Natural History and Vertical Thinking in Germany's Underground Enlightenment: Mining as the Working World of Humboldt's Science

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Where is a discovery whose seed was not already sown?

Alexander von Humboldt to Friedrich Heinrich Jacobi

10 January 1792

Alexander von Humboldt (1769–1859) has long been portrayed as the progenitor of a new kind of science, which took shape during his journey through the Americas from 1799 to 1804. Thanks to this "thirty-volume voyage," Charles Darwin dubbed Humboldt "the parent of a grand progeny of scientific travellers."[1] The historian Susan Faye Cannon also had in mind the Americas and the many instruments Humboldt brought there when in 1978 she coined the term "Humboldtian Science," a study of nature that combined instrumentation and quantification with a geographical sensibility.[2] Today the growing body of scholarship on Humboldt portrays him as a paragon of scientific cosmopolitanism: a savant of global vision who re-discovered South America and connected disparate natural systems with isothermal lines and *tableaux physiques* (see figure 1), a Prussian who spent much of his life in Paris and fancied himself "half American," a proto-ecological visionary whose writings animated modern environmentalism.[3]

Humboldt may have been all of these things to a greater or lesser degree. But it is also important to question the extent to which scholarship on Humboldt reflects an image that he

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[1] Mary Louise Pratt, *Imperial Eyes: Travel Writing and Transculturation* (New York, NY: Routledge, 1992), p. 113; Charles Darwin to Joseph Dalton Hooker, 6 Aug. 1881, in F. Darwin, ed., *The Life and Letters of Charles Darwin* (New York, D. Appleton & Co., 1905), II: pp. 422-424.

[2] Susan Faye Cannon, *Science in Culture: The Early Victoria Period* (New York: Dawson and Science History Publications, 1978), p. 75.

[3] Ottmar Ette, "The Scientist as Weltbürger: Alexander von Humboldt and the Beginning of Cosmopolitics," *Northeastern Naturalist,* 8 Special Issue 1: Alexander von Humboldt's Natural History Legacy and Its Relevance for Today (2001): 157-182; Ottmar Ette, *Weltbewußtsein: Alexander von Humboldt und das unvollendete Projekt einer anderen Moderne* (Weilerwist: Velbrück Verlag, 2002); Aaron Sachs, *The Humboldt Current: Nineteenth-Century Exploration and the Roots of American Environmentalism* (New York: Penguin Group, 2006); Laura Dassow Walls, *The Passage to Cosmos: Alexander von Humboldt and the Shaping of America* (Chicago: University of Chicago Press, 2009); Gregory T. Cushman, "Humboldtian Science, Creole Meteorology, and the Discovery of Human-Caused Climate Change in South America," *Osiris* 26, no. 1 (2011): 16-44.

himself promoted *after* his American journey. In Humboldt's writings prior to 1799, by contrast, one finds a young mining official who zealously devoted himself to resource extraction and practiced science in the name of his Prussian "fatherland."[4] Let us think with the historian Denise Phillips, who suggested that "Rather than assuming we know what science is, and searching through history to find places where people are practicing it, we will need to pay attention to how people themselves described the cause that captured their allegiance."[5] The overwhelming emphasis on Humboldt's American journey has marginalized the vital importance of his training at the Mining Academy in Freiberg, Saxony and led to a general neglect of the fervor for practical knowledge and public utility that captured Humboldt's allegiance to science in the 1790s.

Conventional wisdom holds that Humboldt's decision to join the Prussian Mining Department was essentially a compromise. It would enable him to satisfy the demands of his family and noble birth (by earning an income and serving the state) while continuing to pursue the natural sciences on the side. When his mother died in 1796, the story goes, Humboldt received an inheritance large enough to untether him from Prussia and make possible a freer pursuit of science. But as Ursula Klein's pathbreaking studies of Humboldt's early career have demonstrated, mining was not an obligation for Humboldt; it was an opportunity.[6] Humboldt himself knew that service in the Mining Department, far from inhibiting his science, had actually

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[4] Alexander von Humboldt to Georg Christoph Lichtenberg, 22 Feb. 1791, in Alexander von Humboldt, *Die Jugendbriefe Alexander von Humboldts, 1787-1799*, eds. Ilse Jahn and Fritz G. Lange (Berlin: Akademie Verlag, 1973), p. 126.

[5] Denise Phillips, *Acolytes of Nature: Defining Natural Science in Germany, 1770-1850* (Chicago, University of Chicago Press, 2012), 9.

[6] Ursula Klein has provided the first comprehensive study of Humboldt's career as a miner, while at the same time exploring the broader context of technical science that flourished in Prussia at the turn of the nineteenth century. See Ursula Klein, "The Prussian Mining Official Alexander von Humboldt," *Annals of Science* 69, no. 1 (January 2012); Ursula Klein, *Humboldts Preußen. Wissenschaft und Technik im Aufbruch* (Darmstadt, Germany: Wissenschaftliche Buchgesellschaft, 2015).

opened new frontiers for it. As he bragged to one university-based natural philosopher: "Perhaps no one before me has had as many opportunities to observe [subterraneous plants] as I, who in ¾ of a year spent 4 to 5 hours of every day in the mines."[7] Or as elder brother Wilhelm proudly observed, Alexander's "position as *Oberbergmeister* gave him the opportunity to collect a great quantity of interesting observations, better and more reliably than a mere theorist."[8]

This essay builds upon Klein's insights by ranging outside of Prussia geographically and through the American journey temporally. Humboldt's approach to natural history—with its ambitious program of physical movement across countries and up mountains, its attentiveness to variation along nature's vertical axis, and its innovative use of visual representations—may have crystallized in Spanish America, but it took root in a fundamentally different context: the "underground Enlightenment" of central European mining.[9] Mining was, to speak with Jon Agar, the original "working world" of Humboldt's science, the arena of economic activity that prompted questions to which some of his earliest endeavors provided answers. "The power of science," Agar has argued, "lies in its ability to abstract and manipulate representations relevant to working world problems."[10] So it was for Humboldt, whose theorizing about plant geography and innovations in cartography developed in response to the practical imperatives he faced as a Prussian mining official. Industrial concerns about miners' safety led to a study of the interplay

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[7] Humboldt to Georg Christoph Lichtenberg, 21 Apr. 1792, in Humboldt, *Jugendbriefe*, p. 184.
[8] Wilhelm von Humboldt, "Vorrede," in Friedrich Alexander von Humboldt, *Ueber die unterirdischen Gasarten und die Mittel, ihren Nachtheil zu vermindern: Ein Beytrag zur Physik der praktischen Bergbaukunde* (Braunschweig: Friedrich Vieweg, 1799), iii-iv.
[9] Jakob Vogel, "Aufklärung Untertage: Wissenswelten des europäischen Bergbaus im ausgehenden 18. und frühen 19. Jahrhundert," in *Staat, Bergbau und Bergakademie: Montanexperten im 18. und frühen 19. Jahrhundert*, eds. Hartmut Schleiff and Peter Konečny (Stuttgart: Franz Steiner Verlag, 2013). For the Latin American context, see Heidi V. Scott, "Taking the Enlightenment Underground: Mining Spaces and Cartographic Representation in the Late Colonial Andes," *Journal of Latin American Geography* 14, no. 3 (October 2015): 7-34.
[10] Jon Agar, *Science in the Twentieth Century and Beyond* (Cambridge, UK: Polity Press, 2012), p. 7.

between plants and people, and his exposure to technical methods of locating and extracting mineral ore provided him with a cartographic blueprint to follow.

Far more than a biographical revision, this study of Humboldt makes two larger points about the history of science. First, I want to suggest that the kind of vertical mobility made possible by mining fostered new ways of thinking about nature at the turn of the nineteenth century. If, as Michael Reidy has argued, Humboldt's way of thinking ultimately became the cornerstone of a "vertical consciousness that engulfed science in the early nineteenth century," this study shows how Humboldt drew upon and contributed to a pre-existing mode of vertical thinking generated by late eighteenth-century mining.[11] Secondly, on a broader and more theoretical level, this essay brings Humboldt into a family of arguments about the way in which commercial interests shape practice and theory in the history of science. I demonstrate how some of the more conceptual and theoretical aspects of Humboldt's scientific enterprise were shaped by essentially economic concerns about labor and resource extraction.

Accordingly, this essay seeks to engage and unite three strands of historiography—the first concerning Humboldt specifically; the second, the history of science more generally; and the third, the history of mining and cameralism in the German states. For those interested in Humboldt and the development of his science, this study shows the value of what David Livingstone called "spaces of biography."[12] Return Humboldt to the working world of mining and his global scientific enterprise, his "*physique du monde*," appears in a very different and eminently local light.[13] Only in this biographical space is it possible to see how Humboldt's science of plant migration was motivated by the imperatives he faced as *Oberbergmeister* and

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[11] Michael S. Reidy, *Tides of History: Ocean Science and Her Majesty's Navy* (Chicago: University of Chicago Press, 2008), pp. 274-81.
[12] David Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge* (Chicago: University of Chicago, 2003), p. 183.
[13] Humboldt to Marc-Auguste Pictet, 24 Jan. 1796, in Humboldt, *Jugendbriefe*, p. 487.

Bergrat, how Humboldt's pictorial science drew upon a visual culture that thrived at the Mining Academy in Freiberg, or how a pattern of vertical mobility begun "under [Abraham Gottlob] Werner's instructions [to] go daily into various mines" sparked a "*Totalrevolution*" in Humboldt's "way of thinking."[14] Today these things are considered "Humboldtian." In the 1790s, they were "*bergmännisch*"—miner-like.

Understanding Humboldt's way of thinking means returning the cosmopolitan explorer to his original national-industrial context in the cameralist states of central Europe: Saxony, where he was trained as a miner, and Prussian Franconia, where he served as one. It means acknowledging Humboldt as a central figure in what the historian Jakob Vogel has called the *Aufklärung Untertage*, the "underground Enlightenment"—a body of knowledge and set of practices that proliferated through mining academies, societies, and journals.[15] In essence, the underground Enlightenment was a function of central European cameralism, a science aimed at rationally ordering the productive activity of the state. Historian Andre Wakefield has boldly argued that "mining officials were the Ur-cameralists," an administrative elite trained "to dictate every aspect of behavior in and around the mines" and "see the well-ordered mine writ large" when they "turned their attention to the state."[16] Wakefield reminds us that men like Humboldt were administrators by training, and thus that Humboldt's science in the mines was a kind of hybrid administrative-natural science in which increasing state revenue and advancing natural knowledge coalesced in a single enterprise. In this way, my study of Humboldt contributes to a more comprehensive understanding of the German "practical imagination."[17] Though scholars

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[14] Humboldt to Dietrich Ludwig Gustav Karsten, 26 Nov. 1791, in Humboldt, *Jugendbriefe*, pp. 160-62.
[15] Vogel, "Aufklärung Untertage."
[16] Andre Wakefield, *The Disordered Police State: German Cameralism as Science and Practice* (Chicago: The University of Chicago Press, 2009), pp. 27, 141, 31-33.
[17] David. F. Lindenfeld, *The Practical Imagination: The German Sciences of State in the Nineteenth Century* (Chicago: The University of Chicago Press, 1997). In this tradition of scholarship, consider also

have traditionally pointed to terms like *Geist* and *Bildung* as evidence of the peculiar inwardness of German thought at the turn of the nineteenth century, the *Aufklärung* also saw the flowering of eminently practical knowledge, particularly in mining. Humboldt may have lived in the era in which Germaine de Stael famously described Germany as the land of *Dichter und Denker*, poets and thinkers. But, as Humboldt's story reminds us, many of that land's greatest poets and thinkers—from Leibniz to Goethe—were also mining officials.

The result is an image of Humboldt as a figure who fused technical and theoretical sciences—a man of "practical imagination," an *Aufklärer* of the underground. Convinced that he served the common good of his native Prussia, Humboldt wrote that "In an epoch when political and moral circumstances . . . threaten to distance the technical man of science [*den Techniker*] from the theorist [*dem Theoretiker*] there ought to be an effective example of their joining together."[18] By implying that he himself offered one such "effective example," Humboldt in a sense defined his own naturalist-type—one part technical, one part theoretical.[19]

In this essay's three sections, I view Humboldt accordingly, as a figure whose theoretical and conceptual work is informed by industrial concerns and indebted to technical methods. Beginning with Humboldt's journey to England with Georg Forster in 1790 (Sect. I), I trace the

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Theodore Ziolkowski, *German Romanticism and its Institutions* (Princeton, New Jersey: University of Princeton Press, 1990); Frederick C. Beiser, *The Romantic Imperative: The Concept of Early German Romanticism* (Cambridge, MA: Harvard University Press, 2003); David Blackbourn, *The Conquest of Nature: Water, Landscape, and the Making of Modern Germany* (New York: W. W. Norton & Company, 2007); Ursula Klein, *Nützliches Wissen: Die Erfindung der Technikwissenschaften* (Göttingen: Wallstein Verlag, 2016).

[18] Friedrich Alexander von Humboldt, *Ueber die unterirdischen Gasarten und die Mittel, ihren Nachtheil zu vermindern: Ein Beytrag zur Physik der praktischen Bergbaukunde* (Braunschweig: Friedrich Vieweg, 1799), p. 24.

[19] Ursula Klein aptly described the practical scientists of Humboldt's generation as "*Naturforscher-Techniker*," naturalist-technicians who used their "work environment as an experimental field." Klein's category includes a broad range of figures, from mining officials like Carl Abraham Gerhard to chemists like Martin Heinrich Klaproth. (Klein, "The Prussian Mining Official," p. 33; Klein, *Humboldts Preußen*, p. 296.)

continuities between Humboldt's "Forsterian project" and the "subterraneous meteorology" he carried out in the mines of Freiberg, Saxony and Prussian Franconia. I argue that Humboldt's theories about human-plant relationships, first developed in the company of Forster, crystalized in the working world of Prussian mining. Ultimately, these theories became manifest in the more famous *Essai sur la géographie des plantes*, published in 1805. Turning to the visual culture of Humboldt's science (Sect. II), I demonstrate how the cartographic methods Humboldt employed during and after his American journey depended as much on particular drawing practices indebted to the Mining Academy in Freiberg as they did on regular patterns of vertical mobility above and below the surface of the earth. This is the meaning behind Humboldt's 1803 claim to "have seized upon the idea to represent whole countries as a mine."[20] Moreover, the kind of vertical mobility made possible by mining inspired a "vertical consciousness" in German culture, which Humboldt shaped and was shaped by (Sect. III). I conclude by looking at how this essay's arguments erode the integrity of "Humboldtian Science" as an originally Humboldtian invention. The result is an understanding of Humboldtian Science as a collective enterprise shaped by mines, miners, and the working world they composed.

