TEORIE VĚDY / THEORY OF SCIENCE / 2026
https://doi.org/10.46938/tv.2026.694

////// přehledová studie / survey article //////////////////////////

PHILOSOPHICAL MINING OR THEORIA CUM PRAXI

Abstract: *This paper examines the natural philosophy of the German philosopher Gottfried Wilhelm Leibniz with regard to his ability to apply theoretical reflections in the contemporary (technological) practice and develop a consistent natural-philosophical system. In addition to textual analysis, the paper is also based on an analysis of the historical context. Although Abraham Gottlob Werner is commonly regarded as the founder of so-called* philosophical mining, *i.e., a geo-physics based on empirical data, Leibniz anticipated several ideas later associated with Werner. However, Leibniz's* Protogaea, *in which he applied his metaphysics and geometry to the issue of fossils, is certainly not among the best-known of Leibniz's works. A consequence, or perhaps cause, of that is that Leibniz is thought of as a "mere" theorist. And yet, the only objection that could be raised against him in this respect is his distrust in the practical judgement of his more experienced colleagues.*

Keywords: *G. W. Leibniz;* Protogaea; theoria cum praxi*; A. G. Werner; mining academy*

Filosofická těžba aneb Theoria cum praxi

Abstrakt: *Článek prověřuje přírodní filosofii německého filosofa Gottfrieda Wilhelma Leibnize z hlediska jeho schopnosti aplikovat teoretické úvahy v dobové (technologické) praxi a rozvinout konzistentní přírodně-filosofický systém. Východiskem je kromě textové analýzy také analýza historického kontextu. Přestože totiž bývá za zakladatele tzv.* filosofické těžby, *tj. na empirii založené geo-fyziky, považován teprve Werner, Leibniz mnohé z Wernerovi přisuzovaných myšlenek předjímal. Leibnizova* Protogaea, *kde svou metafyziku a geometrii aplikoval na problematiku fosilií, však rozhodně nepatří k nejznámějším z jeho spisů. Důsledkem, či snad příčinou, je nicméně stav, kdy bývá Leibniz považován za „pouhého" teoretika. Přitom jediným, co by mu v tomto ohledu bylo možno vytýkat, je leda jeho nedůvěra vůči praktickému úsudku zkušenějších kolegů.*

Klíčová slova: *G. W. Leibniz;* Protogaea; theoria cum praxi*; A. G. Werner; báňská akademie*

KATEŘINA LOCHMANOVÁ
Department for Comenius Studies
and Early Modern Intellectual History
Institute of Philosophy, Czech Academy of Sciences
Jilská 1, 110 00 Prague 1
email / lochmanovakatka@gmail.com
iD 0000-0001-9009-1476

This work was supported by the Department of Comenius Studies and Early Modern Intellectual History of the Institute of Philosophy AV ČR.

1. Introduction

This article aims to present German philosopher Gottfried Wilhelm Leibniz (1646–1716) as an important pioneer of "philosophical mining," as David Oldroyd labelled it.[1] By *philosophical mining* I mean a kind of non-utilitarian natural philosophical reflection based on practical (mining and related industrial or technical) experience. In contrast to those who tend to overlook Leibniz's involvement in practical experience, this article presupposes reciprocity of his theoretical ideas and practical designs. Based on both textual analysis and analysis of the historical context, the paper thus examines whether and to what extent Leibniz was able to meet his own motto: *theoria cum praxi*.

The comparison of Leibniz's declared objectives with his actual outcomes (both theoretical reflections and technical proposals) draws mainly on his letters, a posthumously published piece called *Protogaea* (theoretical reflections) and *Denkschrift* to the duke Ernst August (technical proposals). As for the *Protogaea*, the article takes into account both its brief summary published in 1693 and its full version published posthumously; and links it to another one of Leibniz's enduring projects: *analysis situs*. As for the *Denkschrift*, the article supplements it with an overview of Leibniz's technical designs and the state of their (actual) implementation.

The opening description of the historical background including latter remarks about both Leibniz's precursor Nicolas Steno (1638–1686) and especially his successor Abraham Gottlob Werner (1749–1817) aim to delineate the novelty of Leibniz's approach. For, in contrast to those who claim that the conscious union of theory and practice had already characterized seventeenth century thought, only to be emphasized much more strongly in the subsequent century, this article calls into question whether "Leibniz's theoria cum praxi could be taken as the motto of the philosophy of the entire epoch."[2]

[1] David R. Oldroyd, *Thinking about the Earth: A History of Ideas about Geology* (Cambridge: Harvard University Press, 1996), 70.

[2] "Leibnizens Theoria cum praxi könnte als Motto über der Philosophie der gesamten Epoche stehen" [Wolfgang Röd, *Die Philosophie der Neuzeit 2: Von Newton bis Rousseau* (Munich: C. H. Beck, 1984), 14].

2. Historical Background

According to McGrath,[3] in the late seventeenth century, natural philosophy was split into two distinct streams: a speculative one in Descartes's spirit (without effort to corroborate speculations with experiments or observation); and experimental (hostile to speculative hypotheses). Jacob and Stewart[4] do not even shy away from the notion of segregation, since the mechanical application of natural laws was never really Newton's goal. Indeed, as also Newton's contemporary John Conduitt (1688–1737) had confirmed, "Sir Isaac said he first proved his inventions by Geometry & only made use of experiments to make them intelligible & to convince the vulgar."[5] In fact, before the second half of the eighteenth century, the transformations of natural-philosophical knowledge did not, as a rule, result in new or modified technological descriptions, instructions, or reflections, let alone new practices. And to a lesser extent, in turn, changes in the technological field did not result in new or modified theoretical assumptions.[6]

Thus, although, for example, various technical descriptions or instructions in seventeenth-century chemistry manuals were usually preceded by a theoretical section, surprisingly there was no connection between the two. Chemical terminology, such as extraction, sublimation, or distillation, did refer to real technical procedures, but it was treated in the context of natural-philosophical theories concerning the ultimate constitution of matter,[7] which

[3] Alister McGrath, *Natural Philosophy: On Retrieving a Lost Disciplinary Imaginary* (New York: Oxford University Press, 2023), 78.

[4] Margaret Jacob and Larry Stewart, *Practical Matter: Newton's Science in the Service of Industry and Empire 1687–1851* (Cambridge: Harvard University Press, 2004), 14, 70.

[5] John Conduitt, "Account of Newton's Manual Dexterity: The Keynes Ms. 130.09," in *The Newton Project*, accessed April 13, 2025, https://www.newtonproject.ox.ac.uk/view/texts/normalized/THEM00171, 4r–v.

[6] Samuel Florman, *Engineering and the Liberal Arts: A Technologist's Guide to History, Literature, Philosophy, Art, and Music* (New York: McGraw Hill Book Company, 1968), 24; Lynn T. White, Jr., *Medieval Religion and Technology: Collected Essays* (Berkeley: University of California Press, 1978), 89, 127; Jacob and Stewart, *Practical Matter*, 70; Wolfgang Lefèvre, *Minerva Meets Vulcan: Scientific and Technological Literature: 1450–1750* (Cham: Springer, 2021), 60.

[7] Richard Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (Cambridge: Cambridge University Press, 1977), 66; Ursula Klein and Emma Spary, "Introduction: Why Materials?," in *Materials and Expertise in Early Modern Europe: Between Market and Laboratory,* eds. Ursula Klein and Emma Spary (Chicago: University of Chicago Press, 2009), 4; Rhoda Rappaport, *Studies on Eighteenth-Century Geology* (Cornwall: Cornell University Library, 2011), 100, II; Lefèvre, *Minerva Meets Vulcan*, 68.

had developed quite independently of chemical techniques.[8] Contemporary chemistry, on the other hand, was the product of comparative analyses of specific metallurgical processes rather than of deduction alone.[9]

A similar tendency is also evident in the structure of the famous series of manuals published by French iatrochemists (i.e., medicinal chemists) of the seventeenth century, all of which begin with a brief section confirming the theoretical foundations of the field. After another brief section on various techniques and tools, including the relevant terminology, there are extensive sections on the treatment of metallic minerals, providing detailed explanations and instructions on how to treat each commodity, without, however, referring to the preceding theoretical section.[10]

Air resistance also became a subject of interest in the seventeenth century, independently of ballistics, as part of the emerging aerostatics and aerodynamics, especially in connection with the extremely controversial question of the vacuum. Yet almost all contemporary vacuum theorists were no less interested in ballistics than in philosophical questions. The trajectory of projectiles even became the subject of major parts of both Galileo Galilei's *Discorsi* and Isaac Newton's *Principia*. True, it required revisions of basic natural-philosophical assumptions – just as the new astronomical

[8] Isaac Newton has been blamed for the paradigmatic break between general mechanics and theory of matter [Stephen Gaukroger, *The Collapse of Mechanism and the Rise of Sensibility: Science and the Shaping of Modernity, 1680–1760* (Oxford: Clarendon Press, 2010), 57], for he replaced the (too complicated) matter with a simple (undifferentiated) mass [René Dugas, *Histoire de la mécanique* (Neuchâtel: Éditions du Griffon, 1950), 192]. At present, however, he is frequently attributed with precisely the opposite effect [see Ilya Prigogine and Isabelle Stengers, *Order out of Chaos: Man's New Dialogue with Nature* (New York: Bentam Books, 1984), 98; Jacob and Stewart, *Practical Matter*, 31; Nicolae Sfetcu, *Epistemology of Experimental Gravity: Scientific Rationality: Essays Collection* ([E-book]: Multimedia Publishing, 2019), 22; Florestano Evangelisti, *The Concept of Matter: A Journey from Antiquity to Quantum Physics* (Cham: Springer, 2023), 41)].

[9] Westfall, *The Construction of Modern Science,* 104; Theodore Porter, "The Promotion of Mining and the Advancement of Science: The Chemical Revolution and Mineralogy," *Annals of Science* 38 (1981): 543; Pamela Smith, "Vermilion, Mercury, Blood, and Lizards: Matter and Meaning in Metalworking," in *Materials and Expertise in Early Modern Europe: Between Market and Laboratory,* eds. Ursula Klein and Emma Spary (Chicago: University of Chicago Press, 2009), 40f.; Lefèvre, *Minerva Meets Vulcan,* 184; cf. Victor Baker, "Charles S. Peirce and the 'Light of Nature,'" in *The Revolution in Geology from the Renaissance to the Enlightenment,* ed. Gary Rosenberg (Boulder: Geological Society of America, 2009), 260.

[10] Lefèvre, *Minerva Meets Vulcan*, 60.

observations required a fundamental revision of the existing cosmology[11] – but these did not prompt any research into weapons realities.[12]

Nor did the modern literature on calendar creation, the ephemerides, astronomical tables, or instruments and methods of astronomical observation draw on the contemporary scientific (i.e., Aristotelian-Platonic) astronomical literature in any way.[13] Even Johann Kepler's three laws of planetary motion were probably not derived from theoretical principles.[14] Newtonian astronomy simply worked without needing to know the nature of matter, space, and time,[15] or take a clear position in the geo-/heliocentric dispute.[16]

"Newton's synthesis between theoretical concepts and active knowledge [...], technical, practical knowledge on one side, and theoretical knowledge on the other," as belauded by Prigogine and Stengers,[17] was only perfected with the formulation of the laws of thermodynamics in the nineteenth century.[18] Although even the first law of thermodynamics could easily have been derived from the dynamics of Newton by mathematicians of the type of Laplace or Lagrange, its formulation actually required the help of engineers.[19]

The modern mining manuals fared much better, usually dealing with technical matters, such as shaft and gallery construction, rock breaking, mining, or mineral production.[20] For example, the first part of Erasmus Reinhold's manual of underground geometry, *Instruction* (1550), is directly related to the book on surveying in general, on which he collaborated with his father. And while their early work lamented the gross errors of ordinary surveyors, we learn from the sequel that mining surveyors had already achieved their goal and that the measures they produced could sometimes be useful.

