1-1-2010

Leibniz and the Wind Machines

Andre Wakefield
Pitzer College

Leibniz and the Wind Machines

By Andre Wakefield*

ABSTRACT

Gottfried Wilhelm Leibniz visited the Harz Mountains more than thirty times and spent almost three full years there between 1680 and 1686. His aim was to install wind machines for draining the Harz silver mines. Despite Leibniz's best efforts—his commitment bordered on obsession—the enterprise ultimately failed. There is still disagreement about exactly what happened. Biographers and historians have mostly asserted that Leibniz, a universal genius dedicated to the greater good of science and society, was thwarted by stubborn mining officials. Historians of mining, on the other hand, have generally sided with the "professionals" in the Hannoverian mining administration. This essay investigates Leibniz's wind machine project and the narratives it has spawned. Using both Leibniz's published correspondence and unpublished memoranda from the Clausthal mining office, it attempts to answer a series of questions: Was Leibniz thwarted by the mining office? Was he an outsider or an insider? An amateur or an expert? Examining the peculiar role played by investors and shareholders in the Harz silver mines provides the beginning of a solution.

> He [Leibniz] served as a mining engineer, supervising the draining of the silver mines in the Harz mountains. His plan was to use air power, for which he designed windmills, gearing mechanisms, and suction pumps. It all ended in failure, and Leibniz believed that he was undermined by various lower administrators and workers who feared that the technology would cost them their jobs.[1]

Experts are specialists, so a volume about expertise may seem like the wrong place for an essay about Gottfried Wilhelm Leibniz, a man with so many identities and commitments—philosopher, mathematician, inventor, theologian, physicist, diplomat, historian, projector, and philologist—that we, scholars of the present, have lost the ability to treat him as a single individual. Instead, we slice him and dice him, carving his universal genius into the categories of our own specialized world. Anachronism may be unavoidable, but there is no law against examining our prejudices. Who among us, after all, is out building wind machines after a day in the archives?[2]

In examining the role of expertise in Leibniz's life, then, we should not ignore the role of disciplinary specialization in our own time. One effect of such specialization has been disagreement about how to portray Leibniz's activities in the Harz Moun-

* Pitzer College, 1050 N. Mills Avenue, Claremont, CA 91711; awakefield@pitzer.edu.

[1] Roger Ariew, "G. W. Leibniz, Life and Works," in *The Cambridge Companion to Leibniz*, ed. Nicholas Jolley (Cambridge, 1995), 18–42, on 27.

[2] On the vicissitudes of compartmentalizing Leibniz, see Roger Ariew, "Leibniz on the Unicorn and Various Other Curiosities," *Early Science and Medicine* 3 (1988): 267–88, on 287.

tains. Leibniz's biographers, and by extension most of the historians and philosophers who write about him, have accepted the notion, promoted by Leibniz himself, that stubborn officials and miners blocked his efforts at innovation.[3] Historians of mining, on the other hand, have generally argued that Leibniz was out of his depth in the quasi-professional world of the Clausthal mining office (*Bergamt*) and that it was perfectly right for the officials there to block the misguided efforts of this amateur interloper.[4]

The debate over Leibniz's efforts in the Harz contains many unstated assumptions about expertise. Some commentators refer to Leibniz as a "mining engineer," a term that connotes professional expertise, while others consider him an amateur.[5] Leibniz's Harz failure has also been glossed positively as providing the empirical basis for his "geology."[6] The dominant narrative, however, still asserts that stubborn "subordinate agents and workmen" blocked Leibniz, who was motivated only by the general welfare and the greater good of science. In the end, all of this raises more questions than it answers. Was Leibniz really thwarted by the mining office? Was he a mining engineer (i.e., an expert) or an amateur?

All of these depictions are inadequate, because they endeavor to characterize seventeenth-century realities in the categories of the present. It is too easy to fall into the lazy patterns of prefabricated and anachronistic narratives. In fact, collections such as this volume, which look to the past for the origins of the present, are particularly susceptible to such oversimplification. It is an extension of the same problem that Paolo Rossi emphasized three decades ago: "Historians of science—and philosophers of science—flatter themselves that the discipline they study has always existed."[7] In other words, we might be looking for something that is not there. The categories of SEE (studies in expertise and experience), for example, seem to me largely

[3] See E. J. Aiton, *Leibniz: A Biography* (Boston, 1985), 114; John Theodore Merz, *Leibniz* (London, 1902); John M. Mackie, *Life of Godfrey William von Leibniz* (Boston, 1845), 121–2.

[4] See Christoph Bartels, *Vom frühneuzeitlichen Montangewerbe zur Bergbauindustrie: Erzbergbau im Oberharz, 1635–1866* (Bochum, 1992), 92–3; Ulrich Horst, "Leibniz und der Bergbau," *Der Anschnitt* 18 (1966): 36–51.

[5] To Ariew, Leibniz was a "mining engineer" ("Leibniz, Life and Works" [cit. n. 1], 27). To Aiton, on the other hand, "it was hardly a cause for wonder that the professional mining engineers in Clausthal should resent the interference of an outsider, who was in no sense a specialist but whose scheme had been imposed upon them in preference to that of their own expert" (*Leibniz* [cit. n. 3], 108). Alan Cook has argued that Leibniz's episode in the Harz is an example of his propensity for dilettantism. "He was forever thinking up new schemes—scientific, philosophical, historical, engineering, diplomatic—but brought very few to any conclusion. The Elector and his courtiers at Hanover had no illusions about that side of Leibniz's character, but they were never able to get him to concentrate on and complete any one thing" ("The 350th Anniversary of the Birth of G. W. Leibniz, F. R. S," *Notes and Records of the Royal Society of London* 50 [1996]: 153–63, on 158). Nicholas Rescher has used the same information to make the opposite claim, arguing that Leibniz was pleased with his position at the Hannoverian court because "step by laborious step, [he] gradually succeeded in creating for himself a totally nonstandard niche as intellectual factotum, an expert-in-residence on matters of learning, science, and technology in a way unprecedented before and unparalleled after" (*On Leibniz* [Pittsburgh, 2003], 192). The latest biography of Leibniz is excellent on the details of the episode but also perpetuates the narrative of "hard-headed mountain men" standing in the way of Leibniz's success (Maria R. Antognazza, *Leibniz: An Intellectual Biography* [Cambridge, 2009], 210–3, 227–30).

[6] Mackie, *Leibniz* (cit. n. 3), 121–2. By Leibniz's "geology" is meant his history of the earth, the *Protogaea*, written between 1691 and 1693. It first appeared in print in 1749 and has only recently been translated into English. Leibniz, *Protogaea; sive, De Prima Facie Telluris et Antiquissimae Historiae Vestigiis in Ipsis Naturae Monumentis Dissertatio,* ed. Christian Ludwig Scheidt (Göttingen, 1749); Leibniz, *Protogaea,* ed. and trans. Claudine Cohen and Andre Wakefield (Chicago, 2008).

[7] Rossi, *The Dark Abyss of Time: The History of the Earth and the History of Nations from Hooke to Vico* (Chicago, 1984), vii.

useless as a way to analyze the dynamics of Leibniz's seventeenth-century world.[8] We might, along these lines, approach Leibniz's Hannover as a proto-technocracy, seeing in his struggle with the Bergamt sure signs that the state was beginning to monopolize expertise and science. But this begs all of the most important and interesting questions.

