Thinking the Earth with the Body:

How the Anatomist Nicolaus Steno (1638-1686) Read History in the Earth's Strata

In October 1666, news arrived in Florence of an extraordinarily large white shark caught in Livorno, the port city of Tuscany. Having heard this, Grand Duke Ferdinand II de' Medici (1610-1670), the last patron of Galileo Galilei (1564-1642), asked for the shark's head to be shipped up the river Arno to Florence and to have Nicolaus Steno (1638-1686), the new anatomist at court, dissect it.[1] Steno had settled in the Florentine court in the summer. Since dissection was something that Steno did regularly, he accepted the invitation. Moreover, why not use the shark to explore those very same questions about anatomy that he was already researching about muscles, glands, and the reproductive organs?[2] The shark's dissection took place around 18 October and became known for igniting Nicolaus Steno's geological research, which made him known today as "the founder of modern geology."[3] In short, so the story goes, Steno realized during the dissection that shark's teeth were equal to a kind of fossils often found far from the sea.[4] This led him to argue

[1] The original name is "Niels Stensen." I use the Latinized spelling "Nicolaus Steno," which is the most common use in English. The most complete biographies of Steno are still Roberto Angeli, *Niels Stensen: Il beato Niccolò Stenone, uno scienzato innamorato del vangelo e dell'Italia* (Milan, 1996), originally published as *Niels Stensen: Anatomico, Fondatore della Geologia, Servo di Dio* (Florence: Libreria Editrice Fiorentina, 1968); and Gustav Scherz, *Niels Stensen: eine Biographie*, 2 vols. (Leipzig: St. Benno-Verlag, 1987). Scherz's first volume was translated into English in *Nicolaus Steno: Biography and Original Papers of a 17th Century Scientist*, ed. Troels Kardel and Paul Maquet, 2nd ed. (Berlin: Springer, 2018) (hereafter, BOP), pp. 1-410. A recent, well-documented study of Steno, which does not address his geology, is Stefano Miniati, *Nicholas Steno's Challenge for Truth: Reconciling science and faith* (Milan: FrancoAngeli, 2009).

[2] Only the shark's head arrived in Florence, but Steno dissected another shark a few months later in which he observed the sexual organs. See Nicolaus Steno, *Elementorum myologiæ specimen* (Florence, 1667), pp. 111-119.

[3] See, for example, Stephen J. Gould, *Hen's Teeth and Horse's Toes: Further Reflections in Natural History* (New York: W. W. Norton & Company, 1983), p. 72; and Alan Cutler, *The Seashell on the Mountaintop: A Story of Science, Sainthood, and the Humble Genius Who Discovered a New History of the Earth* (New York: Dutton, 2003), p. 187.

[4] Scherz's biography in BOP, p. 196; Angeli, *Niels Stensen*, pp. 151-152; Rudwick, *The Meaning of Fossils*, p. 50; Alan Cutler, *The Seashell on the Mountaintop: A Story of Science, Sainthood, and the Humble Genius Who Discovered a New History of the Earth* (New York: Dutton, 2003), pp. 53-56; Francisco Gómez and Frank Sobiech, "Introduzione," in *Scienza, Filosofia e Religione nell'Opera di Niels Steensen*, ed. María Vitoria and Francisco Gómez (Florence: Pagnini Editore, 2020), pp. 17-33, esp. 22.

that the Earth has a history, which can be known through a series of rules still taught today as Steno's Principles of Stratigraphy.[5] In the words of historian of geology Martin Rudwick, and many others after him, Steno's examination of this shark's teeth "had a striking catalytic effect" in the history of science and the study of fossils.[6]

The problem with associating this shark's dissection with Steno's research on fossils, however, is that none of the eyewitnesses to the dissection mentioned the shark's teeth nor anything related to fossils. One of the eyewitnesses was Lorenzo Magalotti (1637-1712), secretary of the Accademia del Cimento, the Florentine academy of natural experiments supported by the Medici family. About a week after the dissection took place, Magalotti wrote to the intellectually curious Archbishop of Siena that the shark was examined by "the finest knife of Mr. Nicolaus Steno."[7] He also highlighted three different aspects of Steno's anatomical dissection, none of which was related to shark's teeth.[8] Carlo Dati (1619-1676), another intellectual at the Medici court, also mentioned to a friend that the shark was explicitly brought to Florence for Steno to make anatomical observations.[9] Finally, five weeks later, in a recently discovered letter, Prince Leopoldo de' Medici (1617-1675), the main sponsor of the Accademia del Cimento, wrote various praises of Steno but without ever mentioning fossils or the Earth.[10] Therefore, at least in the five weeks after this

[5] See, for example, Michael Brookfield, *Principles of Stratigraphy* (Malden, MA: Blackwell Publishing, 2004), esp. 115-117. The history of how these principles became known as Steno principles has yet to be written.

[6] Martin Rudwick, *The Meaning of Fossils: Episodes in the History of Palaeontology* (London: Macdonald, 1972), pp. 49-100, esp. 49-50.

[7] Lorenzo Magalotti to Archbishop Ascanio Piccolomini, 26 October 1666, in Siena, Biblioteca Communale di Siena, D. V. 7, fol. 16v: "La testa è venuta a Firenze sotto l'esame del finissimo coltello del Sig. Niccolò Stenon." All translations are mine unless where otherwise noted.

[8] Magalotti mentioned the vessels of the skin glands, the connection between arteries, veins, and cartillages, and an optical nerve.

[9] Carlo Dati to Ottavio Falconieri, 25 October 1666, in Michele Mercati, *Metallotheca vaticana* (Rome, 1717), pp. xxxiv-xxxv, esp. xxxiv.

[10] Prince Leopoldo to Alessandro Segni, 27 November 1666, in Copenhagen, Royal Library of Denmark, Acc. 2019/54, fol. 1v: "il S. Stenone Danese, Anatomico gioviane d'età ma insigne nel suo mestiere corredato poi d'ogni sorte di laudazione, e geometra bravo il che molto li giova al suo mestiere et il vero tipo della modestia." The letter begins "D. Aless[andro]"

dissection took place, it seems that no one associated the dissection of this shark with fossils. More importantly, in the months that followed there is no reference at all to fossils in Steno's writings.

How, then, did Steno go from performing an anatomical dissection to making claims about rocks? [11] Two recent attempts to answer this question show how difficult, but significant it is to contextualize Steno's shift from anatomy to Earth history. One attempt is the explanation of continuity, proposed by Stefano Dominici.[12] This explanation argues that Steno was already working on fossils long before making this dissection. This thesis resonates with Steno's familiarity with tongue-stones and fossils since his formation years in Copenhagen.[13] Steno's encounter with English naturalists in Montpellier in 1665 also suggests that they may have discussed fossils before the shark's dissection, since all of them would later write on the topic. The problem with this explanation, however, is that no primary sources show that Steno had a research interest on fossils before publishing on the topic for the first time, six months after the dissection of the shark took place. Steno was certainly familiar with the debate on fossils, but familiarity does not translate to expertise.

The other attempt to explain Steno's turn to fossils is the theory of discontinuity, recently defended by Jakob Bek-Thomsen.[14] It argues that Steno completely shifted his work from the body

[11] Steno once wrote that it was "a shark of prodigious size" that led him away from his anatomical projects, see Nicolaus Steno, *De solido intra solidum naturaliter contento dissertationis prodromus* (Florence, 1669), p. 4. But this was a broad, retrospective comment. He never associated observing this specific shark's teeth with his theory on fossils, as he associated, for example, the skin glands of this shark with his study of sudoriferous glands, see Steno, *Elementorum myologiæ specimen*, pp. 72-75.

[12] Stefano Dominici, "A Man with a Master Plan: Steno's Observations on Earth's History," *Substantia*, 2021, 5(1) Suppl.:59-75.

[13] Scherz's biography in BOP, pp. 195-196; Angeli, *Niels Stensen*, pp. 151-152; Cutler, *The Seashell on the Mountaintop*, pp. 56-59; Troels Kardel, "Prompters of Steno's Geological Principles: Generations of Stones in Living Beings, Glossopetræ and Molding," in *The Revolution in Geology from the Renaissance to the Enlightenment*, ed. Gary Rosenberg (Boulder, CO: The Geological Society of America, 2009), pp. 127-134, esp. 129-130.

[14] Jakob Bek-Thomsen, "From Flesh to Fossils – Nicolaus Steno's Anatomy of the Earth," in *A History of Geology and Medicine*, ed. C. Duffin, R. Moody, and C. Gardner-Thorpe (London: The Geological Society of London, 2013), pp. 289-305; and Bek-Thomsen, "Steno's *Historia*: Methods and Practices at the Court of

to the Earth because of the needs of the Medici court. It claims that Steno adopted a method named *historia*, based on observations and ridden of philosophical interpretation, in order to make his research more similar to works sponsored by the Medici court, such as the *Saggi di naturali esperienze* (Florence, 1667).[15] The *Saggi* famously described experiments done at the Medici court while explicitly avoiding any interpretation of experimental results. In this light, the argument continues, Steno's writings on fossils were of the same genre of the *Saggi* and thus served as a suitable "patronage gift to the Medici court."[16] This argument creates a definite break between Steno's research in anatomy and the history of the Earth. In the words of Bek-Thomsen, Steno "never used *historia* as deliberately and methodologically" as he did at the Medici court.[17] This article defies this claim by arguing that the effect of Steno's new social context in Florence was not as dramatic as it may seem, although it did foster his research interests.

I challenge both theories of continuity and discontinuity to argue that the answer lies somewhere in the middle. The trigger that turned Steno's attention to the Earth, rather than dissecting a shark, was reading a manuscript that challenged his research methods. But this trigger, I demonstrate, was intrinsically linked to his anatomical research. This claim confirms that early modern anatomy was the broad and compelling discipline that Katharine Park, Anita Guerrini, and

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Ferdinando II," in *Steno and the Philosophers*, ed. Raphaële Andrault and Mogens Lærke (Boston, MA: Brill, 2018), pp. 233-258.

[15] Bek-Thomsen, "Steno's *Historia*," pp. 242-248.

[16] Bek-Thomsen, "From Flesh to Fossils," p. 303; Bek-Thomsen, "Steno's *Historia,*" p. 256. On the *Saggi* and the Medici's avoidance of philosophical discussions see Mario Biagioli, *Galileo, Courtier: The Practice of Science in the Culture of Absolutism* (Chicago, IL: University of Chicago Press, 1993), p. 359; Paolo Galluzzi, "L'Accademia del Cimento: «Gusti» del Principe, Filosofia e Ideologia dell'Esperimento," *Quaderni Storici*, 1981, 16:788-844, esp. 800; and Marco Beretta, "At the Source of Western Science: The Organization of Experimentalism at the Accademia del Cimento," *Notes and Records of the Royal Society of London*, 2000, 54(2):131-151, esp. 141. On the importance of gifts of patronage in early modern science, see Biagioli, *Galileo, Courtier*; Paula Findlen, *Possessing Nature: Museums, Collecting, and Scientific Culture in Early Modern Italy* (Berkely, CA: University of California Press, 1994), pp. 346-392.

[17] Bek-Thomsen, "Steno's *Historia,*" p. 248.

others have written about.[18] But I also add to their analysis not just anatomy's fascinating capacity to absorb major changes of seventeenth-century science, like Robert Frank and Domenico Bertoloni Meli demonstrated, but also anatomy's power to change other disciplines, including what is today known as geology.[19]

This question of how Steno shifted from anatomy to Earth history is also significant because it speaks to broader themes in the history of science. How and why did different areas of knowledge intersect and relate to each other? What shared assumptions existed, if any, underneath the various interests of early modern scholars? And, perhaps more importantly, how well do modern views of polymathy and disciplinary boundaries apply to the early modern period? Although historians have called the seventeenth century a golden age of polymaths, the historical analysis of how intellectual disciplines intersected is still an open field.[20]

Nicolaus Steno's career is an example of this research field. Raised in Copenhagen, Steno became a successful anatomist while traveling through the Netherlands, France, and Italy in the third quarter of the seventeenth century – the generation after Galileo. In these places, he rapidly entered the circles of the first scientific academies of Europe, such as the *Académie des Sciences* in Paris and the Accademia del Cimento in Florence. But due to his subsequent work on fossils

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[18] Katharine Park, *Secrets of Women: Gender, Generation, and the Origins of Human Dissection* (New York, NY: Zone Books, 2006); Anita Guerrini, *The Courtiers' Anatomists: Animals and Humans in Louis XIV's Paris* (Chicago, IL: University of Chicago Press, 2015). See also Andrea Carlino, *Books of the Body: Anatomical Ritual and Renaissance Learning* (Chicago, IL: University of Chicago Press, 1999); Cynthia Klestinec, *Theaters of Anatomy Students, Teachers, and Traditions of Dissection in Renaissance Venice* (Baltimore, MD: Johns Hopkins University Press, 2011); Dániel Margócsy, *Commercial Visions*: *Science, Trade, and Visual Culture in the Dutch Golden Age* (Chicago, IL: University of Chicago Press, 2014).

