mitteilungen der Geographischen Gesellschaft in Wien, **74**: 346-352.
- Lang C., 1801 – *Galerie der unterirdischen Schöpfungswunder und des menschlichen Kunstfleißes unter der Erde. Verfasser des Tempels der Natur und Kunst, der Haushaltung des Menschen unter allen Himmelskörpern*. 2 volumes. Karl Tauchnitz, Leipzig, 416 p.
- Lehmann O., 1922 – *Morphologische Beobachtungen, ausführlicher Bericht über die Ergebnisse der Höhlenexpedition der Akademie der Wissenschaften in Wien, 1921*. Speläologisches Jahrbuch, **3**: 51-121.
- Lüdemann K., 1926 – *Ein kleines Universalinstrument für die Vermessung von Höhlen*. Zeitschrift für Instrumentenkunde, **46**: 148-150.
- Lüdemann K., 1927 – *Ein Universalinstrument für die Höhlenmessung*. Mitteilungen des Hauptverbands Deutscher Höhlenforscher, **5** (2): 50-56.
- Martel É.A., 1892 – *Les levés topographiques sommaires. Communication faite au Congrès des Sociétés savantes, à la Sorbonne (section de géographie), le 8 juin 1892, au nom de la Société de Topographie de France*. Congrès des Sociétés savantes, Paris, 7 p.
- Martel É.A., 1894 – *Les Abîmes, les eaux souterraines, le cavernes, les sources, la spéléologie*. Librairie Charles Delagrave, Paris, 578 p.
- Martel É.A., 1909 – *Critique de l'ouvrage du Dr. Alfred Grund „Die Karsthydrographie“*. Notices spéléologiques–Spelunca, **7**: 343-347.
- Mattes J., 2013 – *Alexander von Mörk and Poldi Fuhrich. The conception of heroes in cave exploration in the early twentieth century*. Earth Sciences History, **32** (1): 132-149.
<http://dx.doi.org/10.17704/eshi.32.1.8403887w11p5j125>
- Mattes J., 2015 – *Reisen ins Unterirdische. Eine Kulturgeschichte der Höhlenforschung in Österreich*. Böhlau, Wien, Köln, Weimar, 451 p.
- Meinel C. (Ed.), 2000 – *Instrument—Experiment. Historische Studien*. GNT-Verlag, Diepholz, 423 p.
- Mühlhofer F., 1923 – *Ausschreibungen für 1923*. Mitteilungen des Hauptverbands Deutscher Höhlenforscher, **1** (1): 19.
- Nagel J.A., 1747 – *Beschreibung des auf allerhöchsten Befehl Ihro Maytt. des Römischen Kaisers und Königs Francisci I. untersuchten Oetscherberges und verschiedener anderer, im Herzogthume Steyermark befindlich, bishero vor selten und verwunderlich gehaltener Dingen*. Austrian National Library, manuscript-code: 7920.
- Nagel J.A., 1748 – *Beschreibung deren auf allerhöchsten Befehl Ihro Röm. kaiserlichen königlichen Maytt. Francisci I untersuchten, in dem Herzogthume Crain befindlichen Seltenheiten der Natur*. Austrian National Library, manuscript-code: 7854.
- Neischl A., 1904 – *Die Höhlen der fränkischen Schweiz und ihr Bedeutung für die Entstehung der dortigen Täler*. Schrag, Nürnberg, 95 p.
- Neumann, A. 2000 – *Beiträge zur Kartographie und Visualisierung von Karst- und Höhlensystemen*. Unpublished MS thesis, University of Vienna, 168 p.
- Oedl R., 1922a – *Vermessung, ausführlicher Bericht über die Ergebnisse der Höhlenexpedition der Akademie der Wissenschaften in Wien, 1921*. Speläologisches Jahrbuch, **3**: 5-30.
- Oedl R., 1922b – *Die moderne Höhlenforschung*. In: Rohrer M. (Ed.), *Die Höhle in Sport, Wissenschaft und Kunst*. Verlag der Alpenfreund, München, p. 1-15.
- Oedl R., 1923 – *Auswertungsmöglichkeiten von Höhlenvermessungen*. Speläologisches Jahrbuch, **3**: 138-144.
- Pagenstecher H.A., 1867 – *Die Insel Mallorca. Reiseskizze*. Wilhelm Engelmann, Leipzig, 186 p.
- Pazze P.A., 1893 – *Chronik der Sektion Küstenland des Deutschen und Österreichischen Alpenvereins 1873-1892. Fest-Publikation zur Vollendung des 20. Vereinsjahres*. Sektion Küstenland des Deutschen und Österreichischen Alpenvereins, Triest, 372 p.
- Penck A., 1904 – *Über das Karstphänomen. Vortrag gehalten den 4. November 1903*. Vorträge des Vereins zur Verbreitung naturwissenschaftlicher Kenntnisse in Wien, **44**: 1-38.
- Price D.J. de Solla, 1980 – *Philosophical mechanism and mechanical philosophy. Some notes towards a philosophy of scientific instruments*. Annali dell'Istituto e Museo di Storia della Scienza di Firenze, **5** (1): 75-85.
- Reisner H., 1921 – *Anleitung zur Aufnahme von Grundrißplänen, Längen- und Querprofilen in Höhlen*. Berichte der staatlichen Höhlenkommission, **2**: 10-24.
- Ritter C.W., 1801, 1803, 1806 – *Beschreibung der größten und merkwürdigsten Höhlen der Erde. Allen Verehrern des Erhabenen Schönen in der Natur gewidmet*. 3 volumes. Kratzsch, Hamburg, 112 p., 110 p., 96 p.