That said, the themes developed in this volume are certainly relevant to my case study. Leibniz's struggle with the Bergamt was, in the first instance, about competing forms and locations of expertise. It is not clear, looking back, where exactly the boundaries of the state started or ended. Leibniz cultivated allies at court, while the Bergamt, subordinated to the *Kammer* in Hannover, was part of the territory's administrative apparatus. There existed, then, no inside or outside, no well-defined public or private. It was not even a clear case of Leibniz versus the mining office, because several important mining officials took his side. Instead, this episode played itself out as an internecine struggle within the state. As will become clear, moreover, the locus of conflict was the Kammer, the sovereign treasury or "chamber" that formed the heart of early modern German fiscal administration.[9]

Hannover's Kammer and Bergamt, together responsible for administering the mines of the Harz, were collegial bodies; that is, all decisions were discussed and made in council by those who had the power of *Sitz und Stimme*, that is, those who had a voice. Other than the duke himself, then, the Kammer had the ultimate power of decision on new projects and enterprises. Members of the Kammer would often seek advice about such projects from those with specialized knowledge. But, as in this case, there could be conflicts of interest—Leibniz's involvement with the Harz wind machines seems to have begun when he reviewed a project submitted by Peter Harzingk, a mining official in Clausthal. After rejecting Harzingk's project, Leibniz ended up proposing to do essentially the same thing himself.

If there is any lesson in all of this, it is that our existing categories and language—this includes "state" and "expertise"—are inadequate. Narrative form is part of the problem, because it is too easy to make the state and expertise and "science" into actors that drive our stories. These are, however, exactly the terms that need to be dissected and analyzed. I hope therefore that this case study succeeds in making a bigger mess of the past. There is no unilinear narrative about the rise of the state and the role of expertise in that rise. Looking out from Leibniz's Hannover into the future, there were many possible worlds. We live in only one of them.

THE HARZ: WATER, SILVER, POWER

The administrative landscape of the Harz was extraordinarily complex. The upper Harz had been divided among several masters since 1635, when the three lines of the Guelph dynasty agreed to share revenues from the forests and mines there. When

[8] I am referring to the analysis in Harry Collins and Robert Evans, *Rethinking Expertise* (Chicago, 2007), 1–44. I have no quarrel with the notion that, for example, their research program rests on "Scientism," or the view "that science should be treated not just as a resource, but as a central element of our culture" (11). On the other hand, I do not think that it helps me understand the seventeenth century.

[9] For more on science, mining, and the Kammer, see Andre Wakefield, *The Disordered Police State: German Cameralism as Science and Practice* (Chicago, 2009), 16–22, 26–48.

the Harburg line died out in 1642, its shares were reapportioned between the surviving lines, so that Calenberg-Hannover (receiving four-sevenths) and Wolfenbüttel (three-sevenths) together administered what now became known as the "Communion Harz." After the death of Duke Christian Ludwig of Braunschweig-Lüneburg in 1665, the Hannoverian line acquired more territory, so that Duke Johann Friedrich of Hannover now came to possess most of the upper Harz. His lands now included the so-called Unilateral Harz, which was administered independently, and four-sevenths of the Communion Harz.[10] Leibniz conducted his experiments during the 1670s and 1680s in both the Unilateral and the Communion Harz. The administrative center of these possessions was located in the adjoining mining towns of Clausthal and Zellerfeld.[11]

In the middle of Clausthal was a large central mining office, or *Oberbergamt*, where records were kept, salaries were paid, and the territory's highest-ranking mining officials met in council to discuss business. The Clausthal Oberbergamt was subsumed under the Kammer of the duke. It was thus, first and foremost, a subordinate part of the territory's fiscal administration, with central offices in Hannover. The *Berghauptmann*, head of the Bergamt, answered directly to his colleagues in the Kammer. In fact, the position of Berghauptmann was a common stepping-stone to a powerful position in the Kammer. The Clausthal Oberbergamt—a huge, imposing structure that dominated its isolated mountain town—provided a constant physical reminder of sovereign power.[12]

In the hard-rock mines of central Europe, water was both a bane and a blessing—a bane because standing water and constant flooding in the shafts restricted access to many of the richest veins; a blessing because water constituted the most important source of power for the large silver mines of Leibniz's time, serving to drive pumps, move ore, and run large stamping works. The Harz mines around Clausthal and Zellerfeld were especially famous for their elaborate systems of water control, mechanisms constructed over decades and centuries.[13]

At the heart of the Harz water-management system was a network of holding ponds (*Teiche*). These holding ponds, generally located high above the mines to maximize the force of the falling water, drove the waterwheels that powered the drainage pumps. As the local representative of the duke's central government, the Bergamt took responsibility for planning and building new holding ponds. These expensive projects often demanded hundreds of thousands of man-hours and took decades to

[10] The other three-sevenths still belonged to the Duchy of Wolfenbüttel.

[11] Zellerfeld was the administrative center of the Communion Harz, whereas Clausthal housed the administrative center of the Unilateral Harz. The two towns joined together during the twentieth century into a single municipality, Clausthal-Zellerfeld. Bartels, *Montangewerbe* (cit. n. 4), 48–54; Wilfried Liessmann, *Historischer Bergbau im Harz: Ein Kurzführer* (Berlin, 1997), 17.

[12] Günter Scheel, "Einleitung," in Leibniz, *Sämtliche Schriften und Briefe*, ser. 1, *Allgemeiner Politischer und Historischer Briefwechsel* (hereafter cited as *Sämtliche Schriften*), supp. vol., *Harzbergbau* (Berlin, 1991), xxvii–xlv. This special volume of the *Sämtliche Schriften* covers the second episode of Leibniz's involvement with the Harz mines (1692–6), but Scheel also provides useful information in his introduction about the earlier episode, which is the focus of this article. See also Bartels, *Montangewerbe* (cit. n. 4), 48–54. The Oberbergamt in Clausthal, rebuilt in 1725 after a fire, still dominates the town of Clausthal-Zellerfeld today. The sheer size of the building provides a physical reminder of the scale of administrative operations during the late seventeenth and early eighteenth centuries.

[13] On the water-management system in the upper Harz, see Martin Schmidt, *Die Wasserwirtschaft des Oberharzer Bergbaues* (Bergisch Gladbach, 1989).

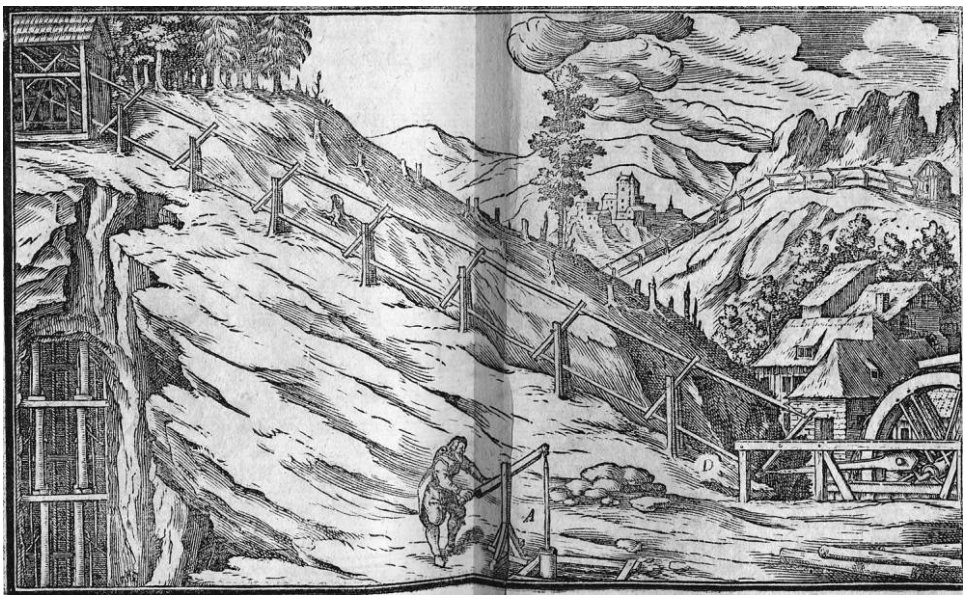

Figure 1. *Reciprocating rods (*Feldstangen*) and hand pumping in the seventeenth-century Harz, as depicted in Georg Engelhard von Löhneyss,* Bericht vom Bergkwerck *(Zellerfeldt, 1617). Reprinted courtesy of Honnold Library Special Collections, Claremont Colleges.*

complete. During Leibniz's time, the fifteen holding ponds around Zellerfeld alone had a capacity of some 70 million cubic feet of water.[14]