[19] Robert Frank, *Harvey and the Oxford Physiologists: Scientific Ideas and Social Interaction* (Berkeley, CA: University of California Press, 1980); Domenico Bertoloni Meli, *Mechanism, Experiment, Disease: Marcello Malpighi and Seventeenth-Century Anatomy* (Baltimore, MD: Johns Hopkins University Press, 2011). See also Andrew Wear, "William Harvey and the 'Way of the Anatomists'," *History of Science*, 1983, 21: 223–49.

[20] Peter Burke, *The Polymath: A Cultural History from Leonardo da Vinci to Susan Sontag* (New Haven, CT: Yale University Press, 2020). Steno is described as polymath in pp. 4, 71, 255. For a serious treatment of a real early modern polymath, see Paula Findlen, "The Last Man Who Knew Everything… or Did He?: Athanasius Kircher, S.J. (1602–80) and His World," in *Athanasius Kircher: The Last Man Who Knew Everything*, ed. Paula Findlen (New York: Routledge, 2004), pp. 1-50.

and his religious conversion in Florence, his life is usually told in fragmented parts. Today, Steno is known either as a hero of modern geology or of science and religion. My goal is to avoid not only presentist descriptions, but also the more-tempting category of polymath. Instead, I read Steno on his own terms and argue that he was an anatomist at his core, but one who became increasingly interested in chemistry, mathematics, and geology.[21] At the same time, I also situate Steno's work in the broader history of how scholars started to study nature under same principles and laws.[22] Just like René Descartes (1596-1650) and Isaac Newton (1643-1727) used the motion of earthly projectiles to understand the motion of things in the heavens, Nicolaus Steno applied his understanding of the body to the Earth.

I start this article by jumping directly to Steno's first year in Florence, in 1666. This is the year in which Steno expanded his research from the body to also include fossils. I show that taking Steno's anatomy seriously also leads to a more sophisticated understanding of his history of the Earth as well as his integration into the Medici court. This article then follows Steno's steps from his dissection of the shark in Florence to the publication of the book *De solido* that is considered his masterpiece in geology, three years later. Throughout, I will also add flashbacks to his early anatomical career which, as I demonstrate, are key to grasp his shift from the body to the Earth.

The Delayed Manuscript

[21] There was no discipline of geology in the early modern period. I use it here as a term encompassing both the study of fossils (usually part of natural history) and the history of the Earth. In Steno's time, the latter topic was not as popular among physicians as the former. For further discussion, see Dal Prete, *On the Edge of Eternity*, pp. xi-xii.

[22] On natural laws, see Margaret Osler, *Divine will and the mechanical philosophy: Gassendi and Descartes on contingency and necessity in the created world* (Cambridge, UK: Cambridge University Press, 1994), pp. 6, 136-140, 234-236; Lynn Joy, "Scientific Explanation from Formal Causes to Laws of Nature," in *The Cambridge History of Science, vol. 3: Early Modern Science*, ed. Katharine Park and Lorraine Daston (Cambridge, UK: Cambridge University Press, 2006), pp. 70-105; Lorraine Daston and Katharine Park, *Wonders and the Order of Nature, 1150-1750* (New York, NY: Zone Books, 1998), pp. 350-355.

When Nicolaus Steno dissected the famous shark in October 1666, he had just completed a manuscript on a new mathematical model of muscle contraction.[23] This is known because the book's first *imprimatur*, the typical ecclesiastical approval of a book, dates from 27 October 1666.[24] However, in light of his dissection of the shark, Steno decided to place the printing on hold so that he could add his anatomical remarks on the shark to the book. This is exactly what happened. The book was published in April 1667 under the title *A sample of the elements of myology* (myology being the study of muscles) with an additional description of the shark's head. It was in this description that Steno included his first treatise on fossils.[25] Historians have assumed that the text on fossils was complete by the end of 1666, two months after the dissection took place.[26] This is because a second and final *imprimatur*, dated from December 1666, is preceded by a censor's report mentioning the shark's head.[27] Yet, if the text on fossils was complete by the end of 1666, then Steno would have written his first treatise on fossils in the month and a half that followed his dissection. This would indicate either that Steno was a genius who wrote a major treatise on fossils in only a few weeks, or that he had already written it before the shark's dissection.

My research has uncovered new materials that indicate that this *imprimatur* is misleading and that the time between the approval of the book and its publication is longer than was previously thought. The book's manuscript, still preserved at the Royal Library of Copenhagen and yet rarely used by historians, shows that the original December approval refers only to "a work on the

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[23] See Steno, *Elementorum myologiæ specimen*, p. 123.

[24] The book's first *imprimatur*, from 27 October 1666, refers only to "Anatomica geometrice demonstrata." See Steno, *Elementorum myologiæ specimen*, p. 123.

[25] Steno, *Elementorum myologiæ specimen*, p. 91.

[26] Dominici, "A Man with a Master Plan," p. 64.

[27] Steno, *Elementorum myologiæ specimen*, p. 123.

elements of myology."[28] Indeed, the censors only reviewed the text on the shark's head at the end of February 1667, two months later.[29] Strikingly, Steno's new ideas on fossils were not included in the original manuscript reviewed by the censors in February. This can be known because the February approval appears in a page before the folios on fossils begin.[30] More importantly, the original manuscript that was reviewed by the censors mentions only one copperplate, namely the copperplate of the shark's head.[31] The final printed version, on the other hand, refers to two copperplates in total. A second plate, on fossils that looked like shark's teeth, known as tongue-stones or *glossopetræ*, was added later.[32] In short, this long process of the manuscript's submission and reviews shows that Steno's treatise on fossils was not yet ready four months after he dissected the shark. That is, Steno probably started writing on fossils after he dissected the shark, but he had a longer period to develop his ideas than historians have assumed until now.

Analogies as Equivalences in Anatomy

Why, then, did Steno decide to write on fossils? To answer this question, it is useful to take a step back and to look at Steno's early formation and research in anatomy. Unlike other areas of knowledge, anatomy in the seventeenth century was deeply Aristotelian because it relied on the comparative method of Aristotle's works on animals. This method, known as *historia anatomica*, unlike other notions of *historia* (such as *historia medica*), has its origins in the Aristotelian

[28] Copenhagen, Royal Library, NKS 4019 kvart, fol. 103v: "Opus elementorum myologiæ … vidi." This passage is crossed out and points to an approval from 3 March 1667 in fol. 102r. The only study of this manuscript is Gustav Scherz, "Danmarks Stensen-Manuskript," *Fund og Forskning* (1959), pp. 19-33.

[29] Copenhagen, Royal Library, NKS 4019 kvart, fol. 75v: "Tractatus hic de capite canis carchariæ nil contra fidem … exhibet … die 23.Feb.1667."

[30] The text on fossils begins in Copenhagen, Royal Library, NKS 4019 kvart, fol. 78r.

[31] Copenhagen, Royal Library, NKS 4019 kvart, fol. 60v: "meis usibus eam concessit, qua Lamiæ caput et dentes expressos vides."

[32] Steno, *Elementorum myologiæ specimen*, p. 70: "meis usibus eas concessit, quibus Lamiæ caput et dentes atque glossopetras maiores expressas vides."

empiricism of late sixteenth-century Padua.[33] Early modern anatomists followed a method best articulated by Hieronymus Fabricius ab Acquapendente (1533-1619) in which complete knowledge of a body part consisted in describing its structure (*historia*), action (*actio*), and purpose (*usus*).[34] These categories, which are originally from Galenic anatomy, parallel the Aristotelian four causes: material and formal (*historia*), efficient (*actio*), and final (*usus*) causes.[35] Various anatomists throughout the seventeenth-century, such as William Harvey (1578-1657), Gaspare Aselli (1581-1626), Jean Pecquet (1622-1674), and Thomas Bartholin (1616-1680), Steno's first professor of anatomy, expanded this philosophical approach to anatomy.[36] They added to the descriptive part of *historia anatomica* new information such as narratives of discovery and a discussion of the organ's name.[37]

Nicolaus Steno was not an exception to this trend. In Leiden, where Steno lived from 1660 to 1664, he undertook a full study of the glands of the head to understand better the structure, function, and use of a new salivary duct he discovered.[38] In his first published book *Observationes anatomicæ* (Leiden, 1662), Steno described the shape and location of various salivary glands (until then anatomists thought there was only one) with observational descriptions and a beautiful copper plate (fig. 1). These descriptions were the *historia* of the glands. As Steno claimed, "I laid out

[33] Pomata, "*Praxis Historialis*: The Uses of *Historia* in Early Modern Medicine," in *Historia* (cit. n. 17), pp. 105-146, esp. 111, 114-122. For the impact of Aristotelian causes on natural history's *historia*, see Ian Maclean, "White Crows, Graying Hair, and Eyelashes: Problems for Natural Historians in the Reception of Aristotelian Logic and Biology from Pomponazzi to Bacon," in *Historia* (cit. n. 17), pp. 147-179.

[34] Hieronymus Fabricius ab Aquapendente, *De visione. De voce. De auditu* (Venice, 1600), dedication to *De visione*. See also Peter Distelzweig, "Fabricius's Galeno-Aristotelian Teleomechanics of Muscle," in *The Life Sciences in Early Modern Philosophy*, ed. Ohad Nachtomy and Justin Smith (Oxford: Oxford University Press, 2014), pp. 65-84; and Nancy Siraisi, "*Historia*, *actio*, *utilitas*: Fabrici e le scienze della vita nel Cinquecento," in *Il Teatro dei Corpi: Le Pitture Colorate D'Anatomia di Girolamo Fabrici d'Acquapendente*, ed. Maurizio Bonati and José Pardo-Tomas (Milan: Mediamed Edizioni Scientifiche Sri., 2004), pp. 63-73.

[35] Pomata, "*Praxis Historialis*," p. 117.

[36] William Harvey, *De motu cordis … anatomica exercitatio* (London, 1628); Gaspare Aselli, *De lactibus sive lacteis venis* (Milan, 1627); Jean Pecquet, *Experimenta nova anatomica* (Paris, 1654); Thomas Bartholin, *Anatomia parentis C. Bartholini* (Leiden, 1641).

[37] Pomata, "*Praxis Historialis*," pp. 114-122.

[38] Nicolaus Steno, *Observationes anatomicæ* (Leiden, 1662), §7, p. 6.

everything historically."[39] He then explained that salivary glands produced saliva by filtering it from the blood. Thus, he completed the trio of *historia*, *actio*, and *usus* by describing the shape, function, and purpose of salivary glands. *Historia anatomica* in the Aristotelian sense was also comparative and consisted in searching for similarities and differences between the same bodily part in as many animals as possible.[40] It reflected the methodology of Aristotle's works on animals.[41] Anatomists developed new knowledge about an organ's *historia* by explaining similarities between the same organ in different animals. For his work on glands alone, Steno dissected a lamb, a cow, a sheep, many dogs and rabbits, and he mentioned his professor's observations of human cadavers at the hospital.[42]

[39] Steno, *Observationes anatomicæ*, p. 68: "Cum disputatione … historice omnia proposuissem."

[40] Andrew Cunningham, *The Anatomical Renaissance: The Resurrection of the Anatomical Projects of the Ancients* (Aldershot: Scolar Press, 1997), pp. 27, 175-177; Francis Cole, *A History of Comparative Anatomy from Aristotle to the Eighteenth Century* (London: MacMillan & Co. Ltd, 1949), pp. 7-21. Gian Battista Vai mentioned the importance of comparative anatomy to Steno in passing, in "The Scientific Revolution and Nicholas Steno's Twofold Conversion," in *The Revolution in Geology* (cit. n. 13), pp. 187-208, esp. 190.

[41] Stefano Perfetti, *Aristotle's Zoology and Its Renaissance Commentators, 1521-1601* (Leuven: Leuven University Press, 2000).

[42] Steno, *Observationes anatomicae*, §16, §18, §47-48, §50, §19, pp. 15, 17, 46-47, 49, 18-19 (BOP, pp. 436, 438, 457-458, 460, 439).

