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National spaces and deepest places: Politics and practices of verticality in speleology

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SPECIAL ISSUE
Verticality in the History of Science

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Abstract

This paper examines the practices and epistemic dimensions relating to subterranean space that led to a new three-dimensional understanding of the terrain, its scientific investigation, and its political acquisition as territory. Although caves had been explored by upright descent since the 18th century, improved techniques for surveying, mapping, and exploring deep shafts established speleology ("cave study") as a scientific discipline. As political interest in the military and economic uses of caves was growing, national cave cadasters, state-owned speleological research institutes, and legal regulations evolved accordingly. This development resulted in a vertical concept of territory in Europe during World War I and the interwar period. Especially in archeology and prehistory—so-called "national" sciences—politics and scholarly research became resources for each other, with both, in their respective ways, being committed to the natural and cultural underground heritage.

KEYWORDS
epistemes, politics, practices, speleology, territory, verticality

1 | INTRODUCTION

> In recent days, a surprising discovery was made in the "Neanderthal" valley. The removal of limestone rocks … revealed a cave that had been filled with clay deposits over centuries. … The examination of a skeleton [found there], namely a skull, has shown that the individual belonged to the Flat Heads' tribe

> that is still living in the American West. … Did this skeleton originate from a primitive tribe settled in Central Europe or simply from (Attila's?) wandering hordes?[1]

The first 1856 newspaper report about the examination of certain human fossils, later identified as the species *Homo neanderthalensis*, marked the beginning of a long-lasting debate about the skull's characteristics and origin. The attempts of researchers to attribute the fossils even to a Russian soldier from the Napoleonic Wars illustrates the entanglement of anthropological, racist, and political discourses on national ancestry.[2] Following the renegotiation of nature, humankind, and the past that had culminated in Charles Darwin's *On the Origin of Species* (1859), the temporal dimension of soil depth needed to be reevaluated as well. Previously established knowledge had to be revised and new findings were eagerly screened for new insights. Growing fields of research such as geology, paleontology, (paleo)anthropology, and prehistory paid special attention to caves as archives of natural and human history.[3] Their practitioners worked in heavy darkness while digging, crawling, descending, or climbing into those archives. The production, practices, control, and circulation of knowledge were not only characterized by horizontal movements but also vertical ones. Guiding our view up and down, vertical dimensions of science intersect with various spheres of knowledge, often studied separately: human life and lifeless, untouched places; anthropogenic impacts on the natural environment and prehistoric finds; and mountains and deep pits.

Since ancient times, the horizontal entrances of grottos had been frequented regularly and were often associated with various cultural practices of fertility. In contrast, their vertical counterparts—deep pits and shafts—evoked experiences such as fear and curiosity when looking down. For scholars, the subterranean space did not solely represent a vertical hole or gap in their knowledge that had to be explored, surveyed, mapped, and finally brought under control. Facing bottomless abysses, visitors experienced the depth both in a spatial, three-dimensional way and a chronological-historical one. At the subterranean level, the beginning of the earth's chronology revealed itself through fossil deposits, speleothems, and different layers of rock or soil. Combining the longing for faraway places with a new perception of the earth's interior as an archive for paleo-environments, the term “depth” became increasingly popular and underwent significant semantic transformations throughout the 19th century. One common analogy linked the depth of subjectivity to the depth of subterranean space. Thus, verticality was attributed to the exploration of caves, which travel writers increasingly compared to an alpine experience.[4] Along with the ability to overcome vertical drops by upright descent and ascent, cave expeditions became multidirectional journeys, adding the down and the up, the depths and the heights of subterranean spaces, to the range of possibilities.

Recent scholarship in political geography has broadened our understanding of vertical spaces as complex three-dimensional landscapes of social practice, and of their entanglement with diverse patterns of power, geopolitics, and the usage of surveillance technologies from the earth's surface. Bruce Braun's 2000 paper discussing the production of vertical territory in 19th-century Canada has traced the process of how a new visual language of geology and new forms of governmentality led to a vertical understanding of state territory.[5] Linking scientific developments to a raison d'état, Braun suggests that the “geologization” of the state's territory, realized through powerful technologies to optimize its use, shaped the ways in which landscapes were seen by the public. Similarly, political technologies play a key role in Stuart Elden's pioneering article “Secure the Volume” (2013), in which he uses examples from the Middle East to analyze the spatial power of state territorializing practices. He suggests that territories and territoriality can be thought of as volumes, not as flat areas.[6] In the following years, Elden's work boosted debates in geographical scholarship on volumetric political strategies and voluminous spaces, paving the way for a broad range of scientific literature dealing with questions of vertical geopolitics, the qualities of volumes, and spatial spheres beyond

[1]N. N. (1856, p. 3).
[2]See Mayer (1864, p. 21).
[3]See Rudwick (1989, pp. 231–251); Shortland (1994, pp. 1–61).
[4]See Mattes (2015a, pp. 152–156).
[5]Braun (2000, pp. 7–46).
[6]Elden (2013, pp. 35–51).

terra. These include, for example, case studies on mines, bunkers, submarine waterscapes, subterranean ecologies, resource extraction, and dumping.[7] A geopolitical approach to earth sciences and the Anthropocene has been provided by the volume *Political Geology* (2019), edited by geographers Adam Bobbette and Amy Donovan. Further developing the concept of "subterranean territorialization," the authors argue that not only politics bases on the appropriation, processing, and distribution of geological resources, but also that "geology too emerges in and through political processes, as it is demarcated, framed, and becomes an object of knowledge."[8] In a recent special issue of the journal *Geopolitics* dedicated to subterranean geopolitics, the guest editors Rachael Squire and Klaus Dodds even noticed a "subterranean turn" in political geography and allied disciplines such as anthropology, environmental studies, and architecture, setting out four characteristics that constitute subterranean geopolitics: voluminous spaces; their impact on "nation-state building" and "strategies of control, enclosure and exclusion"; their "infrastructure"; and their "calculative, legal and technical regimes of regulation."[9]

While none of these approaches focus on naturally formed cavities in particular, an attentive revisit reveals questions about the historicity and homogeneity of underground space(s) and the impact of science on the subterranean world(s) that goes beyond (political) technologies. Are we blending diverse spaces of knowledge, timelines, and scientific practices when speaking about a "common underground sphere," as Athanasius Kircher may still do in his *Mundus subterraneus* (1665)? There is much more to be said about this, and the present article urges greater caution in subscribing to this notion of unity. Even the three-dimensional shapes of caves can differ considerably as a result of the type of rock in which they were formed, thereby influencing the diverse scientific, cultural, and technical ways of dealing with the underground. The first to analyze the social practices and dynamics related to cave research through the lens of (vertical) geographies have been Sarah G. Cant, Paul George Munro, María Melo Zurita, María Pérez, and myself. Examining the historical geographies of speleology in Britain between 1935 and 1953 and in particular the labor of its national associations, Cant explores the extent to which the practice of fieldwork, and specifically "strong personalities," shaped the dual character of British speleology ("cave study") as a sporting science.[10] Munro and Melo Zurita, on the other hand, examine the significance of cenotes (natural pits with groundwater underneath) in the history of the Yucatan Peninsula in Mexico. Studying their physical and symbolical transformations, the authors explain how these unique sites have been "controlled as a source of political and social power, been utilized for resistance, and have preserved certain parts of history."[11] Pérez, having participated personally in several recent cave expeditions in Venezuela, approaches the topic from an ethnographical standpoint and critiques the idea of volumes as containment. She shows how vertical geographies are embodied, experienced, and constructed, as well as the social dynamics, technologies, and masculinist heroics involved in traversing them.[12] In my study *Reisen ins Unterirdische* (*Travelling into the Underground*), I provide a *longue-durée* cultural history of knowledge-based interactions with caves from antiquity until the turn of the 20th century, with a focus on the Habsburg Empire.[13] This includes an analysis of the karst areas' impact on the development of cave cadasters, deep alpinism, and specific body aesthetics. Also noteworthy is a recent article by María Pérez and María Melo Zurita in which the authors embed their topic in a broad review of anglophone geographic scholarship and argue, mostly on the basis of recent speleological projects in Venezuela, Cuba, and Mexico, for a significant "heterogeneity of volumetric territorial projects."[14]

Certainly, human practices of dealing with the underground were manifold and the various political, economic, and scientific claims involved led to a multiplicity of simultaneous, overlapping, and partly contradictory concepts of

[7]See, on bunkers, Bennett (2017); Klinke (2018); on waterscapes, Melo Zurita & Munro (2019, pp. 38–47); Peters & Steinberg (2019, pp. 293–307); for case studies on diverse spaces beyond terra, for example, Peters, Steinberg, & Stratford (2018); and for a popular approach, Macfarlane (2019).
[8]Bobbette & Donovan (2019, p. 3).
[9]Squire & Dodds (2020, p. 4). For a recent interdisciplinary approach to the subterranean realm, see a special issue of the journal *Communications* (EHESS Paris), edited by Peyrière & Ribert (2019, pp. 5–11).
[10]Cant (2006, pp. 775–795).
[11]Munro & Melo Zurita (2011, p. 612).
[12]Pérez (2015, pp. 226–247).
[13]Mattes (2015a).
[14]Pérez & Melo Zurita (2020, p. 7).

territoriality. It is, however, also worth mentioning that the subterranean realm represents a mutable space where verticality per se is negotiated in an experimental setting, and this rather uncertain entity was incrementally being rendered calculable and manageable. "Extreme" environments such as mountains, the deep sea, and caves served as distinct laboratories, visited and harnessed through challenging expeditions, where natural or social phenomena could manifest themselves to a greater extent than in man-made laboratories in cities.[15] Science and politics represent domains analogous to subterranean spaces that are rather mutable and negotiated through application. Analyzing the relationship between science and politics and their continuities and transformations throughout the 20th century, Mitchell G. Ash advocates for a delimitation of both spheres of practice. Science and politics are characterized as "moving targets" of changing alliances, networks, and breaks that interact with each other.[16] Rather than one-sided instrumentalizations, they become "resources for each other" and "mutually mobilizable resource ensembles."[17] Similarly, the early 20th-century ambition to establish speleology as a predominately national form of science coincided with demarcation processes in politics and research, and is closely connected to reallocations of resources. With nation-states no longer conceptualized as two-dimensional environments and with a more open or boundless understanding of space, vertical geographies and verticality per se represent welcome resources for science and politics.

