

RESEARCH ARTICLE

Mapping the invisible: knowledge, credibility and visions of earth in early modern cave maps

Johannes Mattes*

Austrian Academy of Sciences

*Corresponding author: Johannes Mattes, Email: johannes.mattes@oeaw.ac.at

Abstract

This paper examines cave environments as unique spaces of knowledge production and shows how visualizations of natural cavities in maps came to be powerful tools in scientific reasoning. Faced with the challenge of limited vision, mapmakers combined empiricism and imagination in an experimental setting and developed specific translation strategies to deal with the uncertain origin of underground objects and the shifting boundaries between the known and the unknown. By deconstructing this type of cartographic representation, which has barely been studied, this paper furnishes surprising insights into the scholarly practices and tools used to deal with this considerable epistemic uncertainty and to signal credibility and trust to potential users. The array of maps used for this study includes both archival and published sources, depicting caves in Europe, America and Siberia.

In the summer of 1671, the naturalist Nicolaus Steno (1638–86) headed north towards the Alps, equipped with tools to measure length and temperature. Authorized by the Accademia del Cimento and Cosimo III de' Medici (1642–1723), Grand Duke of Tuscany, to revise the ancient scholarly concept of 'antiperistasis' in nature, Steno set out to investigate and gather data in the ice caves of Gresta (Trentino) and Moncodeno (Lombardy). Originating with Aristotle, the concept of 'antiperistasis' was based on the idea that one quality increases the force of another, contrasting quality. It was used as a general explanatory model for numerous natural phenomena.¹ In particular, reports that alpine caves produce their ice during the summer months were invoked to support the existence of 'antiperistasis'. This phenomenon intrigued Steno and motivated him to make his own observations on site. Roughly drawn sketches of Moncodeno Ice Cave (Figure 1), including two sections in astonishing detail, were attached to the two reports he sent to Cosimo.² More than mere illustrations, these images constituted a central part of Steno's argument, clearly distinguishing between the different shapes of ice formations and assigning them specific locations inside the cave. Furthermore, they reinforced his decisive argument against 'antiperistasis', namely that the low temperature inside the cave was caused by the accumulation of snow at the entrance, and not by a concentration of cold air reacting

1 See Martin Mulsow, *Frühneuzeitliche Selbsterhaltung: Telesio und die Naturphilosophie der Renaissance*, Berlin and Boston: Niemeyer, 2013, pp. 57–102; Kirstine Meyer, 'Zur Geschichte der Antiperistasis', *Annalen der Naturphilosophie* (1904) 3, pp. 413–41.

2 See Niels Steensen, *La grotta di Moneoden*, 1671 (National Central Library of Florence, Ms., Gal. 286/32), pp. 58r–61r. For a translation of Steno's letters, see Troels Kardel and Paul Maquet (eds.), *Nicolaus Steno*, Berlin: Springer, 2013, pp. 330–4, 671–7.

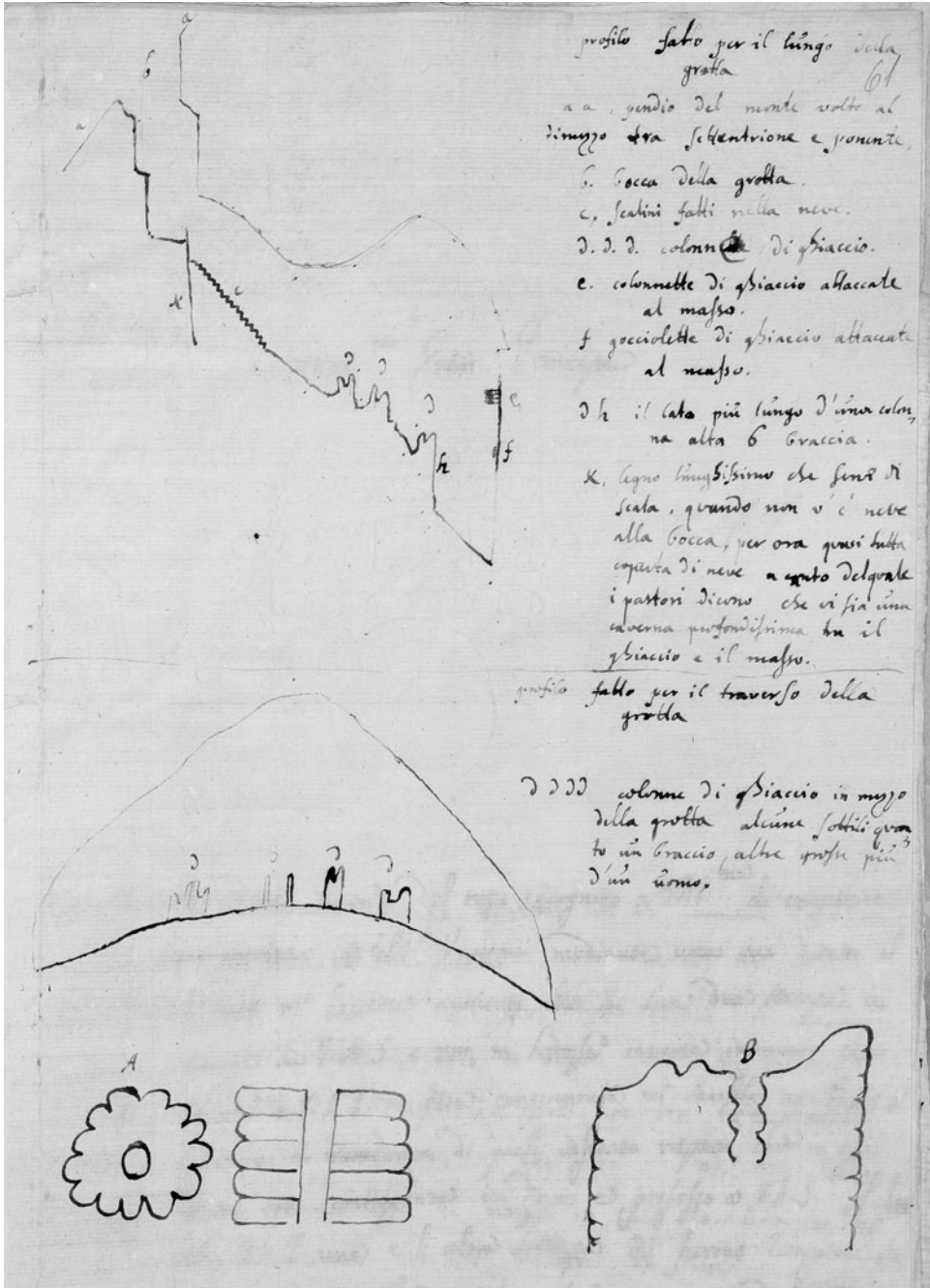


Figure 1. Longitudinal section (top) and cross-section (centre) of Moncodeno Ice Cave (Lombardy), drawn by Nicolaus Steno in 1671 (National Central Library of Florence, Ms., Gal. 286/32, p. 61r). Steno clearly illustrates the descent (c) into the cave and the ice formations that present as columns (d) in the centre of the hall and on its walls (e, f). The text on the right side of the sheet provides additional information, for example, about a deep shaft (x) located next to the steps (c), where shepherds report that stones thrown down there make a long rolling noise. The drawings on the bottom of the page illustrate the different shapes of ice figures which were formed by drops of water falling from the ceiling.

in opposition to the heat outside.³ According to Luca Ciancio, Steno's field research employed interrelated methods including 'the use of measuring instruments for dimensions and temperature [and] the visual representation of structures, plans and profiles'.⁴ To quote M. Norton Wise, Steno's survey was 'not illustration, but argument'.⁵

Maps were often used in epistemic settings that combined various fields of knowledge and empirical observation practices.⁶ Although Steno's naturalistic style and his use of maps in scientific argumentation are rather exceptional for his period, they anticipate the later large-scale adoption of the map format for visualizations of natural cavities. Unravelling the different layers of visual argumentation, this paper will examine early modern cave maps as representations of subterranean space; more precisely, as a space of representation in which knowledge, objects, epistemes and their interactions in space and time are discussed and legitimized.

Towards the end of the eighteenth century, increased awareness of sensory perception and debates around the limits of human knowledge were closely connected to the development of a visual culture in earth sciences and scholarly efforts towards a common geological perspective. Martin Rudwick's 1976 paper 'The emergence of a visual language for geological science', in which he examines the growing number and broader diversity of images in geological literature around the turn of the nineteenth century, draws our attention to naturalists' visualization strategies when carrying out fieldwork or communicating their results in publications.⁷ This milestone paper fostered scholarly interest in visual sources (such as maps, sections and landscapes), as well as in the materials, techniques and artisans involved in their production. Discussing the interconnection of 'major changes in geoscience cartography ... shifting scientific preoccupations and convictions', Kenneth Taylor's essay 'Early geoscience mapping, 1700–1830' analyses the broad range of mineralogical, stratigraphic, mining-related and topographic mapping, tracing its diversity back to the 'theoretical pluralism that characterized geology for many years, well beyond its establishment as a recognized science'.⁸ Referring directly to Rudwick, Taylor points out that the development of these visual representations should be recognized as more than 'a set of changes in technique, since technical alterations are tied to adjustments in ideas about the things it may be profitable to represent cartographically'.⁹

In the wake of Rudwick's paper, a wealth of literature has been written about the visualization of geological features. Important contributions have been made by William

3 Arguments against antiperistasis had already been put forward by numerous early modern scholars, including Robert Boyle. See Robert Boyle, *New Experiments and Observations Touching Cold, Or, an Experimental History of Cold Begun to Which Are Added an Examen of Antiperistasis and an Examen of Mr. Hobs's Doctrine About Cold*, London: John Crook, 1665.

4 Luca Ciancio, "'Voyons maintenant si cette opinion se trouve conforme à l'expérience": Nicola Stenone, Athanasius Kircher e le origini della speleologica', *Accademia roveretana degli Agiati* (2004) 254, pp. 57–72, 71.

5 M. Norton Wise, 'Making visible', *Isis* (2006) 97(1), pp. 75–82, 81.

6 See e.g. John Brian Harley, 'The map and the development of the history of cartography', in John Brian Harley and David Woodward (eds.), *The History of Cartography*, vol. 1, Chicago: The University of Chicago Press, 1987, pp. 1–42, 2; David Turnbull, 'Cartography and science in early modern Europe: mapping the construction of knowledge spaces', *Imago Mundi* (1996) 48, pp. 5–24, 7; Felipe Fernández-Armesto, 'Maps and exploration in the sixteenth and early seventeenth centuries', in David Woodward (ed.), *The History of Cartography*, vol. 3, Part 1, Chicago: The University of Chicago Press, 2007, pp. 738–59, 741; Mark Monmonier, 'Cartography: history', in Douglas Richardson, Noel Castree, Michael F. Goodchild, Audrey Kobayashi, Weidong Liu and Richard A. Marston (eds.), *The International Encyclopedia of Geography*, Chichester and Hoboken: John Wiley & Sons, 2017, pp. 1–12.

7 Martin Rudwick, 'The emergence of a visual language for geological science 1760–1840', *History of Science* (1976) 14, pp. 149–95. See Klaus Hentschel, *Visual Cultures in Science and Technology: A Comparative History*, Oxford: Oxford University Press, 2014, pp. 87–91.

8 Kenneth Taylor, 'Early geoscience mapping, 1700–1830', *Proceedings of the Geoscience Information Society* (1985) 15, pp. 15–49, 15, 45.