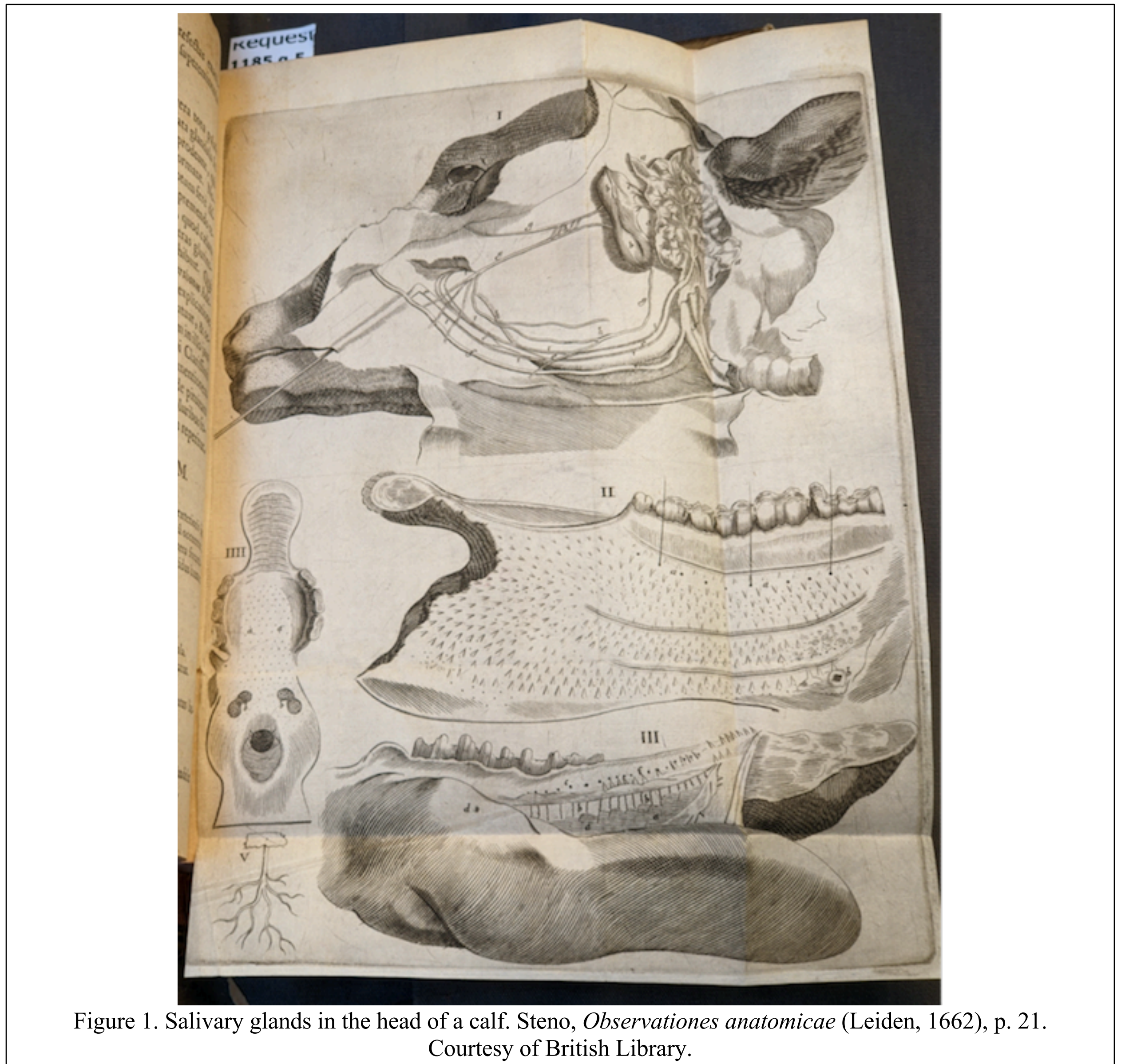

Figure 1. Salivary glands in the head of a calf. Steno, *Observationes anatomicae* (Leiden, 1662), p. 21. Courtesy of British Library.

But what happened when two supposedly different organs shared too many similarities? To answer this question, Steno took anatomy's comparative method a step further – the step that would also lead him to start writing on fossils. When dissecting muscles for the first time, he noticed a great similarity between the tissues of the heart and muscle fibers.[43] Steno explored this

[43] Steno to Thomas Bartholin, 30 April 1663, in Thomas Bartholin, *Epistolarum Medicinalium Centuria IV* (Copenhagen, 1667), pp. 414-421, esp. 417. The rabbit as the first observation is confirmed in Steno, *De musculis et glandulis observationum specimen* (Copenhagen, 1664), p. 11.

similarity in his second book, *De musculis et glandulis observationum specimen* (Copenhagen, 1664). There, he wrote that in muscles, like "in all the substance of the heart, nothing else occurs than *arteries, veins, nerves, fibers, membranes*."[44] Therefore, he continued, "if it is certain" that the heart and muscles are made of the same substance, then "truly the heart must be greeted with the name of muscle."[45] This claim, which was also made by a few others at the time, challenged the traditional understanding of the heart, also shared by William Harvey, that the heart was a unique source of energy for the entire body.[46] But for Steno, equivalence of substance was enough to convince him that the heart was just a muscle. After his book came out, Steno presented his case before several audiences in Paris in 1664. He then responded to criticisms in a public letter published in the *Elementorum myologiæ specimen* (Florence, 1667), the same book where he would launch his geological career.[47] In his answer, Steno mentioned similarities not just between appearances (*historia*) but also between the action (*actio*) of muscles and heart. As he concluded, since "a movement much evident to the senses is observed in the same way in the heart as in what are commonly called muscles, I sufficiently hope to have demonstrated clearly… that the heart is a muscle."[48]

In Florence, in the months after dissecting the shark, when he was already writing on fossils, Steno used again similarities between different organs to demonstrate something new about the female reproductive system. Two years before, he had become intrigued by similarities between the uterus of mammals and the eggs of a ray he dissected in Copenhagen. However,

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[44] Steno, *De musculis et glandulis*, p. 22. Italics in the original.

[45] Steno, *De musculis et glandulis*, pp. 27, 26. Italics in the original.

[46] Honoré Fabri, *Tractatus duo: quorum prior est de plantis et de generatione animalium et posterior de homine* (Paris, 1666), p. 371. Malpighi mentions seeing the spiral fibers of the heart in 1656, see Marcello Malpighi, *Opera posthuma* (Amsterdam, 1700), p. 3. For Harvey's opinion, see William Harvey, *Exercitatio anatomica de motu cordis* (Frankfurt, 1628), p. 59.

[47] Steno, *Elementorum myologiæ specimen*, pp. 45, 55-56.

[48] Steno, *Elementorum myologiæ specimen*, pp. 59.

because the mammalian uterus had more functions than an egg, Steno concluded that no analogy could be used "unless as completely misapplied."[49] Now, in Tuscany, after dissecting bodies of various mammalians, Steno observed that female testicles contained inside eggs.[50] Until then, many anatomists still thought that female ovaries, then called female testicles, contributed little to animal reproduction. They existed only as mere vestiges in women, just like nipples in men. Instead, Steno concluded that the "testicles of females are analogous [*analogi sint*] to an ovary," like in fishes and other animals.[51] Steno published this observation as a side comment to a larger description of another shark that he dissected. Yet, for Steno, this small note and its accompanying illustration – the *historia* of the ovaries – were enough to "show the analogy of the genital parts [*partium genitalium analogia*] and remove this error by which it is believed that the genitals of women are analogous to the genitals of men."[52] Steno promised to work further on this topic, but his emerging interest on fossils led him away from it. In the end, Steno's Dutch friends Regnier de Graaf (1641-1673), who described the development of ovarian or Graafian follicles, and the famous microscopist Jan Swammerdam (1637-1680) took the lead in exploring these matters further.[53] But one thing is true: Steno's firm commitment to comparative anatomy opened the door for a new understanding of female ovaries and, as I will now show, to a new history of the Earth.

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[49] Steno, *De musculis et glandulis*, pp. 61, 63.

[50] Steno, *Elementorum myologiæ specimen*, p. 117.

[51] Steno, *Elementorum myologiæ specimen*, p. 117.

[52] Steno, *Elementorum myologiæ specimen*, pp. 117-118.

[53] Regnier De Graaf, *De mulierum organis generationi inservientibus* (Leiden, 1672), p. 183; Jan Swammerdam, *Miraculum naturæ, sive uteri muliebris fabrica* (Leiden, 1672), p. 20. Steno published two later articles on observations of the ovaries, where he mentioned "observationes amicorum" in Steno, "Observationes anatomicæ spectantes ova viviparorum," in *Acta medica et philosophica hafniensia*, vol. 2, ed. Thomas Bartholin (Copenhagen, 1675), pp. 210-218; and Steno, "Ova viviparorum spectantes observationes aliæ," in *Acta medica*, vol. 2, pp. 219-221. See also Roger, *The Life Sciences in Eighteenth-Century French Thought*, pp. 206-216; and Eric Jorink, "Cartesian Sex: Dutch Anatomists on Genitalia, Lust, and Intercourse (ca. 1660–1680)," *Libertinage et philosophie à l'époque classique (xvie-xviiie siècle)*, 19, 2022, 249-290.

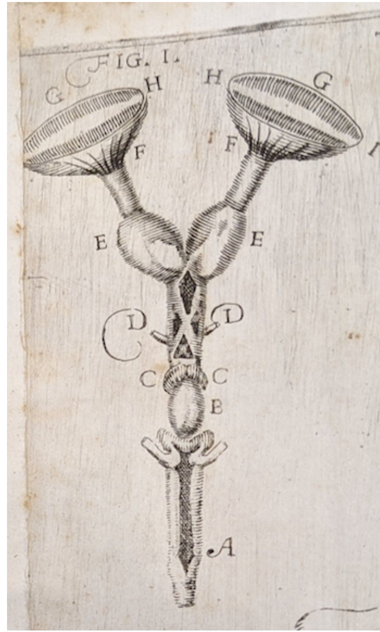

Figure 2. Drawing of a fish's ovaries and uterus. Steno, *Elementorum myologiæ specimen* (Florence, 1667), Tab. VII. Courtesy of Institute for the History of Medicine, Johns Hopkins University.

Analogies as Equivalences in Earth History

Soon after the shark's dissection took place in October 1666, the literary scholar Carlo Dati, one of the eyewitnesses to the shark's dissection, had an idea. He had recently acquired the almost-hundred-years-old manuscript of the *Metallotheca Vaticana*, an extensive description of the Vatican's mineral collection. The text had been written by the collection's curator in the sixteenth century, the Papal physician Michele Mercati (1541-1593).[54] Dati wanted to publish the book in Florence and dedicate it to the pope, but he never managed to.[55] For this reason, he saw Steno's new work on the shark as an opportunity to display one of the beautiful images from the manuscript, namely the head of the great white shark.[56] Dati lent the manuscript to Steno and

[54] For Dati's account, see Dati to Falconieri, 25 October 1666, in Michele Mercati, *Metallotheca vaticana* (Rome, 1717), pp. xxxiv-xxxv.

[55] The book was only printed in 1717 by Giovanni Maria Lancisi (1654-1720) in Rome, see Alix Cooper, "The Museum and the Book: The *Metallotheca* and the history of an encyclopaedic natural history in early modern Italy" *Journal of the History of Collections*, 1991, 7(1):1-23.

[56] The German artist Anton Eisenhout (fl. 1590) made the engravings under the supervision of Mercati.

suggested that he use the plate in his publication, which Steno agreed to (see fig. 3). But Steno also focused on the text itself, especially on what Mercati had to say on shark's teeth.[57] What he read dramatically changed his research career.

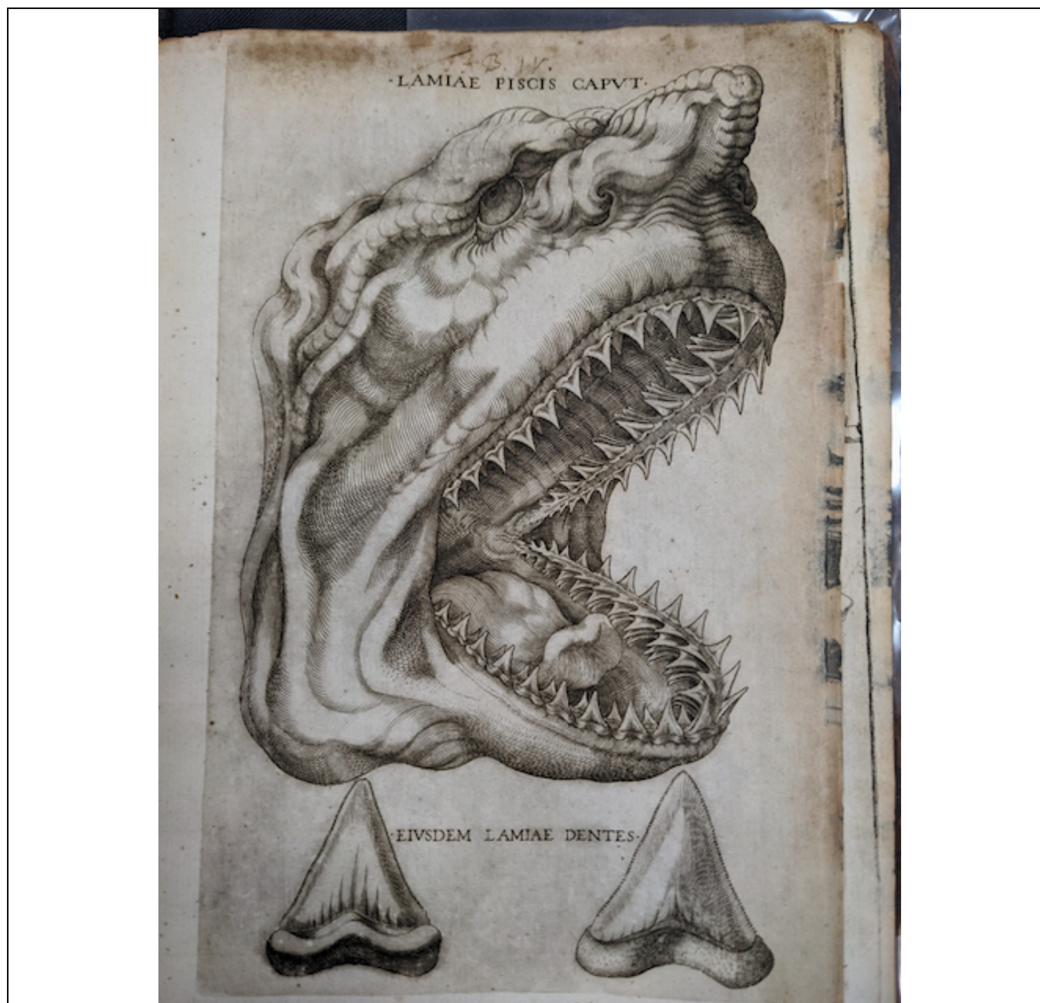

Figure 3. Steno, *Elementorum myologiæ specimen*, tabula IV. Courtesy of The Institute for the History of Medicine, Johns Hopkins University.