I. "Subterraneous meteorology": the shaping of Humboldt's plant geography

Humboldt began his *Essai sur la géographie des plantes* by telling readers he "conceived of the idea for this work" in his "earliest youth," and "communicated the first draft . . . to the celebrated companion of Cook, M. Georges Forster, in 1790."[21] This section takes 1790, the year of Humboldt's much neglected apprenticeship with Forster, as its starting point. It examines

[20] As quoted in Sandra Rebok, *Alexander von Humboldt und Spanien im 19. Jahrhundert: Analyse eines wechselseitigen Wahrnehmungsprozesses* (Frankfurt am Main: Vervuert Verlag, 2006), p. 167.

[21] Al. de Humboldt et A. Bonpland, *Essai sur la géographie des plantes; accompagné d'un tableau physique des régions équinoxiales* (Paris: 1805), p. vi. Humboldt did not, however, begin the 1807 German edition, *Ideen zu einer Geographie der Pflanzen*, by recalling Forster and the 1790 journey.

Humboldt's "cryptogamatic study," "Forsterian project," and "subterraneous meteorology" to demonstrate how the 1790 journey and, subsequently, the working world of mining were instrumental in shaping his ideas on plant migration. Historians have tended to focus on the way in which Forster, who authored *A Voyage Around the World* in 1777 after participating in James Cook's second circumnavigation of the globe, instilled in his protégé "the art of travel writing"—a "style" of composition and "a poetic spontaneity."[22] But Forster and Humboldt's private writings from the 1790s suggest an affinity more concrete than "style." The two shared a strong interest in human-plant interactions, particularly with respect to cryptogams, a group of plants that included mosses, lichens, and fungi in Linnaean taxonomy. Humboldt's study of cryptogams was not, as one of his first biographers wrote, "a mere preliminary study to his later, comprehensive work"; it was the conceptual core of that later work.[23]

Humboldt's 1790 apprenticeship with Forster (a four-month journey from Mainz, down the Lower Rhine, from Amsterdam to England, and back by way of Paris) was, in essence, a data- and artifact-collecting enterprise.[24] Not only was it Forster's chief aim to procure "in the cabinets of Holland and London" artifacts for a "new anthropology," but he and Humboldt also sought to understand the ways in which "climate, mixing with neighboring races, commerce and

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[22] Georg Forster, *A Voyage Around the World*, eds. Nicholas Thomas and Oliver Berghof (Honolulu: University of Hawai'i Press, 2000); Hanno Beck, "Georg Forster und Alexander von Humboldt: Zur Polarität ihres geographischen Denkens," in *Der Weltumsegler und seine Freunde: Georg Forster als gesellschaftlicher Schriftsteller der Goethezeit*, ed. Detlef Rasmussen (Tübingen: Gunter Narr Verlag, 1988), p. 177; Donald McCrory, *Nature's Interpreter: The Life and Times of Alexander von Humboldt* (Cambridge, UK: The Lutterworth Press, 2010), p. 166; Albert Leitzmann, *Georg und Theresa Forster und die Brüder Humboldt: Urkunden und Umrisse von Albert Leizmann* (Bonn: Verlag Ludwig Röhrscheid, 1936), p. 187; Ludwig Uhlig, *Georg Forster: Lebensabenteuer eines gelehrten Weltbürgers* (Göttingen: Vandenhoeck & Ruprecht, 2004), p. 39; McCrory, *Nature's Interpreter*, p. 65.

[23] Karl Bruhns, *Alexander von Humboldt. Eine Wissenschaftliche Biographie. In drei Bänden. Erster Band* (Leipzig: F. A. Brockhaus, 1872), p. 132.

[24] On the 1790 journey more generally, see Bruhns, *Alexander von Humboldt. Erster Band*, pp. 98-108 and Thomas P. Saine, *Georg Forster* (New York, Twayne Publishers, 1972), pp. 93-125. and Thomas P. Saine, *Georg Forster* (New York, Twayne Publishers, 1972), pp. 93-125.

trade, and the influence of the soil and its products" affects a population's "physical and moral *Bildung*."[25] The "most instructive" part of the journey, Humboldt and Forster both wrote, was when they "penetrated the vast subterranean" on what Humboldt described as a "mineralogical tour to the *Peak of Derbyshire*" in England.[26] What survives of Humboldt's journals and correspondence reveal the "mineralogical tour" as a vital moment in the formation of his ideas on the relationship between plant migration and human activity. Forster's notes, which formed the basis of his travel narrative *Views of the Lower Rhine*, colored the tour in a Romantic light. Under his pen "thousand-year-old mosses growing atop the peaks" illustrated the "architecture of Nature," and the "three old women" who led them by torchlight into Poole's Hole, a natural limestone cavern, were none other than the witches of *Macbeth*.[27] Humboldt, too, was moved by the cavern's lore, enshrined in stalagmites like "the Flitch of Bacon and the Queen of Scotts pillar." But he was still more captivated by the plants flourishing in and around the grotto's entrance, especially cryptogams like the "*L*[*ichen*]. *saxat*[*il*], which is borne by every one of our trees, pickets, and posts."[28]

Throughout the 1790s, Humboldt understood his science as part of a larger social program—a sentiment perfectly in keeping with the spirit of natural history in the late

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[25] Georg Forster to Theresa Forster, 1-2 Apr. 1790, in Georg Forster, *Georg Forsters Werke, Sämtliche Schriften, Tagebücher, Briefe, Sechzehnter Band: Briefe 1790 bis 1791*, eds. Brigitte Leuschner and Siegfried Scheibe (Berlin: Akademie Verlag, 1980), p. 49; Forster to Christian Gottfried Körner, 25 Nov. 1789, in Georg Forster, *Georg Forsters Werke, sämtliche Schriften, Tagebücher, Briefe, fünfzehnter Band: Briefe 1787 bis 1789*, ed. Horst Fiedler (Berlin: Akademie Verlag, 1981), pp. 376-77.
[26] Forster to Johannes Müller, 12 July 1790 in Forster, *Werke, sechzehnter Band*, p. 156; Humboldt to Jacobi, 3 Jan. 1791, in Humboldt, *Jugendbriefe,* p. 117.
[27] 12 June 1790, in Georg Forster, *Georg Forsters Werke: Sämtliche Schriften, Tagebücher, Briefe: Tagebücher*, ed. Brigitte Leuschner (Akademie Verlag: Berlin, 1973), pp. 336-38.
[28] Alexander von Humboldt, "Tagesbuch Beilagen," in Karl Bruhns, *Alexander von Humboldt: eine Wissenschaftliche Biographie, erster Band* (Leipzig: F. A. Brockhaus, 1872), p. 291. Bruhns cites this as "Aus der von Radowitz'schen Autographensammlung, Nr. 6255, in der königlishen Bibliothek zu Berlin."

Enlightenment and early Romantic periods.[29] Thus, the same spirit of public utility that would undergird Humboldt's endeavors as a miner was equally palpable in his earlier botanical studies. "To a great many enthusiasts," Humboldt observed in his introduction to a 1789 botanical treatise by Göttingen medical student Steven van Geuns,

> the study of the utility of plants appears promising to a degree that corresponds with the general needs of men. The rise in population, the political relations of the states—everything stimulates us to make use of the natural treasures of our soil. And yet there are only a few statesmen [*Politiker*] who recognize the worth of these treasures, only a very few who have dreamt of such a thing as precious dye materials [*Farbenmaterial*] hidden among the sordid lichens.[30]

Natural resources were, for Humboldt, "natural treasures," and a reverence for nature was entirely consistent with its exploitation. Having taken an interest in cryptogams while botanizing with Carl Ludwig Wildenow in the Berlin Tiergarten in 1789, Humboldt linked cryptogams and political economy—plants and states—in England in 1790.[31] "The cryptogamatic study [*das kryptogamatische Studium*]," Humboldt noted in his journal, "is not so insignificant as one is accustomed to believing." Rather, "in a good political economy, stone mosses will contribute to national prosperity." He referred here to Europe's long history of extracting dyes (or "litmus") from lichens like the above-named *parmelia saxatilis*. Fifteen years later, in the *Essai sur la géographie des plantes*, Humboldt would again list cryptogams among "the factors that link the geography of plants to the political and intellectual history of mankind."[32]

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[29] Klein, *Nützliches Wissen*; Keith Thomas, *Man and the Natural World: Changing Attitudes in England, 1500-1800* (New York: Oxford University Press, 1996 [1983]), esp. pp. 69-70; Beiser, *The Romantic Imperative*.

[30] [Alexander von Humboldt], "Einleitung zur Steven van Geuns *Verhandeling over de inlandische Plantgvvassen*," *Magazin für Botanik*, Bd. 4 (1790): 150-151.

[31] Klein, *Humboldts Preußen*, p. 13.

[32] Humboldt, "Tagesbuch Beilagen," p. 291. Alexander von Humboldt and Aimé Bonpland, *Essay on the Geography of Plants*, ed. Stephen T. Jackson, trans. Sylvie Romanowski (Chicago: University of Chicago Press, 2009), pp. 72-73. On the history of lichen dyes, see Alexander Tilloch, *The Philosophical Magazine: Comprehending the Various Branches of Science, the Liberal and Fine Arts, Agriculture,*

The most immediate consequence of the journey to England was that it spurred Humboldt to "study geognosy and the history of cultivation together with botany," as he wrote to the botanist Paul Usteri in 1791.[33] This desire to study the sciences of earth and life in connection with human activity ultimately led Humboldt to the Mining Academy in Freiberg. Coerced by his mother to attend the Commercial Academy in Hamburg, however, Humboldt left the "happy island" of England "with a heavy heart." "Botany does not evade me," he wrote Usteri from London in June 1790, "but I endlessly evade this venerable study of nature!"[34] And yet, writing from Hamburg in December, Humboldt told Johann Reinhold Forster (Georg's father) "I have designated ["mineralogy"] a matter of necessity for my future."[35] Humboldt's resolution was to do both. And so he wrote two letters to Werner, applying, as it were, to the Mining Academy. In the first, Humboldt told Werner he had done "for mineralogy what Linnaeus did for botany," and attached his recently published and first book, an explicitly Wernerian analysis of Rhenish basalts.[36] In the second letter, having elsewhere noted how "Forster's name provided [him] entrance everywhere" in 1790, Humboldt pointed to his "journey to the *Peak* of *Derbyshire* (in the company of your friend, *George Forster*)" as the animating force behind his "zeal" for geognosy. Entry was provided, and from June 1791 to February 1792 Humboldt continued his "cryptogamatic study" in Freiberg.[37]

About twenty kilometers southwest of the Saxon capital Dresden, Freiberg had been the epicenter of central European mining, metallurgy, and mineralogy since the twelfth century. An

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Manufactures, and Commerce, *Volume Two* (London, 1798), pp. 319-326 and D. H. S. Richardson, *The vanishing lichens: their history, biology, and importance* (New York: Hafner Press, 1975).
[33] Humboldt to Usteri, Herbst? 1791, in Humboldt, *Jugendbriefe,* p. 163.
[34] Humboldt to Usteri, 27 June 1791, in Humboldt, *Jugendbriefe,* p. 95-97.
[35] Humboldt to Johann Reinhold Forster, 24 Sept. 1791, in Humboldt, *Jugendbriefe,* p. 108.
[36] Humboldt to Werner, 25 July 1791, in Humboldt, *Jugendbriefe,* p. 99-100. See Alexander von Humboldt, *Mineralogische Beobachtungen über einige Basalte am Rhein* (Braunschweig: Schulbuchhandlung, 1790).
[37] Humboldt to Werner, 12 Dec. 1791, in Humboldt, *Jugendbriefe,* p. 112.

1802 account of the city from the French engineer Jean-François d'Aubuisson de Voisins (which Humboldt marked up and stored away in a folder of notes on mines around 1820) is telling of the dangers lurking in Freiberg's subterranean spaces.[38] "Due to the decomposition of stagnant water [and] the putrefaction of wooden framing," d'Aubuisson observed, "subterraneous vegetation still contributes to the deterioration of mine air." After noting that such phenomena could cause asphyxiation, d'Aubuisson assured readers that "accidents are unknown in the mines of Freiberg."[39] A decade earlier, when Humboldt arrived in Freiberg, such accidents were all too well known. And it was Humboldt who identified the culprit.

As a student at Freiberg, and subsequently as a mining official in Prussian Franconia, Humboldt continued to study cryptogams in connection with political economy, now homing in on their harmful effects on human respiration and thus on economic yield. As such, Humboldt had unequalled access to "the most exquisite fungi and lichen from depths of 900 to 1,000 feet and an entire subterraneous creation of animals [*Thierschöpfung*]."[40]

It is within this industrial context that Humboldt first uttered his now-iconic dictum "plants . . . follow peoples." In autumn 1791, Humboldt explained to Usteri how his study of mining was particularly significant for his "Forsterian project, which requires one to seek out sunken [*untergegangene*] vegetation . . . in the mines." Although in this sentence "sunken vegetation" meant coal deposits, the "Forsterian project" also included the migration of living plants, and cryptogams in particular. Humboldt then sketched out the core concept of a work that

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[38] SBB-PK IIIA Nachl. Alexander von Humboldt, gr. Kasten 5, Nr. 39. Here Humboldt stored excerpts from an 1820 *Annales de Chimie et Physique Tome XIII*, which re-printed parts of Daubuisson's 1802 work under the title "Observatiosn faites par M. Daubuisson dans les mines de Freyberg." Judging from the marginalia, it appears Humboldt was most interested in the relationship between temperature and depth.

[39] J. F. Daubuison, *Des mines de Freiberg en Saxe et de leur Exploitation* (Leipsic: Pierre Phil. Wolf et comp., 1802), pp. 259-60.

