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HARVESTING UNDERGROUND: (RE)GENERATIVE THEORIES AND VEGETAL ANALOGIES IN THE EARLY MODERN DEBATE ON MINERAL ORES (I)

by

Francesco Luzzini*

Department of Philosophy and Cultural Heritage, Ca' Foscari University of Venice, Dorsoduro 3484/D, Calle Contarini, 30123 Venice, Italy

The early modern use of vegetal terms to explain the origin and growth of ores was widespread in mining industry, alchemy, and natural philosophy. In the writings of authors from many different backgrounds, mineral veins were often described as 'trees' which moved upwards, bore fruits, and underwent a life cycle. Accordingly, the existence in ores of 'seeds' (and, therefore, of a (re)generative power) was frequently invoked to explain the apparent similarities between minerals and plants. This method of describing mineral processes—called here the *botanical model*—also had a lasting terminological influence, as is attested by various expressions that are still common among miners and scientists. The notions underlying these terms are part of a larger body of 'organic interpretations' of mineral resources that endured into the eighteenth century and contributed to the development of the Earth sciences, mining industry, and the human–environment relationship. In focusing mainly on the rise of the *botanical model* in Renaissance Europe, this essay is the first part of a more extensive study (to be completed in a forthcoming paper) on the evolution of this important concept and its interaction with the *new science* throughout the early modern period.

Keywords: mineralogy; mining; alchemy; natural philosophy; environmental history; Renaissance

Of roots and branches

I start from a fairly late point, if not from the very end. In 1722 to be exact: when the German physician, chymist, and mining official Johann Friedrich Henckel (1688–1744) published his essay *Flora Saturnizans.*

The subtitle of this book (*die Verwandschaft des Pflanzen mit dem Mineralreich*, 'The relationship between plants and the mineral kingdom') and the text in the allegorical

*francesco.luzzini@unive.it

frontispiece (*Quod est superius est sicut inferius*, 'As above, so below'—a line from the allegedly Hermetic *Tabula smaragdina*)[1]—seem to leave little or no doubt about the author's view.[2] According to Henckel, both plants and minerals come from the earth, and on the earth both kingdoms depend for their nourishment:

> We find both kinds of relationship between vegetables and minerals, and I don't know which one more than the other. The plants were engendered from the womb of the earth as [if this were] their mother, and from it they receive the food they need …. Thus, since the beginning of times the *Vegetabilia* and *Mineralia* agree in their parts … as if they were siblings ….[3]

The ideas expressed in the *Flora Saturnizans* did not come out of the blue. Besides, Henckel published his book in an epoch when the rising surge of the Enlightenment and a number of new technological achievements encouraged natural philosophy to question with more and more rigour the differences and similarities between animal, vegetable, and mineral, and between living and inanimate beings.[4] Henckel's treatise, however, had deeper roots. His work could be considered as the epitome of an interpretive trend in natural philosophy which dated back to the Middle Ages, and which was still very much alive at the time when the *Flora Saturnizans* was published.[5] In describing plants and minerals as siblings, Henckel deemed these two kingdoms to be so strictly related that an analysis of the former—he claimed—would be of immense help in the study of the latter.[6] This notion would remain an underlying element in his later essay *Pyritologia* (1725),[7] where the insistence on 'the affinity between the vegetable and the mineral kingdoms'[8] was both recurrent and functional to the author's study of pyrites.

1 On the *Tabula smaragdina*, its origin, and its presence in alchemical literature, see Didier Kahn (ed.), *La table d'émeraude et sa tradition alchimique* (Belles Lettres, Paris, 1994); Lawrence M. Principe, *The secrets of alchemy* (University of Chicago Press, 2013), pp. 30–32, 111, 175, 183, 198.

2 Johan Friedrich Henckel, *Flora Saturnizans, die Verwandschaft des Pflanzen mit dem Mineralreich* (Verlegts Johann Christian Martini, Leipzig, 1722).

3 'Beyde Arten der Verwandschafft finden wir zwischen denen Vegetabilien und Mineralien, und ich weiß nicht, welche mehr als die andere. Die Pflanzen sind aus dem Schooß der Erden als ihrer Mutter gezeuget worden, und empfangen daraus ihren bedürffenden Unterhalt (obgleich nicht zu läugnen, daß sie einen grossen Zugang aus ihrem eigenen Reiche, nehmlich vom Mist und Dünger, bekommen). So kommen auch die *Vegetabilia* und *Mineralia* in ihren uhranfänglichen Theilgen, das ist an Wasser und Erde, gleichsam als Geschwister, dergestalt überein, als von vielen nicht dürffte geglaubet …' (Henckel, *op. cit*. (note 2), p. 10). The italics are mine.

4 On this topic, see Fabrizio Baldassarri and Andreas Blank (ed.), *Vegetative powers: the roots of life in ancient, medieval and early modern natural philosophy* (Springer, Cham, 2021), and especially the chapters by Guido Giglioni (pp. 325–346), Raphaële Andrault (pp. 365–382), François Duchesneau (pp. 407–418), and Matteo Favaretti Camposampiero (pp. 419–438); Susannah Gibson, *Animal, vegetable, mineral? How eighteenth-century science disrupted the natural order* (Oxford University Press, 2015).

5 As noted by David Oldroyd, the organic metaphor in the *Flora Saturnizans* 'is pressed so hard that it is, so to speak, pushed into reverse. Minerals and plants are held to be so similar in their constitutions that they may be thought of as "brothers"': Oldroyd, 'Some phlogistic mineralogical schemes, illustrative of the evolution of the concept of 'Earth' in the 17th and 18th centuries', *Ann. Sci.* **31**, 269–305 (1974), at p. 279.

6 Oldroyd, *op. cit*. (note 5), p. 279. On this topic, see also Wim Sissingh, *Deposits of earth science: printing history of early modern geology 1455–1800* (Utrecht University Press, 2017), p. 76; Francesco Luzzini, 'Sounding the depths of providence: mineral (re)generation and human–environment interaction in the early modern period', *Earth Sci. Hist.* **39**(2), 389–408 (2020), at pp. 401–402.

7 Johan Friedrich Henckel, *Pyritologia, Oder: Kieß-Historie, Als des vornehmsten Minerals* (Verlegts Johann Christian Martini, Leipzig, 1725). On this work, see John Norris, 'The mineral exhalation theory of metallogenesis in pre-modern mineral science', *Ambix* **53**(1), 43–65 (2006), at pp. 61–65; Oldroyd, *op. cit*. (note 5), pp. 281–283; Sissingh, *op. cit*. (note 6), pp. 75–77. On Henckel, see also Norma E. Emerton, *The scientific reinterpretation of form* (Cornell University Press, Ithaca and London, 1984), pp. 218, 222–223, 225, 238, 248–249.

8 Johan Friedrich Henckel, *Pyritologia: Or, a history of the pyrites, the principal body of the mineral kingdom* (printed for A. Millar and A. Linde, London, 1757), p. 261 (English translation).

Although Henckel's description may seem at odds with our current understanding of mineral processes, his work was not unsupported by direct experience. Both as a student of the vitalistic physician and chymist Georg Ernst Stahl (1659–1734) and as an inspector of mines in the district of Freiberg, Henckel could boast solid credentials in terms of experimental and empirical practices. Nor did he make a mystery of these skills in his writings, to the point that he has been described as the 'founder of chemical mineralogy'[9]—a flattering title that did not prevent Henckel's research from exceeding in many cases 'the constraints imposed by an empiricist methodology'.[10] But this, as we know, was a common attitude in the eclectic context of early modern natural philosophy, when the boundary between first-hand experience and theory was even more uncertain (and, in many senses, more openly and frequently questioned) than it is today.[11]

In fact, such 'hybrid' approach to the study of nature was as widespread as it was successful in serving the attempt of savants and practitioners to explain a great number of phenomena which at first glance seemed inexplicable. Among these phenomena, the issue of ore generation—and, some argued, *re*generation—held a far from negligible place, given the troublesome contrast between its enduring aura of mystery and its enormous economic (hence industrial, political, social, religious) implications. It was not by chance, therefore, that the debate on the origin and growth of ores absorbed the attention of many authors since the Middle Ages and continued throughout the early modern period, spurring heterogeneous and variously interrelated explanations.