This article aims to contribute to a better understanding of "temporal depth" in the study of vertical geographies and therefore addresses both historians of science and (political) geographers. It offers an in-depth discussion of the emergence of speleology in Europe between circa 1850 and 1930 as well as broader themes beyond this particular field. The scientific study of caves provides a novel lens and point of departure to explain the emergence of a whole new array of metadisciplinary theory and methodology for overcoming the challenging dimension of the vertical. Verticality cannot be regarded solely as a result of new methods for visualizing the earth's subsurface combined with new forms of national governmentality. Building on scholarship that addresses a vertical understanding of terrain, this paper further investigates the complex political implications of this approach with regards to the heterogeneity of the underground and the practices of its exploration and survey. Specifically, how was a vertical concept of terrains and territoriality produced together with a new scientific field, its practices, and social contexts? To put it in a nutshell, scientific boundary-work coincides with political-territorial and social boundary-work, both below and above ground, and these should therefore be analyzed together.[18] Finally, the article suggests that different political, economic, and scientific claims by both the victorious and defeated states of World War I resulted in diverse ways to approach subterranean spaces and the vertical.

This paper does not seek to enter the topical debate on whether verticality or volume is the most appropriate method for analyzing the social world and the spaces of knowledge that surround us. In accordance with the other contributions to this special issue, I am more interested in explaining how both concepts could benefit historians of science. In particular, I would like to address the realm beneath our feet and the knowledge-based practices related to it. In doing so, this article further illustrates how these approaches could become a useful tool for historians to understand the role of space and place in the production, negotiation, and institutionalization of science. Thus, the term "vertical geographies" as it is used in the following should be not understood as an opposite of "volumetric geographies," but rather as putting special emphasis on the dimension of height and depth and their role in the scientific research of caves.

Methodologically, this case study is based on a source-critical and discourse-analytical investigation of extensive primary sources. These mainly consist of scientific literature on caves and karst areas created in Europe between 1850 and 1930, as well as map sources that are compared with a specific regard to the techniques used in them to visualize vertical dimensions. Particular attention will be paid to the improved practices of surveying, mapping, and

[15]See Bigg, Aubin, & Felsch (2009, pp. 311–321); Klemun & Spring (2016). Currently, a very promising research project entitled "The Cave Lab Project: Science, Technology and Other Stories in the Karst of Bizkaia" is being conducted at the University of Edinburgh by the STS scholar Simone Sambento (2020, pp. 80–83).
[16]Ash (2016, p. 537).
[17]See also Ash (2002, p. 32).
[18]On the role of boundary objects in science, see Star & Griesemer (1989, pp. 387–420).

exploring deep shafts that informed speleology as a respectable science. It should be noted that the following propositions are (central and western) European perspectives on caves and notions of verticality and have no claims to universality. Rather than imposing a Eurocentric assumption of the generalizability of European experiences, I suggest that the reason this particular geopolitical area deserves a mention in international scholarly discussions is that it is commonly regarded as the origin of institutionalized, state-supported speleology. Moreover, this approach shows that the development of scientific caving practices was region-specific and that Europe cannot be seen as a monolithic entity. For instance, (supra)national associations for cave research, state-owned research departments, (bio)speleological laboratories, commissions at national academies of sciences, and even a special university chair were founded in continental Europe around World War I. By contrast, the establishment of the British Speleological Association in 1935 and of the first societies in Cuba and North America around 1940 happened considerably later and were broadly based on the field's recognition as a sporting activity with a scientific impetus.[19] In the Soviet Union, institutionalized scientific research was further delayed until the Cold War, during which an interdepartmental Karst Commission (1958) was established in the Soviet Academy of Sciences and a special institution was founded under the auspices of the Ukrainian Academy.

2 | PRACTICES AND EPISTEMES OF VERTICALITY BEFORE 1914

When Antonio Lindner, a mining official in Trieste, Italy, developed his plan to reconstruct the course of the underground river Reka from the sinkhole of Škocjan to its Adriatic estuary 38 km away, economic and political considerations were decisive factors. To solve the shortage of drinking water in Trieste, he intended to tap the stream in its depths. By scouring the terrain for deep pits, tracing the reports of locals on subterranean water noise after heavy rainfall, and linking his records on maps, Linder developed a new understanding of terrain, whereby he compared the main characteristics of aboveground topography with the phenomenology of vertical geographies. In his following attempt to prove his hydrological assumptions through the mining expansion of the vertical cave Abisso di Trebiciano, Lindner and his companions finally reached the underground river 329 m below ground—a cave depth record that was not beaten until 1909, 68 years later.[20] The map (Figure 1) subsequently drawn by the architect and archeologist Giuseppe Sforzi in form of a vertical section (combined with a depiction of the calcareous ground) visualized this mutual understanding of terrain, which can be penetrated by vertical descent via ladders and ropes.[21]

Topographical maps that combined both above and underground landscapes can also be regarded as a visualization of this changed epistemic perception of terrain. Employing the German term "Höhlenkunde" (cave study) about 40 years before it appeared in other languages, Adolf Schmidl even used the three-dimensional direction of caves instead of their formation process as a distinctive feature to categorize them in "vertical abysses, horizontally proceeding cavities [and hybrid] structures."[22] In his later years as a professor of geography in Budapest, he advocated for a new three-dimensional focus for cartography:

> It goes without saying … that accurate surveys of the underground are necessary. The course of caves must be marked aboveground by tags and adopted into regular maps of earth's surface. In this

[19]The first speleological society was founded in Vienna (1879–1889), followed by the first national association "Société de Spéléologie" in Paris (1895–1914), which was comprised of corresponding members from different European countries. Early state-owned institutions for cave research were founded in Cluj, Romania (from 1920), Vienna (1922–1938), and Postojna, Italy (today Slovenia, 1929–1941); early underground laboratories for predominantly biospeleological research were run for shorter periods of time in the catacombs of Paris (1897), a disused quarry near Saint-Paër, France (1910), and the cave "Postojnska jama" in Postojna (1930). Specific commissions dedicated exclusively to cave research at (national) academies of sciences existed in Zagreb (from 1910), Munich (1914–1950), and Vienna (1921–1925). The very first international chair of speleology was established at the University of Vienna (1929–1937).

[20]See Courbon, Chabert, Bosted, & Lindsley (1989, p. 15).

[21]A similar map produced by Sforzi in 1841, formerly preserved in the Archivio Diplomatico (Trieste), has been missing since 2012. This information was kindly provided by the librarian Gabriella Norio.

[22]Schmidl (1854, p. 191).

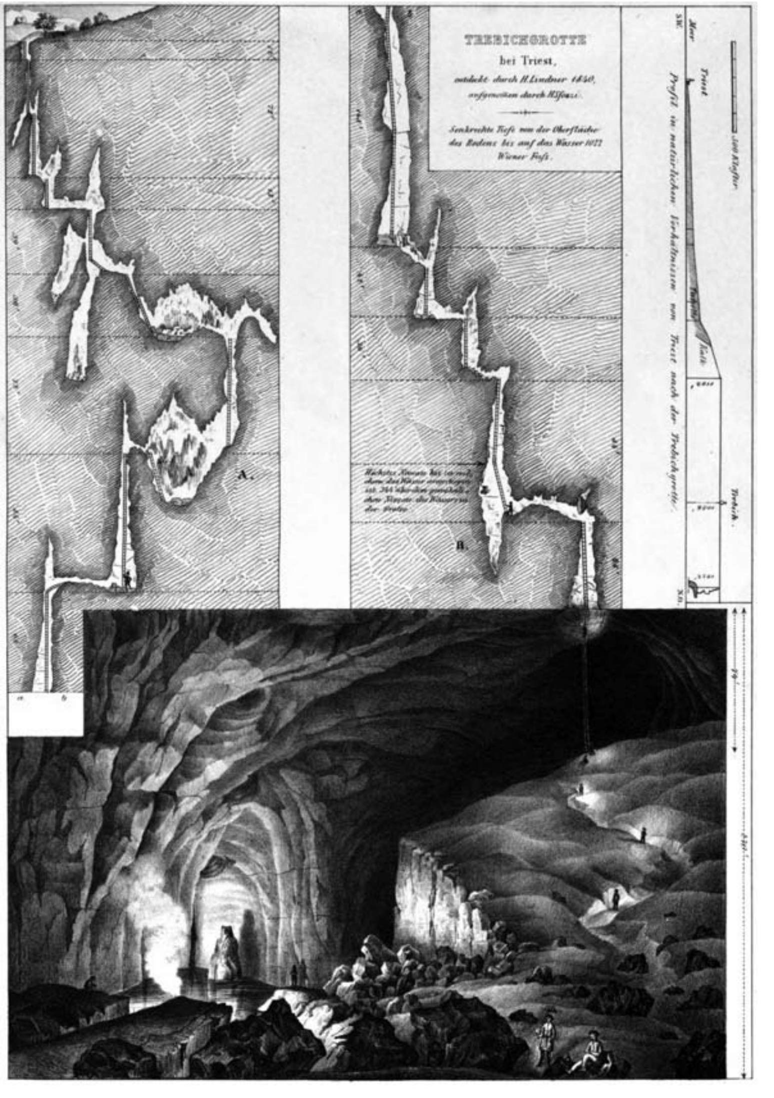

FIGURE 1 Map of the vertical cave Abisso di Trebiciano, drawn by Giuseppe Sforzi and published in 1848. From "Über die geologischen Verhältnisse von Istrien," by A. von Morlot, 1848, *Naturwissenschaftliche Abhandlungen, gesammelt und durch Subscription herausgegeben von Wilhelm Haidinger*, *2*, Table XXVI

> respect, it is very lamentable that the cadastral recordings depict no terrain and the general staff maps have for this purpose a too small scale. The map attached to this volume is an attempt to give a picture of the terrain and the [underground] course of caves and grottos. As imperfect as this effort may be, a glance at the map shows more clearly than all recommendations, of what great interest these subterranean conditions are.[23]

Nevertheless, until the late 19th century, cave maps were not widely accepted as scientific evidence and were therefore not considered accurate enough to examine the vertical relationships between phenomena above and below ground:

> We will learn in the future, how important a comparison of the aboveground terrain with the course of the underlying caves [on the basis of maps] is. Today, it is premature to emphasize this. Only very few people believe it, even among dedicated cave researchers.[24]

[23]Schmidl (1854, p. 206).
[24]Kraus (1894, p. 276).

