The Path to Steno's synthesis on the animal origin of glossopetrae

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ABSTRACT

As a medical student, Steno (1638–1686) entirely belonged to the seventeenth-century cultural context in which the problem of glossopetrae, or fossilized sharks' teeth, was given special attention by a number of scholars. In his Canis (1667), Steno entered the realm of geological studies and advanced, on the basis of his medical knowledge and chemical expertise, a hypothesis concerning the animal origin of glossopetrae. Here, I show that the Canis offers an excellent text in which to understand the changes in geological studies between the Aristotelian and Cartesian frameworks. Thus, based upon the legacy of the medical and chemical traditions, Steno's synthesis of previous views on the animal origin of glossopetrae with Descartes' particle theory becomes a very good example for showing the nature of the transition between Renaissance and early modern geology.

Keywords: Nicolaus Steno, René Descartes, glossopetrae, history of geology, paleontology, Scientific Revolution.

INTRODUCTION

In the Canis carchariae dissectum caput (The Head of a Shark Dissected, hereafter referred to as the Canis; Steno, 1667; Carboe, 1956; Scherz, 1969, p. 65–131), Steno made his first public arguments in favor of the animal origin of glossopetrae.¹ The immediate stimulus for his inquiry into the origin of glossopetrae came at the end of October 1666 when some fishermen near Leghorn, Italy, caught an enormous shark. Medici Grand Duke Ferdinand II heard of this great catch and ordered that the shark's head be cut off and brought to one of his anatomists, Nicolaus Steno, to dissect it. Perhaps by the end of that year Steno completed his report, the Canis. On 3 March 1667, Steno's report received the imprintor (Scherz, 1969, p. 19–20, 22). In the Canis, Steno digressed with a long argument to prove how glossopetrae could be fossils derived from sharks' teeth rather than products spontaneously generated in a process intrinsic to Earth.

As a number of scholars have noted, in light of the fact that Steno was able to report so insightfully on the problem of glossopetrae, in so short an interval of time, it is hardly plausible that he lacked prior knowledge on the question (Adams, 1938, p. 113ff; Albritton, 1986, ch. 2; Ellenberger, 1988, p. 187–192, 235–237, 241; Morello, 1979, p. 50). The aim of this paper is to examine the historical background regarding the main competing views on glossopetrae origins at the time Steno took up the problem, and to explore the ways Steno both utilized his predecessors' work and distinguished his own thinking on this issue. It emerges from this inquiry that Steno's achievement represented a synthesis drawn out of his reading and experience in the fields of medicine, chemistry, and natural philosophy. Both the scientific substance and the rhetorical form of Steno's presentation of the case for the animal origins of glossopetrae were conditioned.

¹Since there was disagreement about what glossopetrae were in the Renaissance and early modern period, the terms glossopetrae/glossopetrae will be used without giving any translation, unless some writers used it in a specific way.

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by his awareness of existing literature on these fossils' origins, and his mediaco-chemical background. Philosophically, Steno's conception of glossopetrae origins also reflected his affinity with Cartesian particle theory (Fig. 1).

TWO COMPETING RENAISSANCE VIEWS ON THE ORIGIN OF GLOSSOPETRA AND THEIR MEDICINAL USES

By the time that Steno tried to clarify the nature of glossopetrae, Renaissance naturalists had already brought some degree of order to this confusing problem. Throughout antiquity and the Middle Ages, a number of different claims had been made about the character and special qualities of "tonguestones." These fossils were variously taken as resembling the tongues of human beings, snakes, or woodpeckers, although the resemblance to sharks' teeth did not go unnoticed. There were many virtues or powers ascribed to tonguestones in different times and places, among which were uses in divination and as antidotes for poison.

Attribution of magical qualities to glossopetrae did not disappear altogether, even though skeptical-minded physician-naturalists of the sixteenth century, such as Georgius Agricola (1494-1555) (Bandy and Bandy, 1955) and Guillaume Rondelet (1507-1566) (1554-1555), tried to take a more thoroughly descriptive approach to these fossils. Authors increasingly noted the diversity in character of glossopetrae—in color, magnitude, and figure—and their broad geographical distribution. Two competing interpretations of glossopetrae emerged. According to one theory, glossopetrae result from mineral growth processes beneath Earth's surface; these fossils were formed inside Earth by its intrinsic generative powers. A prevalent Neoplatonic conviction held that vital principles animate all of nature found support in evident signs that processes of solidification and petrification do occur in the mineral kingdom. Advocates of this conception included Girolamo Cardano (1501-1576) (1550), Michele Mercati (1541-1592) (1717), Ulisse Aldrovandi (1522-1605) (1606), and Anselmus de Bondt (1550-1632) (1609). The second theory, which Steno would come to support, argued for the derivation of fossils like glossopetrae from the organic objects they resemble. It was Steno's special distinction to present with unprecedented clarity an account of the natural processes by which this could be understood. Long before Steno, however, prominent authors emphasized the similarity between glossopetrae and the teeth of different sorts of shark, including Lamia and Carcharia. These included Rondelet, Gabriele Falloppio (1523-1565) (1564), and Conrad Gesner (1516-1565) (1551-1587; 1565).

Throughout the seventeenth century, physician-naturalist authors, e.g., Fabio Colonno (1567-1640) (1616), Thomas Bartholin (1616-1680) (1654-1661; O'Malley, 1961), Mercati, and Johann Daniel Geier (1687), among others, reported on a wide variety of supposed medicinal uses of glossopetrae, even as the fossil's efficacy in certain applications was questioned. Steno, who had been Bartholin's student, would have been well aware of the intellectual and practical interest physicians had in glossopetrae, including the question of their origins, when the shark's head arrived for his examination in 1666.

STENO'S SOURCES CONCERNING THE ORIGIN OF GLOSSOPETRA

When Steno addressed the problem of the origin of glossopetrae in Cenis, he apparently attempted to incorporate as many extant opinions or arguments as possible into his account. This was consistent with the habits of humanistic scholars. As a mem-

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1. Lamiae Rегист Capvt.

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Figure 1. The head and teeth of the Lamia. See Steno (1667). Reproduced by kind permission of the History of Science Collections, University of Oklahoma.
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ber of the Accademia del Cimento, Steno had access to information from two other renowned anatomists, Francesco Redi (1626–1698) and Carlo Dati (1619–1676). Redi, a famous anatomist, had lent Steno an unpublished manuscript, Scene Toscane (Scenes of Tuscany) written by Antonio Nardi, who was a follower of Galileo. In Scene one, Nardi reflected the popular Renaissance view that stones resembling the parts of living animals were generated and grew inside Earth (Nardi, undated, p. 141–144, esp. on p. 141). Steno, probably mentioned Nardi among many well-known men having the same opinion only because Redi had introduced him to Nardi's Scene Toscane (Scherz, 1969, p. 115). For the same reason, Steno mentioned Mercati, for Dati had offered him Mercati's manuscript of Metallotheria (which was published posthumously in 1717) (Scherz, 1969, p. 72–73, 114–115), a focused work dealing with minerals and fossils.

Mercati enjoyed a privileged status as a naturalist because Pope Pius V had selected him to supervise the first Vatican museum. Due to this appointment, Mercati had charge over a very good collection of minerals and fossils, and, based on study of this fine collection, he produced the Metallotheria.

