On the origin of natural history: Steno's modern, but forgotten philosophy of science

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Nicolaus Steno (Niels Stensen, 1638–86) is considered to be the founder of geology as a discipline of modern science, and is also considered to be founder of scientific conceptions of the human glands, muscles, heart and brain. With respect to his anatomical results the judgment of posterity has always considered Steno to be one of the founders of modern *anatomy*, whereas Steno's paternity to the methods known to day of all students of *geology* was almost forgotten during the 130 yr from 1700 to 1830.

Besides geology and anatomy there are still important sides of Steno's scientific contributions to be rediscovered. Steno's *general philosophy of science* is one of the clearest formulated philosophies of modern science as it appeared during the 17th Century. It includes

- separation of scientific methods from religious arguments,
- a principle of how to seek "demonstrative certainty" by demanding considerations from both reductionist and holist perspectives,
- a series of purely structural (semiotic) principles developing a stringent basis for the pragmatic, historic (diachronous) sciences as opposed to the categorical, timeless (achronous) sciences,
- "Steno's ladder of knowledge" by which he formulated the leading principle of modern science i.e., how true knowledge about deeper, hidden causes ("what we are ignorant about") can be approached by combining analogue experiences with logic reasoning.

However, Steno's ideas and influence on the general principles of modern science are still quite unknown outside Scandinavia, Italy, France and Germany. This unfortunate situation may be explained with the fact that most of his philosophical statements have not been translated to English until recent decades. Several Latin philologists state that Steno's Latin language is of great beauty and poetic value, and that translations to other languages cannot give justice to Steno's texts. Thus, translations may have seemed too difficult.

Steno's ideas on the philosophy of science appear in both his many anatomical and in his fewer geological papers, all of which with one exception (in French) were written in Latin. A concentration of his philosophy of science was given by himself in his last scientific lecture "Prooemium" (1673), which was not translated from Latin to English before 1994. Therefore, after the decline of Latin as a scientific language Steno's philosophy of science and ideas on scientific reasoning remained quite unknown, although his ideas should be considered extremely modern and path finding for the scientific revolution of the bio- and geo-sciences. Moreover, Steno's philosophy of science is comparable to Immanuel Kant's 80 yr younger theory on *perception*, Charles S. Peirce's 230 yr younger theory on *abduction*, and—especially—Karl R. Popper's 300 yr younger theory on *scientific discovery by conjecture and refutation.*

The general outset of Steno's philosophy of science constitutes an important step from the Medieval's and the Renaissance's way of thinking into the 17th Century's appearance of modern sciences and the 18th Century's Enlightenment. The 18th Century's as well as present day's dichotomy of science into the traditional creationistic and the new historical interpretations to some extent can be traced back to Steno and his methods.

Keywords: Steno, Philosophy of science, Natural history, Principles of geology, Diachronous science, Enlightenment.

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As indicated by Steno's (Niels Stensen, 1638-1686; Fig. 1) foundation of methods for reconstruction of past events and by his description of Tuscany's geological history as a succession of developments Steno is a forerunner of *a pragmatic gradualistic-evolutionary tradition*. Following Steno's historical understanding of the chaotic development of the Earth a series of important scientists—such as Leibniz, Buffon, Hutton, Lamarck, Halley, Lyell, Darwin, Boltzmann, Gilbert, Wegener, and Bohr—became "Stenonian" representatives of a historical and pragmatic understanding of nature. However, in opposition to Steno's new way of thinking, which later dominated geology and natural history, *the traditional creationistic or categorical thinking* dominated physics and systematic biology. Great names—such as John Ray, Newton, Cuvier, Linnaeus, Laplace, Kelvin, Einstein, Hawking and many other influential scientists of the Enlightenment and the Modernity—quite successfully tried to maintain a cosmology of divine order and predictability determined at the Creation (or in our days at the "Big Bang").

Especially, after Darwin these opposing viewpoints not only led to severe conflicts between science and religion. But it also led to unresolved conflicts between *the diachronous bio-geo-sciences*, where time is an irreversible circumstance tying all natural forces and events to each other, and—on the other hand—*the achronous sciences* of mathematics, physics, chemistry (except for thermodynamics) and molecular biology (except for genetics), where time in all notions and formulas is nothing but a reversible measuring parameter.

Figure 1. Portrait of Steno when he was app. 30 yr old, probably painted by the dutch artist Justus Sustermans who was a member of grand duke Ferdinand II's court. The original painting is found in the Uffizi gallery in Florence.