Even more costly and elaborate than the holding ponds were the drainage tunnels (*Stollen*) that emptied the mines of water. The sheer scale and ambition of these projects, the earliest of which were initiated during the mid-sixteenth century, is staggering. Miners, working mostly with hammer and chisel, carved tunnels many miles long. It was an extraordinary, and extraordinarily expensive, endeavor, because miners produced no silver while digging the Stollen. The legendary "19-Lachter Stollen," started in 1551, took 130 years to complete. Its back end was located next to the Catherina Mine, near the place where Leibniz would erect his first wind machine.[15]

The mines, holding ponds, and drainage tunnels were linked together by a complex network of trenches, waterwheels, and reciprocating rods (*Feldstangen*).[16] And yet, despite all of these technologies for draining water and capturing its energy, the mines of Leibniz's time still relied very much on traditional methods of water

[14] Hugo Haase, *Kunstbauten alter Wasserwirtschaft im Oberharz* (Clausthal-Zellerfeld, 1966), 53. During DDR times, the towns of Clausthal and Zellerfeld still relied on hydropower from the old Teiche. In the German lands, the Harz mining districts were at the vanguard of large-scale, sophisticated dam building. The massive Oderteich, constructed between 1714 and 1721, eventually held enough water to drive forty-seven waterwheels. See Terry Reynolds, *Stronger Than a Hundred Men: A History of the Vertical Water Wheel* (Baltimore, 1983), 130–1. The holding ponds and water-management techniques of Leibniz's time, though not of this scale, were precursors to these later projects.

[15] Leonhard Stiegler, "Leibnizens Versuche mit der Horizontalwindkunst auf dem Harz," *Technikgeschichte* 35 (1968): 265–92.

[16] During the seventeenth and eighteenth centuries, these Feldstangen, or *Stangenkünste*, sprouted up all across the Harz. Though large and extremely expensive to build, they constituted the only way to transfer waterpower from its source to some distant point. One of Leibniz's arguments in favor of the wind machines was the possibility that they would obviate the need for Feldstangen.

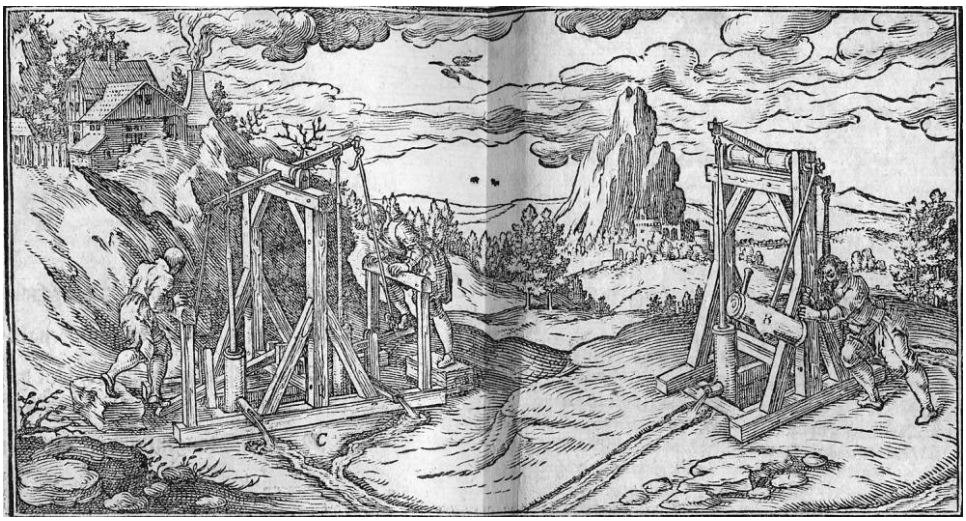

Figure 2. *Though common, hand pumping demanded considerable labor, a scarce commodity in the mines of the Harz Mountains. From Löhneyss,* Bericht vom Bergkwerck. *Reprinted courtesy of Honnold Library Special Collections, Claremont Colleges.*

drainage. Some miners, that is, still hauled leather bags full of water up on drumwheels to drain the mines; others pumped by hand to clear the mine shafts. In addition, some mines used horsepower to haul ore out of the mines.[17]

But somatic energy, the work of men and animals, was a scarce commodity in the Harz. For centuries princes and dukes had offered special privileges and incentives to lure men to do the difficult and dangerous work of the mines. It was easier to recruit soldiers than miners. Territories routinely prohibited planting and grazing in the mountain regions, because it took horses and men away from the work of the mines.[18] But this increased even more the expense and hardship associated with mining, because food had to be shipped to the mountains, and in tough times the mountain people went hungry. For all of these reasons, there was never enough manpower and animal power to do everything that needed to be done. Rich veins had to be abandoned because, at a certain point, the expense of draining water outstripped the gains from additional silver ore.[19]

The mines of early modern Germany collected most of their necessary operating and investment capital from groups of investors (*Gewerken*), who bought shares (*Kuxen*) in the mines.[20] Without support from Gewerken, mines had to be abandoned. One of the main jobs for the mining administration and its officials, therefore, involved courting investors and convincing them to maintain their contributions. Since most mines lost money, this was no easy task. The administration had to convince in-

[17] Stiegler, "Leibnizens Versuche" (cit. n. 15), 266.
[18] Bartels, *Montangewerbe* (cit. n. 4), 231–5.
[19] Stiegler, "Leibnizens Versuche" (cit. n. 15), 266.
[20] Most mines were divided into 128 shares. In some cases, however, especially where large projects demanded much capital, coordinated groups of Gerwerken (each group having 128 shares) would combine resources. See also Liessmann, *Historischer Bergbau im Harz* (cit. n. 11), 254–5; Bartels, *Montangewerbe* (cit. n. 4), 65–6.