In this collective and protracted effort, knowledge was drawn from many different sources: Classical, Islamic, Scholastic philosophy; humanism and empiricism; practical and technical traditions; and (from a certain moment in Western history) the new experimental science with its countless geographical, cultural, and methodological nuances. In different measures and at different times, all these streams contributed to an understanding of mineral processes where the use of analogy became as frequent as it was pivotal in the attempt to make sense of the apparent similarities between minerals and living beings.

Among the analogies that were invoked from time to time, one in particular proved to be pervasive and enduring. I refer to the use of terms and notions related to plants and which, from now on, I shall call for convenience the *botanical model.*[12]

9 Sissingh, *op. cit*. (note 6), pp. 76, 209. See also Warren Alexander Dym, 'Alchemy and mining: metallogenesis and prospecting in early mining books', *Ambix* **55**(3), 232–254 (2008), p. 254.

10 Oldroyd, *op. cit*. (note 5), p. 279.

11 On the coexistence/interaction of theoretical and practical knowledge in early modern natural philosophical and alchemical inquiries, see—among the many—Frederic L. Holmes and Trevor H. Levere (ed.), *Instruments and experimentations in the history of chemistry* (MIT Press, Cambridge, MA, 2000); Pamela Long, *Artisans/practitioners and the rise of the new sciences, 1400–1600* (Oregon State University Press, Corvallis, OR, 2011); Francesco Luzzini, *Theory, practice, and nature in-between. Antonio Vallisneri's* Primi Itineris Specimen (Edition Open Access/Max Planck Institute for the History of Science, Berlin, 2018), pp. 17–21; Luzzini, *op. cit*. (note 6); William R. Newman, *Promethean ambitions: alchemy and the quest to perfect nature* (University of Chicago Press, 2004), pp. 238–289; Oldroyd, *op. cit*. (note 5), pp. 303–304; Pietro D. Omodeo, 'Practices and theories of contingency in Renaissance approaches to nature', in *Contingency and natural order in early modern science* (ed. Pietro D. Omodeo and Rodolfo Garau), pp. 93–114 (Springer, Cham, 2019); Lawrence M. Principe, 'Evidence for transmutation in seventeenth century alchemy', in *Scientific evidence: philosophical theories and applications* (ed. Peter Achinstein), pp. 151–164 (Johns Hopkins University Press, Baltimore, 2005); Matteo Valleriani (ed.), *The structures of practical knowledge* (Springer, Cham, 2017).

12 A terminological disambiguation. Given the assonance/consonance between the words 'vegetal' and 'vegetative', I deemed it more appropriate to use the term 'botanical': this in order to stress as much as possible (even at a terminological level) the difference between the widespread use of vegetal analogies in the description of mineral processes in the early modern period, and, on the other hand, the sincere belief in the existence of a *vegetative* soul in minerals and metals. Although in many cases these two views coincided, it is also true—as I shall try to show—that for a significant number of authors resorting to the *botanical model* did not necessarily entail an adherence to vitalistic and/or hylozoistic perspectives. This distinction is important, as it helps to better

In the following, I will offer an analysis of the reasons that led this model to play a major role in the Renaissance debate on ores. I shall trace its historical and cultural roots; consider how these roots branched out into the European scene with various (and variously successful) theories; and examine how the use of plants as 'metaphorical benchmarks' for the study of minerals contributed to frame the generation and growth of these minerals in a providential view of natural resources and, more in general, of the natural world. Finally, I will offer some reflections on the legacy of the *botanical model* in the natural philosophical debate and in the evolution of the human–environment relationship, a legacy whose influence extended well into the eighteenth century and, in some aspects, continues to this day.

Nourishment, hence (re)growth

Amid the tangle of theories and practices at the crossroads between early modern mining, natural philosophy, and alchemy, there is a striking recurrence of words and concepts suggesting the existence in minerals of a vegetative, vegetal-like, or—more generally—organic development. Equally striking, however, is the elusiveness of these concepts, an issue that was often challenging for the very authors who resorted to it.[13] Challenging, yet crucial: as the English chymist John Webster (1610–1682) acknowledged in his *Metallographia* (1671), demonstrating the vegetative growth of metals and minerals was 'not of the least concern in the promoting of mineral knowledge'.[14] For, either metals had 'an intrinsecal power of vegetability' and 'Nature's ultimate labour' was to ripen them 'to the perfection of gold', or else the art of transmutation (which was nothing but 'an acceleration of the work of Nature') was 'false, and all the grounds of the more abstruse philosophy, without verity'. And this was an unacceptable hypothesis to those who, like Webster, trusted the 'authors of unquestionable veracity' who attested that metals had 'growth and vegetability'.[15]

Vitalists,[16] in any case, were not the only group of scholars using the *botanical model* during the Renaissance and the early modern period. Nor was this model applied merely to the study of minerals and metals, given the importance of the these analogies in addressing central philosophical and medical questions like the origin of the vegetative soul and the

contextualize the factors that influenced the long-lasting success of the *botanical model.* Similar, although subtler, reasons lie behind my choice of the word 'model' instead of 'concept': in doing so, I meant to place more emphasis on the explanatory/functional value of this notion, rather than on its philosophical significance.

13 On this topic, see Luzzini, *op. cit*. (note 6), pp. 390–391.

14 John Webster, *Metallographia, or, a history of metals* (printed for A.C. for Walter Kettilby, London, 1671), p. 59.

15 Webster, *op. cit*., pp. 42–43. On Webster, see also Anamaria Alfonso-Goldfarb and Marcia H. M. Ferraz, 'Gur, ghur, guhr or bur? The quest for a metalliferous prime matter in early modern times', *Br. J. Hist. Sci.* **46**(1), 23–37 (2013), at p. 26; Antonio Clericuzio, 'Alchimie, philosophie corpusculaire et minéralogie dans la *Metallographia* de John Webster', *Revue d'histoire des sciences* **49**(2–3), 287–304 (1996); Clericuzio, *Elements, principles and corpuscles: a study of atomism and chemistry in the seventeenth century* (Kluwer Academic, Dordrecht, 2000), pp. 152–153; Allen G. Debus, *The chemical philosophy: Paracelsian science and medicine in the sixteenth and seventeenth centuries* (Dover Publications, Mineola, NY, 1977), pp. 93–400, 402–409, 457–458, 514–517; Hiro Hirai and Hideyuki Yoshimoto, 'Anatomizing the sceptical chymist: Robert Boyle and the secret of his early sources on the growth of metals', *Early Sci. Med.* **10**(4), 453–477 (2005), at p. 472.

16 A clarification is in order. Although the more explicit discussions of vitalism date from the seventeenth century, here and below, for terminological convenience, I use the term 'vitalism' (along with 'vitalist' and 'vitalistic') in its broader sense—that is, to include also the late medieval and Renaissance notions of a vital force differentiating living matter from inanimate matter. For an insightful comment on this subject, see Charles T. Wolfe, 'Vitalism in early modern medical and philosophical thought', in *Encyclopedia of early modern philosophy and the sciences* (ed. Dana Jalobeanu and Charles T. Wolfe), pp. 1–20 (Springer, Cham, 2021).

generation of living beings.[17] As it often happens, the success of an idea results from the combination of many, even seemingly conflicting, factors: and from this point of view, the idea of a vegetative nature in mineral ores could be fittingly described as a 'thicket' of words and variously nuanced interpretations, given the overlapping of knowledge that forged this notion through the centuries.