In the course of numerous perpendicular ventures, undertaken mainly in the karst areas of southern France, Austria-Hungary, and Britain in the decades before 1914, the perception of the vertical acquired a new quality. In particular, the different aspects of how expedition members dealt with, tried to overcome, and finally took control of vertical geographies both physically and scientifically led to several attempts of demarcation that shaped cave study as a field of scientific research.

With the usage of rope and tree-trunk ladders, descending devices like the so-called "Knebel," and diving equipment, cave expeditions became complex social ventures in order to limit access to knowledge about undiscovered areas underground and regulate its acquisition and dissemination.[25] Thus, vertical geographies demanded from their "conquerors" not only a great deal of practical knowledge and body control in traversing them, but also became a process through which self-appointed explorers in newly founded societies began to distinguish themselves consciously from common travelers or cave tourists as a new elite.

According to the level of difficulty in overcoming vertical geographies, cave expeditions—oftentimes described as an opposite of high alpinism—increasingly relied on a division of labor. Participants had clearly defined tasks when penetrating the depths. The division of labor between cave explorers—scientific personnel, surveyors, cartographers, climbers, rope assistants, and photographers—corresponded to the members' social status and determined how close they were authorized to come to undiscovered areas. Participants had to function with equal precision to their surveying tools. Unsurprisingly, scientific instruments (and other equipment) thus became symbols of social distinction. While regular travelers visited caves accompanied by guides and carriers, vertical geographies enforced the development of research groups with different forms of social cohesion and cooperation that required increased disciplinary action and instruction of members. In Slovenia, locals called "grotto workers" were responsible for maintaining underground paths, holding lamps, or widening narrow passages. Similar phenomena can be noticed in North America and Australia, where Aboriginals, Native Americans, or African-Americans often served as guides or assistants for cave explorers.[26]

In the milestone case study *Leviathan and the Air-Pump*, Steven Shapin and Simon Schaffer show the broad impact of social order on knowledge acquisition.[27] In his review, Bruno Latour goes one step further and argues that science is "co-produced" with its social context, paying special attention to the spaces of action.[28] This also applies to (subterranean) ventures as testing grounds in which social and content-based boundaries intersected. According to the different grades of vertical descent, visitors were confronted with a broad variety of botanical, zoological, prehistorical, anthropological, paleontological, hydrological, or meteorological conditions and discoveries.[29] Bringing together experts from diverse scholarly backgrounds, these findings did not correlate to one single scientific discipline, but rather enforced the development of specialized metadisciplinary communities. This specific form of cooperation became even more relevant as the difficulty of overcoming vertical geographies increased, as did the sheer number of caves surveyed, mapped, categorized, and documented (thousands were known before 1914). This prevented professional scientists from taking samples and making observations on-site. Thus, non-professionals functioned as data collectors or operated measuring instruments that guided the perception of the observer and secured scientific evidence. What really happened underground and the level of care with which measurements or excavations were undertaken remained uncertain—in spite of the often meticulously kept expedition reports—leading to several attempts to subject all subterranean expeditions to official control and scientific guidance.

However, when it came to measuring the current degree of depth, verticality revealed itself to be a surprisingly vague category. As theodolites and other scientific instruments above certain weights or physical dimensions could not be transported through every long vertical section or narrow passage, measuring tools and other reliable

[25] "Knebel" describes a technique adopted from miners that consisted of winches by which men were lowered while sitting on wooden cross-bars at the ends of ropes, partly fixed with a chest harness.

[26] See Mattes (2016, pp. 163–186).

[27] See Shapin & Schaffer (1985, pp. 332–344).

[28] See Latour (1990, p. 147).

[29] On the interdisciplinary approach of speleology, see, for example, Trimmel (1968, pp. 1–5); Shaw (1992, pp. 1–2); Cant (2006, pp. 775–795); Pérez (2013, pp. 293–308); Mattes (2015b, pp. 251–266).

surveying instruments that were appropriate to the task and could be operated at low temperature, in complete darkness, in wet or muddy passages, and with just one hand at best were quite rare. In this regard, early handbooks of cave study remained rather vague and recommended that the "quite annoying surveying business" be relegated to technical staff, mostly mining engineers and surveyors.[30] It is therefore not surprising that the very first instruction manual of cave surveying was not published until 1892 and that it followed a quite pragmatic approach. Describing cave maps as "very summary and approximate" "geographical documents that give some value to the work of researchers," the manual recommended the use of an orienteering compass, measuring only 2 cm in diameter, as the only surveying instrument.[31] In the process of establishing speleology as its own respectable scientific field, the invention of more accurate tools catering specifically to the scientific needs of cave study beyond mining purposes became vital.[32]

While horizontal passages could be measured quite simply with commercially available or more distinct optical and prismatic hand-bearing compasses (for example, geological, mining, and/or reflecting devices), the survey of vertical sections remained a tricky and unsafe task that could easily produce contradictory results. Determinations of the angle of inclination were often particularly inaccurate.[33] Handheld clinometers had high error rates in vertical caves due to difficulties in targeting them. In contrast to the use of altimeters, such errors in measuring depth added up in the course of a survey. Accordingly, before the interwar period, they were rarely used. Instead, measuring cords, plumb lines, and special aneroid barometers became integral pieces of equipment. Some speleological handbooks even recommended estimating the depth with self-made tools.

French attorney Édouard-Alfred Martel, an early popularizer of cave research, wrote an emphatic study of vertical phenomena in his internationally recognized book *Les Abîmes* (*The Abysses*). In it, he described a series of underground explorations in France, Belgium, Austria-Hungary, and Greece.[34] Through scholarly, instructive, or narrative passages, combined with vertical sections, breath-taking paintings, and photographs of extreme environments, readers were exposed to these hardly known vertical geographies. Cave maps, instruments, and techniques aimed to navigate these uncertainties. As one of the main preoccupations of subterranean expeditions, surveying should serve multiple purposes:

> Firstly, to give orientation … secondly, to provide geographical documents that attribute some value to their research. … The equipment, ropes, tools, lights and even boats that need to be dragged behind oneself to descend, to climb, to crawl, to sail in the heavy and humid darkness, are sufficiently bulky … ; and when it comes to going several kilometers and spending up to 24 hours in the underground, … it is absolutely impossible to conduct precise operations. To measure the depth, we use a cord equipped with a weight. … In very deep wells, only self-control can prevent serious errors. … To evaluate the depth by the time a stone takes to hit the ground is a wrong method, and … even highly educated persons have attributed 5[00] or 600 meters to chasms, which did not measure 150. … It is certain that with these primitive manners of operation … none of the underground surveys, which I have carried out, can surely be used either for engineering works or for proving the rights of surface owners on the just discovered caves.[35]

In spite of the uncertainty concerning the accuracy of methods and results, which could hardly be verified even on-site, surveying became the main basis for the scientific claims made by the (national) speleological societies emerging in France, Austria-Hungary, Italy, Germany, Switzerland, and Britain. Collected mostly in private or semi-

[30]Kraus (1894, p. 276).
[31]Martel (1892, pp. 1, 7).
[32]See Mattes (2015b, pp. 251–266).
[33]See Bauer (1957, pp. 123–125).
[34]See Schut (2007).
[35]Martel (1894, pp. 24–28).

public cadasters, maps became more than mere proof of a report's authenticity. By illustrating the stratification of the soil or localizing archeological and paleontological findings, vertical sections of caves that had previously been undefined areas were now given meaning. Maps became powerful tools to promote the vertical as an epistemic dimension. In his comprehensive handbook *Cave Hunting: Researches on the Evidence of Caves Respecting the Early Inhabitants of Europe*, the geologist William Boyd Dawkins aimed to establish a scientific method for undertaking prehistoric and paleontological excavations in caves. Providing numerous vertical sections of subterranean geographies and their sediments, he understood the vertical order of horizontal layers in cave soils as a form of scientific evidence. In this regard, according to Dawkins, caves are "a great laboratory, so to speak, where we can see the natural agents at work."[36] Conclusions about the history of humankind can thus be easily inferred:

> The exploration of an ossiferous cavern with sufficient accuracy to be of scientific value may be carried out in all tunnel caves …. The first step to take in all cases is to make a plan of the entrance, and to cut a passage down to the rock at the entrance, so as to obtain a clear idea of the sequence of the strata. … Our work was measured every evening and each bone and object found was labelled with the date, which was recorded on the ground plan. Vertical sections were also taken from time to time. This mode, supplemented by constant supervision of the workmen, was sufficiently accurate to satisfy the demands of scientific research. … In fine, the cave earth is excavated in vertical slices or parallels four feet high, one foot thick, and as long as the chamber is broad, where this breadth does not exceed thirty feet. … A careful record of the work, and minute sections should be taken daily on the spot.[37]

Although vertical sections of caves or their sediments were already used by scholars as Leibniz, Cuvier, Buckland, Esper, Rosenmüller, and Fuhlrott, Dawkins can be counted among the first who wrote popular instructions of the scientific method for excavating cave soils in vertical slices.

