DOI: 10.1111/1600-0498.12337

SPECIAL ISSUE ARTICLE

Centaurus WILEY

Mines, mountains, and the making of a vertical consciousness in Germany ca. 1800

Patrick Anthony

Vanderbilt University, Nashville, Tennessee

Correspondence
Patrick Anthony, Vanderbilt University, Nashville, TN.
Email: patrick.anthony@vanderbilt.edu

Funding information
German-American Fulbright Commission; Social Science Research Council

SPECIAL ISSUE
Verticality in the History of Science

GUEST EDITORS
Wilko Graf von Hardenberg and Martin Mahony

This Special Issue was selected by a dedicated ESHS committee after a public call for special issues.

Abstract

The insight that scientific theories are "practice-laden" has animated scholarship in the history of science for nearly three decades. This article examines a style of geographical thought that was, I argue, movement-laden. The thought-style in question has been described as a "vertical consciousness that engulfed science in the early nineteenth century," and is closely associated with the geographical vision of Alexander von Humboldt (1769–1859). Humboldt's science spanned nature's horizontal and vertical axes, from Saxon mines to Andean summits, and from the currents of the ocean to those of the aerial ocean. In probing the origins of Humboldt's vertical thinking, this article opens up a broader history about the industrial practices and travel cultures that originally animated it. Humboldt's "global physics" first emerged within a context of vertical travel, up mountains and into mines and caverns. Rhythms of the body—lethal for some, "sublime" for others—became rhythms of the mind. A view of nature as set of vertically complementary spaces rippled through mining culture, Romantic art, and the geographical sciences. To trace the earliest routes of Humboldt's science is to acknowledge the many actors—some celebrated, most unsung—who took part in the making of a vertical consciousness.

KEYWORDS
Alexander von Humboldt, cartography, experience, Humboldtian science, mining, movement, Romanticism, travel

There is a sense in which all knowing is like travelling ….
—David Turnbull[1]

Up, up, to the mines, I call you
I, who stands above
So often as you go into the depths
Think up to the heights.
—The Miner's Bell, Freiberg, Saxony[2]

Church bells sounded the rhythms of life and death in early modern Europe. In mining towns, like Freiberg, Saxony, they choreographed a daily transhumance. The *Bergglöcklein* (Figure 1) aloft in Freiberg's St. Peter Church rang "by ancient decree" at 8-hr intervals, at 3:00, 11:00, and 19:00, harmonizing the descent that began one miner's shift and the ascent that ended another's.[3] In 1756, the bell was re-cast with the inscription above: "Up, up, to the mines, I call you, | I, who stands above …." At mid-century, miners in the Harz Mountains of central Germany and the Ore Mountains sprawling along the Saxon–Bohemian border spent as many as 3 hr of each workday in vertical transit, covering some 200–300 m on the wooden ladders fixed within the shafts.[4] The bell's inscription put a pious gloss on the treachery of those ascents and descents, and, like the theatrics of the mining parade, sanctified the work-time discipline of a well-orchestrated silver mine. But the *Bergglöcklein* also betrays a particular way of thinking borne of these rhythms—"So often as you go into the depths, | Think up to the heights"—a consciousness of verticality embedded in the very language of hard-rock mining.

The language spoken within an 18th-century mine can be compared to that heard aboard a sailing vessel of the same period. "[T]he force of a seamen's language lay in its capacity to relate actions to a precisely named environment," Greg Dening observed. "To a sailor," he continued, "the text of life was in knowing every degree of the relationship of his wooden world to the wind and sea and land outside it and the relationship of every place, role and action within it to himself."[5] So it was for the miner, whose nomenclature coordinated human action with the gases, groundwater, and geological strata that encompassed—and endangered—his own "wooden world." What distinguishes the miner's language, however, is its ability to articulate the verticality of his environs: the deadly threat of "rising weather" (poisonous vapors), the orientation of an ore vein that "falls into the depths" (perpendicular to the surface), the command to "run a mountain" (process the surface tailings), or the many expressions of descent—*einfahren*, *niederfahren*, *absincken*, *abteuffen*, *ablörschen*, *auf der Teuffe seyn*, or *auf einem Gang sinken*, to name a few.[6] Working vertically meant speaking vertically, and speaking vertically meant thinking vertically.

The insight that scientific theories are "practice-laden" has animated scholarship in the history of science for nearly three decades.[7] Around the turn of the century, scholars began to explore the tacit and embodied nature of knowledge in a wide range of epistemic frameworks, from Micronesian navigation to early modern metalworkers.[8] The enduring impact of these works can be seen in recent studies of "experiential" knowledges in which the human body itself serves as sort of instrument, as among seamen, healers, and lay "earthquake observers" of the 18th and 19th centuries.[9] This article contributes to these vibrant traditions by examining a style of geographical thought that was, like the miner's language, *movement*-laden.

[1]Turnbull (2000, pp. 155).
[2]"Auf auf zur Grube ruff ich Euch | ich die ich oben steh | so offt ihr in die Tiefe fahrt | so denket in die Höh." All translations are my own unless otherwise indicated.
[3]Benseler (1853, p. 1132).
[4]Comprehensive studies of mines in Freiberg and the Harz are Wagenbreth & Wächtler (1986) and Liessmann (2010).
[5]Dening (1994, pp. 56–57).
[6]Minerophilo Freibergensi (1784, pp. 487, 82, 9, 44); Jugel (1773, pp. 16, 14).
[7]On the "practice-ladenness of theory," see Warwick (1992; 1993).
[8]Turnbull (1991; 2000); Smith (2004; 2015).
[9]For example, Hellawell (2020); Gómez (2017); Coen (2012); Valencius (2013, pp. 145–174).

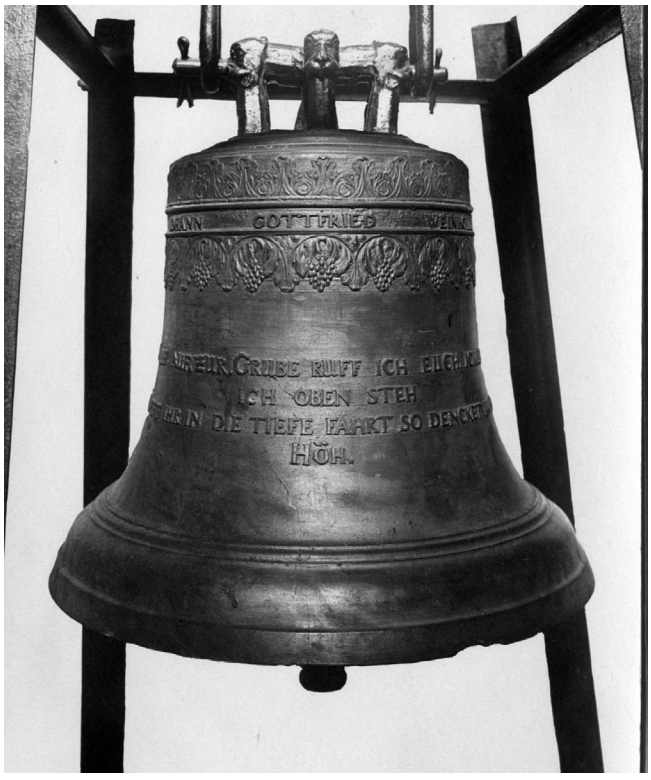

FIGURE 1 The bronze miner's bell ("*Häuerglöckchen*" or "*Bergglöcklein*") formerly in the Petrikirche in Freiberg, Saxony, first produced in 1509, then recast by Johann Gottfried Weinhold in 1756. Inv.-Nr. 50/210, Stadt- und Bergbaumuseum Freiberg, Freiberg, Germany

The thought-style in question has been described by Michael Reidy as a "vertical consciousness that engulfed science in the early nineteenth century," and is closely associated with the geographical vision of Alexander von Humboldt (1769–1859).[10] Humboldt's science spanned nature's horizontal and vertical axes, from subterranean flora to the vegetational regions he plotted on the slopes of the Andes, and from the currents of the ocean to those of the "aerial ocean." But while Humboldt's profound influence on his Victorian successors has been well documented, the origins of his era's vertical consciousness remain obscure.[11]

Returning to mineshafts hewn by generations of skilled laborers and mountain caverns curated by local families, this article locates the roots of a spatial consciousness associated with Humboldt's science in the routes of vertical mobility that proliferated in his time.[12] For Humboldt's *physique du monde*, or "global physics," first emerged in a time and place—central Europe around 1800—when patterns of mobility up and into mountains flourished among a wide range of administrators, artists, and savants who traced miners' rhythms, first with their bodies, then with their pens.[13] The embodied experience of vertical travel was itself constitutive of a geographical imaginary that spanned mineshafts and mountain summits. Mediated in print and visual culture, the experience of verticality circulated among Europe's educated elite through paintings and poems of the Romantic Era.