The popularity of the *botanical model* is also in line with the importance that analogies and metaphors played in the study of nature since antiquity, when their use had been essential for the comprehension of the human body and the natural world. In many influential systems of ancient and classical medicine and philosophy, natural phenomena—be they animal, plant, mineral, atmospheric, geological—were explained as counterparts of human metabolic processes. Just think of Aristotle's meteorological works, replete with suggested relationships between the human and the earthly body; or the Hippocratic comparison of earthquakes with epileptic convulsions; or the description of developing embryos and foetuses as growing seeds and plants, an analogy that we can find both in the Hippocratic and Galenic corpora; or, finally, consider the vast and heterogeneous group of the Platonic, Neoplatonic, and Hermetic doctrines, all promoting an understanding of nature in terms of macrocosmic–microcosmic correspondences.[18]

In a world like that described by these and other classical authors—a world governed and shaped by countless interconnections between its macroscopic and microscopic parts—the idea that minerals would share some common *vital* traits with animals and plants was not unreasonable. This idea became a powerful and widely used interpretive tool: so powerful, in fact, that it was passed on from ancient philosophy to the Byzantine and Islamic civilisations and from there it reached Western culture, growing and branching out at every cultural, geographical, linguistic turn with new elaborations and meanings.[19] Thus, when the Renaissance bloomed in its full glory and new philosophers (along with many practitioners and technicians) took up the challenge of tackling the enigma of ore generation, a number of well-established and variously intermingled notions suggesting the existence of vital features in minerals were already circulating in Europe. These notions, in turn, provided a matrix for the emergence of new theories which—although with important differences—in many cases found common ground not only in the analogy between minerals and living organisms, but also in other well-defined elements of classical and

17 On this topic, see Elisabeth Moreau, 'Vegetal analogy in early modern medicine: generation as plant cutting in Sennert's early treatises (1611–1619)', in Baldassarri and Blank (ed.), *op. cit*. (note 4), pp. 221–240. See also Paolo Savoia, 'Nature or artifice? Grafting in early modern surgery and agronomy', *J. Hist. Med. Allied Sci.* **72**, 67–86 (2017).

18 For an in-depth study of this subject with particular respect to ancient medicine, see John Z. Wee (ed.), *The comparable body: analogy and metaphor in ancient Mesopotamian, Egyptian, and Greco-Roman medicine* (Brill, Leiden, 2017). On the Aristotelian–Hippocratic theories on earthquakes, see the chapter by John Z. Wee (pp. 142–167). On the Galenic and Hippocratic analogy of human beings to plants, see the chapters by Brooke Holmes (pp. 358–386) and Courtney Ann Roby (pp. 387–414). On this last topic, see also Fabrizio Baldassarri, 'In the beginning was the plant: the plant–animal continuity in the early modern medical reception of Galen', in *Galen and the early moderns* (ed. Matteo Favaretti Camposampiero and Emanuela Scribano), pp. 55–81 (Springer, Cham, 2022); Robert Vinkesteijn, 'The vegetative soul in Galen', in Baldassarri and Blank (ed.), *op. cit*. (note 4), pp. 55–72. On the influence of Neoplatonic and Hermetic traditions on early modern natural philosophy, see Francesco Luzzini, 'Through dark and mysterious paths. Early modern science and the search for the origin of springs from the 16th to the 18th centuries', *Earth Sci. Hist.* **34**(2), 169–189 (2015), at pp. 170–171, 174–175; David Oldroyd, 'Some neo-Platonic and Stoic influences on mineralogy in the sixteenth and seventeenth centuries', *Ambix* **21**, 128–156 (1974).

19 On this topic, see Luzzini, *op. cit*. (note 7), p. 392. On the transmission of classical knowledge to the Islamic world (and on the crucial importance that the Graeco-Arabic translation movement had in this process), see—among the many—Dimitri Gutas, *Greek thought, Arabic culture: the Graeco-Arabic translation movement in Baghdad and Early 'Abbāsid Society' (2nd–4th/8th–10th centuries)* (Routledge, New York, 1998).

Islamic knowledge. Among the most notable examples we find the Aristotelian theory of mineral generation by combination of subterranean vapours (the so-called 'exhalationes minerales') and the Arabic notion of the two 'compositional principles', according to which the genesis and growth of ores resulted from the mixing of different relative proportions of sulphur and mercury (considered, respectively, as the male and female seed of metals).[20]

The different levels of moisture in the exhalations, the particular features of the earth or mountain where the ore veins lay, the variable heat of the sun, the climatic differences between geographical areas within and outside Europe, and—last but not least—the astral effect of the seven classical planets on these metal-forming vapours: depending on the interpretations that were formulated (and which, from time to time, highlighted the importance of one or more ingredients), these and other factors influenced the combination of the two compositional principles and their condensation into one of the known metals.[21] As said, these concepts were often (but not necessarily) associated with the *botanical model*, and along with this combination we can almost invariably find two other very important notions—*nourishment* and *regrowth*—that became more and more popular and discussed by scholars and practitioners as the debate on mineral generation took hold and new ideas joined in.

On the 'scholarly side', an interesting example of this coexistence of Classical–Islamic influences, stressed vegetative analogies, and novel interpretations comes from the Italian natural philosopher Girolamo Cardano (1501–1576). In his treatise *De subtilitate* ('On subtlety'), published in 1550,[22] he described and partly supported a theory of ore generation through combination of moist and dry vapours, an explanation that seems to owe much to the Aristotelian–Arabic model of exhalations. At the same time, Cardano was also an enthusiastic supporter of the idea that minerals were living beings whose nature—like that of animals and plants—was to be understood in terms of 'generation', 'birth', 'nourishment', 'growth', 'sickness', and even 'ageing' and 'death'.[23] For, he argued, metals were 'produced by humid exhalations, and stones by dry exhalations', and it was 'clear how they receive[d] nourishment and gr[e]w';[24] and the fact that metals were living beings could also

20 A decisive role in the success of these notions in Europe was played by Albertus Magnus (*ca* 1200–1280), who in his *De mineralibus* (*ca* 1260) provided a personal and quite influential synthesis of classical and Islamic knowledge. On Albertus Magnus and his contribution to the study of minerals, see Norris, *op cit*. (note 7), pp. 49–52, 57, 64. See also Emerton, *op. cit*., pp. 25–26; Dorothy Wyckoff, 'Albertus Magnus on ore deposits', *Isis* **49**(2), 109–122 (1958).

21 According to the classical tradition, the seven main metals—each corresponding to a celestial body—are: gold (Sun), silver (Moon), quicksilver (Mercury), copper (Venus), iron (Mars), tin (Jupiter), lead (Saturn). However, this scheme varied significantly as new metals were discovered and the debate on ore generation (and on *what* a metal and/or a mineral is) evolved. On this topic, see John Norris, 'Mining and metallogenesis in Bohemia during the sixteenth century', in *Alchemy and Rudolf II: Exploring the secrets of nature in central Europe in the 16th and 17th centuries* (ed. Ivo Purš and Vladimír Karpenko), pp. 657–670 (Artefactum, Prague, 2016), at p. 662, note 22.

22 Girolamo Cardano, *De subtilitate libri 21* (Apud Ioh. Petreium, Norimbegae, 1550). Here and in subsequent notes, the quotations are from the second edition (Apud Iacobum Dupuys, Parisiis, 1551).

23 'Vivere superius omnia quae miscentur demostravimus, hoc autem maxime lapidibus convenit. Neque solum vivunt, sed morbos, et senectutem, et post etiam mortem patiuntur' (Cardano, *op. cit*. (note 22), p. 137v).