For his time Steno's ideas on scientific recovery represent an extraordinarily stringent methodology allowing cool science and religious feelings to exist side by side, provided science is considered to be "Man's highest praise to God." This idea led Steno to an—for his time—highly unusual humble and pragmatic attitude to "the search for truth." The *breaking points* of Steno's philosophical ideas—and his eventual importance for the development of the historical or diachronous sciences and their conflicts with some religions as well as with the creationistic or achronous tradition of most disciplines of physics and chemistry—can briefly be summarized as follows:

Religious arguments are invalid in scientific reasoning. Although God has created Nature this divine cause is not meant to show how to understand nature scientifically. On the contrary true scientific understanding should enlighten the Scripture and is Man's highest praise to God.

As shown by Descartes a few decades previously Steno had agreed that it is necessary to reduce all problems, observations and understandings to a number of simple, separate situations *(reductionism)*. However, after having reduced all problems as much as possible a scientist must also observe, describe, analyze and understand these reduced problems *in coherence* as complex, interacting systems *(i.e. yield a systemic or "holistic" understanding)*. Especially, through his methods of "consequent induction" (recognition, conjecture, refutation and generalization) and through his deductive and *forensic* methods for chronological reconstruction ("back-stripping") Steno showed how to integrate such reduced situations to systemic and historic coherent understandings.

On their own premises empirical and analytical methods are scientifically fruitful. However, the highest level of scientific understanding can only be approached by iterative interaction of both methods (as illustrated in Figure 2).

As seen from the present day viewpoint, these ideas may appear to be both modern and elementary. But that was not the case at Steno's time. Arguments taken from the Bible were generally considered superior to any other argument. Moreover, analytical reasoning was by most of Steno's contemporaneous philosophers held superior to empirical observations. Many philosophers even thought that empirical observations could be directly misleading (e.g., Descartes and also Steno's friend in Rome, the renowned Athanasius Kircher). At that time Descartes' newly established methodology of reductionism was about to rule science, whereas "holistic" or *systemic putting things together* was still ruled by speculations on divine forces and powers.

The tradition of reductionism founded by Descartes was followed by Isaac Newton. He also fought against his mathematical peer and competitor, G.W. Leibniz, who was a great admirer of Steno. Newton became President of the Royal Society in London, and from this position he suppressed any opposition. For nearly two centuries the Newtonian "program" also ruled European science and, consequently, the Stenonian way of thinking had large difficulties. Most influential physicists of the 18th and 19th Century, e.g., Lord Kelvin, discredited opponents representing modern life and earth science, e.g., Darwin and Huxley (cf. Lakatos 1971 and Hallam 1988). In this nearly "monoprogrammatic" philosophical environment of European science during the 18th and 19th Century Steno's thoughts may have seemed radical and sometimes made Steno a highly controversial figure.

In 1903 Rutherford's invention of radioactive dating finally broke Lord Kelvin's condemnation of geology, palaeontology and evolution theories. The Darwinian—and before Darwin the Stenonian, Huttonian and Lyellinian—way of making systemic and pragmatic science by conjecture, empiric evidence and refutation became more acceptable among physicists. The value of pursuing science in Steno's way had been ripened and would eventually be recognized, when his philosophical ideas had proven fruitful in practical science.

Finally, in 1915 Alfred Wegener's way of forming his paradigmatic new theory on continental drift ("Die Entstehung der Kontinente und Ozeane") in all important aspects builds on Steno's geological as well as philosophical principles (Hansen 2007a and b; cf. Krause and Thiede 2005). However, the 60 yr it took from 1915 to1975 for Wegener's theory to be generally accepted also shows how difficult it had become not only to "dissect the machine" and describe its individual parts (reductionism), but merely to put the separate parts together and understand them "in coherence," as Steno had already said 250 yr earlier (see quotation herein, p. 5).

Uniting Steno's philosophical ideas from anatomy and geology

With a few exceptions modern historians of science do not connect Steno's many anatomical papers with his no less important geological and paleontological works or with his first scientific thesis on the nature of heat ("De Solido," 1669; "Canis Carchariae," 1667; "De Thermis," 1660). For obvious reasons most historians of science to some extent are limited by their primary interest of a certain branch of science. Consequently, important complementary developments from other disciplines of science may remain undiscussed. Moreover, some of Steno's more important papers containing philosophical viewpoints—especially, the lecture in Paris on the brain (1665) and his "Prooemium" lecture in Copenhagen (1673)—have not been translated into English before during the late 20th Century.

Exceptions are the physiologist and Nobel laureate August Krogh (1874–1949), who together with the medical doctor Vilhelm Maar translated Steno's geological paper "De Solido" from Latin to Danish and gave the first deeper comment on Steno's philosophy of science (Krogh and Maar, 1902). More recent exceptions from a unidisciplinary approach to Steno's philosophy of science has been given by Gustav Scherz (1969), who together with Alex Pollock translated Steno's geological papers and his work on heat from Latin to English and published the translations and Scherz' comments on Steno's theories. Likewise August Ziggelar (1997) translated and—from a multidisciplinary approach—commented on Steno's "Chaos," i.e., Steno's student manuscript containing many of his early thoughts and theories on science.