9 Taylor, op. cit. (8), p. 16.

Ashworth (writing about basalt), Jane Davidson and Martin Rudwick (fossils), Susanne Keller (earthquakes) and David Oldroyd and Simon Winchester (geomaps), to mention only a few.¹⁰ Studies by art historians such as Fritz Emslander and Barbara Stafford have also shown how visualizations of geological phenomena were pre-shaped by artistic representations.¹¹

Although some of the wide-ranging surveys mentioned above also deal with mine maps, comparatively little attention has been paid to caves and their impact on early modern concepts of nature. Ernst Hamm's pioneering article 'Knowledge from underground: Leibniz mines the Enlightenment' identifies mines and caves as objects of scholarly curiosity in the eighteenth century. Recognizing subterranean geographies both as 'an instrument for managing the mine' and as a 'method for understanding the earth', Hamm argues that, due to limited physical access, maps of the underground 'were needed to make the invisible visible, and to do so required many generalizations and hypotheses about the way the earth's crust was structured'.¹² Michael Shortland's 'Darkness visible' takes a similar approach, drawing connections between the power of subterranean imagery, romanticism and politics, and dissecting how the undercurrents of 'cavelove and cavelore' in early nineteenth-century Britain shaped a 'formative period in modern geology'.¹³ Attributing a 'central position in geological theory' to natural cavities, Nicolaas Rupke looks at the study of fossils in Romantic natural philosophy and the visualization of stratigraphic columns.¹⁴ Another valuable paper by Luca Ciancio (see above) uses the activities of Athanasius Kircher and Nicolaus Steno as a basis for examining early practices of scientific fieldwork in caves.¹⁵ Focusing on Central Europe, a volume by Johannes Mattes presents a *longue durée* cultural history of knowledge-based interactions with cavities and other subterranean sites, especially their visualization by scholars and artists.¹⁶ Equally important is the contribution of Patrick Anthony, who comments on the entanglements of 'underground enlightenment' and vertical cartography with reference to mines in the Harz mountains.¹⁷

Covering the spectrum from surveying technologies, via resources, to the significance of vertical spaces, recent scholarship in history of science, environmental history, urban

10 See William Ashworth, *Vulcan's Forge and Fingal's Cave: Volcanoes, Basalt, and the Discovery of Geological Time*, Kansas City: Linda Hall, 2004; Jane Davidson, *A History of Paleontology Illustration*, Bloomington: Indiana University Press, 2008; Martin Rudwick, *The Meaning of Fossils: Episodes in the History of Palaeontology*, London: MacDonald, 1972; Susan Keller, 'Sections and views: visual representation on eighteenth-century earthquake studies', *BJHS* (1998) 31, pp. 129–59; David Oldroyd, 'Maps as pictures or diagrams', in Viktor Baker (ed.), *Rethinking the Fabric of Geology*, Boulder, CO: Geological Society of America, 2013, pp. 41–101. Simon Winchester, *The Map That Changed the World: William Smith and the Birth of Modern Geology*, New York: HarperCollins, 2001. An overview is provided by Luca Ciancio and Domenico Laurenza, 'Visual representation in earth sciences history after "The Emergence"', *Nuncius* (2018) 33, pp. 397–414.

11 See Fritz Emslander, *Unter klassischem Boden: Bilder von Italiens Grotten im späten 18. Jahrhundert*, Berlin: Reimer, 2007; Barbara Stafford, *Voyage into Substance*, Cambridge, MA: MIT Press, 1983.

12 Ernst Hamm, 'Knowledge from underground: Leibniz mines the Enlightenment', *Earth Sciences History* (1997) 16(2), pp. 77–99, 84, 87.

13 Michael Shortland, 'Darkness visible: underground culture in the golden age of geology', *History of Science* (1994) 32(1), pp. 1–61, 43.

14 Nicolaas Rupke, 'The study of fossils in the romantic philosophy of history and nature', *History of Science* (1983) 21(4), pp. 389–413, 392. See Rupke, 'The end of history in early picturing of geological time', *History of Science* (1998) 36(1), pp. 61–90.

15 See Ciancio, op. cit. (4), pp. 57–72.

16 See Johannes Mattes, *Reisen ins Unterirdische: Eine Kulturgeschichte der Höhlenforschung*, Vienna: Böhlau, 2015, pp. 89–95.

17 Jakob Vogel, 'Aufklärung untertage: Wissenswelten des europäischen Bergbaus im ausgehenden 18. und frühen 19. Jahrhundert', in Hartmut Schleiff and Peter Konečný (eds.), *Staat, Bergbau und Bergakademie*, Stuttgart: Steiner, 2013, pp. 13–31. See Patrick Anthony, 'Mining as the working world of Alexander von Humboldt's plant geography and vertical cartography', *Isis* (2018) 109(1), 28–55.

studies and (political) geography has broadened our understanding of subterranean geographies as dynamic multidimensional landscapes of social practice, and of their role as interaction facilitators.¹⁸ Compared to artificial spaces such as mines, catacombs and bunkers, considerably less is known about the scientific impact of natural cavities, especially when it comes to cave surveying and the practices of knowledge involved.¹⁹ Some handbooks, such as the multi-volume *History of Cartography* series, even classify cave plans as a separate type of topographical map, ‘drawn in plan view with generalized walls shown as solid lines. Because ... direct field survey remains the only reliable method for mapping them, cave exploration and mapping have been closely coupled since the 1800s’.²⁰ Although the *Encyclopedia of Caves and Karst Science* mentions more than a dozen cave maps made before 1800, the authors’ interest is focused on the nineteenth and twentieth centuries and on how improved exploration techniques informed the science of speleology (the study of caves) as a whole.²¹ Vlado Božić, Stephan Kempe *et al.*, José Lima *et al.*, Johannes Mattes, Michael Sutton and Petr Zajíček pursue a similar line of inquiry in their own various, very useful approaches to the topic, which mostly deal with the history of cave cartography based on case studies of single caves or regions.²² Trevor Shaw’s

18 See special issues of the journals *Communications* (2019) 109, *Vivants sous terre* (ed. Monique Peyrière and Évelyne Ribert); *Centaurus* (2020) 62(4), *Verticality in the History of Science* (ed. Wilko Graf von Hardenberg and Martin Mahony); *Renaissance Studies* (2020) 34(1), *The Cultural and Material Worlds of Mining in Early Modern Europe* (ed. Tina Asmussen); *Traverse* (2020) 2, *Unter Grund: Eine vertikale Verflechtungsgeschichte* (ed. Tina Asmussen, Silvia Berger Ziauddin, Alexandre Elsig and Bianca Hoenig); *Political Geography* (2019–21), *Earth Politics: Territory and the Subterranean* (ed. Matthew Himley and Andrea Marston). On caves and subterranean space see María Pérez, ‘Volumes, caves, bodies, relatedness: the case of Cuban speleology and national defense’, *Geoforum* (2021) 127, pp. 412–23. A promising PhD project on multidisciplinary collaborations in cave and karst environments is currently led by Simone Sambento at the University of Edinburgh, Science, Technology and Innovation Studies. See also Bruce Braun, ‘Producing vertical territory: geology and governmentality in late Victorian Canada’, *Cultural Geographies* (2000) 7(1), pp. 7–46; Stuart Elden, ‘Secure the volume: vertical geopolitics and the depth of power’, *Political Geography* (2013) 34, pp. 35–51; Steven Graham and Lucy Hewitt, ‘Getting off the ground: on the politics of urban verticality’, *Progress in Human Geography* (2013) 37, pp. 72–92.

19 For example, caves are not considered in the wide-ranging survey by Helen Curry, Nicholas Jardine, James Secord and Emma Spary (eds.), *Worlds of Natural History*, Cambridge: Cambridge University Press, 2018.

20 See John Glennon, ‘Cave map’, in Mark Monmonier (ed.), *The History of Cartography*, vol. 6, Chicago: The University of Chicago Press, 2015, pp. 206–7.

21 See Wookey, ‘Cave surveying’, in John Gunn (ed.), *Encyclopedia of Caves and Karst Science*, New York: Fitzroy Dearborn, 2004, pp. 714–7.

22 Božić provides a compilation of milestone maps in the history of speleology and discusses them in sequence. See Vlado Božić, *Razvoj speleološkog nacrtā*, Zagreb: Hrvatski planinarski savez, 2004. Kempe *et al.* address scholarly descriptions and depictions of Baumannshöhle (Germany) in the early modern literature. See Stephan Kempe, Boris Dunsch, Klaus Fetkenheuer, Gottfried Naumann and Fritz Reinboth, ‘Die Baumannshöhle bei Rübeland/Harz im Spiegel der wissenschaftlichen Literatur vom 16. bis zum 18. Jahrhundert’, *Braunschweiger Naturkundliche Schriften* (2004) 7(1), pp. 171–215. Lima *et al.* deal with the map of Gruta das Onças (Brazil), made by the Portuguese naturalist Alexandre Rodrigues Ferreira in 1790. See José G.A. Lima, Evanoir T. França, Jocy B. Cruz *et al.*, ‘Gruta das Onças: a redescoberta da primeira caverna mapeada no Brasil’, *Congresso Brasileiro de Espeleologia* (2015) 33, pp. 207–17. Mattes examines the influence of fieldwork practices and their standardization in the scientific accreditation of speleology, based on maps made between 1870 and 1930 in Europe and North America. See Johannes Mattes, ‘Underground fieldwork: a cultural and social history of cave cartography and surveying instruments in the 19th and at the beginning of the 20th century’, *International Journal of Speleology* (2015) 44(3), pp. 251–66; Sutton uses maps of Mammoth Cave (Kentucky) to illustrate the ‘progress of underground survey and cartography’ in the nineteenth and twentieth centuries. See Michael Sutton, ‘A history of map-making at Mammoth Cave’, in Horton Hobbs, Rickard Olson, Elizabeth Winkler *et al.* (eds.), *Mammoth Cave: A Human and Natural History*, Cham: Springer, 2017, pp. 77–95. Zajíček studies around fifty maps produced since the 1800s in Bohemia and Moravia and provides facsimiles of these unique sources. See Petr Zajíček, *Jeskyně České republiky na historických mapách*, Prague: Academia, 2016.

History of Cave Science, which contains several reproductions of unique sources that he examines in the context of cave exploration, deserves particular recognition.²³

Since the publication of John Brian Harley's seminal essay 'Deconstructing the map' and Derek Gregory's work on 'imagined geographies', geographers and historians of cartography have paid considerably more attention to the power-related constructive character of spatial knowledge, its relation to imagination and its social and discursive framework.²⁴ The critical approaches of scholars such as Simon Naylor and David Turnbull interrogate established paradigms of cartography and argue for maps as tools of knowledge production and translation, underlining their importance for historians of science.²⁵ Of particular relevance is a recent paper by Charles Withers, who calls for a deeper evaluation of the epistemological issues of trust and credibility in geography and the ways these are secured.²⁶ Referring to the valuable work done in this regard by David Livingstone and Steven Shapin, the author asks how 'technologies' of credibility building, such as surveying and mapping, were able to 'inscribe trust in space' despite 'the instruments involved running slow or breaking'.²⁷ This is especially true for cave environments, which, due to difficulty of access and limited vision underground, created an epistemic setting in which imagination and empiricism interacted and specific scholarly strategies were required to establish credibility.

In recent years, I have been able to study more than 120 maps made before 1800, covering both natural caves and artificial cavities (where these were believed to be of natural origin at the time the plan was made). Starting from an exceptional 1417 drawing of Labyrinth Cave near Gortyn (Crete), the sources comprise maps of caves located in Europe, Siberia (from the early eighteenth century onwards) and the Americas (from the late eighteenth century). In contrast, the earliest preserved maps of caves in Africa, Australia and other parts of Asia date back to the first decades of the nineteenth century and are therefore not considered in this article. While maps made after 1800 vary significantly in their designated use depending on who created or commissioned them, early modern maps were almost exclusively aimed at scholars, travellers and learned aristocrats. They were either made by scholarly authors and publishers or else commissioned by them from engineers, surveyors or painters, and were mostly published within travel accounts, country descriptions or scholarly treatises. Cave maps have also been preserved in provincial and state archives located in karst and cave areas, as well as the personal estates of various scholars. Other commonalities that justify a comparative study are that all of these surveys originated from personal observation, and that they can be clearly distinguished from artistic depictions by the use of cartographic features. From the range of these maps, I will deal primarily with caves which were known among scholars and/or mapped several times. However, schematic representations of underground watercourses (such as in Athanasius Kircher's 'Mundus subterraneus') which do not depict a specific cave are not included in this study.²⁸

23 See Trevor Shaw, *History of Cave Science*, 2nd edn, Sydney: Sydney Speleological Society, 1992.

24 See John Brian Harley, 'Deconstructing the map', *Cartographica* (1989) 26(2), pp. 1–20; Derek Gregory, 'Imaginierte Geographien', *Österreichische Zeitschrift für Geschichtsforschung* (1995) 6(3), pp. 366–425.

25 See Simon Naylor, 'Historical geographies of science: places, contexts, cartographies', *BJHS* (2005) 38(1), pp. 1–12; Turnbull, *op. cit.* (6), pp. 5–24; Charles Withers, 'Reporting, mapping, trusting: making geographical knowledge in the late seventeenth century', *Isis* (1999) 90(3), pp. 497–521.