Like Caspar David Friedrich's iconic "Wanderer above the Sea of Fog" (Figure 6), Humboldt's grand geographical vision may appear to express a sort of *Bergeinsamkeit*, a communion between Man and Nature in the unpeopled

[10]Reidy (2008, p. 280). On verticality more broadly, consider the work of geographers and architectural scholars like Braun (2000), Weizman (2007), Scott (2008), and Elden (2013), who have analyzed the construction of vertical space in the colonial past and the geopolitical present. Similar approaches have been taken up by Reidy (2010) and Hecht (2012), for example, who have shown the importance of vertical geographies in the history of science.
[11]On Humboldt's Victorian followers, see the classic study Cannon (1978).
[12]See James Clifford's concept of "routes/roots": Clifford (1997, pp. 30, 36).
[13]Likewise, Dettelbach (1992) has argued that Humboldt's commitment to administrative oversight as a mining official carried through his broader *physique du monde*, as in the way he used isothermal lines to order the natural world. The influence of administrative traditions and technical traditions on Humboldt's science has been analyzed further in Klein (2012a; 2012b), Güttler (2014), and Anthony (2018). On underground travel, see Hamm (1997); Mattes (2015).

solitude of the mountains.[14] But by viewing movement itself as a practice, it becomes clear that the consciousness shared by Friedrich and Humboldt was grounded in working worlds of industrial activity (mines) and well-trodden sites of aesthetic education (mountains).[15] Humboldt, who trained as a miner in Saxony and served as one in Prussia, was profoundly influenced by the rhythmic practice of ascending mountains and descending mines that he adopted in Germany and extended into Latin America from 1799 to 1804. To play on a quotation from Susan Faye Cannon: if Humboldt was revolutionary, as I think he was, it was not in inventing a style of vertical thinking, but in elevating it to a global scientific enterprise.[16]

This article thus joins in a larger reappraisal of Humboldt's science as an adaptation (if not appropriation) of already-existing traditions. Scholars have shown, for instance, how Latin American traditions were proportionately marginalized as Humboldt's own mythology took shape, first in his writings and later in the historiography of our own age. But scientific communities in New Grenada and New Spain profoundly shaped Humboldt's science.[17] And Humboldt's vertical thinking cannot be understood apart from the creole cultures that informed it. Pablo Vila and Jorge Cañizares-Esguerra have argued that Humboldt's famous "Tableau physique des Andes" drew upon a project already undertaken by Francisco José de Caldas (1768–1816) when the two met in Columbia in 1801. Moreover, both men incurred a heavy debt to indigenous and creole traditions that had long viewed the Andes as "providentially designed" to host a global array of natural products.[18] Cañizares's analysis draws upon the seminal ethnohistoric studies of John Murra, who described pre-Columbian Andean society as being arranged in "vertical archipelagos" whose stratified settlements controlled a range of resources at various ecological levels.[19] In mapping South American biogeography as such, Caldas and Humboldt worked in a cartographic tradition rooted in the very organization of Andean life. Meanwhile, Ulrike Leitner's careful examination of Humboldt's journals from New Spain draws attention to the vast infrastructure of Mexican mining that sustained his cartographic enterprises there, as well as to some of the local draftsmen who converted his geodetic measurements into vertical profiles.[20] Indeed, every meter of vertical travel that Humboldt embarked upon in Latin America—up mountains and volcanoes, into craters, mines, and caverns—was guided by local experts.[21]

In central Europe, too, Humboldt appears not as *the* inventor but as *an* interpreter of a vertical consciousness. To demonstrate this, I resituate Humboldt within a broad culture of vertical travel fashioned by men and women of diverse backgrounds in mountains, mines, and caves across Germany. This article begins, accordingly, with a case study of the movement-laden cartography practiced by mining officials like Heinrich von Trebra (1740–1819). If the naturalist Georg Forster (1754–1794) learned from Trebra how to "unfold" nature's verticality, Humboldt's innovation was to fold the geological profile right-side-up again, from the mine to the mountain. The article's second section goes a step further, setting Humboldt's "global physics" within a broader travel culture that, in linking subterranean depths and mountain heights, yielded a shared understanding of nature as a set of vertically corresponding spaces. This over-and-under trope was as central to Humboldt's science as it was to the paintings and poems of artists like Julie von Bechtolsheim (1751–1847), Caspar Wolf (1735–1783), and Elisaveta Kulmann (1808–1825).

1 | UNFOLDING THE VERTICAL

Savants of Humboldt's time were well aware of the unique opportunities afforded by the mining industry. Mines made it possible to move through the earth and view nature from within. Reflecting on his tenure as a mining official

[14]Note the influential argument by Pratt (1992) about Humboldt's Romantic self-portrayal to European readers as the discoverer of a pristine and unpeopled New World ripe for the taking, indeed as the embodiment of Man and Individual.
[15]Alternatively, Franzel (2012) has studied movement, or *Bewegung*, as a conceptual feature of the "mountain sublime."
[16]Cannon (1978, p. 77): "If Humboldt was a revolutionary (as I think perhaps he was), it was not in inventing all the parts of Humboldtian science. It was in elevating the whole complex into the major concern of professional science for some forty years or so."
[17]Consider Cushman (2011); Serje (2017); Echenberg (2017); Pineda De Ávila (2019).
[18]Vila (1960); Cañizares-Esguerra (2015, p. 152).
[19]Murra (1972; 1985).
[20]Leitner (2005, esp. pp. 20–28).
[21]Matthies (2018).

in Ilmenau, Johann Wolfgang von Goethe (1749–1832) said that the undertaking, though financially disastrous, "earned me a view of nature [*Naturanschauung*]."[22] In a speech he delivered at the reopening of a silver mine in February of 1784, Goethe stressed the link between moving, seeing, and knowing. "Let us not look upon this humble opening … in the surface of the earth with indifferent eyes," Goethe implored, for it is in this mineshaft "where men will ascend and descend, and where we will behold before our eyes with the greatest joy what we now see only in the mind."[23] Later that year, after completing his own apprenticeship in mining, Forster was convinced that "the practical mining expert sees what the theorist never experiences, nor could ever believe."[24] What was this *Naturanschauung* drawn from the mines? What did the technician see that the theorist could not?

An image of this comes, quite literally, from Trebra, who guided the practical education of both Goethe and Forster in the 1780s and stood among the chief architects of a cartographic blueprint that Humboldt later followed in the Americas. The first graduate of the Mining Academy in Freiberg, Trebra now served the Electorate of Braunschweig-Lüneburg as officer of the mines in Clausthal-Zellerfeld, center of the Harz mining industry. There, he called upon miners to become skilled in pairing aerial ground plans (*Grundrisse* or *Situations-Charten*) with vertical profiles (*Saigerrisse* or *Durchschnitte*), collating the two perspectives into one. These maps did not merely represent a new way of depicting mineshafts and mineral deposits; they encouraged a new way of thinking about nature, one rooted in miners' routes.[25] Such was Forster's experience in 1784.

Already hailed as the "*Weltumsegler*" (or Circumnavigator) thanks to his celebrated account of James Cook's second voyage, Forster now wished to become a practitioner of useful science. Hoping to advance his knowledge of "the utilization of domestic products" while en route from Kassel (Hessen) to his new post as professor of natural history in Vilnius (Poland), Forster made his first stop in the Clausthal, lodging in Trebra's own home.[26] By day, Forster honed his mineralogical knowledge in the mines and caverns of the Upper Harz, while by night he discussed vein formation with his host, rising early to study "Trebra's manuscript," which was published the following year as *Erfahrungen vom Innern der Gebirge* (*Experiences from the Interior of the Earth*).[27]

Trebra's use of "experiences," rather than the more sedate "observations" or "considerations" (*Beobachtungen* or *Betrachtungen*), expresses the central idea of the work: advancing knowledge of the subterranean meant moving through it.[28] Composed of a series of letters and reports, *Erfahrungen* begins with Trebra's wish that others will join him in "gathering experiences" from which to "envision the miner within a wider environment." To this end, *Erfahrungen* modeled the practice of combining a series of visuals into "a total and correct image of the whole, from various and of various aspects."[29] The primary instrument here is the multi-dimensional map, which coordinated aerial and cross-sectional views. The "Situational map of Clausthal and Zellerfeld" in Figure 2, for instance, offers a bird's-eye view of the area's primary ore veins, while the adjoining profile invites viewers to unfold the subterranean geography of its southeasternmost terrain.

On the morning of April 27, 1784, Forster woke at 6:30 to study *Erfahrungen* at Trebra's side, then followed his host into the mines to "learn how the strike of a veins typically occurs on the slope of a hill," and how, according to Trebra, "the noblest veins are those where two valleys intersect."[30] A geologizing gaze that unfurled the earth as such could also be performed remotely, with the mere flip of a page. To unfold Figure 2

[22]Goethe to F. T. A. Müller & F. J. Soret [Letter] (1824, Mar. 16), in Goethe (1887, Part 4, Vol. 5, pp. 50–51).

[23]"Reden bey Eröffnung des neuen Bergbaus zu Ilmenau am 24 Feb. 1784" (1784, Feb. 24), GSA 25/W 2776, Goethe- und Schiller-Archiv, Klassik Stiftung Weimar, Weimar, Germany (hereafter GSA).

[24]Forster (1784, Jul. 12), in G. Steiner, B. Leuschner, S. Scheibe, H. Fielder, K. G. Popp (1958–, Vol. 12, p. 77).

[25]See also Rudwick (2005, pp. 85–90), which draws upon the cartography of Trebra to show how geognosy, a science that studied "three-dimensional structures" in the earth, took shape in the German mining industry.

[26]Forster to J. R. Forster [Letter] (1784, Mar. 3), in Steiner et al. (1958–, Vol. 14, p. 26).

[27]Forster (1784, Apr. 26), in Steiner et al. (1958–, Vol. 12, p. 25).

[28]The verb *erfahren* means both "to experience" and "to learn."

[29]Trebra (1785, pp. ii, 234): "Ich wünschte also, dass mehrere mit mir auf gleichem Wege beobachten, Erfahrungen machen, prüfen, und daraus nach und nach, wenigstens hohe Grade der Wahrscheinlichkeit den vorgesetzten Zweck zu erreichen, in einem weitern Kreise dem Bergmann vorzeichnen möchten." "… ein vollständiges und richtiges Bild vom Ganzen, aus verschiedenen, auf verschiedenen Seiten."

[30]Forster (1784, Apr. 27), in Steiner et al. (1958–, Vol. 12, pp. 25–26).

is to lay bare the Harz's most lucrative silver mines, the Dorothea and Caroline (numbered 61 and 62), shown here in relation to known ore deposits (in light grey), unexploited mineral veins (in red and yellow), and the nearby Elisabeth Reservoir ("p."). The idea was to collate profiles of three different perspectives into a single three-dimensional view. "In order to ascertain the entirety of a major ore deposit in its three dimensions of *length* [x-], *depth* [z-] and *breadth* [y-axes], *as it really exists*," Trebra wrote, "one must consider all images of the veins against each other."[31]

So intent was Trebra on giving readers a three-dimensional "experience" that some of *Erfahrungen*'s plates literally invite participation. Figure 3, for instance, sets mineralogical phenomena within the wooden framing of the local adits where they were observed. To the right is a hollow cut-out: peel back the page—*enter* the adit—and encounter an ore-bearing specimen of "natural size" from the adit called Old Glücksrad, such as one might find tucked within the vein shown on the left.