The works most directly connecting Steno's anatomical, geological and physical ideas are found in the three medical doctors Egill Snorrason's reconsideration (1986), Harald Moe's biography (1988, in English 1994), and Troels Kardel's works from the 1980'ies and onward. Similar multidisciplinary approaches are seen in the professor of physics and of science history, Olaf Pedersen's posthumous book (1995) on religion and science, in the geologist Gary Rosenberg's work on Steno as illustrator (2006), and in the geologist Toshiro Yamada's works on the relations between Steno, Gassendi, Kircher, Leibniz and Spinoza (2003, 2006). In more popular terms Steno's ideas have been described recently by Cutler (2003) and Kermit (1998, 2003). My own contributions (Hansen, 1997, 2000a, 2000b, 2005) include Steno's philosophy of science as expressed in both his anatomical and geological works, and deals mainly with Steno's and subsequent naturalist's ideas on geological, paleontological and physical thinking and the major differences between the *achronous* physical sciences and the *diachronous* historical sciences such as geology and palaeontology.

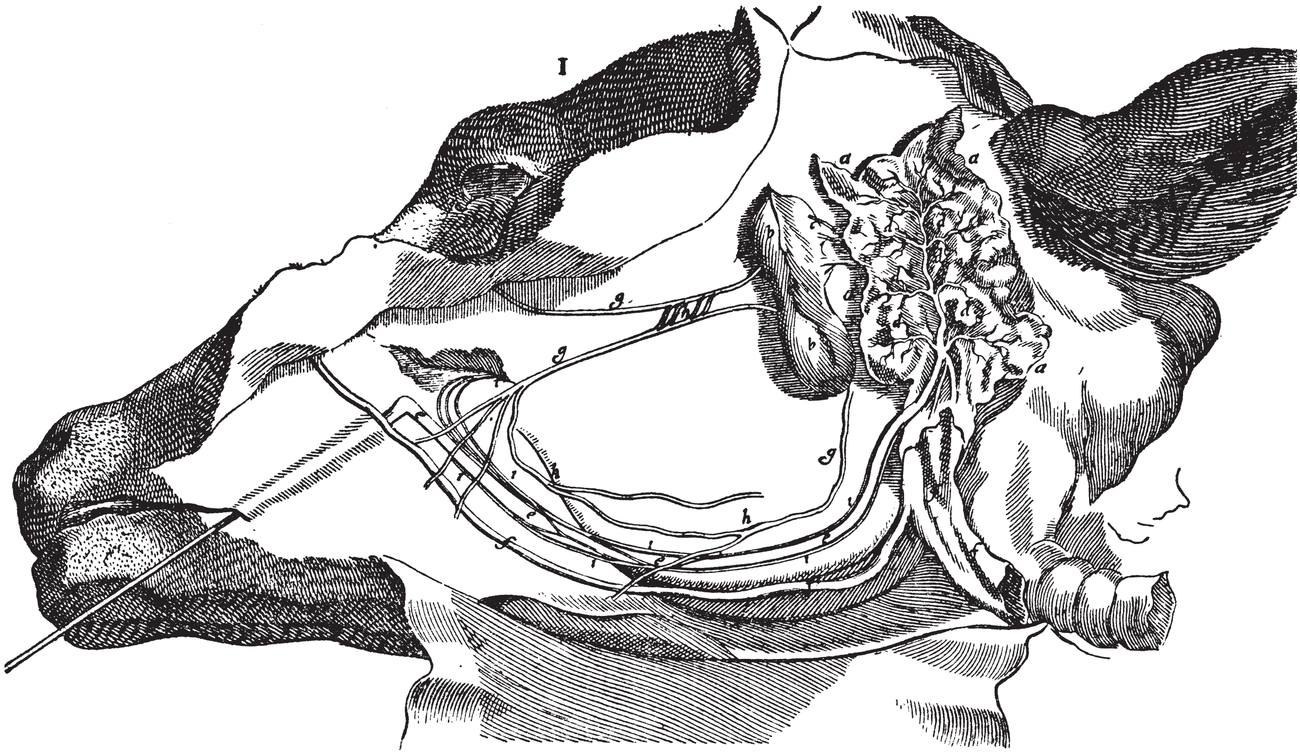

Figure 2. Steno's works before 1665 were purely empirical, and included many anatomical discoveries. Here is seen Steno's accurate and beautiful drawing of a dissected calf's head (from Steno's paper De Glandulis Oris, 1661). Most of Steno's earliest scientific studies were concerned with the lymph system and the glands. Especially, the function of the glands was not understood on Steno's time. Among other discoveries related to the glands Steno showed that the saliva of the mouth is derived from the parotid gland through a duct (now named ductus stenonianus after Steno) ending in the oral cavity. The drawing shows a metal rod pushed from the oral cavity into the duct from the parotid gland. Steno first made this observation in a sheep's head, when he pushed a metal rod from the gland into the duct and then heard a "click," when the rod surprisingly hit the sheep's teeth without having penetrated any tissues: The glands produce saliva!