Both works, at any rate, in determining the depth required for sinking the shafts and the depth of the digging itself, make use of the methods

[11] Ibid., 184; cf. Baker, "Charles S. Peirce and the 'Light of Nature," 260; William Poole, *The World Makers: Scientists of the Restoration and the Search for the Origins of the Earth* (Oxford: Peter Lang, 2010), 43.
[12] Lefèvre, *Minerva Meets Vulcan*, 176.
[13] Ibid., 162.
[14] Ibid., 184.
[15] David R. Oldroyd, Earth Cycles*: A Historical Perspective* (Westport: Greenwood Press, 2006), 3.
[16] Lefèvre, *Minerva Meets Vulcan*, 162.
[17] Prigogine and Stengers, *Order out of Chaos*, 98.
[18] Ibid.
[19] John Ziman, *The Force of Knowledge* (Cambridge: Cambridge University Press, 1976), 26.
[20] Prigogine and Stengers, *Order out of Chaos*, 128.

of practical geometry, a form of Euclidean geometry which had in the meantime spread to a considerable body of scholastic literature thanks to Hugh of St. Victor (1096–1141).[21] As George Agricola (1494–1555) had done before, Reinhold also proposed to construct a smaller triangle with the help of ropes, similar to the physical formation formed by a mine shaft and the mouth of a gallery, and – given Reinhold's mathematical background – in a more abstract way and with more emphasis on the very notion of (geometric) similarity.[22] Such a procedure was typical of surveying practices not only underground, but also in other similarly inaccessible environments, such as polders or lowlands.[23] All surveying methods simply began by measuring and considering similarity of triangles.[24]

3. Similarity of Fossils

Leibniz later placed the (originally geometrical) criterion of similarity[25] or *resemblance* in the center of his reflections on the origin of fossils too,[26] which, as Laudan[27] correctly remarks, may have had repercussions even in later mineralogy or geology. After all, it is well known that, due to the numerous manipulations of plant and animal fossils in connection with mining,[28] the mining industry played a key part in the development of Ger-

[21] Thomas Morel, *Underground Mathematics: Craft Culture and Knowledge Production in Early Modern Europe* (Cambridge: Cambridge University Press, 2023), 25.
[22] Ibid., 43.
[23] Ibid., 41.
[24] Ibid., 32.
[25] Cf. Leibniz's claim that no one has properly defined what *similarity* means. And yet, until this concept is defined, it is impossible to provide natural proofs of many important metaphysical and mathematical propositions (*Letter to Gallois from September 1774*; A, II, 1, 568, § 11–13). "But lacking a general concept of similarity, geometricians have defined figures as similar whose corresponding angles are equal. This is a special case which does not reveal the nature of similarity in general." ["At Geometrae cum generali similitudinis notione carerent, figuras similes ex aequalibus respondentibus angulis definierunt, quod speciale est, non ipsam naturam similitudinis in universum aperit" (*De analysi situs*; GM, V, 179–181). See also *Specimen geometriae luciferae* (GM, VII, 281f.); *Uniformis locus* (G&M, 583).
[26] Claudine Cohen, "Leibniz's Protogaea: Patronage, Mining, and the Evidence for a History of the Earth," in *Proof and Persuasion: Essays on Authority, Objectivity, and Evidence*, eds. Suzanne Marchand and Elizabeth Lunbeck (Turnhout: Brepols, 1996), 134. See *Protogaea* (P, 42–49, § 18; 60f., § 24).
[27] Laudan, *From Mineralogy to Geology*, 97.
[28] Warren A. Dym, *Divining Science: Treasure Hunting and Earth Science in Early Modern Germany* (Boston: Brill, 2011), 138; Lefèvre, *Minerva Meets Vulcan,* 140; Ivano D. Prete, *On the Edge of Eternity: The Antiquity of the Earth in Medieval & Early Modern Europe* (New York:

man mineralogy since the sixteenth century.[29] Understanding the structure of the rocks into which the shafts were to be subsequently sunk, and especially the veins of the mined material, was in the miners' own interest,[30] as Leibniz emphasizes in the *Denkschrift*.[31]

Meanwhile, the distinction between artificially composed (minerals) and natural substances gradually disappeared in the course of time, in connection with routine attempts to compose even natural substances from their components. Since Leibniz likened the process of mineral formation to the construction of artificial machines based on a juxtaposition of parts, rather than to embryogenesis, the key distinction for him lies not so much between the natural and the artificial. Rather it lies between organic matters on the one hand and anything that can be exhaustively understood on the basis of geometrical relations of parts, including crystals as well as machines, on the other.[32] However, Leibniz aimed to fundamentally surpass pure geometry through his own geometry called *analysis situs*. He therefore saw its greatest potential – except for the description of machines, regardless of how complex they were[33] – especially in classifying plants and animals,[34] as Serres[35] hopes for.

As confirmed by Ephraim Chambers (1680–1740), the botanists of the time indeed based their classifying acts, for example, regarding leaves, primarily on geometric characteristics, such as position (or the relationship of the parts). Especially with respect to position they distinguished between

Oxford University Press, 2022): 82. According to Martin Rudwick, *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution* (Chicago: University of Chicago Press, 2005), 97, most mining, with the exceptions of coal and iron ore, was conducted in so-called primary mineral layers, in which no fossils are generally found. But that did not mean that geognostics would not at least be aware of the occurrence of fossils.

[29] Laudan, *From Mineralogy to Geology*, 66; Rudwick, *Bursting the Limits of Time*, 84; Martin Rudwick, *Earth's Deep History: How It Was Discovered and Why It Matters* (Chicago: University of Chicago Press, 2014), 82. Cf. Comenius' note that ore mines testify to the presence of water in underground spaces (*Pansophia*; CC, I, 324, 489f./V, § VI).

[30] Rudwick, *Bursting the Limits of Time*, 87; see also Dym, *Divining Science*, 159.

[31] *Denkschrift* (A, I, 3, 152, § 23–30).

[32] Justin Smith, *Divine Machines: Leibniz and the Sciences of Life* (Princeton: Princeton University Press, 2011), 227.

[33] *Letter and Enclosure to Letter to Huygens from 8/18 August 1679* (A, III, 2, 846, § 21f.; 852, § 6); *Characteristica geometrica* (GM, V, 143, § 7). Leibniz repeated his vision of inventing and describing machines also in *De analysi situs* (GM, V, 183).

[34] *Letter to Huygens from 8/18 August 1679* (A, III, 2, 852, § 11f.); *Characteristica geometrica* (GM, V, 143, § 7).

[35] Michel Serres, *Le système de Leibniz et ses modèles mathématiques* (Paris: P.U.F, 1982), 604.

alternate, i.e., alternately ordered, and mutually opposite.[36] The distinction of organic bodies in general from inorganic bodies was also seen, according to Chambers, in a certain disposition or organization of parts, such as is suitable for the reception and distribution of nutrition, so that the body could not only persist, but at the same time also form wood, bark, leaves, etc., which is analogous in the case of animals.[37]

Position, as Suárez (1548–1617) had already observed,[38] is most intimately connected with animals, in which there are parts of different significance and shape, so that they can be, of their own disposition, variously composed and arranged with respect to the place.[39] Later, also Werner supplemented the same distinction by saying that while animals and plants were composed (*composita*) of distinct parts (organs), minerals are relatively simple and consist of similar parts (aggregates).[40]

Werner's distinction would certainly have been alright, if in the context of the same note he had not attributed composition to minerals, while attributing association to animals and plants,[41] and admitted that both result by aggregation, including the chemical association of parts.[42] He further insisted that the distinctive character of minerals must consist in the mere

[36] Ephraim Chambers, *Cyclopaedia: Or, An Universal Dictionary of Arts and Sciences: Containing the Definitions of the Terms, and Accounts of the Things Signify'd thereby, in the Several Arts, Both Liberal and Mechanical, and the Several Sciences, Human and Divine: The Whole Intended as a Course of Antient and Modern Learning* (London: James and John Knapton, 1728), 438.

[37] Ephraim Chambers, *Cyclopaedia*, 370. See also Pavel Floss, *Atomy, pohyb, teplo: Pokus o výklad některých tendencí Komenského kosmologie* (Přerov: Vlastivědný ústav, 1970), 3, fn. *.

[38] *Disputationes metaphysicae* (DM, 52/2:3).

[39] See also Herman Boerhaave, *A New Method of Chemistry: Including the Theory and Practice of that Art: Laid down on Mechanical Principles, and accomodated to the Uses of Life,* eds. Peter Shaw and Ephraim Chambers (London: J. Osborn and T. Longman, 1727), 53.

[40] "The latter [mineral and meteoretic kingdom], on the contrary, are quite simple or consist of similar parts (aggregata) [...]" (*On the External Characters of Minerals*; W, XXVI, fn. d).

[41] "In the first one [kingdom of animals and plants], the essential features occur in their mode of association, whereas in the second [mineral and meteoric kingdom], they occur in their composition" (ibid.).

[42] "Both [...] are aggregated and their parts chemically associated [...]" (ibid.).

composition,[43] while plants, not minerals,[44] were established by association of each part with all the others.[45] Thus, he claimed, when parts were isolated, it was impossible to determine to which plant which part belonged,[46] whereas in the case of minerals any part would certainly be a part of that same mineral.[47]

Even this conclusion, however, was again retracted by Werner, for we learn that when a (component of) a mineral was split, its parts would no longer form the same mineral.[48] And to finally darken the matter even more, we learn that the equivalent of *composition* could be used to translate both – association and composition.[49] Admittedly, I am basing this on a translation since I have not found the note in the original. However, Laudan[50] also quotes and paraphrases Werner's conception based on the same translation, without giving any pause to the contradictions.

Leibniz also acknowledged that the structure of homogenous bodies, liquids, salts, or metals was simpler than the structure of plant and animal organisms, which consist of distinct parts.[51] That is also why according to

[43] "Since these bodies [mineral and meteoric] are really different from each other, i.e., they display really different essential features, these [...] as I have already said, must necessarily be found in their composition;" "The essential features of minerals [...] must necessarily exist in their composition;" "The essential features of [...] mineral and meteoric kingdoms exist in their composition" (*On the External Characters of Minerals;* W, XXVIIf., fn. d).

[44] "The essential features of the mineral cannot [...] have lain in the mode of association" (*On the External Characters of Minerals*; W, XXVII, fn. d).

[45] "*[...]* Their association with each other in the plant, this association constituting a given plant" (ibid.).

[46] "I can no longer state that each single part belonged to the same plant, because these single parts no longer possess the same relations they displayed in their association with each other in the plant [...]" (ibid.).

[47] "If [...] I divide a mineral, [...] each of its parts [...] will still be the same mineral [...]" (ibid.).

[48] "But if I destroy the composition of a mineral, [...] if I resolve it into its constituents, each single constituent will no longer form the same mineral [...]" (ibid.).

[49] "The [...] succession of essential features in the former [animal and vegetal kingdom] follows their mode of association (compositionibus) and in the latter [the mineral kingdom] their composition [...]" (*On the External Characters of Minerals*; W, XXVIII, fn. d).

[50] Rachel Laudan, *From Mineralogy to Geology: The Foundations of a Science 1650–1830* (Chicago: University of Chicago Press, 1993), 80f.

[51] Graham Timothy Solomon, "Leibniz's Analysis Situs in Mathematical Context." PhD. diss. *Dissertation Abstracts International* 51 (1990), 98. Cf. *Principia logico-metaphysica* (A, VI, 4, 1645, § 24f.). Cf. also Comenius' distinction between the homogeneous plants and the non-homogeneous animals (*Pansophia;* CC, I, 337, 516/V, § VIII), although, at other times, he considered both to be non-homogeneous: „Rearrange [...] the parts of a tree, an animal, or human. Does not something else always come out?" [„Transpone [...] in arbore, animali, homine partes, annon aliud atque aliud prodibit?" (Janua rerum reserata; SPF, 312f., § 11)]. Anyway,

Suárez (on whose writings Leibniz's position was apparently based)[52] – it was customary to attribute position to at most such (inorganic) bodies that have parts of different significance, as in the case of a house, whose foundations are lower, roof higher, etc. Even an army, which is a kind of unity, enjoyed a position of its own, if it had been assembled in an orderly manner.[53]

Leibniz, however, did not regard this property as a specificity of animals, since indistinguishably similar parts strictly speaking did not exist anywhere: "Not even parts of the universe, nor the insides of an animal are like each other, neither they are evenly distributed on both sides of that vertical plane. [...] Even in a human perfect balance between the two sides is impossible [...]."[54] Thus, while for Aristotle it was the decomposability into homogeneous, i.e., universally similar parts that defined living bodies, for Leibniz everything organic decomposed into inhomogeneous, i.e., universally dissimilar parts.[55]

Ultimately, Leibniz's intentions with *analysis situs* – founded in mutual situations of points represented by shapes – were rather metaphysical than geometrical. Leibniz considered (geometrical) shape of organic fossils to be something invariant which remains even after its (accidental) material had changed. According to him, shape determines the aristotelian form – i.e., soul, substance or nature of a body[56] –, whereas "things generally assume disguises rather than changing their nature [...]."[57] Principally, the "same material, which is everywhere identical with itself, can take on any form."[58] And yet it sometimes takes on exactly the form of a specific biological spe-

„the air, water, sand and dust will always remain the same, however you rearrange its particles. For they are all similar." [„Ita in aëre, aqua, arena et pulvere quovis quia particulae omnes sunt similares, quomodocunque transposueris, semper idem erit" (ibid., § 9)].