26 See Charles Withers, 'Trust – in geography', *Progress in Human Geography* (2018) 42(4), pp. 489–508.

27 David Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge*, Chicago: The University of Chicago Press, 2003, p. 147; Withers, *op. cit.* (26), p. 500. See Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century England*, Chicago: The University of Chicago Press, 1994, p. 245.

28 Although Athanasius Kircher's two-volume *Mundus subterraneus* contains numerous visualizations of subterranean space, none of these images depicts a specific cave. In the first edition, Kircher discusses caves in

Comparing these unique sources raises questions regarding their ‘experimental’ character, which interweaves various spheres of knowledge, evidence-based practices and elements of the contemporary imagination about the Earth’s interior. Constituting a shared point of interest for early modern naturalists, surveyors, travellers, artists and (local) collectors, caves can also be understood as ‘boundary objects’ connecting different meanings and communities of practice.²⁹ It is my contention that, unlike mines and other subterranean or remote spaces of knowledge production, the specific conditions of cave environments – such as their labyrinthine topography, impassability, isolation and obscurity – gave rise to distinct ways of handling both knowledge and the different kinds of objects found there, such as minerals, fossils and artefacts. In these underground sites, limited vision presented a challenge to the early modern practice of providing evidence based on experience, casting contemporary cultures of perception into doubt.

The premise of this article is that mapping subterranean geographies was an important technology of credibility building, even though any such endeavour was founded on non-empirical aspects such as ambiguity and lack of knowledge. Cave maps showed significantly more than early modern surveyors could actually see. I contend that the act of making them was not just knowledge-based, but creative: a translation process that blurred the traditional boundaries between natural, unnatural and supernatural. This means that cave maps are not only a ‘sensitive indicator of the changing thought of man’ about the subterranean world, but also epistemic tools that made it possible to observe the invisible, empowering the viewer to see and believe in structures within the Earth’s crust that would otherwise remain unknown to them.³⁰ In its broad scope, this article discusses in depth the process by which early modern visualizations of underground space in the form of cave maps became powerful tools of scientific reasoning, even as they confronted considerable epistemic uncertainty. The interplay of empiricism and imagination, cartographic practices, the techniques involved in the legitimization of knowledge and the subsequent embedding of these maps in scholarly discourse are all focuses of my analysis. My case study therefore contributes to a better understanding of the grounds and means of scientific credibility and cartographic representation by furnishing new insights into these under-studied sites of natural history.

First of all, I will discuss the impact of limited vision and the intermediate meaning of caves in early modern maps, and show how a complex set of interrelations between empiricism and imagination gave rise to certain epistemic conventions in visualizing underground sites. In the second section, I will focus on the development of map design; interactions between naturalists, artisans and map users; and how surveying practices and measuring instruments shaped the process of credibility building and the claim to accuracy. Outlining their changing epistemic functions, the final section analyses how cave

Chapter 20 (‘About caves, cracks, and innumerable passages of earth’) at the end of ‘Liber secundus’, but quotes mainly ancient authors. In the third edition, a letter by Cornelius Magni from Parma is reproduced at the end of the chapter with an account of his visit of Antiparos Cave in 1673. Kircher himself only refers to having visited the Monte Serana Cave near Trevi (Umbria). See Stephan Kempe, Gottfried Naumann and Boris Dunsch, ‘Athanasius Kircher’s chapter XX “About caves, fractures and the innumerable passages of the earth” and the Grotto of Antiparos from “Mundus subterraneus”, 1678, translated from Latin’, in Michal Filippi and Pavel Bosák (eds.), *Proceedings 16th International Congress of Speleology, Brno, 2013*, vol. 1, Prague: Czech Speleological Society, 2013, pp. 59–64. Athanasius Kircher, *Mundus subterraneus*, 1st edn, vol. 1, Amsterdam: Jansson & Weyerstraten, 1664, pp. 118–20. Kircher, *Mundus subterraneus*, 3rd edn, vol. 1, Amsterdam: Jansson & Filios, 1678, pp. 120–31.

²⁹ Susan Star and James Griesemer, ‘Institutional ecology, “translations” and boundary objects: amateurs and professionals in Berkeley’s Museum of Vertebrate Zoology’, *Social Studies of Science* (1989) 19(4), pp. 387–420.

³⁰ Norman Thrower, *Maps and Man: An Examination of Cartography in Relation to Culture and Civilization*, Englewood Cliffs: Prentice Hall, 1972, p. 1. See Arthur Robinson, *Early Thematic Mapping in the History of Cartography*, Chicago: The University of Chicago Press, 1982; Harley, op. cit. (6), pp. 1–42.

maps were used as scientific arguments and became embedded in causal thinking about natural history.

Landscapes of translation: between empiricism and imagination

Limited vision

For many scholars of the early modern world, studies of natural history were unthinkable without the first-hand, arduous experience of personal travel. Like above-ground journeys, excursions underground followed predetermined itineraries and were associated with visual expectations, encounters and illusions. Since Plato's analogy of the cave, subterranean sites, with their inherent liminality, have been understood as the prototype of an epistemic laboratory where the limitations of human perception are examined in an experimental setting.³¹ According to contemporary accounts, the multi-sensory experience of descending into heavy and humid darkness and encountering objects of uncertain origin not only overwhelmed many naturalists, but also undermined their trust both in their own observations and in the descriptions of previous visitors.

The *Protogaea*, a posthumously printed treatise on the history of the Earth by the prominent German polymath Gottfried W. Leibniz (1646–1716), includes probably the best-known early modern map of a cave.³² Based on a survey published fifty years earlier by Hermann von der Hardt (1660–1746) and modified most likely according to Leibniz's directives – or even by Leibniz himself – the unsigned map is a visual representation of the detailed report of his subterranean sightseeing trip to Baumannshöhle cave (Harz mountains). In this report, Leibniz addresses the curiosities, such as mineral formations and fossils, that he encountered along the way and their distorted perception by many visitors:

In one column, they think they see a monk; in another, Moses with two horns. Not far from Moses, and in various other places, are the bones of large animals and river pebbles, enclosed as if by the same mortar. But the games of nature presented in these caves demand the support of imagination. For they point out the Ascension of Christ stamped in the rock, a baptismal font, something that looks like an oven, an organ, a forest, and who knows what else ... To consider the nature of the rock more carefully, I ordered that some pieces be broken off to examine with leisure at home.³³

Leibniz recognized caves as mutable spaces where the narrowing and delimitation of the visitor's field of vision generated an illusionary world shaped by the viewer's prior experience and imaginative power. Although he personally distinguished between in-depth observation and imagination, the map as revised by Leibniz unites both domains. While he took over some of the anthropomorphic depiction of stalactites and other curiosities from the previous survey, Leibniz also added highly detailed depictions of his own findings, such as petrified bones, which he inserted around the part adopted from von der Hardt's original map. His critical examination of sensory perception and the mind's reflection on what the senses perceive exemplifies the tension in which most early modern cave

31 See Johannes Mattes, 'Entre nature et culture: les grottes, cabinets de curiosités naturelles à l'époque moderne' (tr. Claudine Cohen), *Communications* (2019) 105(2), pp. 13–26.

32 See Gottfried W. Leibniz, *Protogaea*, ed. Christian Scheid, Göttingen: Schmid, 1749, map on Tab. I; Hermann von der Hardt, 'Descriptio speluncae ad sylvam Hercyniam', *Acta eruditorum* (1702), pp. 305–8.

33 Leibniz, op. cit. (32), p. 68. Translation in Gottfried W. Leibniz, *Protogaea* (1749) (ed. Claudine Cohen and Andre Wakefield), Chicago: The University of Chicago Press, 2008, p. 113.

maps are embedded. As media of translation, cave maps engage with the dual function of the subterranean realm as a space of empiricism and imagination. The frequent reuse and adaptation of existing visualizations complied with the user's expectations of how the space should look, and satisfied their habits of reception.

The three-dimensional topography of caves, and the impossibility of illuminating them, mean that many areas (e.g. ceilings, slopes, deep pits or vast chambers) remain partly invisible. This in turn means that 'translating' subterranean landscapes into map format may have been even more demanding for surveyors than were above-ground topographic maps.³⁴ In narrow passages or canyons, the field of view is blinkered and does not extend beyond the next turn. Similarly, the low intensity of the available light sources had a considerable effect on the observation of large-scale sections. For example, the English naturalist John Beaumont (c.1650–1731) reported on his 1681 visit to Lamb Leer Cavern (Somerset) in the *Philosophical Collections* that 'by the light of our candles we could not fully discern the roof, floor, nor sides' of the cave.³⁵ Lowered by miners fourteen fathoms on a rope, Beaumont did not hold back from giving details of the dimensions of a vast chamber even though he himself could only see part of it.

Travellers and their guides chose from the broad variety of illuminants according to different needs. While wax candles were reserved for prestigious public and private rooms due to the scarcity of raw material, the 'dull light' of miners' lamps and smoky pinewood spills could only illuminate a narrowly confined space.³⁶ Torchlight – which is brighter, but produces a lot of smoke – met the visual expectations of an experience-oriented audience.³⁷ Contrasting shadows transformed the 'dark night of the cave' into a 'starry firmament ... in which the stalactites shone like stars'.³⁸ However, this did not satisfy the demands of the surveyors.

Maps display no evidence of these adversities, nor of the other visual limitations naturalists faced while crawling, descending or climbing in total darkness. The scholars' awareness of enormous areas in the Earth's underground, which cannot be illuminated by torches or penetrated by human perception, gave rise to specific strategies for dealing with the invisible and establishing credibility. Rather than employing 'cartographic silence' – a term coined by John Brian Harley to designate spaces intentionally left blank in order to denote the unknown – cave maps dissected the Earth's subsurface by choosing a very detailed form of presentation and/or providing imaginative illustrations of hidden areas.³⁹ Like artists, mapmakers were urged to 'complete similarities that nature had only outlined'.⁴⁰ But maps, which penetrated beyond the surface of the Earth and incorporated experiences gathered in exploration, were more reliable than paintings.

34 The underground's perceived exclusionary character was supported by the fact that early cave maps often omitted above-ground topographies. Likewise, overground maps frequently did not show cave entrances, thus denying the existence of a subterranean topography. The first topographical map to use uniform cartographic symbols for the designation of cave entrances was probably a hydrological map of Slovenia published in Belsazar Hacquet's *Oryctographia Carniolica* (1778–89). See Belsazar Hacquet, *Oryctographia Carniolica*, vol. 1, Leipzig: Breitkopf, 1778. A section of the Sveta Jama cave (Slovenia) is depicted on the cover of the first volume.

35 John Beaumont, 'A Letter, giving an account of [W]okey-hole', *Philosophical Collections* (1681) 2, pp. 1–7, 4.

36 Georg Agricola, *De re metallica libri XII*, Basel: Froben, 1556, p. 81.

37 Humboldt, for example, complained during his visit to Cueva del Guácharo (Venezuela) that 'the thick smoke of torches in narrow underground space hurts the eyes and makes breathing difficult'. Alexander von Humboldt, *Reise in die Aequinoctial-Gegenden* (ed. Hermann Hauff), Stuttgart: Cotta, 1859, p. 366.

38 Friedrich Lesser, *Anmerckungen von der Baumanns-Höhle*, 4th edn, Nordhausen: Groß, 1745, pp. 17–8.

39 John Brian Harley, 'Silences and secrecy: the hidden agenda of cartography in early modern Europe', *Imago Mundi* (1988) 40, pp. 57–76.

40 Paul d'Holbach, 'La Grotte', in Denis Diderot and Jean-Baptiste d'Alembert (eds.), *Encyclopédie*, vol. 7, Paris: Braisson, 1757, pp. 967–8, 967.

Powerful tools of persuasion, ground plans and longitudinal sections lifted off the top or the side of a mountain and illuminated hidden geographies.