Notably, Trebra's case for a three-dimensional view that collated "*length*, *depth* and *breadth*" also mirrored his argument for the coordinated use of vertical shafts and horizontal adits. Whereas coal typically lies in horizontal beds, mineral deposits tend to have a more vertical orientation, hence the bell-shaped pits and vertical shafts that then characterized hard-rock mining. And yet, as improved water-pumping technologies enabled miners to exploit new depths in the late 18th century, Trebra also believed horizontal adits (*Entwässerungsstollen*) remained invaluable, particularly for draining shafts and galleries below the reach of the pumps.[32] In this way, the Dorothea and Caroline mines featured in Figure 2 underwent a 100-year descent into unfathomed depths, from 73 m and 190 m, respectively, in the first decades of the 18th century to 576 m and 489 m in the first half of the 19th century—so deep, some joked, that "you can hear the people in America shouting 'Hurrah for Lafayette!'"[33] For a somewhat more reliable sense of scale, imagine the two mines inverted on a profile map, soaring up among the tallest skyscrapers of our own time (the Dorothea amounts to some 175 stories), and challenging even the highest peak in the Harz, the Brocken, with its topographical prominence of 856 m. Humboldt himself used similar measuring rods when communicating the profound depths attained by miners of the period. In Volume 1 of *Kosmos* (1845), he noted that the depth of the "Old Kuttenberger Mine" (today Kutná Hora, Czech Republic) was not only "greater than the height of our Brocken" but also eight times greater than "the tallest man-made structures," the Pyramids of Giza and the Strasbourg Cathedral.[34] Mining at such depths meant carefully coordinating the flow of air, water, ore, and men through vertical and horizontal nature, just as Trebra's maps coordinated nature's x-, y-, and z-axes.

By pairing Trebra's *Erfahrungen* with his own "experiences," Forster learned to unfold—or, as he wrote, "open"—nature's verticality. The day after studying Trebra's manuscript, he donned the miners' garb and followed his host, lamp in hand, into the nearby New Glücksrad Adit (the lower, hence "newer," portion of the same mine that one can remotely enter in *Erfahrungen*'s interactive plate, Figure 3). It was here, in the mines, that officials and cartographers like Trebra gathered data from the chain of command: inspectors, foremen, and laboring miners.[35] In his journal, Forster studiously recorded "the strike, crisscrossing and shattering of the vein in the slate and greywacke," and restated *Erfahrungen*'s argument about the primacy of aqueous (rather than thermal) forces in the "generation of a vein"—a hypothesis that "the steady dripping of water in all the mines naturally impresses upon us." Putting Trebra's theory in a language more familiar to him, Forster likened mineral veins to "islands formed within the mountains." Fittingly, Forster retraced his and Cook's "entire voyage on a world map" for Trebra that evening.[36]

[31]Trebra (1785, p. 234): "So halte man, um das Ganze eines Hauptzuges nach seinen drey Dimensionen der *Länge*, *Teufe* und *Mächtigkeit*, *so wie es ist* in den Blick zu fassen, die hier vorgelegten sämmtlichen Bilder von den Gängen gegen einander." On the creation of a three-dimensional understanding of terrain, see Mattes (2020).

[32]Trebra (1785, pp. 142–143).

[33]The joke was recounted by Heinrich Heine (2006, p. 44), who toured the Caroline and Dorothea Mines in 1824. The Marquis de Lafayette had recently made a triumphant return to the United States in whose War of Independence he had gained a heroic reputation.

[34]Humboldt (1845–1847, Vol. 1, p. 418).

[35]Felten (2018).

[36]Forster (1784, Apr. 27), in Steiner et al. (1958–, Vol. 12, pp. 25–26).

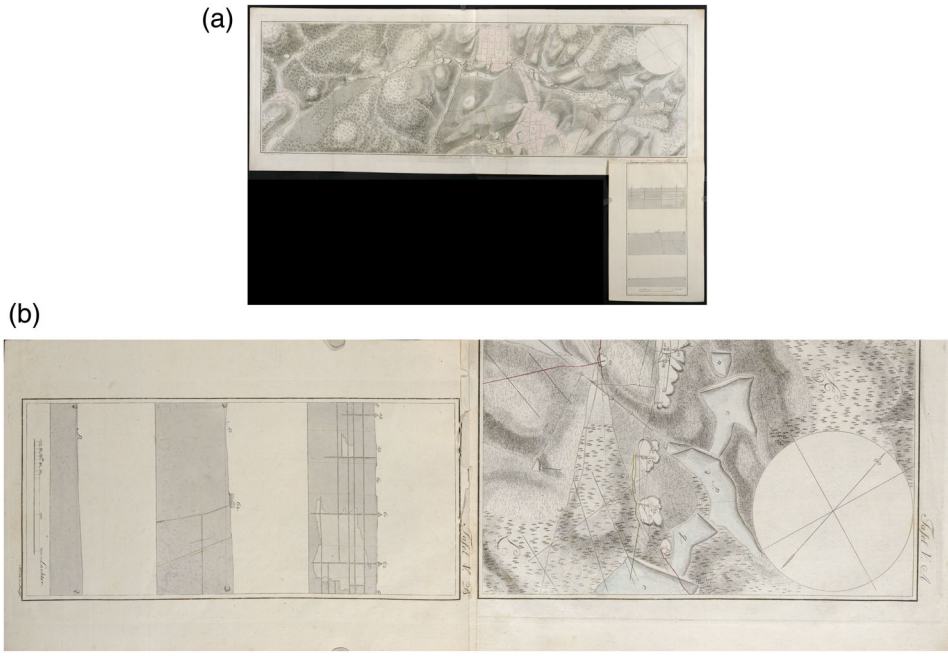

FIGURE 2 (a) Tafel V^A-V^B from Trebra's *Erfahrungen vom Innern der Gebirge* (1785). The wide view in Tafel V^A, a "Situations-Charte der Gegend um Clausthal und Zellerfeld," is adjoined in Tafel V^B by "three cross-sections of this area." GR 2° H. N. Mineral. III, 1700 Rara, Niedersächsische Staats- und Universitätsbibliothek Göttingen, Göttingen, Germany. (b) Detail from Tafel V^A-V^B. The three cross-sections that unfold in V^B depict the area around the Dorothea and Caroline Mines from various aspects. Their contents correspond to the mineshafts, mineral deposits, ore veins, and reservoirs shown in V^A [Color figure can be viewed at wileyonlinelibrary.com]

But it was Trebra's cartography that now gave a new dimension to the Circumnavigator's worldview. When Forster continued his practical education in Freiberg that summer, he saw the Saxon subterranean through Trebra's eyes. After noting how the veins there "confirmed the observations of Trebra" about the location of the richest ore deposits, Forster went one step further, envisioning a three-dimensional cartographic project:

> But one should still identify and chart all veins throughout the entire Ore Mountains, and perhaps draw from this something important and, for theory, applicable and reliable. Such a map, which designated all *converging* veins, would make for a rare sight, especially if one were to include a profile that indicated the ~~heights of mountains~~ form of mountains, and in this way determine the richer bodies of ore.

Earlier that day, Forster had observed to the east of Freiberg, as to the south, vast tracts of land "still entirely unopened [*noch gar nicht geöffnet*]." Yet Forster's cartographic vision did just that—it opened the mountains. Beginning, like Trebra, with the aerial view, Forster's imaginary map then unfolded into a profile. Initially, that profile portrayed the "heights of mountains." True to his training, though, Forster quickly dashed his pen through those two-dimensional "~~heights~~." In their stead, he reimagined the three-dimensional "form of mountains." This, as Forster concluded at the end of the journal entry, is what the "practical mining expert sees."[37]

[37]Forster (1784, Jul. 12), in Steiner et al. (1958–, Vol. 12, pp. 76–77): "Man sollte doch billig überall durchs ganze Erzgebirge alle Gänge aufsuchen, und aufzeichnen, so käme vielleicht etwas wichtiges, und für die Theorie anwendbares, sicheres, heraus. Eine solche Charte mit der Angabe aller sich durch kreuzenden Gänge, würde curios anzusehen seyn, zumal, wenn man überall Profile beyfügte, um die ~~Höhe der Berge~~ Form der Berge anzuzeigen, und dadurch die reichern Erzpunkte zu bestimmen."

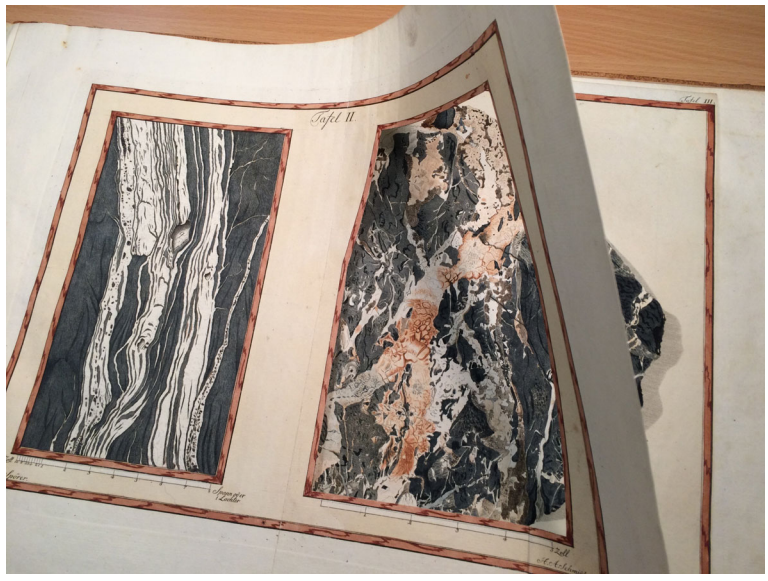

FIGURE 3 Tafel II from Trebra's *Efahrungen vom Innern der Gebirge* (1785). Designed to appear like the wooden framing of an adit, the hollow cut-out on the right of Tafel II invites readers to peer into, or open up, Tafel III for closer inspection of ore-bearing rock from Altes Glücksrad Stolln. GR 2° H. N. Mineral. III, 1700 Rara, Niedersächsische Staats- und Universitätsbibliothek Göttingen, Göttingen, Germany. Photograph by the author [Color figure can be viewed at wileyonlinelibrary.com]