Steno's long citation and his use of two pictures from Mercati's Metallotheria suggest that it was a valuable source for Steno concerning the origin of glossopetrae (Scherz, 1969, p. 72–75, 119, 121). The significance of Mercati's manuscript for Steno lies in the fact that it contained an argument against the animal-origin assumption of glossopetrae, an assumption that he criticized as an error (Mercati, 1717, p. 333–334). Instead, Mercati argued that the "true" view of their origin is that they grow in the place where they were found, for their color is not different from that of the surrounding stones (Mercati, 1717, p. 331).

Beyond the information offered by his colleagues in the Accademia del Cimento, Steno may have done some library studies, just as he did in the summer of 1666 when he wrote Eleventhurnon Malicie Specimen (Steno, 1667). He knew there were many famous men holding the view of intrinsic mineral generation of fossils (Scherz, 1969, p. 115). On the other hand, there were some observations relevant to the opposite view. Immediately after the long quotation from Mercati's text, he wrote:

And these are the things Mercati relates about the Laminia. I might have added to these various other observations relevant to the same study, collected from various writers, but since these are readily available to those who own or can visit libraries, I proceed to these observations which I believe are not common knowledge, with particular reference to the skin, the eyes, the brain and the teeth (Scherz, 1969, p. 75).

There were other sources that he used to establish the possibility of the animal origin of glossopetrae. Elsewhere, Steno clearly stated that "I produce, from what has been observed in the past, the proofs of those who reckon those bodies to be of animal origin" (Scherz, 1969, p. 95). Who could those "various writers" be who made "observations relevant to the present study"? Were their works "readily available" to Steno? Who could those authors have been, who offered evidence that the fossils in question were of animal origin? Although Steno did not specify them, this group may have consisted of at least three writers: Rondel, Fallopio, and Colonna. With his own anatomical observations, Rondel initiated the opinion of the animal origin of glossopetrae. Steno became aware of Rondel's work no later than his reading of Mercati's manuscript, which contains part of Rondel's description of Laminia teeth. Fallopio and Colonna were highly important to Steno, since they made some arguments that could have helped Steno unravel the animal origin of glossopetrae.

Fallopio should be counted as one of Steno's authorities on this topic because Fallopio was the only authority cited by Steno when he wrote Dissertatio physicca de hornis (1660) (Scherz, 1969, p. 45–63; Hsu, 1993, sec. 3). In the same work, Fallopio also presented his view of the animal origin of glossopetrae. I will analyze this in the next section. Steno may have known something about Colonna's arguments, first through Bartholin, and then through his own reading of Colonna's De glossopetris dissertatio. I will discuss his arguments in Fabio Colonna's defense of the animal origin of glossopetrae.

Bartholin was one of the earliest sources for Steno's study of the origin of glossopetrae. In the Canon, Steno mentioned that Bartholin's observations on Maltese glossopetrae were made during Bartholin's journey to Malta (Scherz, 1969, p. 95). Bartholin was interested in glossopetrae for medicinal reasons. In his Medical Travel, glossopetrae were among the things that he suggested future physicians collect for medicinal uses (O'Malley, 1961, p. 72). In 1644, he traveled to Malta to study the famous glossopetrae found there. Although he never completed this study, he later published his observations under the title "Glossopetramum Mettenium usus medicus" (Medical Use of Maltese Glossopetrae) in the Historiarum Anatomicarum (Bartholin 1654–1661, v. 3, p. 193–201), which is listed in the bibliography of Steno's undergraduate notebook (Schepler, 1987, p. 111).

XII. De Glossopetris Maltensisis Dissertatio. This dissertation was born in me, when formerly I visited the island of Malta, when I collected fossil sharks' teeth of all shapes and sizes which the inhabitants of that place brought to me, and I myself searched here and there for every sort of the completion of the study. However, distracted by other studies, I was unable to complete what I had begun, but I indicated the substance of this dissertation in the Historiae Anatomicae, (O'Malley, 1961, p. 28).

With its focus on the medicinal uses of glossopetrae, Bartholin's study contained information useful to Steno. At the very beginning, he stated that there were four traditions regarding the...
origin of glossopetrae (Bartholin, 1654–1661, v. 3, p. 194). Besides the possibilities that they were serpents' tongues changed into hard stone, or darts of thunderbolts, he thought that generative powers inherent in mineral bodies, and derivation from animal origin, merited consideration as truly plausible views about the origin of glossopetrae (Bartholin, 1654–1661, v. 3, p. 194).

Bartholin preferred the view that glossopetrae grew inside Earth (Bartholin, 1654–1661, v. 3, p. 194–195), but he never provided an argument against the animal origin of glossopetrae. In his introduction to the view asserting the animal origin of glossopetrae, Bartholin mentioned that Andrea Cesalpino, Pierre Potier (1587–1640), and Cleandro Amombo (ff. 1602) believed that glossopetrae were the remains of marine animals. More importantly, Bartholin especially emphasized that Colonna had declared the animal origin of glossopetrae with various arguments in the Perspectiva (Bartholin, 1654–1661, v. 3, p. 194). This passage probably caught Steno's attention.

In De metallica, Cesalpino expressed his belief that glossopetrae were the remains of parts of aquatic animals. He made a distinction between the formation of glossopetrae and that of crystals. He also pointed out the substantive difference between preserved animal parts and their earthy medium. He found that these fossils became less soft (or rotten) than their surrounding material (Cesalpino, 1596, p. 132–133). Even after being burned, these fossils retained the same figure (Cesalpino, 1596, p. 133–134).

Potier had been in the medical faculty of Paris before he was expelled in 1609 for using antimony. He subsequently moved to Italy. In 1622, he published a work, Pharmacopoeia singularia nova et medita, which Bartholin interpreted as maintaining that glossopetrae were the remains of the parts of animals.

Amombo's work, Il Tesoro delle Gioie (The Treasure of Precious Stones), gave special attention to glossopetrae. The title of the 20th chapter—De denti di Lanna, cioè glossopetra (The teeth of the Lanna, that is, glossopetra)—reveals that he believed that glossopetrae were derived from the teeth of Lanna. His treatment amounts to an account of contemporary knowledge of the variety of glossopetrae. He reported that there were six species of glossopetrae and that they differed in color, magnitude, and form (Amombo, 1602, p. 176). He paid attention to the healing power of glossopetrae. By burning glossopetrae found in different areas, Amombo concluded that they still had similar (healing) powers or virtues (Amombo, 1602, p. 176). For example, he claimed that glossopetrae, regardless of their origin, were useful for healing malignant fever (Amombo, 1602, p. 179). Although Amombo did not explicitly distinguish glossopetrae from their surrounding material, he knew these were made of different substances. On the one hand, the surrounding soil was consumed in cultivation (Amombo, 1602, p. 178); on the other hand, glossopetrae became testaceous by combustion. While different kinds of glossopetrae became testaceous by artificial or natural heating, their variable appearance (such as having a fragmentary surface or a bark-like covering) indicated that some glossopetrae would be more effective than others in healing (Amombo, 1602, p. 179). Bartholin was aware of Amombo's distinction among glossopetrae based upon the nature of their calcination (Bartholin, 1654–1661, v. 3, p. 200).

Among various arguments made by Colonna to demonstrate the animal origin of glossopetrae, Bartholin mentioned one in which Colonna appealed to chemical considerations to distinguish glossopetrae from their surrounding testaceous material. Here, Colonna identified a method of distinguishing extraneous fossils from intrinsically generated minerals using the agent of heat in transforming materials.