A comparison of two sketches of Kungur Ice Cave (Ural mountains), based on surveys by the Russian cartographer and polymath Semyon Remezov (1642–1720) and the German Johann Berckhan (1709–51), the painter attached to the second Kamchatka expedition, reveals these epistemic strategies. The first map (Figure 2A) was made in 1703 by order of Tsar Peter the Great and was subsequently copied by the Swedish military officer and cartographer Philipp von Strahlenberg (1676–1747), who printed the survey in his widely translated treatise on the Russian Empire.⁴¹ The map guides visitors along an underground track past natural, unnatural and supernatural curiosities such as ice figures, an icon of Saint Nicholas and a fertile place where plants grow in darkness. Rather than leave invisible or unknown areas blank, the draftsman added fictional passages and chambers, emphasizing the cave's labyrinthine structure. Although this map became quite popular in eighteenth-century Europe and was reprinted in different styles and with variations in the objects depicted, the outlines of the galleries remained unchanged.

On the contrary, Berckhan's unpublished map (Figure 2B), drawn during a 1733 venture together with the German botanist Johann Gmelin (1709–55) and the historian Gerhard Müller (1705–83), uses another strategy to prove its credibility to potential users.⁴² Although, as the survey indicates, direction was measured by a magnetic compass and length was counted in steps, the draftsman was aware of the insufficiency of his empirical observations underground and of the tools used. Accordingly, he uses shading and transitions between grey and black to emphasize the uncertainty of sight and of the exact position of the outlines of the galleries. However, he precisely marks the track that he and his companions took during their venture and explains the curiosities and religious monuments he encountered in more detail in the map legend. Even though this sketch also contains imaginary sections intended to reinforce the impressive scale of the cave, the depiction of the paths actually taken conveyed confidence in the validity of the survey. Overall, the phenomenon of 'cartographic silence' – in other words, the acknowledgement of empirical limits – is rarely, if ever, found in early modern cave maps.

Shifting boundaries underground

Caves are polyvalent places, as we can see by their diversity of use: as burial places, religious sites, dwellings, refuges, food stores, repositories for natural resources, features (in the form of grottos) in landscape gardens and popular destinations on the Grand Tour. This polyvalence is also evident in the research accounts of scholars of the early modern world. Alchemists and naturalists assigned special significance to caves and mines as access points to fertile processes such as mineral growth and the genesis of ores.⁴³ Likewise, scholars experienced caves as 'whole museums of stone' that had apparently

41 See Philipp von Strahlenberg, *Das Nord- und Östliche Theil von Europa und Asia*, Stockholm: self-published, 1730, p. 372; Elena Trofimova, 'Ice cave map pioneering: Russian experience', *Journal of the Croatian Cartographic Society* (2017) 16, pp. 154–9.

42 Johann Berckhan, *Ichnographia specus subterraneae Kunguriensis* (The Russian State Archive of Ancient Acts, F. 199, Opt. 2, Portfolio 430, D. 20, p. 1). See Johann Gmelin, *Reise durch Sibirien von dem Jahre 1733 bis 1743*, vol. 1, Göttingen: Vandenhoeck, 1751, pp. 106–8.

43 The symbolic representation of Jesus' birthplace – and also of Mary's womb – as a cave originated in the Eastern Catholic Church and is exemplified by the grotto of the Church of the Nativity in Bethlehem. This representation spread through Europe during the Middle Ages, entrenching the sense of underground cavities as feminine, fertile sites. For the perception of the Earth's interior as the 'womb' of minerals see Carolyn Merchant, *The Death of Nature: Women, Ecology and the Scientific Revolution*, 2nd edn, San Francisco: Harper, 1983, pp. 28–41; Horst Bredekamp, 'Die Erde als Lebewesen', *Kritische Berichte* (1981) 9(4–5), pp. 5–37, 14.

fallen into disarray, blurring the boundaries between the categories of natural history acknowledged in the scientific discourse of the time and making it difficult to identify the curiosities they encountered.⁴⁴ Furthermore, the presence of famous caves in mining areas, such as the Harz mountains, upper Hungary and the Yorkshire Dales, meant that there was little differentiation of knowledge related to diverse underground spaces, with cave and mine studies arising and developing in parallel.

Canonizing the growing curiosity about underground sights, the guidebooks to subterranean destinations that appeared in eighteenth-century Europe were not limited to natural caves but also included tombs and catacombs; the ancient ruins of baths, cisterns and temples; and garden grottos and pits.⁴⁵ Travellers distinguished less clearly than we might expect between natural and artificial cavities, as well as between the different kinds of objects discovered there.⁴⁶ The ontological hybridity of these boundary spaces can be seen, for instance, in scholarly hypotheses about cave formation. Drawing on their visits to underground quarries and catacombs in Rome, Syracuse and Paris, a number of naturalists concluded that particular natural caves were also the result of human excavation. The majority of hypotheses in which a given cave was assumed to be artificial were based on the observation of individual objects, and did not in themselves constitute an overarching theory. They mostly concerned naturally formed caves that had been expanded by humans; for example, for use as sites of worship.⁴⁷ For instance, the French naturalist Georges-Louis de Buffon (1707–88) argued that the caves of Arcy-sur-Cure (Bourgogne) were an underground quarry. Not long afterwards, the English topographer and antiquarian Samuel Rudder (c.1726–1801) maintained that Pen Park Hole near Bristol was a lead mine, no doubt on the basis that evidence of mining activity can be seen in parts of the cave.⁴⁸

Referring to and incorporating scholarly assumptions about the origins of particular caves in their own work, mapmakers developed specific strategies to deal with the hybridity and shifting boundaries of underground spaces. This is particularly evident in the case of cavities of uncertain origin, where the lack of clear information meant that maps had to convey an especially compelling narrative. The first example I would like to mention in this respect is a map made by the French military officer Mathieu Dumas (1753–1837) of the Labyrinth Cave (Crete): a system of underground galleries, probably used as an ancient quarry (Figure 3A).⁴⁹ The Labyrinth Cave was well known among travellers and was assumed to be the ruins of the mythological labyrinth of the Minotaur. Dumas investigated the cave in 1783 during a mission by order of the French king to gather information on the island's government and topography. Dumas's secret report to the sovereign, which included a map of Labyrinth Cave, was finally published in 1839.⁵⁰ In the scholarly debate over the hybrid origin of the cave, Dumas excluded its use as an ancient quarry,

44 Franz Brückmann, *Thesaurus subterraneus*, Braunschweig: Meisner, 1728, p. 8.

45 See Johann Rosenmüller, *Beschreibung merkwürdiger Höhlen*, 2 vol., Leipzig: Breitkopf & Härtel, 1799/1805; Carl Lang, *Galerie der unterirdischen Schöpfungswunder*, 2 vols., Leipzig: Tauchnitz, 1801.

46 See Horst Bredekamp, *The Lure of Antiquity and the Cult of the Machine*, Princeton, NJ: Wiener, 1995. Frequently, mapmakers took up the analogy of nature and architecture and varied it in a playful way, as a 1753 drawn comparative profile depiction of Drachenhöhle (Austria) and a mine near Pirschfeld illustrates. Geyer, *Plan der L.F. Kupfer und Plei Bergwer[k] Pirschfeld, sambt den Rettelsteiner Berg in der Breitenau*, 1753 (Moravská zemská knihovna, Brno, Map Collection, Moll-0001.494).

47 See Shaw, op. cit. (23), pp. 112–13; Mattes, op. cit. (16), pp. 119–27.

48 See Georges-Louis de Buffon, *Histoire naturelle des minéraux*, vol. 1, Paris: Imprimerie royale, 1783, pp. 275–6; Samuel Rudder, *A New History of Gloucestershire*, Cirencester: Rudder, 1779, pp. 796–8.

49 Mathieu Dumas, *Plan de Labyrinthe de Crète*, 1783 (Archives départementales des Yvelines, Collection graphique, FR/FR-AD078/A 1604).

50 See Mathieu Dumas, *Souvenirs du lieutenant général comte Mathieu Dumas*, vol. 1, Paris: Gosselin, 1839.

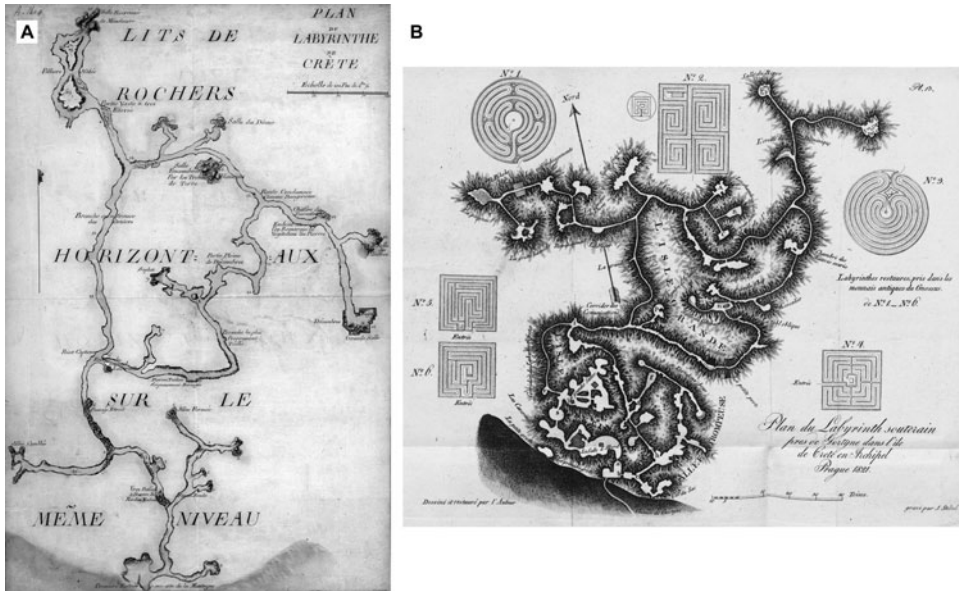


Figure 3. (A) Mathieu Dumas's 1783 ground plan of Labyrinth Cave (Crete) (Archives départementales des Yvelines, Collection graphique, FR/FR-AD078/A1604). (B) Ground plan of the same cave, made by the botanist Franz Sieber in 1821 and published in Franz Sieber, *Reise nach der Insel Kreta im griechischen Archipelagus*, vol. 2, Leipzig: Sorau, 1823, Tab. XIII. Similar to Figure 2B, Sieber adopted shading techniques to depict the outlines of galleries. Shading had already been used to depict elevation differences in maps of mountainous or hilly terrain.

since other sites were more favourable and the labyrinth had only one entrance. Rather, he argued that 'some parts of this cave are a whim of nature, and existed before the hand of man added anything to it'.⁵¹ Dumas's ground plan, surveyed using compass and pacing, serves as a convincing argument for this hypothesis, making visual the on-site observations described in more detail in his report.⁵² The map shows no traces of quarry work and the outlines of the galleries largely resemble a natural cavity. However, the addition of architecture-like straight and rectangular elements is intended to indicate that the cave had been artificially enlarged, but only to a small extent. According to Dumas, his 'exact copy' of this hybrid space favoured its natural origin.⁵³

A map made about thirty years later by the Bohemian botanist and collector Franz Sieber (1789–1844) and surveyed using compass and measuring line depicted the same cave, albeit in a completely different form (Figure 3B).⁵⁴ Sieber had visited the Labyrinth Cave on a collecting trip to Crete in 1817. Based on his assumption that the labyrinth was an ancient quarry, he sketched in large chambers and merged natural and artificial elements, with a preponderance of the latter. Since Sieber produced the map specifically for the purpose of publication in his two-volume travel account, he

51 Dumas, op. cit. (50), p. 255.

52 Early cave explorers were accustomed to see their own bodies as measuring tools, striding out the length of a cave's galleries. The hours or footsteps incurred during a given tour underground counted as evidence of the length of the cave. Like Theseus in the mythological labyrinth of the Minotaur, Dumas and his companions used a cord to orient themselves inside the cave.

53 Dumas, op. cit. (50), p. 248.

54 Franz Sieber, 'Plan du Labyrinthe souterrain', in Sieber, *Reise nach der Insel Kreta im griechischen Archipelagus*, vol. 2, Leipzig: Sorau, 1823, pp. 293–7.

was aware of the publicity it would receive. He further reinforced his argument for the cave's primarily artificial origin by adding illustrations of labyrinth motifs found on Minoan coins; his map also contains more circuits than that of Dumas.