52 See *Autobiography* (PG, I, 4, 168); *Nouveaux essais* (A, VI, 6, 431, IV, 8, § 9/5–10); *De Principio Individui* (A, VI, 1, 12, § 4); *Preface to Nizolius' De Veris principiis* (A, VI, 2, 418, § 12–16).

53 *Disputationes metaphysicae* (DM, 52, 2:3).

54 "Ny les parties de l'Univers, ny les visceres de l'animal, ne sont pas semblables, ny egalement situés de deux cotés de ce plan vertical. [...] Encor dans l'homme le cas d'un parfait equilibre entre deux partis est impossible *[...]*" (*Theodicée*; GP, VI, 130, § 49). See also *Theodicée* (ibid., 306, § 320).

55 Smith, *Divine Machines,* 97. See *Principia logico-metaphysica* (A, VI, 4, 1645, § 25f.).

56 See *Theoria motus concreti* (GP, IV, 208, § 56); *De machina animata* (LoC, 280f.). Therefore, he goes beyond a mere resemblance, asserting its actual essence (see Cohen and Wakefield in *Protogaea;* P, 87, fn. 76).

57 *„[...] Plerumque res magis larvas sumant, quam naturam deponant [...]*" (*Protogaea*; P, 30f., § 10).

58 *„[...] Ipsaque materies per se ubique similis sibi quamcunque formam induere potest [...]*" (*Protogaea*; P, 6f., § 3).

cies. This, Leibniz deduced, cannot be just a coincidence. Therefore, the need for a clear distinction between decidedly mineral products of nature based on a mere juxtaposition of parts, and shapes indicating different origin was emphasized by Leibniz specifically for the purpose of clarifying the discrepancy between *matter, form,* and *position*[59] of the individual fossils.[60] The question many observers tackled at the time was clear: why do we "find mineral substances in the shape of seashells at the top of mountains?"[61]

It was no coincidence then, that another key use of *analysis situs*, and probably the only one that Leibniz actually developed during his lifetime, was in the context of his metaphysics of space. He investigated the nature of situated [items] (*sitarum indolem*) of the Harz region[62] because "the disposition of the place provides an important argument [...]"[63] for the organic origin of fossils. Also Werner's method of identifying and classifying strata

[59] Poole, *The World Makers,* 116f.) mentions the Aristotelian concept of *development in situ* in this context, but the concept *situs* (*situation*) as it was employed in the modern age was quite foreign to Aristotle [see Kateřina Lochmanová, "Ontologický status ideálního prostoru u Leibnize," *Pro-Fil* 20, no. 2 (2019): 32f., fn. 3; Kateřina Lochmanová, *"Analysis situs" a teorie prostoru v kontextu Leibnizovy korespondence s Clarkem* (Prague: Filosofia, 2025), 120–124; Kateřina Lochmanová, "The Leibniz-Clarke Correspondence: Looking Back to Czech and Slovak translations of Leibniz," *Acta Comeniana* 37, no. 61 (2023): 160]. However, even with respect to location in the modern sense of *place within the sequence,* this was not the kind of connection that geological taxonomy of the time was looking for [Rachel Laudan, *From Mineralogy to Geology: The Foundations of a Science 1650–1830* (Chicago: University of Chicago Press, 1993), 140]. Indeed, for a long time, no one was even sure whether the mountain ranges themselves were just isolated phenomena, or whether they were arranged in chains, and whether such chains were possibly arranged according to a particular systematic pattern. Moreover, if the entire vertical sequence of formations could not be observed at once, geologists had to piece it together from individual sections, often miles or even continents apart (cf. *Denkschrift*; A, I, 3, 159, § 2f.). Still less was a similar question asked about their components, i.e., the individual minerals. Just as biologists faced complications with respect to the individuation of individual plant or animal species, and geologists faced even more fundamental complications with respect to the individuation of individual formations, mineralogists faced complications with respect to the individuation of minerals [ibid., 40, 97, 140, 163; Hugh Simon Torrens, "Some Thoughts on the Complex and Forgotten History of Mineral Exploration," *Journal of the Open University Geological Society* 17 (1997): 8].

[60] Poole does not mention the (Aristotelian) concept of *matter*, but *substance.* See Poole, *The World Makers*, 115, 119. However, both Aristotle and Leibniz contrasted (*substantial*) *form* with matter [See Lochmanová, *Analysis situs*, 51f.; *Letter to Jaquelot from* 22. 3. 1703 (GP, III, 457f., § 8); *De serie rerum* (A, VI, 4B, 1670, § 14f.); *Discours de métaphysique* (A, VI, 4, 1558f., § 18/6f.; GP, IV, 444, § 18); *Notizen zur Wissenschaft und Metaphysik* (A, VI, 3, 393, I, § 17–21)].

[61] Poole, *The World Makers*, 115. See *Protogaea* (P, 14f., § 6).

[62] *Protogaea autore G. G. L.* (PR, 40).

[63] *Protogaea* (P, 52f., § 20).

— by their relative position, superposition, lateral continuity, and mutual boundaries — rests on the same core principle that underlies Leibniz's *analysis situs:* that the structure and arrangement of parts, not their material composition, reveal the natural history of the Earth. Where Leibniz applied *analysis situs* to the geometry of fossils and the structural resemblance of petrified forms to organic originals, Werner applied positional analysis to entire rock formations, treating strata as relational objects defined by their order, connection, and spatial disposition,[64] as suggested by Steno.[65]

Thus, both Leibniz and Werner grounded natural knowledge in structural relations *independent of matter.* However, considerations regarding fossils tend to be placed in the context of space only with respect to Werner's work, not Leibniz's. Moreover, given that geology deals with a wide range of spatial relationships, from the cosmic to the solar system, to the globe including its climatic zones, to crystals and to the cells contained therein,[66] Werner's conception of Earth history has been considered a direct temporal extrapolation of the history written by political and cultural historians.[67] In fact, however, the main promoter of the connection between the spatial and the political before Werner had already been Leibniz.[68] Leibniz's interest in geography (with the possible exception of his follower Immanuel Kant) was probably the broadest and most enduring of his time.[69]

[64] I owe this formulation to an anonymous reviewer.
[65] Claudine Cohen and André Wakefield, "Introduction," in *Protogaea: Sive de prima facie telluris et antiquissimae historiae vestigiis in ipsis naturae monumentis dissertatio,* eds. Claudine Cohen and André Wakefield (Chicago: University of Chicago Press, 2008), XXV.
[66] Gary Rosenberg, "Introduction: The Revolution in Geology from the Renaissance to the Enlightenment," in *The Revolution in Geology from the Renaissance to the Enlightenment*, ed. Gary Rosenberg (Boulder: Geological Society of America, 2009), 2f.
[67] Martin Rudwick, *The Meaning of Fossils: Episodes in the History of Palaeontology* (New York: American Elsevier Publishing Company, 1972), 13; Laudan, *From Mineralogy to Geology*, 111.
[68] Stuart Elden, "Leibniz and Geography: Geologist, Paleontologist, Biologist, Historian, Political Theorist and Geopolitician," *Geographica Helvetica* 68 (2013): 88.
[69] Ibid., 83. Cf. Mokyr's claim that although mathematical knowledge and drawings are based on spatial knowledge and representation, this is primarily true for machines, much less so for chemical or biological processes [Joel Mokyr, *The Gifts of Athena: Historical Origins of the Knowledge Economy* (Princeton: Princeton University Press, 2005), 61].

4. The Protogaea (1693)

It holds that also “the great courtier of Hanover [i.e., Leibniz] went underground – quite literally.”[70] – he kept visiting mines and spilled much ink on them. Moreover, his reflections were so generalizing and unrestrained or ”interdisciplinary” that we could justly label them as philosophical. We nonetheless learn from Oldroyd[71] that *philosophical mining,* including the primary stipulation of the basic disposition of stratigraphic layers, was established only by Abraham Gottlob Werner while he was teaching at the mining Academy in Freiberg.[72]

The work in which *philosophical mining* was developed by Leibniz, viz. his *Protogaea,* must had been known to Oldroyd. As he stated in 2012, “over the years I have had some dealings with Leibniz’s “geological” ideas” and even “co-authored the first English translation of his 1693 synoptic account of his theory of the Earth.”[73] Yet, on the occasion of writing a review of the edition of a newly discovered manuscript by Leibniz, he admitted that it was an interesting novelty for him[74] and got surprised by Leibniz’s “‘curious’ experiment to reproduce the impression of a spider,”[75] as Rappaport[76] had misleadingly labelled it. (In fact, Leibniz did not conduct any experiment with a spider. At the relevant place in the *Protogaea*, he was merely describing the contemporary practice of goldsmiths.)[77]

Leibniz, in spite of his appeal to take up „not only theory and geometry but many practical observations [...],”[78] is often credited with a predilection

[70] Matthew Stewart, *The Courtier and the Heretic: Leibniz, Spinoza, and the Fate of God in the Modern World* (London: W. W. Norton & Company, 2006), 225.
[71] David R. Oldroyd, *Thinking about the Earth: A History of Ideas about Geology* (Cambridge: Harvard University Press, 1996), 70.
[72] Cf. Herbert Clark Hoover and Lou Henry Hoover, “Introduction,” in *De Re metallica*, transl. Herbert Clark Hoover and Lou Henry Hoover (London: The Mining Magazine, 1912), XIII; Gabriel Gohau, *Les sciences de la terre aux XVII*[e] *et XVIII*[e] *sciècle: Naissance de la géologie* (Paris: Éditions Albin Michel, 1990), 46.
[73] David R. Oldroyd, “Early Geology in Focus,” *Metascience* 21 (2012): 570.
[74] Ibid.
[75] Ibid., 571.
[76] Rhoda Rappaport, ed., “Leibniz on Geology: A Newly Discovered Text,” *Studia Leibnitiana* 29, no. 1 (1997): 8.
[77] See *Protogaea* (P, 48f., § 18).
[78] “Nicht nur theoretica und Geometrica sondern viel observationes practicae [...]” (*Denkschrift;* A, I, 3, 152, § 24f.).

for theory at the expense of practice.[79] This, however, fundamentally impoverishes the depth of the former, while at the same time diminishing the historical significance of the latter.[80] While scholars have recently stressed the importance of mines and mining for the *Protogaea*,[81] the detailed history of Leibniz's ambitions in Harz has over a substantial period received less attention.[82] But if the breadth of his insight into the details of the mining industry, and especially into the Brunschwick's economy, is not fully known,[83] then it is not evident whether in fact "the great scientific and mathematical advances of the seventeenth century – the age of Bacon, Galileo, Leibniz, and Newton – were not applied to contemporary engineering tasks," as Florman[84] or Westfall[85] claim.

Compared to Pierre Bayle, René Descartes, Jacob Thomasius, and most other philosophers of the time, Leibniz had a much greater motivation (and commitment) to transform the mining industry.[86] None of his myriad activities cost him as much time and energy as his efforts to harness the wind power for the benefit of the silver mines at Harz.[87] Nor does the correspondence relating to any of the other tasks with which he was charged in the service of the Brunschwicks come anywhere near the volume of the correspondence devoted specifically to mining research at Harz.[88] He

[79] See Friedrich Naumann, *Vom Abakus zum Internet: Die Geschichte der Informatik* (Darmstadt: Primus Verlag, 2009), 69.
[80] Laudan, *From Mineralogy to Geology*, 47, 232, fn. 1; Ernst Hamm, "Knowledge from the Underground: Leibniz Mines the Enlightenment," *Earth Sciences History* 16, no. 2 (1997): 93.
[81] Cf. for instance *Protogaea* (P, 18f., § 7).
[82] See Cohen and Wakefield, "Introduction," XIV. However, exceptions already existed in 2008, e.g., Leonhard Stiegler, "Leibnizens Versuche mit der Horizontalwindkunst auf dem Harz," *Technikgeschichte* 35, no. 4 (1968): 265–292.
[83] Jürgen Gottschalk, "Der Oberharzer Bergbau und Leibniz' Tätigkeit für Verbesserungen," in *Leibniz und Niedersachsen: Tagung anlässlich des 350. Geburtstages von G. W. Leibniz, Wolfenbüttel, 1996,* eds. Herbert Breger and Friedrich Niewöhner (Stuttgart: Franz Steiner Verlag, 1999), 183; Fettweis, *Zur Geschichte und Bedeutung*, 193f.
[84] Florman, *Engineering and the Liberal Arts*, 24.
[85] Richard Westfall, *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century* (London: Macdonald, 1971), X.
[86] Dym, *Divining Science*, 157.
[87] Cohen and Wakefield, "Introduction," XVI; see also Günter Scheel, "Einleitung," in *Sämtliche Schriften und Briefe,* Volume 1: Supplementband: Harzbergbau 1692–1696 (Berlin: Akademie Verlag, 1991), XLII.
[88] Scheel, "Einleitung," XXVII; see also Fettweis, *Zur Geschichte und Bedeutung*, 204; Stewart, *The Courtier and the Heretic,* 226.

therefore repeatedly returned to Clausthal-Zellerfeld, where he often stayed for several months.[89]

In 1680–1685/6[90] and then again in 1692–1696[91] he made 31 trips to the location and spent over three years there.[92] In the meantime, in 1688, he also visited the mining operations in the Saxon for several weeks, and subsequently also the Bohemian Ore Mountains, including a stop in region Ústí nad Labem with the mining expert Johann Daniel Crafft (1624–1697).[93] (The *Graupen* village near Pilsen mentioned by Fettweis[94] probably refers to Krupka near Teplice.) In addition to participating in guided tours of Ger-

[89] Fettweis, *Zur Geschichte und Bedeutung*, 211; Fettweis, "Leibniz und der Bergbau," in *Theoria cum praxi: Aus der Welt des Gottfried Wilhelm Leibniz: Beiträge anlässlich der Ausstellung Gottfried Wilhelm Leibniz, Philosoph, Mathematiker, Physiker, Techniker: 10. Juli bis 4. Oktober 2002*, ed. Hermann Hunger (Vien: Verlag der Österreichischen Akademie der Wissenschaften, 2012), 41.