[40] Humboldt to Lichtenberg, 21 Apr. 1792 in Humboldt, *Jugendbriefe,* p. 184.

would have taken him "20 to 30 years" to complete had Forster not "already incorporated [him] into his own illustration of this neglected part of universal history." Together, mentor and protégé envisioned "a history of plant migration" that included "a map of socially living plants [*gesellschaftlich lebenden Pflanzen*]." In Humboldt's words, it was to illustrate how "Europe became inundated with Caucasian plants" when "Arabs, Greeks, Persians, and especially the Vandals and Goths" spread across the continent.[41] It was around this time, however, that Forster disappeared from Humboldt's life, taking a leading role in the founding of the Mainz Republic in 1793 and ultimately dying in Paris in 1794. Undeterred, Humboldt made the "Forsterian project" his own, recording the discovery of "18 new *species*" of subterranean plants. Among them was "the largest *Cryptogamatic* plant known to date, 4–6 feet in breadth. I call it *Usnea verticillata*," Humboldt proudly wrote.[42] In 1792, Humboldt turned these findings into a dissertation, published in 1793 as a taxonomic monograph under the title *Florae Fribergensis specimen*, *plantas cryptogamicas praesertim subterraneas exhibens*. Humboldt's second book, the *Florae Fribergensis* classified 258 cryptogams in the Linnaean System, including the *Lichen saxatilis* he had collected with Forster in Derbyshire.[43] Over the next six years, his cryptogamatic study would fuse cutting edge instrumentation with industrial and humanitarian impulses to improve the air-quality of mines.

The backdrop of Humboldt's "Forsterian project" and his inquiry into the curiously green color of subterranean flora was Antoine Laurent de Lavoisier's self-proclaimed revolution in Chemistry. In the eighteenth century the phlogiston theory of combustion held sway among most

[41] Humboldt to Usteri, Autumn? 1791, in Humboldt, *Jugendbriefe,* pp. 163-64.
[42] Humboldt to Dietrich Ludwig Gustav Karsten, 26 Nov. 1791, in Humboldt, *Jugendbriefe,* p. 159-61.
[43] Fredericus Alexander ab. Humboldt, *Florae Fribergensis Specimen. Plantas Cryptogamicas Praesertim Subterraneas Exhibens* (Berlin: Heinrich August Rottmann, 1793); Wolfgang-Hagen Hein, "Notizen zur Humboldt-Chronologie aus seiner 'Flora Fribergensis'," *Sudhoffs Archiv* Bd. 81, H. 1 (1997): 120-123, on p. 121.

men of science. Phlogiston, from the Greek word for "inflammable," was thought to be an imponderable, subtle fluid, which is lost when a substance burns. In the 1770s, the English practitioner of "pneumatick chemistry," Joseph Priestley, conducted a series of experiments submerging candles, mice, and plants in different "airs" under bell jars. His conclusion was that "phlogisticated air" (or "fixed air") was produced by both combustion and respiration. On the other hand, he found that plants, unlike mice, could "restore" the air and render it "fit for sustaining flame [and] for breathing again." This type of air Priestley called "dephlogisticated air," and Lavoisier later called "oxygen." Lavoisier's revolution in nomenclature thus replaced a theory of phlogiston, a substance that is *lost* during combustion, with one of oxygen, which is *gained* during combustion.[44]

I interpret Humboldt's study of the "corruption" of mine air as a Priestleyan program steeped in Lavoisian nomenclature.[45] In 1791, Humboldt was indeed a self-proclaimed Lavoisian, convinced that his "discoveries of carbon and carbon dioxide have forged the path to great things." Having been "occupied with antiphlogistic works" since his acquaintance with the English chemist Henry Cavendish in 1790, Humboldt now studied alongside Andrés Manuel del

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[44] Joseph Priestley, *Experiments and Observations on Different Kinds of Air and Other Branches of Natural Philosophy, Connected with the Subject: Being the Former Six Volumes Abridged and Methodized, with Many Additions* (Birmingham, England: J. Thompson, 1790), pp. 255-56; Jan Golinski, *Science as Public Culture: Chemistry and Enlightenment in Britain, 1760–1820* (New York, NY: Cambridge University Press, 1992), esp. pp. 77-78, 130-55; Steven Johnson, *The Invention of Air: A Story of Science, Faith, Revolution, and the Birth of America* (New York: Riverhead Books, 2008), 77-109.

[45] My evidence here substantiates Ursula Klein's claim that Humboldt "was able to move seamlessly back and forth between these two theoretical systems." This mobility shows how the nomenclatures of Priestley and Lavoisier were not "incommensurable" paradigms for Humboldt, but equally viable—and not necessarily mutually exclusive—approaches to the same questions. (Klein, "The Prussian Mining Official," p. 57. See also Frederic L. Holmes, "The 'Revolution in Chemistry and Physics': Overthrow of a Reigning Paradigm or Competition between Contemporary Research Programs?" *Isis* 91, no. 4 (Dec. 2000): 735-753).

Río Fernández, once a student of Lavoisier.[46] But in spite of his anti-phlogiston professions, Humboldt positioned himself between the Priestleyan and Lavoisian nomenclatures in his experiments on the green flora of the underground. The conventional wisdom of the time was that of Aristotle, who in *De Coloribus* wrote: "where Water and sunbeams act together, there emerges a green color; where Earth and Water alone operate, there emerges a white color—and thus all plants under the earth, roots, onions, stalks &c. appear white."[47] After cultivating gardens at various depths in the mines, and seeing that the plants "often do not lose their leaves, & grow again as *green* as before," Humboldt agreed with the "discoveries, which Messrs. Ingen-Housz, Senebier & Priestl[e]y have made on the physiology of vegetables." Importantly, though, he concurred in the language of Lavoisier. For "Oxygen," Humboldt surmised, "entices the plant to breathe." Humboldt was convinced that "the nitrogen and hydrogen, which corrupt [*empestée*] the atmosphere of our mines, generally act on subterraneous vegetation, as light acts on those found on the surface of the earth."[48]

That Humboldt, a Lavoisian chemist, practiced a Priestleyan program is revealing of how he worked in a tradition that valued practicality as much as precision. A friend of Franklin and

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[46] Humboldt to Dietrich Ludwig Gustav Karsten, 26 Nov. 1791, in Humboldt, *Jugendbriefe,* pp. 159-60; Humboldt to Usteri, 10 Jan. 1791, in Humboldt, *Jugendbriefe,* p. 165. In 1851, Humboldt fondly recalled the time when in 1790 "Georg Forster led me into that distant world [*Vorwelt*] of Sir Joseph Banks, Cavendish, and William Herschel." Banks and Cavendish each took a strong liking to Humboldt, allowing him to study in their respective libraries. Cavendish's one condition was that the twenty-one-year old silently exit so soon as Cavendish entered. That Forster ushered Humboldt into this elite intellectual "*Vorwelt*" provides yet another example of how he influenced Humboldt in ways far more concrete than a mere "style." (Leitzman, *Georg und Theresa Forster und die Brüder Humboldt*, p. 164.)

[47] Humboldt also appears to have projected Priestley's theory of airs into Aristotle's theory of color. Quoting Aristotle, Humboldt noted that "[t]here are, after the teachings of the Greeks, three primary colors, white, blacks, and yellow. They arise from the Elements. Air, Water, and Earth are white; Fire (Phlogiston, and sunbeams, too) is yellow; black is an absence of light." (Humboldt to Jacobi, 10 Jan. 1792, in Humboldt, *Jugendbriefe,* p. 117.)

[48] Humboldt to Jean-Claude de Lamétherie, 10 Jan. 1792, in Humboldt, *Jugendbriefe,* p. 165; Humboldt to Lorenz von Crell, early 1792, in Humboldt, *Jugendbriefe,* p. 169. These experiments on the color of subterranean flora culminated in Humboldt's book, *Aphorismen aus der chemischen Physiologie der Pflanzen*, trans. Gotthelf Fischer von Waldheim (Leipzig: Voss und Compagnie, 1794).

the American Revolution, Priestley consciously charged his chemistry with the populist impulses and reforming ethic of the radical Enlightenment. Indeed he believed that "the English hierarchy, if there be anything unsound in its constitution, has reason to tremble even at an air-pump or an electrical machine."[49] This comment exhibits Priestley's unbridled faith in reason as the catalyst of social progress—his belief that by measuring the virtue of airs, pneumatick chemistry could effect social reformation.[50] "Air receives, in a great measure, the very same *kind* of injury from flame, as from respiration," Priestley wrote.[51] In pneumatic chemistry, this "*kind* of injury" was called "vitiation," a term for which Humboldt used the German "*Verderbniss*" or the French "*empestement*." Yet Priestley also found that "every individual plant is serviceable to mankind" in so far as it restores to the air a respirable quality.[52] Employing the eudiometer (a glass tube fashioned to detect changes in gas volume) practitioners of pneumatick chemistry like John Pringle believed they could locate "dangerous miasmata [that] emanated from marshes" and, with such knowledge, gain control over the "goodness" of air.[53] Humboldt fits squarely in this tradition. After developing his own eudiometer in 1796, Humboldt (now *Bergrat*, or Chief Mining Councilor, of the principalities of Bayreuth and Ansbach) began to assail the problem of the vitiation of mine air, which had long wreaked havoc on miners' lungs and Prussian profits.

This aspect of Humboldt's underground science is also telling of how he came to view the body itself as an instrument. After attempting to summit Mt. Chimborazo in 1802, Humboldt wrote that his body had served as "a kind of gauge" for measuring atmospheric rarefaction at

[49] As quoted in Peter J. Bowler and Iwan Rhys Morus, *Making Modern Science: A Historical Survey* (Chicago: The University of Chicago Press, 2005), p. 64.
[50] As quoted in Ibid., p. 66.
[51] As quoted in Holmes, "The 'Revolution in Chemistry and Physics'," p. 746.
[52] Priestley, *Experiments and Observations on Different Kinds of Air*, p. 256.
[53] As quoted in Golinski, *Science as Public Culture*, p. 120.

high altitude.[54] It was not on mountains, however, but in mines that Humboldt learned to employ his own and others' respiratory systems to register the effects of various types of air. In 1796, Humboldt wrote that he himself "nearly became the victim of [his] own experiment," and had to be "dragged out" of a mine by his miner-assistants after falling unconscious.[55] Ursula Klein has argued that Humboldt illuminates "the persona of [the] savant-technician," one who utilizes one's workspace to perform scientific experiments.[56] I would add that the "savant-technician" cannot be understood apart from the "invisible technicians"—common miners—who made that workspace and those experiments possible.[57] What is more, miners also served as living eudiometers in Humboldt's cryptogamatic study, experimental organisms whose respiration he incorporated into his scientific program, and who, on at least one occasion, kept him breathing, too.

By 1799, this study had taken the form of a book titled *On subterraneous species of gas, and the means of mitigating their harmful effects*. Here Humboldt made practicality and verticality the pillars of a science he called "subterraneous meteorology." Aside from purporting "a new theory of mine airs," the book argued that "the glory of the sciences" ought to be determined by the extent to which they have "a more or less direct influence upon the industry [*Gewerbe*] of men." And after dismissing the trivial pursuits of natural philosophers "busy replicating instruments" and miners incessantly "modifying the shape of a barrel, sledge, or shovel," Humboldt laid out own ambitions:

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[54] As quoted in Livingstone, *Putting Science in its Place*, p. 75.
[55] Humboldt to Carl Freiesleben, 18 Oct. 1796, in Humboldt, *Jugendbriefe*, p. 532.
[56] Klein, "The Prussian Mining Official," pp. 31-32.
[57] Steven Shapin, "The Invisible Technician," *American Scientist* 77, no. 6 (1989): 554-563. On miners as invisible technicians, see Martin J. S. Rudwick, *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution* (Chicago: The University of Chicago Press, 2005), p. 33 and Warren Alexander Dym, *Divining Science: Treasure Hunting and Earth Science in Early Modern Germany* (Boston: Brill, 2011), pp. 12-13.

> My wish . . . is to bring to the attention of practicing *Physiker* an exceptionally significant field, namely, the culture, life, and prosperity of one of the most valuable and industrious classes of men; I wish to draw downwards what *Deluc*, *Saussure* and *Lichtenberg* have drawn up toward the region of the clouds. Nature knows no over- and underground. All that is contained in fluid elements is counteractive, *mixed*. No sooner does the miner begin his underground work . . . than he confronts the daunting afflictions caused by a shortage of respirable air.[58]

What did the natural philosophers Jean-André Deluc, Horace-Bénédict de Saussure, and Georg Christoph Lichtenberg draw up toward the clouds? I would suggest instrumentation and vertical thinking—an effort to measure and quantify variation along nature's vertical axis. Deluc, for instance, published an account of "Barometrical observations on the depth of the mines in the Hartz" in 1777, employing in mines a method he had proven useful on mountains.[59] Humboldt effectively made this approach his own.

Humboldt's keen eye for the causes and consequences of plant migration above ground revealed to him the irony that the plants for which miners had inadvertently established subterranean habitats needed to be eradicated in order to preserve human presence in those very habitats. In other words, the aim of his "subterraneous meteorology" was to facilitate the extraction of one natural resource by exterminating another. His eudiometric experiments led him to conclude that subterranean cryptogams contribute to the vitiation of the air in two ways: first, by decomposing water, and secondly, by absorbing oxygen from the air without replenishing it. "Whereas the green plants in sunlight exhale life-air [*Lebensluft*], thereby contributing to the enhancement of the atmosphere above ground, we find the opposite is true for subterraneous plants, which grow in mines." The primary cause of vitiation, Humboldt believed, was a particularly resilient "white fungus" that absorbed and decomposed water by

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[58] Humboldt, *Ueber die unterirdischen Gasarten*, pp. 24-26.
[59] Jean André de Luc, *Barometrical Observations on the Depth of the Mines in the Hartz. By John Andrew de Luc* [...] *Read at the Royal Society, March 20, 1777* (London: W. Bowyer and J. Nichols, 1777).