Similarly, the epistemic value of vertical geographies gained importance in geological and (practical) hydrological research. Especially in the debates on karst formation in central Europe towards the end of the 19th century, and as vertical scaling became an important solution to problems like underground drainage or the localization of the subterranean water table, vertical geographies gained traction. While popular studies on caves already contained schematic vertical sections to explain various tectonic, hydrological, and meteorological interactions between the surface and the subterranean space, such arguments were soon adopted by scientifically recognized works.[38] During the early debates on phreatic solution, scientific papers by Édouard F. Dupont and Jonathan Barnes & William F. Holroyd utilized schematic cross-sections of different cave passages to support their hypotheses.[39] When the Serbian geographer Jovan Cvijić published his internationally recognized work on the karst phenomenon in 1893, his research was only partly based on personal observations on-site. To a considerable extent, his study relied on cave surveys, reports on subterranean ventures, and knowledge-based hypotheses by early popular writers like Adolf Schmidl or Johann G. Kohl. It was they who first "experimented" with different topographical attributions of the term "karst" before it was accepted as an international geological term for the specific concurrence of above- and belowground phenomena in mainly carbonate rocks.[40]

The practical applications of the research on "horizontal" and "vertical water drainage" in karst terrains aroused a growing political and economic interest in cave study and paved the way for its funding by public institutions or even its practical execution by state officials.[41] Notably, periodic flooding and poor harvests in Slovenia's and Moravia's

[36]Dawkins (1874, p. 73).
[37]Dawkins (1874, pp. 438–440).
[38]For example, see Kraus (1894, pp. 116–119).
[39]Dupont (1894, pp. 190–297); Barnes & Holroyd (1896, pp. 215–252).
[40]See Cvijić (1893). For early (popular) studies on the karst phenomenon, see Schmidl (1850, pp. 701–705); Kohl (1851, pp. 1–62). See also Vogel (2019, pp. 102–111). The term "karst" was originally the toponym of a cavernous mountain range between Slovenia and the hinterland of Trieste, Italy.
[41]Willner (1917a, p. 20).

poljes before 1914 led to official plans for karst melioration, rural engineering, and abyss exploration, which correlated to the sporadic examination of caves and their sediments by academy commissions and geological surveys.[42] These ambitions were closely linked to the contemporary controversy on cave formation as occurring primarily through a process of dissolution in the groundwater zone.[43] Originally initiated by cavers' observations, the debate was mainly carried out in the academic sphere, but simultaneously promoted the scientific value of cave exploration and its practice as a form of vertical fieldwork and data collection.

Progressively described as the study of the "comparison between aboveground terrain and subjacent caves," their "closest relationship," and vertical "communications," speleology was incrementally seen as a scientific field that pursued a universal vertical interest: the restoration or maintenance of hidden, narrow, or buried communication paths between two different places and fields of knowledge.[44] It should therefore not only consider geological or archeological appearances, but the "fullness of interrelations that exist between individual phenomena of the underworld to each other and with the upper world."[45] The prehistorian Georg Kyrle, in later years the first university chair-holder of speleology, went one step further. For him, "cave formation is mostly not dependent from the morphology of earth's surface, quite the contrary, today's formation of earth's surface is determined in many places by the existence of caves, which is particularly noticeable when it comes to karstification."[46]

3 | FROM TERRAIN TO TERRITORY: WORLD WAR I AND THE IMPLEMENTATION OF SPELEOLOGY AS A SCIENCE

During World War I, the increased relevance of vertical geographies further accelerated the institutionalization of cave science in Europe. In this regard, politics and scholarly research did not only become resources for each other, but also used vertical spaces in various ways as military, economic, and epistemic resources, resulting in a new scientific, three-dimensional concept of territory. The aforementioned processes of delimitation that controlled the vertical grade of penetration during subterranean expeditions were transferred to the perception of terrain. Instead of a boundless or open-ended approach to space, national politics in Austria-Hungary, the Balkan states, and Italy tipped the balance and gave rise to an increasingly competitive, bordered understanding of the vertical.

While cave entrances were originally (re)discovered with the help of guides and the study of local legends, increasing competition between partly overlapping regional and urban groups dedicated to mountaineering and speleology led to caves being frequented and surveyed several times. The privilege of having been "the first" to see a cave and the monopoly on interpreting the evidence went hand in hand with the social demarcation from underprivileged groups, such as lumberjacks, alpine dairymen, hunters, or small farmers. These processes of social boundary-work were increasingly underpinned by national prejudices. Especially in the Austrian Littoral (near Trieste), German-, Italian-, and Slovene-speaking speleological societies rivaled each other with restricted access and the exclusivity of the first glance at underground geographies.[47] Therefore, caves were often (re)discovered, (re)mapped, and (re)named by different national groups who, in public reports, often described their vertical ventures as conquests of enemy territory. The nationalistic tensions between the Commissione Grotte of the Italian Alpine Club, the mixed-language Club Touristi Triestini, the Slovene Speleological Society Društvo za raziskovanje jam, and the

[42]A polje, in geological terminology, is a depression with a flat floor and steep walls in limestone karst that commonly occurs as a large-scale landform.

[43]For an overview of this scholarly debate, see Shaw (2000, pp. 21–29).

[44]Kraus (1894, p. 276); Knebel (1906, p. 1). During the 19th century, the term "communication" (as used in English, French, and German) also described tunnels or underground connections between two different places. For example, see Dawkins (1874, p. 205); Martel (1894, p. 40); Schmidl (1854, p. 52).

[45]Willner (1919, p. 1).

[46]Kyrle (1923, pp. 3–4). The aforementioned Serbian geographer Cvijić, one of the most powerful scientific consultants who engaged in the demarcation of southeastern Europe's national borders at the Paris Peace Conference (1919–1920), even attributed to karst phenomena a certain influence on the development of ethnic groups on the Balkan peninsular.

[47]Due to national rivalries, the idea of tracking the depth records of cave ventures was first developed in the Austrian Littoral.

German-speaking Sektion Küstenland of the German and Austrian Alpine Club led to the production of separate cave cadasters and the defense of claimed underground "territories" against the others.[48]

These assumptions refer to the concept of territory condensed by political geographer Stuart Elden in a theoretical article entitled "Land, Terrain, Territory": "Territory is more than merely land, and goes beyond terrain, but is a rendering of the emergent concept of 'space' as a political category: owned, distributed, mapped, calculated, bordered and controlled."[49] As mutual and bounded spaces produced by specific strategies and practices, territories are deconstructed and reconstructed through continuous negotiations. Representing rather a process than an outcome, territories can be imagined as an entity that has to constantly be made and remade.[50] In contrast, the term "terrain," used among geographers and the military, describes a mainly static landform or topographical relief, interrelating the physical geographical features with human interactions. While Elden particularly focuses on "territories as political technologies," I, in the following, would like to analyze how knowledge-based practices during World War I were worked into the ground and how these modified ways of experiencing and dealing with territorial space coproduced a new science of caves and its social context. Hereafter, the diverse use of the vertical for (a) military, (b) economic, and (c) epistemic purposes and related processes of delimitation will be examined.

3.1 | Military resources

According to recent studies on underground warfare by Simon Jones and Daphné Richemond-Barak, 2.5 years of intense state-to-state tunnel mining began in late 1914, which structured the battlefields of the Western Front and turned them into an intricate complex of multiple horizontal layers.[51] Although several of these partly above- and partly belowground military architectures were called "caves," they were almost exclusively artificial due to the lower occurrence of karstified rock along the frontline.[52] Not all warring parties were well prepared. While the German headquarters reissued extracts of old mining books as instructional literature, British tunnelers "benefited significantly from the input of civilian experts mainly mining engineers," especially when it came to the implementation of modern technology in underground warfare.[53]

Slightly different processes can be observed in the less-studied (subterranean) battlegrounds of the Balkan peninsular and along the front between Austria-Hungary and Italy, where greater amounts of vertical geographies, collected data, and practical knowledge in traversing them led to cooperation between scientific and military groups. In particular, the Austro-Hungarian army, whose Military-Geographical Institute had already been involved in cave research and mapping activities in Bosnia-Herzegovina since the 1880s, sought the expertise of cavers and mountain guides before it started to participate in underground warfare. During the occupation of Bosnia-Herzegovina, military strategists like Franz Conrad von Hötzendorf, later chief of the general staff for the entire Austro-Hungarian military, already had scientific experience with the special conditions of the karst terrain:

> We argue that a final assessment of military operations in the karst is unthinkable without a theoretical knowledge of the specific type of terrain. … The impact of karst features on military operations is threefold: the difficult character of the ground, [the practical knowledge] of locals if they are enemies and finally the lack of resources.[54]

[48]See Mattes (2015a, pp. 244–245, 253).
[49]Elden (2010, p. 810).
[50]See Elden (2013, p. 36) and Foucault's (2006) concept of "governmentality."
[51]See Jones (2010) and Richemond-Barak (2018), who focus exclusively on operations undertaken by French, British, and German forces on the Western Front.
[52]A well-known example is Thompson's Cave, used as an underground hospital for 700 wounded during the Battle of Arras in France.
[53]Richemond-Barak (2018, p. 7).
[54]Hötzendorf (1882, pp. 1, 19). See also Nerad (1900, pp. 353–359).