Steno's separation of science from religion

At the time of Steno nearly nobody doubted that the world had been created by God. Extremely few Medieval and Renaissance scientists and philosophers had felt reason to describe the world from any other viewpoint. Giordano Bruno is one of them, and his execution in 1600 may have discouraged others from following this path.

However, in Steno's time the true existence of God was as real to everybody as the true existence of "hidden forces" such as gravity, electricity, and magnetism is today. After Galileo the general viewpoint was that the truth about the Creation could be read in two places, in the Holy Scripture and in Nature. Most of those days' important contributions to the establishment of modern science to some extent argued that the Creation and our understanding of it should explain God's will. References to or arguments directly from the Bible could be taken granted. This applies for the greatest scientists of the late 16th and early 17th Century, e.g., Brahe, Kepler, Descartes and in most respects for Galileo as well, while other slightly younger scientists—first and foremost Isaac Newton—more speculatively tried to find a connection between *the first cause* (God) and the laws of nature. Thus, Newton came to the conclusion that causal explanations are irrelevant. All causality is from the very beginning already contained in the mathematical laws of nature (Koyré, posthumous 1973).

Despite his strong Christian faith Steno took a completely different position, when he founded palaeontology by conjecture and refutation (1667) and, particularly, when he founded geology as a discipline of modern science (1669). Deeply religious as Steno was, it seems that he was fully aware of the weaknesses such an inclination might induce on his scientific work. Steno had observed that religious arguments had undermined the scientific value of the work of many of his contemporaries, e.g., Athanasius Kircher and Descartes. Moreover, Steno's religious speculations and final conversion from Protestantism to Catholicism had taught him that interpretations of the Bible may differ from time to time and from region to region. Maybe therefore, Steno quite early proclaimed that an important role of science is to rule out uncertainties, errors and misinterpretations. Early in his scientific career he came to the viewpoint that a true perception is not *given* once and for all. The truth must be *sought*, and the truth will only be partly understood. The approach to and knowledge about the truth is as pragmatic and incomplete as our sensing and reasoning capacities. Therefore, we must begin with findings, which we—without reasonable doubt—can be *certain* about:

"In order to defend the study of reality, conscious of the risks of error and in order to avoid the errors of others, I will not seek the truth by arguments alone [pure reasoning] or by experiments alone [empirical investigations and sensing], but by such a mixture of both, so that most, if not all results, after everybody's calculations will be of demonstrative certainty"

(Steno, 1665, my translation and explanations in brackets. Steno's original text may be found in Kardel 1994a, p. 126, together with M.E. Collins' and P. Maquet's slightly different translation from Latin to English).

Steno believed that the use of scientific methods can make many ideas certain—i.e., without *reasonable* doubt—although there always will be a few people who will contradict what is of *demonstrative certainty* after "everybody's calculations."

Steno also quite early realized, that Descartes' new reductionistic method is incomplete, although necessary. Things must be understood *both* as individual things *and* in coherence. In his work on the brain, where he contradicts Descartes machine-mechanistic conception of the brain, Steno claims:

"There are two ways to understand complicated things as a complicated machine. Either can the master, who has built the machine, show you what he has done and how the machine works. Or you can investigate every single part and—to begin with—understand them individually. Thereafter, you must also put all the individual parts together in order to understand how they work in coherence."

(Steno, 1665, my interpretative translation. Steno's original text may be found in Maar [1910]. Find also original text and translation to Italian, Latin, English, Danish, and German in Rafaelsen [1986, p 67]. Also translated to Danish in Kardel & Møllgaard [1997, p. 32])

In Steno's conception the overall understanding of a complicated system cannot be considered just to be the *sum* of the understandings of the individual parts of the system. The overall understanding of a complicated system also should include how the understanding of the individual parts shall be understood in coherence. In other words, the understanding of a system is *more* than the sum of separate understandings. Steno is both a Cartesian reductionist and a scientifically stringent "holist."