[90] This was the time when the individual mechanisms, from wind-powered engines to pumps extracting water from mines, were being implemented. See 2.–4. part of the first volume of the academic edition [Paul Ritter, "Einleitung," in *Sämtliche Schriften und Briefe,* Series 1, Volume 3: *Allgemeiner Politischer Und Historischer Briefwechsel,* ed. Paul Ritter (Leipzig: K. F. Koehler Verlag, 1938), XXIX; Scheel, "Einleitung," XXIII; Friedrich W. Wellmer and Jürgen Gottschalk, "Leibniz' Scheitern im Oberharzer Silberbau: Neu betrachtet, insbesondere unter klimatischen Gesichtspunkten," *Studia Leibnitiana* 42, no. 10 (2010): 187; Friedrich W. Wellmer and Jürgen Gottschalk, "Die Beschäftigung des universalgelehrten Gottfried Wilhelm Leibniz (1646–1716) mit Geologie und Bergbau," *BHM: Berg- und Hüttenmännische Monatshefte: Zeitschrift für Rohstoffe, Geotechnik, Metallurgie, Werkstoffe, Maschinen und Anlagentechnik* 160, no. 2 (2015): 65]. Fettweis, *Zur Geschichte und Bedeutung,* 212, on the other hand, pre-dated the first phase to 1677–1678 [presenting designs to the duke], prolonged the second phase to 1678–1686 [construction and opening of two wind-powered pumps] and let it overlap with the concluding phase of 1685–1686 (and again 1692–1695) [three mining devices according to own design].

[91] These were various attempts to perfect the mining process, i.e., to achieve higher energy efficiency and thereby save water. See 9.–12. part of the first volume of the academic edition (Wellmer and Gottschalk, "Leibniz' Scheitern," 187; id., "Die Beschäftigung," 65, 67; Scheel, "Einleitung," XXIII).

[92] Ritter, "Einleitung," XXIX; Bernhard Sticker, "Leibniz' Beitrag zur Theorie der Erde," *Sudhoffs Archiv* 51, no. 3 (1967): 248f.; Fettweis, *Zur Geschichte und Bedeutung*, 196; Daniel Garber, "De ortu et antiquissimis fontibus Protogaeae Leibnizianae dissertatio: Observation, Exploration, and Natural Philosophy," in *Leibniz y las ciencias empíricas/Leibniz and the Empirical Sciences*, ed. Juan A. Nicolás (Granada: Editorial Comares, 2011), 175; Thomas from Padova, *Leibniz, Newton und die Erfindung der Zeit* (Munich: Piper, 2013), 221; Wellmer and Gottschalk, "Die Beschäftigung," 64.

[93] Fettweis, "Leibniz und der Bergbau," 36.

[94] *Graupen bei Pilsen* (Fettweis, *Zur Geschichte und Bedeutung*, 204).

man caves,[95] he devoted many months to the design and construction of mining facilities,[96] and the remains of his work in the Harz region are still part of a UNESCO World Heritage Site.[97] Ironically, the reason why his plans ultimately failed[98] was according to some interpreters that he was simply too far ahead of his time. At present, his designs for shaft lifting mechanisms are among the most modern achievements of technology.[99]

[95] Hans Joachim Waschkies, "Leibniz' geologische Forschungen im Harz," in *Leibniz und Niedersachsen: Tagung anlässlich des 350. Geburtstages von G. W. Leibniz, Wolfenbüttel, 1996,* eds. Herbert Breger and Friedrich Niewöhner (Stuttgart: Franz Steiner Verlag, 1999), 204. It would be a mistake, however, to see Leibniz as a protopaleontologist, as he probably came closer a well-informed amateur speleologist. At the time he visited the caves they were well-known sites on every traveller's itinerary. Baumann's Cave was already a popular destination for naturalists, tourists, and travellers of all kinds in his day. Matthaeus Merian, in his *Topographia* of 1654, advised them to hire an experienced guide and advised those without guides to literally unwind an Ariadne's ball, for once one got lost among the myriad caves, it was impossible to find one's way back, so one would then have to stay there, die, and rot, as the countless dead bodies or skeletons trapped on the site attested. And although Leibniz did not mention it, his expedition almost certainly took place in the company of such a local guide (Garber, "De ortu et antiquissimis fontibus," 182). Leibniz's account of his visit to the Scharzfeld cave, where he encountered a narrow underground passage, further suggests that he may indeed have taken Merian's advice to heart [Andre Wakefield, "The Origins and History of Earth," in *The Oxford Handbook of Leibniz,* ed. Maria Rosa Antognazza (New York: Oxford University Press, 2018), 459]: "But I didn't want to crawl any further, for the guides said that there was nothing more to see there." ["Sed longius repere non placuit. Nihil enim ultra magnopere visendum offerri aiebant ductores [...]" (*Protogaea*; P, 104f., § 36)]. Finally, the drawing of the cave he made was adopted, not original (Garber, "De ortu et antiquissimis fontibus," 182).

[96] Hamm, "Knowledge from the Underground," 82; Toshihiro Yamada, "Stenonian Revolution or Leibnizian Revival?: Constructing Geo-History in the Seventeenth Century," *Historia Scientiarum* 13, no. 2 (2003): 86.

[97] Wellmer and Gottschalk, "Die Beschäftigung," 65.

[98] Even when the whole project had failed, Leibniz was still involved in correspondence about the improvement of mining pumps with Daniel Linsen, manager of the Goslauer sawmill in 1707–1709, or about the levelling of the mines, the length of the second pendulums, and the construction of the slide rule (*Rechenscheibe*) with the mechanical director Bernhard Ripking from 1712–1716 (Scheel, "Einleitung," XLII). On his return from his stay in Vienna he did not forget to make an excursion to the gold mines in Hungary [John Mackie, *Life of Godfrey William von Leibnitz* (Boston: Gould, Kendall & Lincoln, 1845), 182] and again planned a trip to Bohemia, which, however, as in the case of the Salzburg and Tyrolean mines, was thwarted by the weather (Fettweis, *Zur Geschichte und Bedeutung*, 204). He also made his Italian stay more enjoyable by visiting the mercury mines in Istria (Mackie, *Life of Godfrey William von Leibnitz*, 182).

[99] See Fettweis, *Zur Geschichte und Bedeutung,* 193, 221; Fettweis, "Leibniz und der Bergbau," 49; Maria Rosa Antognazza, *Leibniz: An Intellectual Biography* (New York: Cambridge University Press, 2009), 335; Wellmer and Gottschalk, "Die Beschäftigung," 60, 67.

First, it is the endless rope, or rather the endless chain. The continuous rope, without which the later introduction of the Koep disc would not have been possible, was (re)discovered in Clausthal in 1834 by Albert, the Chief Mining Counsellor. Leibniz's technological invention was also the conical drum to compensate for momentum of force, which was later introduced only in 1975 at the Achenbach shaft above Bad Grund. To compensate for momentum of force Leibniz also proposed a coil drum to regulate the depth of the shaft during operation. This is now a standard tool in shaft sinking where the introduction of a bottom rope is not possible.[100] Last but not least, the entire proposal for recycling fuel water by means of horizontal wind machines and retention lakes can be considered too advanced for its time – whoever its real author was[101] – and is nowadays provided by storage power plants.[102]

Perhaps only one of Leibniz's mining designs, the new driving mechanism ("*neue Treibwerck*"), on which he worked *de facto* from the first phase of the project, can be considered obsolete today. It aimed to integrate the two processes necessary for mining (water pumping and ore extraction) through a single mechanism. With the help of an additional inverted water wheel mounted on top of the original unidirectional wheel, reverse operation was to be ensured so that the mining vessels could be transported upwards and downwards. The jerky running of the gear mechanism, which usually occurred during testing, was then to be solved by the new mechanism.

And although all Leibniz's other proposals for wind machines, gear mechanisms, and suction pumps eventually failed,[103] it was in Harz that he wrote, in his spare time, his first comprehensive and most extensive philosophical work: the *Discourse on Metaphysics*.[104] He may have been inspired

[100] Fettweis, *Zur Geschichte und Bedeutung*, 217; Wellmer and Gottschalk, "Die Beschäftigung," 67.

[101] See the crucial objections by Eric Aiton, *Leibniz: A Biography* (Boston: Adam Hilger, 1985), 87f. or Andre Wakefield, "Leibniz and the Wind Machines," *Osiris* 25, no. 1 (2010): 180–182.

[102] Wellmer and Gottschalk, "Die Beschäftigung," 67.

[103] Cohen, "Leibniz's Protogaea," 142; Wellmer and Gottschalk, "Die Beschäftigung," 67.

[104] Fettweis, *Zur Geschichte und Bedeutung,* 211, 240, fn. 6; Fettweis, "Leibniz und der Bergbau," 41, fn. 6; Antognazza, *Leibniz*, 239. See *Letter to Ernst August from 1/11 February 1686* (A, I, 4, 399, § 4n.). Although the Harz projects had failed, it was a period of unusual productivity for Leibniz in mathematics and philosophy. In 1684 he wrote, among other things, his first mature philosophical work, *Meditationes de cognitione, veritate et ideis*, and it was also during this period that he began his first important extensive philosophical correspondence with Arnauld [Brandon Look, "Introduction: Leibniz's Life and Works," in *The Bloomsbury Companion to Leibniz*, ed. Brandom Look (London: Bloomsbury, 2014), 8]. And

by discussions with the mine supervisor and theologian Caspar Calvör (1650–1725) in whose house he stayed.[105] The regret of later philosophers at Leibniz's futile distraction from theoretical matters in favour of mining is thus somewhat misplaced.[106] For it was the years he spent competing with the winds of the region during which he fulfilled the ambition he had announced in February 1676, namely, to piece together a secret philosophy of the universe.[107] It is even possible that he accepted the offer of employment in Hannover precisely because he saw it as an opportunity to combine theory with practice in the Harz.[108]

immediately after the Harz project *fiasco,* he finally found the long-desired peace of mind and intellectual energy necessary to apply the ideas that had occupied his mind for several years, to compress them into four key texts (milestones) on physics, metaphysics, theology and logic (Antognazza, *Leibniz*, 239).

[105] Fettweis, "Leibniz und der Bergbau," 41, fn. 6.

[106] Antognazza, *Leibniz*, 211.

[107] Stewart, *The Courtier and the Heretic*, 234.

[108] Fettweis, *Zur Geschichte und Bedeutung*, 210.