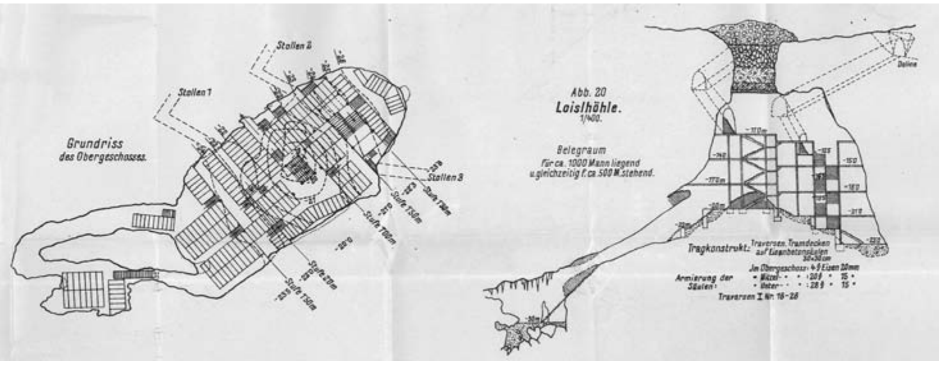

FIGURE 2 The installation of several floors in the vertical cave Loislhöhle near Novelo, Slovenia provided sleeping accommodations for 1,000 soldiers and had additional space in form of a shelter for 500 soldiers. Reconstruction of the cave took 4 months and was accomplished by around 60 soldiers of the "Cave Construction-Detachment of the k.u.k. 7th Corps." From "Die Verwertung der Karsthöhlen an der Isonzofront und die dabei gewonnenen Erfahrungen," by A. P. Bock, 1920–1921, *Technische Mitteilungen*, *6*, Table II

Since the outbreak of World War I, the majority of Austro-Hungarian speleological societies had readily provided their knowledge and cadastral data to the general staff, while officials of Italian-speaking clubs fled across the border or were interned in POW camps. Some arrested speleologists, such as Eugenio Boegan, were able to escape and handed over their cadaster to the Italian forces. In the form of a "cave military service," the "acquisition of grottos for military purposes [should] transform caves into important war resources."[55] Some societies even boasted that they had trained hundreds of young people for warfare in vertical geographies. However, in most cases only society officials were conscripted as officers in the so-called Cave (Re)search or Cave Construction Detachments (with up to 500 soldiers) that compiled cave cadasters along the front, took over vertical geographies, extended them to military bases, and searched for underground water resources. The transformation of naturally developed subterranean spaces represents one of the most striking examples of how knowledge-based practices and geopolitics were worked into the depths of the earth and how the vertical became a significant dimension of power. The concurrence of aerial and subterranean attacks transformed the battlefields of World War I into above- and belowground "battlespaces."[56] According to contemporary handbooks, there were ways manifold underground geographies could be appropriated for "karst warfare": "defensive [or] offensive operations," "static [or] mobile warfare."[57] As shown in Figures 2 and 3, these "underground fortresses" served as shelters and accommodations, artillery emplacements, commanders' offices, chapels, mews, storage depots for supplies and ammunition, and so on.[58]

By the end of the war, 1.7 km^2 of underground space was taken over for military purposes by the Austro-Hungarian army. Although concrete plans to set up a central authority for cave warfare (k.u.k. Kriegshöhlenzentrale) at the Vienna Ministry of Defense were not implemented before the armistice of November 1918, army groups operating in Italy and the Balkans had their own staff positions that dealt with speleological issues, the supply of drinking water, and fortification in karst areas.[59] The Austro-Hungarian general staff saw the usage of caving knowledge as an advantage over Italian armed forces, who also relied on geologists, alpinists, and speleologists, like Michele

[55]Willner (1917b, pp. 20–21).
[56]See Elden (2013, p. 36); Virilio (1989).
[57]Willner (1917b, pp. 22–25).
[58]See Bock (1920–1921, pp. 13–25, 215–231). Fabbricatore (2020) provides a comprehensive overview of the caves used in karst warfare.
[59]Kyrle (1927a, p. 53).

FIGURE 3 Soldiers of the Austro-Hungarian army in the cave Munitionshöhle near Temnica (Slovenia) in 1917. No. WK1/ALB072/20641, Image Archive of the Austrian National Library, Vienna, Austria. Additional information can be found in Fabbricatore (2020)

Gortani, especially for high-altitude warfare, but did not maintain dedicated military units for cave research.[60] Similarly, a Milanese newspaper reported on an attack on enemy positions:

> Severe bombardment had destroyed completely a fortified section. … Where everything was shattered and splintered to the ground, fresh battalions … appeared like a real ghost-army. … It was the karst itself: all Austro-Hungarian trenches run out here in the rock funnels of the karst terrain. You can follow them wherever you want, you will end up in one of those caves that cover the karst like the craters of a lunar landscape. Some of the underground passages run into numerous branches and form extensive halls where entire battalions can gather … so that a whole system of mysterious fortifications can arise out of nothing, nullifying an attack.[61]

Regarding the understanding of the vertical, two points are remarkable. Firstly, in contrast to the Western Front, the mountainous and cavernous terrain of the battlefields in southern Europe led to different techniques for appropriating underground space. Secondly, mountaineers and cavers were often used in both terrains, which resulted in a lively exchange of knowledge and practice in dealing with vertical geographies. For example, the officer and alpinist Leo Handl, responsible for the construction of a 24 km-long and up-to-1,000 m-high “ice city” inside the Marmolada glacier in South Tyrol, adopted caving methods that in turn reshaped descending techniques in caves after 1918.[62]

Although, around World War I, there was a lively exchange of geographical knowledge in order to overcome the vertical in the depths and heights, there were also differences in the spaces, practices, and concepts involved in the fields of alpinism and speleology in central Europe. On the one hand, numerous caving associations emerged from

[60]See Baron (2003).
[61]Barzini (1916, p. 4).
[62]See Trimmel (1997, pp. 72–77); Angetter & Schramm (2014, pp. 135–160).

mountaineering clubs, based on partly overlapping personnel resources. The construction of alpine huts and hiking paths emerged largely in parallel to the establishment of show caves. On the other hand, the specific conditions of the underground required different knowledge-based practices, which led to unique forms of cooperation and resulted in a slightly earlier participation of women than was the case in alpinism. For instance, during cave expeditions, uniform clothing (for example, trousers and overalls) became the standard, while in mountaineering clubs a heated debate ignited during the interwar period about appropriate and practical clothes for women in alpinism. As I argued in an earlier paper from 2016, "speleological expeditions always remained a marginal phenomenon and included space for improvisation and experimentation"—a noteworthy difference to the mass movement of mountain climbing.[63]

3.2 | Economic resources

Due to the blockade of the Central Powers that prevented the import of phosphorous fertilizers for agriculture, Austro-Hungarian government officials developed an unrealistic plan to compensate for this deficiency with the exploitation of organic cave deposits (mainly accumulations of cave bear remains and bat guano). After the establishment of a specific Ministry Commission of Cave Research in 1917, cave-trained geographers, geologists, paleontologists, prehistorians, engineers, and agricultural scientists were recalled from the front to develop the very first state-owned underground cadaster and retrieve samples from 1,500 caves across the entire Habsburg Empire and the occupied Balkan states. In a law enacted subsequently, the government not only secured its monopoly on the exploitation of phosphorous cave deposits, but also initiated the development of a state commission to both realize the industrial excavation plans and examine the huge amount of paleontological and archeological findings scientifically. Although exploitation operations did not start in earnest before the collapse of the monarchy, the legal regulations adopted by numerous successor states resulted in an overlap of state and scientific interests in cave study and extensive extraction projects in Austria, Czechoslovakia, Hungary, Romania, and Bavaria during the interwar period. For example, 30,000 m^3 of guano deposits were exploited in the Cioclovina Cave in Romania until 1941.[64]

Indirectly, the regulation of the state monopoly on cave fertilizers also addressed open questions of ownership over vertical geographies. Reflecting the scientific, economic, and political acquisition of caves as a legal "act of occupation," several juridical publications after 1918 pointed out that the

> economic value of caves is much higher [than expected] because of their content of "useful things." Mineralogical, paleontological, prehistoric and historical, faunistic and floristic finds can be useful and valuable because of their often very high museal and commercial value … ; Cave ice can be used for commercial and industrial purposes, cave guano … and other phosphorus deposits have a high value as fertilizers, which can amount to many millions in one single cave; of particular importance is the usage of cave waters for drinking and industrial water supply. … Thus, caves represent a characteristic object both in nature and in the sense of national economies, and because of its suitability to serve human needs, it is an economic good.[65]

Due to the vertical projection of aboveground boundaries and ownership into the depths, the state, through its forestry authorities, came into the possession of hitherto unimagined vertical geographies, whose untapped contents had to be economically and scientifically examined and safeguarded. This also applies to profitable show caves and new tourism projects in the successor states of the Habsburg Empire and Italy, which were sometimes carried out by

[63]See Mattes (2016, p. 181).

[64]See Tomuş, Breban, & Onac (2018); Götzinger (1919). Equally, the coinage of technical terms such as "cave economy policy" and "cave education policy," which were introduced by scientific papers after 1918, could be regarded as a result of these new resource constellations.

[65]Willner (1921, pp. 68–69, 87).

the government itself or at least by public authorities. For example, the state-administrated show cave Postojnska jama in Slovenia, which already attracted around 140,000 annual visitors before 1914, was expanded by Russian prisoners of war and later became even a favorite project of Italian Fascist politics.

3.3 | Epistemic resources

The claims on vertical geographies described above and the sheer amount of uncategorized data demanded a higher quality of scientific evidence from the methods that dealt with underground spaces. These included surveying and documentation practices, as well as studies of sediments, the execution of meteorological measurements, and the use of colorants as dye tracers to reveal subsurface water connections. During World War I, the numerous state-directed expeditions to identify and investigate exploitable phosphorous deposits became the starting point for the development of new ways of working with large samples. The provision of comparable data and maps of thousands of caves increasingly required the standardization of surveying instruments and techniques. This did not only apply to the military and economic uses of caves, but also to further broad-scale research that allowed, for example, insights into animal geography. Thus, the French-Romanian zoologists René Jeannel and Emil Racoviţă published the first proposal for uniform map symbols in 1918, followed by the Viennese cartographer Ludwig Teißl, who adopted the symbols of the Austro-Hungarian general staff's maps.[66]

Processes of standardization in cave mapping corresponded with the emergence of quantifying methods. For example, mathematical models were used to calculate the amount and quality of extractable resources at the scale both of individual caves and of the sovereign nation. Further efforts to quantify individual observations were made with the implementation of mathematical–physical methods for describing meteorological and hydrological phenomena in ice, water, and blowing caves.[67] These approaches were intensified after 1918 and led to the development or adaptation of surface-based instruments, intended to require low maintenance, which would measure parameters such as ice thickness, karst springs' amplitude of discharge, water-level changes, air temperature and humidity, atmospheric pressure, and airflow (speed and direction).