Steno elsewhere compares the "master way" of understanding with divine inspiration, where God may lead the anatomist's hand during dissections and lead the anatomist's eyes to the interesting and telling parts of the body. However, the great master does not tell the anatomist how to understand, what he sees. God only leads our *attention* to what we need to see in order to understand. What we really see is a matter of the senses' reflection of the real things, and of the signals "transmitted" from the senses to the brain. What the brain perceives about the things in question differs from the things as they are "by themselves." The senses only show those *aspects* of the real things, which are needed for Man's understanding. In "Prooemium" Steno explains this early and almost Kantian theory of perception in this way:

"It is not the function of the senses to show or to judge things as they are by themselves [res ut sunt], but to transmit those circumstances by the observed things to the reasoning, so that it will be sufficient for Man to obtain the perceptions of things [notitiam rerum] appropriate to Man's purpose."

(Steno, 1673, my interpretative translation. Steno's original text may be found in Kardel [1994a, p. 120] together with M.E. Collins' and P. Maquet's translation to English [p. 121], also translated by Larsen [1933] and Kragelund [1976] to Danish.)

However, the real scientific problem—and the *beauty of human understanding*—is that we due to our incomplete capacities will remain *ignorant* about the *first cause*, God's will. Unlike Newton's categorical ideas a few years later—namely that all causality is contained in the laws of nature—Steno came to the pragmatic and nearly opposite conclusion, that we can only obtain incomplete or vague ideas about the deeper causes through a mixture of observation and reasoning. This idea may also be seen as a forerunner of David Hume (1711–1776) and his philosophy on how deeper causes gradually disappear to our perception with depth of time. This thought inspired Immanuel Kant (1724–1804) to his ideas on human perception. Thus, Kant distinguished between things as they are in themselves ("das Ding an sich") and as we perceive things ("das Ding für uns"), while Steno app. 80 yr earlier made a similar distinction between things as they are ("res ut sunt") and as we perceive them ("notitiam rerum").

In "Prooemium" Steno expresses the consequences of this viewpoint in a famous maxim, which in my opinion has been misunderstood by some believers, who wish to see Steno's shift from a scientific to a clerical career as a condemnation of his geological ideas. Steno's famous maxim says:

"Beautiful is what we see.
More beautiful is what we understand.
Far most beautiful is what we are ignorant about."

(Steno, 1673, my translation. Steno's original text may be found in Kardel [1994a, p. 120] together with translation to English. Find a slightly different translation by myself in Hansen [2005, p. 233], where "quae ignorantur" is translated to "that about which we are insensible," whereas the translation in Kardel is "what we do not know.")

However, Steno's three levels of scientific understanding do not describe a ladder from secular to religious understanding. When Steno as newly appointed *anatomicus regius* (royal anatomist) was about to begin a public dissection of a young female body in the anatomical theater of Copenhagen University he explained, what he meant:

"Beautiful is what directly is revealed to the senses without dissection. More beautiful is what the dissection draws forth from the hidden interior parts. But far most beautiful—although escaping the senses—is what [nevertheless] can be approached through reasoning about what the senses have already [or elsewhere] perceived."

(Steno, 1673, my translation [and interpretation]. Steno's original text may be found in Kardel [1994a, p. 118] together with M.E. Collins' and P. Maquet's translation to English [p. 119]. Their translation of the late phrase sounds "yet by far the most beautiful is what, escaping the senses, is revealed by reasoning helped by what the senses perceive.")

Thus, the ladder of Steno's philosophy of science does not go from secular to divine understanding, but—in the search for the deeper causes—from sensing ("beautiful" [pulchra]) over empiric investigations and reasoning ("more beautiful" [pulchriora]) to iterative combination of sensing and reasonable analogies with logic reasoning and what already has been perceived ("far most beautiful" [longe pulcherrima]).

Olaf Pedersen (1996) has noted that Steno's way of reasoning differs fundamentally from his contemporaries by *seeking causes*, not by explaining nature by causes already given, e.g., in the Bible or in mathematical notions. Especially, with respect to fossils the 16th and 17th Century's religious ideas on causes were widely used in order to explain nature. As documented by Pedersen (1996) that was also the project of e.g., the 17th Century scientists John Ray and Kircher and even later the project of Sedwick and several other 19th Century scientists, whereas the controversial 18th Century French scientist Buffon was more in line with Steno.

In Steno's thinking the role of science is not to explain effects by means of a priori given causes. That is merely the role of religion—and in our time, may I say, the role of forecasting, prospecting and mathematic modeling. In Steno's thinking the role of science is to study the visible things in nature and man (the effects) and, thereafter—e.g., by assuming that the forces now in action also have been active in the past—to "back-strip" and reconstruct and thereby understand, what the causes may have been to the observed effects.