- Rosenmüller J.C. & Tilesius von Tilenau W.G. (Eds.), 1799, 1805 – *Beschreibung merkwürdiger Höhlen, ein Beitrag zur physikalischen Geschichte der Erde*. 2 volumes. Breitkopf & Härtel, Leipzig, 294 p., 391 p.
- Schimanski J. & Spring U., 2015 – *Passagiere des Eises. Polarhelden und arktische Diskurse 1874*. Böhlau, Wien, Köln, Weimar, 719 p.
- Schmidl A., 1850 – *Die Untersuchung einiger Höhlen im Karst*. Jahrbuch der k. k. Geologischen Reichsanstalt, **1**: 701-705.
- Schmidl A., 1853 – *Wegweiser in die Adelsberger Grotte und die benachbarten Höhlen des Karst*. Braumüller, Wien, 88 p.
- Schmidl A., 1854 – *Zur Höhlenkunde des Karstes. Die Grotten und Höhlen von Adelsberg, Lueg, Planina und Laas. Mit Beiträgen von Alois Pokorny, Johann Rudolf Schiner und Wilhelm Zippe*. Wilhelm Braumüller, Wien, 317 p.
- Schut P-O., 2011 – *L'exploration souterraine, une histoire culturelle de la spéléologie*. L'Harmattan, Paris, 394 p.
- Seegel S., 2012 – *Mapping Europe's Borderlands. Russian cartography in the age of empire*. Chicago University Press, Chicago, London, 168 p.
<http://dx.doi.org/10.7208/chicago/9780226744278.001.0001>

- Shaw, T.R., 1978 – *Adolf Schmidl (1802-1863). The father of modern speleology?* International Journal of Speleology, **10**: 253-267.
<http://dx.doi.org/10.5038/1827-806X.10.3.3>
- Shaw T.R., 1992 – *History of cave science, the exploration and study of limestone caves, to 1900*. Sydney Speleological Society, Sydney, 338 p.
- Shaw T.R., 2008 – *Foreign travellers in the Slovene karst 1486-1900*. Karst Research Institute at ZRC SAZU, Ljubljana, 338 p.
- Shaw T.R., 2010 – *Aspects of the history of Slovene karst 1545-2008*. ZRC Publishing, Ljubljana, 306 p.
- Soler L., Zwart S. & Lynch M. (Eds.), 2014 – *Science after the practice turn in the philosophy, history, and social studies of science*. Routledge Chapman & Hall, London, New York, 346 p.
- Stummer G., 1984 – *Die Entwicklung der Vermessung und Darstellung von Höhlen in unserem Jahrhundert*. In: Mais K., Mrkos H. & Seemann R. (Eds.), *Akten des Internationalen Symposiums zur Geschichte der Höhlenforschung Wien 1979*. Wien, Landesverein für Höhlenkunde in Wien und Niederösterreich, p. 78-80.
- Teiřl L., 1925a – *Der Plan der Drachenhöhle bei Mixnitz*. Berichte der Staatlichen Höhlenkommission, **2**: 25-29.
- Teiřl L., 1925b – *Die Herstellung von Kartenskizzen natürlicher Höhlen*. Österreichischer Bundesverlag für Unterricht, Wissenschaft und Kunst, Wien, 54 p.
- Thompson B. & Thompson J., 2003 – *Mammoth Caves and the Kentucky cave region*. Arcadia Publishing, Charleston, Chicago, Portsmouth, 128 p.
- Trimmel H., 1968 – *Höhlenkunde*. Friedrich Vieweg, Braunschweig, 300 p.
<http://dx.doi.org/10.1007/978-3-663-07259-1>
- UIS – Informatics Commission, Survey and Mapping Working Group. <http://www.uisic.uis-speleo.org/wgsurmap.html> [accessed April 1, 2015].
- Vaccari E., 2007 – *The organized traveler. Scientific instructions for geological travels in Italy and Europe during the eighteenth and nineteenth century*. In: Wyse Jackson P.N. (Ed.), *Four centuries of geological travel: The search for knowledge on foot, bicycle, sledge and camel*. Geological Society, London, p. 7-17.
- Valvasor J.W., 1689 – *Ehre dess Hertzogthums Crain*. Volume 1. Wolfgang Moritz Endter, Laybach, 696 p.
- Verne J., 1864 – *Voyage au centre de la Terre*. Pierre-Jules Hetzel, Paris, 219 p.
- Wankel H., 1868 – *Die Slouper Höhle und Ihre Vorzeit*. Denkschriften der Kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Klasse. Zweite Abtheilung. Abhandlungen von Nicht-Mitgliedern der Akademie, **28 (2)**: 95-131.
- Willems W., 1893-94 – *Étude de la circulation de l'eau dans les calcaires et visite des grottes de la Lesse*. Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie, **7**: 298-377.
- Willner R., 1917a – *Kleine Höhlenkunde*. Verlag des k. k. Ackerbauministeriums, Wien, 113 p.
- Willner R., 1917b – *Die Auswertung von Karsthöhlen*. Verlag des k. k. Ackerbauministeriums, Wien, 156 p.
- Wookey, 2004 – *Cave Surveying*. In: Gunn J. (Ed.), *Encyclopaedia of caves and karst science*. Fitzroy Dearborn, New York, London, p. 714-717.
- Wyse Jackson P.N. (Ed.), 2007 – *Four centuries of geological travel: The search for knowledge on foot, bicycle, sledge and camel*. Geological Society, London, 415 p.