24 'Igitur … metalla ex humida exhalatione, lapides e sicca generantur, nutriuntur autem ut diximus et clara ratione cum augeantur' (Cardano, *op. cit*. (note 22), p. 142v). On Cardano's theory of mineral generation, see Hiro Hirai, *Le concept de semence dans les théories de la matière à la Renaissance. De Marsile Ficin à Pierre Gassendi* (Brepols, Thournout, 2005), pp. 136–156. See also the forthcoming study by Johannes Mattes, 'Animated Earth: collecting cave minerals and debating their formation in early modern times', in *Armenia between archaeology and history of geosciences* (ed. Barry J. Cooper, Marianne Klemun, Khachatur Meliksetian and Ezio Vaccari) (Springer, Basel, in press).

> … be inferred by this evidence, their growth in the mountains is not dissimilar from [that of] plants: for [ores grow] with spreading branches, roots, trunks, flowers, and fruits, as if mines or the hidden metallic matter that originates underground were nothing more than plants.[25]

Accordingly, this growth could also be a *re*growth, a common feature of living beings. Thus, 'cut out stones' could regrow (or were said to do so) *because* they lived: just as this happened in plants as well as the claws of crabs and the tails of lizards, which regenerated 'when torn off'.[26]

The acknowledgement of the existence in ores of a regenerative power aligns Cardano with a great number of authors (Paracelsus (1493–1541), Georgius Agricola (1494–1555), Johann Mathesius (1504–1565), Bernard Palissy (1510–1589), Andrea Cesalpino (1524–1603), Gabriele Falloppio (1523–1562), Alvaro Alonso Barba (1569–1661), Johann Gerhard (1582–1637), Robert Boyle (1627–1691), Johann Joachim Becher (1635–1682), Thomas Sherley (1638–1678), Antonio Vallisneri (1661–1730), and many others) who upheld this notion and supported it with quotations, references, and with well-attested examples. The phenomenon of depleted mines mysteriously returning to abundance was held to have occurred everywhere in Europe: from the iron mines on Elba west of the Italian shores, to the Polish mines in Sagan/Żagań; from the silver lodes of Joachimstahl/Jáchymov in Bohemia, up to some tin ores in Cornwall and down to the salt mines of Spain, there was no scarcity of reports confirming that some sites could replenish themselves some time after being exploited.[27] Cardano's view, however, went beyond a mere association of *lapides* and *metalla* with living beings. Minerals and plants did not just share a vegetative nature: their correspondence was such that the two kingdoms vied for the same resources. A sort of competition (and I ask forgiveness for the reprehensible, yet irresistible, conceptual anachronism) that also explained why minerals and plants occupied different 'ecological niches', the former growing (mostly) underground and the latter (mostly) on the surface of the earth:

> How remarkable it is when a pregnant woman also breastfeeds a child! For the same nourishment is common to metals and plants, and the same resource could barely satisfy both. But metals consume more [nourishment] than plants: for the offspring of metals is far more numerous than that of trees, just like the marine beasts [are more numerous] than the terrestrial animals.[28]

Although not explicitly stated here, this passage seems to offer theoretical support for another commonly held notion in early modern mining according to which the mountains rich in ores tended to be barren on the surface, as if the scarcity of nourishment in certain areas did not allow a balanced coexistence of minerals and plants (figure 1).[29] This opinion, too, was grounded on

25 '… metallica vivere etiam hoc argumento deprehenditur, quod in montibus non secus ac plantae nascuntur, patulis siquidem ramis, radicibus, truncis, ac veluti floribus, ac fructibus, ut non aliud sit metallum aut metallica substantia quam plantae sepulta, ac tota sub terra nascens' (Cardano, *op. cit*. (note 22), p. 107r).

26 'Crescunt et hac de causa lapides excisi, quoniam vivunt. Nam et plantarum partes, et chelae cancrorum, et lacertarum caudae avulsae reparantur' (Cardano, *op. cit*. (note 22), p. 138r).

27 On this topic, and for a list of studies and sources, see Luzzini, *op. cit*. (note 6), pp. 390–391.

28 'Quid mirum cum velut lactanti puero nutrix praegnans adhibetur, nam metallis et plantis commune est alimentum idem, ideo vix natura loci ambobus poterit satisfacere. Sed metalla amplius hauriunt quam arbores: nam propago metallorum arboribus longe maior est, ut etiam belluae maris ipsis animalibus terrestribus' (Cardano, *op. cit*. (note 22), pp. 109r–109v).

29 See—for example—these passages by Andrea Cesalpino, *De metallicis libri tres* (Ex Typographia Aloysii Zannetti, Rome, 1596), pp. 193–194: 'Testantur … arbores eius loci, et si vireant, frugiferas tamen non esse, ac tardius germinare: his signis artifices loca scrutari, ubi proveniat argentum vivum'; Bernardo Cesi, *Mineralogia, sive naturalis philosophiae thesauri* (Sumptibus Iacobi & Petri Prost, Lugduni, 1636), p. 124: 'Montes steriles, metallici omnes sunt; nam humor absumitur intus, unde plantae generari

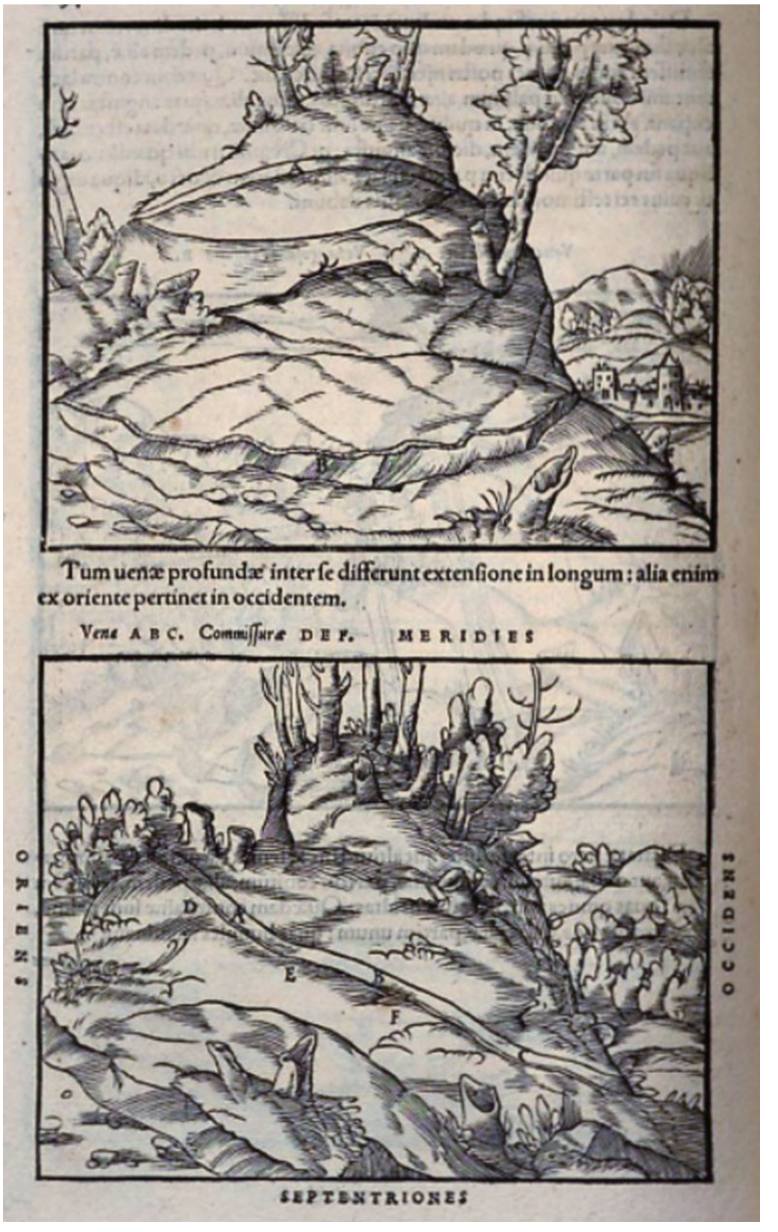


Figure 1. Mountains, vegetation, and mineral veins. A woodcut from Georgius Agricola, *De re metallica libri XII* (Per Hieronimymum Frobenium et Nic. Episcopum, Basileae, 1556), p. 34.