So far we have seen that Steno's concern with the origin of glossopetrae emerged from a vigorous Renaissance interest in this topic that had been spurred by the medicinal uses of glossopetrae. Steno's contemporaries and immediate predecessors largely held one of two competing views: intrinsic mineral generation and the animal origin of glossopetrae. Judging from textual evidence, Steno may have read some of the sources listed in Table 1.

**FALLOPIO'S VIEW ON THE ANIMAL ORIGIN OF GLOSSOPETRAE**

The historical situation just prior to Fallopius (1564) included the emergence of two views of the origin of glossopetrae, championed by Cardano and Rondelus, respectively. While these two views coexisted with each other with only minor mutual criticism, Fallopius began to solidify the animal-origin view of glossopetrae. He developed his argument within a scholastic framework that began with a review of and commentary on extant views on the generation of stones or intrinsic mineral generation. Then, within the same framework, he formulated his own view on the animal origin of glossopetrae. Concerning their origin, he focused on three points: the relation between fossils and their surrounding material, their different origins in substance, and the way by which parts of living things become fossilized.

Fallopius believed that fossil teeth that were similar to sharks' teeth had animal origins. He expressed his view on the animal origin of glossopetrae in a discussion of the generation of figured stones. The distinguishing feature of these stones is their derivation from living things, such as wood, snail-shells, worms, or shark's teeth (Fallopius, 1564, fol. 109r).

In Fallopius's view, although there are different kinds of stones formed in various places and in different ways, the cause is the same in every case (Fallopius, 1564, fol. 110r). In the eighth chapter of part two of De medicinis aequi, "De efficienti lapidum causa" ("Concerning the efficient cause of stone"), Fallopius said that the glossopetrae are formed by nature into that form from testaceous material, and if they are heated by fire, the test material changes into testaceous glossopetrae, on the other hand, being burned, change into coal, which Fabio Colonna perceives" (Bartholin, 1654–1661, v. 3, p. 209).
searched for the universal efficient cause of generation of stones. Within a scholastic framework, he reviewed previous views on the generation of stones. Falleppio found Aristotle did not systematically treat the place from which stones could be generated, and he thought this followed from Anaximander's inappropriate handling of fossils as a meteorological subject (Falleppio, 1564, fol. 86v). Agricola's lapidifying juice was not the efficient cause but rather the material cause of his second kind of stone (figured stones) (Falleppio, 1564, fol. 97r).

Falleppio also took issue with the popular Renaissance view of the intrinsic mineral generation of stones in order to sustain his belief in the organic origin of figured stones. He criticized several versions of intrinsic mineral generation of stones, including Cardano's view of a vegetative soul (Falleppio, 1564, fol. 103r–104v) and Albertus Magnus's view of "mineralizing power" (Wyckoff, 1967, p. 18, 20).

In his inquiry into the immediate efficient cause of the generation of stones, and through his review of views posed by chemists, and the case of the generation of precious stones or crystals, Falleppio concluded that there are two causes of generation of stones: heat and cold (Falleppio, 1564, fol. 108v). He was ready to discuss the mode by which a particular kind of "figured stone" is formed.

The first is a wet mode. According to this mode, worms, snail-shells, wood, and sharks' teeth had been once-living things or parts of them, before they were destroyed by the lapidifying juices flowing over them. When the lapidifying juice cooled, they were lapidified (Falleppio, 1564, fol. 109r). However, these stones are also found in some dry places such as mountains and rocks (Falleppio, 1564, fol. 109v). He believed that these particular stones found in mountains were generated there, rather than being made by the sea or the Deluge, because the places were far from the sea (Falleppio, 1564, fol. 109r-v).

After rejecting the possibility of a wet or hydrological explanation, Falleppio created a dry mode to explain the formation of these specific stones “at the same time with the [surrounding] petrified stone” in mountains and in rocks far from the sea, rather than account for how these figured stones were moved to the mountains from the sea (Falleppio, 1564, fol. 109v).

Based on his belief that these figured stones were once-living before being lapidified in the surrounding material, Falleppio did not explain how the parts of a marine animal were buried in lapidifying stones. Instead, he simply pointed out that while these figured stones were surrounded by tufts or petrified stones, a chemical operation, fermentation, came into existence. It first generated a kind of vapor and spirit vital to the generation of snail-shells (Falleppio, 1564, fol. 109v). Furthermore, he gave an example of the process: "Sometimes I saw certain larger water stones had been cut into powder, and on the spot little frogs arose. From where did these come? Certainly from the excited spirit made by fermentation when those water stones were reduced to powder" (Falleppio, 1564, fol. 109v).

In a similar way, the shells of oysters are generated in mountains (Falleppio, 1564, fol. 110). If these marine animals were exposed to the sun, they would not be lapidified, even in the rock (Falleppio, 1564, fol. 109v–110r). For example, oysters found in the rocks were not lapidified, for they were near the sea, from which they were nourished (Falleppio, 1564, fol. 109v).

Finally, Falleppio mentioned that other things are found in the (figured) stones that are produced by coldness, such as worms, snail-shells, or other similar things. Perhaps in the mountains, the insufficient food supply causes them to die and become lapidified.

As an advocate of the organic origin of story teeth that resemble sharks' teeth, Falleppio wrote of burning as a method for determining the characteristics of certain stones. For example, he observed that when a block of tuft becomes powder and crystal is reduced to ash (Falleppio, 1564, fols. 97v, 100r, 108r). However, he did not record efforts to test either glosopetrae or sharks' teeth by combustion, nor did he systematically test the difference between figured stones and their embedding material.

**FABIO COLONNA’S DEFENSE OF THE ANIMAL ORIGIN OF GLOSSOPETRAE**

Colonna came to the study of the origin of glosopetrae in a different historical situation. In Morello's opinion, "there is no first-hand evidence which might reveal" why he took up this

"In 1817, John Woodall gave a definition of fermentation as follows: "Fermentation is the conversion of a mass substance, by the action of a fermentum, which destroys the water or sugar and turns it into its own nature." (Woodall, 1817, p. 433).

This view sounds like a kind of intrinsic mineral generation of living things in the rocks or tufts, although Falleppio used an external cause to explain it.
problem. She suggests that Colonà's friendship with Ferrante Imperato and his son Francesco and his frequent visits to the Imperatos' museum were factors that led him to the study of fossils (Morello, 1981, p. 69). However, since Ferrante Imperato did not seem to have a clear conviction on the origin of *glossopteris*, and his son held the view of intramolecular mineral generation,* these factors seem to be an inadequate explanation. Nevertheless, for whatever reasons, Colonà started to build his arguments for the animal origin of *glossopteris* and he identified the process of combustion as a means to make a clear distinction between the nature of *glossopteris* and that of their surrounding material.

No later than the middle of the sixteenth century, combustion had been used as a method to differentiate between fossils resembling the parts of living things and their surrounding material. Agricola and Fallopio knew tufas turned to ash by burning (Bandy and Bandy, 1955, p. 12; Fallopio, 1564, fol. 97r, 199r, 108r). Pietro Andrea Mattioli (1512–1566) found that the internal part of fossils exhibited different characteristics from their surrounding material when burned (Mattioli, 1554, p. 568). In *De medicina* (1596), Cesalpino also recognized the difference in substance between *glossopteris* and their surrounding material. He mentioned that they had different results upon combustion (Cesalpino, 1596, p. 133–134). In *Il nuovo delle storie* Amario expressed a similar view (Amario, 1602, p. 178).