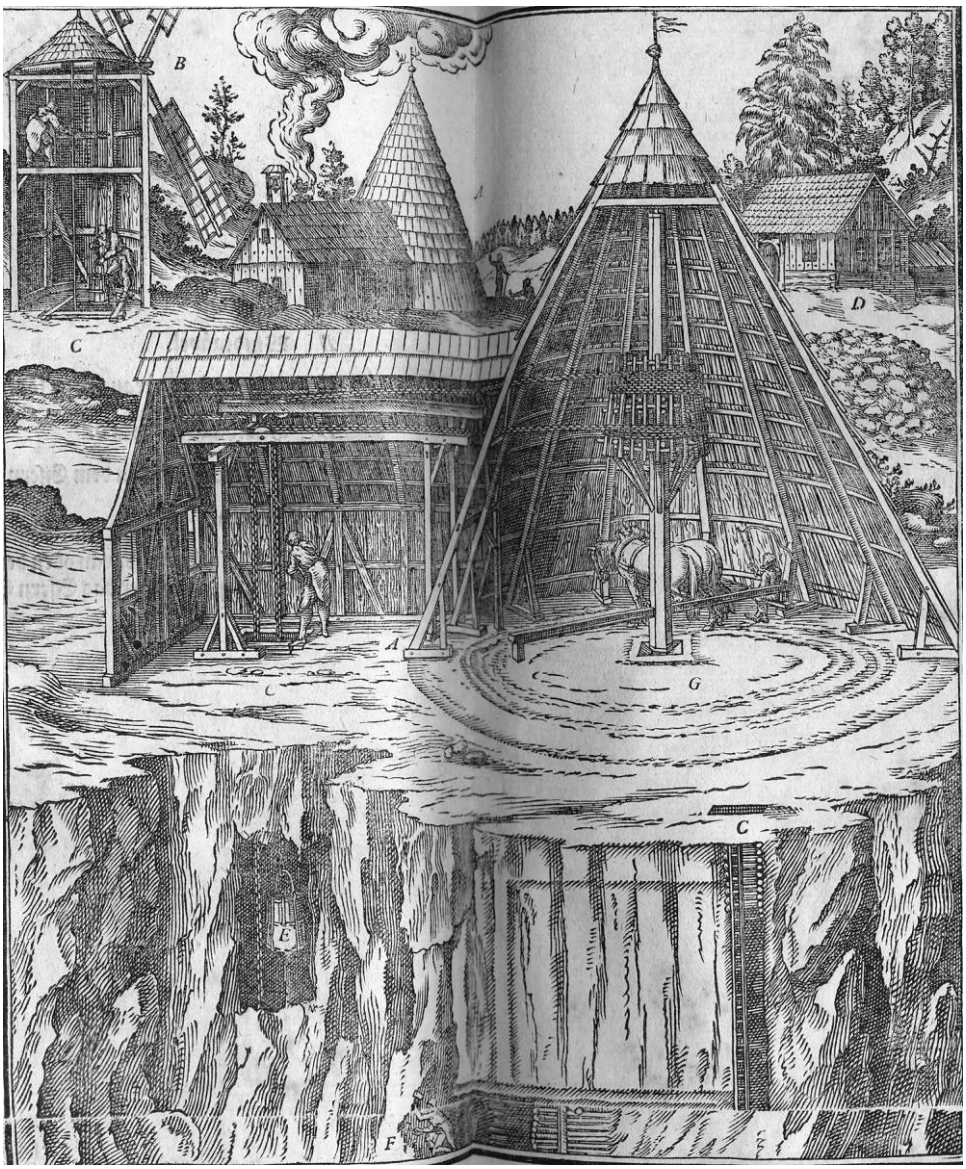

Figure 3. *The so-called* Pferdegöpel, *a common though expensive technique for lifting ore and other materials out of the mineshafts. From Löhneyss,* Bericht vom Bergkwerck. *Reprinted courtesy of Honnold Library Special Collections, Claremont Colleges.*

vestors that the odds of a rich strike were good. Most of the mining districts in central Europe witnessed a tripartite division of capital, labor, and management during the seventeenth and eighteenth centuries. In the Habsburg lands of "lower Hungary" and the Erz Mountains of electoral Saxony, for example, state officials increasingly took control over the everyday planning and operation of mines during this period; the role of miners' groups (*Gewerkschaften*) and Gewerken, meanwhile, became increasingly limited to providing labor and capital, respectively.

But the Harz mines followed a different path. Here, many state officials were also important members of the Gewerken, combining the interests of administration and capital. Some historians have recently emphasized the importance and peculiarity of these "shareholder-officials" (*Beamten-Gewerken*) in the Harz.[21] For example, it is a well-known fact among mining historians that a 1684 edict guaranteed a considerable percentage of shares to Hannoverian mining officials. Still, much recent scholarship continues to emphasize the mining administration's commitment to the general welfare, without reference to the manifest financial self-interest of a shareholding bureaucracy. Christoph Bartels, who stresses the importance of shareholder-officials, finds it "amazing that recent publications mostly do not bring up the ownership of shares by *Beamten* and create the impression that the mining administration was composed of neutral officials."[22] For our purposes, it is important to note that the formalization of claims for shareholder-officials during the early 1680s coincided precisely with Leibniz's efforts to establish his wind machines in the Harz.

LEIBNIZ IN THE HARZ

If you wander the streets of Clausthal-Zellerfeld, a (now) romantic little town in the Harz Mountains, you may stumble upon the house where Leibniz worked. There is a small plaque above the door that reads, "Former Ludwig Zechenhaus . . . In this house, the court councillor Leibniz conducted many discussions with mining officials about the wind machines established at the Catharina Mine during the years 1680–1685." That is a nice way to put it—probably too nice—but it is true that Leibniz spent a lot of time there. Between 1680 and 1686, he visited the Harz Mountains more than thirty times and spent almost three full years there.[23] You might say they were his obsession. These were productive years: Leibniz published his first papers in the *Acta Eruditorum*, developed the differential calculus, created diplomatic strategy for the House of Hannover, worked on reconciliation between the Catholic and Protestant churches, and composed the *Discourse on Metaphysics*. Given how much has been written about Leibniz, it is strange how little we know about his failed venture in the Harz.[24]

[21] See Bartels, *Montangewerbe* (cit. n. 4), 269–79, 295–300.

[22] Ibid., 53. Not everybody agrees with Bartels's assessment. Johannes-Traugott Greuer, especially, has questioned his evidence and rejected some of the claims about the self-interest of the mining administration; see his *Kuxbesitz von Bergbeamten und Oberharzer Bergwerksverwaltung (1650–1750)* (Clausthal-Zellerfeld, 1997).

[23] Paul Ritter estimates that Leibniz spent a total of 165 weeks in the Harz between 1680 and 1686 (Ritter, "Einleitung," in *Sämtliche Schriften*, 3:xxvii–lxvi; Aiton, *Leibniz* [cit. n. 3], 108). He returned again to conduct more experiments during the years 1692–6.

[24] Most intellectual biographies of Leibniz do not mention his Harz venture at all. Others mention it in passing. Antognazza, *Leibniz* (cit. n. 5), and Aiton, *Leibniz* (cit. n. 3), are best on the details of the Harz episode. There exist a handful of detailed studies by historians of technology, all in German. See Stiegler, "Leibnizen's Versuche" (cit. n. 15); Horst, "Leibniz und der Bergbau" (cit. n. 4); Ulrich Horst and Jürgen Gottschalk, "Über die Leibnizschen Pläne zum Einsatz seiner Horizontalwindkunst im Oberharzer Bergbau und ihre mißglückte Durchführung," in *Akten des II. Internationalen Leibniz-Kongresses Hannover, 17.–22. Juli 1972*, 4 vols. (Wiesbaden, 1973), 1:35–59. Scholars have come to recognize the significance of mines and mining for Leibniz's geology, but the detailed history of his ambitions in the Harz has received less attention. See Claudine Cohen, "Leibniz's *Protogaea*: Patronage, Mining and the Evidence for a History of the Earth," in *Proof and Persuasion*, ed. Suzanne Marchand and Elizabeth Lunbeck (Turnout, 1996), 125–43, and Ernst Hamm, "Knowledge from Underground: Leibniz Mines the Enlightenment," *Earth Sciences History* 16 (1997): 77–99. The definitive Berlin Academy edition of Leibniz's writings (the *Sämtliche Schriften*), which treats the Harz

Figure 4. *The Ludwig Zechenhaus, where Leibniz frequently met and debated with Clausthal's mining officials. Photo by the author.*

Over the course of almost two decades, Leibniz cultivated close relationships with Hannoverian rulers and officials—that is, with those who controlled policy in the Harz mines. During the 1680s Leibniz began corresponding with Otto Arthur von Dithfurth, an influential official who, during the period of Leibniz's experiments, would rise through the ranks of the mining office until, in 1686, he was appointed Berghauptmann in Clausthal.[25] During this time, Leibniz also got to know Heinrich Albert von dem Busch, who would become Berghauptmann himself after Dithfurth's death.[26] Busch would eventually rise to become president of the Kammer, the highest fiscal official in the land. When Dithfurth and the mining office got into trouble with the Gewerken, Leibniz provided free legal advice. He also provided advice to Dithfurth about the claims of alchemist David Kellner. Leibniz's efforts to cultivate important allies worked so well that he ended up staying at Dithfurth's house during one of his frequent visits to the Harz.[27]

Leibniz accomplished the same thing in Hannover, where another supporter, Otto Grote, headed up the Kammer. Other allies in the Hannoverian Kammer, especially Albrecht Philipp von dem Busch, gave Leibniz considerable influence at court. Most important, these friends and supporters gave Leibniz access to the secret proceedings

material as a special case, reproduces only a fraction of the available archival sources on Leibniz's activities there. See also Ritter, "Einleitung" (cit. n. 23), xxviii–xxix.