“assimilating” oxygen and exhaling “carbonized hydrogen.” “Because they know no alteration in year- and day-time,” Humboldt explained, “they enjoy an everlasting spring night, and so it is not difficult understand how these curious plant genera so quickly make their atmosphere irrespirable through an uninterrupted operation.” Thus, he called upon miners to “strenuously endeavor to eradicate” all cryptogams.[60]

Humboldt’s “cryptogamatic study,” “Forsterian project,” and “subterraneous meteorology” provided the conceptual basis for his more famous *Essai sur la géographie des plantes*. Humboldt began the *Essai* by defining the geography of plants as a “science that concerns itself with plants in their local association in the various climates . . . from the regions of perpetual snows to the bottom of the ocean, and into the very interior of the earth, where there subsist in obscure caves some cryptogams that are as little known as the insects feeding upon them.” Cryptogams then figure centrally in Humboldt’s argument for two types of correspondence in botanical geography: the first, between high elevation and low latitude (mountaintops and poles), and the second, between high elevation and deep subterranean (mountaintops and mines). “The opposite limits of plant life,” Humboldt believed, “produce beings with a similar structure and a physiology equally unknown to us.” For “the rocky and icy peaks above the clouds . . . are covered only with mosses and lichenous plants,” just as “cryptogams, sometimes pale, sometimes colorful, branch out on the roofs of mines and underground caves.”[61]

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[60] Humboldt, *Ueber die unterirdischen Gasarten*, pp. 160, 201, 233. Humboldt’s call for the extermination of plants and his Romantic nature-loving sensibility were not mutually exclusive. Consider how both he and Carl Freiesleben were awed by the bioluminescent quality of the very “white fungus” whose extermination they called for. As Freiesleben wrote, they had the effect of transforming the shaft into a “magic castle [*Zauberschloss*]” bathed in “faint moonlight.” (J. C. Freiesleben, “Lichterscheinungen. I. Leuchten der Rhizomorphen,” *Journal der Chemie & Physik* 44 (1825): 65-73.)
[61] Humboldt, *Essay on the Geography of Plants*, pp. 64-65.

Alongside Humboldt's argument for correspondence in botanical geography was his thesis on "social plants" and plant migration. What Humboldt described as "socially living plants" in 1791, he now defined as plants that "live in an organized society…and occupy immense terrains," such as lichens, mosses, and strawberries. But the strongest line of continuity between Freiberg and the *Essai* lies in the relationship between plant migration and human activity. In 1791, recall, Humboldt told Usteri about his idea for a history of plant migration that demonstrated how "plants assuredly follow peoples," and more particularly how "Europe became inundated with Caucasian plants." Humboldt's argument in the *Essai* is strikingly similar. "The Greeks took with them vines, the Romans, wheat, and the Arabs, cotton," Humboldt wrote, explaining how the Persian walnut and peach trees, the Armenian apricot tree, and the Syrian fig, pear, pomegranate, olive, plum, and mulberry trees spread across Europe. Humboldt's conclusion, even after five years of botanizing in the Americas, was unchanged: "Winds, currents, and birds are not the only ones that help plants migrate," he wrote, "the primary factor is man."[62]

II. "To represent whole countries as a mine": the shaping of Humboldt's cartography

"I have seized upon the idea to represent whole countries as a mine," Humboldt proclaimed in 1803, reflecting in 1809: "The Mexican Atlas contains a series of vertical cross-sections or geognostic profiles. I have sought to represent whole countries after a method, which, until now, has only been applied in mining and canal projects."[63] These quotations are the explananda of this section, and the explanans is twofold. First, I suggest that the "vertical

[62] Humboldt, *Essay on the Geography of Plants*, p. 65; Humboldt to Usteri, Autumn? 1791, in Humboldt, *Jugendbriefe,* pp. 163-64; Humboldt, *Essay on the Geography of Plants*, p. 70.
[63] As quoted in Rebok, *Alexander von Humboldt und Spanien im 19. Jahrhundert*, p. 167; Alexander von Humboldt, *Versuch über den politischen Zustand des Königreichs Neu-Spanien* (Tübingen: J. G. Gotta'schen Buchhandlung, 1809), p. 43.

projections" Humboldt had in mind in 1803 and 1809 (figures 5 and 6) are best understood as variations on a theme by German miners and surveyors.[64] In the eighteenth century, mining encouraged new forms of cartography, like the geognostic profile map—a vertical cross-section depicting mineralogical information (see figure 2). In turn, the profile encouraged among miners and surveyors both three-dimensional and vertical thinking.[65] And this is precisely the kind of map Humboldt was trained to make and make use of as a mining official. The second argument in this section is that Humboldt's cartographic methods were equally dependent upon patterns of vertical mobility above and below the surface of the earth. Indeed, this ascent-descent rhythm marks one of the most continuous red threads in Humboldt's practice between 1791 and 1804. Humboldt's vertical cartography thus combined two types of practice: drawing and mobility. And both were rooted in his training and experience as a miner.

Humboldt's maps and *tableaux* have traditionally been viewed in the pedigree of the French Enlightenment, if not as direct descendants of maps made by Charles Marie de La Condamine, whom one scholar called a "Humboldtian scientist *avant la lettre*." Referring to the "Tableau physique des Andes" (figure 1) the same scholar wrote "It is as if Humboldt looked at the correctly scaled representation of Chimborazo, zoomed in on two of La Condamine's tiny mountains, and blew them up to large proportions."[66] Meanwhile, revisionist scholars have argued for the "other" Latin American origins of Humboldt's cartography. While David Y. Allen has highlighted affinities between Humboldt's relief maps and those of Mexican cartographer

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64 Humboldt, *Versuch über den politischen Zustand des Königreichs Neu-Spanien*, p. iii.
65 Rudwick, *Bursting the Limits of Time*, p. 87.
66 Sylvie Romanowski, "Humboldt's Pictorial Science: An Analysis of the *Tableau physique des Andes et pays voisins*," in Alexander von Humboldt and Aimé Bonpland, *Essay on the Geography of Plants*, ed. Stephen T. Jackson, trans. Sylvie Romanowski (Chicago: The University of Chicago Press, 2009), pp. 176-77.

José Antonio de Alzate y Ramírez, Jorge Cañizares-Esguerra traced Humboldt's "Tableau physique des Andes" to the work of Columbian naturalist José de Caldas.[67]

I do not deny the significance of Humboldt's admiration for La Condamine, who had himself traveled to South America between 1735 and 1745. Nor would I dismiss the admirable decentering impulse behind scholarship that shows how Humboldt's science was also shaped by non-Europeans. But my approach seeks to move beyond the recognition of visual affinities to the identification of shared practices. The "Tableau physique des Andes," first sketched February 1803, was not, as some have supposed, "Humboldt's first large-scale illustration."[68] This is to ignore the "geognostic profiles" Humboldt claimed to have drawn "on the spot [in Latin America] in 1802 and 1803," along with those he had been drafting since the beginning of his practical education in Freiberg in June 1791.[69]

The historian Rachel Laudan has argued that "Before Humboldt's campaign for accurate measurement in the early nineteenth century, no heights had been measured with any precision. Scales and conventions varied from one map to another."[70] The depths of mines, like the depths of waters, had however been subjected to such a campaign for accurate measurement. And if Humboldt's approach to mountains was novel in this regard, it was because he learned to see them as mines, appropriating underground conventions to suit overground landscapes. It is widely recognized that Humboldt infused natural history with a new visual culture with his

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[67] Jorge Cañizares-Esguerra, "How Derivative Was Humboldt? Microcosmic Nature Narratives in Early Modern Spanish America and the (Other) Origins of Humboldt's Ecological Sensibilities," in *Colonial Botany: Science, Commerce, and Politics in the Early Modern World*, eds. Londa Schiebinger and Claudia Swan (Philadelphia: University of Pennsylvania Press, 2005), p. 152; David Y. Allen, "Alexander von Humboldt and the Mapping of Mexico," *E-Perimetron* 9, no. 2 (2014): 78-96.
[68] Romanowski, "Humboldt's Pictorial Science," p. 177.
[69] Alexandre de Humboldt, *A Geognostical Essay on the Superposition of Rocks; in both Hemispheres* (London: A. & R. Spottiswoode, New-Street-Square, 1823), p. 177.
[70] Rachel Laudan, *From Mineralogy to Geology: The Foundations of a Science, 1650-1830* (Chicago: The University of Chicago Press, 1987), p. 163.

innovative *tableaux physiques*. But Humboldt did this by drawing upon the visual culture in which he was trained and practiced.[71] On a still broader scale, moreover, it is important to recognize that Humboldt worked within a larger culture of visuality that emerged in representational studies of earthquakes, in what Martin Rudwick called a "visual language" in the earth sciences, and in new forms of publication like the *Voyages pittoresques*.[72] When the Frenchman Jean-Pierre Houël declared "I prove my drawings through my words and bear testimony to my words through my drawings," he spoke for a generation of travellers and surveyors that bound word and image in new ways.[73] Humboldt's pictorial science must be seen against this backdrop.

What were the cartographic methods that, according to Humboldt, had "only been applied in mining and canal building projects"? Humboldt attended the Mining Academy in Freiberg at a time when miners, surveyors, and hydrographers were taught to represent a variety of landscapes from both aerial and vertical perspectives. Cartography was in fact central to Abraham Gottlob Werner's pedagogical program. As Rachel Laudan observed, Werner himself "had urged his pupils to construct maps, had personally directed some surveys, and had drawn up instructions for their coloring."[74] In this way students were taught to visualize nature's volume and

[71] On the visual culture of mining in the late nineteenth and twentieth centuries, see Eric C. Nystrom, *Seeing Underground: Maps, Models, and Mining Engineering in America* (Reno, Nevada: University of Nevada Press, 2014).
[72] Susanne B. Keller, "Sections and Views: Visual Representation in Eighteenth-Century Earthquake Studies," *The British Journal for the History of Science* 31, no. 2 (June 1998): 129-159; Martin Rudwick, "The emergence of a visual language for geological science, 1760-1840," *History of Science* 14 (1976): 149-95; Fritz Emslander, ed., *Reise ins unterirdischen Italien: Grotten und Höhlen in der Goethezeit* (Karlsruhe: Info Verlag, 2002), pp. 22-23.
[73] Jean Houel, *Prospectus du Voyage de la Sicile, de Malte et de Lipari* (Paris, 1781), p. 12.
[74] Laudan, *From Mineralogy to Geology*, p. 163. See also Nystrom, *Seeing Underground*, p. 194; Rudwick, *Bursting the Limits of Time*, p. 87; Mott T. Greene, *Geology in the Nineteenth Century: Changing Views of a Changing World* (Ithaca, NY: Cornell University Press, 1982), p. 27.

verticality.[75] In mining projects, aerial ground plans ("*Grund Risse*") were typically accompanied by vertical cross-sections ("*Durchschnitts Risse*") depicting the shafts, as in profiles by Freiberg surveyor Carl Friedrich Freiesleben (see figure 3), in whose house "Humboldt felt as though he was family."[76] Canal and dam building projects, moreover, were still closely linked to the mining industry, as evidenced by the education of hydrographers like Johann Gottfried Tulla who trained alongside miners in Freiberg.[77] Dams in particular tended to be visualized from both perspectives in single displays, as in the "Ground Plan and Cross-Section" of a dam built near Freiberg to collect the water drawn from its mines (see figure 4).[78] On top is the aerial view, complemented by a vertical projection with corresponding letters and coloration below. Based upon the "practice tasks of the mining students [*Probearbeiten von Bergschülern*]" in the 1790s, it is evident that Freiberg's training regimen fused technical and artistic cultures. Students were sent into the mines to construct written reports that included sketches of building structures, mineshafts, and mechanical apparatus.[79] Freiberg was, to borrow from Nick Hopwood, a "school for sight," a place where students were disciplined not in rote memorization but practical visualization.[80]

Humboldt readily integrated these methods into his approach to natural history. After taking up a position as *Oberbergmeister* in the principalities of Bayreuth and Ansbach in August

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[75] For a suggestive study of volume and its political ramifications, see Stuart Elden, "Secure the volume: Vertical geopolitics and the depth of power," *Political Geography* 34 (2013): 35-51.
[76] Carl Friedrich Freiesleben, "Durchschnitts Riss einen Theil des Grubenbaus in Bunge-Hohebirge," 1786. Sächsisches Staatsarchiv — Bergarchiv Freiberg, 40174 Grubenakten des Bergreviers Freiberg, Nr. 194; Bruhns, *Alexander von Humboldt. Erster Band*, p. 123.
[77] Blackbourn, *The Conquest of Nature*, pp. 85-92.
[78] August Friedrich Bollner, "Grund und Durchschnitts Riss von einen theil des Ober Groshartmannsdorfer Bergwerks Teichdammes," 1796. Sächsisches Staatsarchiv—Bergarchiv Freiberg, 40010 Bergamt Freiberg, Nr. 2927, Blatt 351.
[79] Sächsisches Staatsarchiv—Bergarchiv Freiberg, 40001 Oberbergamt Freiberg, Nr. 3296.
[80] Nick Hopwood, *Haeckel's Embryos: Images, Evolution, and Fraud* (Chicago: University of Chicago Press, 2015), p. 35.