In his manuscript, Mercati claimed that, because of their similarity, fossils and the teeth of sharks "are confused even by the learned," and that it was an error to say that they were the same.[58] That is, for Mercati, despite their great resemblance, fossils and shark's teeth were not the same

[57] Steno, *Elementorum myologiæ specimen*, p. 70.
[58] Steno, *Elementorum myologiæ specimen*, pp. 70-71.

thing. On its own, this claim directly contradicted Steno's radical exploration of analogies of equivalence in anatomy. Whereas Steno claimed that two distinct but similar organs were of the same substance, like muscles and heart, Mercati concluded the exact opposite in a different field. Moreover, from Steno's perspective, there was another problem with Mercati's text. Mercati mentioned a few "very little" differences between tongue-stones and shark teeth.[59] One of them was that shark teeth had "a single and unbroken white [color], or yellowish with age," whereas tongue-stones often appeared in more colors.[60] But Steno knew from his research that colors were often epistemologically unreliable.[61] Thus, Mercati's attempt to differentiate tongue-stones from teeth based on color was, in Steno's eyes, unconvincing.

By this time, Steno was fully engaged in using comparative methods in anatomy. In addition, he often associated this method with an intense desire to fight uncertainty in anatomy. Yet, adding fuel to the fire, Mercati also claimed to fight uncertainty in natural history. He wrote that he wanted to "be as clear as possible" and "not only to teach but also to remove" false and supposed things.[62] How could Mercati aim for scientific rigor in the same terms as Steno and yet conclude that shark's teeth and fossils were different despite their obvious similarities? Faced with this stark methodological difference, Steno had to respond. Therefore, he added to his account of the shark's head what he called a digression on the origin of fossils and on the soils themselves where these fossils are found.[63]

In this digression, which occupied half of the text on the white shark, Steno scrupulously applied the methods he had developed as an anatomist to study fossils.[64] He described the various

[59] Steno, *Elementorum myologiæ specimen*, p. 71.
[60] Steno, *Elementorum myologiæ specimen*, p. 71.
[61] See note 63.
[62] Steno, *Elementorum myologiæ specimen*, p. 70.
[63] Steno, *Elementorum myologiæ specimen*, p. 91.
[64] The two parts are Steno, *Elementorum myologiæ specimen*, pp. 69-90, and pp. 90-110.

soils where fossils resembling parts of sea animals are found. And, as a good anatomist, he entitled this observational description a *historia*.[65] It was in this *historia* description that Steno first wrote that these soils are "composed of layers imposed on each other and inclined to the horizon" – ideas that resemble the modern principles of superposition of strata and of original horizontality.[66] In the end, this *historia* of soils allowed Steno to apply his comparative method to fossils. He argued that fossils "are teeth of the great white shark" because of their great similarity, "since planes are most similar to planes, sides to sides, [and] base to base."[67] Ironically, he relied on Mercati's copperplate to support his point visually (see fig. 4).

But if fossils were really teeth of sharks, how did they end up on mountaintops?[68] To answer this, Steno channeled his anxiety for certainty in anatomy to explain the formation of soils and of fossilization. That is, he wrote a history of the Earth with the same methods that he used in his *historia* of the body.

[65] Steno, *Elementorum myologiæ specimen*, p. 91.
[66] Steno, *Elementorum myologiæ specimen*, p. 91. On these principles see Cutler, *The Seashell on the Mountaintop*, pp. 110-111.
[67] Steno, *Elementorum myologiæ specimen*, p. 109. This argument resonates with Steno's comment in *Observationes anatomicæ*, p. viii: "observation must lead to reasoning and the object itself must be examined, as far as possible from all its sides so that its figure be imprinted in the mind, corresponding truly to the object itself."
[68] I am borrowing from the title of Cutler, *The Seashell on the Mountaintop*, which draws from Ovid, *Metamorphoses*, Book XV:264-265.

Figure 4. Steno, *Elementorum myologiæ specimen* (Florence, 1667), Tab. VI. Courtesy of The Institute for the History of Medicine, Johns Hopkins University.

Search for Certainty in Anatomy

Nicolaus Steno's deep interest in finding certain or reliable knowledge about nature was present since his early days studying the body.[69] This interest was a response to the crisis of certainty of his time.[70] Steno was well aware that new systems that explained natural phenomena in a sound way, often differed to their core. For instance, Gassendi believed in the existence of the vacuum and Descartes rejected it; and Jesuit mathematicians adopted a geo-heliocentric astronomy, versus Galileo's heliocentrism.[71] That is, there were theories that could explain all the available observations, but which were often opposite to one another. In anatomy, Steno also faced this problem and became obsessed with solving it. But for him, certainty did not always mean finding the absolute certitude of geometry. Rather, it also meant finding knowledge that was reliable and that described natural phenomena in compelling and accurate ways. In the preface to the *Observationes anatomicae*, Steno stated that "observation must lead to reasoning" in order for the mind to fully understand the organs and their interconnections.[72] He admired "that power divinely attributed to the human mind" that perceives what is unobserved "through the senses."[73] And yet,

[69] This was a common attitude in the second half of the seventeenth century, see Margaret Osler, *Reconfiguring the World: Nature, God, and Human Understanding from the Middle Ages to Early Modern Europe* (Baltimore, MD: Johns Hopkins University Press, 2010), pp. 77-93; Ann Blair, "Natural Philosophy," in *The Cambridge History of Science, vol. 3: Early Modern Science* (cit. n. 23), pp. 365-406, esp. 393-403; and Mark Waddell, *Jesuit Science and the End of Nature's Secrets* (Burlington, VT: Ashgate, 2015), pp. 17-28.

[70] This was a common attitude in the second half of the seventeenth century, see Margaret Osler, *Reconfiguring the World: Nature, God, and Human Understanding from the Middle Ages to Early Modern Europe* (Baltimore, MD: Johns Hopkins University Press, 2010), pp. 77-93; Ann Blair, "Natural Philosophy," in *The Cambridge History of Science, vol. 3: Early Modern Science* (cit. n. 23), pp. 365-406, esp. 393-403; and Mark Waddell, *Jesuit Science and the End of Nature's Secrets* (Burlington, VT: Ashgate, 2015), pp. 17-28.

[71] On the vacuum, see Osler, *Divine Will and the Mechanical Philosophy*, pp. 182-188, 201-202, 208-210. On heliocentrism, see Christopher Graney, *Setting Aside All Authority: Giovanni Battista Riccioli and the Science Against Copernicus in the Age of Galileo* (Notre Dame, IN: University of Notre Dame Press, 2015).

[72] Steno, *Observationes anatomicae*, Preface.

[73] Steno, *Observationes anatomicae*, Preface.

despite centuries of anatomical research, he lamented that there was still no "certain knowledge [*certa cognitio*]" of the body's individual parts.[74] For Steno, the way to go was combining intellectual reasoning with as many observations as possible.

This reliance on observations – typical of early modern anatomy – was understood by Steno and his peers to be in contrast with Cartesian medicine, which they criticized for not relying enough on observations.[75] For this reason, Steno also thought that good research should rule out that which is not certain.[76] Steno had some strong words about this, saying that not distinguishing certain from uncertain knowledge in anatomy could lead to fatal errors in medicine.[77] In a dissection of the brain in Paris in 1665, Steno unveiled the errors of Thomas Willis (1621-1675) and René Descartes' recent works on the brain, but did not add any explanation as a substitute.[78] Steno's discourse on the brain was later published in 1669, in an essay where he wrote that the dissection's goal was showing that "the substance of the brain is [still] poorly known." [79]

Analogies as Models in Anatomy

This search for certain knowledge about the body, led Steno to use knowledge and observations from various disciplines to make his claims more intelligible and reliable. Since analogies between

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[74] Steno, *Observationes anatomicae*, Preface.

[75] Evan Ragland, "Mechanism, the Senses, and Reason: Franciscus Sylvius and Leiden Debates Over Anatomical Knowledge After Harvey and Descartes," in Peter Distelzweig, Benjamin Goldberg and Evan Ragland (eds.), *Early Modern Medicine and Natural Philosophy* (New York: Springer, 2016), pp. 173-206

[76] The purpose of Jean Pecquet, *Experimenta nova anatomica* (Paris, 1651) was also to show that the liver did not produce blood.

[77] On the role of the new anatomy in medicine see Domenico Bertoloni Meli, "Mechanistic Pathology and Therapy in the Medical *Assayer* of Marcello Malpighi," *Medical History*, 2007, 51:165-180; and Marta Cavazza, "The uselessness of anatomy: Mini and Sbaraglia versus Malpighi," in *Marcello Malpighi anatomist and physician*, ed. Bertoloni Meli (Florence: Olschki, 1997), 129-145.

[78] See Gustav Scherz, "Introduction," in *Nicolaus Steno's Lecture on the The Anatomy of the Brain*, ed. Gustav Scherz (Copenhagen: Nyt Nordisk Forlag, 1965), pp. 61-103; and Raphaële Andrault, "Introduction," in Niels Stensen, *Discours sur l'anatomie du cerveau*, ed. Raphaële Andrault (Paris: Editions Classiques Garnier, 2009), 7-74.

[79] Steno, *Discours sur l'anatomie du cerveau* (Paris, 1669), p. 7.

anatomy and other areas of knowledge became a central aspect of Steno's history of the Earth, they are worth further exploration. For instance, Steno often drew on examples from mechanics and hydrostatics. He compared glands to sieves of blood that functioned according to the speed of blood flow; he described glandular secretions as lubrication fluids of the body; he compared veins to siphons, and muscles to complex pulleys.[80] He also used examples from chymistry, such as when arguing that blood carries several substances within itself despite its uniform red color. He spoke of the chymical reaction of two non-red substances that also resulted in a red product (he mentioned the reaction between butter of antimony and spirit of niter).[81] This and other chemical analogies reflected an approach that was especially popular at the University of Leiden, where Steno studied and worked before moving to Florence.[82]

But Steno's most sophisticated analogy appeared in Florence. In the book that he had submitted to the press right before the shark's dissection, Steno argued that anatomy had to embrace mathematics in order to improve the epistemic strength of its claims. As he put it, there is no other cause for the innumerable errors of anatomy then its "disdain of the laws of mathematics until now."[83] Although rarely mentioned outside of the history of anatomy, this book is perhaps

[80] Steno, *De musculis et glandulis*, p. 44; Steno, *Observationes anatomicæ*, p. 85; Nicolaus Steno to Thomas Bartholin, 30 April 1663, in Thomas Bartholin, *Epistolarum medicinalium centuria IV* (Copenhagen, 1667), pp. 414-421; and Steno, *De musculis et glandulis*, pp. 19-20. See also Nuno Castel-Branco, "Dissecting with Numbers: Mathematics in Nicolaus Steno's Early Anatomical Writings, 1661-64," *Substantia*, 2021, 5(1) Supp.:29-42; and Castel-Branco, "Physico-Mathematics and the Life Sciences: Experiencing the Mechanism of Venous Return, 1650s-1680s." *Annals of Science*, 2022, 79(4): 442–67.