nequeunt, & mali halitus, iam natis etiam plantis vitam eripiunt'; Gabriel Plattes, *A discovery of subterraneall treasure* (I. Okes, for Iasper Emery, London, 1639), p. 9: 'When we come to the rocky and craggy mountaynes, the first thing we are to observe, is the barrennesse of them; for the more barren they are, the greater probability there is that they contain rich mines and minerals'. On the Renaissance and early modern association of barren landscapes with the presence of mines, see also Luzzini, *op. cit*. (note 11), pp. 161–162, 169, 193.

empirical evidence, as was another very important concept in the *De subtilitate* which makes this book exemplary of the Renaissance debate on mineral generation: the acknowledgement of the role of water. To Cardano, in fact, exhalations were not the only ingredients required for the growth of ores (not of *all* ores, at least). While the origin of metals was explainable with vapours alone, minerals and crystals were believed to be made from watery substances 'dripping down into hollow spaces, like an infant' was 'made from maternal blood'.[30] Still, another ingredient was also needed, a 'matrix' that was specific to each different kind of mineral: hence the variety of precious stones that lay below the earth.[31]

In highlighting the importance of water in the formation of ores and in stressing the affinity between plants and minerals, Cardano was not alone. In those years, many other authors—*theorists* and *practicians* alike—were turning their attention to this subject, producing explanations that were more or less independent of each other and supported with variable doses of speculative and empirical remarks.

This confluence of interests and investigations did not happen by chance. It responded to the emergence of new economic, social, and political issues which monopolized the attention of early modern Europe and whose impact went far beyond the natural philosophical concern. And yet, as we shall see, natural philosophers would turn out to have much to say in this regard.

Harvesting underground

As new research and new knowledge built up, the discussion on mineral generation seemed to focus with increasing urgency around themes like *predictability*, *exhaustibility*, *renewability*. This was a revealing sign of the challenges that were being faced by the mining industry in the mid-sixteenth century and thereafter, when a combination of factors (political instability, protracted warfare, the influx of precious metals from the New World and the consequent inflation, and the gradual depletion of important mining sites) spurred a general decline in the European economy and, at the same time, fostered the technological and scientific innovation of the following decades.[32]

In becoming (even more) central to economy and industry, the issue of understanding *how* and *where* minerals were generated worked as a catalyst for interaction between miners,

30 'Inter saxa plerunque generantur gemmae distillante e lapidibus succo in concava, velut in fans materno sanguine' (Cardano, *op. cit*. (note 22), p. 136v). Here, Cardano's thought seems to share some common ground with the opinion—popular among Islamic and European scholars during the Middle Ages—that metals and minerals had different origins, the former resulting from the mixing of vapours and the latter requiring an aqueous medium. On this topic, see John Norris, 'Early theories of aqueous mineral genesis in the sixteenth century', *Ambix* **54**(1), 69–86 (2007), at pp. 69–71.

31 'Caeterum quae inter lapides generantur non passim, sed habet unaquaeque gemma suam matricem' (Cardano, *op. cit*. (note 22), p. 136v). On this topic, see also Mattes, *op. cit.*

32 On this topic, see Tina Asmussen, 'Glück auf! Fortuna und Risiko im frühneuzeitlichen Bergbau', *FKW // Zeitschrift für Geschlechterforschung und visuelle Kultur* **60**, 30–41 (2016); 'The Kux as a site of mediation: economic practices and material desires in the early modern German mining industry', in *Sites of mediation: connected histories of places, processes, and objects in Europe and beyond, 1450–1650* (ed. Susanna Burghartz, Lucas Burkart and Christine Göttler), pp. 159–182 (Brill, Leiden, 2016); 'Wild men in Braunschweig: economies of hope and fear in early modern mining', *Renaiss. Stud.* **34**(1), 31–56 (2020); 'Spirited metals and the oeconomy of resources in early modern European mining', *Earth Sci. Hist.* **39**(2), 371–388 (2020); Tina Asmussen and Pamela Long, 'The cultural and material worlds of mining in early modern Europe', *Renaiss. Stud.* **34**(1), 8–30 (2020); Dym, *op. cit*. (note 9); *Divining science: treasure hunting and earth science in early modern Germany* (Brill, Leiden and Boston, 2011); Robert Friedel, *A culture of improvement: technology and the western millennium* (MIT Press, Cambridge, MA, 2007), pp. 130–140; Pamela Long, *Openness, secrecy, authorship: technical arts and the culture of knowledge from Antiquity to the Renaissance* (Johns Hopkins University Press, Baltimore, 2001), pp. 176–178, 182–183; Long, *op. cit*. (note 11), pp. 107–108.

craftsmen, technicians, scholars, alchemists, and other actors who turned mining sites into field laboratories where theories and practices met and influenced each other. It is not accidental, for example, that another famous champion of the *botanical model*—Paracelsus—had strong cultural and professional ties with the mining context of central Europe and discussed extensively the issue of mineral resources.

Paracelsus understood the generation of metals and minerals as a complex process of fertilization where a natural vital principle (*Archeus*), a liquid matrix ('elemental water'), and three seminal principles (sulphur, mercury and salt: the so-called *tria prima*) contributed to the final result. In accordance with this perspective, he found it natural to describe the growth of ores in vitalistic terms, which in his case were more frequently 'plant-like' than 'animal-like'. Thus, minerals were the 'fruits' of subterranean 'trees' that needed water in order to develop from their seeds and flourish, just like their vegetal counterparts on the surface.[33]

And not just *theorists.* As we said, the idea of a link between water and ores also found strong support among the vast and diverse group of practitioners: especially those who in their work insisted on the contrast between the ('vain') speculation of philosophers and the concrete experience of miners and technicians, claiming themselves as proud members of the latter group. And since the presence of water *is* a commonly observed fact in mines, it comes not as a surprise that many *aqueous* theories appearing in the Renaissance seemed to be more empirically grounded than those relying exclusively on mineral vapours and the frequently related notion of *sulphur–mercury*.[34] From the German engineer and physician Ulrich Rülein von Kalbe (1465–1523), who already in 1505 highlighted in his *Bergbüchlein* ('Booklet on mining')[35] the disagreement of some experts with the model of exhalations, to *De la pirotechnia* ('On pyrotechnics') of the Sienese metallurgist Vannoccio Biringuccio (1480–1539) who described water as 'the first and proper companion of mines';[36] from Agricola's accounts of ores forming with the passage of 'mineral juices' ('humores') through underground fissures ('canales'),[37] to the 'congelation' of minerals and metals from solutions reported by the French craftsman Bernard Palissy in his *Discours admirables* ('Admirable discourses'):[38] a mass of observations and experiments performed in mines and in laboratories intermingled with pre-existing knowledge and theories, fostering the creation of new models where exhalations were replaced, or supplemented by, water. And if the use of vegetal analogies and terms ('seed', 'nourishment', 'regrowth', 'soil', 'lymph', 'tree', 'branches', just to mention a few) was already widespread before the introduction of these

33 On Paracelsus and his theory of mineral generation, see Hiro Hirai, 'Logoi Spermatikoi and the concept of seeds in the mineralogy and cosmogony of Paracelsus', *Revue d'histoire des sciences* **61**(2), 1–21 (2008), at pp. 9–10; Luzzini, *op. cit*. (note 6), pp. 394–397; Oldroyd, *op. cit*. (note 5), pp. 134–135. See also Friedel, *op. cit*. (note 32), pp. 129–130.

34 As explained in Norris, *op. cit*. (note 30), pp. 70, 75–76, 86. On this topic see also Dym, *op. cit*. (note 9), pp. 232–233.