Curiosities found underground similarly challenged the previous empirical observations made by visitors. In particular, the existence of specimens that could, potentially, be classified in a number of ways made it necessary to interrogate the description and naming of objects, resulting in various attempts to reorganize knowledge about the organic and inorganic world. As 'hybrid objects', speleothems (e.g. stalactites, flowstones, moonmilk) undermined the nature–culture opposition by 'combining art and nature in form and matter'.⁵⁵ They were collected not only by naturalists but also by locals; they were sold, placed in garden grottos, ground up and administered as medicine to pregnant women, sick people and cattle, and added to flour during food shortages. The attempts of scholars to distinguish and differentiate the sub-categories of speleothem reflect their varying uses across diverse contexts and communities. Nonetheless, speleothems were often thought to be fossils, and vice versa.⁵⁶ For example, the Swedish chemist and naturalist Johan Gottschalk Wallerius (1709–85) claims in his treatise *Mineralogia* that the basis for the formation of stalactites is a fossil substance that hardens under the influence of air like an icicle in winter.⁵⁷

Thus early cave maps prioritized the various types of minerals, fossils and artefacts encountered over geographical direction, distance and projection planes. Striking map symbols that mimicked the shape of natural specimens served to guide the reader through the labyrinths. As these were often arranged along preset underground pathways, the objects also structured the plan itself. The resulting combination of empiricism and imagination transformed these maps into wonder rooms or 'curiosity cabinet[s] of natural science'.⁵⁸ The shape, order and cross-referenced meaning of the specimens depicted were key to building on the prior knowledge of potential users and signalling that the map was trustworthy. By rendering hybrid specimens into more approachable objects, such as religious figures or architectural features, mapmakers made these specimens visually descriptive and comprehensible.

I would like to illustrate this hypothesis using a sketch of Baumannshöhle (Figure 4), drawn by a certain 'Studiosus von Alvensleben', who visited the cave in 1656 as a companion of the Saxonian theologian Gottfried Olearius (1604–85). In this map, consisting of two sheets, the curiosities found in the cave are arranged along a winding path with obstacles, emphasizing the labyrinthine structure, while the galleries are only sketched in outline.⁵⁹ The draftsman uses features familiar to readers to represent his empirical observations in visual form. Narrow parts and climbable passages such as the 'Roß' (horse) are depicted as intestine-like tubes. Speleothem formations such as the 'monk beside two other images' and a 'beautiful and miraculous wall of all kinds of figures' are illustrated as anthropomorphic figures or as a cluster of very detailed objects. One eye-catching combination of stalactite and stalagmite is even depicted as a broken antique column, while other speleothems are visualized as pyramid-shaped aggregations of stones. Nevertheless, the mapmaker is well aware of possible sensory illusions and affirms the uncertainty of empirical

55 Bruno Latour, *Nous n'avons jamais été modernes*, Paris: Découverte, 1990; Donna Haraway, *Simians, Cyborgs, and Women: The Reinvention of Nature*, New York: Routledge, 1991; Lorraine Daston and Katharine Park, *Wonder and the Order of Nature, 1150–1750*, New York: Zone Press, 1998, p. 277.

56 See John Hill, *A History of Fossils*, vol. 1, London: Osborne, 1748, p. 370.

57 See Johan Gottschalk Wallerius, *Minéralogie ...*, vol. 2, Paris: Durand et Pissot, 1753, p. 8.

58 Georg Behrens, *Hercynia Curiosa*, Nordhausen: Neuenhahn, 1703, p. 2.

59 Studiosus von Alvensleben, *Bumanshöhle*, 1656 (Landeshauptarchiv Sachsen-Anhalt, Rep. H66, Gutsarchiv Erxleben II, Nr. 952, two map sheets); Kempe et al., op. cit. (22), pp. 184–88.

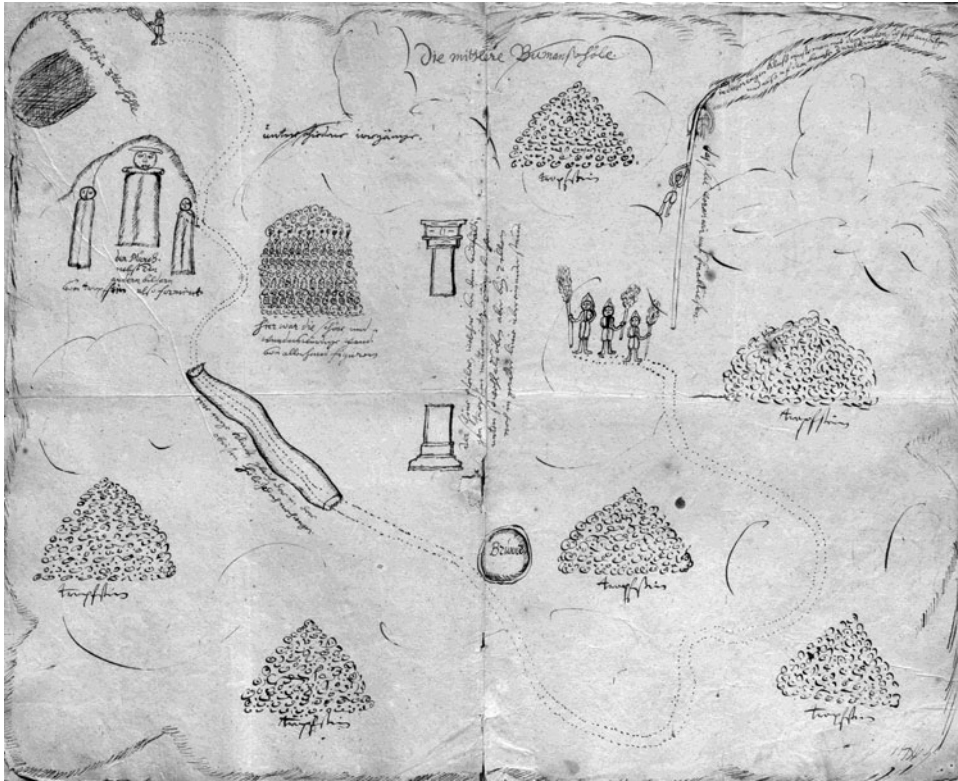


Figure 4. Ground plan of Baumannshöhle (Saxony-Anhalt), made by the Studiosus von Alvensleben in 1656 (Landeshauptarchiv Sachsen-Anhalt, Rep. H 66, Gutsarchiv Erxleben II, Nr. 952, p. 15). The figure shows the second page of the map with the heading 'Die mittlere Bumannshöhle' (The middle Baumannshöhle cave). In the upper right corner, a narrow passage is depicted, from where a visitor lowers himself with a rope. Once there, three torch-bearing companions with headgear indicate the continuation of the tour. It leads past speleothems, a 'Brunner' (well), another narrow passage and a stalactite formation called 'monk', to the upper left edge of the map, where another visitor is depicted with a torch.

perception underground, noting in the margin, 'Here, [the speleothem] falsely appears to be a ghost.'

Communicating trust: techniques of persuasion

If we imagine scholars of the early modern world dressed in their court garb, crawling on all fours or stuck in pits or being carried piggy-back by their guides through wet passages, we can understand the underground as a space in which hypotheses, methods and instruments faced challenges which they might fail. Draftsmen regularly went along on underground voyages, but in some cases they also produced maps based on reports or sketches supplied by their clients. Likewise, scholars and publishers hired local naturalists, especially if they were unable to visit the cave(s) themselves.⁶⁰ This meant that mapmakers

⁶⁰ For example, the Prussian military doctor Johannes Hain, who in 1672 had published a richly illustrated treatise on supposed 'dragon bones' found in Carpathian caves, commissioned the priest of a Piarist high school and a nobleman from Liptov (Slovakia) to map the local ice caves. See Johannes Hain, 'De Draconum Carpathicorum cavernis', *Miscellanea Curiosa* (1672) 3, pp. 366–70.

were all the more concerned with conveying trustworthiness, even though the empirical data behind the maps were, most likely, not trustworthy at all. Since there were no standardized methods for the cartographic depiction of natural cavities, features such as map symbols performed a special role in ordering knowledge, while surveying practices and scale bars took on a legitimizing function. As this section argues, these were not just visual features, but powerful techniques of persuasion that communicated a sense of accuracy and enabled potential users to understand the complex topographies underground, and so supported and enhanced the use of maps in scientific reasoning.

Visual narratives and map symbols

Maps aim to create order and orient the viewer via the distribution of symbolic meaning. Accordingly, early cave maps depicted the dynamics and disruption within the Earth's crust as a systemic form of disorder. Based on his readings of Kenneth Burke, the philosopher Pierre Smolarski draws a connection between the 'rhetoric of maps' and their organizing function, pointing out that motifs represent 'acronyms' and 'pathways to orientation'.⁶¹ The ordering of figurative symbols along pathways in cave maps resembles the rhetorical practice of 'memoria': an ancient technique for learning a speech by heart by systematically associating its parts with figurative signs and places. Here, motifs are essential in helping the viewer to make sense of the map and shaping their understanding of it. By simplifying the knowledge represented, they offer a clearer and more convincing narrative than the written accounts of cave visits, which are often rather confusing. The rhetoric of maps and their potential to create order only become really evident when they break new ground in their design, or else fail. Otherwise, the order they depict appears natural and convincing.

Visual narratives use recognizable symbols to communicate (non-)knowledge and make it commonly understandable. As the prevailing visual narrative used in early modern cave maps, the labyrinth motif fulfilled a central epistemic function: specifically, identifying the unknown.⁶² Referring to Richard Yeo,

when knowledge is ordered, subdivided, and controlled, we speak of ... maps ... metaphors suggesting definite structures and relationships. When knowledge is regarded as chaotic, overwhelming, undifferentiated, we speak of labyrinths, mazes ... still perhaps implying that an order exists but acknowledging that it is not yet visible.⁶³

By attributing order and comprehensibility to that which is invisible to the eye, cave maps made it possible to evaluate, measure and ultimately control the unknown in nature. The labyrinth motif symbolized non-knowledge by visually contrasting centre and periphery, proximity and distance, order and mess. In this respect, the motif both marked the limits of perception and established trust. A good example of this is the depiction of the Labyrinth Cave by the Florentine humanist Cristoforo Buondelmonti (1386–c.1430), who visited the site in 1415. His manuscript 'Descriptio insulae Cretae', written two years later, contains the first map-like drawing of a cave incorporating orientation

⁶¹ Pierre Smolarski, 'Dispositio des Raumes', in Christian Haß and Eva Noller (eds.), *Was bedeutet Ordnung: Was ordnet Bedeutung?*, Berlin: Gruyter, 2015, pp. 273–90, 274–7. See Kenneth Burke, *Permanence and Change*, Berkeley: University of California Press, 1984, p. 29.

⁶² Other motifs, some of which relate to the labyrinth mythos, reflect an understanding of the subterranean world as counterpart of mountains or cities. These motifs came to have a degree of influence on early modern representations of mines and mining towns.

⁶³ Richard Yeo, 'Classifying the sciences', in Roy Porter (ed.), *The Cambridge History of Science*, vol. 4, Cambridge: Cambridge University Press, 2003, pp. 241–66, 241.

information.⁶⁴ Enriched by material from ancient Greek and Roman writers and from contemporary oral accounts, Buondelmonti's description links mythological narratives with detailed information about the length and direction of the cave. His map, in contrast, quotes the visual narrative of the labyrinth by depicting several interconnected corridors that extend beyond the edge of the map format. Buondelmonti's personal observations made on site, and his detailed report, indicate that his depiction of the cave as a labyrinth is not purely imaginative; the motif itself serves to indicate the limits of knowledge.

Towards the end of the eighteenth century, the use of uniform map symbols, rather than individual objects or visual narratives, arose from fundamental shifts both in epistemological interest and in the classification of natural specimens. In the new context, experience-based knowledge had to be ranked into a hierarchy and brought into relation. What was important had to be distinguished from what was unimportant. This development made it possible to compare different caves by reading their respective maps. The use of symbols also required a higher degree of abstraction and generalization of observed natural phenomena. Some maps even included formal legends, or entire paragraphs explaining the abbreviations and clarifying the relationship between a sign and what it signified: in other words, accessible sign systems intended for a wider audience.