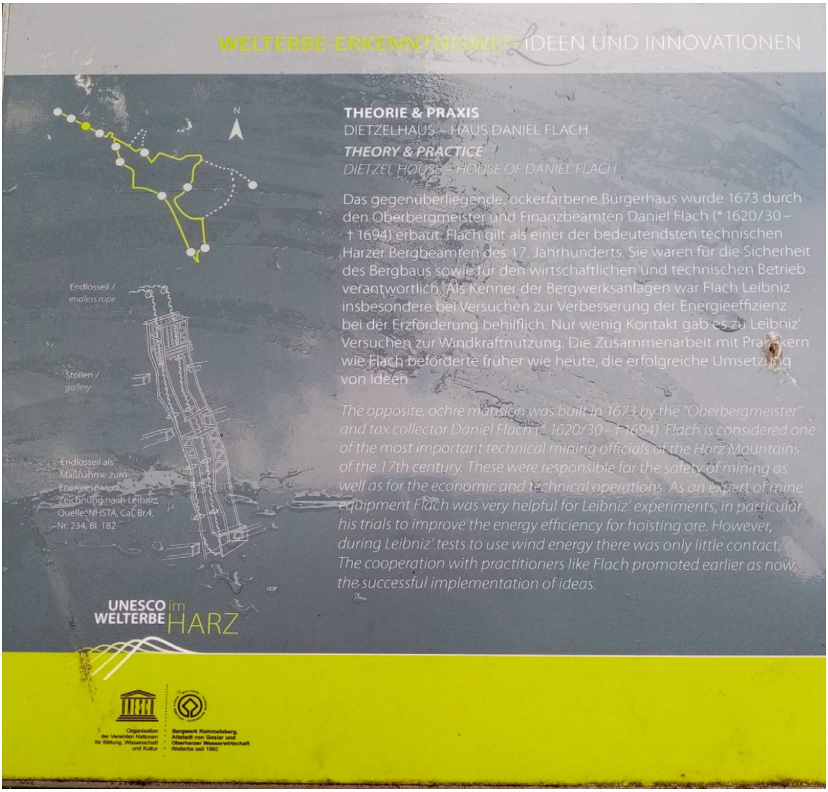

Figure 1: Information Board in Clausthal-Zellerfeld (source: Kateřina Lochmanová)

5. Theoria Cum Praxi?

Particularly in the context of the later *Protogaea*, however, it may be objected with Garber[109] that, despite what has been stated above, a purely theoretical interest in speculative knowledge preceded Leibniz's empirical research of mines. Besides the *Discours de Métaphysique*, even the knowledge grouped in the *Protogaea* at least arouses the suspicion that Leibniz

[109] Garber, "De ortu et antiquissimis fontibus," 173.

indeed extracted it from reading books and speculations, rather than from his own walks in the mountains. The contribution of the mining experience would then – as in the case of his predecessor Nicolas Steno[110] – consist in purely incidental circumstances, i.e., in merely inspiring his already existing interest in the subject of the *Protogaea*, rather than leading him directly to a specific theory.[111]

The sources of Leibniz's unflagging curiosity about the history of the Earth (geology) and prehistoric life forms (paleontology), culminating in the *Protogaea,* date back to his time in Leipzig.[112] It is one of his earliest scientific interests, deeply connected with the *Hypothesis physica nova* of 1671.[113] Moreover, indications are already apparent in the text, probably written immediately after he arrived in Paris, but no later than January 1678.[114]

However, as Garber himself acknowledges,[115] Leibniz's assurance in the pages of the (shorter) *Protogaea* of 1693 that the writing had been conditioned by empirical research in the Harz region[116] is at least partially fulfilled by the (longer) *Protogaea* of 1749, where he made numerous references to his observations there.[117] In fact, he did not articulate his intention to write

[110] See Elsebeth Thomsen, "*Niels Stensen: Steno, in the World of Collections and Museums*," in *The Revolution in Geology from the Renaissance to the Enlightenment,* ed. Gary Rosenberg (Boulder: Geological Society of America, 2009), 87.

[111] Garber, "De ortu et antiquissimis fontibus," 173.

[112] Eike Christian Hirsch, *Der berühmte Herr Leibniz: Eine Biographie* (Munich: C.H. Beck, 2001), 258.

[113] Garber, "De ortu et antiquissimis fontibus," 168.

[114] Ibid., 170.

[115] Ibid., 169, fn. 6; 173, 175.

[116] "For this reflection, an investigation was carried out into the region between the Hercynian Mountains and the Ocean, concerning the nature of situated [bodies]." ["Huic meditationi inquisitio in regionem intra Hercynios montes & Oceanum sitarum indolem facta [...]" (*Protogaea autore G. G. L*; PR, 40)]. Cf. his pledge " to explore rather than to bild [...]" ["[...] tentare [...] potius quam astruere [...]" (*Protogaea*; P, 10f., § 5)].

[117] Also Walter Kertz, "Diskussionsbemerkung zu Leibniz' Protogaea," in *Leibniz und Niedersachsen: Tagung anlässlich des 350. Geburtstages von G. W. Leibniz, Wolfenbüttel, 1996,* eds. Herbert Breger and Friedrich Niewöhner (Stuttgart: Franz Steiner Verlag, 1999), 212; Dale Jacquette, "Leibniz's Empirical, Not Empiricist Methodology," in *Tercentery Essays on the Philosophy and Science of Leibniz*, eds. Lloyd Strickland, Erik Vynckier and Julia Weckend (Cham: Springer, 2017), 195. See e.g. *Protogaea* (P, 6, 9, § 3; 38f., § 16; 44f., § 18). Moreover, it is often forgotten that the process of observing nature, which only came to a head during the Enlightenment, was already preceded during the Middle Ages by a slow, cumulative and anonymous process passed down [locally and] orally by outdoor workers from generation to generation [Lorraine Daston, "Observation and Enlightenment," in *Scholars in Action: The Practice of Knowledge and the Figure of the 18th century*, eds. André Holenstein, Hubert

a treatise on minerals until 1682, viz. four years after his first visit to the Harz Mountains, and only then did he simultaneously publish his *Denkschrift*, a detailed analysis[118] of many aspects of mining practice, including economic and [though very concisely] legal ones.[119]

But he certainly addressed the question of pressing ore before his first visit to the Harz, in 1679.[120] And, as the first volume of the eighth series of the academic edition demonstrates, many of the technological solutions that Leibniz presented in the context of his mining activities were actually formulated during his youth, when he was about 25 years old.[121] Thus, what we currently call the *Protogaea* – written in between two key mining projects – can probably indeed be regarded as a product of Leibniz's theoretical and practical interests simultaneously.[122]

Leibniz's claim that I "discover more with five or six men of practice, who could be employed in these regions [of the Harz] than with twenty of the most learned in Europe"[123] could also be contrasted with his obstinate distrust of the judgment of just such men of practice: "Experience [...] is in my view a better judge than these gentlemen."[124] Generally speaking, the completion of the history of the whole Earth would require even thousands of similar local observers, each of whom would contribute detailed, situated

Steinke and Martin Stuber (Boston: Brill, 2013), 658], which was also a substantial source for Leibniz's *Protogaea* (see *Protogaea*; P, 14f., § 6).

118 All the minig-process thoroughly from beginning up to the end [*des ganzen Bergwercks-proceßes vom anfang bis zum ende ad minutissima usque* (*Denkschrift*; A, I, 3, 151, § 14; 157, § 2)].

119 Smith, *Divine Machines*, 220. See *Denkschrift* (A, I, 3, 152, § 31–153, § 3).

120 Wellmer and Gottschalk, "Die Beschäftigung," 65.

121 Hartmut Hecht and Jürgen Gottschalk, "The Technology of Mining and Other Technical Innovations," in *The Oxford Handbook of Leibniz*, ed. Rosa Maria Antognazza (New York: Oxford University Press, 2018), 538.

122 Smith, *Divine Machines*, 220; Garber, "De ortu et antiquissimis fontibus," 182.

123 "De decouvrir plus avec cinq ou six hommes de practique, qui pourront avoir de l'employ dans ces pays la, qu'avec une vingtaine des plus sçavans de l'Europe" (*Letter to Johann Friedrich from February 1679;* A, I, 2, 130, § 15–19). See also his claim that "one should have not only supposedly great chemists and arcanists, but also about a pair of bad yet good laboratory workers" ["Man solle nicht sowohl grosse vermeinte Chymicos und Arcanisten, als etwa ein paar schlechte doch guthe laboranten haben *[...]*" (*Letter to Von Platen from the end of January 1680;* A, I, 3, 19, § 8/23–27)]. See also *Lettre from Christian Philipp to Leibniz from 4/14 February 1680* (A, I, 3, 354, § 3–7).

124 "*L'experience [...] est à mon avis un meilleur juge qve ces Messieurs-la*" (*Letter to Johann Friedrich from middle October 1679;* A, I, 2, 207f., § 1–3).

knowledge of individual cases.[125] But Leibniz probably did not count mining officials among such observers. Moreover, as witnessed by his attempt to impress mining officials with abstract speculations about force and friction, implying that the officials themselves did not understand the fundamentals of mechanics, he certainly could not have relied on experience alone.[126] In any case, his attitude was extremely unfair on both counts. First, because many of them had studied at leading European universities, and second, because – as archival evidence shows – they had a comparable sense not only of experience and experimentation, but also of linking universal knowledge with the local.[127]

[125] Laudan, *From Mineralogy to Geology*, 101; Fettweis, *Zur Geschichte und Bedeutung*, 250; Cohen and Wakefield, "Introduction," XXXV. See *Protogaea* (P, 2f., § 1). Cf. a similar assumption already in Aristotle (Mt., 366b 29f.) who, based on observations in many places, reached the conclusion that the universal corresponds with the local and the history of the universe corresponds with the history of the Earth. Purely local geography entirely in Leibniz's spirit was cultivated by later chorographies, i.e., detailed academic descriptions of specific places or regions, usually supplemented with descriptions of all kinds of local *antiquities*, whether historical buildings, megaliths, and other artefacts, or even local histories derived from documents, oral traditions, or folklore (Rudwick, *Bursting the Limits of Time,* 186). However, given the difficulty of travelling in the eighteenth century, independent fieldwork on a larger scale was out of the question, so there was really no choice but to rely on the observations of others. It was only with the improvement of roads and canals, and eventually the construction of railways, that real merging of the individual local narratives was made possible (Laudan, *From Mineralogy to Geology*, 40; Rudwick, *Bursting the Limits of Time*, 46; Richard Fortey, "In retrospect: Leibniz's *Protogaea*," *Nature* 455, no. 4 (2008): 35.

[126] The conventional narrative that this was merely a trivial conflict between the artisanal *know-how* of the miners and the developing spirit of the scientific revolution is, however, somewhat exaggerated (Wakefield, "Leibniz and the Wind Machines," 180, 188). After all, another 'outsider', Emanuel Sweedenborg (1688–1782), secured his position as a respected mining official not long afterwards precisely by his extensive publishing activities, spanning many fields, including not only mining science or metallurgy, but also physics, strongly influenced by the work of Christian Wolff [Hjalmar Fors, *The Limits of Matter: Chemistry, Mining & Enlightenment* (Chicago: University of Chicago Press, 2015), 87], and through him also by Leibniz! Just as the sailors also respected the cosmographer Amerigo Vespucci precisely because – although lacking practical experience – he had achieved, purely by virtue of his education, a greater competence in navigation than all the sailors in the world [Amerigo Vespucci, *Mundus novus* (Augsburg: Johannes Otmar, 1504), 2]. And although Daniel Špelda, "Mundus novus a kosmografická tradice," *Kuděj* 12, no. 1 (2011): 116 translates the term *navigandi disciplina* with the equivalent *navigating* (*navigování*), that may have been regarded as a doctrine no less theoretical than cosmography itself. The truly and extremely dangerous challenge was the sailing itself, whereby this "was the pattern of voyages for many centuries. It can be recognized on the course taken by Columbus" [Norbert Wiener, *The Human Use of Human Beings: Cybernetics and Society* (Cambridge: The Riverside Press, 1950), 165].

[127] Wakefield, "Leibniz and the Wind Machines," 188.