35 Ulrich von Kalbe, *Das Bergbüchlein* (Erhard Ratdolt, Augsburg, 1505), p. 4. This edition is considered to be one of the oldest surviving versions of von Kalbe's book. On the *Bergbüchlein,* see also Dym, *op. cit*. (note 9), pp. 238–239; Norris, *op. cit*. (note 7), pp. 53–55; Norris, *op. cit*. (note 30), pp. 71–72; Luzzini, *op. cit*. (note 6), pp. 392–394.

36 '… sempre avevo inteso che de le miniere l'acqua era la lor prima & propria compagna, anzi forse quella cagione donde le sustantie proprie de la lor generatione procedeno' (Vannoccio Biringuccio, *De la pirotechnia* (Per Curzio Navò et Fratelli, Venezia, 1540), from the Introduction). On Biringuccio, see the exhaustive monograph by Andrea Bernardoni, *La conoscenza del fare: Ingegneria, arte, scienza nel De la Pirotechnia di Vannoccio Biringuccio* (L'Erma di Bretschneider, Rome, 2011).

37 Georgius Agricola, *De ortu et causis subterraneorum lib. V* (Per Hieronimymum Frobenium et Nic. Episcopum, Basileae, 1546), pp. 5–13, 35–38, 43, 48–50, 63–82. On this topic, see Norris, *op. cit*. (note 30), pp. 73–76. See also Dym, *op. cit*. (note 9), pp. 234–235, 237–238, 248; Alfonso-Goldfarb and Ferraz, *op. cit*. (note 15), pp. 29–30.

38 Bernard Palissy, *Discours admirables de la nature des eaux et fonteines* (Chez M. le Ieune, Paris, 1580). On Palissy and his theory of mineral generation, see especially Norris, *op. cit*. (note 30), pp. 80–86. See also Hirai, *op. cit*. (note 24), pp. 327–349.

aqueous interpretations, the gradual acknowledgement of water as the prime actor in the formation of ores further propelled the success of the *botanical model.*

To better understand the reasons behind such conceptual and terminological pervasiveness, it is important to consider that resorting to the *botanical model* did not always mean that an author had to believe *literally* that minerals and metals had a vegetative soul. In fact, not all those who used this kind of analogy in discussing mines and ores belonged to the (howsoever heterogeneous) group of 'hard vitalists'; nor were they invariably committed Renaissance Platonist or Hermetic thinkers like, say, Cardano, Bernardino Telesio (1509–1588), Paracelsus, Joseph du Chesne (Quercetanus, 1546–1609), or Jan Baptist van Helmont (1579–1644). True, the work of these authors was often decisive in allowing certain *organic* notions to pierce through disciplinary, professional, cultural, and social boundaries. This, for example, was the case with du Chesne—under whose influence the concept of 'seed' was applied with increasing frequency to the study of animal, vegetal, and mineral generation in the early seventeenth century.[39] However, many who employed terms such as 'mineral seeds' or 'mineral generation' in their works were sceptical about the idea that minerals were living creatures, if not openly hostile to this concept.

Far from being a contradiction, the fact that both 'vitalists' and 'sceptics' tended to consider metaphors and metaphorical language as valid explanatory tools (and sometimes even as evidence) is revealing of how the premodern mind thought about nature. According to this perspective, both notions of living and inanimate minerals were acceptable, though debatable, options. What was not an option (to the vast majority of authors, at least) was the idea of a world lacking structure and coherence in all its parts, a world where the *aptness* of a metaphor did not also prove its *usefulness* in understanding natural laws. As seen through this lens, therefore, analogies and metaphors were reliable methods for rationalizing observations and experiments, regardless of their literal or non-literal interpretation.

A good example of 'sceptical use' of metaphors is Palissy, an author renowned for his empirical pride and his sharp criticism of *théoriques.* Practique, his pugnacious alter ego in the *Discours admirables*, affirms that minerals develop through water from 'saline' seeds. Yet, he also points out that this process is only analogous to the generation and growth of living beings: minerals (and, more generally, rocks) 'grow' through 'congelative increase', not through a real 'vegetative action', and any literal interpretation of this analogy is contrary to the truth.[40] The same sharp rejection of the vitalistic/hylozoistic perspective can

39 See Hirai, *op. cit*. (note 24), pp. 267–294; 'The world-spirit and quintessence in the chymical philosophy of Joseph Du Chesne', in *Chymia: science and nature in medieval and early modern Europe* (ed. Miguel López-Pérez, Didier Kahn and Mar Rey Bueno), pp. 247–261 (Cambridge Scholars, Cambridge, 2010); 'Seed concept in the Renaissance', in *Encyclopedia of Renaissance philosophy* (ed. Marco Sgarbi), pp. 1–4 (Springer, Cham, 2020); 'Bodies and their internal powers: natural philosophy, medicine, and alchemy', in *Routledge companion to sixteenth-century philosophy* (ed. Henrik Lagerlund and Bejamin Hill), pp. 394–410 (Routledge, New York and London, 2017), at p. 408.

40 'Ie te le nie bien encores: car les pierres n'ont point d'âme vegetative: mais insensible. Parquoy elles ne pouvent croistre par action vegetative: mais par une augmentation congelative' (Palissy, *op. cit*. (note 38), p. 197); 'Ceux qui ont escript que les metaux croissent aux minieres comme les arbres, n'ont rien entendu & ont parlé contre verité' (Palissy, *op. cit*. (note 38), *Extrait des sentences principales*, unnumbered page). On this topic, see Norris, *op. cit*. (note 30), p. 81. At the same time, some other passages in the *Discours admirables* acknowledge the existence of a common root in living and inanimate beings: according to Palissy, in fact, the 'congelative water' responsible for the generation of crystals and stones is also 'the substance and generation of all living and vegetative things' ('… le cristal est formé de ladite eau generative au meillieu des eaux communes, que ladite semence, ou eau generative n'est pas seulement pour servir à la generation des pierres, mais aussi est substance et generation de toutes choses animées et vegetatives'. Palissy, *op. cit*. (note 38), pp. 312–313). As David Oldroyd (*op. cit*. (note 18), p. 136) highlighted, the fact that both Palissy and Paracelsus supported the notion of mineral growth from 'seeds'—despite the important differences between the two

be found in the work of another Frenchman, the alchemist Gaston DuClo (*alias* de Claves, 1530–159?). In his *Apologia chrysopoeiae et argyropoeiae* (1590) he explicitly criticized the idea that minerals shared common vital traits with animals and plants: as inanimate objects, he argued, minerals lacked the 'internal force' (*vi insita*) typical of living matter, therefore their development was subject to different natural laws.[41] At the same time, however, DuClo relied heavily on vegetative/organic analogies (including terms like *anima* and *semen*) in his explanation of mineral processes: to the point that in the *Apologia* the research of alchemists is translated into vegetal terms and compared in its importance, goals, and methods to the work of farmers.[42]

This 'agricultural extension' from the vegetal to the mineral was not exclusive to DuClo. The description of ores as the 'miner's harvest' is a recurring motif in the Renaissance and early modern literature on the subject. 'Harvest', 'reward', 'punishment', 'crop', 'maturation', 'too early'/'too late': we find these words used by authors from different (sometimes, very different) contexts and beliefs. Think, for example, of Agricola's vindication of mining as an act of 'underground cultivation' against those who deemed it 'the downside—in a literal and moral sense—of … agriculture';[43] or Paracelsus' interpretation of minerals and metals as 'fruits' to be 'harvested by man' in 'due season';[44] or the powerful sermons of the Lutheran pastor Johann Mathesius (perhaps the most theologically committed member of this heterogeneous group), who 'saw the occurrence' of the subterranean harvest 'as evidence of God's generosity' (figure 2);[45] or again, let us consider Basil Valentine, primarily (but not univocally) identified as the German alchemist and miner Johann Thölde (*ca* 1565–*ca* 1614), who likened the 'metal fruits' to the 'fruits of animals and plants', all having been produced by God from water for the use of man.[46]

authors—tells a lot about the popularity of this concept (and about the mutual influences between *theorists* and *practicians*, I shall add) during the Renaissance. On the rhetorical use of the contrast between theory and practice in Renaissance and early modern authors, see Long, *op. cit*. (note 11); Luzzini, *op. cit*. (note 6), pp. 395–396; Norris, *op. cit.* (note 30), pp. 80–83.