[81] Steno, *Observationes anatomicæ*, §33, pp. 30-31. In Florence, Steno also compared the process of boiling a lobster to its chymical reaction with spirit of vitriol, see Angelo Fabroni, *Delle Lettere Familiari del Conte Lorenzo Magalotti e di altri insigni uomini a lui scritte*, 2 vols. (Florence, 1769), vol. 1, pp. 172-173. See also Domenico Bertoloni Meli, "The Color of Blood: Between Sensory Experience and Epistemic Significance," in *Histories of Scientific Observation*, ed. Lorraine Daston and Elizabeth Lunbeck (Chicago: University of Chicago Press, 2011), pp. 117–134.

[82] Evan Ragland, "Chymistry and Taste in the Seventeenth Century: Franciscus Dele Boë Sylvius as a Chymical Physician Between Galenism and Cartesianism," *Ambix* 59:1 (2012): 1-21; and Ragland, "Experimenting with Chymical Bodies: Reinier De Graaf's Investigations of the Pancreas," *Early Science and Medicine* 13.6 (2008):615-64.

[83] Steno, *Elementorum myologiae specimen*, preface.

the first serious attempt to join mathematics with anatomy in the early modern period. Therefore, it is a prime example of how these two disciplines intersected at this time.

The main argument of this book was that muscle flesh should be understood as an oblique parallelepiped, with bases as rectangles and lateral surfaces as parallelograms.[84] But why did this parallelepiped model matter? Since at least the time of Galen, anatomists used to explain muscle contraction through the inflation of animal spirits. Everyone knows that if the bicep (or any muscle) contracts, it looks inflated or larger. Premodern scholars explained this by saying that something entered the muscle to increase its size, namely the so-called animal spirits.[85] A new version of this influx theory of spirits had just been proposed by René Descartes in the posthumous *De homine* (Leiden, 1662) This book was published in Leiden right when Steno lived there. Steno's model of the parallelepiped was important because it threatened to shatter the role of animal spirits in muscle contraction. His argument is easier to understand in two dimensions. Imagine two parallelograms, which are cross-sections of two parallelepipeds (see fig. 5). The parallelograms have different inclination angles. The one on the left corresponds to a relaxed muscle and the one on the right to a contracted muscle. Steno explains that the thickness of the parallelogram increases from one to the other because line CS is longer than line CR. But since these parallelograms have the same base and height, their areas remain the same, because it is only base times height. In short, if this model could really be applied to muscle fibers, a muscle could change shape while keeping its volume.[86] No spirits were needed, geometry alone explained the inflation. Steno did not add

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[84] Steno, *Elementorum myologiæ specimen*, p. 3.

[85] On the vast topic of animal spirits, see Maria Conforti, "Succo Nerveo e Succo Seminale nella Macchina del Vivente di Giovanni Alfonso Borelli" *Medicina nei Secoli Arte e Scienza*, 2001, 13:577-595; Matthew Cobb, "Exorcizing the animal spirits: Jan Swammerdam on Nerve Function" *Nature Reviews Neuroscience*, 2002, 3:395-400; C. Smith, E. Frixione, S. Finger, and W. Clower, *The Animal Spirit Doctrine and the Origins of Neurophysiology* (Oxford: Oxford University Press, 2012).

[86] Steno, *Elementorum myologiæ specimen*, p. 30. For further studies see Troels Kardel, *Steno on Muscles: Introduction, Texts, Translations* (Philadelphia, PA: The American Philosophical Society, 1994), pp. 15-18; Domenico Bertoloni Meli, "The Collaboration between Anatomists and Mathematicians in the mid-Seventeenth

anything else. He was happy just to show that "the idea of animal spirits is built on an uncertain foundation."[87]

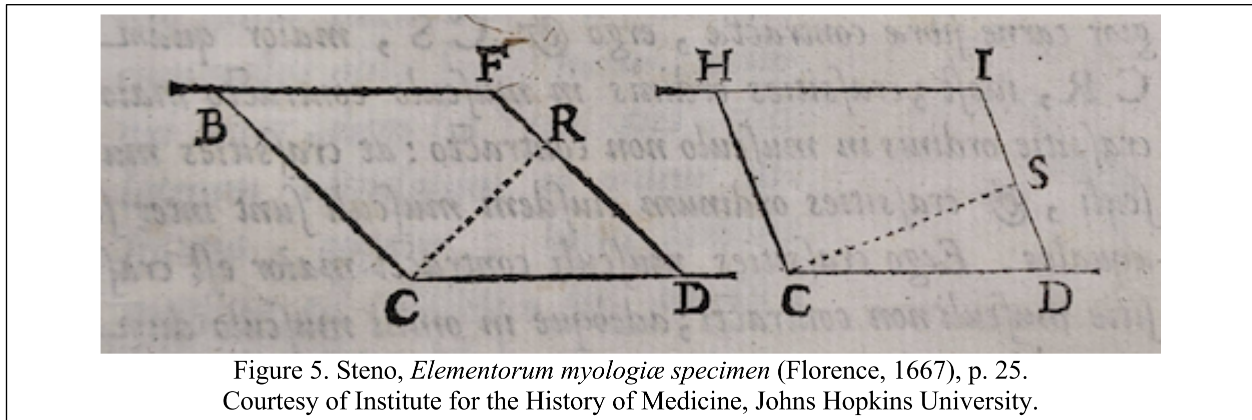

Figure 5. Steno, *Elementorum myologiæ specimen* (Florence, 1667), p. 25.
Courtesy of Institute for the History of Medicine, Johns Hopkins University.

But how does this abstract model relate to Steno's emphasis on observations? Steno admitted that he did not see "all muscles of all animals to the extent that I believe with certainty [*adeoque certo crederem*]" that all planes were perpendicular.[88] This attitude confirmed Steno's anxiety for rigorous knowledge and why he only made claims "with certainty in so far as I perceived it in many things [*id duntaxat certo hic affirmo me in plurimis talem deprehendisse*]."[89] Steno explicitly associated his mathematical insights with an innovative cross-sectional cut of muscles along the length of their fibers. It took him a while to decide on how to write and illustrate his geometrical ideas since he first cut muscles by the slices in Leiden.[90] The solution only came to him a few years later in Florence, in collaboration with the mathematician Vincenzo Viviani, Galileo's last disciple.[91] In Florence, Steno was confident enough to claim that the structure of

Century with a Study of Images as Experiments and Galileo's Role in Steno's Myology," *Early Science and Medicine*, 2008, 13(6):665-709, esp. 696-706; and Raphaële Andrault, "Mathématiser l'Anatomie: La Myologie de Stensen (1667)," *Early Science and Medicine*, 2010, 15:505-536.

[87] Steno, *Elementorum myologiæ specimen*, pp. v-vi.

[88] Steno, *Elementorum myologiæ specimen*, p. 7.

[89] Steno, *Elementorum myologiæ specimen*, p. 7.

[90] See Nuno Castel-Branco and Troels Kardel, "Drawing Muscles with Diagrams: How a Novel Dissection Cut Inspired Nicolaus Steno's Mathematical Myology (1667)," *Notes and Records of the Royal Society of London*, 2022.

[91] Bertoloni Meli, "The Collaboration between Anatomists and Mathematicians in the mid-Seventeenth Century," pp. 699-700.

muscles “requires almost by necessity that they must be explained mathematically.”[92] Therefore, although Steno did not exactly see a parallelepiped, he observed parallelograms in his cross-sections of muscles, which he generalized for three dimensions. For the rest of the book, he also relied on the format of Euclid’s *Elements*, with a sequence of definitions, lemmas, and corollaries, all illustrated with diagrams.

In short, comparisons and analogies were central for Steno’s research in anatomy and he used them with an awareness of their varying degree of certainty.[93] In his first work on muscles, Steno described muscle contraction as a pile-driver machine “because an explanation by similar things [*per similia explicatio*] greatly pleases many people,” but “this being only a comparison [*cum simile hoc tantum sit*]” he decided to pursue it no further.”[94] However, in most cases, Steno used analogies for more than just illustrations. Mechanical metaphors of sieves and lubrication were central to his view on glands.[95] And the way he wrote about chymical reactions also carried enough epistemic strength for him to speak about the composite nature of blood. This reliance on analogies was not unusual, since they were also central to early modern mechanical worldviews.[96]

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[92] Steno, *Elementorum myoloiæ specimen*, p. iv.

[93] I am using the words “metaphor,” “analogy,” and “comparison” in a loose way as synonyms. For a deeper discussion of these terms, see Dedner Gentner and Michael Jeziorski, “The Shift from Metaphor to Analogy in Western Science,” in *Metaphor and Thought*, ed. Andrew Ortony, 2nd ed. (Cambridge: Cambridge University Press, 1993), pp. 447-480; and Andrew Ortony, “The Role of Similarity in Similes and Metaphors,” in *Metaphor and Thought*, pp. 342-356. On analogies and science, see Thomas Kuhn, “Metaphor in Science,” in *Metaphor and Thought*, pp. 533-542, esp. 538; Peter Machamer, “The Nature of Metaphor and Scientific Description,” in *Metaphor and Analogy in the Sciences*, ed. Fernand Hallyn (Dordrecht: Springer, 2000), pp. 35-52. For a more general argument beyond science, see George Lakoff and Mark Johnson, *Metaphors We Live By* (Chicago: Chicago University Press, 1980).

[94] Steno, *De musculis et glandulis*, pp. 19-20.

[95] See Bertoloni Meli, *Mechanism, Experiment, Disease*, pp. 105-129, 150-169.

[96] Peter Dear, *Discipline and Experience: The Mathematical Way in the Scientific Revolution* (Chicago, IL: Chicago University Press, 1995), pp. 151-153; Peter Dear, “Intelligibility in Science,” *Configurations*, 2003, 11(2):145-161; Peter Dear, *The Intelligibility of Nature: How Science Makes Sense of the World* (Chicago, IL: Chicago University Press, 2006), pp. 15-38; Alan Gabbey, “Mechanical Philosophies and Their Explanations,” in *Late Medieval and Early Modern Corpuscular Matter Theories*, ed. Christoph Lüthy, John Murdcoh, and William Newman (Leiden: Brill, 2001), pp. 441-466. For a recent overview, see Domenico Bertoloni Meli, *Mechanism: A Visual, Lexical, and Conceptual History* (Pittsburgh, PA: University of Pittsburgh Press, 2019), esp. 7-8. For a general discussion beyond mechanics see Richard Boyd, “Metaphor and Theory Change: What is ‘Metaphor’ a Metaphor for?” in *Metaphor and Thought*, pp. 481-532.

Other kinds of analogies, such as those between macrocosm and microcosm, were also used by Johannes Kepler (1571-1630) or Johannes Van Helmont (1580-1644) with argumentative force.[97] Even Aristotle, who acknowledged the epistemological problems of analogies, used them often and consciously, such as when attributing the intentionality of a craftsman to nature ("nature does nothing in vain").[98] Therefore, analogies held significant and varying cognitive benefits in Steno's anatomical project, and would continue to do so in his subsequent research on fossils. Taking this into consideration, the article now turns, one last time, to how Steno developed a history of the Earth.

Search for Certainty in Earth History

When Steno started writing on fossils, he did not start from a blank slate. As a learned anatomist, he mastered typical works of natural history such as those by Guillaume Rondelet (1506-1566), Conrad Gesner (1516-1565), and Johannes Jonston (1603-1675), all of whom he quoted in his anatomical work.[99] Danish physicians even had a specific legacy in natural history. Ole Worm

[97] Lawrence Principe, *The Secrets of Alchemy* (Chicago, IL: University of Chicago Press, 2013), pp. 201-206, esp. 205; Gérard Simon, "Analogies and Metaphors in Kepler," in *Metaphor and Analogy in the Sciences*, pp. 71-83; and, although slightly outdated, Gentner and Jeziorski, "The Shift from Metaphor to Analogy in Western Science." For the case of natural history see William Ashworth, "Natural History and the Emblematic Worldview," in *Reappraisals of the Scientific Revolution*, ed. David Lindberg and Robert Westman (Cambridge: Cambridge University Press, 1990), pp. 303-332; and Paula Findlen, "Jokes of Nature and Jokes of Knowledge: The Playfulness of Scientific Discourse in Early Modern Europe," *Renaissance Quarterly*, 1990, 43(2):292-331.

[98] On the epistemic weakness of analogy see Aristotle, *Prior Analytics*, Bk 2, Chap. 24 (68b38ff); on the epistemic need for analogies, regarldess of its shortcomings, see Aristotle, *Physics,* Bk 1 Chap. 7 (191a8). For an in-depth discussion, see G. E. R. Lloyd, *The Revolutions of Wisdom: Studies in the Claims and Practices of Ancient Greek Science* (Berkeley, CA: University of California Press, 1989), pp. 172-214, esp. 187-190, 200-203; and William Wallace, *The Modeling of Nature: Philosophy of Science and Philosophy of Nature in Synthesis* (Washington, D.C.: The Catholic University of America Press, 1996), esp. xi-xii. For the specific case of analogies in medicine see Ian Maclean, *Logic, Signs and Nature in the Renaissance: The Case of Learned Medicine* (Cambridge: Cambridge University Press, 2002), pp. 166-167.