Colonà's use of combustion as a chemical method to distinguish figured stones (including *glossopteris*) from their surrounding material in his 1616 *De glossopteris dissertatio* was thus the product of a practice over half a century old. However, the question still remains: Why and how did Colonà come to be interested in *glossopteris*, and how did he come to know that by combustion one could distinguish the nature of *glossopteris* from their surrounding material? Perhaps his use of combustion in his work had something to do with his bad health, as we shall see shortly.

Colonà was born in Naples in 1567 and was educated by his father, Gerolamo Colonà. His education covered many areas such as philosophy, mathematics, painting, music, and Greek. In 1589, he received a degree in civil and canon law from the University of Naples. His weak health, including susceptibility to epilepsy, directed him away from a potential career in law and drove him to investigate pharmacology. With this new orientation, it is natural to suppose that he paid special attention to *glossopteris* because one of its medicinal functions was to cure epilepsy. Although there is no firsthand evidence to show that Colonà was interested in *glossopteris* for this reason, his citation of Rondel's introduction to the medicinal uses of the serpent tooth at the end of his dissertation suggests that he was concerned with the medicinal functions of *glossopteris* (De Ferreri, 1982, p. 286; Paraglia, 1885, pp. 672–677; Morello, 1981, p. 65).

The medicinal uses of *glossopteris* were discussed within texts dealing with their origin. Works that exemplify this were written by authors such as Rondel, Mercati, Aldrovandi, and de Boede. Given this fact, it was not difficult to know these authors' views of the origin of *glossopteris* through an analysis of their medicinal uses. There are two other significant implications in Rondel's work about the animal origin of *glossopteris*. First, if *glossopteris* came from Lania teeth through the liquefication of bony material, they were actually products of bones rather than of stones. Second, in order to use *glossopteris* as a gargoyle for cleaning human teeth, one might have to boil them in water and reduce them to powders in the solution. The internal uses of *glossopteris* also suggest that *glossopteris* had been reduced to powders. Thus, the pharmacists probably carried on the combustion of *glossopteris* no later than the middle of the sixteenth century when *glossopteris* were used in medicaments. At least Amario did this no later than 1602. By burning them, he was attempting to compare the healing powers of *glossopteris* dug up from different regions (Amario, 1602, p. 178–179). This may explain why and how Colonà came to distinguish between the nature of *glossopteris* and that of their surrounding material.

If we judge that Colonà was aware of the literature cited here from the mid-sixteenth century onward, the mystery of his interest in *glossopteris* vanishes. His ability to master scientific literature was recognized by the members of a famous learned society, the Accademia dei Lincei, founded in 1603 by Duke Federigo Cesi (1585–1630). Colonà was elected as a fellow member in 1612 on the basis of his reputation as a "naturalist of the first rank" (Drake, 1966, p. 119; Paraglia, 1885, p. 693; Morello, 1981, p. 65).

In the period between the initial publication of Fallopio's *De medicinis aquis* in 1564 and the appearance of Colonà's *De glossopteris dissertatio* in 1616, although a number of writers managed to accept and to advocate the animal origin of *glossopteris*, in 1569, Jan Gorpisius Beatus (1518–1572) published the *Originum Aeternitatis*, in which he asserted the spontaneous generation of *glossopteris* by categorically denying the possibility of their animal origin. In 1606, Aldrovandi reproduced Gorpisius' text concerning spontaneous generation of *glossopteris* in *De rebus animalibus* (Gorpisius, 1569, pp. 233–243; Aldrovandi, 1606, pp. 239–243). Since Colonà really wanted to defend the animal origin of *glossopteris* in a compelling way, in *De glossopteris dissertatio*, he targeted Gorpisius' view (Ellberger, 1988, p. 188–189), namely that *glossopteris* were spontaneously born by the innate power of nature in the places where they were found (Colonà, 1616, p. 31).

Colonà challenged three elements of Gorpisius' view. One was concerned with the nature of *glossopteris*. According to Gorpisius, they were generated inside Earth by the formative force of nature, "just as other inferior sorts of stones, having nothing to do with living things" (Gorpisius, 1569, p. 240). The second stated that this formative force was limited by
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the matter in its place (Goropius, 1569, p. 242). In addition to these two points, Colonna opposed another of Goropius' ideas: that bones passed into stones through the nature of juices (Goropius, 1569, p. 242).

In order to refute Goropius' view, Colonna concentrated on Maltese glossopteridae and built his arguments around three key ideas: the nature of glossopteridae, the relation between glossopteridae and their surrounding material, and the way they are formed in the surrounding material.

First, Colonna attempted to clarify his idea of the nature of glossopteridae. He claimed that Maltese glossopteridae can be identified as bones rather than congealed stones according to three of their characteristics: "By the appearance, the effigy, and the whole substance alone, at least, we say that [Maltese glossopteridae] are not congealed stone of this kind" (Colonna, 1616, p. 31).

Second, in his comparative examination of the Maltese glossopteridae and their surrounding material, Colonna found that the two substances reacted in combustion in two ways. This constituted a "chemical consideration" in identifying the characteristics of fossils. The figured stones first became charcoal and then, after further burning, were reduced to ash. The surrounding stones changed directly into calxes or ashes without passing through charcoal (Colonna, 1616, p. 31). In other words, fire was a decisive means for distinguishing things of organic nature from inorganic or rocky material. For Colonna, this chemical procedure yielded a sharp differentiation between the nature of Maltese glossopteridae and their surrounding material. The nature of the former was bone; that of the latter was stone. Here, Colonna regarded teeth as having the nature of bone. He most probably had tested sharks' teeth by burning them and compared them with the results of the combustion of Maltese glossopteridae. Otherwise, he could not declare that fossil teeth "are of the nature of bones, not stones." That is, he would have no empirical basis for making this declaration. This is also suggested by his comparison of the effigies of Lamia teeth with Maltese glossopteridae. In Colonna's view, the effigies of Lamia teeth meant their whole shapes, including the internal fibrous and porous structure, external appearance, and the root. According to Colonna, a comparison of the effigies of Lamia teeth with Maltese glossopteridae would show that the latter were made of bone (Colonna, 1616, p. 31).

In the comparison of the whole shapes of glossopteridae with the shape of sharks' teeth, one needs to keep in mind the similarities between them in terms of three characteristics: the outer appearance, the internal structure, and the roots. The similarity between the outer appearance of glossopteridae and that of sharks' teeth is recognized relatively easily. The roots and the internal structure of glossopteridae are more difficult to compare with the corresponding parts of sharks' teeth because minerals usually adhere to the roots and fill the fibrous and porous internal structure of glossopteridae. However, if glossopteridae are subjected to combustion, then their whole shapes, including their roots and internal structures, may be recognized without too much trouble. In this process, mineral or earthy material that adheres to glossopteridae will be reduced to ash or powder and separated from the effigy of glossopteridae. Thus, when Colonna compared the bony nature of the effigy of Lamia teeth and Maltese glossopteridae, he must have subjected them both to combustion. Since he found that both Lamia teeth and Maltese glossopteridae were converted into charcoal and then acquired very similar effigies, Colonna could also conclude that they both have "the nature of bone." By this means, Colonna stressed that the three characteristics of the effigy of Maltese glossopteridae established their bony nature.