In their ambitious geographical scale and immense vertical reach, the "Tableaux" that Humboldt drafted in Latin America bear a striking resemblance to that which Forster imagined in Freiberg. This is no coincidence. The training Forster underwent in a matter of months, Humboldt experienced over the course of 5 years, studying first at Freiberg's Mining Academy from 1791–1792, then serving the Prussian Mining Administration in Franconia's Fichtel Mountains through 1796. Humboldt extended the cartographic practices learned in these years into the Americas—vertical movement chief among them. If in Freiberg Humboldt "regularly spent 4 to 5 hours of every day in the mines" while making comparative geognostic and meteorological inquiries aboveground, his American journey took him up mountains and volcanoes and into mineshafts and craters.[38] There, Humboldt understood his own body as "a kind of gauge" with which to measure the effects of vertical travel.[39] The cartographic undertaking that culminated in Humboldt's *Atlas géographique et physique du royaume de la Nouvelle-Espagne* (1811) bears the stamp of this ascent-descent rhythm of natural inquiry, and of his collaboration with technicians at the Royal School of Mines in Mexico City. Indeed, one of the *Atlas*'s maps began, as Ulrike Leitner has observed, with a set of geodetic measurements recorded by the local draftsman Luis Martín from the "roof of the School of Mines" in Mexico City.[40] It was there, in 1803, that Humboldt had "conceived of the idea of representing entire countries as one would a mine."[41]

The result: his *Atlas*'s three-part, continent-spanning profile (Figure 4). Shorn of mineralogical data, Humboldt's Mexican Tableaux depict an entire landmass in what he understood as a set of inverted mine profiles. Flipped upright, as it were, and spread across the eastern third of New Spain, Figure 4 displays the territory's cross-sectional form above sea level, as determined by barometric and trigonometrical measurements that Humboldt grafted onto surveys made by Mexican miners. The middle profile even indicates the elevation (1,186 toises, roughly 2,312 m) and greatest depth (264 toises, or 515 m) of the mines of Valenciana in Guanajuato, measurements he had taken himself. "Humboldt inspected every silver mine and climbed every mountain in the immediate region," Myron Echenberg noted of the month he spent in Guanajuato, including "three descents to the bottom of Valenciana."[42]

Humboldt's maps thus declare, with Trebra and Forster, that what can be unfolded into the subterranean can be folded up again into the mountains. This is illustrated by the fact that Humboldt's more famous "Tableau physique

[38]Humboldt to G. C. Lichtenberg [Letter] (1792, Apr. 21), in Jahn & Lange (1973, p. 184).
[39]Livingstone (2003, p. 75); also Dettelbach (1999, p. 478).
[40]Leitner (2005, p. 23).
[41]Beck (1958, p. 37): "Jai concu l'idee de figurer des pays entiers comme on represente une mine."
[42]Echenberg (2017, pp. xxv, 124–131).

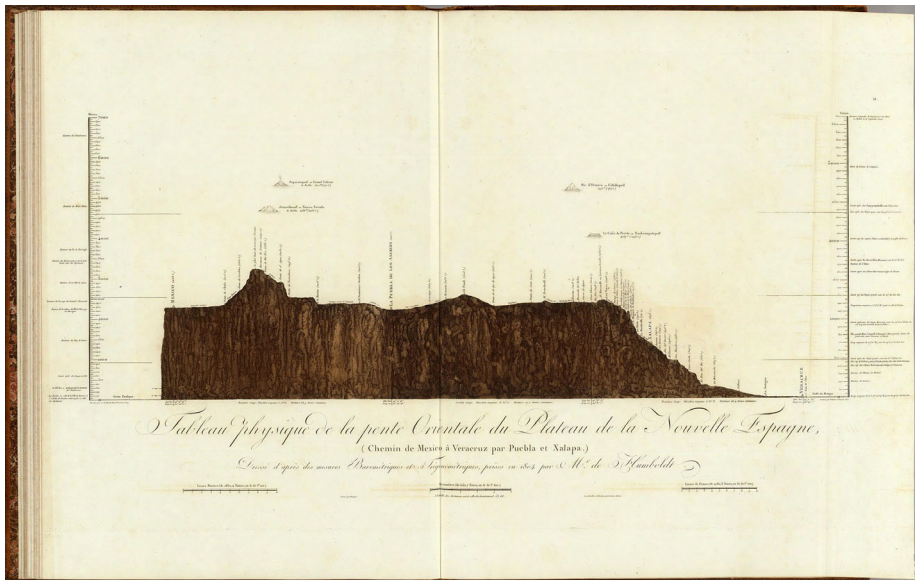

FIGURE 4 Humboldt's "Tableau physique de la pente Orientale du Plateau de la Nouvelle Espagne," drafted by Humboldt in collaboration with miners at the School of Mines in Mexico City in 1804, engraved in 1807, and published in the *Atlas géographique* (1811). From Cartography Associates, 2000 (http://www.davidrumsey.com/maps2879.html). CC BY-NC-SA 3.0 [Color figure can be viewed at wileyonlinelibrary.com]

des Andes," commonly thought to be inspired by the Ecuadorian volcano he and his porters nearly summitted in 1802, Mt. Chimborazo, also belongs to a whole family of "Tableaux physiques" that he himself attributed to mining.[43] Both attributions are true, and truer still when taken together. For Humboldt saw nature as a set of corresponding spaces—over and under, mountain and mine, summit and sea—to be studied and mapped with corresponding methods. That sense of geographical analogy, as we will see, was the unifying idea behind a far-reaching culture of verticality whose most famous interpreter was Humboldt himself.

2 | CORRESPONDING SPACES

There is a simple logic of correspondence to the cartographic imagination outlined above, namely that what can be unfolded may be folded up again. Drawing on that logic, Humboldt's *physique du monde* constructed nature as a system of corresponding spaces, an arrangement of "contrasts and analogies" between the strata of earth, ocean, and atmosphere.[44] Indeed, as Karen Wigen has suggested, the related "notion of a correspondence between latitude and altitude," popularized by Humboldt, "was in fact a central principle of nineteenth-century geography," from the Andes to the Japanese Alps.[45] But this logic of correspondence—in method and in nature—was deeply rooted in routes of vertical travel and vertical thinking plotted long before Humboldt.[46]

[43]Humboldt (1809–1812, Vol. 1, p. v): "Ich habe den Verusch gewagt, ganze Länder nach einer Methode darzustellen, welche bis jetzt nur für Bergwerke oder bei Canalprojecten angewendet wurde." On the "Tableau physique" as part of a cartographic genre of tableaux commonly rooted in mining practice, see Kraft (2014, pp. 137–154); Anthony (2018, pp. 41–53).
[44]Humboldt (1845–1847, Vol. 2, p. 529).
[45]Wigen (2005, p. 25).
[46]Reidy (2015) explores the critical role of islands and equatorial peaks in the making of Humboldt's "correspondence principle."

On the eve of his journey through the Americas, Humboldt published a 350-page study of the airs in mines, which sought to mitigate the effects of noxious gases (or "*böse Wetter*") on miners' lungs. In it, he declared: "Nature knows no over- and underground. All that is contained in fluid elements is counteractive, *mixed*."[47] Here Humboldt refashioned an ancient expression of verticality, which had also become a common feature of mining lore. The Emerald Tablet, produced by Arab scholars in the early medieval period and later associated with the philosophers' stone in early modern Europe, declared a nearly identical principle of analogy between alchemy and astrology, the earthly and the astral: "As above, so below," the tablet reads; "Everything is in movement."[48] Miners were well-versed in such expressions, from 17th-century songs about "the golden firmament" hidden in the earth's "shafts and chasms," to Romantic works that described miners as "inverted astrologers." Just as astrologers "study the force and influence of the stars," says the wise hermit in Novalis's *Heinrich von Ofterdingen*, which he wrote shortly after graduating from the Mining Academy in Freiberg, so miners study "the manifold effects of stratified earth and rock."[49]

Later appropriated by Romantics like Novalis, miners' folk traditions originally formed around the industry's unique division of labor. The vertical orientation of mining produced a distinctive "cartography of risk."[50] In the Harz, the age of 17 or 18 marked a harrowing rite of passage, the descent of "miners' sons" from unskilled over-ground tasks (for example, winching rock out of the shafts or crushing ore) to more specialized, and far more dangerous, underground labor: blasting and hewing, as well as framing and masonry, in the depths. One study of the Upper Harz lists 1,190 mining deaths between 1751 and 1863, most of them caused by collapsing tunnels and accidental explosions of black powder. Hewers and borers alone (*Gedinghäuer* and *Bohrhäuer*) accounted for nearly half of these deaths (457), as compared to the 52 ore-crushers (*Pocharbeiter*), 21 smelting operators (*Hüttenleute*), and 5 administrators (*Bergbeamte*) who died in over-ground accidents.[51]

This reality profoundly shaped the spatial orientation of miners' spirituality. The miner's bell poised above the gables of Freiberg commanded those who "go into the depths" to "Think up to the heights." Miners' own songs appealed to "Mine Counselor Jesus Christ" (*Berg Rath Jesum Christ*) for angels to guard them from the evil wrought by the "Mine-Devil."[52] A traditional song sourced from Joachimsthal (Jáchymov) in the Ore Mountains, whose deepest mines Humboldt recorded some 650 m beneath the surface of the earth, goes follows:

> We miners hidden in the deep …
> God wishes to send us angels
> For when we climb in and out.
> Wager with our lives we must
> down into the noble mine.[53]

For laborers, as for elite travelers, transit through vertical space was both a physical and spiritual experience, no less enchanted for the miner than for the Romantic. But if sublime enthusiasts found in the subterranean evidence of the Creator's awe-inspiring artifice, miners drew divinity into the depths as a matter of life and death. They did not have the luxury of enjoying fear.