The loss of perceived authenticity caused by this increase in abstraction required the invention of new means of conveying empirical evidence. Likewise, the interest of naturalists and mapmakers was no longer directed solely towards the individuality of a given object, but towards its comparability to other objects too. These developments, in turn, gave rise to changes in the hierarchies of representation. Significantly more attention was paid to the representation of topographical knowledge and the exact localization of mineralogical, palaeontological or archaeological findings. Topographical features such as gradient arrows, gradient lines, differences in elevation, heights of chambers and symbols representing drops, pits or domes were particularly effective in persuading the reader to trust the information presented in the map. These features allowed conclusions to be drawn about tectonics and speleogenesis (cave formation). At the same time, collecting this kind of detailed information required the surveyor's presence on site and the taking of measurements, especially with regard to vertical difference.

A sketch of Madison's Cave in Virginia demonstrates these shifts in the scholarly interest in caves and the rhetoric of maps. The first known survey of a US cave, it was drawn by the American statesman Thomas Jefferson (1743–1826), who visited with two travel companions in 1783.⁶⁵ After his time as governor of Virginia and following the death of his wife, Jefferson had retired from politics and devoted himself to the exploration of Virginia's natural history, even conducting systematic archaeological excavations. His life-long interest in caves may have been driven by his convictions about the potential production of saltpetre from soils. Saltpetre was essential to the manufacture of gunpowder, so finding new methods of production was an important question of national defence.⁶⁶ Jefferson's sketch supports his hydrological hypotheses. Although he mentions the cave's 'elegant drapery', stalactites and massive columns in his description – later

64 Cristoforo Buondelmonti, 'Lamberintus', in 'Descriptio insulae Cretae' (1417), Biblioteca Medicea Laurenziana, Florence, Ms. Plut. 29.42, p. 23r. See Bernard Chirol, 'The oldest cave map in the world', *UIS Bulletin* (2015) 57(2), pp. 25–6; Johanna Heinrichs, 'The topography of antiquity in descriptions of Venetian Crete', in Nebahat Avcioglu and Emma Jones (eds.), *Art, Architecture and Identity in Venice and Its Territories*, London: Routledge, 2016, pp. 205–18.

65 See Thomas Jefferson, *Madison's Cave Plan*, 1783 (Massachusetts Historical Society, Coolidge Collection); Kevin Hayes, *The Road to Monticello: The Life and Mind of Thomas Jefferson*, New York: Oxford University Press, 2008, pp. 260–2.

66 From the turn of the nineteenth century to the collapse of the domestic saltpetre market in 1814, saltpetre resources found in caves in the United States were used for the production of gunpowder, and their extraction boosted the surveying of caverns.

published, together with a generalized version of the map, in *Notes on the State of Virginia* – they do not appear on the map itself.⁶⁷ Rather, Jefferson's sketch indicates two water basins 'of unknown extent' at the rear of the cave as well as the difference in elevation of the galleries, marked using gradient arrows and numerical data in feet and degrees. Although Jefferson observed that the basins were at the same elevation as a nearby river, he concluded from the clarity of the water and the constant water table that they were 'probably one of the many reservoirs with which the interior parts of the earth are supposed to abound and yield supplies to the fountains of water distinguished from others only by being accessible'.⁶⁸ Jefferson's map symbols, therefore, did not have a purely visual function. In fact, they were abstractions of topographic knowledge based on measurements and were embedded in the context of a specific scientific argument, even though the surveying techniques and tools employed often did not and could not provide accurate data.

Surveying and accuracy

Today's surveyors face the same problems they did three hundred years ago. They typically underestimate the size of large halls, while overestimating that of smaller chambers. Besides restricted visibility, vertical or narrow sections that are difficult or impossible to traverse can also cause significant errors of measurement. This becomes particularly obvious when a loop within a cave is surveyed, or when two traverse lines, drawn on the basis of a sequence of measurements along a cave passage, happen to cross. In addition, equipment such as measuring tools and instruments – which have to be dragged behind during the descent – are exposed to extreme conditions that affect their precision. Reliable observation depends on conditions that cannot be guaranteed in practice. In short, cave maps claim a degree of accuracy that is impossible to achieve.

A surviving ink-and-wash drawing from 1749 by the Italian engineer and painter Carlo Beduzzi (c.1710–c.1770), depicting the artist in the process of making a sketch of the Magdalena Cave in Slovenia for a factual report to the Vienna court (Figure 5), provides an insight into early modern surveying practices. Torchbearers are placed to illuminate an extensive hall within the cave. An assistant winds a tape on a reel, while the surveyor, dressed in a frock coat, knee breeches, tricorne hat and wig, sketches a draft on a large sheet: the back of another assistant serves as his drawing board. In narrow or steep cave sections, the surveying process was undoubtedly much less orderly and careful than Beduzzi's picture suggests.

Although surveying methods that enabled accurate scale mapping were developed, mainly in the seventeenth century, it is doubtful that these were applied in cave environments.⁶⁹ This is also true of well-established mine surveying techniques, which were only of limited use in natural cavities. In particular, surveying conditions in mine tunnels following the course of ore veins – which tended to be rather easier to access – were significantly different to the geographies of natural caves, which were winding and hard to traverse. There, the traditional method of triangulation was at a disadvantage compared to traverse surveying, even if we allow for a higher degree of inaccuracy. There is also little evidence of professional mine surveyors engaged in mapping before 1800. Although a number of tools and instruments used in early modern mine surveying – such as the measuring rod, miner's level, compass and plumb line – are mentioned in reports of early modern cave visits, it is uncertain to what extent these were actually used in practice.

67 Thomas Jefferson, *Notes on the State of Virginia*, London: Stockdale, 1787, pp. 32–3.

68 Jefferson, op. cit. (67), pp. 31, 33.

69 See Uta Lindgren, 'Land surveys, instruments, and practitioners in the Renaissance', in Woodward, op. cit. (6), pp. 477–508, 487–8.



Figure 5. Detail of an ink-and-wash drawing of Magdalena Cave (Slovenia) in Joseph Nagel, 'Beschreibung deren auf allerhöchsten Befehl ... untersuchten, in dem Herzogthume Crain befindlichen Seltenheiten der Natur' (Austrian National Library, Ms. 7854, Tab. VII). Its painter, Carlo Beduzzi, an Italian engineer working in Vienna, accompanied the imperial mathematician Joseph Anton Nagel (1717–94) on a trip to Carniola. Nagel visited caves and other natural wonders in lower Austria, Styria, Carniola and Moravia in 1747 and 1748 on behalf of Emperor Franz Stephan (1708–65). Beduzzi made no less than four maps and nineteen drawings of caves for one of the two reports to the emperor, including this drawing showing the impressive stalactites of Magdalena Cave. Fitting for an official report to the court, the speleothems were depicted quite realistically. Note: see Johanna Schönburg-Hartenstein, *Josef Anton Nagel: Ein Direktor des physikalischen Kabinettes*, Vienna: Austrian Academy of Sciences, 1987; Trevor R. Shaw and Alenka Čuk, *Slovene Caves and Karst Pictured 1545–1914*, Ljubljana: Založba ZRC, 2012, p. 88.

The most common tool was certainly the measuring cord, supplemented as necessary with a hand-bearing magnetic compass, angle meter and plumb line. In many cases, just a cord and compass may have been used for taking measurements along more or less continuous traverse lines. Surveying steep sections was a tricky and unsafe task that could easily produce contradictory results. Determining the angle of inclination of these sections was particularly challenging. Since pits in caves are not always vertical, plumb lines were of limited use. Angle meters also had high error rates due to difficulties in targeting. As inaccuracies in measuring depth added up in the course of a traverse survey, vertical data in cave surveys were marked by a high margin of error and uncertainty.

The challenge of translating the empirical data obtained by surveyors into cartographic codes was not only a practical one, but also epistemological. Mapmakers in the early modern period had to use specific strategies to deal with questions of accuracy and to communicate trustworthiness to potential users. While some mapmakers openly admitted the uncertainty of their maps by giving them titles such as 'eye-draught', others asserted their credibility by including depictions of measuring tools. Before the appearance of scale bars, human figures were depicted as a comparative sizing method. The inclusion

of these figures, shown holding lights in the cave's corridors – they sometimes included the mapmaker himself – conveyed a sense of authenticity. During the eighteenth century, mapmakers tried to enforce their claims to accuracy by illustrating epicartographic elements as scale bars and by referring in various ways to surveying practices.⁷⁰ Within a given map, the scale of the objects depicted also varied in accordance with the mapmaker's sense of the user's expectations. Areas of particular significance to clients might be drawn on a larger scale, while other, less interesting, galleries might be left out altogether. Other convincing epicartographic elements such as north arrows or compass roses would be depicted on the map even if measuring tools were obviously not used when exploring the cave.

Projection planes and verticality

The complex three-dimensional topography of cave systems presented early modern mapmakers with a considerable challenge. In particular, multiple over- and underlays of corridors were difficult to depict in a two-dimensional drawing. The need to present whole cave systems and natural specimens in a traceable and comprehensible manner gave rise to the development of consistent projection planes in cave surveying, such as ground plans, longitudinal sections and cross-sections.

Originating as drawings incorporating orientation information, the basis of cave maps gradually shifted from the subjective perspective chosen by a given observer to the kind of abstract projection plane already used in the topographical maps of the period. Perspective map projections functioned as an intermediate stage between the two, providing a three-dimensional overview while still enabling the reader to inhabit the mapmaker's chosen viewpoint.⁷¹ This change in the use of projection planes also threw up a number of hybrid forms.⁷² In order to give an overview of phenomena that could not be represented solely by a ground plan or sections, the draftsmen combined different projection planes within a single map and illustrated the galleries' outlines multidimensionally. This was intended to reinforce the credibility of the sketch.

The interpenetrating power of maps and their ability to render a mountain transparent were key to persuading the reader to trust the information presented in them. In particular, the switch from horizontal to vertical projection planes exposed areas of the Earth's subsurface that were previously inaccessible to human perception and aroused interest in their examination. As naturalists gradually came to understand the underground in terms of the Earth's development over time, they experienced, in the words of the German naturalist Georg Christoph Lichtenberg (1742–99), 'phenomena that raise questions such as How? Why? and Whence?'⁷³ Growing interest in geological and archaeological phenomena made verticality an increasingly important dimension of knowledge acquisition, although

⁷⁰ Epicartographic elements are map symbols that are not subject to graphic generalization or projection.

⁷¹ Providing a three-dimensional view of an object, cave maps of Geldloch and Taubenloch (Austria), drawn by the architect and painter Franz Rosenstingl (1702–85), met the visual expectations of the map users by enabling them to scan the entire cave by eye. See Joseph A. Nagel, 'Beschreibung des auf allerhöchsten Befehl ... untersuchten Oetscherberges', 1747 (Austrian National Library, Ms. 7920), Tab. III, IV. Leibniz, for example, argued for a perspective map projection: 'Hence, it would be necessary to draw a scenographic or perspective map of the mine, as if the eye were floating in the air and the mountain were transparent'. Gottfried W. Leibniz, *Sämtliche Schriften und Briefe*, Part 1, vol. 3, Berlin: Akademie, 1970, p. 159 (memorandum probably written for Ernst August, Duke of Brunswick-Lüneburg, in 1682). See Hamm, op. cit. (12), p. 84.

⁷² For a hybrid projection plane see the map of S. Rosalia Cave on Monte Pellegrino. Giordano Cascini, *Di S. Rosalia, vergine Palermitana, libri tre*, Palermo: Cirilli, 1651, Tab. XVI.

⁷³ Georg C. Lichtenberg, *Vermischte Schriften nach dessen Tode gesammelt*, vol. 7, Göttingen: Dieterich, 1804, p. 63.

the measurement of vertical dimensions remained strikingly unreliable and produced wildly varying results. While early cave maps were mostly ground plans and did not show vertical differences, such as pits, steps and chimneys, longitudinal sections of caves soon became common map projection planes.

Longitudinal sections were especially important: they opened up new opportunities for viewing phenomena in comparison and bringing them into the context of a given scientific argument. Drawing a longitudinal section, early mapmakers were embarrassed by so much blank space between the surface of the Earth and the roof of the cave, and they started to use this previously neglected area to enhance the map's scientific value. This allowed them to make an explicit connection between the topography of the cave, the findings made there and the conditions on the Earth's surface: for example, drawing in fissures in order to attribute the occurrence of stalactites to the intrusion of vadose water from subsurface soils.⁷⁴ As I will discuss in more detail in the following section, cross-sections of cave passages, which were sometimes made in supplement to ground plans and longitudinal sections, allowed the mapmaker to draw connections between the location, type and frequency of findings and the process by which the cave is thought to have formed.