1792, he drew an extensive map of Germany's salt springs, which in Ursula Klein's words "attempted to establish relations between salt springs and mountain formations."[81] In 1794, now a high ranking *Bergrat*, Humboldt told former classmate Carl Freiesleben (son of the aforementioned surveyor and fellow cartographer) about his plans to "have engraved geognostic views from drawings" for his "major geognostic project."[82] Humboldt's oft-envisioned but never published "major" geognostic work reveals the endurance of a vertical way of thinking about and representing nature that visual affinities alone could not have explained. Steeped in Saxon geognosy and cartography, this approach remained integral to Humboldt's enterprise long after his years as a mining official. As Ursula Klein observed, it was "only some three decades later" that "Humboldt could actually publish a work on the stratification of rocks."[83] Klein referred to his *Geognostical Essay on the Superposition of Rocks; in both Hemispheres*, published in French and English in 1823. But even in the *Geognostic Essay* (hardly a "major" work by comparison with those he had already published) Humboldt envisioned a still greater "*geognostic atlas*" comprised of "profiles or vertical *sections*."[84]

Humboldt's idea for a "major project" goes back at least to September 1792, when he wrote to Freiesleben about "the project of jointly printing geognostica in the future." By 1794, he referred to a similar project as "my book, *Strata and Bedding*."[85] "My idea is this," he told Freiesleben in January of that year: "To employ the most admirable flora and geognostic

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[81] Klein, "The Prussian Mining Official," p. 44.
[82] As quoted in Klein, "The Prussian Mining Official," p. 48.
[83] Klein, "The Prussian Mining Official," p. 44.
[84] Humboldt, *A Geognostical Essay on the Superposition of Rocks*, pp. 78-79. This essay reveals Humboldt's continued engagement with Freiberg educated mining officials. Here he noted that Johann von Charpentier, director of salt works in Switzerland, had shown him "his excellent description of the Pyrenees, the most complete work which we possess on a great chain of mountains." He also acknowledged that "much of the information of the porypheries of Europe" was "taken from a sketch that [he] wrote in some degree under the inspection of M. Werner, when that celebrated man came, for several days, from Carlsbad to Vienna, (in 1811)." (Ibid., p. 77.)
[85] As quoted in Klein, "The Prussian Mining Official," pp. 43, 48.

descriptions of the whole region as *vehicula* with which to bring to the world a *single* observational overview." By September Humboldt was convinced he knew "how exactly everything in western Germany is *composed*." Having "travelled into the mines [and] described their veins," he fixed upon the idea for a "major mineralogical work, *A Geognostic View of Germany*." Two years later Humboldt assured Werner of his tireless efforts on an even more expansive work to be titled *On the Construction of the Terrestrial Body in Central Europe, Particularly on the Strata and Bedding of Rock Masses*. In his last letter from the European continent in 1799, Humboldt regretfully told a friend that his "work on the construction of the terrestrial body" would have to wait until his return.[86] That Humboldt never wrote this book does not, however, mean he left its conceptual basis behind. On the contrary, I would suggest that Humboldt took with him the very set of practices that had sustained this project since 1792: ascending mountains, descending mines, and depicting nature, from strata to summit, in geognostic profiles. Ultimately, Humboldt's geognostic aspirations had become something much more than a "major work." They had crystalized into a vertical approach to natural history.

Part of this approach was a pattern of vertical mobility above and below the surface of the earth, a program begun in the Old World and continued in the New. Just as Humboldt's eudiometric experiments in Europe had included "measurements on high mountains" and "tests on my own mines," so his ascent of nine peaks and volcanoes in the Americas was matched by his descent into the shafts of eight mining districts.[87] Between Humboldt's near ascent of Mt. Chimborazo and his first draft of the "Tableau physique des Andes" (figure 1) was a descent into the mines at Chimborazo's base, an ascent of the neighboring Cerro el Tablón, a return to the

[86] Humboldt to Carl Freiesleben, 20 Jan. 1794, in Humboldt, *Jugendbriefe,* pp. 310-15; Humboldt to Carl Freiesleben, 10 Sept. 1794, in ibid., p. 352; Humboldt to Abraham Gottlob Werner, 21 Dec. 1796, in ibid., p. 561; Humboldt to Karl Maria Erenbert von Moll, 5 June 1799, in ibid., p. 682.
[87] Humboldt to Carl Freiesleben, 2 Oct. 1796, in Humboldt, *Jugendbriefe,* 528-29.

subterranean in Cajamarca, and a visit to the State Mining Archives in Lima, Peru, where he made the acquaintance of fellow Freiberg graduate Fürchtegott Leberecht von Nordenflycht. After drafting the "Tableau physique des Andes" Humboldt and travel companion Aimé Bonpland boarded a ship for New Spain, where—having climbed Cerro las Navajas, descended into four mining areas, and scaled Jorullo Volcano—Humboldt drafted the geognostic profiles (figures 5 and 6) that later composed the *Atlas géographique et physique du royaume de la Nouvelle-Espagne*, published in 1811. In Mexico City Humboldt wrote his only Spanish work, *Tables de pasigrafica geognostica*, intended "for the use of the school of mines at Mexico." And it was here that Humboldt first boasted of having "seized upon the idea to represent whole countries as a mine."[88] Humboldt's trajectory was that of a polynomial of the third degree, a wave-like line continually rising above and dipping below the x-axis.[89]

To be sure, Humboldt's profiles in the *Atlas géographique*, with their emphasis on mountains and comparatively massive scale, differ markedly from their Saxon predecessors. But given Humboldt's training in Freiberg and continued engagement with mining in Latin America, I want to suggest that these differences are best seen as innovations within a single visual tradition grounded in resource extraction and water management. To see "whole countries as a mine" meant first and foremost to visualize nature in all its verticality. But, in a more subtle way, it also meant appropriating a set of conventions. Compare figures 3 and 6, Carl Friedrich Freiesleben's "Cross-sectional plan of part of a mine in Bunge-Hohebirge" and a section of Humboldt's continent-spanning series of vertical profiles published as the "Tableau physique de

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[88] As quoted in Rebok, *Alexander von Humboldt und Spanien im 19. Jahrhundert*, p. 167. In the *Essai* Humboldt claims to have "sketched out the tableau for the first time in the port of Guayaquil, in February 1803. (Humboldt, *Essay on the Geography of Plants*, p. 80.)

[89] Humboldt to Carl Freiesleben, 2 Oct. 1796, in Humboldt, *Jugendbriefe,* pp. 528-29. The chronology assembled here is taken from a far more extensive chronology created by contributors to Alexander-von-Humboldt-Forschung at the Berlin-Brandenburgische Akademie der Wissenschaften. http://avh.bbaw.de/chronologie/.

la Nouvelle Espagne." In a simple and legible manner, the "Cross-sectional Plan" shows mineshafts from a vertical perspective. And just as the "Cross-sectional plan" shows no geological layers (then known as *Gebirge*), but simply displays the depths of mines with a single, clear line slanting across the bottom of the page, so Humboldt's "Tableau physique de la Nouvelle Espagne" reveals none of the stratigraphic content of the landforms it depicts, only their heights. Indeed, a closer look at the middle section of the three-part "Tableau physique de la Nouvelle Espagne" (figure 7, "Tableau du Plateau central des Montagnes") reveals Humboldt's inclusion of the Valenciana mine in New Spain, the deepest point of which he recorded on the map's scale. Depicted in a symbolic rather than technical or *wissenschaftlich* fashion (by turn-of-the-century mining academy standards), the single mineshaft serves to indicate the relationship between mines and mountains so central to Humboldt's biography and science. Furthermore, although Humboldt claimed to have "sketched" the "Tableau physique de la Nouvelle Espagne" in 1803, he also wrote that it had been "drawn" again "under my eyes" in 1804 by Rafael Devalos, "a very diligent . . . pupil of the Mining Academy in Mexico City."[90] Cartographically, Humboldt and his draftsmen gave a visual reality to his dictum "Nature knows no over- and underground," turning the "Cross-sectional plan" of the mine right side up, as it were.

The "Geographical-Astronomical Introduction" to Humboldt's *Political Essay on the Kingdom of New Spain* gives a detailed, if retrospective, overview of the commercial impulses behind the maps he produced "shortly before [his] departure from the Royal Mining Academy (*Real Seminario de Mineria*)" in 1803. It also shows how mining institutions were truly central to Humboldt's cartography in this period. As in Prussia, the *sine qua non* for Humboldt's cartographic undertaking was, as Alistair Sponsel wrote of Darwin aboard the *Beagle*, his

[90] Humboldt, *Versuch über den politischen Zustand des Königreichs Neu-Spanien*, pp. cxliii-cxliv.

"autocratic position with respect to data created and collected by a variety of people."[91] The Real Seminario offered him the most rigorous and far-reaching data-collecting enterprise in the land. Indeed, there is a sense in which Humboldt's *Atlas géographique* had been in the making before he ever set foot there. As Humboldt noted, director of the Mining Academy Don Fausto d'Elhuyar (and many more besides him) "had long been collecting information on the state of the mines of New Spain." Echoing the socio-political agenda of an *Oberbergmeister*, Humboldt believed this cartographic campaign "as necessary for the administration of [New Spain] as it was for an understanding of the industry [*Gewerbfleißes*] of its people."[92] Importantly, Humboldt understood his own project as drawing upon and contributing to that of the Real Seminario. Upon returning to Europe, moreover, Humboldt actively marketed the *Atlas géographique* and related data on Mexican silver mines to English business circles.[93] Humboldt's map-making in New Spain was no less tied to imperialism than his eudiometric chemistry in Prussia had been to cameralism.

The iconic "Tableau physique des Andes" was in fact one of many *tableaux*. Collectively, these *tableaux* form a single branch in a phylogenic tree of maps for which mining provided nourishing soil. Given Humboldt's patterns of vertical mobility, though, my analysis goes one step further. I interpret the "Tableau physique des Andes" as the product of an ascent-descent rhythm of natural inquiry through which Humboldt used meteorological instruments to

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[91] Alistair Sponsel, "An Amphibious Being: How Maritime Surveying Reshaped Darwin's Approach to Natural History," *Isis* 107, no. 2 (June 2016): p. 30.
[92] Humboldt, *Versuch über den politischen Zustand des Königreichs Neu-Spanien*, pp. v.
[93] Douglas Botting, *Humboldt and the Cosmos* (London: Sphere Books Ltd., 1973), p. 185. After visiting Washington and Philadelphia in 1804, Humboldt promoted his Mexico works among U.S. statesmen. See Sandra Rebok, *Humboldt and Jefferson: A Transatlantic Friendship of the Enlightenment* (Virginia: University of Virginia Press, 2014) and Ingo Schwarz, "Alexander von Humboldt's Visit to Washington and Philadelphia, His Friendship with Jefferson, and His Fascination with the United States," *Northeastern Naturalist* 8, Special Issue 1: Alexander von Humboldt's Natural History Legacy and Its Relevance for Today (2001): 43-56.

measure mine airs and mining methods to measure mountains. The poet Goethe, who had himself been a mining official in the Duchy of Saxe-Weimar, was so enamored of the "Tableau physique des Andes" (the German edition of which Humboldt dedicated to him) that he drafted his own "Humboldtian landscape." In Goethe's words, it brought the "Old and New Worlds into a single comparative illustration" with the Alps to one side of a great valley and the Andes to the other. Goethe later wrote that while viewing Humboldt's "geological maps . . . one is upon the Humboldtian trail, all caution left behind." Humboldt may have thought Goethe's *tableau* laughable (with its yellow open-mouthed crocodile and stick-figure mountaineers), but Goethe was right about Humboldt's cartography. Humboldt's maps were indeed representations of vertical movement, as only mountains and mines could offer.[94]

III. Mining and the shaping of a "vertical consciousness"

"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." So goes the inscription on the St. Peter's Tower bell in Freiberg (hewn in 1756), which still sounded the daily rhythms of the miners in Humboldt's time.[95] What here expressed a religious meaning for common miners rang true also for their naturalist counterparts. "Nature knows no over- and underground," Humboldt proclaimed in 1799 as he laid "the foundations of a subterraneous meteorology."[96] That same year, the poet Novalis (Friedrich von Hardenberg, a fellow Freiberg graduate) described miners as "inverted

[94] Johann Wolfgang von Goethe, "Annalen, 1807," in Franz Thomas Bratranek, ed., *Goethes Briefwechsel mit den Gebrüdern von Humboldt, 1795-1832* (Leipzig: Brockhaus, 1876), pp. 349-50; Goethe to Frau von Stein, 18 Apr. 1808, in ibid., pp. 350-51; Goethe to Sternberg, 18 Jan. 1828, in ibid., p. 355.
[95] Today this bell is kept in the Stadt- und Bergbaumuseum in Freiberg, where the inscription by Johann Gottfried Weinhold can still be read: "*Auf, Auf, zur Grube ruf ich Euch, ich, die ich oben steh; so offt Ihr in die Tiefe fahrt, so denket in die Höh*."
[96] Humboldt, *Ueber die unterirdischen Gasarten*, 201.

astrologers" in his novel *Heinrich von Ofterdingen*. As the astronomer "beholds the heavens, and wanders through its immeasurable firmament," spoke a hermit to a miner,

> so you turn your gaze to the earth, and fathom its structure. They study the force and influence of the stars; you investigate the force of rocks and mountains, and the manifold workings of the layers of the earth and its rock bedding. To them, heaven is the book of the future, while to you, the earth reveals the monuments of the primordial world."[97]

A "vertical consciousness" was certainly in the air—above and below ground.

Historian Michael Reidy first wrote about the emergence of a "vertical consciousness" in nineteenth-century science. From John Tyndall's high altitude physiology and Joseph Dalton Hooker's Himalayan botany to Charles Darwin's theory of coral reef formation and William Whewell's quest to determine the "zero point" of sea level, Humboldt's vertical thinking provided a potent and versatile model. "Following Humboldt," Reidy wrote, "scientists used both a horizontal and vertical orientation in understanding the oceanic environment, one that extended from the heavens through the earth's atmosphere all the way down to the tidal oscillations on its surface and eventually to submarine tides in the ocean's depths."[98] But it was the depths of the earth from which this way of thinking sprang. For the kind of vertical mobility made possible by mining fostered new ways of thinking about nature, which Humboldt imbibed as a miner and applied to the wider world of natural phenomena thereafter. If Humboldt's science had been the animating force behind the rise of a "vertical consciousness," it was his descent into mines that made this possible.

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[97] Novalis, "Heinrich von Ofterdingen," in *Novalis Schriften. Fünfte Auflage. Erster Theil.*, eds. Ludwig Tieck and Friedrich Schlegel (Berlin: Verlag von G Reimer, 1837), p. 115.

[98] Reidy, *Tides of History*, p. 281. See also Michael S. Reidy, "From Oceans to Mountains: Spatial Science in an Age of Empire," in *Knowing Global Environments: New Historical Perspectives on the Field Sciences,* ed. Jeremy Vetter (New Jersey: Rutgers University Press, 2010), pp. 17-38; Michael Reidy, "Mountaineering, Masculinity, and the Male Body in Mid-Victorian Britain," *Osiris* 30, *Scientific Masculinities* (2015): 158-81.