The stuff of song and poem for some was reconfigured as scientific practice for Humboldt, who elevated vertical correspondence to a globe-spanning enterprise. His 1799 work on mine airs, which overlapped with miners' own

[47]Humboldt (1799, p. 201): "Die Natur kennt kein Oben und Unten. Alles im beweglichen Element ist gegenwirkend, ist *mischend*."
[48]Conventional translations of the second and third principles of the Emerald Tablet or Tabula Smaragdina.
[49]An "old miner's song" written circa 1681 and recorded in Engelschalln (1723, pp. 190–193); Novalis [Friedrich von Hardenberg] (1837, p. 115). The same interplay of astral and subterranean phenomena can be found in E. T. A. Hoffmann's "The Mines of Falun" (1818).
[50]Andrews (2008, p. 137).
[51]Liessmann (2010, pp. 41, 46–50).
[52]Engelschalln (1723, p. 193); Krause (2001, pp. 25–26).
[53]Heilfurth (1988, p. 84): "Wir Bergleut sind tieff verborgen | in den Schächten tieff und lang | wir trauen Gott, und wolln nicht sorgen | preisen ihn mit Lob-Gesang … Gott woll uns sein Engel senden | wenn wir fahren aus und ein. | Wagen müssn wir unser Leben | in das edle Bergwerck nein." Humboldt's recording of the "Jung Häuer Zechen- und Andreasgang" mine in Joachimsthal comes from Humboldt (1845–1847, Vol. 1, p. 418). As Humboldt used Prussian feet, I have used an English translation's "2,120 ft" to convert into meters.

concerns about safety, can be read as an early iteration of that enterprise. Inverting the heavily instrumentalized physics and high-altitude chemistry of his contemporaries, Humboldt called this study "subterraneous meteorology." "I wish to draw downwards what [Jean-André] Deluc, [Horace-Bénédict de] Saussure and [Georg Christoph] Lichtenberg have drawn up toward the region of the clouds," he wrote.[54] The passage illustrates how, for Humboldt, the underground was not a space apart but one that corresponded, in ways familiar and unfamiliar, to the world above. The expression that Nature knows no over- and under-ground was not meant to equate or confound terrestrial and sub-terrestrial spaces. Rather, it is a methodological statement, suggesting that the same scientific practices and instruments may be applied above as below the surface of the earth. In fact, Humboldt's theory of mine airs rested upon a fundamental distinction between meteorological phenomena above and below the earth's surface. Whereas "the *over-ground* aerial regions are differentiated in regular stratified increments (decreasing in oxygen and carbon dioxide, strengthening electrical charge and so on)," Humboldt believed that "*underground* aerial regions" are primarily "modified by local-relations"—for example, the amount and rate of airflow, the size and shape of the shafts and galleries, and the presence of water, wood, and subterranean plants.[55] Analogous methods yielded contrasting results.

This conception of vertical space had already been decades in the making by the time Humboldt set foot in the mines of Freiberg and Franconia. Fixed within a set of poetic tropes and aesthetic motifs, vertical correspondence unified an otherwise heterogenous travel culture. In 1767, the Hessian miner Franz Ludwig von Cancrin published a description of mining operations throughout central Europe "in order to give dilettantes and travelers a taste of the mines" before venturing in themselves.[56] The work heralded a new era in which the travel routes of the educated classes drew inspiration from the revitalization of central Europe's mining industry after the Seven Years War (1756–1763). This period saw the establishment of mining academies in Schemnitz (1762–1770) and Freiberg (1765). A series of lectures on mining and smelting sciences followed in Berlin around 1770, along with a mining school in Clausthal-Zellerfeld in 1775.[57] From this "underground Enlightenment" arose a culture of travel that combined scientific inquiry and sublime aesthetics in the subterranean.[58] Indeed, as Albrecht Classen has observed, it was not mountains themselves but the treasures within them that gave alpine peaks their allure in the late medieval and early modern literature that anticipated the 18th century's aesthetic embrace of elevation.[59]

In the second half of the 18th century, shifting sensibilities were documented, however unwittingly, by travelers' entries in the logbooks kept atop mountain summits and in the homes of local "cave guides." In the same year as Cancrin's underground travel guide, a telling exchange can be read between two parties who climbed the Harz's highest peak, the Brocken, some 30 km east of Clausthal-Zellerfeld. Speaking for a group of seven middle-class men (identified variously as "preacher" and "magister"), one traveler noted the party's preference for the Brocken's summit over its underground counterpart, the nearby Baumann's Cave. The judgment elicited a defense not of the cave itself, but of a vision that beheld summit and subterranean together. Under the pseudonym "Hans Sachs reincarnate," harkening to the 16th-century poet and *Meistersinger*, the anonymous traveler observed in verse how the Brocken "has borne those, | Who would spurn Baumann's Cave | And rejoice, with body and soul, only in him." But a change was underfoot, and Baumann's Cave could now be counted "amongst the landmarks of our time." "Happy is the wise man," the poem concludes, "who esteems both."[60]

Logbooks like the *Brocken-Stammbuch* (beginning in 1753), or the *Jahrbuch* kept by the guide of Baumann's neighboring Biel's Cave (beginning in 1788), help re-trace the travel patterns that took shape in the second half of

[54]Humboldt (1799, p. 201): "[M]öchte ich sie herabziehen wie Deluc, Saussure und Lichtenberg sie aufwärts in die Regionen der Wolken zogen."
[55]Humboldt (1799, p. 57): "In der *überirdischen* Luftregion unterscheiden sich die höhern Schichten wesentlich (durch mindern Sauerstoff und Kohlensäure-Gehalt, stärkere elektrische Ladung u. s. f.) von den untern, der Erdfläche näheren Schichten. In der *unterirdischen* Luftregion lassen sich ähnliche Unterschiede nicht angeben. Hier wird alles durch Lokal-Verhältnisse modificirt."
[56]Cancrinus (1767, "Vorrede").
[57]Klein (2012a); Engel (2013).
[58]See Rupke (1983); Vogel (2013).
[59]Classen (2012, p. 46).
[60]August 1767, in *Jahrbücher des Brockens* (1791, p. 95): "Die Baumannshöhle auch wohl ist |Ein Sehenswürdig Ding zu dieser Frist, | Doch von dem Brocken kann man sagen, | Daß er schon manchen hat getragen, | Der verachtet die Baumannshöhle | Und freut sich des Brockens mitt Leib und Seele | Zufrieden ist der weise Mann,| Der beides hat gesehen an. (Hans Sachs redivivus.)"

the 18th century. The most well-trodden route connected the depths of Biel's and Baumann's Caves, notched in the valley of Elbingerode, with the heights of the Brocken, which rises some 680 m above the caverns—an ascent (or descent, depending) just greater than the era's deepest mines. "It is an unforgettable thing," wrote a Nürnberg baron in 1780, "to inspect the famous Baumann's Cave and climb the Brocken, and to have beheld both on a single day."[61] That same year, Goethe made a request of his mentor Trebra, namely that he produce a geognostic map that proceeds "from the summit of the Brocken … to the deepest shafts of the Harz mines" in order to "see such various rock formations with a single set of eyes."[62] Three years later, Goethe attained such a view with his own eyes, making a Baumann-to-Brocken tour with Trebra himself. At the end of the decade, a 20-year-old Alexander von Humboldt signed his own name in the Biel's Cave *Jahrbuch*, 2 days after summitting the Brocken with Göttingen University classmates. Inverting Humboldt's route, three students from Halle wrote in June of 1792 that, having "climbed and crawled through Biel's Cave," they would carry on "to the higher regions and climb the old Brocken."[63]

Humboldt was one of over 1000 visitors who recorded their names in Biel's Cave between 1788 and 1795. From its logbook we know that an astonishingly wide range of people participated in the rhythms he later made so famous—men and women, noble and bourgeois, miners, lawyers, rectors, philologists, musicians, whole families, groups of university students, and many more. Where bodies wandered, minds followed. For while the juxtaposition of height and depth, over and under is surely an ancient trope, it is also one that found renewed expression through experience. And this over-and-under motif pervades both logbooks. "Seize my hand, brother," waxed one Swiss traveler in 1784, "and feel joy upon the high mountain summits, as in the valley's depths." "[I] rose out of the depths and up to the heights," wrote a Saxon miner atop the Brocken in 1818, describing his ascent from the mines of Clausthal-Zellerfeld.[64]

A vertical Romanticism thus took hold in the Harz, linking spiritual elevation and physical descent. "Great is the architect of worlds!" wrote a Berlin statesman in August of 1788, having found the works of his god "High in the airs of heaven [and] Deep in the chasms of the earth." Similar verses echoed again and again through Biel's Cave, as in April of 1791 when a traveler from Hamburg found the "rich blessings" of God "Atop the Biel-Stone's green heights, | As in its abysmal depths."[65] The following winter, Eisenach *salonnière* and poet Julie von Bechtolsheim climbed through the 11 chambers of Biel's Cave alongside her two sisters and her two nieces. "With deep admiration," she wrote in the logbook, "three sisters navigated the remarkable Biel's Cave on 20 February."[66] One of 46 women counted among the logbook's 1,130 visitors, Bechtolsheim's entry struck a defiant tone. Publishing later under the pseudonym "a mountain-dweller," Bechtolsheim asked her readers if they could hear her lyrics "echo over the shelves of the mountains."[67] Moral descent and spiritual transcendence marked the routes of her verse. In one poem, she chronicled the fate of a woman who, having been cheated by "the false man," scaled a treacherous path to a high cliff. There she "leapt from the precipice" "down into the kingdom of shadows!" so that she may "rise up" again "in the form of an angel."[68] For the forgotten bards of Biel's cavern, poetry had become a vehicle of verticality, and verticality a language of solace.