[25] Dithfurth served as Berghauptmann from 1686 to 1695. He oversaw sweeping technical innovations before his death in 1695. Bartels, *Montangewerbe* (cit. n. 4), 182–3.

[26] Son of a major shareholder in the Harz mines, Busch came from a family of shareholder-officials. In 1689, after attending the University of Leipzig, he became a mining official in Clausthal. In 1695, at the age of 31, he rose to become the youngest Berghauptmann in Clausthal's history. See Bartels, *Montangewerbe* (cit. n. 4), 285–90, and Hans Burose, "Markscheider Bernhard Ripking: Sein Leben, sein Wirken und sein Briefwechsel mit Gottfried Wilhelm Leibniz," *Der Anschnitt* 19 (1967): 17–25.

[27] Scheel, "Einleitung" (cit. n. 12), xxxii.

of the Kammer. Albrecht Philipp von dem Busch, especially, would send him copies of relevant proceedings and decisions. It was privileged access, because members of the Kammer were sworn to secrecy about all proceedings. Most important of all, however, Leibniz had direct access to Dukes Johann Friedrich and Ernst August, who could overrule any decision made by the Bergamt or the Kammer (advisory bodies to the sovereign).[28]

Given Leibniz's impeccable connections, it is hard to explain why his efforts ultimately failed to achieve support. One thing is clear, however: the most common explanation for Leibniz's failure does not make sense. It is, in other words, difficult to maintain that Leibniz, a genius from the outside, was blocked by backward mining officials, who were on the inside. Leibniz was the consummate insider, a man who had the firm support of Hannover's most influential people. We must look for other explanations.

Henning Calvör's 1763 history of Leibniz's Harz venture began not with Leibniz, but with Peter Harzingk, a prominent official in the Clausthal Bergamt who had studied in Leiden and was thus well acquainted with the latest Dutch wind machines.[29] Harzingk, Calvör explained, "had proposed to pump the water out of the mines with windmills, and to store up the water when the wind was blowing." He had prepared a model wind machine, and his proposal had gotten favorable reviews from both the duke and the Bergamt. Even the Gewerken had expressed support for the plan, providing 800 taler to cover costs. But then something strange happened. According to Calvör's account, soon after Duke Johann Friedrich had resolved to build Harzingk's machine, he informed the Bergamt that Leibniz was its true inventor. "One can therefore assume," explained Calvör, "that the model had been sent from Hannover—from whom one did not know—to Court and Mining Councillor Harzingk, in order to gauge the Bergamt's opinion about it."[30]

In light of the documents we now have, Calvör's explanation makes even less sense than it did two and a half centuries ago. Witness the memorandum to Duke Johann Friedrich on December 9, 1678, in which Leibniz dismissed Harzingk's plan as completely worthless. Harzingk had proposed that windmills be used to pump water back into the holding ponds, but Leibniz argued that evaporation would render the system ineffective. "I find that the effect will be very small and that the expense will be very considerable." The whole thing was unnecessarily complex, and it would be "easy to prove" that most of the water would be lost to seepage and evaporation. "I believe I have demonstrated the loss of water," he continued, but there might be an even greater loss of force due to the friction of the pumps. The memorandum denigrated Harzingk's vision of using wind to recycle the water because of these manifest inefficiencies. One could do much better. Leibniz could do much better.[31]

In place of Harzingk's scheme, Leibniz offered more efficient pumps and a more effective type of windmill. He was at this time—the winter of 1678/9—engaged in a bitter priority dispute with Harzingk, who was an important official in Clausthal.

[28] Ibid., xxxiii.

[29] Horst and Gottschalk, "Leibnizschen Pläne" (cit. n. 24), 40.

[30] Calvör, *Acta Historico-Cronologico-Mechanica circa Metallurgicam in Hercynia Superiori. Oder Historisch-chronologische Nachricht und theoretische und practische Beschreibung des Maschinenwesens, und der Hülfsmittel bey dem Bergbau auf dem Oberharze* (Braunschweig, 1763), 101. These translations and all others in the article are my own, unless otherwise noted.

[31] Leibniz to Duke Johann Friedrich, 9 December 1678, in *Sämtliche Schriften*, 2:99–103.

Harzingk had the mining office on his side, but Leibniz, with his own connections at court, was not without important friends. His memoranda from this period were not only crafted to convince duke, court, and Kammer that he had the best plan; they were also meant to convey that it was *his* plan (and not Harzingk's).[32]

Leibniz could be a sweet-talker. And when he talked sweet, pitching one project or another, he often did it in French, the language of dignitaries, dukes, and princesses. Early in 1679, after visiting the Harz Mountains, Leibniz promised Duke Johann Friedrich that he knew how to tap vast new riches in the mines there. One only had to harness the combined forces of wind and water while eliminating unnecessary friction. With new pumps and wind machines, Leibniz promised, one could drain the mines and keep them drained. He had designed a pump that could lift water from more than a thousand feet down, a pump "so new, and so important, that if there is one thing in mechanics that merits being kept secret, I believe this is it."[33] He promised to keep costs as low as possible while maximizing benefits. Nor did he doubt that there were hidden riches in the Harz, waiting to be discovered. One simply had to go deeper. That meant eliminating troublesome groundwater, the age-old curse of the mines, a problem that had preoccupied, frustrated, and defeated mining men for centuries. Leibniz claimed to have solved it. His memo to the duke imagined a subterranean world largely free of flooding.

> The mines will be in a flourishing state, the miners will always have work, but most important, the success of this venture will encourage people to undertake new mines or to reestablish old ones that have been neglected for lack of water. The noise of such a great success will also attract strangers to invest money in the mines.[34]

Leibniz played on alchemical dreams of transmutation to sell his own venture. Like the alchemists before him, he promised vast wealth from the fruits of secret knowledge. If the forces of nature could be harnessed to work the mines, there would be no need for transmutation; the silver was there already, in the bowels of the Harz. The issue was simply how to recover it.

Johann Friedrich was convinced, and he promised to support the plan. Leibniz in turn demanded full control over the project, and he took the opportunity to pitch other projects, including an academy of sciences and a universal language. Officials in Clausthal were not so sure, but they could not keep Leibniz from drawing up agreements with the Bergamt. He had already worked out a lifelong stipend of 1,200 taler annually, to be paid after a successful trial period. But trouble was brewing behind the scenes. There was concern about expenses, and there were suggestions that "some persons versed in mechanics" should be consulted to determine the viability of his machines. Leibniz, however, rejected all outside interference, arguing that the trial period would be sufficient to judge his inventions. "Experience," he explained, "is in my opinion a better judge than those gentlemen." Duke Johann Friedrich, to the dismay of his officials, sided with Leibniz, who concluded a formal agreement with the Bergamt in October 1679.[35]

[32] Aiton, *Leibniz* (cit. n. 3), 87–8; *Sämtliche Schriften*, 2:99–103.
[33] *Sämtliche Schriften*, 2:126–30, quotation on 129–30; Aiton, *Leibniz* (cit. n. 3), 87–9.
[34] *Sämtliche Schriften*, 2:129–30.
[35] Ibid., 2:207–12, quotations on 207–8. Aiton describes these "persons versed in mechanics" as "experts" (*Leibniz* [cit. n. 3], 89–90).