6. Conclusion

Beringer[128] and Langer[129] were convinced that geology drew much more intensively on the new horizons, disclosed ultimately by Nicolaus Copernicus or Christopher Columbus, rather than on mining.[130] According to them, geology did not arise from the practical needs or requirements of the mines, but was much more theoretical in origin, although mining provided useful impulses to it. At the same time, Beringer's etymology of the term *θεωρία* does not exclude Leibniz's orientation towards a natural-scientific factually oriented description later applied to the description of history.[131] In spite of it, he also adds that miners obtained such knowledge in the *Academia*. For him, Leibniz was a philosopher and mathematician by origin.[132]

However, Leibniz's effort must have been acknowledged in Freiberg.[133] Werner also relied on a theoretical infrastructure and – although he did not explicitly reveal it in his work – he could count on most eighteenth-century mineralogists to reveal his assumptions.[134] According to Carozzi, "Werner failed to reach a true understanding of the structure and history of the earth [...]."[135] Not to mention that (compared to Agricola) Werner's approach was more counter-productive to the progress of geology than it was conducive to it.[136] Anyway, it has turned out that, after Nicolas Steno – who was still dealing only with singulars – offering local analyses but not a unifying

[128] Carl Christoph Beringer, *Geschichte der Geologie und des Geologischen Weltbildes* (Stuttgart: Ferdinand Enke Verlag, 1954), 143.
[129] Wolfhart Langer, "Zur Erforschung der Geologie und Paläontologie Westfalens: Von den Anfängen bis 1900," in *Geologie und Bergbau im Rheinisch-Westfälischen Raum: Bücher aus der historischen Bibliothek des Landesoberbergamtes Nordrhein-Westfalen in Dortmund,* eds. Christoph Bartels, Reinhard Feldmann, and Klemens Oekentorp (Münster: Universitäts- und Landesbibliothek Münster, 1994), 13.
[130] See also Hannah Arendt, *Vita activa: Oder Vom tätigen Leben* (Munich: Piper, 1994), 281f.
[131] Alois Schmid, "Die Herkunft der Welfen in der bayerischen Landeshistoriographie des 17. Jahrhunderts und bei Gottfried Wilhelm Leibniz," in *Leibniz und Niedersachsen: Tagung anlässlich des 350. Geburtstages von G. W. Leibniz, Wolfenbüttel, 1996,* eds. Herbert Breger and Friedrich Niewöhner (Stuttgart: Franz Steiner, 1999), 142. Also Rudwick, *Bursting the Limits of Time*, 53; Jacquette, "Leibniz's Empirical, Not Empiricist Methodology," 195. See *Nova methodus discendae docendaeque jurisprudentiae* (A, VI, 1, 284, I, § 32, § 7 – 32a, § 13). Cf. Plato's *Phaedo* (HS, 96a).
[132] Beringer, *Geschichte der Geologie*, 143.
[133] Dym, *Divining Science*, 161.
[134] Laudan, *From Mineralogy to Geology*, 124.
[135] Albert Carozzi, "Preface," in *On the External Characters of Minerals*, transl. Albert Carozzi, V–VI (Urbana: University of Illinoa Press, 1962), V.
[136] Hoover and Hoover, "Introduction," XIII; 53, fn. 1, conclusion.

theory of everything[137] –, Werner was by far not the first "geologist" capable of synthetizing local knowledge.[138]

Laudan[139] argues that Werner was the first to be able to disengage himself from the naturally utilitarian orientation of the mineralogy of his day. According to her, research on stratigraphic formations, defined in terms of their age rather than of their composition, was only marginally relevant for economic matters. "*While miners,*" according to Oldroyd, "knew how to excavate pits and wells, drive shafts, pump out mine waters and recognize signs [...] that might indicate profitable or unprofitable digging [...] mining did not, in itself, furnish new ways of thinking about the earth."[140]

Let's leave aside that mining officials and other elites supervised miners and locals with the assumption that they possessed the necessary knowledge about the Earth.[141] In any case, the obsolete academic language could not keep up with the vivacity of their slang (*Bergsprache*).[142] And seeing that before the establishment of the Freiberg Academy university or scholarly training, including awareness of the new philosophy, was an exception rather than the rule among mining officials,[143] the Saxon mining officials

[137] Poole, *The World Makers*, 67. Even though, according to Leibniz, "Steno had already thought this way [...] after visiting a considerable part of Europe [...]." ["Cogitaverat jam ante Stenonius, non contemnenda Europae parte lustrata" (*Protogaea,* P, 18f., § 6)]. And even the proclaimed goal of the *Geological Society* (and not only of the *Mineralogical* one), i.e., studying nature on a large scale, was not fulfilled because only one of the thirteen founding members published a geological work, in contrast to a mineralogical one (Laudan, *From Mineralogy to Geology*, 111).

[138] See Laudan, *From Mineralogy to Geology*, 101; Rudwick, *Bursting the Limits of Time*, 31f. Cf. the observation that tertiary remains included not only those of the Paris Basin, but also many other types of terrain distributed over the entire surface of the earth, "almost entirely unknown to the geologists of the famous Freiburg school" ["presque entièrement inconnue aux géologues de la célèbre école de Fryberg" [Georges Cuvier and Alexandre Brongniart, *Description géologique des environs de Paris: nouvelle édition, dans laquelle est inséré la description d'un grand nombre de lieux de l'Allemagne, de la Suisse, de l'Italie, etc., qui présentent des terrains analogues à ceux du bassin de Paris* (Paris: G. Dufour and E. D'Ocagne, 1822), 9], i.e., to Werner and his followers (Rudwick, *Bursting the Limits of Time*, 550).

[139] Laudan, *From Mineralogy to Geology*, 102.

[140] Oldroyd, *Thinking about the Earth*, 70.

[141] Dym, *Divining Science*, 137. Mining thus provided geognosis not only with empirical data regarding the dimesion of depth in the Earth's crust but also – which was much more important – a specific way of thinking, and even of seeing (ibid., 168). Geognosis thus owes much to mining (Rudwick, *Bursting the Limits of Time*, 84).

[142] Dym, *Divining Science*, 168; Morel, *Underground Mathematics*, 10, 46, 249f.

[143] Dym, *Divining Science*, 103. That is also why Leibniz in his *Denkschrift* doubted the mine workers' and officials' assumed faith in further progress of the Earth science (ibid., 161).

had a disproportionate share in the development of mineralogy and geology over the next few centuries.[144]

However, Rudwick[145] referred to Werner as the leading representative of utilitarian geognosis of the time, i.e., someone for whom it would be downright insulting to be placed in the context of speculating about the Earth's history. In fact, the entire Heynitz Mining Academy in Freiberg, the first mining academy in the world,[146] was an institution designed primarily for the pragmatic instruction of mining officials or experts.[147] In some respects it was even the direct predecessor of today's technical universities, which emerged only in the nineteenth century.[148]

In any case, Lefèvre[149] placed it in stark contrast to early modern scientific academies, such as the Royal Society of London, or the Royal Academy of Sciences in Paris,[150] whose roots ultimately go back to the medieval University of Paris.[151] Leibniz must allegedly have those in mind[152] when, in his first reflections on the establishment of an academy of sciences in Germany, he praised the Central European mines, "for no nation can be compared to the Germans in mining matters [...]."[153] This would also be consistent with the very designation of a (scientific) society, not a mere (educational) academy.[154]

144 Laudan, *From Mineralogy to Geology*, 48; Thomas Biskup, "Transnational Careers in the Service of Empire: German Natural Historians in Eighteenth-Century London," in *Scholars in Action: The Practice of Knowledge and the Figure of the 18th century*, eds. André Holenstein, Hubert Steinke and Martin Stuber (Boston: Brill, 2013), 53.
145 Rudwick, *Bursting the Limits of Time*, 84f., 510.
146 Andre Wakefield, *The Disordered Police State: German Cameralism as Science and Practice* (Chicago: University of Chicago Press, 2009), 34f.
147 Laudan, *From Mineralogy to Geology*, 50; Rudwick, *Bursting the Limits of Time*, 25; Dym, *Divining Science*, 173.
148 Fettweis, *Zur Geschichte und Bedeutung*, 252.
149 Lefèvre, *Minerva Meets Vulcan*, 141, fn. 49.
150 Also Pauline Phemister, "Theoria cum praxi: Leibniz's Legacy into the Future," in *Leibniz's Legacy and Impact,* eds. Lloyd Strickland and Julia Weckend (New York: Routledge, 2020), 295.
151 Rudwick, *Bursting the Limits of Time*, 23; Alain de Libera, *La philosophie médiévale* (Paris: Presses Universitaires de France, 2019), 367f.
152 Fettweis, "Leibniz und der Bergbau," 36. Cf. Phemister, "Theoria cum praxi," 296.
153 "Weil keine Nation der Teutschen in Bergwergssachen gleichen können [...]" (*Bedenken von Aufrichtung einer Akademie oder Societät;* A, IV, 1, 543, § 2/26f.). From Europe to the American colonies, specialists from Germany were at least overseeing the newly developing mining exploration (Fettweis, *Zur Geschichte und Bedeutung*, 250; Morel, *Underground Mathematics*, 99f.).
154 Antognazza, *Leibniz*, 389.

However, Leibniz was probably not inspired by any of these societies. „Such an Electoral society," he made clear, „should not be focused on mere curiosity or thirst for knowledge and fruitless experiments, nor should it be based on the mere invention of useful things without application or use, as is the case in Paris, London or Florence [...]."[155] It is therefore no coincidence that the oldest international scientific society in the world later became the German *Die Societät der Bergbaukunde*.[156]

Even at the newly recognized Royal Society in London, defining itself against traditional universities precisely by its interest in the new science and technology,[157] there was constant demand for the German expertise.[158] And Leibniz with his *Denkschrift* reciprocally referenced the *Articles of Inquiries Touching Mines of the Royal Society* of 1666.[159] In this way he strove to emphasize that he could bring something to the Academy that even the famous mathematician and physicist Christiaan Huygens (1629–1695) could not provide[160] and that his predecessor Steno had lacked,[161] viz. the experience he had acquired in the Harz.[162]

It can be agreed, then, that although the Mining Academy was created in accordance with what Leibniz would have approved, the teaching and mining practice nevertheless required professors and officials to consult not

[155] "Solche Churfürstl. societät müste nicht auf bloße curiosität oder wissensbegierde und unfruchtbare experimenta gerichtet seyn, oder bey der bloßen erfindung nüzlicher dinge ohne application und anbringung beruhen, wie etwa zu Paris, London und Florenz geschehen [...]" (*Die Societät der Wissenschaften in Berlin*; K, X, 299).
[156] Fettweis, *Zur Geschichte und Bedeutung*, 250.
[157] Philip Beeley, "Leibniz and Hobbes," in *The Bloomsbury Companion to Leibniz*, ed. Brandon Look (London: Bloomsbury, 2014), 33. Also Jacob and Stewart, *Practical Matter*, 41, 49n.
[158] Dym, *Divining Science*, 140.
[159] Ibid., 160; see *Denkschrift* (A, I, 3, 152, § 3). When this unique interconnection between the British Empire, natural history, and continental academics fell victim to the Napoleonic wars, it was almost forgotten (Biskup, "Transnational Careers," 69).
[160] Huygens can validly be called engineer and inventor in the modern sense of the word, who performed his – primarily technical – work based on precise calculations and an effective use of scientific knowledge [Vitaly Gorokhov, "Scientific and Technological Progress by Galileo," in *Departure for Modern Europe: A Handbook of Early Modern Philosophy (1400–1700)*, ed. Hubert Busche (Hamburg: Felix Mainer Verlag, 2011), 145]. It was the studies of Huygens, rather than the famous but apocryphal apple, that inspired Newton's grand synthesis [Abbot Payson Usher, *A History of Mechanical Inventions* (New York: McGraw-Hill, 1929), 64].
[161] Thomsen, "*Niels Stensen*," 87. Cf.: "I weight Steno's careful observation against the authority of Pliny [...]" ["Plinianae autoritati Stenonii diligentiam oppono [...]" (*Protogaea*; P, 26, 29, § 9)].
[162] Garber, "De ortu et antiquissimis fontibus," 168.

only the insights of their predecessors but also those of dowsers,[163] against which Leibniz had a bias.[164] However, the Freiberg professors lacked a sufficient alternative to traditional dowsing – despite the Enlightenment rhetoric to the contrary and contrary to their original intentions.[165] Thus, even the newly founded scientific academies, such as that of Prussia by Leibniz,[166] fulfilled their purpose only gradually, since for a science as little developed as geology their importance must have been at first almost nil.[167]

Whatever the intention of their patrons, the general tendency of all their members, according to Laudan,[168] was to return to pure theory whenever possible. One example is the Bavarian Academy of Sciences, which was initially hostile to the optical engineer and future member Joseph Ritter von Fraunhofer (1787–1826) simply because he lacked a university education.[169] Furthermore, since, according to Torrens,[170] even "the practical men did not want to know," according to Dym,[171] the geological knowledge at the new academy in Freiberg in turn hardly influenced the mining practice.

A fundamental advance was made in Leibniz's *Denkschrift,* which includes both *Universalia*, i.e., matters concerning mines in general, and *Singularia*, i.e., matters locally conditioned.[172] Beginning with *universalia,*[173] Leibniz, like Agricola and other mining authorities, began with the first step in any mining enterprise, namely, digging. At the same time, however, he also called for a theory of underground ore indications and for a science of stones, by which he meant knowledge of how mineral fragments confirm the distribution of veins and the quality of the ore.[174] After the exposition on stones and ground, there came an overview of mining exploration, mining law, mechanical technology (ventilation, hydraulics, transport), sorting, and smelting. In this last section, Leibniz promised to build on the famous 1574 drilling manual by Lazarus Ercker, once the mining master at Goslar.[175]

163 Dym, *Divining Science*, 166.
164 Ibid., 157. See *Protogaea* (P, 26f., § 9).
165 Dym, *Divining Science*, 169f.
166 Ibid., 158.
167 Beringer, *Geschichte der Geologie*, 143.
168 Laudan, *From Mineralogy to Geology*, 47.
169 Dym, *Divining Science*, 173.
170 Torrens, "Some Thoughts," 10. Dym, *Divining Science*, 182 erroneously cites p. 20.
171 Dym, *Divining Science*, 182.
172 *Denkschrift* (A, I, 3, 151, § 7–12).
173 See *Denkschrift* (A, I, 3, 151, § 13 –157, § 9).
174 Dym, *Divining Science*, 159.
175 Ibid., 160.