Physical mobility was central to the genesis of this "vertical consciousness." Historians have shown how, as a sea change in views of nature swept across Europe around the turn of the nineteenth century, contemporaries imbued mountains and oceans with fresh meaning.[99] Europeans learned to admire what they had once feared, and the subterranean was no exception. In 1734, Carl Linnaeus described mines at Falun, Sweden as a "full portrayal of hell."[100] By the end of the century, though, many savants of Linnaeus's social station zealously devoted themselves to this underground industry. A good starting point for understanding this change is Carolyn Merchant's *The Death of Nature*, the main thrust of which is that commercial interests shaped Europeans' image of nature in ways that legitimized resource exploitation.[101] Enthusiasm for mining around 1760 did indeed spark enthusiasm for the subterranean more generally; and the subterranean, in turn, was reimagined as a site for science and a destination for travellers.[102] In the same decades that hundreds of social elites steeped in neo-Classicism flocked to the grottoes of Italy, German publishers began printing descriptions of mines by and for travellers.[103] The architect and metallurgist Franz Ludwig von Cancrin, for instance, wrote his *Description of the Most Excellent Mining Works* (1767) "in order to give dilettantes and travellers a taste of the

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[99] Marjorie Hope Nicolson, *Mountain Gloom and Mountain Glory: The Development of the Aesthetics of the Infinite* (Seattle: University of Washington Press, 1997); Alain Corbin, *The Lure of the Sea: The Discovery of the Seaside in the Western World, 1750–1840*, trans. Jocelyn Phelps (New York: Penguin, 1994).
[100] Carl Linnæus, "Journeys to the Mines and Works," in *The Dalarna Journey. Together with Journeys to the Mines and Works*, trans. Andrew Casson (Dalarna, Sweden: Gullers Förlag, 2007), p. 302.
[101] Carolyn Merchant, *The Death of Nature: Women, Ecology and the Scientific Revolution* (New York: Harper Collins, 1983), pp. 2-4.
[102] James C. Scott has identified an analogous case in late eighteenth-century Prussia and Saxony, where the "geometric, uniform forest" manipulated by the cameralist subdiscipline of scientific forestry "quickly became a powerful aesthetic as well." (James C. Scott, *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed* (New Haven: Yale University Press, 1998), p. 18.)
[103] See Emslander, ed., *Reise ins unterirdischen Italien*.

mines" before venturing in themselves.[104] Thus, in 1793, the writer Wilhelm Heinrich Wackenroder privately described the aim of his Franconian travels as "coming to know Nature over and under the earth." Upon seeing the decrepit state of mining in Bayreuth, moreover, Wackenroder took heart in the news that "soon the young Herr von Humboldt . . . will arrive as overseer of the Bayreuth mining operations."[105]

Many of the most influential figures in Humboldt's life had already taken a passionate interest in mining and subterranean travel when their protégé-to-be was still a boy. Goethe, remembered best in Humboldt's biography as the Romantic luminary who encouraged his studies of galvanism and *Lebenskraft* in Jena, was also the mining official with whom Humboldt tested his self-made "safety lamp" in Ilmenau. When Goethe was placed in charge of mining operations there in 1784, he describe the mine as a "child" he vowed to "nourish, protect, and raise." "Let us not look upon this humble opening . . . in the surface of the earth with indifferent eyes," Goethe admonished in his speech at the mine's re-opening. For it was in this mineshaft "where men will ascend and descend [*auf- und niederfahren*], and where we will see and behold before our eyes with the greatest joy what now we see only in the mind, what God has bestowed upon us. *Glück auf*!"[106] Unsuccessful though he was as a mining official, Goethe wrote thirty-seven years later of his "special fondness for mining and smelting operations" and continued throughout his life to visit mines, believing geological phenomena "reveal themselves as much through Nature as through the hands of men."[107]

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[104] Franz Ludwig Cancrinus, *Beschreibung der vorzüglichsten Bergwerke* (Frankfurth an dem Main, 1767), Vorrede.
[105] Wilhelm Heinrich Wackenroder, *Reisebriefe*, ed. Heinrich Höhn (Berlin, 1938), pp. 23, 51.
[106] GSA 25/W 2776. *Glück auf* is the traditional salutation of German miners, translating close to "good luck."
[107] Johann Wolfgang von Goethe, "Sangerberg, 1821," in Johann Wolfgang von Goethe, *Johann Wolfgang von Goethe Sämtliche Werke nach Epochen seines Schaffens Münchner Ausgabe, Band 12. Zur Naturwissenschaft überhaupt, besonders zur Morphologie Erfahrung, Betrachtung, Folgerung, durch*

Georg Forster also shared Goethe's "special fondness" for mining. Two months after Goethe's speech in 1784, Forster travelled to Saxony where he studied *Bergbaukunde*, the science of mining, under Friedrich Wilhelm von Trebra and Abraham Gottlob Werner from April to August. There the so-called "*Weltumsegler*" (the circumnavigator) found in the "practical mining expert" a figure who "sees what the theorist never experiences, nor could ever believe." Indeed, Forster himself imbibed a new view of nature in the mines, which he expressed through cartographic imagery in his journal:

> One should indeed locate all the veins throughout the Ore Mountains, and so potentially arrive at something important, and surely yield something for applicable theories. Such a map, with indications of all *converging* veins, would be curious to display, particularly if one were to include a profile that indicated the form and heights of mountains, and *in this way* determine the richest bodies of ore.[108]

As for Humboldt in the 1790s, so for Forster in 1784: practicality and verticality coalesced in a science generated by the working world of mining. Indeed, it was Humboldt who, in the *Atlas géographique*, created profiles indicating "the form and heights of mountains." Whether or not a causal link exists here is difficult to tell. What is more certain, however, is that Forster and Humboldt participated in the same culture of subterranean travel and vertical thinking.

The "vertical consciousness" epitomized by Humboldt's declaration that "Nature knows no over- and underground" can also be found in the art and literature produced by his Romantic contemporaries. Consider the painter Caspar Wolf, whose well-known fascination with grottos earned him the name "*Höhlenwolf*" (cave-wolf).[109] Wolf's 1777 painting *Inside the Bear Cave at Welschenrohr* (see figure 8) displays his *Thinker*, a solitary figure gazing out into daylight, which in turn illuminates him. To be underground, Wolf seems to suggest, is to look

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Lebensereignisse verbunden, eds. Hans J. Becker, Gerhard H. Müller, John Neubauer, and Peter Schmidt (München: Carl Hanser Verlag, 1989), p. 761; Goethe to Herr von Leonard, 25 Nov. 1807, in ibid., 765.
[108] 12 July 1784, in Forster, *Tagebücher*, p. 76.
[109] Ziolkowski, *German Romanticism and its Institutions*, p. 23.

aboveground. Or, as the bell in St. Peter's Tower would have it, to "go into the depths" is to "think up to the heights." Similarly, in E. T. A. Hoffmann's story "The Mines of Falun," an old miner tells a young sailor that "if the blind mole burrows by blind instinct, it may be that the eyes of man acquire more penetrating sight in the deepest depths of the earth, until they can recognize in the wonderful stones . . . a reflection of that which is hidden above the clouds."[110] For Hoffmann, as for Humboldt, descent and ascent were natural correlates, and the one informed the other.

Humboldt remained fascinated with nature's verticality to the end of his life. In the "Tableau physique de la Nouvelle Espagne" published in 1811, for instance, Humboldt added to its central section a scale that rises vertically (and ranges geographically) from the "greatest depth to which the Valenciana mine descends," through the Pic du Canigou in the Alps, the Pass of Mont-Cenis in the Pyrenees, various mines in Peru, a volcano in Mexico, the "lowest boundary of perpetual snow" at three latitudes, and up, finally, to the "Height of Chimborazo." In later years, while living in Berlin from 1827 until his death in 1859, Humboldt painstakingly compiled notes on the depths of mines and oceans and the heights of mountains, using the mines of Valenciana and Freiberg as vertical reference points.[111] Tellingly, he sometimes grouped them together, as in the case of his "Sea and Depths [*Meer u. Tiefe*]" folder. And like a number of his mid-century contemporaries, Humboldt often tried to make sense of new depths with the familiar measuring rod of a mountain, while conceptualizing new heights with that of a deep-sea sounding. On one note (see figure 9) Humboldt observed how British naval officer James Clark Ross described the deepest point of the ocean as being "beneath its surface very little short of the

[110] E. T. A. Hoffmann, "The Mines of Falun," in E. T. A. Hoffmann, *Tales of Hoffman*, trans. R. J. Hollingdale, Stella, Vernon Humphries, and Sally Hayward (New York: Penguin Books, 2004), pp. 316-18.
[111] SBB-PK IIIA Nachl. Alexander von Humboldt, gr. Kasten 11, Nr. 59a.

elevation of Mount Blanc above it."[112] Beside this note lies a letter from the Irish astronomer Edward Sabine, who in 1853 wrote to Humboldt "of a successful attempt which has been made by Captain Denham of the Royal Navy . . . to reach the bottom of the sea at a depth much exceeding that of the highest summits of the Himalaya."[113] Humboldt's notes on the summits of the Himalaya illustrate the same method in reverse, now using the depths of the ocean to register the heights of mountains. When in 1849 Joseph Dalton Hooker sent Humboldt the latest trigonometrical measurements of Tibet's tallest peaks, the latter compared them not only with Chimborazo and Mont Blanc, but also with "sea soundings [by James Clark] Ross" (see figure 10).[114] Elsewhere, Humboldt and his self-consciously Humboldtian followers sought to estimate nature's vertical expanse in single measurements, as in 1855 when the American oceanographer Matthew Fontaine Maury recorded a distance of "nine miles" "[f]rom the top of Chimborazo to the bottom of the Atlantic" in his *Physical Geography of the Sea*.[115] Maury's use of Chimborazo as a measuring rod is a telling nod to Humboldtian vertical thinking. In the first volume of *Kosmos* (1845) Humboldt had recorded a distance of 45,000 feet "from the highest pinnacles of the Himalayas to the lowest basins that contain the vegetation of a primordial world," the "deepest coal deposits" of which "lay as far below the surface of the sea as Chimborazo is elevated above it."[116] That Humboldt cited Ernst Heinrich von Dechen and Karl von Oeynhausen—mining officials from whom he received numerous reports and manuscripts—

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[112] SBB-PK IIIA Nachl. Alexander von Humboldt, gr. Kasten 11, Nr. 72, Blatt 7r; Captain Sir James Clark Ross, A *Voyage of Discovery and Research in the Southern and Antarctic Regions, During the Years 1839-43. In Two Volumes. Vol. I* (London: John Murray, Albemarle Street, 1847), p. 26.
[113] Edward Sabine to Humboldt, 21 Jan. 1853, SBB-PK IIIA Nachl. Alexander von Humboldt, gr. Kasten 11, Nr. 65.
[114] SBB-PK IIIA Nachl. Alexander von Humboldt, gr. Kasten 8, Nr. 48a, Blatt 4r.
[115] Matthew Fontaine Maury, *Physical Geography of the Sea* (New York: Harper & Brothers Publishers, 1855), p. 208.
[116] Alexander von Humboldt, *Kosmos. Entwurf einer physischen Weltbeschreibung. Erster Band* (Stuttgart und Tübingen: J. G. Cotta'scher Verlag, 1845), pp. 419-420, n. 95.

exhibits his continued engagement with Prussian mining, and its continued influence on his vertical thinking.[117]

When Humboldt said "Nature knows no over- and underground" in 1799, he was not dismissing the boundary between the terrestrial and the subterrestrial, but acknowledging the equal significance and interrelation of scientific inquiry in both spaces. Though a half-century had passed between Humboldt's career as a miner and his years spent authoring *Kosmos* (1845–1859), the same core concept of verticality remained palpable in the 1850s. In 1853, while communicating Sabine's letter to the *Königliche Akademie der Wissenschaften* in Berlin, Humboldt reported that the ocean's deepest point was beyond earth's tallest measuring rod: "nearly 17,000 Paris feet greater than the heights of Kintschinjunga. [...] Only once we view the earth like the moon, without its liquid shroud [*flüssige Umhüllung*]," Humboldt declared, "will the mountain-masses and peaks, indeed the entire surface of the earth, appear in their true form."[118] By acknowledging the equal significance of geography above and below the surface of the sea, Humboldt had applied to oceans a concept he learned in mines.

The story of Humboldt and verticality is rich and complex. For now, though, it suffices to say that undergirding this dynamic mode of thought was the experience of mining and the "vertical consciousness" it generated amongst Humboldt and his vertically mobile contemporaries. A nineteenth-century biographer once asked: "in what epoch of history has a man moved [*durchwandert*] through air and sea and land, over mountaintops and into mineshafts, *like our Alexander von Humboldt*?" His patriotic answer was, of course, that "*He is*

[117] For fragments of Ernst Heinrich von Dechen's and Karl von Oeynhausen's correspondence with Humboldt, see SBB-PK IIIA Nachl. Alexander von Humboldt, gr. Kasten 11, Nr. 60, gr. Kasten 11, Nr. 42, gr. Kasten 11, Nr. 14; gr. Kasten 11, Nr. 116-17; kl. Kasten 14, Nr. 10.
[118] SBB-PK IIIA Nachl. Alexander von Humboldt, gr. Kasten 11, Nr. 72, Blatt 72r and 61a, Blatt 36r.

the only one!"[119] Yet, at least with respect to movement through mines, Humboldt was certainty not alone. For the vertical mobility so integral to the working world of late eighteenth-century mining, and the subterranean travel culture it spawned, begat a vertical mode of thinking and seeing that left its mark on the art and science of Humboldt, his contemporaries, and his followers.

Mining and "Humboldtian Science": Conclusion

The most immediate implication of this essay is that Humboldt's science cannot be understood apart from the industrial context in which it first developed. In 1792, while explaining the curiously green color of subterranean plants to the philosopher Friedrich Heinrich Jacobi, Humboldt queried: "Where is a discovery whose seed was not already sown?"[120] By re-situating Humboldt in his pre-voyage national-industrial context, it becomes evident that the seeds of his own discoveries were sown in the people, practices, and places that made central Europe's dynamic mining industry possible. The same Jacobi whom Humboldt queried about the nature of scientific discovery had, upon meeting the nineteen-year-old in 1788, described his rare "speculative genius" in a letter to Georg Forster.[121] But if there was something like genius behind "Humboldtian Science," it was not so much "speculative" as it was "smelted genius [*verschmelzendes Genie*]." This is the phrase Humboldt used to describe the way in which Forster's approach to natural history fused into coherence the organic and the inorganic, the

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[119] *Alexander von Humboldt's Leben und Wirken, Reisen und Wissen. Ein biographisches Denkmal von Dr. Herm. Klencke, 7th ed.* (Leipzig: Spamer, 1876), pp. 485-86.
[120] Humboldt to Friedrich Heinrich Jacobi, 10 Jan. 1792, in Humboldt, *Jugendbriefe,* p. 117.
[121] Friedrich Heinrich Jacobi to Georg Forster, 16 Nov. 1788, in Georg Forster, *Georg Forsters Werke, Sämtliche Schriften, Tagebücher, Briefe, Achtzehnter Band: Briefe an Forster*, eds. Siegfried Schibe, Klaus-Georg Popp, Annrose Scheider, and Brigette Leuschner (Berlin: Akademie Verlag, 1982), p. 383.

natural and the political.[122] Humboldt's science, I have argued, smelted together the visual thinking of a Freiberg graduate, the economic imperatives of a Prussian *Oberbergmeister*, and the vertical mobility of both.