Duke Johann Friedrich died about two months later, in January 1680. Leibniz now needed to secure the patronage of the new duke, Ernst August, before his Harz project could move forward. Once again members of the Bergamt raised objections; and once again they were overruled by the duke, who accepted Leibniz's explanations. By April 1680 Leibniz had a new agreement in hand, but the terms were even better: the cost of the trial would be borne equally by Leibniz, the Bergamt, and the duke. If it proved successful, Leibniz would have his lifetime pension.[36]

Leibniz arrived in the Harz in the late summer of 1680 and stayed for a while. He seems to have changed his mind about the Harz project by this time. Instead of draining water directly with his newfangled pumps and windmills, Leibniz now proposed to recycle water by pumping it back up into the holding ponds, where it could be reused again as waterpower. The new scheme looked much like what Harzingk (now dead) had proposed earlier (recall that Leibniz had dismissed that plan as unworkable in 1678).[37] The Bergamt protested vigorously. Leibniz had gotten a contract to do one thing, and he was now promising to do something else. Not only that, but he was hoping to reap financial rewards from Harzingk's idea. Eventually, a special commission determined that Leibniz should build both models: (1) the direct wind machine that he had originally proposed, and (2) the indirect wind machine that would recycle water from the mines back into the holding ponds.[38]

Despite Leibniz's many claims about uniqueness and originality, there was little new about what he was proposing.[39] Harzingk, who served in Clausthal from 1672 to 1680, had established his own laboratory in the Harz to experiment with wind machines. Moreover, he had claimed the right of invention over those machines. Harzingk's years of experience gave him more authority on the subject than Leibniz could hope to claim, and he had explained as much to the Kammer in Hannover. As one of Leibniz's intimates wrote in April 1680, only Harzingk's death could clear the way for Leibniz's plans. Happily for Leibniz, that is just what happened. After Harzingk's death, Leibniz had more freedom to move ahead with his inventions, but Harzingk's colleagues at the Bergamt in Clausthal continued to resent the newcomer and his elaborate, even dishonest, promises.

How innovative were Leibniz's wind machines? He made many claims about their novelty. Moreover, those claims have been repeated because virtually every treatment of Leibniz's activities in the Harz has relied on the *Sämtliche Schriften* published by the Berlin Academy of Sciences to reconstruct what happened.[40] But Leibniz's published correspondence, imposing though it may be, represents only one side of the story. The voices of the mining officials who disagreed with Leibniz have mostly been silenced by generations of editors. Leibniz's claims to novelty were part of a strategy designed to secure lasting future benefits—patents, monopolies, privileges—from his inventions. Bartels, who actually looked at the archival materials in Clausthal, came away with a different perspective. "It is not at all true," he claims, "that the mathematician Leibniz provided lessons in scientific method to mining technicians. It was much more the other way around, that they were extremely skeptical about

[36] Aiton, *Leibniz* (cit. n. 3), 100–4.
[37] *Sämtliche Schriften*, 3:66–73.
[38] Aiton, *Leibniz* (cit. n. 3), 108.
[39] Bartels, *Montangewerbe* (cit. n. 4), 91.
[40] For reconstructions based on these materials, see, e.g., Aiton, *Leibniz* (cit. n. 3), and Stiegler, "Leibnizens Versuche" (cit. n. 15).

his plans, and that they favored the use of waterpower. And they were correct in their arguments."[41]

During the next few years Leibniz spent a lot of time in the Harz. He traveled there at every opportunity, struggling with ornery miners, skeptical mining officials, and weather that refused to cooperate. His letters from these years indicate that despite his close relationships with some high-ranking officials, there were others who disliked him and thought that he was purely self-interested.[42] During 1681 and 1682, the situation deteriorated. Leibniz, who was now spending months at a time in the Harz, believed that recalcitrant and dishonest officials were obstructing his work. Even as he struggled with the Bergamt, he sang the praises of the Harz to Duke Ernst August. The riches were there, in the ground, waiting to be extracted. One only had to develop the right techniques and machines.[43]

While Leibniz dreamed of possible futures, costs kept rising and his machines kept breaking. Every time a machine broke, Leibniz invented something new to deal with the problem: thicker pipes to handle the compressed air he had introduced, or special sails that would regulate the speed of the windmills he had built. By 1683 costs had risen to 2,270 taler, over seven times what Leibniz had originally proposed for the construction of a windmill. One can only imagine the frustration at the Bergamt. In December 1683 the duke cut off funding, but Leibniz decided to continue on at his own expense. Testing of the wind machines began in the spring of 1684.[44] Unfortunately, the wind hardly ever blew, and when it did blow it usually came from the wrong direction. Once or twice, in the middle of the night, the machine seems to have worked, but the subaltern mining officials who observed the tests, thrown out of bed in the middle of the night, did not offer much useful information. Mostly, though, Leibniz's wind machines just sat there, waiting for the wind to blow.

On February 23, 1684, seven prominent members of the Clausthal Oberbergamt sent a report about Leibniz's wind machines to the Kammer in Hannover.[45] After years of testing, the officers rendered a starkly negative verdict on Leibniz's machine. Reports from the field, they argued, made it clear that his windmill had rarely functioned. In fact, it had operated far less often than the local windmill that was used for grinding grain. "The proponent," they emphasized, "has not accomplished what he promised to do; namely, that as often as this one [the grinding mill] operated, the other one should operate too." It was clear to them that Leibniz's machine fell far short of the criteria stipulated in the official contract he had signed years earlier.

But the officials did not reject Leibniz's plan on a mere legal technicality. They also wondered about the viability of the entire project. The machine seemed very unreliable, so that one never knew when it would pump. Equally troubling was its small capacity, so that when it did operate, it drained less water than an ordinary water-powered pump. The whole affair seemed impractical; that is to say, it seemed incapable of paying for itself. "If one regard[ed] the reported operation with a trained

[41] Bartels, *Montangewerbe* (cit. n. 4), 92. The archival materials that detail some of the discussions between Leibniz and the mining officials are located in Clausthal-Zellerfeld: Oberbergamt (hereafter cited as OBA) Clausthal, F. 761, Nr. 27, "Die Windmühlenkünste des Hofrats Leibniz."

[42] *Sämtliche Schriften*, 3:109.

[43] Ibid., 3:149–66.

[44] These tests occurred under the supervision of Leibniz's secretary, Jobst Dietrich Brandshagen, because Leibniz was back in Hannover at the time.