The *Singularia*, or specific mining knowledge, includes underground topography, viz. a complete exposition of the watersheds, forests, and lands of the various mining areas.[176] Detailed knowledge of this kind should therefore, according to him, underpin the decision-making of managers. Otherwise they either risked tunneling on the basis of relying purely on previous success or, on the contrary, could discontinue tunneling due to unfounded fears.[177]

This way Leibniz's *philosophical mining* meets the *theoria cum praxi* requirement: practical mining experience draws on theoretical natural philosophical reflection and *vice versa.* And as Hannah Arendt[178] claims, the world could hardly maintain its current technological level, let alone develop it further, if theoretical, seemingly useless basic research were really abandoned as mere speculation.[179] The growing importance of basic, theoretical research, dictated by the needs of the accelerating scientific and technological progress, is indeed being confirmed.[180]

Bibliography:

Primary sources

A Leibniz, Gottfried Wilhelm. *Sämtliche Schriften und Briefe.* Darmstadt: O. Reichl, 1923–2013.

CC Comenius, Jan Amos. De rerum humanarum emendatione consultatio catholica. Prague: Academia, 1966.

DM Suárez, Francisco. *Disputationes Metaphysicae.* Hildesheim: Georg Olms, 1965.

GM Leibniz, Gottfried Wilhelm. *Leibnizens Mathematische Schriften*, edited by Carl Immanuel Gerhardt. Halle: H. W. Schmidt, 1849–1863.

GP Leibniz, Gottfried Wilhelm. *Die philosophischen Schriften.* Edited by Carl Immanuel Gerhardt. Berlin: Weidmann, 1875–1890.

[176] See *Denkschrift* (A, I, 3, 157, § 10 – 162, § 15).

[177] *Letter to Ernst August from 20 February/4 March 1682* (A, I, 3, 159, § 29–31).

[178] Arendt, *Vita activa*, 271, 282 and 288.

[179] See also White, *Medieval Religion and Technology,* 41; Eric Schatzberg, *Technology: Critical History of a Concept* (Chicago: University of Chicago Press, 2018), 12.

[180] Vitaly Gorokhov, "Engineering Sciences: History and Theory," *Herald of the Russian Academy of Sciences* 84, no. 6 (2014): 442–444.

HS Plato. *Platonis opera quae extant omnia,* edited by Henricus Stephanus. Genève: Henricus Stephanus, 1578.

K Leibniz, Gottfried Wilhelm. *Die Werke von Leibniz: Gemäss seinem Hanschriftlichen Nachlasse in der Königlichen Bibliothek zu Hannover,* edited by Onno Klopp. Hannover: Klindworth Verlag, 1873.

LoC Leibniz, Gottfried Wilhelm. *The Labyrinth of the Continuum: Writings of 1672 to 1686,* edited by Richard Arthur. New Haven: Yale University Press, 2001.

Mt. Aristotle. *Meteorologica: With an English Translation by H.D.P. Lee,* edited by Henry Desmond Pritchard Lee. Cambridge: Harvard University Press, 1952. https://doi.org/10.4159/DLCL.aristotle-meteorlogica.1952

P Leibniz, Gottfried Wilhelm. *Protogaea: Sive de prima facie telluris et antiquissimae historiae vestigiis in ipsis naturae monumentis dissertatio,* edited by Claudine Cohen and Andre Wakefield. Chicago: University of Chicago Press, 2008. https://doi.org/10.7208/chicago/9780226112978.001.0001

PR Leibniz, Gottfried Wilhelm. "Protogaea autore G. G. L." *Acta eruditorum* (1693), 40–42.

PG Leibniz, Gottfried Wilhelm. *Leibnizens gesammelte Werke,* edited by Georg Heinrich Pertz. Hannover: Hahnsche Hof-Buchhandlung, 1843–1847.

SPF Comenius, Jan Amos. *Spisy o první filosofii,* edited by Vojtěch Balík and Věra Schifferová. Prague: Oikoymenh, 2017.

W Werner, Abraham Gottlob. *On the External Characters of Minerals,* translated by Albert Carozzi. Urbana: University of Illinois Press, 1962.

Secondary sources

Aiton, Eric. *Leibniz: A Biography.* Boston: Adam Hilger, 1985.

Antognazza, Maria Rosa. *Leibniz: An Intellectual Biography.* New York: Cambridge University Press, 2009. https://doi.org/10.1017/CBO9781139012805

Arendt, Hannah. *Vita activa: Oder Vom tätigen Leben.* 8th ed. Munich: Piper, 1994.

Baker, Victor. "Charles S. Peirce and the 'Light of Nature.'" In *The Revolution in Geology from the Renaissance to the Enlightenment,* edited by Gary Rosenberg, 259–266. Boulder: Geological Society of America, 2009. https://doi.org/10.1130/2009.1203(18)

Beeley, Philip. “Leibniz and Hobbes.” In *The Bloomsbury Companion to Leibniz,* edited by Brandon Look, 32–50. London: Bloomsbury, 2014.

Beringer, Carl Christoph. *Geschichte der Geologie und des Geologischen Weltbildes.* Stuttgart: Ferdinand Enke Verlag, 1954. https://doi.org/10.1080/11035895409453548

Biskup, Thomas. “Transnational Careers in the Service of Empire: German Natural Historians in Eighteenth-Century London.” In *Scholars in Action: The Practice of Knowledge and the Figure of the 18th century,* edited by André Holenstein, Hubert Steinke and Martin Stuber, 45–69. Boston: Brill, 2013. https://doi.org/10.1163/9789004243910_003

Boerhaave, Herman. *A New Method of Chemistry: Including the Theory and Practice of that Art: Laid down on Mechanical Principles, and accomodated to the Uses of Life,* edited by Peter Shaw and Ephraim Chambers. London: J. Osborn and T. Longman, 1727.

Carozzi, Albert. “Preface.” In *On the External Characters of Minerals, translated by* Albert Carozzi, V–VI. Urbana: University of Illinois Press, 1962.

Cohen, Claudine. “Leibniz’s Protogaea: Patronage, Mining, and the Evidence for a History of the Earth.” In *Proof and Persuasion: Essays on Authority, Objectivity, and Evidence,* edited by Suzanne Marchand and Elizabeth Lunbeck, 124–143. Turnhout: Brepols, 1996.

Cohen, Claudine, and André Wakefield. “Introduction.” In *Protogaea: Sive de prima facie telluris et antiquissimae historiae vestigiis in ipsis naturae monumentis dissertatio,* edited by Claudine Cohen and André Wakefield, XIII–XLII. Chicago: University of Chicago Press, 2008.

Conduitt, John. “Account of Newton’s Manual Dexterity: The Keynes Ms. 130.09.” In *The Newton Project.* University of Oxford: Faculty of History, 2025. Article published November 2024. https://www.newtonproject.ox.ac.uk/view/texts/normalized/THEM00171.

Cuvier, Georges, and Alexandre Brongniart. *Description géologique des environs de Paris: nouvelle édition, dans laquelle est inséré la description d’un grand nombre de lieux de l’Allemagne, de la Suisse, de l’Italie, etc., qui présentent des terrains analogues à ceux du bassin de Paris.* Paris: G. Dufour and E. D’Ocagne, 1822. https://doi.org/10.5962/bhl.title.149831

Daston, Lorraine. “Observation and Enlightenment.” In *Scholars in Action: The Practice of Knowledge and the Figure of the 18th century,* edited by André

Holenstein, Hubert Steinke and Martin Stuber, 657–677. Boston: Brill, 2013. https://doi.org/10.1163/9789004243910_029

Dugas, René. *Histoire de la mécanique.* Neuchâtel: Éditions du Griffon, 1950.

Dym, Warren A. *Divining Science: Treasure Hunting and Earth Science in Early Modern Germany.* Boston: Brill, 2011. https://doi.org/10.1163/ej.9789004186422.i-218

Elden, Stuart. "Leibniz and Geography: Geologist, Paleontologist, Biologist, Historian, Political Theorist and Geopolitician." *Geographica Helvetica* 68 (2013): 81–93. https://doi.org/10.5194/gh-68-81-2013

Fettweis, Günter. *Zur Geschichte und Bedeutung von Bergbau und Bergbauwissenschaften: 21 Texte eines Professors für Bergbaukunde zur Entwicklung des Montanwesens in Europa.* Vien: Österreichischen Akademie der Wissenschaften, 2004. https://doi.org/10.1553/0x0004481a

Fettweis, Günter. "Leibniz und der Bergbau." In *Theoria cum praxi: Aus der Welt des Gottfried Wilhelm Leibniz: Beiträge anlässlich der Ausstellung Gottfried Wihelm Leibniz, Philosoph, Mathematiker, Physiker, Techniker: 10. Juli bis 4. Oktober 2002,* edited by Hermann Hunger, 29–68. Vien: Verlag der Österreichischen Akademie der Wissenschaften, 2012.

Florman, Samuel. *Engineering and the Liberal Arts: A Technologist's Guide to History, Literature, Philosophy, Art, and Music.* New York: McGraw Hill Book Company, 1968.

Floss, Pavel. *Atomy, pohyb, teplo: Pokus o výklad některých tendencí Komenského kosmologie.* Přerov: Vlastivědný ústav, 1970.

Fors, Hjalmar. *The Limits of Matter: Chemistry, Mining* & *Enlightenment.* Chicago: University of Chicago Press, 2015. https://doi.org/10.7208/chicago/9780226195049.001.0001

Fortey, Richard. "In retrospect: Leibniz's *Protogaea.*" *Nature* 455, no. 4 (2008): 35. https://doi.org/10.1038/455035a

Garber, Daniel. "De ortu et antiquissimis fontibus Protogaeae Leibnizianae dissertatio: Observation, Exploration, and Natural Philosophy." In *Leibniz y las ciencias empíricas/Leibniz and the Empirical Sciences,* edited by Juan A. Nicolás, 65–85. Granada: Editorial Comares, 2011.

Gaukroger, Stephen. *The Collapse of Mechanism and the Rise of Sensibility: Science and the Shaping of Modernity, 1680–1760.* Oxford: Clarendon Press, 2010. https://doi.org/10.1093/acprof:oso/9780199594931.001.0001

Gohau, Gabriel. *Les sciences de la terre aux XVII*[e] *et XVIII*[e] *sciècle: Naissance de la géologie*. Paris: Éditions Albin Michel, 1990.

Gorokhov, Vitaly. "Scientific and Technological Progress by Galileo." In *Departure for Modern Europe: A Handbook of Early Modern Philosophy (1400–1700),* edited by Hubert Busche, 135–147. Hamburg: Felix Mainer Verlag, 2011.

Gorokhov, Vitaly. "Engineering Sciences: History and Theory." *Herald of the Russian Academy of Sciences* 84, no. 6 (2014): 441–448. https://doi.org/10.1134/S101933161406001X

Gottschalk, Jürgen. "Der Oberharzer Bergbau und Leibniz' Tätigkeit für Verbesserungen." In *Leibniz und Niedersachsen: Tagung anlässlich des 350. Geburtstages von G. W. Leibniz, Wolfenbüttel, 1996,* edited by Herbert Breger and Friedrich Niewöhner, 173–186. Stuttgart: Franz Steiner Verlag, 1999.

Hamm, Ernst. "Knowledge from the Underground: Leibniz Mines the Enlightenment." *Earth Sciences History* 16, no. 2 (1997): 77–99. https://doi.org/10.17704/eshi.16.2.5204u8j628w3027l

Hecht, Hartmut, and Jürgen Gottschalk. "The Technology of Mining and Other Technical Innovations." In *The Oxford Handbook of Leibniz,* edited by Rosa Maria Antognazza, 526–540. New York: Oxford University Press, 2018.

Hirsch, Eike Christian. *Der berühmte Herr Leibniz: Eine Biographie*. 2nd ed. Munich: C.H. Beck, 2001.

Hoover, Herbert Clark, and Lou Henry Hoover. "Introduction." In *De Re metallica,* translated by Herbert Clark Hoover and Lou Henry Hoover, V–XIV. London: The Mining Magazine, 1912.

Chambers, Ephraim. *Cyclopaedia: Or, An Universal Dictionary of Arts and Sciences: Containing the Definitions of the Terms, and Accounts of the Things Signify'd thereby, in the Several Arts, Both Liberal and Mechanical, and the Several Sciences, Human and Divine: The Whole Intended as a Course of Antient and Modern Learning.* London: James and John Knapton, 1728.