This history of science abounds with analogous cases. Consider, for instance, Peter Galison's study of Albert Einstein and Henri Poincaré, two figures who independently developed theories of relativity, not as solitary thinkers contemplating an abstract cosmos, but as a Swiss "tinkerer" and a French "polytechnician" responding to industrial and technological concerns about clock coordination, railway schedules, telegraphy, and cartography.[123] The Bern patent office and the Paris Bureau of Longitude were to Einstein and Poincaré's respective theories of relativity what the mineshafts of Freiberg, Bayreuth, and Ansbach were to Humboldt, his plant geography, and his cartography.

Nor am I the first to wonder about the relationship between mining and Humboldtian Science. Ursula Klein posited that Humboldt's "visit of the Freiberg Mining Academy paved the way for this approach."[124] And Alistair Sponsel has argued that part of what made Darwin appear "Humboldtian" on the *Beagle* voyage was the way in which his approach to natural history was shaped by hydrographers' practices.[125] Building upon this scholarship, I have argued that a core feature of Humboldtian Science—namely, the effort to measure and quantify variation along nature's vertical axis through an ambitious program of physical movement—was already in place by the time Humboldt developed a "subterraneous meteorology" in 1799. The experience of mining, in central Europe as in Latin America, not only paved the way for Humboldt's approach

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[122] As quoted in Uhlig, *Georg Forster*, p. 258.
[123] Peter Galison, *Einstein's Clocks, Poincaré's Maps: Empires of Time* (New York: W. W. Norton, 2003), pp. 46, 38.
[124] Klein, "The Prussian Mining Official," p. 34.
[125] Sponsel, "An Amphibious Being," p. 262. "Humboldt had himself previously been a surveyor of sorts," Sponsel wrote, noting Humboldt's study of "the distribution of vegetation in mines" in Freiberg.

to natural history, but also shaped his ideas on plant migration and endowed him with a cartographic imagination that saw nature in all its verticality. Humboldt's case, moreover, far from being unique, actually suggests he was one of many figures whose experience of vertical mobility in mines furnished him with a "vertical consciousness."

Indeed, the very question of how mining shaped Humboldtian Science reveals the extent to which it was not an originally Humboldtian invention. On the level of individuals and ideas, Humboldt himself recognized the enormous influence of Forster and the "Forsterian project," acknowledging the way in which Werner's tutelage effected a "*Totalrevolution*" in his "way of thinking," and attributing his earliest vertical science to Deluc, Saussure, and Lichtenberg.[126] Scaling out, it becomes clear that the economic ambitions of cameralist states and the raw circumstances of late eighteenth-century resource extraction were equally powerful factors in shaping that which scholars have come to call "Humboldtian." In striking out for the New World, furthermore, Humboldt followed a path blazed by earlier mining officials who radiated out from Freiberg to Latin America. Upon returning, Goethe would call Humboldt "our conqueror of the world," and the reading public would hail him as "the *second* Columbus."[127] But in 1799, Humboldt was one of many Freiberg graduates to pursue natural history in Latin America—an individual participant in that remarkable migration of young men to and from Freiberg captured in Rachel Laudan's apt phrase "the Wernerian radiation."[128] In Lima, as noted above, Humboldt met Nordenflycht, who had helped found the Peruvian Mining School after the Freiberg model under which he was trained. And at the Real Seminario de Minería in Mexico City, Humboldt conducted experiments alongside Freiberg classmate Andrés Manuel del Río,

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[126] Humboldt to Dietrich Ludwig Gustav Karsten, 26 Nov. 1791, in Humboldt, *Jugendbriefe*, pp. 160-62.
[127] As quoted in David Blackbourn, "Germany and the Birth of the Modern World, 1780-1820," *Bulletin of the German Historical Institute* 51 (Fall 2012): 9-21, on p. 13; Walls, *The Passage to Cosmos*, p. 13.
[128] Laudan, *From Mineralogy to Geology*, pp. 102-05, 178-79.

one of four Latin America-based members of the Saxon *Societät der Bergbaukundige*.[129] Thus, while I am critical of the argument that Humboldt "could not have failed" to be impressed by local traditions that viewed "the Andes as a microcosmic space for testing theories of biodistribution," I at the same time see my argument about the influence of commercial interests on Humboldt's science as being in concert with the decentering impulse of post-colonial scholars like Jorge Cañizares-Esguerra and Mary Louise Pratt.[130] My contribution to a history of Humboldt *from below* has only been more literal, and it has focused on cameralism where others have emphasized imperialism.

Humboldt himself was well aware—even proud—of his debt to mining, and he knew that his debt would outlive his career. In 1794, Humboldt told Carl Freiesleben that "in order to pursue higher scientific plans" he must "leave the Mining Department [*Dienst*]." This would seems to suggest that his quitting the Mining Department and lighting out for South America marked the beginning of an unencumbered pursuit of science. Yet in the following lines Humboldt explained how "only then will I truly *begin* to live as a miner, the *métier* to which I wholly belong, and to perform those essential services [*wesentliche Dienste*], services which will endure for posterity."[131] Klein concluded that this letter "is not easy to interpret for those historians who argue that Humboldt saw a fundamental contradiction between his activity as a mining official and his scientific inquiries."[132] Klein is right to be critical of such arguments. In this essay I have tried to show why.

For Humboldt, being a miner *was* pursuing higher scientific plans. Writing in the spirit of the underground Enlightenment, with its fervor for practical knowledge and public utility,

[129] F. W. H. v. Trebra, *Bergbaukunde. Erster Band* (Leipzig: Georg Joachim Goeschen, 1789), pp. 405-08.
[130] Cañizares-Esguerra, "How Derivative Was Humboldt?" p. 152; Pratt, *Imperial Eyes*.
[131] Humboldt to Carl Freiesleben, 21 Nov. 1794, in Humboldt, *Jugendbriefe,* p. 378.
[132] Klein, "The Prussian Mining Official," p. 49.

Humboldt determined to leave one service for another, using the German word *Dienst* while referring to both the Prussian Mining Department and the enterprise of science. Through both *Dienste*, moreover, he would remain a "*Bergmann*," a miner. And in so far as regular vertical mobility and the application of mining methods to mountainous landscapes lay at the very core of what it means to be "Humboldtian," there is indeed an important sense in which Humboldt's career as a miner never ended at all.

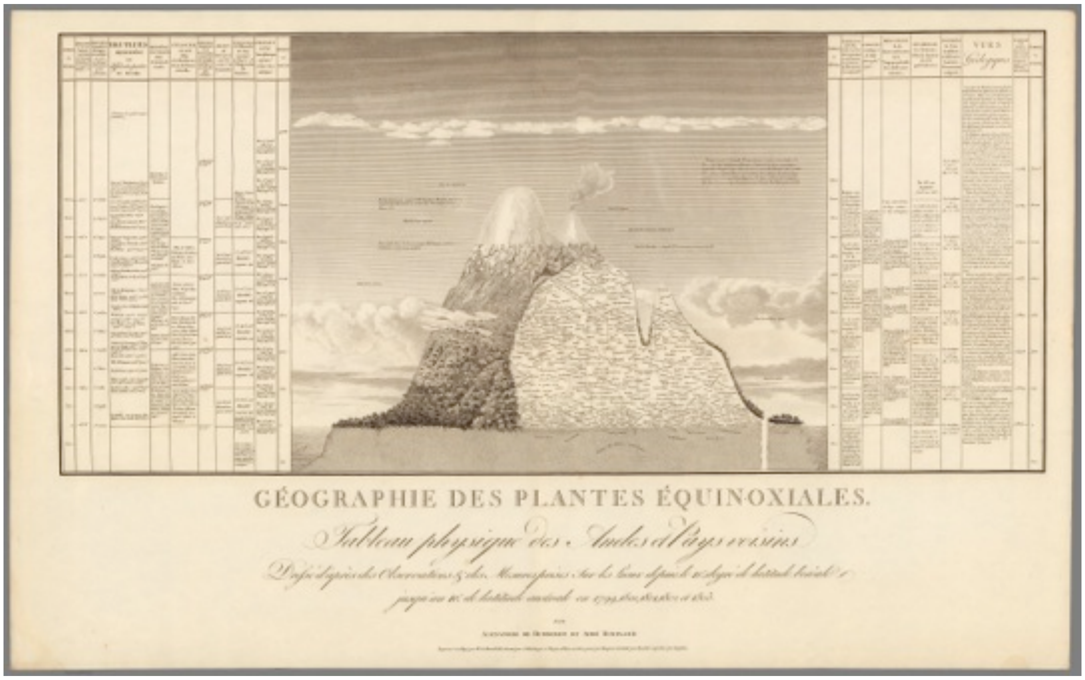

Figure 1. Humboldt's "Tableau physique des Andes et pays voisins" (called the "Naturgemälde der Anden" in the 1807 German edition), published in Paris in 1805 with the *Essai sur la géographie des plantes*. www.davidrumsey.com

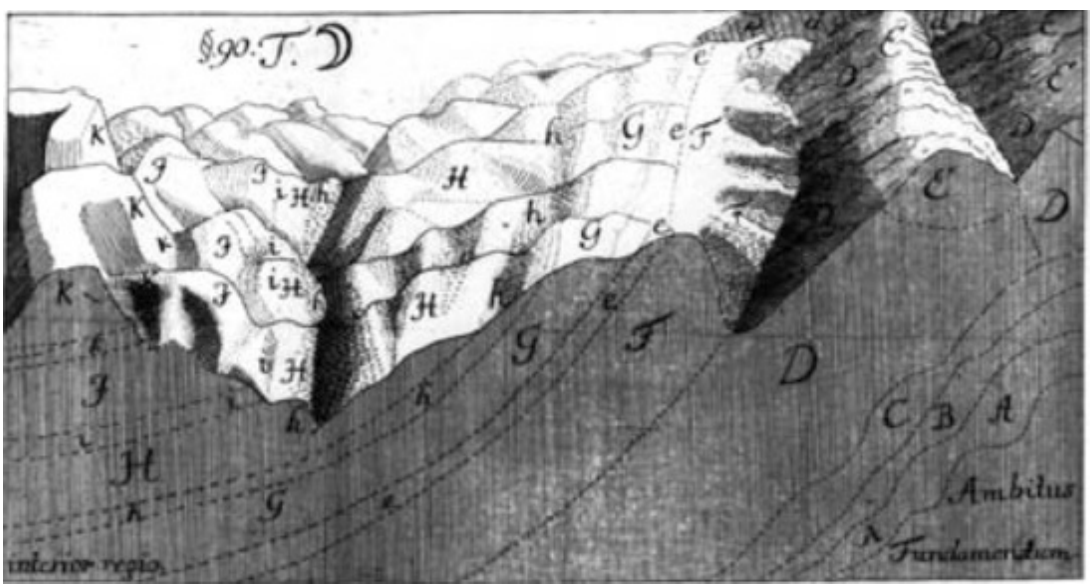

Figure 2. Profile from Georg Christian Füchsel's *Historia terrae et maris, ex historia Thuringiae* (Erfurt, 1761). Here Füchsel inferred fourteen "secondary" strata from an inspection of the surface "primary" *Gebirge* (rock masses). See Martin J. S. Rudwick, *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution* (Chicago: The University of Chicago Press, 2005), p. 89, fig. 2.16.

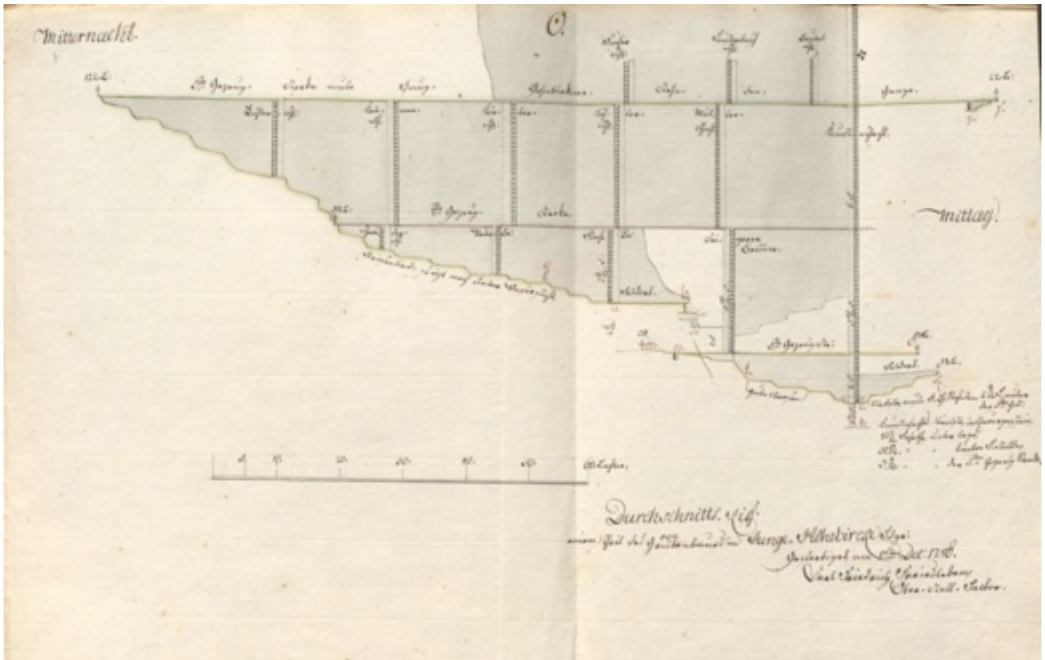

Figure 3. Carl Friedrich Freiesleben, "Durchschnitts Riss einen Theil des Grubenbaus in Bunge-Hohebirge," 1786. "*Mitternacht*" (midnight) indicated north and "*Mittag*" (midday) indicated south. Sächsisches Staatsarchiv — Bergarchiv Freiberg, 40174 Grubenakten des Bergreviers Freiberg, Nr. 194.