Stepping out beyond the Harz and its logbooks, we find the same aesthetics of correspondence and contrast in visual art. Consider the Swiss painter Caspar Wolf, whose fascination with grottos earned him the name "*Höhlenwolf*" (cave-wolf). In his 1778 painting *The Interior of the Bear Cave at Welschenrohr* (Figure 5), Wolf depicted his subject on a rocky pedestal, gazing out through the threshold-space that divides nature's "over- and underground." To be underground, Wolf seems to say, is to look above. In Friedrich's "Wanderer above the Sea of Fog" (Figure 6), an analogous figure stands atop a Saxon peak pondering the abyss below him. The one inverts the other, much as Humboldt's

[61]K. Welser (1780); Nehse (1850, p. 46).
[62]Goethe to Herzog Ernst von Gotha [Letter] (1780, Dec. 27), in Herrmann (1955, p. 50).
[63]Entries for June 3, 1789 and July 21, 1792, in Schröder (1796, pp. 154, 188).
[64]J. Ronca (1784, May 31); F. A. Kramer (1818, Aug. 21), in Nehse (1850, pp. 67, 143–144).
[65]J. F. Gedike (1788, Aug. 4); D. R. Hudtwalcker (1791, Apr. 2), in Schröder (1796, pp. 147, 162).
[66]J. Bechtolsheim (1792, Feb. 20), in Schröder (1796, p. 169).
[67]"Abschiedsworte einer Bergbewohnerin" (1810), GSA 20/129.
[68]Bechtolsheim to Friedrich Schiller [Letter] (1805, Mar. 27), GSA 83/194. The poem communicated to Schiller in 1805, "Der Sprung von Felsen," was first published in Bechtolsheim (1806, pp. 61-67).

maps inverted the mine. In fact, 6 years before beginning his famous *Wanderer* in 1817, Friedrich wandered into the Harz, where he illustrated mountains and caverns alike. Among his subjects were the grotto-feature "Krochstein," not 2 km from Biel's Cave, and a "stalagmitic cavern" thought to be Baumann's Cave.[69]

Through paintings and poems, the motifs of the Harz logbooks spread far and wide, increasingly untethered from the travel routes that inspired them. A striking example of this comes from Elisaveta Kulmann (1808–1825). Despite styling herself as a poet of the underground—"a child of the depths," as she wrote in one verse—Kulmann had seen neither mountains nor mines nor caves with her own eyes. The daughter of a German family that emigrated to Russia and fell into dire financial straits, Kulmann's tragically short life was largely confined to their home in St. Petersburg. There, Kulmann wandered nature's vertical limits in the mind, extrapolating like Trebra from an array of visuals—paintings, ceiling frescos, copper engravings. "She seemed to have taken great pleasure in arranging all these mountain scenes alongside one another," her tutor recalled, "and began to work on grottos with a special passion."[70]

In Kulmann we find verticality at a distance. And in her posthumously published poems and letters, we see how she conceived of the earth-system, like Humboldt, as a set of vertically complementary domains. For her, nature was composed of two elemental spheres, which envelop the solid earth: the "overworld" or "aerial kingdom," and the "underworld" or "water-kingdom."[71] Humboldt, as we will see, made a similar tripartite distinction: "The solid surface of the earth has two envelopes [*zweierlei Umhüllungen*]," he wrote, "the liquid and the aeriform."[72] And if, for Humboldt, islands were submarine mountains and mountains were "green forested shoals" rising through the "aerial ocean," Kulmann's poetic *physique du monde* viewed subterranean aquifers as inverted clouds and clouds as floating aquifers.[73] Astonished by this last feature of Kulmann's cosmos, her tutor reflected that "with respect to underwater phenomena, everything appeared inverted by her estimation, all heads flipped under, all feet turned up."[74] But this, of course, was just the point.

For Humboldt, the interplay of disparate natural phenomena above and below the surface of the earth and its oceans was governed by the laws of correspondence. As studies in mines had shown Humboldt that nature—by which he meant *the study of* nature—"knows no over- and underground," so his *Essai sur la géographie des plants* (1805) argued "the opposite limits of plant life produce beings with a similar structure." As you walk toward the poles, he wrote, you will encounter the same changes in plant life as you would climbing a mountain in the tropics. Likewise, the same lichenous plants found growing atop the "rocky and icy peaks above the clouds" can also be seen "branch[ing] out on the roofs of mines and underground caves."[75]

Humboldt found a similar correspondence in temperature changes above and below sea level. His famous isothermal maps charted mean annual temperatures across the globe, their "iso-lines" linking diverse regions with common climates. These maps already accounted for the prominence of continents and their mountain chains. Yet this perspective, too, could be unfolded into a cross-sectional view of the aqueous and aerial oceans. "So wonderful is the distribution of heat across the globe," Humboldt wrote in his *Political Essay on the Kingdom of New Spain*,

> that we find colder strata as we ascend through the aerial ocean, while in the depths of the sea the temperature decreases in proportion as we descend below its surface. In both elements the same latitudes, so to speak, indeed all climates, are unified. At different distances from the surface of the ocean, but upon the same vertical plane, we encounter air- and water-strata of the same temperature.[76]

[69]Zschoche (2008, pp. 35–40).
[70]Großheinrich (1847, pp. 53, 94).
[71]Großheinrich (1847, p. 14).
[72]Humboldt (1845–1847, Vol. 2, p. 529).
[73]Humboldt (1845–1847, Vol. 1, p. 321).
[74]Großheinrich (1847, p. 14).
[75]Humboldt & Bonpland (2009, p. 64).
[76]Humboldt (1809–1812, Vol. 3, p. 2): "So wunderbar ist die Hitze über die Erdkugel vertheilt, dass je höher man sich im Luft-Ozean erhebt, man auch immer kältere Striche findet; da sich hingegen Temperatur in der Tiefe des Meers in dem Maas, wie man sich von der Wasserfläche entfernt, vermindert. In beiden Elementen vereinigt dieselbe Breite, so zu sagen, alle Klimate, und in ungleichen Entfernungen von dem Spiegel des Ozeans, aber auf gleicher Vertikal-Fläche, trift man Luft- und Wasser-Lagen von derselben Temperatur an."

FIGURE 5 Caspar Wolf, *Das Innere der Bärenhöhle bei Welschenrohr* (*The Interior of the Bear Cave at Welschenrohr*), 1778, oil on canvas, 42.5 cm × 34.5 cm. Kunstmuseum Solothurn, Solothurn, Switzerland [Color figure can be viewed at wileyonlinelibrary.com]

In other words, the climatic characteristics of the earth typically associated with latitudinal change could also be read in profile, mapped onto alpine heights and oceanic depths.

"Strata" is the word on which this view hinges, hearkening back again to the subterranean roots Humboldt's global physics. Recall Humboldt's Kulmann-like tripartite conception of nature: the two "envelopes" (liquid and aeriform) that encompass the solid earth. In each of these three domains, Humboldt saw stratigraphy. By the time he wrote his five-volume work *Kosmos* (1845–1862), Humboldt regularly employed the phrase "superimposed strata" to describe earth, ocean, and atmosphere alike.[77]

[77]See variations of "*über einander gelagerten Schichten*" in Humboldt (1845–1847, Vol. 1, pp. 64, 84, 335); Humboldt (1845–1847, Vol. 2, pp. 146, 378); gr. K. 11, Nr. 59a, Nachl. Alexander von Humboldt, Preußischer Kulturbesitz, Staatsbibliothek zu Berlin, Berlin, Germany.

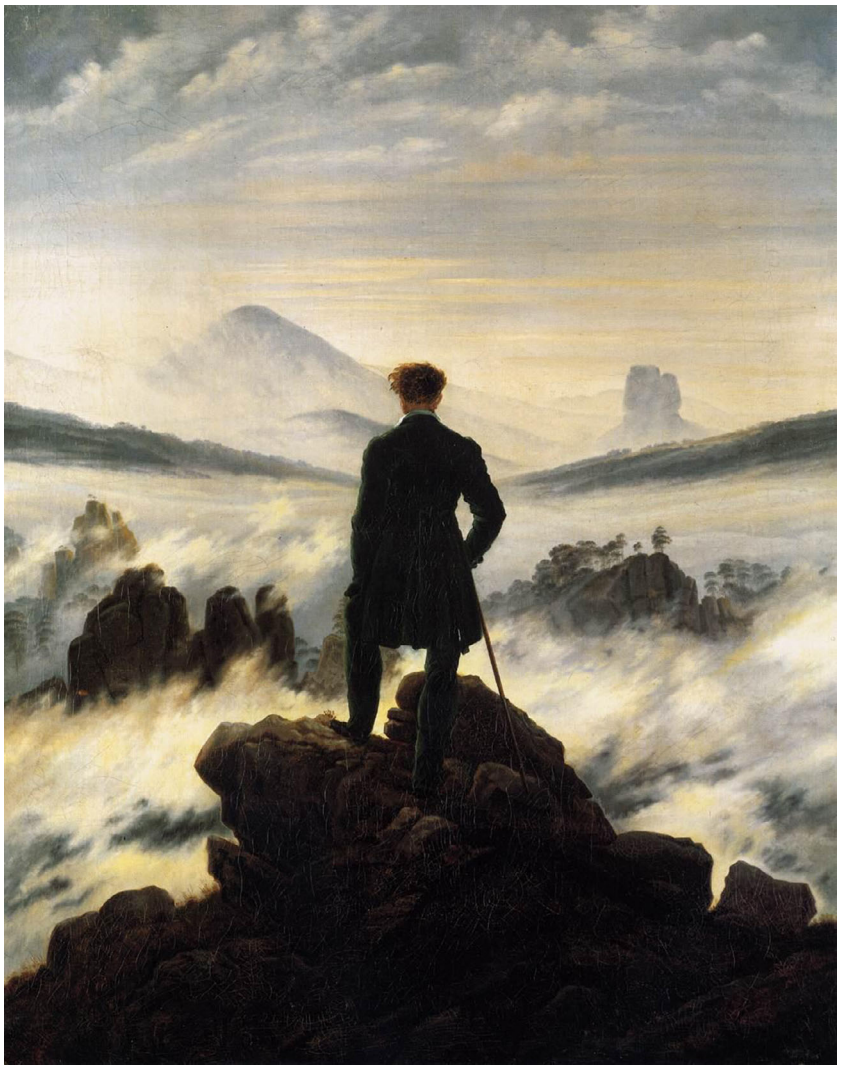

FIGURE 6 Caspar David Friedrich, *Der Wanderer über dem Nebelmeer* (*Wanderer Above the Sea of Fog*), 1817–1818, oil on canvas, 74.8 cm × 94.8 cm. From Wikimedia Commons, 2009 (https://commons.wikimedia.org/wiki/File:Caspar_David_Friedrich_-_Der_Wanderer_%C3%BCber_dem_Nebelmeer.jpg). In the public domain [Color figure can be viewed at wileyonlinelibrary.com]

Not only in word, but also in deed, Humboldt's stratified cosmos leads back to working worlds of human industry.[78] Continuing with the passage quoted above from the essay on New Spain, we see how, in the eyes of the erstwhile mine administrator, the great value of vertical correspondence lay in its function as a virtual map of possibilities for human enterprise. Echoing the physiocratic traditions that, as Nils Güttler has shown, so influenced ideas about plant geography, Humboldt concluded that the corresponding decrement of heat above and below the surface of the earth demarcates zones suitable for "the development of organic life."[79] Projected onto New Spain, whose vertical prominence he had mapped from coast to coast (Figure 4), this "arrangement of nature" suggested that "in a country as vast and mountainous as Mexico … there is scarcely a plant in the world

[78]Compare Dettelbach (1992).
[79]Güttler (2015); Humboldt (1809–1812, Vol. 3, p. 2).

that could not be cultivated in some part of New Spain." Mining, moreover, would serve as the primary catalyst in the ascent of agriculture to "uninhabited regions of the Cordilleras, and upon isolated, barren plateaus."[80] The concept of vertical correspondence at the heart of Humboldt's global physics did not merely describe nature; it aimed to shape nature, too.