In particular, the political decision that all exploitation works should be supervised and guided equally by professional scientists and government officials led to the publication of a broad variety of instructional literature on systematic data collection, mapping, and cadaster projects. The fact that many series of scientific books and journals were financed by the state in spite of paper shortage and the high costs of the war underlines the importance attributed to cave study by officials of the Central Powers. Especially in the successor countries, where the determination of European state borders during the Paris Peace Conference was experienced as a loss of two-dimensional territory, the scholarly engagement with caves became a welcome scientific target. In this respect, the vertical extension of the territory into the depths of the earth and its use as an epistemic resource can be understood as a result of unfulfilled aboveground territorial claims and as compensation for former traditional research areas on the Balkan peninsular and overseas. In contrast, in the victor states (excluding Italy), cave study received considerably less recognition. The lack of government support and acceptance from established scientists in France and Britain resulted in different, long-lasting developments and tied the research field closely to the activities of alpine, touring, and scout clubs. Practiced mostly as a leisure or tourist activity dedicated to physically overcoming vertical spaces, speleology was recognized as an explorative “adventure” and “sporting-science” that incorporated elements of fieldwork and assigned control of the body an important role in knowledge acquisition.[68] The states' low levels of interest in speleological matters led to a lower level of institutionalization and the comparatively late founding of national caving clubs in France (1930) and England (1935).

[66] Jeannel & Racoviță (1918, p. 214); Teißl (1925).
[67] See Bock (1913, pp. 102–104).
[68] Schut (2007, p. 147); Cant (2006, p. 778).

In central Europe, however, a broader engagement with underground geographies gave rise to new processes of social demarcation. Along with the introduction of the French/English term "speleology" into German, a distinction was made between scholarly, state-organized speleology and amateur cave research, which organized in societies with lower scientific reputation.[69] With reference to Thomas F. Gieryn's classical paper on boundary-work in science, the increasing differentiation between the different levels of speleological scholarship—its practitioners, institutions, methods, knowledge basis, values, and modes of cooperation—was caused by the "professional" scientists' claim to authority and resources.[70] At the same time, the consolidation of territorial space also had an impact on densification processes in the epistemic conception of speleology. Handbooks of cave science, such as Georg Kyrle's *Grundriß der theoretischen Speläologie* (*Outline of Theoretical Speleology*), not only established a new scientific terminology but also reorganized all knowledge related to caves according to established scholarly disciplines that were to be concentrated into a new form of integrative science. Due to the growing amount of finds, collaboration between experts such as botanists and hydrologists, who dealt with phenomena localized at different grades of vertical penetration,

> has sharpened our focus on the whole phenomenon and the observation of parts of the phenomenon and thereby a comparative research of its interrelated dependency. … The prosperous development of speleology rest upon a uniform research and teaching method that considers all phenomena, but not in the rupture and division [of the field] into sub-disciplines.[71]

Finally, the reshaping of Europe's national territories and their associated vertical spaces added to speleology's epistemic legitimacy as a scientific metadiscipline. As Richard von Wettstein, botanist and vice-president of the Viennese Academy of Sciences, argued:

> We have become a small state, and this, of course, results in an intensification of interest in what we still possess and I believe that this is also the cause why we finally … have increased our attention. … Speleology is therefore not merely a scientific intermediate discipline, but rather a group science, whose development is excellently interested in a whole series of sub-disciplines that are only slightly or not at all related. … The tasks of speleology consist methodically of collecting these sub-results, classifying them according to speleological aspects and to process them into a unified whole.[72]

4 | NATIONAL ACQUISITION OF VERTICAL GEOGRAPHIES: CAVE PROTECTION AND RESEARCH METHODS AFTER 1918

Although the aboveground war ended after the capitulation of the Central Powers, it was continued in symbolic forms underground. Performing a new, endless frontier, vertical geographies and their encroachment meter by meter as "new land" were celebrated like the conquest of enemy territory. During the interwar period, cave expeditions in continental Europe were still described as a frontal experience and a hard-fought "underground battle" that deserved medals, demanded sacrifices, and forced explorers to traverse the vertical in military formations.[73] Similar to mountaineering associations, whose members tried to find new and more dangerous routes up already ascended high Alpine peaks, speleological societies quickly recognized the propagandistic value of vertical ventures. National politics used the public appeal of "deep alpinism" as a metaphor for national ascent and predominance. In particular,

[69]See Abel, Willner, Kyrle, Saar, & Wettstein-Westersheim (1923, pp. 1–13). The French and English term "spéléologie/speleology" was originally used for any activity associated with caves.

[70]See Gieryn (1983, pp. 781–795). Considerations on boundary-work in science go back to the concept of "boundary objects" developed by Star & Griesemer (1989, pp. 387–420) and others. See also Bowker, Timmermans, Clarke, & Balka (2016); Star (2010).

[71]Kyrle (1923, pp. 4, 10).

[72]Wettstein (1921, pp. 90, 112–113).

[73]See Mattes (2016, pp. 166–167).

researchers who lost their lives in the examination of the—at that time—deepest and longest caves were instrumentalized by nationalist rhetorics as "comrades" that "died like soldiers in the battle for the progress of science and the homeland."[74] Whether ascending an Alpine peak or reaching the bottom of a pit in a subterranean expedition, the overcoming of vertical limits became a symbol of the self-esteem and scientific or cultural dominance of one's nation. Although underground ventures did not reach the popularity of mountain expeditions in the Himalayas, adventure novels written by speleologists such as Norbert Casteret achieved the status of bestsellers and communicated the significance of vertical geographies as national heritage sites to the general public.[75]

With reference to Bruce Hevly's and Franziska Torma's works on glaciology and mountaineering, it is worth mentioning that many speleological societies adopted the strengthening of the (male) body and achievement-oriented thinking from extreme alpinism and enforced them through heroic values.[76] The understanding of speleology as a national endeavor was not limited to the losers of World War I, but fell here on more fertile ground. The foundation for the attribution of political meaning to vertical geographies was laid by ideas of "national renewal" and war experiences that were transferred to the conquest of deep pits and mountain peaks. In this context, masculinity, elite status, and territorial and scientific claims became important aspects influencing and framing the modes through which both professionals and scientific amateurs dealt with vertical geographies during the interwar period. In addition, the adoption of military equipment (such as steel helmets, wire rope ladders, or explosives), officers, military jargon, and drill, as well as the use of regular military units for research operations, can be regarded as phenomena associated with the political radicalization of many speleological societies, particularly in central Europe. Thus, "cave study, very lately and against a great deal of resistance recognized as a branch of science … has received a powerful promotion due to their engagement in national defense and gained friends … in many circles, who have previously behaved negatively."[77]

Following the dense entanglement of scientific, economic, and political purposes, the growing relevance of vertical geographies as manifestations of national legacy can also be seen in several attempts to establish "underground" national parks during the 1920s. As many karst areas, divided between the successor states of the Habsburg Empire, Italy, and the Kingdom of Yugoslavia, represented language borderlands, they were of considerable political significance. Transferring subterranean space into state property, the establishment of communication platforms sought to nationalize the karst environments in both a topographical and a cultural way.[78] In addition to public authorities, which had a keen interest in puting these borderlands and the minorities living there under their direct administration and control, the idea of subterranean national parks was promoted mainly by speleologists such as Karel Absolon (Moravian Karst, today Czech Republic), Luigi Bertarelli (Classical Karst, Slovenia/Italy), and Ottokár Kadić (Aggtelek Karst, Hungary/Slovakia).[79] Often, the intention was to keep unwanted competitors away and to guarantee the priority of national interests:

> We have to get rid of this amateurishness in scientific cave research. … There are not many caves left [in our national territory], but if we develop them, we have one—and I say it on purpose—underground national park. I don't see why we should not develop our caves in the same way as a national park in North America. There is no doubt that the state is called to run an underground national park.[80]

[74]Bock (1926, p. 70).
[75]For popular books on cave research, see, for example, Casteret (1933).
[76]See Hevly (1996, pp. 66–86) and Torma (2011, pp. 431–458). On the issues of masculinity, hierarchies, and the military qualities of caving, see, for example, Cant (2003, pp. 67–81); Mattes (2013, pp. 132–149); Pérez (2015, pp. 226–247).
[77]N. N. (1917, p. 2).
[78]For the relationship between nature and state, see Kelly, Leal, Wakild, & Hardenberg (2017, pp. 1–15).
[79]See, for example, Absolon (1921, p. 139); Bertarelli (1919, pp. 129–135); Kadić (1928, pp. 42–43); Káan (1931, pp. 187–230).
[80]Speech by Othenio Abel during a meeting of the Austrian Ministry of Agriculture and Forestry (1921, p. 107).

These ultimately partly-successful ambitions were closely tied to regional and countrywide cave cadaster projects, accomplished either by state-owned speleological institutes, independent societies, or individuals. In Italy, where several caves were originally examined by Slovenian- and German-speaking researchers, the territorial appropriation of the underground went hand in hand with its scientific review. The comprehensive handbook *Duemila grotte* (*Two Thousand Caves*), published with state support in 1926, not only contained detailed descriptions of all known caves in Venezia Giulia, but also changed all foreign cave names in Italian territory into Italian.[81] The intention was both to subject the underground space to a national interpretation and to delete all references to the former Slovenian- and German-speaking researchers and their banned societies. Likewise, national cadastral projects were often associated with the concrete intention of preventing the use of vertical geographies by dissidents. For example, in the parts of Carniola that fell to Italy after 1918, caves became hidden meeting-places where the forbidden Slovene language was practiced in secrecy.