Once he made clear that Maltese glossopteridae were composed of bone rather than stone matter, Colonna proceeded to refute another of Goropius' ideas, namely that bones are born inside Earth. Colonna wanted to show that bones are bones, always derived from living bodies, whether or not they are found in the living state. First, he made a distinction between the formation or growth of glossopteridae and that of congealed stones. Although crystals or gems have smooth surfaces, as do Maltese glossopteridae, they are naturally shaped following the nature of juice (ex nature succi). The way they are generated and grown never produces an angular shape like that of the Maltese glossopteridae. On the other hand, teeth, horns, and claws of living animals grow very slowly by nourishment (ex uactu) (Colonna, 1616, p. 32). Even in the subterranean region, living things are dead, and bones found in the stones will not change, though they slowly lose their growing nature. Therefore, bones are bones, and even when they are in dead bodies in the subterranean area, they remain unchanged.

In response to Goropius' opinion that bones pass into stones inside Earth, Colonna asked how bones could be changed into another nature (i.e., stony nature) (Colonna, 1616, p. 34). According to the natural tendency (aptitude) of the teeth, in the rocks or dry tufts, he recognized a shortage of their nourishment supply, so that they could not have originated there (Colonna, 1616, p. 34).* But if one still supposes their spontaneous generation, one has to explain either how these teeth had been generated spontaneously as they were found at the beginning, or how their sizes in tufts gradually approached those in living animals (Colonna, 1616, p. 34). Colonna hypothesized a variety of relational conditions between the fossils' teeth and their surrounding tufts in order to show that in all of these conditions, the spontaneous generation of teeth in the earth is negated either by experience or by observation.

He started by dividing the first part of the question into two conditions: if the teeth had been generated at the beginning in tufts, did this happen before or after tufts were congealed (Colonna, 1616, p. 34)? In what follows, Colonna expressed his shrewd understanding of site or position as a decisive issue in explaining fossil teeth. Instead of answering directly, he asked,

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*Morello thought it is "the aptitude of the soil." Since he looked for the type of putrefaction in Colonna's texts he found "the type of putrefaction depends on the aptitude of the soil" (Morello, 1881, p. 69).
"If a tooth was generated in the tufa before it congealed, it is asked: was the position of that tooth in the tufa in the shape and magnitude? Or did a tooth prepare its own position?" (Colonna, 1616, p. 34). Colonna tried to show the impossibility of the suggestion that the tufa had been congealed without there having been a previously existing cavity by emphasizing the physical contact between the tooth and tufa (Colonna, 1616, p. 34-35). If one supposes that a tooth gradually generates spontaneously in rocks, one needs to argue that it grew in a way totally different from our experience, because the rock has not kept the tooth from growing. Thus, one might suppose that the living force had animated the congealed tufa to function as a womb for an embryo, in which case the conglutination of humors formed the effigy of the tooth (Colonna, 1616, p. 35).

Colonna doubted that the tooth was really generated in this way. First, he argued that if the animating force worked in the rock, how could it produce incomplete or fragmentary glossopteris, which we find in rocks? Moreover, a comparison of the bases of glossopteris with the roots of sharks' teeth showed that both kinds were irregular and fractured in random fashion. Hence, he believed that a formative nature could not be responsible for the formation of glossopteris (Colonna, 1616, p. 35).

If the formative force failed to produce complete teeth, Colonna thought it hard to believe that the humors could produce the teeth in tufa like the serrated, bright, and growing teeth of Lamia. He also maintained that intrinsic mineral generation is false, because nature does not make anything that lacks a purpose (Colonna, 1616, p. 32).

Moreover, there are different kinds of humors, and glossopteris are various in form, size, quality, and natural tendency. How could they be created without purposes (Colonna, 1616, p. 35)? The teeth must have been generated in an animal's mouth for intended use, rather than by an intrinsic power within the earth, for an apparent purpose.

In contrast to the unconvincing view that the formative force produces glossopteris inside Earth, Colonna compared the ctenation of a shark with glossopteris removed from tufa. As Morello says, Colonna "mixed the analogy between the range of the forms and inclinations of sharks' teeth (which vary according to the position in the mouth) and the observed variety of glossopteris" (Colonna, 1616, p. 35-36; Morello, 1981, p. 69).

As the way glossopteris were formed inside Earth, Colonna had a different interpretation than Fallopio's. If glossopteris were the remains of sharks' teeth and not generated inside Earth, how can they appear in rock, in dry sandy land, or in high mountains? The places glossopteris were found were not the original places where they had been formed. In his view, they must have been buried accidentally in the sea in the accumulation of deposits from above, in which they did not have any chance to live.

There is no doubt that this place was changed, and that many things which were buried can be found under them. Nor is the least could they grow in the accumulation of the deposition from above made in past time. (Colonna, 1616, p. 36-37)

He concluded that they were living things that moved in various places before they "were crushed down by the pressure of winds, buried and wrapped by mud [in the seabed] with other marine things, as well as heaped up by terrestrial things, and finally after the water withdrew, they were changed to a story nature with the same mud, according to the character of the place, mud, and the type of juice" (Colonna, 1616, p. 37). With this hydrological account, Colonna explained the process through which the parts of living aquatic animals became fossils in the earth, including the formation of glossopteris.

In this discussion, we have evaluated Colonna's response to Goriopius' arguments against the animal origin of glossopteris. Colonna presented an alternative explanation of the formation of glossopteris. He theorized that aquatic animals were first buried in the seabed, and after the water withdrew, the surrounding material of glossopteris became petrified.

STENO'S SYNTHESIS ON THE ANIMAL ORIGIN OF GLOSSOPTERIS IN THE CANIS

Half a century after the publication of Colonna's De glossopteris dissertatio, while writing the Canis, a report on the dissection of a shark's head, Steno continued the argument for the possibility of the animal origin of glossopteris, a view criticized by Mercati as an error. In doing so, Steno relied heavily on a number of observations and propositions made by his predecessors. As he said,

... so I produce, from what has been observed in the past, the proofs of those who reckon these bodies to be of animal origin... But lest the reader be led to expect many new ideas and because of this expectation complain that he has been deceived, I wish to warn him beforehand that some of the propositions have been made already by others; that many are owed to the observation of my teachers; there will be very few to which I have not been an eyewitness. (Scharz, 1969, p. 95)

Thus Steno informed his readers that his work should be located within a tradition with which, to some extent, they might be familiar. This tradition included a host of observations, propositions, and arguments.

Although he drew upon this tradition, Steno took a quite different approach from those of his two major predecessors, Fallopio and Colonna. Unlike either Falcoppis, who retitl Cardano's account of the intrinsic mineral generation of glossopteris, or Colonna, who rejected Goriopius' mineral-generative view of glossopteris, Steno was very cautious about claiming to be certain in his opinions. He prudently asserted, "while I allow that my opinion has the semblance of truth, I do not maintain that holders of contrary views are wrong" (Scharz, 1969, p. 113). Steno's modesty, careful, and prudent way of supporting the animal origin of glossopteris has been recognized by Schatz and Albritton (Scharz, 1969, p. 29; Albritton, 1986, p. 27-29).

From another perspective, one may find Steno's modesty and prudence associated with legal affairs.
Thus just as in legal affairs, one takes the part of the plaintiff and the other submits himself to the decision of the judge, so I produce, from what has been observed in the past, the proofs of those who reckon these bodies to be of animal origin, setting down perhaps at another time the reasons for contrary opinions, and looking always for a true judgement from more learned men. (Scherz, 1969, p. 95)

Redwick is aware of the judicial style of Steno's argumentation and attempts to connect it with the method used by Steno, but he provides no clear account of why Steno chose the judicial style to proceed in his argument.