3 | CONCLUSION. RE-ROUTING HUMBOLDT'S SCIENCE

Humboldt's global physics first emerged within a context of vertical travel, up mountains and down into mines and caverns. Rhythms of the body—lethal for some, "sublime" for others—became rhythms of the mind. A way of seeing nature as a set of complementary spaces, inspired by the vertical orientation of hard-rock mining and mountain travel, found expression in a wide range of media, from miners' songs and Romantic art to the science of "subterraneous meteorology."[81]

This wide-angle approach to Humboldt, which re-situates his science amongst miners and mountain-goers, also reveals the multidimensionality of vertical thinking in his time. Passages from the essay on New Spain, for instance, have illustrated how movement through vertical space was, for Humboldt, bound to cameralist-turned-colonial visions of its administration. This brings us back, full circle, to the cartography of Trebra, in which a three-dimensional visualization of the subsoil served extractive ends. Meanwhile, for the poets and painters of the Harz, vertical travel offered communion with God, sublime aesthetic education, and, in Bechtolsheim's case, a language of solace and emancipation. And yet, amid the diverse aspirations that gained expression on the vertical plane, a strikingly consistent logic undergirded this way of moving and thinking. The *Bergglöcklein* said it best: "So often as you go into the depths, | Think up to the heights."

A 19th-century biographer once asked: "in what epoch of history has a man wandered through air and sea and land, over the summits and into the shafts of the mountains [*Gipfel und Schachte der Berge so durchwandert*], like our Alexander von Humboldt?" His patriotic answer was, of course, that "He is the only one!"[82] But Humboldt was just the tip of the *Berg*. To trace the earliest routes of Humboldt's science is to acknowledge the many actors—some celebrated, most unsung—who took part in the making of a vertical consciousness.

ACKNOWLEDGEMENTS

I am extremely grateful for the inspiration and encouragement I received from all participants in the 2019 Verticality Workshop at the Max Planck Institute for the History of Science in Berlin, organized by the issue's co-editors Wilko Graf von Hardenberg and Martin Mahony. The Lichtenberg-Kolleg – Göttingen Institute for Advanced Study generously provided a workspace and academic community that sustained me while developing this article, and I thank Dominik Hünniger for his guidance and friendship during my time there. Financial support for this research was provided by the Fulbright Program and the Social Science Research Council.

ORCID

Patrick Anthony https://orcid.org/0000-0002-0285-2552

REFERENCES

Achermann, D. (2020). Vertical glaciology: A second discovery of the third dimension in climate research. *Centaurus*, *62*(4), 720–743.

[80]Humboldt (1809–1812, Vol. 3, pp. 2, 7–8).

[81]See Dania Achermann's analysis of how the vertical orientation of oil drilling technologies and ice-coring similarly affected epistemic shifts in mid-20th-century climate research: Achermann (2020).

[82]Klencke (1876, pp. 485–486).

Andrews, T. (2008). *Killing for coal: America's deadliest labor war*. Cambridge, MA: Harvard University Press.
Anthony, P. (2018). Mining as the working world of Alexander von Humboldt's plant geography and vertical cartography. *Isis*, *109*(1), 28–55.
Bechtolsheim, J. (2006). Der Sprung von Felsen. *Journal für deutsche Frauen*, *2*, 61–67.
Beck, H. (1958). Alexander von Humboldt's "Essay de Pasigraphie" (Mexiko 1803/04). *Forschungen und Fortschritte*, *32*(2), 33–39.
Benseler, G. E. (1853). *Geschichte Freibergs und seines Bergbaues* (Pt. 2). Freiberg, Germany: J. G. Engelhardt.
Braun, B. (2000). Producing vertical territory: Geology and governmentality in late Victorian Canada. *Ecumene*, *7*(1), 7–46.
Cancrinus, F. L. (1767). *Beschreibung der vorzüglichsten Bergwerke*. Frankfurth an dem Main, Germany: Andreäischen Buchhandlung.
Cañizares-Esguerra, J. (2015). How derivative was Humboldt? Microcosmic nature narratives in early modern Spanish America and the (other) origins of Humboldt's ecological sensibilities. Londa Schiebinger & Claudia Swan In *Colonial botany: Science, commerce, and politics in the early Modern world* (pp. 148–165). Philadelphia, PA: University of Pennsylvania Press.
Cannon, S. F. (1978). *Science in culture: The early Victorian period*. New York, NY: Dawson/Science History Publications.
Cartography Associates. (2000). Tableau physique de la pente Orientale du Plateau de la Nouvelle Espagne Humboldt, Alexander von, 1769–1859, 1807. *David Rumsey Map Collection*. Retrieved from http://www.davidrumsey.com/maps2879.html
Classen, A. (2012). Terra incognita? Mountains in medieval and early modern German literature. In S. Ireton & C. Schaumann (Eds.), *Heights of reflection: Mountains in the German imagination from the middle ages to the twenty-first century* (pp. 20–56). Rochester, NY: Camden House.
Clifford, J. (1997). *Routes: Travel and translation in the late twentieth century*. Cambridge, MA: Harvard University Press.
Coen, D. R. (2012). The tongues of seismology in nineteenth-century Switzerland. *Science in Context*, *25*(1), 73–102.
Cushman, G. T. (2011). Humboldtian science, creole meteorology, and the discovery of human-caused climate change in South America. *Osiris*, *26*, 16–44.
Dening, G. (1994). *Mr Bligh's bad language: Passion, power and theatre on the Bounty* (2nd ed.). Cambridge, England: Cambridge University Press.
Dettelbach, M. S. (1992). *Romanticism and administration: Mining, galvanism and oversight in Alexander von Humboldt's global physics*. (Doctoral thesis, University of Cambridge, Cambridge, England).
Dettelback, M. S. (1999). The face of nature: Precise measurement, mapping, and sensibility in the work of Alexander von Humboldt. *Studies in History and Philosophy of Biological and Biomedical Sciences*, *30*, 473–504.
Echenberg, M. (2017). *Humboldt's Mexico: In the footsteps of the illustrious German scientific traveller*. Montreal, Canada: McGill-Queen's University Press.
Elden, S. (2013). Secure the volume: Vertical geopolitics and the depth of power. *Political Geography*, *34*, 35–51.
Engel, M. (2013). Der Berg- und Hüttenmännische Unterricht in Berlin 1770 bis 1810, die sogenannte Bergakademie. Hartmut Schleiff & Peter Konečný In *Staat, Bergbau und Bergakademie: Montanexperten im 18. und frühen 19. Jahrhundert*, (161–192). Stuttgart, Germany: Steiner.
Engelschalln, J. C. (1723). *Bechreibung der Exulantend- und Bergstadt Johann Georgen Stadt*. Leipzig, Germany: Friedrich Lankisch.
Felten, S. (2018). The history of science and the history of bureaucratic knowledge: Saxon mining, circa 1770. *History of Science*, *56*(4), 403–431.
Franzel, S. (2012). Time and narrative in the Mountain Sublime around 1800. In S. Ireton & C. Schaumann (Eds.), *Heights of reflection: Mountains in the German imagination from the middle ages to the twenty-first century* (pp. 98–115). Rochester, NY: Camden House.
von Goethe, J. W. (1887–1919). *Goethes Werke. Herausgegeben im Auftrage der Großherzogin Sophie von Sachsen* (133 Vols.). Weimar, Germany: Hermann Böhlau.
Gómez, P. F. (2017). *The experiential Caribbean: Creating knowledge and healing in the early modern Atlantic*. Chapel Hill, NC: University of North Carolina Press.
Großheinrich, K. F. (1847). *Sämmtliche Gedichte von Elisabeth Kulmann* (5th ed.). Leipzig, Germany: Wigand.
Güttler, N. (2014). *Das Kosmoskop: Karten und ihre Benutzer in der Pflanzengeographie des 19. Jahrhunderts*. Göttingen, Germany: Wallstein.
Güttler, N. (2015). Drawing the line: Mapping cultivated plants and seeing nature in nineteenth-century plant geography. In D. Phillips & S. Kingsland (Eds.), *New perspectives on the history of life sciences and agriculture*, (27–52). Basel, Switzerland: Springer.
Hamm, E. P. (1997). Knowledge from underground: Leibniz mines the enlightenment. *Earth Sciences History*, *16*(2), 84–91.
Hecht, G. (2012). *Being nuclear: Africans and the global uranium trade*. Cambridge, MA: MIT Press.

Heilfurth, G. (1988). *Neuvermehrtes vollständiges Bergliederbüchlein: Eine buntgemischte Singgut-Sammlung aus Mitteldeutschland um 1700*. Hildesheim, Germany: Georg Olms Verlag.

Heine, H. (2006). The Harz journey. In R. Robertson (Ed.), (Trans., Ed.) *Heinrich Heine: The Harz Journey and Selected prose*, (31–88). New York, NY: Penguin.

Hellawell, P. (2020). "The best and most practical philosophers": Seamen and the authority of experience in early modern science. *History of Science*, *58*(1), 28–50.