[99] Steno, *De musculis et glandulis,* p. 60. See also Harold Cook, "Physicians and Natural History," in *Cultures of Natural History*, ed. Nicholas Jardine, James Secord and Emma Spary (Cambridge: Cambridge Univ. Press, 1996), pp. 91-105.

(1588-1654) is the most famous example, due to a widely read book on his cabinet of curiosities.[100] Thomas Bartholin, Steno's professor of anatomy in Copenhagen, also wrote specifically on the tongue-stones that he saw in the island of Malta, an observation that made Steno want to go there.[101] Even Ole Borch (1626-1690), Steno's travel companion in Europe, wrote a short essay "on the generation of stones in the macro and microcosm," commenting on similar formation processes of stones outside and inside the body (e.g. minerals and bladder stones).[102] Steno also mentioned chatting about seashells with Simon Paulli (1603-1680), a senior physician from Copenhagen whom he met before starting university.[103] For these reasons, Steno knew well the literature on fossils.

Yet, while many physicians wrote about fossils at the time, few of them wrote a history of the Earth's mountains and valleys before Steno. Indeed, Steno's familiarity with the history of the Earth spanned beyond natural history into commentaries on Aristotle's *Meteorology*, which was the discipline that dealt with Earth history in the early modern period.[104] Steno defended a short dissertation on hot springs – a meteorological topic – in 1660 in Amsterdam.[105] And, in the

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[100] Ole Worm, *Museum wormianum, seu historia rerum rarioum* (Leiden, 1655), pp. 67-68. See also Ella Hoch, "Diagnosing Fossilization in the Nordic Renaissance: An Investigation into the Correspondence of Ole Worm (1588-1654)," in *A History of Geology and Medicine* (cit. n. 16), pp. 307-327.

[101] Thomas Bartholin, "Historia I: Glossopetrarum Melitensium Usus Medicus," in Bartholin, *Historiarum anatomicarum et medicarum rariorum centuria V et VI* (Copenhagen, 1661), pp. 193-201. Bartholin had a longer manuscript on tongue-stones, *De glossopetris melitensibus dissertatio*, but it was lost in a 1670 fire before publication, see Thomas Bartholin, *De bibliothecæ incendio dissertatio* (Copenhagen, 1670), pp. 73-74, translated in *On the Burning of His Library*, trans. Charles O'Malley (Lawrence, KS: The University of Kansas Libraries, 1961), p. 28. For other Bartholin references on fossils, see Troels Kardel, "Prompters of Steno's Geological Principles" (cit. n. 13), pp. 129-130. On Steno's comment, see *Elementorum myologiæ specimen*, p. 90.

[102] Ole Borch, "De generatione lapidum in macro et microcosmo" in *Acta medica et philosophica hafniensia*, ed. Thomas Bartholin, vol. 5 (Copenhagen, 1680), pp. 184-196. See also Steno, *De solido*, p. 20.

[103] Steno, *De musculis et glandulis*, pp. 59-60.

[104] Ivano Dal Prete, *On the Edge of Eternity: The Antiquity of the Earth in Medieval and Early Modern Europe* (Oxford: Oxford University Press, 2022), pp. xi-xii, 45-47, 114-119, 122-125, 149.

[105] Nicolaus Steno, *Disputatio physica de thermis* (Amsterdam, 1660), as translated in Gustav Scherz, "Niels Stensen's First Dissertation," *Journal of the History of Medicine and Allied Sciences*, 1960, 15(3):247-264. Steno's professor was likely the main author of this thesis, see Dirk Van Miert, *Humanism in an Age of Science: The Amsterdam Athenæum in the Golden Age, 1632-1704* (Leiden: Brill, 2009), 156. On hot springs as part of the tradition of Aristotle's *Metereology*, see Craig Martin, *Renaissance Meteorology: Pomponazzi to Descartes* (Baltimore, MD: Johns Hopkins University Press), p. 89.

introduction to *Observationes anatomicae*, he referred to scholars studying stars and planets alongside "the inside of the earth" and its "concealed mysteries of minerals."[106] Steno mentioned them when describing the human mind's capacity to discern patterns between the micro and macrocosm, but in the end the book was only about glands. In brief, Steno's knowledge of fossils and the Earth formed part of his intellectual background.

Accordingly, Steno knew that various other scholars also argued that fossils had an origin in sea animals. As Ivano Dal Prete has recently shown, the organic origin of fossils was the common argument among ancient and medieval writers.[107] Scholars as varied as Aristotle, Isidore of Seville (c. 560-636), Avicenna (980-1037), and Albert the Great (c. 1200-1280) all agreed that sea fossils showed that dry land was once underwater. For this reason, Steno acknowledged that the true explanation of sea fossils had "become very uncertain in most recent times."[108] Indeed, according to a previously unknown letter to Carlo Dati, Steno was working on a list – now lost – of "all the ancients who believed that the ocean before was higher than their time."[109] Now, the problem was that "many and great" were "the men" who did not agree with this opinion.[110] Authors whom Steno respected favored an origin of fossils completely detached from animals, such as Ulisse Aldrovandi (1522-1605), Athanasius Kircher (1602-1680), and Michele Mercati himself.[111] In their views, fossils were the result of incomplete processes of spontaneous generation, literally

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[106] Steno, *Observationes anatomicæ*, Preface.
[107] Dal Prete, *On the Edge of Eternity*, pp. 38-50.
[108] Steno, *De solido*, p. 5.
[109] Nicolaus Steno to Carlo Dati, 2 March 1669 in BNCF, Baldov.258.VII.31, fol. 105r: "fo una lista de' tutti quelli che fra gli antichi hanno creduto, che il mare altri tempi sia stato più alto di quello era ne' tempi loro."
[110] Steno, *Elementorum myologiæ specimen*, p. 109. On Cesalpino and Colonna, see respectively Dal Prete, *On the Edge of Eternity*, p. 140, and Nicoletta Morello, *La Nascita della paleontologia nel Seicento: Colonna, Stenone e Scilla* (Milan: F. Angeli, 1979).
[111] Ulisse Aldrovandi, *Musaeum metallicum* (Bologna, 1648), p. 820; Gabriele Falloppio, *De medicatis aquis* (Venice, 1564), p. 109r-109v. Steno mentioned reading Aldrovandi and Falloppio in, respectively, Steno, "Ova viviparorum spectantes observationes aliæ," p. 220, and *Elementorum myologiæ specimen*, p. 43. Kuang-Tai Hsu wrongly attributes the organic theory to Falloppio in Hsu, "The Path to Steno's synthesis on the animal origin of glossopetrae" in *The Revolution in Geology* (cit. n. 13), pp. 93-106, esp. 96-97.

"jokes of nature" that displayed hidden links between the macro and microcosm. But from the perspective of a seventeenth-century anatomist, how could great scholars differ so much in their views if fossils and animal parts were so obviously similar? Steno had shaped his career around a crisis of certainty in anatomy. Now, the time had come to apply to the Earth the same methods that he had applied to the body.[112]

Similar to his thoughts on muscles, Steno's ideas on the history of the Earth took a while to develop. He concluded his first text on fossils with six conjectures that offered "a glimpse of truth from the observations presented."[113] These conjectures were simple, but offered significant blows to the idea that fossils were spontaneously generated in dry land. For instance, the first conjecture is that the soil where fossils are found does not seem to produce fossils today, whereas the third is that such soils were once covered with water.[114] Steno called these claims "conjectures" because he did not want to necessarily argue "that defenders of contrary views are wrong" and said that his opinion was only "similar to truth."[115]

Historians such as Paula Findlen have attributed this attitude to Steno's desire to please respectable authors with differing opinions, such as the Jesuit Athanasius Kircher.[116] This is, in part, correct. Others, have said that Steno was being careful to avoid the censorship of the Catholic Church.[117] In fact, scientific publications sponsored by the Medici at this time were notoriously famous for avoiding any interpretations of experimental results and a few historians have

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[112] For a similar problem regarding snakestones, see Marta Baldwin, "The Snakestone Experiments: An early Modern Medical Debate" *Isis*, 1995, 86(3): 394-418.

[113] Steno, *Elementorum myologiæ specimen*, p. 93.

[114] Steno, *Elementorum myologiæ specimen*, pp. 93, 95.

[115] Steno, *Elementorum myologiæ specimen*, p. 109.

[116] Findlen, *Possessing Nature* (cit. n. 16), pp. 235-237; Francesco Luzzini, *Il miracolo inutile: Antonio Vallisneri e le scienze della terra in Europa tra XVII e XVIII secolo* (Florence: Olschki, 2013), pp. 21-23.

[117] Matthew Cobb, *Generation: The Seventeenth-Century Scientists Who Unraveled the Secrets of Sex, Life, and Growth* (New York: Bloomsbury Pub, 2006), pp. 97-98.

associated this with acts of self-censorship.[118] The problem with this argument is that, *pace* the old historiography on censorship, making claims about rocks or the history of the Earth did not raise censorship problems in the seventeenth century.[119] Moreover, Steno's non-dogmatic approach resonated with most scholarship on Aristotle's *Meteorology*, best exemplified by the probabilistic approach of Kircher's *Mundus subterraneus* (Amsterdam, 1665).[120] Instead, I argue that the best explanation for Steno's hesitations is the intellectual rigor of his search for certainty. Steno's careful approach derived from his interest in distinguishing certain from uncertain knowledge, an approach that he carried forth from his research in anatomy. Steno himself said so: "knowledge of [these] things is not yet there for me, to the point that I would interpose here my judgement."[121]

[118] Paolo Galluzzi, "L'Accademia del Cimento: «Gusti» del Principe, Filosofia e Ideologia dell'Esperimento," *Quaderni Storici* 16 (1981), pp. 788-844, esp. 800-801, 823-832; and Luciano Boschiero, *Experiment and Natural Philosophy in Seventeenth-Century Tuscany: The History of the Accademia del Cimento* (Dordrecht: Springer, 2007), pp. 192, 229-231; Luzzini, *Il miracolo inutile*, pp. 11, 17-18, 32.

[119] See Ivano Dal Prete, "'Being the World Eternal…': The Age of the Earth in Renaissance Italy" *Isis*, 2014, 105:292-317, esp. 294, 308-309, 313-317. The works of Camilla Erculiani (fl. 1570), Isaac La Peyrère (1596-1676), and Antonio Vallisneri (1661-1730), which questioned different aspects of the biblical account of Noah's flood, raised problems in ecclesiastical circles. But the problem with Erculiani and La Peyrére was challenging theological doctrines such as original sin; see Richard Popkin, *Isaac La Peyrére: His Life, Work, and Influence* (Leiden: Brill, 1987), pp. 1-3, 14-18; and Eleonora Carinci, "Una 'speziala' Padovana: Lettere Di Philosophia Naturale Di Camilla Erculiani (1584)," *Italian Studies* 68.2, 2013: 202-229, esp. 221-229. Yet, even Erculiani and La Peyrére were not censored; and Vallisneri was a six-year-old child when Steno published in Florence, and thus his work is not representative of censorship in the 1660s; see Dal Prete, *On the Edge of Eternity*, pp. 132-137, 155; and Francesco Luzzini, "Flood Conceptions in Vallisneri's Thought," *Geological Society Special Publication* 310.1, 2009, 77-81. Recent research has also shown that censorship in another book published under Medici patronage in 1666 had little to do with religion, see Domenico Bertoloni Meli, "Shadows and Deception: From Borelli's *Theoricae* to the *Saggi* of the Cimento" *The British Journal for the History of Science*, 1998, 31(4):383-402, esp. 384, 389. For recent studies on censorship see Francisco Malta Romeiras, "The Inquisition and the censorship of science in early modern Europe: Introduction," *Annals of Science*, 2020, 77(1):1-9; Hannah Marcus, *Forbidden Knowledge: Medicine, Science, and Censorship in Early Modern Italy*. (Chicago: Chicago University Press, 2020); and Neil Tarrant, *Defining Nature's Limits: The Roman Inquisition and the Boundaries of Science* (Chicago: University of Chicago Press, 2022).

[120] Mark Waddell, "The World, As It Might Be: Iconography and Probabilism in the *Mundus Subterraneus* of Athanasius Kircher," *Centaurus*, 2006, 48(1): 3–22; Craig Martin, "Conjecture, Probabilism, and Provisional Knowledge in Renaissance Meteorology," *Early Science and Medicine* 2009, 14(3): 265–89; Dal Prete, *On the Edge of Eternity*, pp. 59-60, 123-125. For probabilism in seventeenth-century science, see Barbara Shapiro, *Probability and Certainty in Seventeenth-Century England: A Study of the Relationships between Natural Science, Religion, History, Law, and Literature* (Princeton, 1983); and Osler, *Divine will and the mechanical philosophy*, pp. 106-111.