Jacob, Margaret, and Larry Stewart. *Practical Matter: Newton's Science in the Service of Industry and Empire 1687–1851.* Cambridge: Harvard University Press, 2004.

Jacquette, Dale. "Leibniz's Empirical, Not Empiricist Methodology." In *Tercentery Essays on the Philosophy and Science of Leibniz,* edited by Lloyd Strickland, Erik Vynckier and Julia Weckend, 179–202. Cham: Springer, 2017. https://doi.org/10.1007/978-3-319-38830-4_8

Kertz, Walter. "Diskussionsbemerkung zu Leibniz' Protogaea." In *Leibniz und Niedersachsen: Tagung anlässlich des 350. Geburtstages von G. W. Leibniz, Wolfenbüttel, 1996,* edited by Herbert Breger and Friedrich Niewöhner, 211f. Stuttgart: Franz Steiner Verlag, 1999.

Klein, Ursula, and Emma Spary. "Introduction: Why Materials?" In *Materials and Expertise in Early Modern Europe: Between Market and Laboratory,* edited by Ursula Klein and Emma Spary, 1–23. Chicago: University of Chicago Press, 2009. https://doi.org/10.7208/chicago/9780226439709.003.0001

Langer, Wolfhart. "Zur Erforschung der Geologie und Paläontologie Westfalens: Von den Anfängen bis 1900." In *Geologie und Bergbau im Rheinisch-Westfälischen Raum: Bücher aus der historischen Bibliothek des Landesoberbergamtes Nordrhein-Westfalen in Dortmund,* edited by Christoph Bartels, Reinhard Feldmann and Klemens Oekentorp, 13–33. Münster: Universitäts- und Landesbibliothek Münster, 1994.

Laudan, Rachel. *From Mineralogy to Geology: The Foundations of a Science 1650–1830.* Chicago: University of Chicago Press, 1993.

Lefèvre, Wolfgang. *Minerva Meets Vulcan: Scientific and Technological Literature: 1450–1750.* Cham: Springer, 2021. https://doi.org/10.1007/978-3-030-73085-7

De Libera, Alain. *La philosophie médiévale.* 3rd ed. Paris: Presses Universitaires de France, 2019. https://doi.org/10.4000/annuaire-cdf.14302

Lochmanová, Kateřina. "Ontologický status ideálního prostoru u Leibnize." *Pro-Fil* 20, no. 2 (2019): 30–41. https://doi.org/10.5817/pf19-2-1959

Lochmanová, Kateřina. "*Analysis situs*" *a teorie prostoru v kontextu Leibnizovy korespondence s Clarkem.* Prague: Filosofia, 2025.

Lochmanová, Kateřina. "The Leibniz-Clarke Correspondence: Looking Back to Czech and Slovak translations of Leibniz." *Acta Comeniana* 37, no. 61 (2023): 153–168.

Look, Brandon. "Introduction: Leibniz's Life and Works." In *The Bloomsbury Companion to Leibniz,* edited by Brandon Look, 3–15. London: Bloomsbury, 2014.

Mackie, John. *Life of Godfrey William von Leibnitz.* Boston: Gould, Kendall & Lincoln, 1845.

McGrath, Alister. *Natural Philosophy: On Retrieving a Lost Disciplinary Imaginary.* New York: Oxford University Press, 2023. https://doi.org/10.1093/oso/9780192865731.001.0001

Mokyr, Joel. *The Gifts of Athena: Historical Origins of the Knowledge Economy.* 5th ed. Princeton: Princeton University Press, 2005.

Morel, Thomas, *Underground Mathematics: Craft Culture and Knowledge Production in Early Modern Europe.* Cambridge: Cambridge University Press, 2023. https://doi.org/10.1017/9781009267274

Naumann, Friedrich. *Vom Abakus zum Internet: Die Geschichte der Informatik.* Darmstadt: Primus Verlag, 2009.

Oldroyd, David R. *Thinking about the Earth: A History of Ideas about Geology.* Cambridge: Harvard University Press, 1996.

Oldroyd, David R. Earth Cycles*: A Historical Perspective.* Westport: Greenwood Press, 2006. https://doi.org/10.5040/9798400643132

Oldroyd, David R. "Early Geology in Focus." *Metascience* 21 (2012): 569–573. https://doi.org/10.1007/s11016-012-9646-5

Phemister, Pauline. "Theoria cum praxi: Leibniz's Legacy into the Future." In *Leibniz's Legacy and Impact,* edited by Lloyd Strickland and Julia Weckend, 287–307. New York: Routledge, 2020. https://doi.org/10.4324/9781315103570-12

Poole, William. *The World Makers: Scientists of the Restoration and the Search for the Origins of the Earth.* Oxford: Peter Lang, 2010.

Porter, Theodore. "The Promotion of Mining and the Advancement of Science: The Chemical Revolution and Mineralogy." *Annals of Science* 38 (1981): 543–570. https://doi.org/10.1080/00033798100200371

Prete, Ivano D. *On the Edge of Eternity: The Antiquity of the Earth in Medieval & Early Modern Europe.* New York: Oxford University Press, 2022. https://doi.org/10.1093/oso/9780190678890.001.0001

Prigogine, Ilya, and Isabelle Stengers. *Order out of Chaos: Man's New Dialogue with Nature.* New York: Bentam Books, 1984.

Rappaport, Rhoda, ed. "Leibniz on Geology: A Newly Discovered Text." *Studia Leibnitiana* 29, no. 1 (1997): 6–11.

Rappaport, Rhoda. *Studies on Eighteenth-Century Geology.* Cornwall: Cornell University Library, 2011.

Ritter, Paul. "Einleitung." In *Sämtliche Schriften und Briefe,* Series 1, Volume 3: *Allgemeiner Politischer Und Historischer Briefwechsel,* edited by Paul Ritter, XXIX–XLVIII. Leipzig: K. F. Koehler Verlag, 1938.

Rosenberg, Gary. "Introduction: The Revolution in Geology from the Renaissance to the Enlightenment." In *The Revolution in Geology from the Renaissance to the Enlightenment,* edited by Gary Rosenberg, 1–11. Boulder: Geological Society of America, 2009. https://doi.org/10.1130/978-0-8137-1203-1-203.0.1

Röd, Wolfgang. *Die Philosophie der Neuzeit 2: Von Newton bis Rousseau*. Munich: C. H. Beck, 1984.

Rudwick, Martin. *The Meaning of Fossils: Episodes in the History of Palaeontology.* New York: American Elsevier Publishing Company, 1972.

Rudwick, Martin. *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution*. Chicago: University of Chicago Press, 2005. https://doi.org/10.7208/chicago/9780226731148.001.0001

Rudwick, Martin. *Earth's Deep History: How It Was Discovered and Why It Matters*. Chicago: University of Chicago Press, 2014. https://doi.org/10.7208/chicago/9780226204093.001.0001

Serres, Michel. *Le système de Leibniz et ses modèles mathématiques*. Paris: P.U.F, 1982.

Sfetcu, Nicolae. *Epistemology of Experimental Gravity: Scientific Rationality: Essays Collection*. [E-book]: Multimedia Publishing, 2019. https://doi.org/10.58679/TW77080

Schatzberg, Eric *Technology: Critical History of a Concept*. Chicago: University of Chicago Press, 2018. https://doi.org/10.7208/chicago/9780226584027.001.0001

Scheel, Günter. "Einleitung." In *Sämtliche Schriften und Briefe,* Volume 1: Supplementband: Harzbergbau 1692–1696, XXV–XLV. Berlin: Akademie Verlag, 1991.

Schmid, Alois. "Die Herkunft der Welfen in der bayerischen Landeshistoriographie des 17. Jahrhunderts und bei Gottfried Wilhelm Leibniz." In *Leibniz und Niedersachsen: Tagung anlässlich des 350. Geburtstages von G. W. Leibniz, Wolfenbüttel, 1996,* edited by Herbert Breger and Friedrich Niewöhner, 126–147. Stuttgart: Franz Steiner, 1999.

Smith, Justin. *Divine Machines: Leibniz and the Sciences of Life*. Princeton: Princeton University Press, 2011. https://doi.org/10.23943/princeton/9780691141787.001.0001

Smith, Pamela. "Vermilion, Mercury, Blood, and Lizards: Matter and Meaning in Metalworking." In *Materials and Expertise in Early Modern Europe: Between Market and Laboratory,* edited by Ursula Klein and Emma Spary, 29–49. Chicago:

University of Chicago Press, 2009.
https://doi.org/10.7208/chicago/9780226439709.003.0002

Solomon, Graham Timothy. "Leibniz's Analysis Situs in Mathematical Context." PhD. diss. *Dissertation Abstracts International* 51 (1990).

Stewart, Matthew. *The Courtier and the Heretic: Leibniz, Spinoza, and the Fate of God in the Modern World.* London: W. W. Norton & Company, 2006.

Sticker, Bernhard. "Leibniz' Beitrag zur Theorie der Erde." *Sudhoffs Archiv* 51, no. 3 (1967): 244–259.

Stiegler, Leonhard, "Leibnizens Versuche mit der Horizontalwindkunst auf dem Harz." *Technikgeschichte* 35, no. 4 (1968): 265–292.

Špelda, Daniel. "Mundus novus a kosmografická tradice." *Kuděj* 12, no. 1 (2011): 101–118.

Thomas from Padova. *Leibniz, Newton und die Erfindung der Zeit.* Munich: Piper, 2013.

Thomsen, Elsebeth. "*Niels Stensen: Steno, in the World of Collections and Museums.*" In *The Revolution in Geology from the Renaissance to the Enlightenment,* edited by Gary Rosenberg, 75–91. Boulder: Geological Society of America, 2009. https://doi.org/10.1130/2009.1203(05)

Torrens, Hugh Simon. "Some Thoughts on the Complex and Forgotten History of Mineral Exploration." *Journal of the Open University Geological Society* 17 (1997): 1–12.

Usher, Abbot Payson. *A History of Mechanical Inventions.* New York: McGraw-Hill, 1929.

Vespucci, Amerigo. *Mundus novus.* Augsburg: Johannes Otmar, 1504.

Wakefield, Andre. *The Disordered Police State: German Cameralism as Science and Practice.* Chicago: University of Chicago Press, 2009.
https://doi.org/10.7208/chicago/9780226870229.001.0001

Wakefield, Andre. "Leibniz and the Wind Machines." *Osiris* 25, no. 1 (2010): 171–188. https://doi.org/10.1086/657268

Wakefield, Andre. "The Origins and History of Earth." In *The Oxford Handbook of Leibniz,* edited by Maria Rosa Antognazza, 453–465. New York: Oxford University Press, 2018.

Waschkies, Hans Joachim. “Leibniz’ geologische Forschungen im Harz.” In *Leibniz und Niedersachsen: Tagung anlässlich des 350. Geburtstages von G. W. Leibniz, Wolfenbüttel, 1996,* edited by Herbert Breger and Friedrich Niewöhner, 187–210. Stuttgart: Franz Steiner Verlag, 1999.

Wellmer, Friedrich W., and Jürgen Gottschalk. “Leibniz’ Scheitern im Oberharzer Silberbau: Neu betrachtet, insbesondere unter klimatischen Gesichtspunkten.” *Studia Leibnitiana* 42, no. 10 (2010): 186–207.

Wellmer, Friedrich W., and Jürgen Gottschalk, “Die Beschäftigung des universalgelehrten Gottfried Wilhelm Leibniz (1646–1716) mit Geologie und Bergbau.” *BHM: Berg- und Hüttenmännische Monatshefte: Zeitschrift für Rohstoffe, Geotechnik, Metallurgie, Werkstoffe, Maschinen und Anlagentechnik* 160, no. 2 (2015): 60–70. https://doi.org/10.1007/s00501-015-0344-7

Westfall, Richard. *Force in Newton’s Physics: The Science of Dynamics in the Seventeenth Century.* London: Macdonald, 1971.

Westfall, Richard. *The Construction of Modern Science: Mechanisms and Mechanics.* 2nd ed. Cambridge: Cambridge University Press, 1977.

White, Lynn T., Jr. *Medieval Religion and Technology: Collected Essays.* Berkeley: University of California Press, 1978.

Wiener, Norbert. *The Human Use of Human Beings: Cybernetics and Society.* Cambridge: The Riverside Press, 1950.

Yamada, Toshihiro. “Stenonian Revolution or Leibnizian Revival?: Constructing Geo-History in the Seventeenth Century.” *Historia Scientiarum* 13, no. 2 (2003): 75–100.

Ziman, John. *The Force of Knowledge.* Cambridge: Cambridge University Press, 1976.