A fascinating example of an early longitudinal section and its techniques of persuasion is a 1719 survey of Demänovská Ice Cave in Slovakia, where ice was routinely cut for the Vienna court. A detail of the map is provided in [Figure 6](#). It was made in 1719 by the naturalist Georg Buchholtz (1688–1737), rector of the Protestant lyceum in Kežmarok, and possibly commissioned by the Hungarian polymath Mátyás Bél (1684–1749). Buchholtz also printed the sketch in the style of a formal, scholarly map in his 1723 country description *Hungariae antiquae et novae prodromus*.⁷⁵ Since this map is the only cartographical representation included in the treatise apart from a single topographical map, it was clearly intended to make an impression on the reader. Although it is questionable whether Buchholtz actually used surveying tools, these are depicted together with a scale bar below the title cartouche. Two scale figures with torches shown standing inside the cave, and the figures of two scholars approaching its entrance, accompanied by a porter, underpin the authenticity of the depiction. Ice figures, speleothems and fossils encountered underground are sometimes illustrated in anthropomorphic form, and about fifty abbreviations, explained at the edge of the map, offer detailed information on the occurrence and origin of the curiosities. Buchholtz also uses the map to furnish evidence of the location where he had found some supposed 'dragon bones' (mammoth fossils), which he sent as a gift to the art and natural cabinet in Dresden.⁷⁶ His choice of a vertical projection plane certainly makes the course of the cave appear longer, easier to grasp and therefore more impressive than it would appear on a ground plan due to its labyrinthine topography. However, this choice meant that the map was far from suitable for helping other visitors find their way inside the cave. Probably unsure how to fill the white space between the surface of the Earth and the roof of the cave, Buchholtz depicts the stratification of the Earth using a rockface pattern inhabited by single, anthropomorphic faces. In contrast to later mapmakers, however, he does not sketch in a hypothetical geological relationship between the course of the cave and the surface of the Earth.

The use of abstract projection planes certainly made maps less accessible to inexperienced readers. However, the consistency of projection planes and the possibility of

74 Buffon, for example, broke new ground in explaining the different speeds of speleothem growth by the structure and material of the overlying ground. See Buffon, *op. cit.* (48), p. 283.

75 Georg Buchholtz, 'Antra Deminfalvensia admiranda', in Mátyás Bél (ed.), *Hungariae antiquae et novae prodromus*, Nuremberg: Monath, 1723, p. 141.

76 See Jakob Buchholtz, 'Reise auf die Karpatischen Gebirge', *Ungarisches Magazin* (1787) 4(1), pp. 34–58, 45.



Figure 6. Detail of the longitudinal section of Demänöská Ice Cave (Slovakia), surveyed by Georg Buchholtz in 1723, engraved by Sámuel Mikoviny and published by Mátyás Bél (ed.), *Hungariae antiquae et novae prodromus*, Nuremberg: Monath, 1723, p. 141 (Sammlung Woldan, Austrian Academy of Sciences). The two wind roses indicate the direction of expansion of the upper and lower cave entrances.

comparing different sketches were key to establishing credibility, and met the growing need to examine different natural phenomena in a comparative way. Due to the complex three-dimensional structure of caves, ground plans were extremely limited in their ability to render vertical differences such as pits, or how far one gallery lies above another. In contrast, longitudinal sections were unsuitable for depicting labyrinth cave systems, and broadly useless in pathfinding due to the lack of directional information. Therefore mapmakers came to adopt a technique already used in architectural drawings, in which ground plan, vertical section and profile view were all created in the same process.⁷⁷

Cave maps as devices in scientific reasoning

As the Saxonian mining engineer Friedrich von Trebra (1740–1819) argues in his geological–mineralogical description of the Harz mountains titled *Erfahrungen vom Innern der Gebirge* (Experiences from Inside the Mountains) (1785), visualizations of subterranean spaces stimulated efforts in stratigraphic mapping, paving the way from descriptive–local observations to causal–general exploratory models:

Were it possible to remove all the tops from the mountains and so place them before you as bare rock, or even to take them apart right down to their deepest points, then we would have opportunity enough to educate ourselves fully about their interior structure. And if we could even depict the mountains as one skeletonizes sheets of

⁷⁷ For a synchronous depiction of different projection planes see the maps of Mondmilchloch (Switzerland) and Antiparos Cave (Greece). Mauritius Cappellet, *Pilati montis historia*, Basel: Imhof, 1767, Tab. VII; Marie Gabriel de Choiseul-Gouffier, *Voyage pittoresque de la Grèce*, vol. 1, Paris: Tiliard, 1782, p. 73.

paper, then, O! it would doubtless be very easy to establish a theory of the fabric of the galleries, to seek their origin in the transverse rock, to research their development to the very last detail.⁷⁸

As the following section argues, cave maps began simply as a way to ascribe a specific location to natural curiosities. Over time, however, they came to be seen as reliable natural-historical evidence in their own right. At the turn of the nineteenth century, these maps – although still reliant on dubious data – came to play an active role in scholarly argumentation and emerged as powerful tools in scientific reasoning.

Localizing findings of natural-historical significance

According to Nicolaas Rupke, caves ‘were believed to be pervasive and primordial features, present since the birth of the earth as a planet, providing essential information as to the manner of its origin’.⁷⁹ At the subterranean level, the beginnings of the Earth’s chronology became visible in fossil deposits, speleothems and different layers of rock or soil. The human lack of awareness of immeasurable periods of the Earth’s history and the growing realization of ‘geological deep time’ transformed caves into enlightening and challenging sites of natural history.⁸⁰ Martin Rudwick’s interpretation of the well-known caricature *The Hyæna’s Den at Kirkdale*, which depicts the renowned English geologist and palaeontologist William Buckland (1786–1856) crawling into a cave and encountering living hyenas from the prediluvial period, illustrates how naturalists broke the ‘epistemic barrier that separated the observable present from the prehuman past’.⁸¹ Formerly inaccessible periods materialized under the scholars’ feet, were made transparent by vertical sections, and thus became a topic for scientific reasoning.

Cave maps did not only provide insights into the places where the discoveries were made. Increasingly, they also functioned as veritable archives of natural history, where the deposition of fossils or mineral formations could be seen on display. The aforementioned map of Baumannshöhle, included in Leibniz’s posthumously printed *Protogæa*, sheds light on the fundamental nature of evidence building in drawing conclusions about the history of the Earth. Unlike the original map by Hermann von der Hardt, Leibniz’s revised and supplemented version was not a tool for other visitors, indicating the underground curiosities most worth seeing. Illustrating the shift in function from merely locating specimens to placing them in a causal relationship with natural history, the map was intended to designate the sites of specimen discovery and to differentiate and highlight the findings through detailed, naturalistic representations.⁸²

During his visit to the cave, Leibniz collected fossils and speleothems. His descriptions of these findings identify similarities with the bones of animals or the minerals found in mines. Likewise, he saw in the structure and stratification of speleothems ‘something like

78 Friedrich von Trebra, *Erfahrungen vom Innern der Gebirge*, Dessau: Verlagskasse für Gelehrte, 1785, p. 11.

79 Rupke, ‘The study of fossils’, op. cit. (14), p. 392.

80 Stephen Jay Gould, *Time’s Arrow, Time’s Cycle: Myth and Metaphor in the Discovery of Geological Time*, Cambridge, MA: Harvard University Press, 1987. See Paolo Rossi, *The Dark Abyss of Time* (tr. Lydia Cochrane), Chicago: The University of Chicago Press, 1984, pp. 107–12.

81 Martin Rudwick, ‘Encounters with Adam, or at least the hyenas: nineteenth-century visual representation of the deep past’, in James Moore (ed.), *History, Humanity and Evolution*, Cambridge: Cambridge University Press, 1989, pp. 231–52, 244. See Shortland, op. cit. (13), pp. 30–1.

82 See Hole Rößler, ‘Der anatomische Blick und das Licht im “theatrum”’, in Helmar Schramm, Ludger Schwarte and Jan Lazardzig (eds.), *Spuren der Avantgarde: Theatrum anatomicum*, Berlin: Gryter 2011, pp. 97–128, 110; Tina Asmussen, Lucas Burkart and Hole Rößler, *Theatrum Kircherianum: Wissenskulturen und Bücherwelten im 17. Jahrhundert*, Wiesbaden: Harrassowitz, 2013.

the rings that designate years in trees ... since nature rested intermittently and then resumed her work again with a new inundation'.⁸³ In Leibniz's map, the image of one distinctive fossil specimen, enlarged and placed at the centre, alludes to his hypothesis mentioned in *Protogaea* that specimens 'did not arise in those places but came from the ocean, carried there by the violence of the waters'.⁸⁴ Remains of 'sea monsters and of other animals',⁸⁵ they were swept, together with those of terrestrial animals, into caves by a great flood as its waves retreated into the Earth's interior. According to the valuable work of Claudine Cohen and Andre Wakefield, Leibniz's ideas about the origins of fossils changed considerably during his lifetime; however, caves as sites of discovery remained crucial to his thought.⁸⁶ Although the Baumannshöhle map was not in itself intended to support a particular hypothesis, his detailed comparison of various specimens and his specific identification of fossils enabled a better understanding of universal principles, contributing to the generalization of local knowledge.

As well as cartographic features and the depiction of surveying practice, who made a given map and where it was published were crucial factors in establishing its credibility. Maps often furnished evidence for the hypotheses of their authors, and as such were closely tied to the argumentative context of their publication. Only rarely did naturalists refer in their hypotheses to maps made by or for others. The reputation of the editor and the scientific recognition of the publication medium contributed to the perceived trustworthiness of the depiction. This explains why maps that were not printed in scientifically accredited treatises, country descriptions or journals were only afforded limited consideration in the scientific debate. In individual cases, a scholar's credibility and authority might even allow him to present his hypothetical map as concrete evidence for his argument, without actually carrying out any fieldwork.

But implicit acceptance was far from guaranteed. Serving as a key foundation for his hypothesis about the origin of fossils, the cave maps printed by William Buckland in his *Reliquiae Diluvianae* were openly criticized for being a 'hypothetical presentation' rather than the 'result of an investigation'.⁸⁷ Buckland's sketches, mapped by the geologist Thomas Webster (1773–1844) using a vertical projection plane, stimulated lively scholarly debate.⁸⁸ Evidence found in caves had drawn considerably more attention from naturalists after Johann F. Esper's (1732–81) groundbreaking identification of rich fossil deposits in Gailenreutherhöhle (Franconia) as the remains of extinct animals such as cave bears.⁸⁹ One such naturalist was the anatomist John Hunter (1728–93), who argued in his paper presented to the London Royal Society that the 'vast accumulation' of fossils in Gailenreutherhöhle required the presence of living animals in the cave for

83 Leibniz, op. cit. (33), p. 113.

84 Leibniz, op. cit. (33), p. 99.

85 Leibniz, op. cit. (33), p. 97.

86 Leibniz was influenced both by the idea of a biblical flood disintegrating the Earth's crust and by Nicolaus Steno's hypothesis that fossil aggregations in sediments were deposits from vanished seas. See Claudine Cohen, 'Un manuscrit inédit de Leibniz sur la nature des objets fossiles', *Bulletin de la Société géologique de France* (1998) 169(1), pp. 137–42; Andre Wakefield, 'The origins and history of earth', in Maria Antognazza (ed.), *The Oxford Handbook of Leibniz*, Oxford: Oxford University Press, 2018, pp. 453–65.

87 Adolph Erman and Paul Herter, 'Bericht über eine Nachgrabung in der Baumannshöhle', *Zeitschrift der Deutschen geologischen Gesellschaft* (1851) 3, pp. 320–9, 323.