[45] OBA Clausthal, F. 761, Nr. 27.

miner's eye," the officials continued, then it was clear that the machine was pumping much too little water. Even when it worked (which was almost never), and even when the wind was just right (hardly ever), the mines stood to gain very little from the venture. There had been one somewhat successful trial—and Leibniz brought it up as evidence of success—but that could by no means serve as a baseline, or as a foundation for future experiments. What about the hundreds of tests and the years of waiting? The officials had not, in all that time, "seen anything the least bit useful."[46]

None of this was very positive, but the really damning section of the report came toward the end. Leibniz, the officials explained, had signed a binding contract with the Gewerken. The agreement stipulated that he would demonstrate, by a specific time, "that such a machine could produce the anticipated effect in both shallow and deep shafts." But Leibniz had failed to show that his machine, even if it did work, would be feasible in the deeper mines. Without such a demonstration, one could no longer ask the Gewerken to support his experiments. The report concluded with a warning—almost a threat—to the Kammer: "If we press the Gewerken too far with additional expenses, and the costs keep rising, this could lead to the ruin of the mines."[47]

But Leibniz had already been working on something else: a sensitive "horizontal machine" that could capture even slight gusts of wind from any direction. Duke Ernst August had provided 200 taler for the venture, and the carpenter Hans Linsen proceeded to build a model that was finished by March—the month after the Oberbergamt issued its report. Leibniz then put the millwright to work in April, using Linsen's model as the basis for full-scale construction. Leibniz's secretary, Brandshagen, supervised construction. The horizontal machine was to be situated alongside a pond near the Zellbach, a small stream that runs between Clausthal and Zellerfeld.[48] The idea was to create a circulation system. Water would run down the Zellbach, into a storage pond, and from there the horizontal machine would pump it back up into an existing holding pond for reuse in generating power.[49] In this way, the wind power could be stored as waterpower for future use. Moreover, there would be no need for elaborate Feldstangen to transfer power across large spaces.[50]

Officials in Clausthal, now thoroughly fed up with the endless delays and rising costs, listed a series of objections to Leibniz's new plan. The wind, they explained, could not be controlled, nor did it have enough power to do the necessary work; the Harz was, in any case, a bad place for wind power; the potential gains of the project were outweighed by the costs; and, most important, continuation of the project would scare away the Gewerken. Leibniz responded point-by-point to these doubts in a March 1684 memorandum to Duke Ernst August, who (as always) would have to arbitrate the dispute.[51] Leibniz now stated his strongest case for continuing the development of his

[46] Ibid.

[47] Ibid.

[48] For efforts at reconstructions of the wind machines, see Horst and Gottschalk, "Leibnizschen Pläne" (cit. n. 24); Stiegler, "Leibnizens Versuche" (cit. n. 15).

[49] Stiegler, "Leibnizens Versuche" (cit. n. 15), 279.

[50] Stangenkunst was a mainstay of central European mining technology from Agricola's time (the late sixteenth century) well into the nineteenth century. The standard Stangenkunst consisted of an extended series of reciprocating rods (the Feldstangen) that carried power from a waterwheel to some distant point. See Robert P. Multhauf, "Mine Pumping in Agricola's Time and Later," *United States National Museum Bulletin*, no. 218, *Contributions from the Museum of History and Technology* 7 (1959): 113–20.

[51] OBA Clausthal, F. 761, Nr. 27; *Sämtliche Schriften*, 4:41; Stiegler, "Leibnizens Versuche" (cit. n. 15), 275–6.

wind machines. But it had been over five years since his original proposals, and the duke and his mining office were losing patience. This was, as Leibniz knew, the last chance to salvage all the hours and money that he had invested in the project.

There was, Leibniz began, a lack of "motive force" (*Bewegungskraft*)[52] in the mines due to a chronic lack of available waterpower. Holding ponds regularly ran dry in both winter and summer, so that "all wheels and machines, stamping works, smelting huts, and so forth, came to a complete standstill, so that the sovereign and the Gewerken lost many thousands of taler. And there is the worry, because there have been no heavy rains this spring, that there will also be water shortages in the summer, because the holding ponds are already quite depleted."[53] Nor could the mines have too much motive force from wind and water. There was always a need for more power to drive additional stamping works, waterwheels, and pumps. Holland and France had tapped the power of the wind; why not Hannover?[54]

Leibniz also disputed the claim that there was inadequate wind to power his machines. It would be strange indeed, he countered, if the Harz were the one place in the world where one could not harness wind power. Moreover, wind was a more accessible source of power than water, because in using it one was not constrained in the same ways: "Where one merely has freedom and space, one can build very much." Moreover, Leibniz claimed that his machines were more powerful than the Bergamt admitted.[55] "What was thought impossible has thus been made possible, and if I had accomplished nothing else than this, I would have done a great deal." Leibniz also dismissed objections about the maintenance of his machines. He explained that many novel machines experienced problems. The trouble, however, was not with the machines but with the workers, who damaged them "partly through ill will, partly through ignorance or laziness."

Horizontal windmills were not as novel as Leibniz suggested. They had appeared in China and Persia during the thirteenth century, and Europeans, including Leonardo da Vinci, had drawn and described them. Nor were they entirely unknown in the German lands.[56] It was very common, in fact, to use bellows and horizontal panes to ventilate the mines. It seems doubtful, then, that Leibniz would have been oblivious to the existence of horizontal windmills. Rather, he seems, once again, to have claimed novelty and originality as a way to assert exclusive rights to the profits from his inventions.

Leibniz made the strongest case for installing his wind machines toward the end of the memorandum, where he addressed the objections of the mining office directly.

> The new horizontal machine has important advantages, for this wind machine costs no more than 200 taler, requires no more maintenance than a waterwheel, and is ready to

[52] On Bewegungskraft, see Ed Dellian, "Einführung," in Leibniz and Samuel Clarke, *Der Briefwechsel mit G. W. Leibniz von 1715/1716: A Collection of Papers Which Passed between the Late Learned Mr. Leibniz and Dr. Clarke in the Years 1715/1716 Relating to the Principles of Natural Philosophy and Religion*, ed. and trans. Dellian (Hamburg, 1990), xi–cxxii.

[53] *Sämtliche Schriften*, 4:41.

[54] Ibid., 4:42.

[55] The Bergamt claimed that his machines could lift the water no more than 50 meters; he claimed to have lifted it 140 meters (ibid.).

[56] Stiegler, "Leibnizens Versuche" (cit. n. 15), 278. On the older history of the "primitive horizontal mill," which had lower costs but more inefficiencies, see Reynolds, *Stronger Than a Hundred Men* (cit. n. 14), 108.

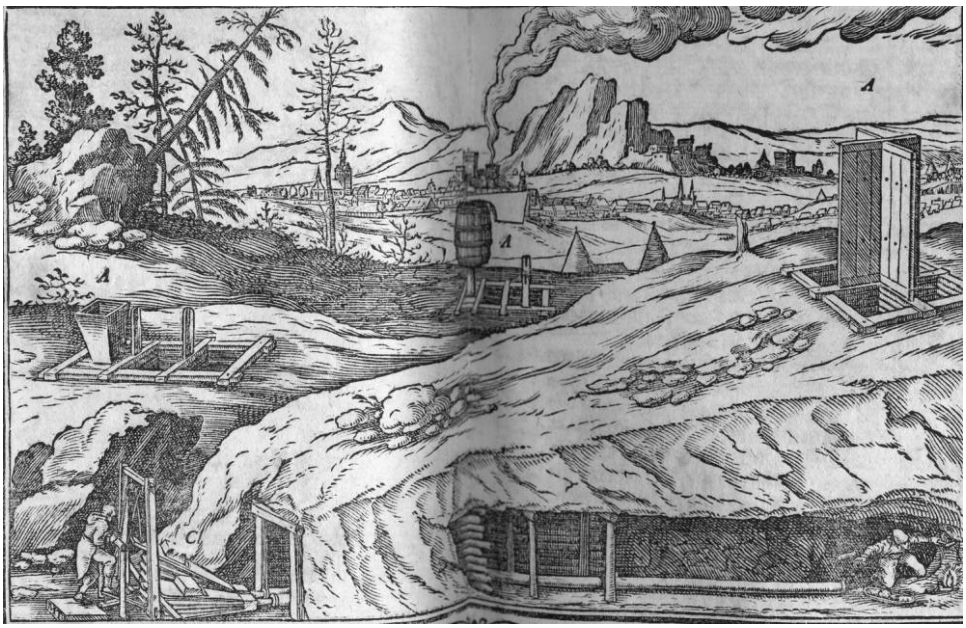

Figure 5. *Bellows and horizontal panes were common forms of underground ventilation in the seventeenth-century Harz mines. From Löhneyss,* Bericht vom Bergkwerck. *Reprinted courtesy of Honnold Library Special Collections, Claremont Colleges.*