[121] Steno, *Elementorum myologiæ specimen*, p. 90.

Besides, since he had more travels ahead, he preferred not to claim that "that which I will observe in the rest of the journey is similar to what I have observed until now."[122]

But, as time passed, every new observation seemed to confirm Steno's theory. Right before his first text on fossils came out of the press, Manfredo Settala (1600-1680), a prominent collector from Milan, visited Florence. After talking with him, Steno realized that "there were many things among the rarer pieces of his collection which quite clearly favor my conjectures."[123] Similarly, in a visit to the city of Lucca, a physician showed Steno "vertebrae found on the island of Malta most similar to the vertebrae of fish," one of which was found "clung to a lump of earth."[124] Steno was still in time to add both notes to his text, but the last remark could only fit in the book's index.

In the following months, Steno dedicated increasingly more time to fossils and the Earth. One year later, he was not hesitant anymore.[125] He no longer feared the "objections of friends," reading other books, or even the "inspection of [new] sites."[126] Thus, he wrote another book, the *De solido intra solidum naturaliter contento dissertationis prodromus [Preliminary publication of a dissertation on a solid naturally contained within a solid]* (Florence, 1669), which became his most important geological publication. The book was a preliminary publication because Steno wanted only to show a few results to the Grand Duke, like people in debt "pay what they have when they lack the means to pay it in full."[127] He still wanted to do more research for a final book on the topic. This was not the first time that Steno published preliminary research that announced future publications, because his books of anatomical observations often promised longer books on the topic.[128] Unfortunately, the final work in geology is lost, but it is listed at least in three

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[122] Steno, *Elementorum myologiæ specimen*, p. 90.
[123] Steno, *Elementorum myologiæ specimen*, p. 110.
[124] Steno, *Elementorum myologiæ specimen*, p. 122.
[125] The *imprimatur* is from December 1668 in Steno, *De solido*, pp. 77-78.
[126] Steno, *De solido*, p. 8.
[127] Steno, *De solido*, p. 4.
[128] Steno, *De musculis et glandulis*, p. 24; and Steno, *Elementorum myologiæ specimen*, p. 47.

seventeenth-century catalogues as the *Liber de solido in solidis, de glossopetris et aliis lapidibus qui in terra generantur vel alia quacunque re solida [Book on a solid within solids, on tongue-stones, and on other stones that are generated in the earth and in any other solid things*] (Florence, 1672), meaning that it was close to being printed.[129]

De solido was entirely framed around Steno's search for certainty. Steno regretted again that "things which cannot be determined with certainty are not kept separate from those that can be so determined."[130] For Steno, it was because this separation was rarely made that there were absolute skeptics, "who are prevented by scruples from putting faith even in demonstrations," and fideists, who believed in "all things that seem admirable and ingenious."[131] This time, however, there were no more conjectures. Instead, Steno argued with "principles of nature … [that are] in common use, widely accepted, and considered admissible by all from every school of thought."[132] He was looking for an explanation that forced assent across his diverse readers. Similar to the main publication of the Accademia del Cimento, Steno also detached his theory on the formation of fossils from philosophical worldviews.[133] Yet, nowhere in his book does he suggest that he did this in order to please his patrons or to avoid religious censorship.[134] Instead, I suggest that he did so in order to reinforce the reliability of his claims.[135] His arguments about the formation of rocks

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[129] Martin Lipen, *Bibliotheca realis philosophica* (Frankfurt, 1682), p. 781; Cornelius Beughem, *Bibliographia mathematica et artificiosa novissima* (Amsterdam, 1688), p. 129; Johannes Mollerus, *Bibliotheca septentrionis eruditi sive syntagma tractatuum de scriptoriibus illius* (Leipzig, 1699), p. 34. A folio at the end of Steno's papers in Florence, BNCF, Gal. 291, fol. 243v, also lists the book, following Mollerus.

[130] Steno, *De solido*, p. 9. For a similar claim on muscle anatomy, see Steno, *Elementorum myologiæ specimen*, p. 66.

[131] Steno, *De solido*, p. 9.

[132] Steno, *De solido*, p. 10.

[133] *Saggi di naturali esperienze* (Florence, 1667), Preface to the readers.

[134] Even Alan Cutler, who suggests that Steno framed his account within a biblical chronology in order to avoid ecclesiastical suspicions, stated that there is "no evidence that he [Steno] personally feared imminent persecution by Catholic or Protestant authorities for any of his scientific conclusions." See Alan Cutler, "Nicolaus Steno and the problem of deep time," in *The Revolution in Geology from the Renaissance to the Enlightenment*, ed. Gary Rosenberg (Boulder: The Geological Society of America, 2009), pp. 143-148.

[135] On the avoidance of philosophy among early modern anatomists, see Dmitri Levitin, *The Kingdom of Darkness: Bayle, Newton, and the Emancipation of the European Mind from Philosophy* (Cambridge: Cambridge

worked regardless of the worldview that one followed, be it corpuscular, chymical, or Aristotelian. Steno stated this explicitly: "those things that I asserted on matter have a place … regardless of whether matter has atoms, particles changing in a thousand ways, four elements, [or] chymical principles."[136] In short, Steno's philosophy-ridden approach allowed him to promote knowledge that was certain. The other method that he used was to apply the same analogies to the Earth that he had applied to the body.

Analogies as Models in Earth History

Steno's history of the Earth hinged on the claim that the soil containing fossils was mixed with water a long time ago. He explained that it was perfectly reasonable to believe this because, among other things, he had seen his Danish friend and chymist, Ole Borch, "reducing a very hard stone into water inside insipid water [*durissimum calculum insipida aqua in aquam redigentem*]."[137] But if solids and water become one big mixture, how do they separate back again to form the Earth that we see today?[138] To answer this, Steno spoke of various natural events in which fluids produce solids. First, he spoke of physiological phenomena, such as the appearance of stones inside the bladder and the cooling of blood. Blood only flows when warm, otherwise "it is separated in particles different in color and consistency."[139] Thus, by the same reason, "warm juices" or "vapors from the earth" separate "the more solid dust carried within them when the heat disappears."[140]

University Press, 2022), esp. 33-50. For the specific case of Florence in the 1660s, see Marco Beretta, "At the Source of Western Science: The Organization of Experimentalism at the Accademia del Cimento" *Notes and Records of the Royal Society of London* 54 (2000), esp. 139-141.

[136] Steno, *De solido*, p. 12.

[137] Steno, *Elementorum myologiæ specimen*, p. 97, 99.

[138] Steno, *Elementorum myologiæ specimen*, p. 100.

[139] Steno, *Elementorum myoligiæ specimen*, p. 101.

[140] Steno, *Elementorum myoligiæ specimen*, p. 101.

Then, Steno turned to chymical examples to support his reasoning.[141] He mentioned the chymical reaction in which "things dissolved in acids are precipitated by the arrival of salts."[142] By the same reason, he continued, "extracted tinctures are separated from volatile spirit by the addition of water."[143] Finally, he also saw something similar in Paris where "Borel[ly], greatly versed in chymistry, joined two very limpid liquors, which immediately thickened, so that turning the glass upside down not even a drop fell."[144]

In addition to anatomy and chemistry, Steno also used mechanical accounts of bodies to explain how liquids deposited solids in layers. As he put it, "once the water gradually returned to quietness, first the heavier bodies, then the less heavy settle down, whereas the lightest bodies float for longer … until they attach themselves" to the ground.[145] Steno concluded his list of examples with the common, early modern comparison between macro and microcosms, showing the longevity of this analogy well into the seventeenth century.[146] In his words, "what the diversity of a diet affects in the fluids of the microcosm [i.e. the body], so the vicissitudes of the Sun and the Moon and the changes of various other things may produce in the fluids of the Earth."[147] Steno

[141] On Steno's chemistry see Antonio Clericuzio, "The Other Side of the Accademia del Cimento: Borelli's Chemical Investigation," in *The Accademia del Cimento and its European Context*, ed. Marco Beretta, Antonio Clericuzio, and Lawrence Principe (Sagamore Beach, MA: Science History Publications, 2009), pp. 17-30; and Clericuzio, "Meccanismo ed empirismo nell'opera di Stensen," in *Scienza, Filosofia e Religione nell'Opera di Niels Steensen*, pp. 123-138. For chemical analogies with the Earth in the medieval period, see Dal Prete, *On the Edge of Eternity*, p. 46.

[142] Steno, *Elementorum myoligiæ specimen*, p. 102.

[143] Steno, *Elementorum myoligiæ specimen*, p. 102.

[144] Steno, *Elementorum myoligiæ specimen*, p. 102. "Borellum" was probably Jacques Borelly and not Pierre Borel, see Pierre Chabbert, "Jacques Borelly (16..-1689): Membre de l'Académie Royale des Sciences," *Revue d'histoire des sciences et de leurs applications* 23 (1970), 203-227.

[145] Steno, *Elementorum myologiæ specimen*, p. 100.

[146] For a different opinion, see Gary Rosenberg, "Introduction: The Revolution in Geology from the Renaissance to the Enlightenment," in *The Revolution in Geology* (cit. n. 13), pp. 1-11, esp. 3.

[147] Steno, *Elementorum myologiæ specimen*, p. 102.

said he read this comparison while reading Gassendi, who wrote "on the production of stones in his *philosophia*."[148]

These previous analogies were all written in 1667. By 1669, in *De solido*, Steno firmly concluded that "if a solid body is produced according to the laws of nature, it is produced from a fluid."[149] This time, he supported this statement with an analogy between Earth and body that reflects Steno's whole understanding of the body.[150] In this complex analogy, he spoke of external and internal bodily fluids. External fluids were those present in organs open to the outside, such as the mouth, stomach, intestines, the uterus, or the bladder.[151] "Worms and stones generated inside our body are mostly produced in the external fluid," he concluded.[152] Steno then divided internal fluids in "common internal fluid [*fluidum internum commune*]" and "proper internal fluid [*fluidum internum proprium*]."[153] Common internal fluids were those "contained in veins, arteries and lymphatic vessels," whereas proper fluids were those located in specific parts of the body such as "around muscle fibers."[154] With these categories, Steno explained the formation of solids from bodily fluids in this complex way:

> particles that are separated … from external fluids are carried into the internal common fluid by an interceding sieving, from which they are also in several ways secreted and

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[148] Steno, *Elementorum myologiæ specimen*, pp. 102-103. For Gassendi on fossils see Toshihiro Yamada, "Kircher and Steno on the 'geocosm,' with a Reassessment of the Role of Gassendi's Works," in *The Origins of Geology in Italy*, ed. Gian Battista Vai, W. Glen, and E. Caldwell (Boulder, CO: Geological Society of America, 2006), pp 65-80.

[149] Steno, *De solido*, p. 18.

[150] Body-Earth analogies had been used as early as the thirteenth century, see Restoro d'Arezzo, *La composizione del mondo*, as quoted in Stefano Dominici, "The Volterra cliff in the mind of philosophers, savants, and geologists (1282-1830)," *Geological Society, London, Special Publications*, 543, 2023.

[151] Steno, *De solido*, p. 20.

[152] Steno, *De solido*, p. 20.

[153] Steno, *De solido*, p. 21.

[154] Steno, *De solido*, p. 21.

> transmitted into the internal proper fluids through another sieving. [Then these particles] are added to solid parts either in the manner of fibers or organ tissue [*parenchyma*].[155]

An example drawn from Steno's physiology makes this description clearer. The stomach digests solid food by means of external fluids that produce chyle in the intestines. This chyle flows via the thoracic duct to the subclavian vein where it is mixed with blood (chyle and blood being common internal fluids). Then, the blood stream reaches the glands and muscles where blood is filtered into proper internal fluids. The latter's particles are then incorporated in muscle fibers. Steno then concluded the analogy saying that external fluids of the Earth produced sediments, incrustations, or crystals; and that internal fluids produced things such as "the hard substance joining broken bones."[156] Steno does not go into more specifics on the analogy with internal fluids, perhaps because most fossils were, after all, of organic origin.

Having explained the mechanisms through which fluids secrete solids, Steno expanded his analysis to the formation of rocks in time with two propositions. First, he concluded that "bodies entirely similar to one another are also produced in similar ways." And then, that "in two solids contiguous with each other, the first to harden is that which represents the properties of its own surface in the surface of the other."[157] Both propositions resonate with molding processes that Steno saw in his family's goldsmithing workshop – e.g., wax hardening within a plaster mold and receiving its shape.[158] In the end, Steno stated that "given a solid and its location, it will be easy to say something certain [*certum quid pronunciare*] about its place of production," even when that

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[155] Steno, *De solido*, p. 23.