The judicial style of Steno's argumentation may partially explain the caution that characterizes his Canis; since Steno played the role of a plaintiff rather than a judge, he needed to construct his arguments carefully to persuade the "judge." This may also solve a question raised by Albright, namely, why Steno presented his case for the animal origin of glossopetrae "with less confidence than the logic of his arguments might seem to justify" (Albright, 1986, p. 28). However, this kind of answer raises more basic questions: Why did Steno choose to imitate himself to the role of a plaintiff in attempting to present evidence in his arguments for the animal origin of glossopetrae? Why did he not instead adopt the posture of a judge, as Colonna did in confidently asserting the animal origin of glossopetrae and rejecting Korpus's view of intrinsic mineral generation?

Although there is no direct evidence that reveals why Steno chose a judicial style, the Canis contains a number of suggestive clues. The dissection of the shark's head was an anatomical "report" commissioned by the Grand Duke of Tuscany, Ferdinando II. Steno understood that it should be primarily an anatomical description and an expert's opinion on this specific topic (Scherz, 1969, p. 73). To this Steno added an unexpected set of arguments on the problem of the origin of glossopetrae. He needed to show how this unexpected part of the report was relevant to the main objective of anatomical study. So, in his description of the dissection of the shark's head, he left to last the consideration of the shark's teeth in order to make possible a smooth transition to his arguments about the derivation of glossopetrae. At that point, Steno could have put together his description of the shark's teeth with a forceful philosophical argument in favor of glossopetrae originating from sharks' teeth, just as many Renaissance and early modern writers mixed their descriptions of glossopetrae with views on their origin. Instead, he did not go that far; he chose a more cautious way. As he wrote:

While I show that my opinion has the semblance of truth, I do not maintain that holders of contrary views are wrong ... it would be imprudent to recognize only one method out of them all as true and condemn all the rest as erroneous. Many and great are the men who believe that the said bodies have been produced without the action of animals... These men have their reasons too... (Scherz, 1969, p. 113-115)

Steno had good reasons to be cautious because he knew the proponents of the animal origin of glossopetrae were a minority within the community of European naturalists, which included many famous physician-naturalists and physician-natural philosophers who held the opposing view of intrinsic mineral generation. To express his argument forcefully meant to regard those opposing views as explicitly erroneous beyond any doubt. Steno evidently did not want to do that. On the other hand, he was clearly motivated to present his own view on the animal origin of glossopetrae. So he needed to find a careful manner of expressing his argument. In this respect, medical jurisprudence may have offered Steno the tools he needed to argue his point in a more cautious manner.

Medical jurisprudence constituted a branch of medicine that applied medical knowledge to the elucidation of those problems upon which legal authorities needed consultation. Its origin as a modern discipline can be traced back to the early sixteenth century. In 1507, the Bishop of Bamberg drew up a penal code that ordered judges to summon physicians in certain cases of violent death. This code was adopted in 1516 in Bayreuth, Anspach, and Brandenburg. The rest of Germany resisted it until 1532 when Emperor Charles V in the Diet of Ratisbon issued the Constitutio criminalis Carolina, which laid the foundation for recognizing medicine as an indispensable tool for the administration of justice (Smith, 1933, p. 274-278, esp. p. 274-276). With the need for physicians to work in forensic medicine, many practitioners acted as judicial consultants. For example, Ambroise Paré (1510-1590), a famous surgeon, acted as a medical judicial consultant and left some autopsy records about the practice of legal medicine in the late sixteenth century. Paré limited his role to a very prudent judicial consultant both in the expression of his advice and in his treatment of the advice of others (Paré, 1840-1841, v. 3, p. 661-666; Humby, 1960, p. 151-153).

With the development of medical jurisprudence in the first half of the seventeenth century, the connection of medical practitioners (physicians, anatomists, surgeons, or apothecaries) with legal affairs may have provided a common background in understanding the role of their advice within legal procedure. They performed the role of medical judicial consultants in offering advice to the judge who made a final ruling on the case. Thus, their views were best couched in the language of conjectures rather than definitive statements. While there is no firsthand evidence showing his reliance on medical jurisprudence, there are hints of this connection in his arguments for the animal origin of glossopetrae. Steno knew that the readers of the Canis included anatomists, physician-naturalists, and physician-natural philosophers. Among them, many famous and great men held opposing views on the origin of glossopetrae. In this situation, the style of
argumentation of medical judicial consultation would have been useful. It made his arguments for the animal origin of *glossopteris* look like “conjectures,” which are inferences from incomplete evidence, rather than definitive statements. At the same time, he could refrain from explicitly asserting that the advocates of intrinsic mineral generation were in error. This posture would be more acceptable to those readers who advocated the views of intrinsic mineral generation. Nevertheless, Steno was also strongly motivated to express the “true” view of the origin of *glossopteris*. He needed to take a stronger but still prudent position to do that. The role of a “plaintiff” appropriately corresponded to his wish not to alienate his opponents and yet to show his “true” view. In addition, it retained the advantage he had already derived from adopting the style of medical judicial consultation.

Thus, just as a plaintiff (or a prosecutor) would put together pieces of evidence in conformity with certain assumptions about the cause of a wound or murder, Steno (in the *Cànis*) put together evidence from anatomy, chemistry, and geological observations in accordance with the assumption of the animal origin of *glossopteris*. The “judge” in Steno’s case would have been his “learned” readership.1 Beginning with his assumption of the animal origin of *glossopteris*, Steno listed eleven observations that he thought were reliable and supportive of his assumption. As he stated, “many [observations] are owed to the observation of my teachers; there will be very few to which I have not been an eyewitness” (Scherz, 1969, p. 95). The eleven observations may be briefly summarized as follows (Scherz, 1969, p. 94–97; Garboe, 1958, p. 9–11):

1. Some parts of the earth, from which the fossils resembling parts of aquatic animals are dug out, are hard, like tufas and other kinds of stone, while others are soft, like sand and clay.
2. This earth, regardless of degree of hardness, is compacted and resistant to moderate pressure.
3. These earths are seen in various places, composed of superimposed layers, at an angle to the horizon.
4. In claylike earth, layers are seen differing in color, with more or less perpendicular fissures filled with material of one color.
5. In these earths, whether hard or soft, different kinds of bodies are hidden.
6. In clay, a large number of bodies are seen on the surface of the earth, only a few within the earth.
7. The deeper one finds the bodies, the more fragile they are. Even at the surface, they can be pulverized easily.
8. These bodies are more abundant in rock with the same consistency throughout and are attached to the embedding rock.
9. The aquatic bodies, dug out from both hard or soft earth, resemble not only each other, but also corresponding parts of aquatic animals in form and texture.

10. These aquatic bodies may be hard, like stones, or less hard, so that they are reduced to powder easily.
11. Sometimes, many *glossopteris*, which are not complete nor of the same size, are embedded in the same matrix in which broken, deformed, and hardened scallops, mussels, and oyster shells are found.

Based upon these observations about fossils resembling parts of aquatic animals and about their surrounding material, in order to “offer some glimpses of the truth” about the origin of *glossopteris* (Scherz, 1969, p. 97), Steno proposed the six conjectures listed next as key connected steps in understanding the process through which the parts of aquatic animals, such as sharks’ teeth, became fossilized bodies, such as *glossopteris* (Scherz, 1969, p. 97, 99, 101, 105, 109).