Compared to the majority of his contemporaneous philosophers Steno came to another—and scientifically much more fruitful—way to understand the relation between nature and God *(the first cause)*. In Steno's opinion there are two ways in order to approach the truth: Science and the Holy Scripture. The entire scientific and theological work of Steno shows—in particular Steno's letter to Spinoza (in Latin, 1671, text translated to German in Scherz, 1963, p. 279–287, and to Danish in Larsen 1933, p. 114–125)—Steno's modern position: *Scientific and religious arguments must be kept separate.*

Scientific methods should rule reasoning. Religious belief should rule actions. True science on its own premises is man's highest praise to God. If science is contradicting the Holy Scripture or *vise versa*, there are things we have still not understood (we are "ignorant" about the "far most beautiful"), although our understanding of the deeper causes may be approached by combination of analogies and what we already know with logic reasoning. Steno seems never to have doubted, that contradictions between science and the scripture would only be a question of becoming better at reading the causes and effects laid down in e.g., the structure of nature's "solid bodies" as well as the Bible.

Steno's rejection of religious arguments and scientific arrogance

Steno's path to his—*de facto* materialistic—philosophy of science originated from his anatomical studies. In the beginning he was inspired from Descartes' and Galileo's work. He *wished to describe biological phenomena mathematically* (Fig. 3).

Consequently, Steno constructed a *geometric* explanation to the function of the individual muscle fibers and the pennate bundles of muscle fibers, and showed how the geometric relations are between relaxed and contracted muscles (contraction by shortening and thickening of the individual fibers). Thus, Steno on a purely geometric basis showed that the volume of a contracted and a relaxed muscle is the same. Steno's student friend, Jan Schwammerdam made experiments confirming Steno's theory (but first published 70 yr later), whereas the conception of their time and many years ahead was that muscles contract by thickening to a larger volume as a result of inflation by blood. Although Steno's correct idea, on how muscles work, for a long time was considered to be "Perhaps the Weakest" of his entire production (cf. Kardel, 2000) and consequently was erroneously rejected by most contemporaneous anatomists—and even during the two following centuries—Steno was convinced that he was right. We now know he was right (Kardel, 1994b)!

A similar mathematic approach is also seen in Steno's measurements of the angles of crystals, which led to "Steno's law" about crystal's constant angles. But in all other respects, where he tried a mathematic-geometric description of biological and geological phenomena, he realized that nature is more complex.

Steno's purely materialistic understanding of the muscles also led him to dissections of the human heart, which in his time by most scientists was believed to be the seat of the soul and the throne of our spirit. However, Steno concluded in a letter to Thomas Bartholin (1663 and published 1664 by Bartholin):

"I say, you will find nothing in the heart, which is not also found in every muscle, and in every muscle, you will find nothing, which is not also found in the heart. The heart is a muscle!"

(My interpretative translation. Bartholin's quotation of Steno's original letter may be found in Kardel [1986, p. 115], together with Kardel's translation to English. Find also Kardel's interpretation of Steno's statement in Kardel [1994a, p. 29-30])

Thomas Bartholin felt that this conclusion was too radical (Pedersen, 1986 p. 20), while others concluded that Steno was to become a great scientist. It should be remembered, that Steno's conclusion on the function of the heart neither reduces man to a machine nor rejects the existence of neither God nor the soul. Steno's statement simply rejects religious explanations on the function and role of the heart. He simply explains what the heart's anatomical function is, when it is described solely by means of scientific methods. And as a side-effect he noted, as the first scientist, that the human heart is *asymmetric*—an observation also reducing the heart's divine status. He was very fond of this observation and in his *ex libris* and *episcopal sigilum* he included a symbolic asymmetric heart from which a cross arises. (This symbol, but with a symmetric heart, had already been in use in his family in Scania (Elsebeth Thomsen, pers. comm. 2008), and in 2006 I have observed the same symbol in use on several fishing boats in Southern Ireland.)

A similar approach is seen in Steno's lecture in Paris (1665) on the anatomy and function of the brain. Steno criticized Descartes and other contemporaneous celebrities to have neglected careful dissection and observation of the brain in order to make their anatomical speculations coincide with their speculations on the soul and how God and/or the soul rules man. Steno said:

"These people, who think they know about everything, will give you a description of the brain and the positions of all its functions as if they, themselves, had been present at the creation of this "wonderful machine" and had penetrated the deepest thoughts of its master."