41 Gaston DuClo, *Apologia chrysopoeiae et argyropoeiae adversus Thomam Erastum* (Pierre Roussin, Nevers, 1590). I refer here to the (less rare) second edition, *Apologia chrysopoeiae et argyropoeiae adversus Thomam Erastum* (Excudebat Cornelius Sutorius, Ursel, 1602), p. 97: 'Materia inanimatorum corporum pulsu externo agitatur, non vi insita'. On DuClo, see Lawrence M. Principe, 'Diversity in alchemy: the case of Gaston "Claveus" DuClo, a scholastic mercurialist chrysopoeian', in *Reading the book of nature: the other side of the scientific revolution* (ed. Allen G. Debus and Michael T. Walton), pp. 181–200 (Sixteenth Century Journal Publishers, Kirskville, 1998); *The aspiring adept: Robert Boyle and his alchemical quest* (Princeton University Press, 1998), pp. 41, 83–84, 154–155; Charles D. Gunnoe, *Thomas Erastus and the Palatinate: a Renaissance physician in the second reformation* (Brill, Leiden, 2011), p. 290; Jennifer Rampling, 'Transmission and transmutation: George Ripley and the place of English alchemy in early modern Europe', *Early Sci. Med.* **17**, 477–499 (2012), at p. 486.

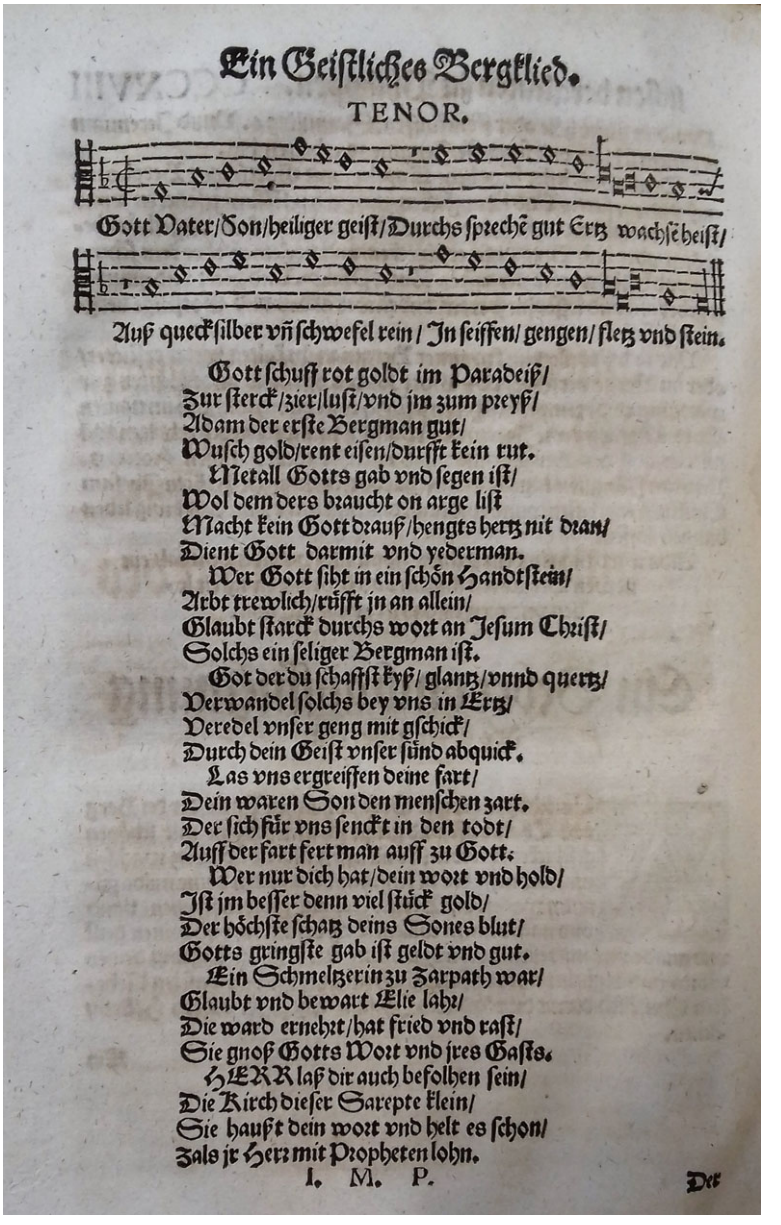
42 'Quemadmodum autem iactis in agros seminibus caetera Naturae committit agricola, dum messis tempus adventarit: sic argyropoeiae cultor …' (DuClo, *op. cit*. (note 41), p. 111). On this topic, see Principe, *op. cit*. (note 41), pp. 195–196.

43 Asmussen, 'Spirited metals', *op. cit*. (note 32), p. 381. The comment refers (especially) to book I of Georgius Agricola, *De re metallica libri XII* (Per Hieronimymum Frobenium et Nic. Episcopum, Basileae, 1556).

44 Oldroyd, *op. cit*. (note 18), pp. 134–135. See also Hirai, *op. cit*. (note 33), pp. 10–11.

45 John Norris, 'The providence of mineral generation in the sermons of Johann Mathesius (1504–1565)', in *Geology and religion: a history of harmony and hostility* (ed. Martina Kölbl-Ebert), pp. 37–40 (Geological Society, London, 2009), at p. 38. On Mathesius and his book *Sarepta oder Bergpostill, sampt der Jochimssthalischen kurtzen Chroniken* (Johann von Berg, Nuremberg, 1562), see also Warren Alexander Dym, 'Mineral fumes and mining spirits: popular beliefs in the *Sarepta* of Johann Mathesius (1504–1565)', *Reform. Renaiss. Rev.* **8**(2), 161–185 (2006); Dym, *op. cit*. (note 9), pp. 235–236, 241–253; John Norris, '*Auß Quecksilber und Schwefel Rein:* Johann Mathesius and sulfur-mercurius in the silver mines of Joachimstal', *Osiris* **29**(1), 35–48 (2014); Norris, *op. cit*. (note 21), pp. 664–670.

46 I refer here to Basil Valentine, *Letztes Testament und Offenbahrung der himmlischen und irrdischen Geheimnüß so in einem Altar gefunden* (Hans Eyring und Johann Perfert, Jena, 1626), pp. 203–204: '… die Erden aus der Triebekeit des Wassers formiret, sampt allen Früchten der Metallen, und die jemals in der Erden erschaffen und geboren, die sind Wasser gewesen, un kommen auch wider in Wasser und Wassers Gestalt, und verkeret werden, so sind auch alle Dinge in allen, durch bey Hilffe der Elementen wie in der Erden, so wol auch ausserhalb der Erden, in allen ihren Animalischen und Vegetabilischen Früchten …'. On this passage (but from a



Ein Geiſtliches Bergklied.

TENOR.

Gott Vater/Son/heiliger geiſt/Durchs ſprechē gut Ertz wachſē heiſt/

Auß queckſilber vñ ſchwefel rein / Jn ſeiffen/ gengen/ fletz vnd ſtein.