“Conjecture 1. Soil from which bodies resembling parts of animals are dug does not seem to produce these bodies today.”

“Conjecture 2. The said soil does not seem to have been firm when the bodies referred to were produced in it.”

“Conjecture 3. Nor can there be strong opposition to the belief that the said soil was once covered with water.”

“Conjecture 4. There seems also to be no objection to the belief that the said soil was at some time in the past mixed with water.”

“Conjecture 5. I cannot see anything to prevent us from regarding the said soil as a sediment gradually accumulated from water.”

“Conjecture 6. There seems to be no objection to the opinion that bodies dug from the ground which resemble parts of animals should be considered to have been parts of animals.”

The most notable general characteristic of these six conjectures lies in their tentative phraseology such as “... does not seem to...” “Nor can there be strong opposition to the belief that...” “There seems also to be no objection to the belief that...” “I cannot see anything to prevent us from...” and “There seems to be no objection to the opinion that...” As in a legal case, the plaintiff wished to strengthen his own position tactfully while weakening the plausibility of the opposing interpretations. The first two conjectures were rebuttals of the assumption of intrinsic mineral generation of *glossopteris*. The remaining four conjectures were aimed at supporting the animal origin assumption. All six conjectures were designed to achieve the goal of persuading the “judge” to determine the animal origin of *glossopteris* as the most acceptable position.

Since Steno adopted the strategy of playing the role of a plaintiff, in order to win the case, he needed to organize his evidence to form a consistent argument presented in front of the “judge.” Steno’s long argument generally assumes the structure of Colonna’s work on *glossopteris*. In addition, Steno developed his arguments for the animal origin of *glossopteris* by focusing mainly on the relation between *glossopteris* and their surrounding material. In doing so, Steno may have found that his predecessors provided no detailed account of some problems such as sedimentation, stratification, and the lipidifying process in which parts of...
In the first conjecture, Steno began with a rebuttal of the hypothetical relation between fossil teeth and their surrounding material (as addressed in the views of intrinsic mineral generation) (Scherz, 1969, p. 97). From observation and experience, he found that in the unconsolidated material, the surrounding material seemed to destroy these fossils rather than produce them. The case with which naturalists and pharmacists had reduced these fossils to powders was a proof of their tendency to decay. If these fossils were growing in consolidated material, the surrounding material would have to give way to them rather than wrap around them consistently on all sides. Since these fossils were surrounded consistently on all sides by consolidated material, they could not be growing in this consolidated material in Steno’s lifetime. Hence, Steno concluded that the surrounding material did not produce these fossils during his lifetime. An extrapolation from this conjecture to previous times seems to be implied here; that is, these fossils were not even produced by their surrounding material before Steno’s time.

In the second conjecture, Steno continued to rebut the hypothetical relation between these fossils and their surrounding material (as addressed in the views of intrinsic mineral generation). According to that view, some fossils were generated in the rock. But according to Steno, if living things grew slowly in the rock, they would create some gaps in the rocks that contain them, and they would also be deformed by the resistance of those same surrounding rocks. By analogy, the roots of trees were found to be much more twisted and compressed in hard ground than in unconsolidated material. Thus, if these fossils had originally grown in consolidated material, they should be deformed in different ways. Nevertheless, these fossils were always found to assume the same shape, and therefore, they could not have been produced in hard, compact, or firm soil (Scherz, 1969, p. 97). In the first two conjectures, Steno elaborated on Colonna’s rebuttal of the plausibility of fossils growing in their surrounding material by using a legal form.

If fossils resembling parts of aquatic animals had been growing in unconsolidated materials, how were they originally deposited in this medium? How did these unconsolidated materials become hard before the fossils were removed from them? How could one explain fossils found in layers with almost perpendicular fissures? In order to answer these questions, Steno proposed four more conjectures. In the elaboration of these four conjectures (Scherz, 1969, p. 99ff), Steno articulated the terms of an argument for detrital sedimentation in water, and the gradual enclosure of hard organic parts within the accumulated sediments. In doing so, Steno connected the relationship

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This hypothetical condition had been discussed and rebutted by Colonna, as seen in the last section.

But the bodies that we are dealing with here are in fact always of the same shape (1), whether they are dug up from water ground, torn from rocks, or taken out of animals; it would seem then that since these bodies do not appear to be produced today (2) in the places where they are found, and since things that grow in from soil are found to be strangely deformed, but these are everywhere alike, the soil would not have been from when the bodies referred to were produced in it (Scherz, 1969, p. 97).
between *glossopteris* and their surrounding material with some key steps related to the process through which sharks' teeth are changed into *glossopteris*. This idea had already been discussed by Palladio and Colonna. Palladio had proposed two modes of explanation for the formation of these fossils in places near and distant from the ocean, respectively. For him, the mode of formation depended on the place where the stones were formed. By contrast, Colonna had advocated a universal hydrological mode to explain how aquatic animals were buried in the seabed and later petrified.

Ellenberger recognized that Steno gave a geological meaning to a medio-chemical term: *sedimentum*, but he offered no detailed explanation for how this step was taken (Ellenberger, 1988, p. 238). Basically, in conformity with his assumption of the organic origin of *glossopteris* and related observations (such as figured stones that appeared in strata), Steno adopted Colonna’s hydrological account of deposition, synthesizing it with chemical sedimentation, stratification, and Descartes’ particle theory. On the basis of this hydrological process of the formation of *glossopteris*, Steno developed a view of the formation of sediment and stratification that entailed processes invisible to the human eye. The strata explained by this view were thought to contain fossils of aquatic origin (including *glossopteris*). Concerning his explanation of the formation of sediments, Steno had adopted an invisible process that entailed the combination and separation of particles (from chemical considerations), as well as Descartes’ particle theory. Steno synthesized previous views on sedimentation with Descartes’ particle theory. Those previous views included: the formation of solids in a hydrological mode, the formation of solids in limpid waters, the cause of the formation of solids in fluids, and Descartes’ idea of sedimentation.

Likewise, Steno came to the problem of stratification and its connection with sedimentation. Steno handled the problem of stratification in a way similar to his synthesis of previous views on sedimentation. He drew together diverse elements from three previous views on stratification. By adopting a hydrological explanation of a sedimentary process in which parts of aquatic animals such as sharks’ teeth were buried in deposits laid down on the seabed, he assimilated Descartes’ mechanical account of the formation of “layers” in connection with sedimentation in his version of this process. With Descartes’ particle theory, Steno could see that there was no significant difference between what happens in nature and chemical art. In the bosom of the earth, nature behaved analogously to chemical operations performed in art. If there is *stratificatio* in chemical art, “natural stratificatio” constitutes its counterpart in the bosom of the earth. Because *stratificatio* in chemical art results in an ordered relation among color, sediment, and strata, “natural stratificatio” will produce a similar order in the earth. In so doing, Steno appropriated the term *stratificatio* for geology.

In his elaboration of the sixth conjecture, Steno followed Colonna’s hydrological mode to address the earlier stage of the formation of *glossopteris*—how once-living animals were buried in sediments. When aquatic animals—whether they were alive but unable to move, or dead—were at the bottom of a sediment, an additional layer of sediment would place them inside the said soil.