88 Rupke, 'The study of fossils', op. cit. (14), pp. 391–5; Shortland, op. cit. (13), pp. 32–5.

89 See Johann Friedrich Esper, *Ausführliche Nachricht von neuentdeckten Zoolithen unbekannter vierfüßiger Tiere*, Nuremberg: Knorr, 1774.

many thousand years ... these caves have their bottoms covered with animal earth, for some feet in depth, in all degrees of decomposition, the lowermost the most pure, and the uppermost but little changed, with all the intermediate degrees; in which caves are formed a vast number of stalactites, which might incrust the bones of those that die there.⁹⁰

Building on Hunter's hypothesis that fossil findings in caves were the remains of animals that had once lived there, Buckland attributed a larger role to a prehistoric flood. Although he argued that, in most cases, the waters did not wash the bones into the cave, he specified that they were responsible for covering the fossils with mud.⁹¹ To reinforce this statement, Buckland's maps, such as the longitudinal section of Gailenreutherhöhle, do not depict successive layers of cave deposits but show the specimens as being of similar age.⁹² The Gailenreutherhöhle map clearly distinguishes between fossiliferous strata and the speleothems that formed above them, indicating that the latter came after the deluge. Although he himself had visited Gailenreutherhöhle, Buckland also depicts layered deposits and stratifications of findings that had not, in fact, been verified *in situ*. Combining a vivid sense of the fascination of the underground with the depiction of caves as palaeontological sites, Buckland's maps became powerful epistemic tools capable of advancing a hypothesis and apparently confirming it at the same time.

Reasoning about speleogenesis

The variety of early modern concepts about speleogenesis cannot be understood in isolation from scientific ideas about fossil and speleothem formation and how these specimens came to be found in the earth. Some of these hypotheses were tied to universal exploratory models of the Earth's formation; others were made in the course of personal observations on site, but did not claim universal validity. Alongside a gradual shift from catastrophic to actualistic viewpoints, greater significance was accorded to the development of universally valid models of speleogenesis, which combined different factors such as corrosion, erosion, volcanism, gases and tectonic causes. Trevor Shaw, who has carefully collected and categorized the various historical theories about cave formation, classifies them according to the following factors: tectonic origins (uplift, collapse, underground expansion); drains for the deluge; gas bubbles in limestone; erosion of soft material or limestone; solution by thermal, vadose or phreatic waters; volcanism; and atmospheric corrosion.⁹³

Arising as they did from a general interest in natural-history specimens, it was relatively late before cave maps were employed in causal reasoning about speleogenesis. The reason for this was that longitudinal sections tended to focus on depicting cave deposits, whereas ground plans were more suitable for pathfinding. Cross-sections of galleries, which were important for attempts to reconstruct the process of speleogenesis, did not become a common feature of cave maps until the nineteenth century. Often, naturalists used artistic drawings instead of maps to explain the formation of a given cave.⁹⁴

90 John Hunter, 'Observations on the fossil bones', *Philosophical Transactions* (1794) 84, pp. 407–17, 409–10.

91 See William Buckland, 'Account of an assemblage of fossil teeth and bones ...', *Philosophical Transactions* (1822) 112(1); pp. 171–236, 204–7.

92 See William Buckland, *Reliquiae Diluvianae*; London: Murray, 1823, maps on Tab. XIV–XVII (Gailenreutherhöhle).

93 Shaw, *op. cit.* (23), pp. 109–70.

94 The French plutonist Barthélemy Faujas de Saint-Fond used an engraving of the famous Fingal's Cave in Scotland to support his hypothesis about its volcanic origin. See Barthélemy F. de Saint-Fond, *Voyage en Angleterre ...*, vol. 2, Paris: Jansen, 1797, pp. 45, 49.

Others employed diagram-like maps showing supposed subterranean water reservoirs and channels to explain the fluctuating level of intermittent lakes and springs.⁹⁵

For many mapmakers in this period, it was more important to give a visual representation of a particular scientific argument than it was to make a claim to accuracy. In particular, the shape of the galleries' outlines and the way in which they were visualized on a given map underpinned the author's own hypothesis about how the cave was formed.⁹⁶ One of the few pre-1800 ground plans to serve as an argument about speleogenesis is a 1753 map of the lava tube cave Surtshellir in Iceland. Based on a survey by the Icelandic naturalist Eggert Ólafsson (1726–68) and the physician Bjarni Pálsson (1719–79), the map was not printed until 1772 in Ólafsson's posthumously published and widely translated account *Reise igiennem Island*.⁹⁷ Entrusted by the Royal Danish Academy of Sciences with the task of studying the island's topography and mineral deposits, the two naturalists travelled their homeland for several years. In the course of their research, they also surveyed Surtshellir, a cave that was of particular interest to scholars at the time. Stalactites collected there had been circulating among scientists since the seventeenth century, stimulating the development of widely differing hypotheses about the nature of their origins. In his description, Ólafsson pays specific attention to the cave's structure, such as walls, shelves, horizontal benches, speleothems and the glazed ceramic appearance of the walls. He attributes these features to the effect of lava flowing through the cave. In order to support this hypothesis about the cave's volcanic origin, the map shows an exaggeratedly worn and smoothed texture in the outline of the galleries, as if shaped by a river. This resulted in

a clear testimony to the paths of the underground fire and its effects, in particular the passages and rivers it melted out beneath the earth's crust; it also shows, if only on a small scale, how easily this fire can bring soil and stone types to the point of flowing, and carry them away with the molten material as it flows past.⁹⁸

While surveys like those of Surtshellir served as evidence both for the detailed observations made by the draftsmen on site and for the credibility of the arguments on which they were based, other maps themselves stimulated the development of new hypotheses. This is especially true for cross-sections of cave passages. Providing evidence of mechanical erosion, dissolution and tectonic processes, these maps inspired scholars to consider a combination of different factors in cave formation. This insight became clear to the French engineer and mathematician Nicolas Brémontier (1738–1809), in later years inspector general of bridges and roads, when he surveyed Rouffignac Cave in Dordogne, now famous for its prehistoric paintings.⁹⁹ Most likely made in 1765, the map comprises a surprisingly accurate ground plan and no less than twenty-seven cross-sections of passages. The highly irregular shape of the cross-sections, depicted side by side and aligned along a common datum line, led Brémontier to hypothesize about speleogenesis in his

95 See Franz von Steinberg, *Gründliche Nachricht von dem in Inner-Crain liegenden Czirknizer-See*, Ljubljana: Wittib, 1758, Tab. III, XIV.

96 On the significance of time in maps cf. Veronica Della Dora, 'Lifting the veil of time: maps, metaphor, and antiquarianism in the seventeenth and eighteenth centuries', in Kären Wigen and Caroline Winterer (eds.), *Time in Maps: From the Age of Discovery to Our Digital Era*, Chicago: The University of Chicago Press, 2020, pp. 103–26.

97 See Eggert Ólafsson, *Reise igiennem Island*, vol. 1, Soroe: Lindgren, 1757, pp. 238–53.

98 Ólafsson, op. cit. (97), p. 253.

99 The map was published by Charles-Nicolas Allou, 'Sur la grotte de Miremont', *Annales des mines* (1822) 7, pp. 597–600, Tab. V, VI. See Jean Bouchereau, 'La grotte de Miremont en Périgord', *Spelunca Mémoires* (1967) 5, pp. 116–26; Shaw, op. cit. (23), pp. 25, 255; an anonymous map in the Archives départementales de la Dordogne, possibly by Brémontier (Bibliothèque numérique du Périgord, Cartes et plans, 1_Fi_1_24356_1).

later report to the Academy of Caen. According to him, some parts of the cave were primarily formed by stream erosion, after an earthquake caused fissures in the rock and allowed the water to infiltrate; other parts developed through rock corrosion caused by air: 'The walls and roof provide a tangible proof of this ... This difference in hardness has resulted in pendants, domes, partitions ... hollows and projections.'¹⁰⁰ By understanding speleogenesis as a complex interaction of different geological forces, such as mechanical erosion, and tectonic and corrosive action, scholars and their cave maps were able to cast doubt on previously accepted universal models of the Earth's history, despite the uncertainty of the evidence from which they worked.

Conclusion

This essay has shed light on natural cavities as both stimulating and challenging sites of knowledge production. Thus far, they have not been given appropriate consideration by history-of-science scholarship, particularly in the case of early modern natural history. Caves, like other subterranean and vertical sites of scientific inquiry (mines, mountains), were the focus of a wide range of scholarly approaches in this period. Practitioners from different areas brought a great diversity of methodologies and means of translation to their work in the emerging field of cave studies. Striking observational results, untrustworthy visitor reports, and findings that furnished evidence of geological or 'deep-time' processes all intensified this scientific interest. However, demanding conditions underground – such as remoteness, limited vision and topography that was difficult to navigate – posed a considerable challenge for early modern experience-based knowledge acquisition, casting empirical methods of observing, measuring and recording into doubt. In this sense, my paper has argued that natural cavities are unique knowledge spaces which, in this period, required specific strategies for dealing with ambiguity at various levels of scientific practice. Maps, and the use of surveyors, instruments and techniques in their creation, were key to communicating authenticity and credibility, although the data behind them were at times erroneous and prone to epistemic uncertainty.

An analysis of the processes by which cave maps, even before standardization, provided support for causal thinking about the history of the Earth reveals that these largely neglected sources were more important to naturalists than was previously believed. In the early modern world, where understanding was structured through analogies, maps represented a meta-level of abstract reasoning, combining the scaled-down rendering of distant, out-of-sight geographies with the construction of an analogical space on two-dimensional materials. Struggling as they did with the imprecision of perception, draftsmen combined experience and inspiration to legitimize the process of attributing meaning to previously undefined areas. While early maps had a strong narrative component that structured the underground topography around striking naturalistic symbols, the practice of surveying dissolved this spatial order and concealed the inaccuracy of the drawings behind a clear, comprehensive (and therefore convincing) representation. Ever more frequently invoked in support of arguments that aimed to reveal and elucidate processes at work in natural history, maps were increasingly required to meet a certain standard of comparability. As this paper has shown, longitudinal sections and cross-sections used as projection planes not only became powerful tools that could render the Earth's subsurface transparent, but also contributed to establishing verticality as an important dimension of knowledge, bringing previously invisible periods of natural history into the light.

¹⁰⁰ Nicolas Brémontier, ['Sur la grotte de Miremont'], *Mémoires de l'Académie nationale des sciences, arts et belles-lettres de Caen* (1783), pp. 137–8.

Taking these considerations into account, this paper has addressed topical issues of academic debate around the role of evidence, witnessing and trust in pre-1800 scholarship and cartography. A critical study of cave maps suggests that more attention should be paid to the nature and epistemic difficulties of empirical knowledge production and their impact on early modern credibility building. In this regard, surveying techniques were not the basis for the faithful mapping of a given site, but functioned as tools of persuasion, conveying an accuracy that was impossible to achieve in practice. In closing, let us return to Steno's celebrated visit to Moncodeno Ice Cave. As he notes in his report to the grand duke, Steno was well aware of the practical obstacles he faced in drawing up his sketches in the freezing cold and by candlelight. Exhausted by the 'terrifying steep drops above and below the cave, as well as by the strenuous climb, and overwhelmed by all the new impressions', his initial enthusiasm for conducting extensive measurements had abruptly died down.¹⁰¹ Obviously worried about the dangers of the cave and its remoteness from the nearest settlement, he sketched his sections swiftly and 'not with the accuracy of a proper measure'.¹⁰² Like the maps of other scholars, Steno's sketches were concise representations of his scientific claims rather than detailed depictions of the cave itself. In short, maps made darkness visible, but only to an extent. The uncertain could still stimulate both reasoning and imagination.

Acknowledgements. I would like to thank Ernst Hamm (York University, Toronto), Norman Henniges (Berlin), Sandra Klos (Austrian Academy of Sciences), Simone Sambento (University of Edinburgh), Elena Trofimova (Russian Academy of Sciences) and Steffen Zierholz (University of Bern), who read and commented on this essay and/or provided sources. Thanks are owed to the Archives départementales de la Dordogne, the Archives départementales des Yvelines (both France), the Austrian National Library, the Austrian Academy of Sciences, the Landeshauptarchiv Sachsen-Anhalt (Germany), the Moravian Library (Czech Republic), the Massachusetts Historical Society (United States), the National Central Library of Florence (Italy), and the Russian State Archive of Ancient Acts for access to their collections. I am also grateful for the constructive and enriching suggestions of the two anonymous reviewers, who helped me to improve the content of the manuscript. Last but not least, I especially thank Kirsty Jane Falconer (Ferrara) for her language editing of this paper.

101 Kardel and Maquet, op. cit. (2), p. 674.

102 Kardel and Maquet, op. cit. (2), p. 647.

Cite this article: Mattes J (2022). Mapping the invisible: knowledge, credibility and visions of earth in early modern cave maps. *The British Journal for the History of Science* 55, 53–80. <https://doi.org/10.1017/S0007087421000789>