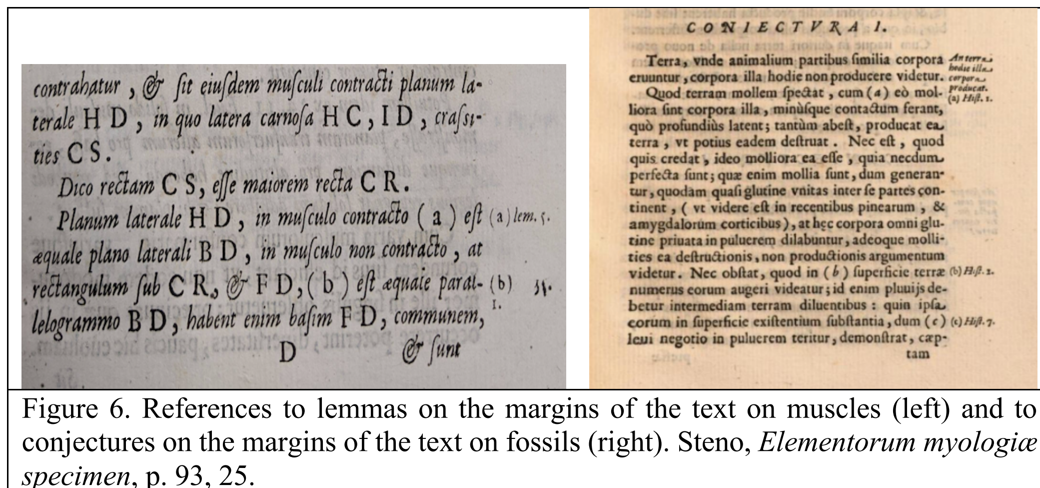
[156] Steno, *De solido*, p. 24.

[157] Steno, *De solido*, p. 24. Steno supported these claims with observations in *De solido*, pp. 15-18.

[158] This was first suggested in Kardel, "Prompters of Steno's Geological Principles" (cit. n. 13), pp. 131-132. Steno mentions wax modelling in *Elementorum myologiæ specimen*, p. 119. For similar cases, see Hanna Shell, "Casting Life, Recasting Experience: Bernard Palissy's Occupation between Maker and Nature" *Configurations*, 2004, 12:1-40; and Ivano Dal Prete, "Ruins of the Earth: Learned Meteorology and Artisan Expertise in Fifteenth-Century Italian Landscapes," *Nuncius*, 2015, 33:415-441, esp. 428-429.

place is completely different from its current location.[159] This is still one of the main claims of modern geology.

But the strongest links between Steno's history of Earth and body are in his approaches to muscles – the topic that occupied him when he shifted his research to fossils. The first link has to do with format. In his mathematical treatise on muscles, Steno used a format similar to that of Euclid's *Elements*. He started with a list of definitions and then followed them with lemmas and corollaries that referred back to these definitions. In a striking parallel, he started his first text on fossils with a list of observations to which he had recourse to in the following conjectures. He even printed in the book's margins the relevant observations used in each conjecture (see fig. 6). That is, just as he used a systematic model to understand muscle contraction, so too he developed a systematic model to explain fossilization.


contrahatur, & ſit eiuſdem muſculi contracti planum laterale H D, *in quo latera carnoſa* H C, I D, *craſsities* C S.

Dico rectam C S, *eſſe maiorem recta* C R.

Planum laterale H D, *in muſculo contracto* (a) *eſt æquale plano laterali* B D, *in muſculo non contracto, at rectangulum ſub* C R, & F D, (b) *eſt æquale parallelogrammo* B D, *habent enim baſim* F D, *communem,*

D & *ſunt*

(a) *lem.* 5.
(b) 51. I.

CONIECTVRA I.

Terra, vnde animalium partibus ſimilia corpora eruuntur, corpora illa hodie non producere videtur.

Quod terram mollem ſpectat, cum (a) eò molliora ſint corpora illa, minùſque contactum ferant, quò profundiùs latent; tantùm abeſt, producat ea terra, vt potius eadem deſtruat. Nec eſt, quod quis credat, ideo molliora ea eſſe, quia necdum perfecta ſunt; quæ enim mollia ſunt, dum generantur, quodam quaſi glutine vnitas inter ſe partes continent, (vt videre eſt in recentibus pinearum, & amygdalorum corticibus), at hęc corpora omni glutine priuata in puluerem dilabuntur, adeoque mollities ea deſtructionis, non productionis argumentum videtur. Nec obſtat, quod in (b) ſuperficie terræ numerus eorum augeri videatur; id enim pluuijs debetur intermediam terram diluentibus: quin ipſa eorum in ſuperficie exiſtentium ſubſtantia, dum (c) leui negotio in puluerem teritur, demonſtrat, cæp-

tam

An terra hodie illa corpora producat.
(a) *Hiſt.* 1.
(b) *Hiſt.* 2.
(c) *Hiſt.* 7.

Figure 6. References to lemmas on the margins of the text on muscles (left) and to conjectures on the margins of the text on fossils (right). Steno, *Elementorum myologiæ specimen*, p. 93, 25.

More interestingly, Steno's visual arguments of the Earth's strata owe much to his muscle diagrams. In *De solido*, Steno had to account not only for the aspect of sediments and strata (*historia*) but also their formation in time (*actio*). He explained the origin of mountains by saying

[159] Steno, *De solido*, p. 24.

that "strata were themselves solids naturally contained within solids."[160] Like fossils, he wrote, "whenever a certain stratum was formed, it was either surrounded by another solid body on the sides or it covered the entire globe of the Earth."[161] This is an early formulation of what is now known as Steno's principle of lateral continuity.[162] Steno then applied his ideas to the formation of the Tuscan landscape.[163] Strikingly, he relied on cross-sectional slices of these landscapes which he represented with geometrical diagrams. Steno was not the first nor the last to use diagrams in this context. Agostino Scilla (16291-1700), for example, used in those years observational and painting techniques to depict fossils as animal parts.[164] And René Descartes drew cross-sections of the Earth years before Steno in his *Principles of Philosophy* (Amsterdam, 1644), which Steno knew well.[165] Nonetheless, Steno's diagrams resemble Descartes' only in external appearances. First, Steno's diagrams represent an opposing view to the Cartesian theory of the origin of mountains.[166] Descartes spoke of mountains growing through the Earth, with the destruction of the Earth's crust leading to a new mountain rising. But Steno spoke of waters drying down and strata breaking into valleys. More importantly, Steno's strata diagrams have a direct antecedent in his diagrams of muscle contraction. Just as his first diagrams were a result of observing cross-sections of muscles, so too his new diagrams represent a cross-sectional view of the Earth's strata. Indeed, cross-sectional diagrams became so useful to Steno that, even though he did not publish more

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[160] Steno, *De solido*, pp. 26-37, esp. 37.

[161] Steno, *De solido*, p. 30.

[162] Cutler, *The Seashell on Mountaintop*, p. 112.

[163] Steno, *De solido*, pp. 67-76.

[164] Paula Findlen, "Projecting Nature: Agostino Scilla's Seventeenth-Century Fossil Drawings," *Endeavour*, 2008, 42:99–132, esp. 122.

[165] Steno mentions Descartes in *De solido*, p. 28. See also Garber, "Steno, Leibniz, and the History of the World," pp. 202-204.

[166] See Garber, "Steno, Leibniz, and the History of the World," pp. 202-204, 210.

geology books, he used them again to depict a cave that he explored in the Alps, two years later.[167] In short, Steno's diagrams, alongside his comparative and cross-disciplinary methods, confirmed to him the epistemic strength of his approach. "How well then everything fits! How [well] these things conspire between themselves in unanimous agreement!"[168]

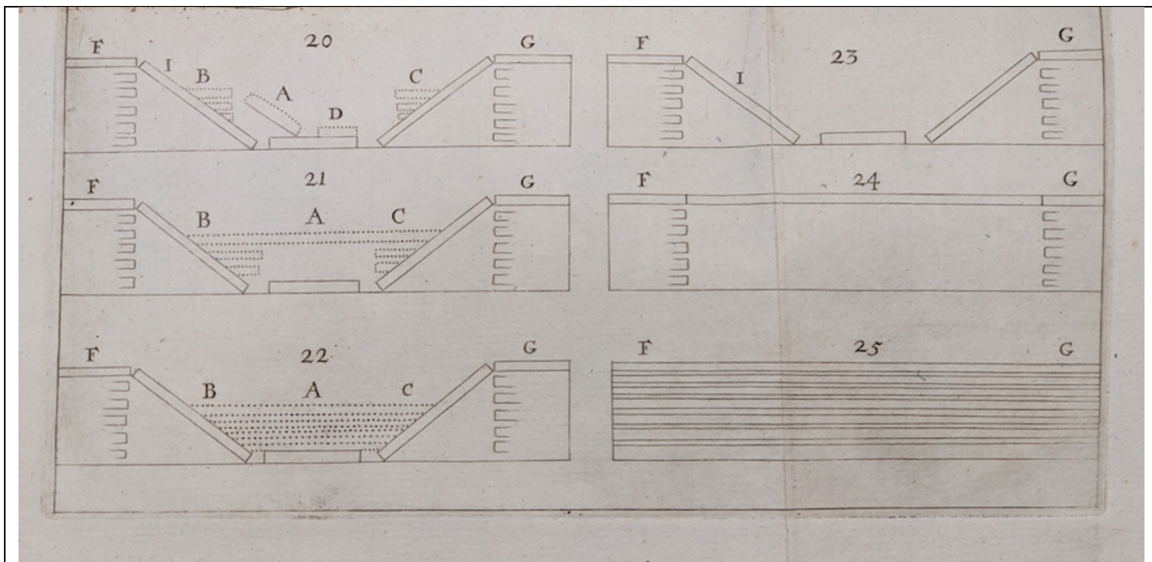

Figure 7. Diagram of the geological formation of Tuscan mountains, in Steno, *De solido*. Courtesy of Florence, BNCF.

Conclusion

While crossing the roads of Europe from north to south, Nicolaus Steno, just like all those who go out on hikes, probably marveled at spectacular landscapes around him and wondered how they were formed. Through his research on fossils, Steno found a solution that in turn opened new fields of research that encompass more than just modern geology.[169] For instance, Charles Lyell's book *Principles of Geology* (London, 1830-32), one of the main influences behind Darwin's theory of

[167] Johannes Mattes, "Mapping the invisible: knowledge, credibility and visions of earth in early modern cave maps" *The British Journal for the History of Science*, 2022, 55:53-80, esp. 53-55, 72-74, 77, 79. Mattes claims that Steno inaugurated a history of cross-sections in geological maps.

[168] Steno, *Elementorum myologiæ specimen*, pp. 103-104. Exclamation marks in the original.

[169] Rhoda Rappaport, *When Geologists Were Historians, 1665-1750* (Ithaca, NY: Cornell University Press, 1997); William Poole, *The World Makers: Scientists of the Restoration and the Search for the Origins of the Earth* (Oxford: Peter Lang Ltd, 2010); Martin Rudwick, *Earth's Deep History: How It Was Discovered and Why It Matters* (Chicago: University of Chicago Press, 2014), esp. 31-54.

evolution, states that Steno's geology was "the most remarkable work of that period."[170] But I suspect that neither Lyell nor Darwin knew that it all started with Steno's anatomy.

In this article, I showed that rather than a geological genius or a Renaissance polymath, Nicolaus Steno was an anatomist seriously concerned with method. The disciplines of anatomy, Earth history, physico-mathematics, and chemistry intersected at his hands as part of his response to the crisis of certainty. Moreover, Steno's claims about the Earth were not entirely new. What was original and convincing were his empirical and analogical arguments, which he developed out of his anatomical training and research at the University of Leiden. His writings in geology were as much a product of his northern European career as they were of the context of the Accademia del Cimento. I am not, hereby, diminishing the role of the Italian context in Steno's work. Instead, my analysis suggests that Florentine intellectual culture reinforced what Steno was already doing before arriving in Italy, such as using mathematics and chemistry in anatomy. In short, this analysis confirms that geographical generalizations of early modern European science are not helpful.

Reading Steno's geology in light of his anatomy also brings new light to other aspects of seventeenth-century science. Steno's geological methods, such as using analogies and diagrams, had direct antecedents in his anatomy, which was often anti-Cartesian. This suggests that Cartesian influence in the 1660s should be addressed with greater care and, perhaps, softened. Moreover, Steno's detachment of his work from philosophical commitments for epistemic reasons, and not religious censorship, confirms the recent reassessments of early modern censorship of science. This does not mean that religion did not have other roles in Steno's history of the Earth, but such a discussion falls outside the purviews of this article.[171] In a nutshell, Steno expanded his interests

[170] Charles Lyell, *Principles of Geology*, 3 vols. (London, 1830), vol. 1, p. 40. See also Janet Browne, *Darwin's Origin of Species: A Biography* (New York: Grove Press, 2006), p. 22.

[171] See Dal Prete, *On the Edge of Eternity*, pp. 143-144; Dominici, "A Man with a Master Plan."

from anatomy to geology as a response to his search for certainty within his specific historical context. But it is precisely because of this context that they were so significant to him, to his peers, and to historians of science today.