For whether a cream-like crust of stone hardens on the surface of the water, sinking to the bottom when it has become heavier, or particles of stones are produced evenly throughout the water, settling out gradually, the sediment grows only at a slow rate, thus, only these things which are already adhering to the bottom, whether they be dead animals, skins of dead creatures, or living animals unuseful for locomotion, will be covered over by new sediment; the rest of the living animals, straying above the said sediment, fill the water with numerous prospect before a new sediment is laid down there. (Scherz, 1969, p. 111)

Next, he adopted Rendel’s anatomical report of the dentition of the teeth of Lamia is important evidence in support of this earlier stage of the formation of *glossopteris*, since the dentition of *glossopteris* in the matrix is similar to that of sharks’ teeth:

But if several tongue stones of various size, not all of them complete, are observed sometimes to stick together, as if in the same matrix, the same is noted in the jaw of a living animal where neither are all the teeth of the same size nor are the teeth arranged in the inner rows completely hardend. (Scherz, 1969, p. 111–113)

Noting that “the similarity of forms seems to suggest a similarity of origin,” he thought this evidence would not be an obstacle to the organic origin of *glossopteris* (Scherz, 1969, p. 111–113).

In addition to drawing a parallel between the dentition of the teeth of Lamia and *glossopteris*, Steno raised two further parallels in order to infer that the substantive differences between *glossopteris* and their surrounding material also suggested that they have different origins. In one, he compared the substance of sharks’ teeth with their surrounding material under the action of subtle fluid (or heat). Using combustion analysis, Steno distinguished their substantive difference as Colonna had done. On combustion, sharks’ teeth first passed through a charred state, whereas stones or minerals reduced directly to ashes or powder (Scherz, 1969, p. 113; Colonna, 1616, p. 31). However, Steno used Descartes’ idea of subtle matter to explain these phenomena and made another parallel. In the bosom of the earth, *glossopteris* (the supposed sharks’ teeth) underwent a natural combustion and reacted in a way similar to the combustion of sharks’ teeth in chemical art (Scherz, 1969, p. 113; Hsu, 1992, ch. 2, sec. 4).

Having presented his first two conjectures as two rebuttals suggesting minimal plausibility of intrinsic mineral generation and the remaining four conjectures as propositions supporting the plausibility of the animal origin of *glossopteris*, at the end of his elaboration of the sixth conjecture, Steno concluded his argument in the style of a plaintiff as follows:

I reckon that I have shown sufficiently clearly that neither in the soil from which bodies resembling parts of animals are dug nor in those bodies themselves is it easy to find anything which is an obstacle to the belief that these same bodies may be regarded as the parts of animals. (Scherz, 1969, p. 113)

*This had been used by Colonna (Colonna, 1616, p. 35).*
CONCLUSIONS WITH A NOTE ON HOOKE

The principal conclusion of this paper is that Steno drew from the medical and chemical traditions of the time to synthesize the animal origin of *glossopteridae* in the *Canis*. This contribution to geology is best appreciated within the context of the broader themes of science and culture that surface in appraisals of the transition from medieval earth studies to early modern geology.

Twenty-five years ago, Jacques Roger convincingly argued for a connection between Descartes' "theory of the earth" and the "Scientific Revolution" (Roger, 1973, p. 23). Gabriel Gohau, furthermore, claimed that the birth of geology can be traced back to the "theory of the earth" genre (Carozzi and Carozzi, 1991, p. 1). Thus, Gohau found an important connection between early modern geology and the Scientific Revolution, a line of development that links the Copernican Revolution, Descartes' physical cosmology, and eventually Steno's work. It seems that Gohau thought that geology had its point of origin in the Scientific Revolution.²

If the change in worldview associated with the Scientific Revolution made an essential (revolutionary or global) change in seventeenth-century geology, then it raises a more general problem: What was the nature of the change from medieval geology to seventeenth-century geology? Or, put otherwise, was the change from medieval and early modern geology continuous or discontinuous? In this paper, the author suggests that Steno's *Canis* is a very good example of the transition between medieval and early modern geology.

While medieval geology was set in the Aristotelian or scholastic framework, seventeenth-century geology acquired a largely Cartesian framework. Nevertheless, medieval and early modern geology shared questions such as the animal origin of some fossils. The *Canis* thus offers an excellent opportunity to understand the transition from the scholastic to Cartesian frameworks in geological studies, especially given that the problem of *glossopteridae* was a very concrete case that had a long and sustained tradition within medical-chemical literature. A focus on this problem allows for a very specific case study to shed light on the degree of continuity and discontinuity between medieval and early modern geology.

According to Troels Kardel, "[Steno's] writings represent one of the turning points between the scholastic and the scientific approach to biology and geology" (Kardel, 1994, p. 96). He reflects on Steno's scientific method in the *Canis* and finds resemblances between Steno and Popper (Kardel, 1994, p. 73–74). He also stresses that Steno questioned Cartesian authority (Kardel, 1954, p. 92). Yet, this may not be the case of the *Canis*, for Steno was still a convinced Cartesian in this geological work.

We have seen that the historical development of ideas concerning the animal origin of *glossopteridae* can be regarded as a consequence of a series of transitions from the medieval view of the origin of fossils (stressing the petrifying power of the place), through the Renaissance rivalry between the views of spontaneous generation and animal origin, to Steno's view expressed in his *Canis*. He not only brought chemical considerations into the debate concerning the nature of *glossopteridae* (by using combustion to identify their nature as being that of bones), but he also appealed to the medical-chemical tradition to formulate some rudimentary concepts of sedimentation and stratification. Descartes relied on chemical considerations in a number of his ideas such as sedimentation, the formation of layers in Earth's exterior crust, the appearance of fissures and tilted strata, and the production of metals in the bosom of Earth. Steno synthesized previous views on the problem of sedimentation, stratification, and the animal origin of *glossopteridae* with Descartes' particle theory. By adopting Descartes' particle theory, medical contributions and chemical considerations helped Steno transform this problem from the older views of the animal origin of fossils (largely based upon the more outward similarity between fossils and living animals) to a specific identification of the distinct nature of *glossopteridae*.

Before we conclude this paper, we should not neglect the contribution of Robert Hooke (1633–1703), who was also a great pioneer of geology and the organic origin of fossils with resemblances to living animals, in his work beginning in the late 1660s. He thought that fossils were animal remains that had been turned into stones by petrification rather than by the inherent "plastic power" in nature. In some historical comparisons with Steno's *Prodromus*, published in 1669, it has been said that Hooke developed his view of the organic origin of fossils in England first, even before Steno in Italy (Oldroyd, 1956, p. 60; Carozzi, 1999, p. 87). However, in contrast to Steno's *Canis* in 1667, they might have simultaneously considered the organic origin of fossils. To my knowledge, Hooke paid no attention to *glossopteridae*. Steno appears to have arrived at his conclusions on the animal origin of *glossopteridae* without knowledge of or reference to Hooke's views. Their paths to understanding the animal origins of extraneous fossils were different. As the curator of experiments in the Royal Society of London, Hooke was an avowed Baconian with emphasis on observations and inductive method (Oldroyd, 1972; Vickers, 1987, p. 133). Although Steno showed his interest in Bacon's work and method in his *Chave* manuscript in 1659 (Scheperius, 1987, p. 124; Ziegler, 1997, p. 465, 475, 483), in *Canis*, he heavily relied upon his awareness of existing Renaissance literature on fossils' origins, his medical-chemical background, and his affinity with Cartesian particle theory.

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