(My translation. The portion in quotes is my interpretation of Steno's irony on Descartes' machine-mechanistic conception of the brain. Steno's original text may be found in French in Maar [1910]. Find also original text and translations to Italian, Latin, English, Danish, and German in Rafaelsen [1986, p. 39]. Also translated to Danish in Kardel and Møllgaard [1997, p. 9])

Especially, Descartes speculations on the divine role of the pineal gland in the brain's center, as well as Descartes' sloppy dissections and description of the brain had forced Steno to argue against Descartes and once again to reject religious arguments as valid in scientific reasoning. In order to find a connection between God's will, the soul and the human body Descartes had figured out, that the pineal gland was acting by "vibrations" and "rotations" induced by the soul and that these postulated movements of the pineal gland in the center of the brain would make the gland touch various parts of the brain's inner surfaces and thereby induce impulses from the brain

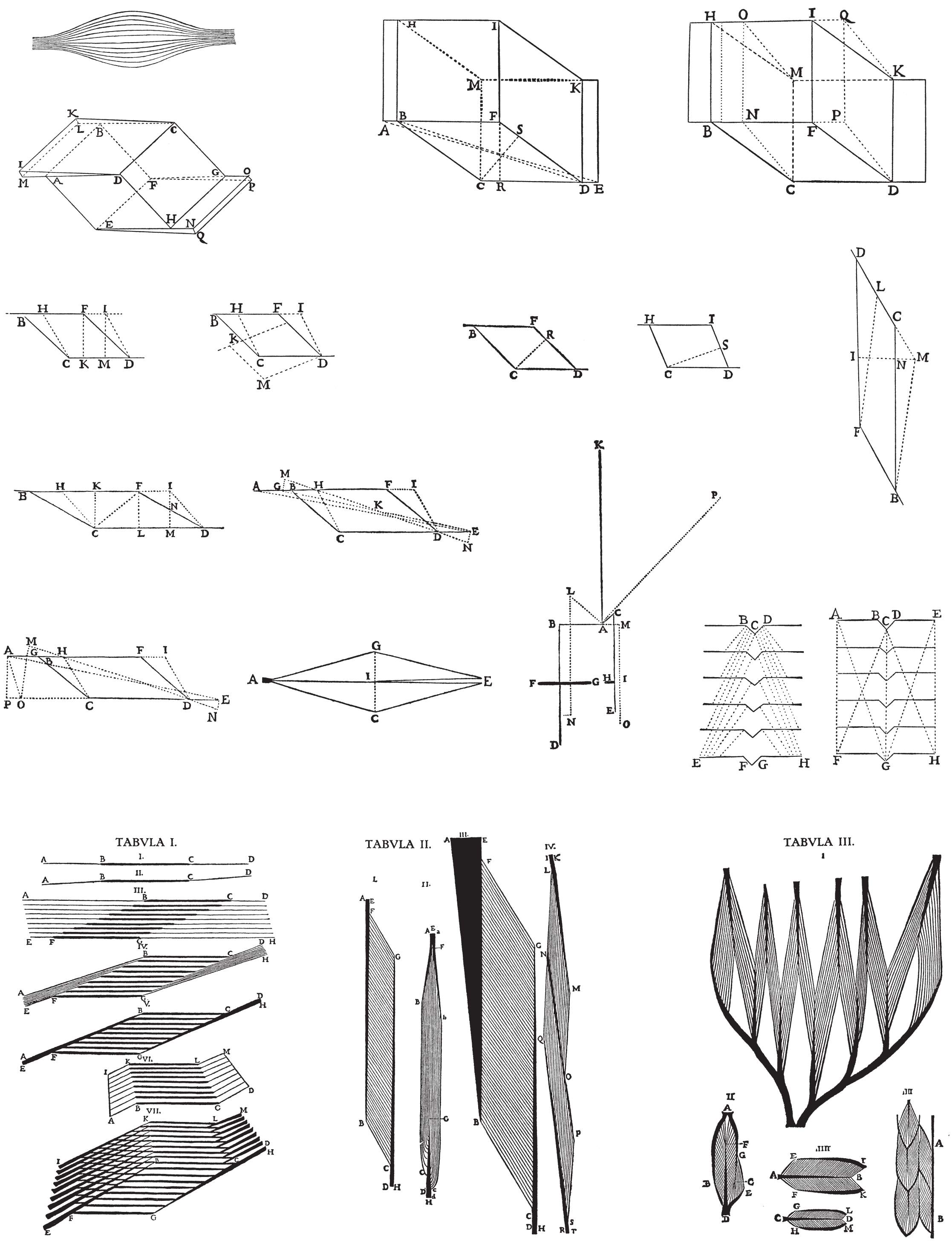

Figure 3. As a Cartesian Steno wished to give "mathematical" explanations on biological and geological phenomena. However, with the exception of muscles (and later crystals) he soon realized that this project was not fruitful when dealing with