The close connection between scientific and state interests manifested itself not only in the political ideologization of science and its rhetoric, but also in research funding and questions of scientific organization. With the foundation of specialized departments for the scientific examination of vertical geographies underground, several governments tried to recapture a unique position in the international research landscape, even when scientists of the defeated states were mostly unable to participate in international conferences until the mid-1920ies. While a state-owned speleological institute was founded at the University of Cluj, Romania to compensate for the emigration of German- and Hungarian-speaking scholars and establish "an international scientific center" specialized in biospeleology, similar foundations in Austria, Italy, and Hungary aimed to "cover the whole field of cave science, namely the theoretical and practical speleology and cave economics."[82] Bringing national and scholarly claims together, these departments especially benefited from government funding of publications and extensive research projects. To distinguish themselves from scientific amateurs, state-owned institutes developed new methods of investigation, science-based excavation techniques, and the accurate documentation of finds, which involved a greater emphasis on surveying and mapping methods. At the same time, they continued to rely on cooperation with the speleological societies and their collection activities, especially when it came to difficult vertical ventures.

In particular, an extensive excavation project, realized in the Styrian cave Drachenhöhle in Austria during the 1920s, became an important scientific testing-ground where the various forms of cooperation between representatives of different disciplines were practiced and the epistemic basis for the understanding of speleology as a "group science" was laid.[83] Representing the first huge cave excavation with an interdisciplinary approach, the project was generously funded by the Austrian Ministry of Agriculture and Forestry, the Viennese Academy of Sciences, the Emergency Society for German and Austrian Science and Art (New York), and the wealthy industrialist family Stonborough-Wittgenstein (New York–Vienna), which had subsidized several outstanding research projects in the postwar years. With the support of more than 25 scientists and 50 diggers, the paleontologist Othenio Abel, later president of the University of Vienna, and the prehistorian Georg Kyrle were able to examine 20,000 tons of cave deposits and produced a two-volume monograph on the interdisciplinary relevance of their findings and the stratified cave sediments. Particular attention was paid to the consistency, chronological relevance, recovery, and conservation of findings, as well as the stratification, accumulation, and origins of the deposits, which were recorded by the shift foreman in specific notebooks and formed (together with depictions of vertical sections) the basis for later scientific interpretation of the results. The seminar room of the paleo-biological institute, where the constantly growing stock of paleontological discoveries was examined, became the meeting room of a secret society of anti-Semitic professors (nicknamed Bears' Cave) that began to dominate scientific politics at the University of Vienna and finally implemented speleology as an academic discipline with its own chair, curriculum, and department.[84]

[81]See Bertarelli & Boegan (1926).
[82]University of Cluj (1920, p. 9); Kyrle (1927b, p. 82).
[83]See Abel & Kyrle (1931).
[84]See Taschwer (2016, pp. 221–242); Mattes (2015c, pp. 275–295).

The closer attention paid to the vertical section of cave soils also had a political dimension. The stratigraphic context of findings and particularly the simultaneous occurrence of cultural artifacts and fossils allowed conclusions to be drawn about the site and about the circumstances and date of its occupation. Prehistory, understood after the title of Gustaf Kossinna's book of 1912 as an "excellent national science," went hand in hand with ideological ambitions.[85] According to Philip L. Kohl's study of the relationship between nation-building and archeology, nationalist interpretations of prehistoric sites played a key role in the construction of political identities.[86] In the interwar period, this particularly applied to underground spaces. The discovery of prehistoric cave art in France and northern Spain and its scientific recognition at the beginning of the 20th century led to efforts to locate equivalent discoveries in central and southeastern Europe, particularly cult objects and Venus figurines. After 1918, assumptions about the geographic extent, time horizon, cultural levels, and homogeneity of the Aurignacian (ca. 43,000–28,000 BP) and the Magdalenian (ca. 17,000–12,000 BP) were increasingly influenced by racist prejudices and concepts of "tribes" and of cultural areas of ethnic unity. In the case of the newly founded nation-states, these ideas were used to justify claims to cultural dominance. In Czechoslovakia and Hungary, vertical geographies underground quickly gained importance as resources for scientific and political claims, in the course of successful excavation projects by Karel Absolon in the cave sites Pekárna jeskyně (1925–1930) and Býčí skála (1936–1938), and by Ottokár Kadić in the so-called Mussolini Cave (1932).[87]

Until the beginning of the 20th century, there existed no specific piece of legislation for the protection of subterranean space and the natural and cultural heritage associated with it. In France, thanks to the joint action of Édouard-Alfred Martel and the geographer Eugène Fournier, Article 28 was introduced to the law on public health (1902), prohibiting the throwing of animals carcasses into deep pits— still a common practice at the time. National laws on the conservation of caves and their deposits were enacted about 20 years later: in Austria in 1924, in France in 1930, in Germany and Hungary in 1935, and in Italy in 1939. At this time, many of these states were already ruled by fascist or right-wing governments, and the aim of protecting a (prehistoric) cave dwelling was connected to the intention to supervise the process of attributing scientific meaning to findings. Therefore, exclusive access to caves as potential excavation sites ensured interpretative dominance over the finds and the historical narratives related to them. Unauthorized excavations were deemed to be "attacks on ancestral heritage," and unrestricted political access to vertical geographies underground was justified as a necessary means to "protect valuable cultural assets of our nation."[88] Likewise, the interpretation of the prehistory of caves and their inhabitants included the possibility of legitimizing historically derived political claims to power.

Thus, entangled scientific, political, and economic interests in vertical geographies placed new demands for accuracy on the instruments and maps used in speleology. Whereas before 1914 the handling of surveying tools served as a means of social distinction between cave researchers and visitors, in the interwar years, the supervision of surveyors, the interpretation of generated data, and finally the production of maps were counted among the primary duties of expedition leaders. Some caves were even repeatedly surveyed by various expeditions, which sometimes revealed considerable differences in map display. However, speleological publications barely addressed this issue: "For the evaluation of a map, the specific form and traversal difficulty of a subterranean terrain must never be disregarded. They often have a higher influence on the execution and accuracy of a survey than its purpose."[89] On the one hand, deviations in the measurement of traverse lines were quite common. On the other, the display of the galleries' outline was not usually based on polygonization, but was left to the discretion of the cartographer, leading to similarly significant differences in map display.[90] The former was mainly due to the inaccuracy of inclination

[85]Kossinna (1912).

[86]See Kohl (1998, pp. 223–246).

[87]For example, see Oliva (2014, pp. 9–245); Mattes (2020, pp. 190–223); Bartuez et al. (1940). Since 1945, the Mussolini Cave (Mussolini-barlang) has been named Suba-lyuk.

[88]Brand (1935, p. 53).

[89]N. N. (1925, p. 55).

[90]In a survey, many polygons are strung together (polygonization). Thus, small measurement errors can add up to considerable deviations in large cave systems.

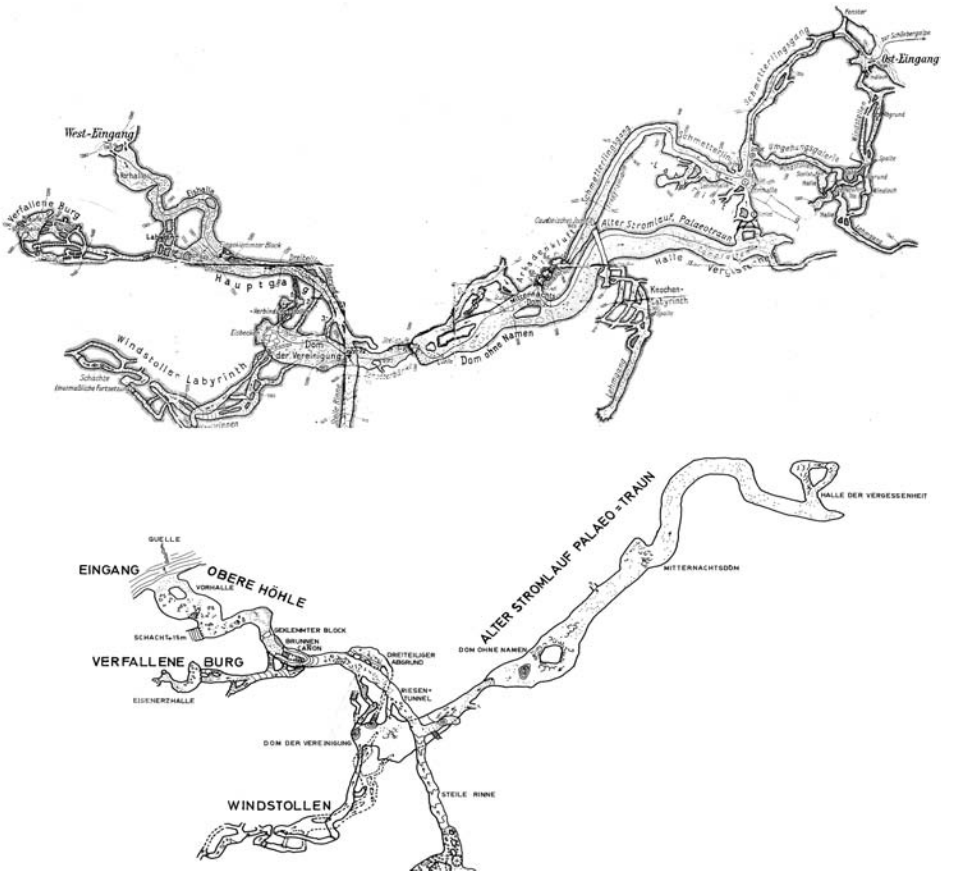

FIGURE 4 Comparison of two maps of the cave Dachstein-Mammuthöhle near Obertraun in Austria, drawn by Rudolf von Saar (1922, above) and Hermann Bock (1910, below). Austrian Cave Cadastre, No. 1547/9, Archive of the Karst and Cave Working Group, Natural History Museum, Vienna, Austria

measurements, so that various methods and instruments, such as barometric altimeters, balloons, plumb lines, tube levels, or (self-made) clinometers, were often used simultaneously to determine vertical dimensions. In contrast, the display of the galleries' outlines corresponded to different concepts of speleogenesis, which divided the speleological community around 1920 between supporters of Alfred Grund's theory of cave formation by dissolution in the groundwater zone and followers of Friedrich Katzer or Walther von Knebel, who explained the origin and development of caves with the power of subterranean streams.[91] A comparison of two maps of the Dachstein-Mammuthöhle cave in Austria (Figure 4), drawn in 1910 and 1922, underlines the significance that both map authors attributed to underground streams as the main reason for speleogenesis. In particular, the earlier map tried to overemphasize this assumption with its use of round forms to depict the outline of galleries.