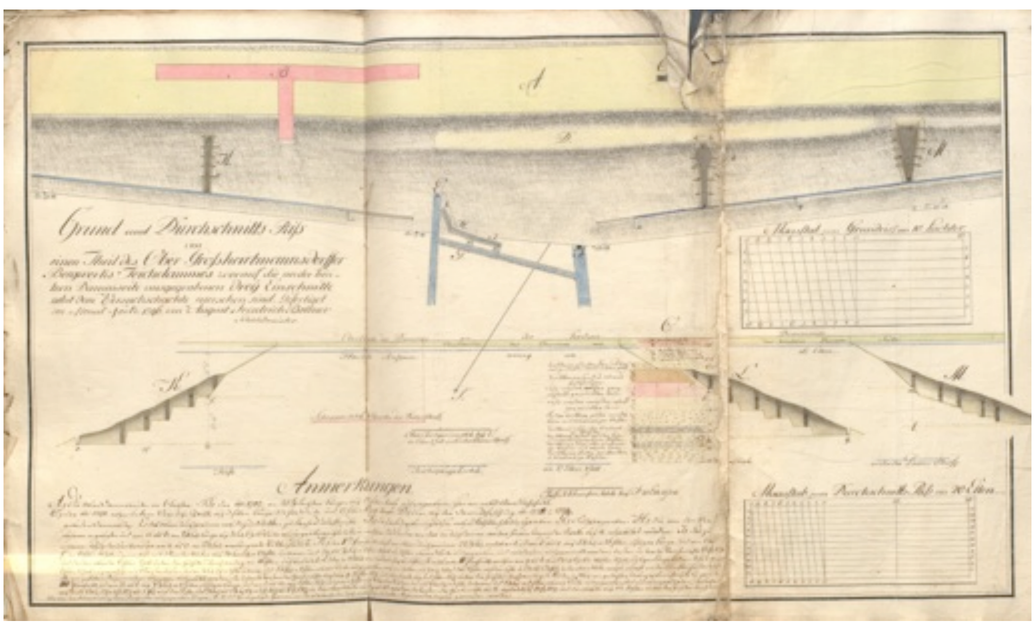

Figure 4. August Friedrich Bollner, "Grund und Durchschnitts Riss von einen Theil des Groshartmannsdorfer Bergwerks Teichdammes," 1796. Sächsisches Staatsarchiv — Bergarchiv Freiberg, 40010 Bergamt Freiberg, Nr. 2927, Blatt 351.

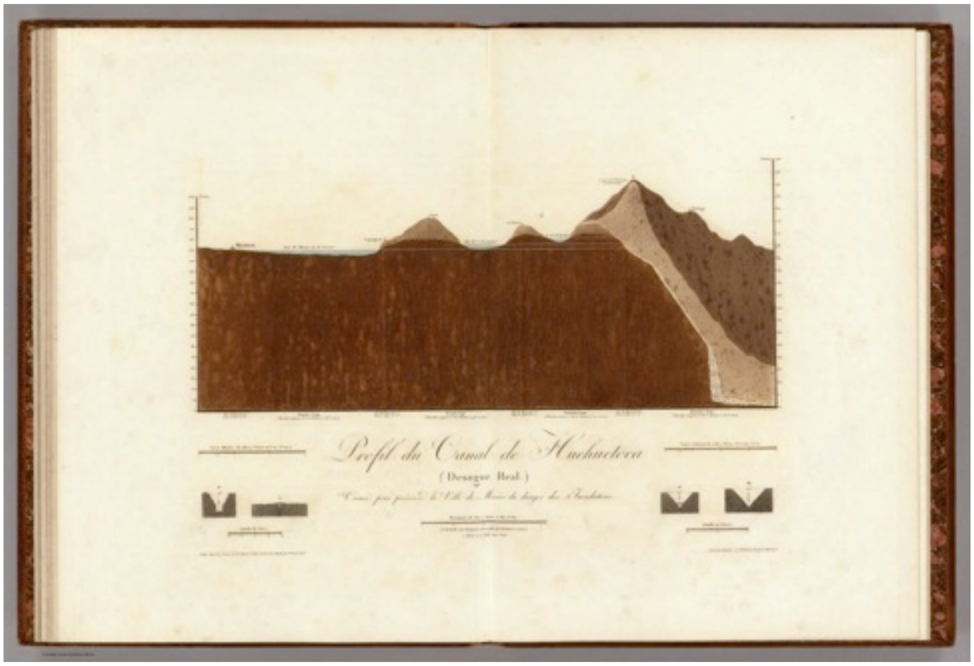

Figure 5. Humboldt's "Profile du Canal de Huehuetoca," engraved in 1808 and published in Paris in 1811 as part of the *Atlas géographique*. It contains large-scale human and natural phenomena as well as the heights of mountains. www.davidrumsey.com

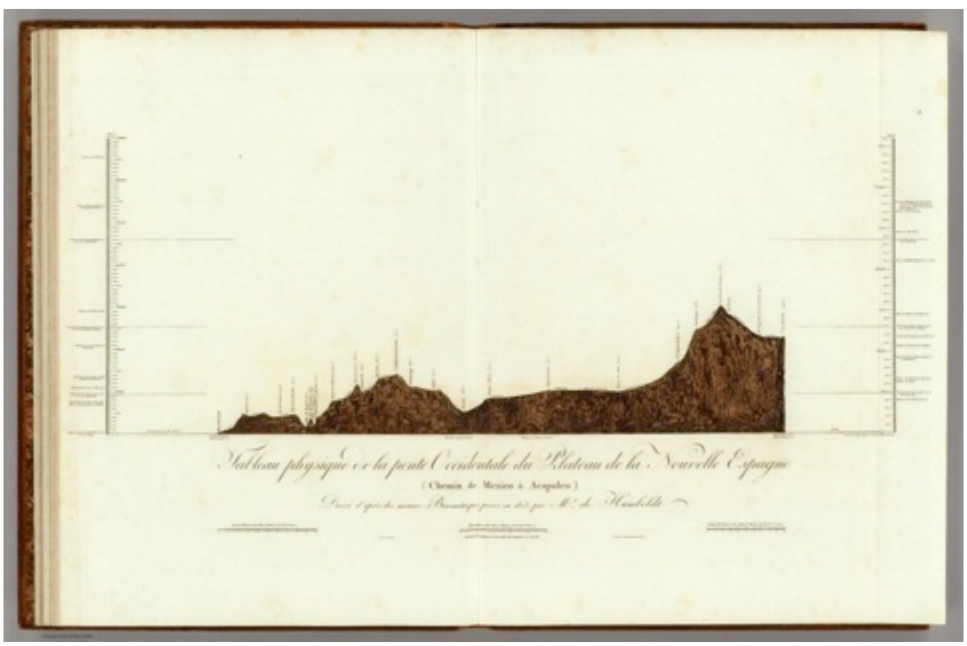

Figure 6. Humboldt's "Tableau physique de la pente Occidentale du Plateau de la Nouvelle Espagne," engraved in 1807 and published in the *Atlas géographique* in 1811. This profile is the left-most third of a three-part series spanning New Spain from coast to coast. www.davidrumsey.com

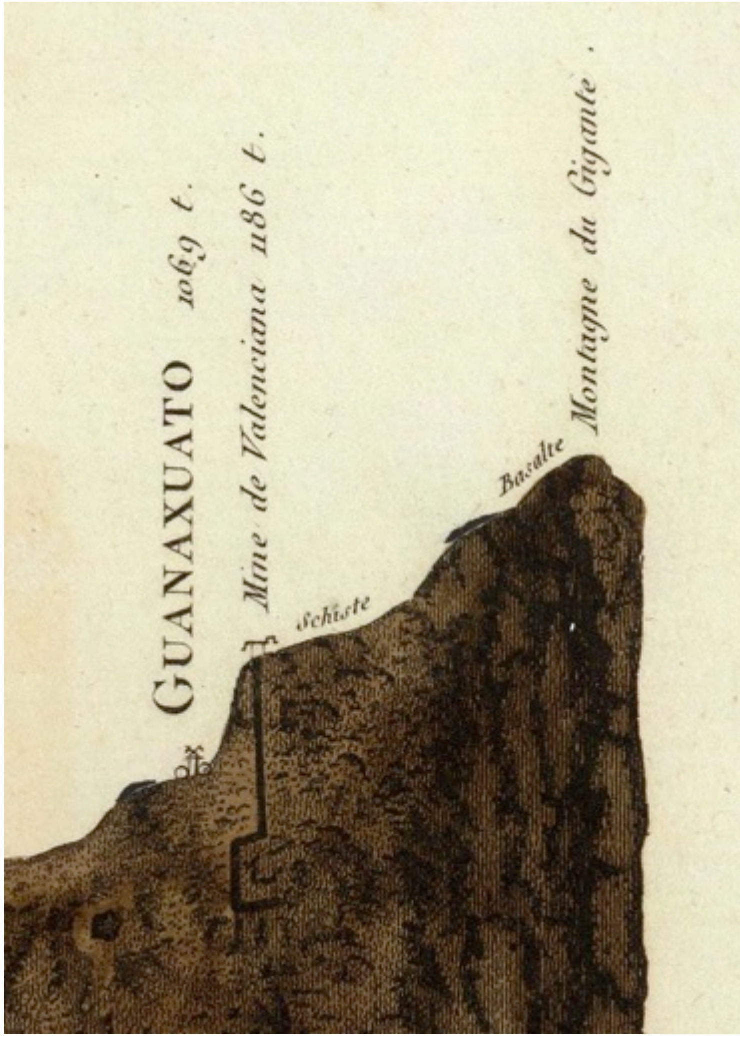

Figure 7. Detail from Humboldt's "Tableau du Plateau central des Montagnes du Mexique, entre les 19 et 21° de Latitude boréale," sketched in 1803 by Humboldt, drafted again in 1804 by Rafael Davalos, and published in the *Atlas géographique* in 1811. The "Tableau du Plateau" is the central section of the three-part series. www.davidrumsey.com

Figure 8. Caspar Wolf, *Innere der Bärenhöhle in Welschenrohr* (*Inside the Bear Cave at Welschenrohr*), 1777, oil on canvas, 42.3 cm. x 34.5 cm., Kunstmuseum Solothurn.

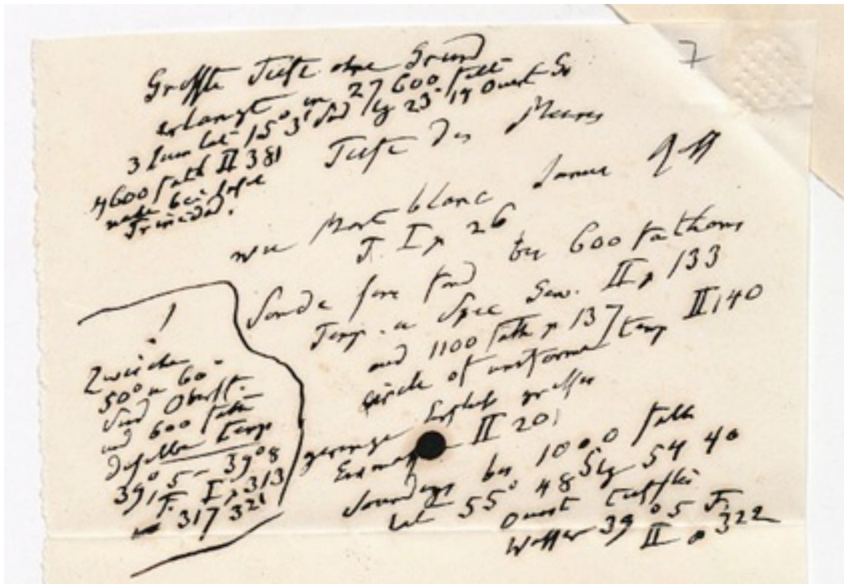

Figure 9. Humboldt's notes on James Ross's *A Voyage of Discovery and Research in the Southern and Antarctic Regions* (1847). Notice in the upper middle part of the note: "Tiefe des Meeres wie Montblanc James Ross T. I p. 26," meaning "depth of the sea like Montblanc." SBB-PK IIIA Nachl. Alexander von Humboldt, gr. Kasten 11, Nr. 72, Blatt 7r.

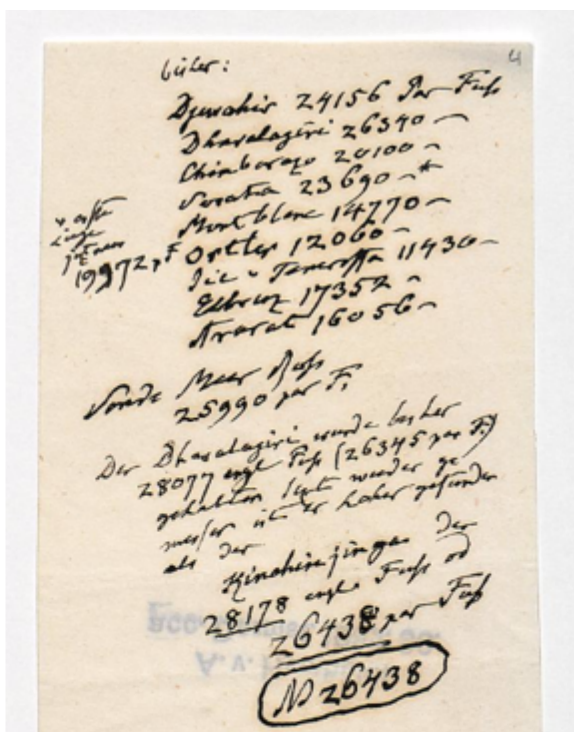

Figure 10. Humboldt's notes on personal letters from Joseph Dalton Hooker. In the center of the note, below Mt. "Ararat 16056," are the words "Sonde Meer Roß 25990 par[iser] F[uss]," meaning "sea soundings [by James Clark] Ross." SBB-PK IIIA Nachl. Alexander von Humboldt, gr. Kasten 8, Nr. 48a, Blatt 4r.