> operate day and night in all winds, regardless of direction and position. It is very secure against storms. . . . One can save the force [*Kraft*] of the wind and, as it were, store it up. That is what it means to use the wind to lift water into the holding ponds, so that it is stored in them as stock [*Vorrat*], and afterward can be distributed to machines, stamping works, and the like for the general use of the mines. Thus ends also this main objection, namely, that one is not master of the wind and that one cannot have it when one wants. All the water that one lifts into the holding ponds is as good as ready money [*Bargeld*]; no matter how much one had of it, one could certainly use it.[57]

We should resist the temptation to see this argument as a descriptive or accurate account of the horizontal machine. It should be clear by now that Leibniz was making a case, and that he had adversaries in the mining office who were making a different case. The audience for their dispute was, in the first instance, the Kammer and, after that, Duke Ernst August. Leibniz's memoranda were strategic documents designed to make a case for his inventions. Here and elsewhere, he wrote about wind power and waterpower as capital, suggesting that the stored energy of the wind was like ready money. More important for the Kammer and the duke, however, was the opinion of the Gewerken, those providers of the real capital that kept the mines in operation. In the end, the battle over Leibniz's wind machine was a battle over these shareholders. Toward the end of the March 1684 memorandum he made an explicit appeal to them.

> The complete execution will not only be useful to Your Highness and to the mine, but also glorious. It is certain that this machine will give the mine no small reputation [*Ruf*],

[57] *Sämtliche Schriften*, 4:43; cf. Stiegler, "Leibnizens Versuche" (cit. n. 15), 275.

> especially since a horizontal machine like this one has never been seen in the world, and will soon be imitated because of its affordability and benefit. And everything that gives the mine a reputation helps to attract Gewerken. Not to mention that everyone will see in it the expression of your highness's most praiseworthy purpose and fatherly concern.[58]

In June, Leibniz repeated the same theme, arguing that periodic water shortages were scaring investors away from the mines.[59]

As construction and testing of the horizontal machine continued into the fall and winter of 1684, Leibniz kept making promises. As late as December 1,1684, he wrote to his friend (now minister) Albrecht Philipp von dem Busch that "the new horizontal machine, which is now so far along that it can spin around, and which will even this week be used to drain water, promises a great profit." It was not expensive; it worked in all kinds of wind and weather; it did not break easily; and it would free the Gewerken from paying substantial "pumping wages" to the miners.[60] Leibniz made it sound like a dream, and maybe it was. When the frosts arrived in early December it still was not ready. Leibniz blamed the Bergamt for delaying and denying him materials. The officials blamed him, again, for wasting money and time. Leibniz's wind machine project was over.

CONCLUSION

Leibniz's failed mining venture can be read as a story about competing forms of expertise. Mining officials in Clausthal had great pride in being *bergverständig*, or having a thorough knowledge of mining acquired through many years of experience. When the duke and his Kammer needed advice about whether to support some mining venture or other, which happened frequently, they asked knowledgeable mining people for help. When Leibniz arrived in Clausthal with his plans and inventions, the Bergamt immediately regarded him with suspicion because he was no Bergverständiger. He might have specialized knowledge of mechanics and mathematics, but he lacked adequate experience. Every high mining official had passed through a period of apprenticeship, learning the various aspects of the mining economy. That tradition of apprenticeship would be formalized in the mining academies that appeared in Freiberg, Berlin, and Schemnitz during the eighteenth century.[61] The Bergamt's stance was that without the right kind of experience, there could be no expertise.

Leibniz, of course, had entirely different ideas. He argued that new discoveries in mechanics could revolutionize the mines, and that principles of force and friction, properly understood and applied, could create a new silver age. Moreover, Leibniz was making the case (to the duke and members of the Kammer) that his own special blend of knowledge and experience—his expertise, if you will—trumped that of Clausthal's mining officials. He tried to turn their strength into a weakness: whereas they had been confined to the mining districts, he had traveled the world; whereas their experience was provincial, his was both cosmopolitan and local. When the mining officials denigrated Leibniz's impractical schemes on the basis of past

[58] *Sämtliche Schriften*, 4:43.
[59] Stiegler, "Leibnizens Versuche" (cit. n. 15), 275–6; *Sämtliche Schriften*, 4:49–61.
[60] Stiegler, "Leibnizens Versuche" (cit. n. 15), 288–9.
[61] See Andre Wakefield, "The Fiscal Logic of Enlightened German Science," in *Making Knowledge in Early Modern Europe: Practices, Objects, and Texts, 1400–1800*, ed. Pamela H. Smith and Benjamin Schmidt (Chicago, 2007), 273–86.

failures, he replied with abstract disquisitions about force and friction, implying that the men in Clausthal did not understand the basic principles of mechanics. When the Bergamt suggested that knowledgeable men should review Leibniz's proposals, he argued that they were not knowledgeable enough: "Experience is in my opinion a better judge than those gentlemen." For him, the mining office was an impediment to be overcome, and he largely dismissed the practical expertise of the *Bergverständiger*.

It would be a bad mistake, though, to read this episode as a conflict between the old and the new, as a struggle between the artisanal know-how of mining men and the burgeoning spirit of the scientific revolution. That is too easy and too comfortable; it is also wrong. Archival evidence indicates that mining officials in Clausthal were every bit as dedicated to experimentation as Leibniz was. Nor were they flummoxed or wowed by his disquisitions on force. (They were, however, annoyed.) It seems more useful, then, to see Leibniz's efforts in this regard as strategic. Playing to an audience of dukes, courtiers, and fiscal officials, he made sure to bring up his knowledge of mechanics and mathematics and his connections to famous scientific academies. He made sure, that is, to emphasize his superiority and cosmopolitanism. But the mining officials in the Harz were not bumpkins. Many of them came from venerable old families and had been educated at Europe's best universities. Some were local gentry; others, such as Harzingk, came from foreign lands. Like Leibniz, they had all been trained to believe that the success of the mines depended on a combination of good principles and long experience, of universal and local knowledge.

Truth be told, Leibniz *had* to distinguish himself starkly from other pretenders, especially Harzingk. His lifetime pension—the ultimate goal of the whole enterprise—rested on a strong claim to novelty. It can be easy to forget that Leibniz was a lawyer. His many memoranda to the Bergamt, the Kammer, and the dukes were not just natural philosophical ruminations; they were always also legal claims to priority. That is certainly how members of the Bergamt read them. Mining officials in Clausthal mostly rejected these claims because Leibniz's final plan looked so much like what Harzingk had originally proposed. In other words, they rejected his claims to priority, and they were probably right to do so.

Leibniz was eventually undone by the logic of the Gewerken. He needed their support to continue his work, and he recognized that. He appealed to them in his memoranda by arguing that his inventions would save money for shareholders, and that they would make Clausthal's mines famous, thereby drawing more investments from all over Europe. But Leibniz apparently misread the situation. As we have seen, the Harz was just then formalizing a system of shareholder-officials who would control a large percentage of shares in the most important silver mines. This situation was different from that of other large German mining districts, where foreign investment remained crucial. In 1684, at the moment that Leibniz's windmill project reached the critical stage, mining officials and Gewerken, management and capital, were coming together in the Harz. So while Leibniz was appealing to foreign investors, the Kammer was looking increasingly to local shareholder-officials for capital. Leibniz had alienated the audience he most needed to persuade.