The contradiction between obvious problems in measuring vertical geographies and the use of cave maps as evidence in debates in related scientific disciplines led to various epistemic strategies and practices to deal with the vertical as a dimension of knowledge. With the introduction of the term “speleotopography” to describe the “most important task of practical research,” speleologists at universities and other research institutions attempted to assign a higher status to cartography.[92] To reject accusations of scientific amateurishness, a federal Committee for the

[91]See Mattes (2015b, pp. 251–266). The term “speleogenesis” describes the process of cave formation.
[92]Kyrle (1923, p. 8).

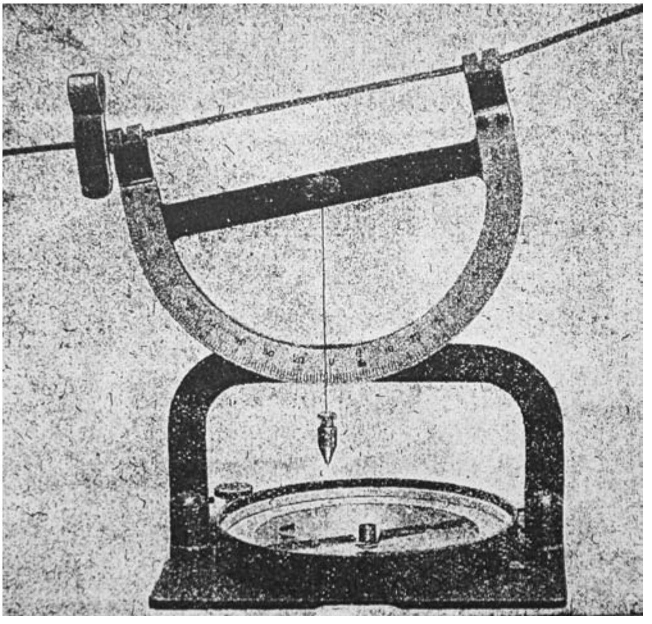

FIGURE 5 Prototype of a small universal instrument for cave surveying. From "Ein kleines Universalinstrument für die Vermessung von Höhlen," by K. Lüdemann, 1926, *Zeitschrift für Instrumentenkunde*, 6, Table I

Preparation of Scientific Fundamentals and Uniform Viewpoints for Cave Surveying was established in Vienna in 1921, consisting mostly of professional geodesists and cartographers. Subsequently, several sets of (state-funded) instructions for cave surveyors were published in order to ensure accuracy in data-collection processes.[93] Efforts to introduce uniform scientific instruments adopted from land or mine surveying and the provision of training courses represented further attempts to create a comparable data basis. At the same time, speleologists were keen to differentiate their methods from the surveying techniques of related disciplines such as archeology, emphasizing the distinctiveness of vertical geographies in the underground:

> The well-developed mine surveying differs significantly from the neglected cave surveying. Due to the high diversity of the caves' vertical sections … it is impossible to give an approximate idea of the caves' shape by means of traverse lines [as in mine surveying].[94]

Keeping this in mind, it is astonishing that state-owned research projects, such as the abovementioned interdisciplinary excavation in the cave Drachenhöhle, still relied on scientifically recognized geodesists rather than on experienced surveyors of speleological societies.

Furthermore, the implementation of new surveying techniques, such as stereophotogrammetry, which was first used in the cave Škocjanske jame (today in Slovenia) in the course of a PhD project at the Technical University of Munich, allowed claims for more objectivity, particularly regarding vertical dimensions.[95] However, since the degree of illumination necessary for photography was often not available in vertical geographies for practical reasons, the application of stereophotogrammetry as a surveying technique remained limited to single cavities (for example, Altamira).

Finally, the need to deal with verticality as a measurable and scientifically interpretable dimension of knowledge also had a deep impact on the use, adoption, and invention of new instruments. While some speleologists argued in favor of using different commercially available devices in the same cave depending on the terrain to be surveyed (for

[93]See, for example, Reisner (1921, pp. 10–24).
[94]Killian (1937, p. 116).
[95]See Oedl (1924); Shaw (2018, pp. 63–79).

example, theodolites and prismatic compasses), others recommended the use of a weatherproof universal instrument due to the lower weight, size, and transport cost. This also involved the development of self-made cave-surveying instruments, which was spearheaded by scientific amateurs in German speleological societies and led to the construction of several different prototypes.[96] Although the increasing use of theodolites in cave surveying provided accurate results, vertical or narrow sections where large instruments could not operate remained a significant source of uncertainty. Devices especially designed for cave surveying eventually dealt with this specific problem. These included, for example, the Speläometer by Richard Spöcker, the Polygometer by Helmuth Cramer, and a purpose-built item from the Hildebrand workshop in Freiberg-Sachsen (Figure 5), in which the suspension hanger of the compass was connected to the graduated arch.[97] All these devices shared not only the quality that all measured values (direction, inclination, and sometimes even length) of a traverse line could be read simultaneously, but also that the inclination (that is, the vertical dimension) was indicated clearly on a graduated arch. The fact that the prototypes never reached marketability and were used only within a local speleological society is likely due to the expectation of low sales, the multitude of competing instruments for cave surveying, and the lack of interest from academic speleologists, who favored scientifically accredited and commercially available devices.

5 | CONCLUSION

When we understand space as a socially-constructed, "practiced place," spaces and their borders are not set in stone; they are under permanent reconstruction, delimitation, and negotiation.[98] The same applies to the vertical as an epistemic dimension that corresponded to the idea of depth in order to gain control over spaces that had previously defied scientific measurement and documentation. Geographies of science take landscapes and locations of scholarly knowledge-production into consideration.[99] Knowledge is situated in a spatial context; it is formatted topographically and can accumulate in specific sites where it is more easily studied. In the case of subterranean spaces, one of these hubs where different strands of knowledge come together is the intersection between vertical and horizontal scales of knowledge. There, humans, epistemes, and objects circulate and create density through mobility, communication, and the permanent negotiation of proximity and distance.

Disentangling the different layers of spatial reasoning, this paper has examined the interlinking of various claims to natural cavities. As a result, a correlation between scientific, political-territorial, and social boundary-work has been suggested. Verticality, in these instances, did not represent a stable entity, but has always been subject to a continuous process of negotiation and coproduction between new fields of research, their practices, technologies, and social contexts. Throughout the 19th century, the spatial visualization of the earth and its porous, cavernous body in the form of vertical sections became a powerful epistemic tool for new insights into nature. Climbing techniques were as important as the long-term development of a visual language of speleology. The possibility of upright descent became the basis for vertical boundary-work in the depths of the earth and led to a three-dimensional understanding of terrain, its scientific investigation, and territorial acquisition. At first, the introduction of measuring and mapping tools facilitated the social distinction between cave visitors and speleologists. Soon, however, during and after World War I, the invention of more complex scientific instruments and of quantifying methods that required more user instruction and training led to the implementation and legitimization of new academic disciplines. The official rejection of measuring instruments used in established disciplines like geology, archeology, or mining, and the ultimately unsuccessful attempt to develop uniform and universally applicable instruments for cave surveying that could provide comparable scientific data of vertical geographies became pivotal moments in the emancipation of speleology. Despite the instruction, disciplinary action, and scientific monitoring of cave surveyors, the

[96]See Killian (1937, pp. 116–128); Götze (1930, pp. 106–111).
[97]See Teißl (1925, pp. 43, 45); Lüdemann (1926, pp. 148–150).
[98]Certeau (1984, pp. 122–130).
[99]For example, see Livingstone (2003); Meusburger, Livingstone, & Jöns (2010).

difficulties in traversing vertical terrain had a key impact on the quality of maps. In the end, verticality remained a surprisingly obscure category—a noteworthy aspect when considering the simultaneous (nationally charged) competition for the latest depth records between 1909 (Nidlenloch, Switzerland, 394 m) and 1934 (Corchia Caves, Italy, 541 m).

Finally, the article suggests that the territorial reconfiguration of Europe after 1918 boosted awareness of the world beneath our feet. Differences in the political, economic, and scientific claims to caves between the loser and victor states of World War I resulted in diverse ways of dealing with the vertical. In accordance with the growing interest in the military and economic usage of caves, the development of national cave cadasters, speleological research institutes, and legal regulations in central Europe represented this new three-dimensional understanding of territory. As climbers conquered new routes to alpine peaks with heroic gestures and with first ascents staged as the conquest of enemy territory, subterranean vertical ventures and the “protection” of vertical geographies as pristine spaces of natural and cultural heritage became the sites of national scrambles for power. Hence, science and politics, understood as resources for each other, used space and its vertical dimension to transform the ways in which they were understood, practiced, and organized. The variety of affiliated institutions and fields of study in which speleology was—and still is—practiced indicates a reallocation of resources and their metadisciplinary usage: at universities, academies of sciences, (private) research departments, museums, preservation agencies, (popular) scientific societies, and alpine clubs.

In closing, let us return once again to the initial quote about the first discovery of Neanderthal fossils in 1856. The destruction of the entire cave site and its stratigraphy, caused by quarry work, resulted in a long-lasting scholarly debate about the meaning and chronological classification of the findings there. Like in archeology, verticality could become an important tool for historians of science, and also other fields of research, by empowering them to discover structures that would otherwise remain unknown. If we imagine, for a brief moment, a growing line of literally descending scholars, dressed in corduroy coats with elbow-patches, crawling on all fours or stuck in pits or being carried piggy-back by their guides through muddy cave passages, we can understand the underground as a space in which hypotheses, methods, and (epistemic) instruments faced challenges that they might fail. As this article suggests, closer attention to the scientific practices and divisions of labor used in “subterranean fieldwork” will help us avoid getting trapped.

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