Gott ſchuff rot goldt im Paradeiß/
Zur ſterck/zier/luſt/vnd jm zum preyß/
Adam der erſte Bergman gut/
Wuſch gold/rent eiſen/durfft kein rut.
Metall Gotts gab vnd ſegen iſt/
Wol dem ders braucht on arge liſt
Macht kein Gott drauß/hengts hertz nit dran/
Dient Gott darmit vnd yederman.
Wer Gott ſiht in ein ſchön Handtſtein/
Arbt trewlich/trifft jn an allein/
Glaubt ſtarck durchs wort an Jeſum Chriſt/
Solchs ein ſeliger Bergman iſt.
Got der du ſchaffſt kyß/ glantz/vnnd quertz/
Verwandel ſolchs bey vns in Ertz/
Veredel vnſer geng mit gſchick/
Durch dein Geiſt vnſer ſünd abquick.
Las vns ergreiffen deine fart/
Dein waren Son den menſchen zart.
Der ſich für vns ſenckt in den todt/
Auff der fart fert man auff zu Gott.
Wer nur dich hat/dein wort vnd hold/
Jſt jm beſſer denn viel ſtück gold/
Der höchſte ſchatz deins Sones blut/
Gotts gringſte gab iſt geldt vnd gut.
Ein Schmeltzerin zu Zarpath war/
Glaubt vnd bewart Elie lahr/
Die ward ernehrt/hat fried vnd raſt/
Sie gnoß Gotts Wort vnd jres Gaſts.
HERR laß dir auch befolhen ſein/
Die Kirch dieſer Sarepte klein/
Sie haußt dein wort vnd helt es ſchon/
Zals jr Herr mit Propheten lohn.

I. M. P.

Der

Figure 2. *Ein Geistliches Bergklied* ('A spiritual mining song'). From Johann Mathesius, *Sarepta oder Bergpostill, sampt der Jochimssthalischen kurtzen Chroniken* (Johann von Berg, Nuremberg, 1562), p. 318v. Image courtesy of The History of Science Collections, University of Oklahoma Libraries.

different edition of the *Letztes Testament*), see Dym, *op. cit.* (note 9), pp. 248–253. On Basil Valentine/Johann Thölde, see also Claus Priesner, 'Johann Thölde und die Schriften des Basil Valentins', in *Die Alchemie in der europäischen Kultur- und Wissenschaftsgeschichte* (ed. Christoph Meinel), pp. 107–118 (Harassowitz, Wiesbaden, 1986); 'Basilius Valentinus und die Labortechnik um 1600', *Berichte zur Wissenschaftsgeschichte* **20**, 159–172 (1997); Lawrence M. Principe, 'Chemical translation and the role of impurities in alchemy: examples from Basil Valentine's *Triumph-Wagen*', *Ambix* **34**(1), 21–30 (1987); Hans-Henning

Cultural, social, and religious differences aside, these and other stances express a shared understanding of the world where human hopes and concerns about mineral exploitability, exhaustibility, and renewability were framed in an essentially providential (and punitive) view. In being extended from agriculture (a context where divine providence and divine punishment were well known and widely accepted notions) to the 'mineral crops', this view served to explain the profits as well as the struggles, the dangers, and the tragedies of mining.[47]

Perhaps it is in the need to make unified sense of this tangle of fortune and disaster that we can identify the main reason for the success of the *botanical model.* For this need was and still is universal, just like the hopes and concerns that fuelled it. In providing a coherent explanation (or even just a solid analogy) for the affinity between the mineral and the vegetal world, the *botanical model* was versatile enough to be accepted by many *theorists* in search of a unifying view of nature, but also by countless *practicians* who—by choice or chance—strived to rationalize an existence spent working in mines.

As a conclusion: surviving fruits

As we have seen, the use of vegetal (and, more generally, organic) terms and analogies during the Renaissance did not always correspond to vitalistic beliefs. This fact urges us to question whether—and if so, to what extent—many authors who have been traditionally and superficially labelled as 'vitalists' (sometimes just because of their esoteric and/or alchemical interests) actually believed in the existence of a mineral life, or if they just stressed the plant–mineral metaphor with particular emphasis but for mere explanatory purposes. Although some important examples in this regard have already been discussed by scholars, an extensive (and much-needed) analysis of this complex topic still seems far from being complete.[48]

In any case, it is unquestionable that the *botanical model* remained an important actor in natural philosophy, alchemy, and mining industry throughout the early modern period, whatever the theoretical allegiances and the more or less literal (or metaphorical) intentions of its users. In serving both as an interpretive and an explanatory tool, this model was too flexible and too helpful to be set aside lightly. And since the more a concept is popular, the more nuanced and blurred are its uses and meanings, this versatility of the *botanical model* turned out to be at the same time a cause and an effect of its widespread success: a sort of virtuous circle that allowed the 'vegetal interpretation' of ores to exert a strong and enduring influence on our perception and description of mineral resources and processes, as well as on

Walter (ed.), *Johann Thölde/um 1565 – um 1614: Alchemist, Salinist, Schriftsteller und Bergbeamter* (Drei-Birken-Verlag, Freiburg, 2011). For a study of Basil Valentine's complex corpus of writings, see Lawrence M. Principe, 'The development of the Basil Valentine corpus and biography: pseudepigraphic corpora and Paracelsian ideas', *Early Sci. Med.* **24**, 549–572 (2019).

47 On this topic, see Asmussen, *op. cit*., 'Wild men in Braunschweig' (note 32), pp. 31–56; Luzzini, *op. cit.* (note 6), pp. 400–401. On the relationship between a providential perspective of natural resources and the human–environment interaction, see also Peter Clarke and Tony Claydon (ed.), *God's bounty? The Church and the natural world* (Boydell, Woodbridge, 2010); Philip Jenkins, *Climate, catastrophe, and faith: how changes in climate drive religious upheaval* (Oxford University Press, 2021).

48 See, for example, the contrasting opinions of Lawrence Principe and Antonio Clericuzio on DuClo. Whereas Principe argues that 'It is wise to extend this observation on DuClo's terminology into a more general caveat for reading and interpreting alchemical texts—words like seed, soul, growth, and maturation do not necessarily imply a vitalistic or hylozoic worldview' (Principe, *op. cit*. (note 41), p. 196), Clericuzio dissents from the view 'that DuClo's use of *semina* is purely metaphorical. Though DuClo rejected the view that metals are alive, he believed that in seed of gold and of silver is contained a specific *vis*' (Clericuzio, *Elements*, *op. cit*. (note 15), p. 13).

the very development of mineralogy (which, as a discipline, seemed to resonate with the fertile tension between 'high' and 'low' knowledge—theoretical and practical traditions—in a more profound and evident manner than other 'institutionalized' scientific fields).

As I intend to show in a subsequent article,[49] not even with the advent of the *new science* and the progressive standardization of the experimental method did the *botanical model* disappear from the scene—or at least, not completely. It continued to play a role not only in the combined effort of practitioners and savants to explain a growing mass of data gathered underground and in laboratories, but also in shaping a collective understanding of the human–environment relationship.

It does not seem unreasonable to argue that something of this notion has survived into our times. We can see it in some technical and colloquial expressions that are still commonly used among miners and scientists (two examples being the words 'cultivation' and 'fertility' which refer, respectively, to the concepts of exploitation and productivity in mining). And we can also see it in the countless warnings and pleas against the 'overexploitation of nature' and to 'avert catastrophe' or to 'save the planet before it is too late' which are so common in the current environmental debate, and which seem to retain a lot of the concept of human stewardship and of the providential (and, therefore, punitive) emphasis that we have seen to be often associated with the *botanical model*.[50]

Perhaps these are not mere terminological vestiges or metaphors justified by common sense. Perhaps, something of the early modern notions underlying these words and metaphors has reached us—carried in the stream of knowledge that shaped our understanding of the human–environment system. If so, this legacy could teach us a lot about how such understanding has evolved, and could also give us precious hints on how to make it better for the future.

Data accessibility

This article has no additional data.

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49 Francesco Luzzini, '*Inversi arboris instar:* (Re)generative theories and vegetative analogies in the early modern debate on mineral ores (II)', unpublished.

50 For some interesting considerations on this point, see Lauren A. Rickards, 'Metaphor and the Anthropocene: presenting humans as a geological force', *Geogr. Res.* **53**(3), 280–287 (2015).