Herrmann, W. (1955). *Goethe und Trebra: Freundschaft und Austausch zwischen Weimar und Freiberg. Freiberger Forschungshefte: Kultur und Technik D9*. Berlin, Germany: Akademie-Verlag.

Hudtwalcker, D. R. (1791). *Jahrbücher des Brockens von 1753 bis 1790*. Johann Adam Creutz: Magdeburg, Germany.

Humboldt, A. (1799). *Ueber die unterirdischen Gasarten und die Mittel, ihren Nachtheil zu vermindern: Ein Beytrag zur Physik der praktischen Bergbaukunde*. Braunschweig, Germany: Vieweg.

Humboldt, A. (1809–1812). *Versuch über den politischen Zustand des Königreichs Neu-Spanien* (Vols. 1–3). Tübingen, Germany: Cotta.

Humboldt, A. (1845–1847). *Kosmos. Entwurf einer physischen Weltbeschreibung* (Vols. 1–2). Stuttgart & Tübingen, Germany: Cotta.

Humboldt, A., & Bonpland, A. (2009). *Essay on the geography of plants* (S. T. Jackson, Ed.; S. Romanowski, Trans.). Chicago, IL: University of Chicago Press.

Jahn, I., & Lange, F. G. (1973). *Die Jugendbriefe Alexander von Humboldts, 1787–1799*. Berlin, Germany: Akademie Verlag.

Jugel, J. G. (1773). *Geometria Subterranea, oder Unterirdische Meßkunst der Berg- und Grubengebäude, insgemein die Markscheidekunst genannt*. Leipzig, Germany: J. P. Kraus.

Klein, U. (2012a). Ein Bergrat, zwei Minister und sechs Lehrende, Versuche zur Gründung einer Bergakademie in Berlin um 1700. *NTM*, *18*(4), 437–468.

Klein, U. (2012b). The Prussian mining official Alexander von Humboldt. *Annals of Science*, *69*, 27–68.

Klencke. (1876). *Alexander von Humboldt's Leben und Wirken, Reisen und Wissen. Ein biographisches Denkmal* (7th ed.). Leipzig, Germany: Spamer.

Kraft, T. (2014). *Figuren des Wissens bei Alexander von Humboldt: Essai, Tableau und Atlas im amerikanischen Reisewerk*. Berlin, Germany: De Gruyter.

Krause, O. (2001). Sagenhafter Rammelsberg: Historie, Berggeister und zauberhafte Kräfte in der bergmännischen Erlebniswelt und Volksdichtung. Reinhard Roseneck In *Der Rammelsberg: Tausend Jahre Mensch-Natur-Technik*, (14–33). Goslar, Germany: Verlag Goslarsche Zeitung.

Leitner, U. (2005). *Alexander von Humboldt von Mexiko-Stadt nach Veracruz. Tagebuch. Beiträge zur Alexander-von-Humboldt-Forschung 25*. Berlin, Germany: Akademie Verlag.

Liessmann, W. (2010). *Historischer Bergbau im Harz. Kurzführer* (3rd ed.). Berlin, Germany: Springer.

Livingstone, D. (2003). *Putting science in its place: Geographies of scientific knowledge*. Chicago, IL: University Chicago Press.

Mattes, J. (2015). *Reisen ins Unterirdische: Eine Kulturgeschichte der Höhlenforschung in Österreich bis in die Zwischenkriegszeit*. Vienna, Austria: Böhlau.

Mattes, J. (2020). National spaces and deepest places: Politics and practices of verticality in speleology. *Centaurus*, *62*(4), 670–696.

Matthies, V. (2018). *Im Schatten der Entdecker: Indigene Begleiter europäischer Forschungsreisender*. Berlin, Germany: Ch. Links.

Minerophilo Freibergensi. (1784). *Mineral- und Bergwerks-Lexicon* (3rd ed.). Chemnitz, Germany: Stößel.

Murra, J. V. (1972). El "control vertical" de un máximo de pisos ecológicos en la economie de las sociedades Andinas. Iñigo Ortiz de Zúñiga In *Visita de la provincial de Léon de Huánuco en 1562* (Vol. 1, pp. 427–476). Huánuco, Peru: Universidad Nacional Hermilio Valdizán.

Murra, J. V. (1985). Limits and limitations of the "vertical archipelago" in the Andes. In *Andean ecology and civilization* (pp. 15–20). Tokyo, Japan: University of Tokyo Press.

Nehse, C. E. (1850). *Brocken-Stammbuch mit Scherz und Ernst, Witz und Laune, Weisheit und Einfalt in Gedichten und Prosa vom Mai 1753 bis Mai 1850*. Sondershausen, Germany: Eupel.

Novalis (1837). In L. Tieck & F. Schlegel (Eds.), *Heinrich von Ofterdingen*, Novalis Schriften 1, 5th ed.). Berlin, Germany: Reimer.

Pineda De Ávila, N. (2019, July). *A selenography in New Spain: Colonial strategies for mapping local knowledge*. Paper presented at the Annual History of Science Society Meeting, Utrecht, The Netherlands.

Pratt, M. L. (1992). *Imperial eyes: Travel writing and transculturation*. New York, NY: Routledge.

Reidy, M. S. (2008). *Tides of history: Ocean science and Her Majesty's navy*. Chicago, IL: University of Chicago Press.

Reidy, M. S. (2010). John Tyndall's vertical physics: From rock quarries to icy peaks. *Physics in Perspective*, *12*, 122–145.

Reidy, M. S. (2015). Oceans through islands to mountains: Creating the "correspondence principle.". In J. Gillis & F. Toma (Eds.), *Fluid frontiers: New currents in marine environmental history* (pp. 192–210). Cambridge, England: White Horse Press.

Rudwick, M. (2005). *Bursting the limits of time: The reconstruction of geohistory in the age of revolution*. Chicago, IL: University of Chicago Press.

Rupke, N. A. (1983). The study of fossils in the romantic philosophy of history and nature. *History of Science*, *21*, 389–413.

Schröder, C. F. (1796). *Naturgeschichte und Beschreibung der Baumanns und Bielshöhle. Nebst den Jahrbüchern der Bielshöhle von 1788 bis 1796*. Berlin, Germany: Vieweg.

Scott, H. V. (2008). Colonialism, landscape and the subterranean. *Geography Compass*, *2*(6), 1853–1869.

Serje, M. (2017). The national imagination in New Grenada. In R. Erickson, M. A. Font, & B. Schwartz (Eds.), *Alexander von Humboldt: From the Americas to the Cosmos, 2005* (Revised ed., pp. 83–98). New York, NY: Bildner Center for Western Hemisphere Studies.

Smith, P. H. (2004). *The body of the artisan: Art and experience in the scientific revolution*. Chicago, IL: University of Chicago Press.

Smith, P. H. (2015). Itineraries of materials and knowledge in the early modern world. In *The global lives of things: The material culture of connections in the early modern world*, (31–61). Florence, Italy: Taylor & Francis.

Steiner, G., Leuschner, B., Scheibe, S., Fielder, H., & Popp, K. G. (1958). *Georg Forsters Werke. Sämtliche Schriften, Tagebücher, Briefe. Herausgegeben von der Berlin-Brandenburgischen Akademie der Wissenschaften* (20 Vols.). Berlin, Germany: Akademie Verlag.

Trebra, F. W. H. (1785). *Erfahrungen vom Innern der Gebirge, nach Beobachtungen gesammlet*. Dessau & Leipzig, Germany: Verlagskasse für Gelehrte und Künstler.

Turnbull, D. (1991). *Mapping the world in the mind: An investigation of the unwritten knowledge of the Micronesian navigators*. Geelong, Australia: Deakin University Press.

Turnbull, D. (2000). *Masons, tricksters and cartographers: Comparative studies in the sociology of scientific and indigenous knowledge*. Amsterdam, The Netherlands: Harwood Academic Publishers.

Valencius, C. B. (2013). *The lost history of the New Madrid earthquake*. Chicago, IL: University of Chicago Press.

Vila, P. (1960). Caldas y los orígenes eurocriollos de la geobotánica. *Revista de la Academia Colombiana de Ciencias*, *11*, 16–20.

Vogel, J. (2013). Aufklärung untertage: Wissenswelten des europäischen Bergbaus im ausgehenden 18. und frühen 19. Jahrhundert. In H. Schleiff & P. Konečny (Eds.), *Staat, Bergbau und Bergakademie: Montanexperten im 18. und frühen 19. Jahrhundert* (pp. 13–31). Stuttgart, Germany: Steiner.

Wagenbreth, O., & Wächtler, E. (1986). *Der Freiberger Bergbau. Technische Denkmale und Geschichte*. Leipzig, Germany: Verlag für Grundstoffindustrie.

Warwick, A. C. (1992). Cambridge mathematics and Cavendish physics: Cunningham, Campbell, and Einstein's relativity, 1905–1911. Part I: The uses of theory. *Studies in History and Philosophy of Science*, *23*, 625–656.

Warwick, A. C. (1993). Cambridge mathematics and Cavendish physics: Cunningham, Campbell, and Einstein's relativity, 1905–1911. Part II: Comparing traditions in Cambridge physics. *Studies in History and Philosophy of Science*, *24*, 1–25.

Weizman, E. (2007). *Hollow land: Israel's architecture of occupation*. New York, NY: Verso Books.

Wigen, K. (2005). Discovering the Japanese Alps: Meiji mountaineering and the quest for geographical enlightenment. *The Journal of Japanese Studies*, *31*(1), 1–26.

Wikimedia Commons. (2009, February 17). "File:Caspar David Friedrich—Der Wanderer über dem Nebelmeer.jpg." *Wikimedia Commons*. Retrieved from https://commons.wikimedia.org/wiki/File:Caspar_David_Friedrich_-_Der_Wanderer_%C3%BCber_dem_Nebelmeer.jpg

Zschoche, H. (2008). *Caspar David Friedrich im Harz*. Dresden, Germany: Verlag der Kunst.

How to cite this article: Anthony P. Mines, mountains, and the making of a vertical consciousness in Germany ca. 1800. *Centaurus*. 2020;62:612–630. https://doi.org/10.1111/1600-0498.12337