more complex structures. Here are shown some of Steno's drawings of the function of muscle fibers and muscles from his paper Elementorum Myologiae Specimen from 1669. Already in 1663, in a letter to Thomas Bartholin, Steno had given a sketch of the muscle's pennate structure and claimed that the heart is a muscle. The upper part of the figure shows his geometrical explanation to the function of a muscle fiber, and the lower part shows how single fibers, bundles of fibers i.e., muscles ("Tabula I and II") and bundles of muscles ("Tabula III") work and work in coherence. The little figure to the top left shows the contemporary idea on how muscles work and which Steno opposed to, namely that muscles contract as a result of inflation by blood i.e., that contracted muscles have a larger volume than relaxed muscles. Steno's geometrical explanation shows that the volume is constant. Inspired from Steno's studies his friend, Jan Schwammerdam made experiments showing that Steno was right. Nevertheless, Steno's muscle theory was generally rejected until centuries later.

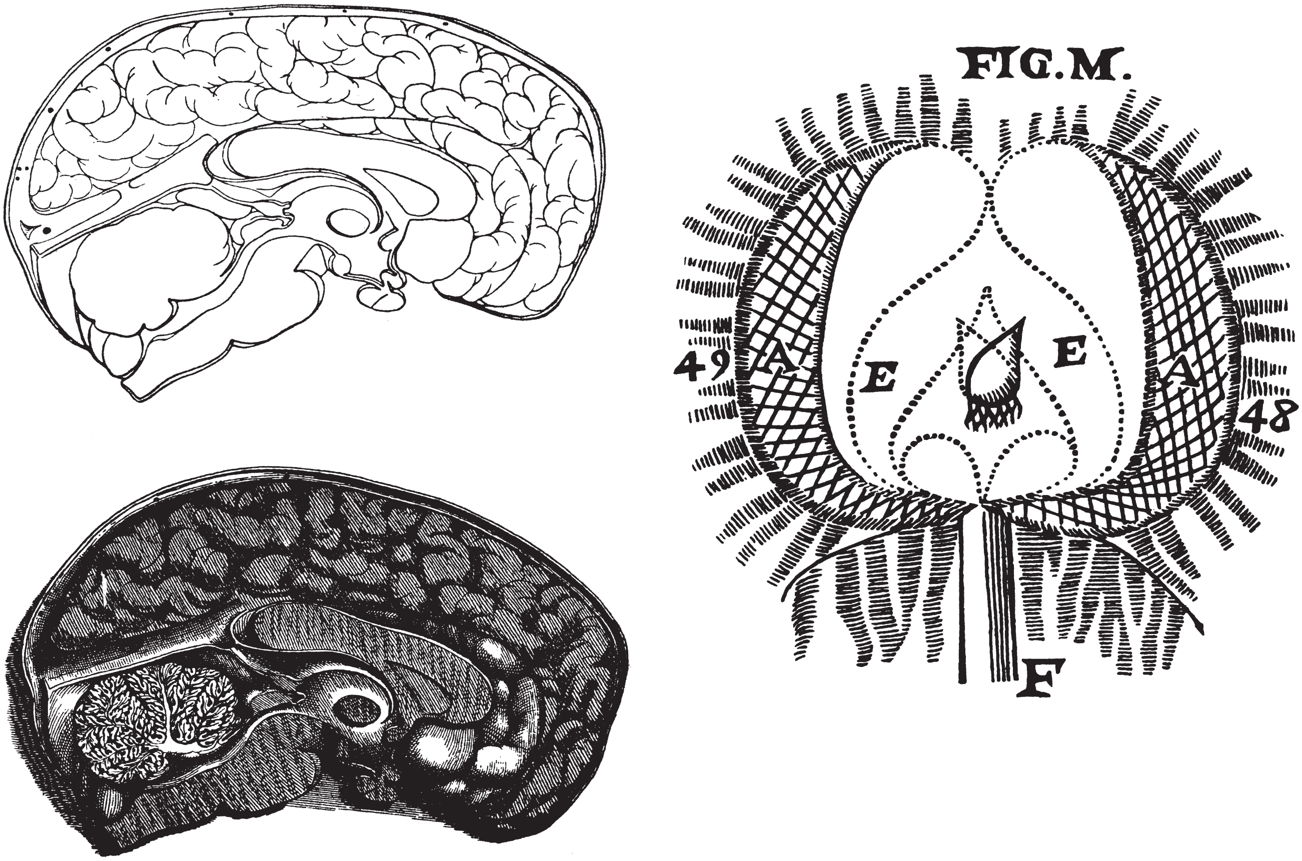

Figure 4. To the left (Fig. 4A) Steno's drawings of the human brain, i.e., history's first example of a drawing almost similar to present days' conception of the human brain (from Steno's paper Discours sur l'anatomie du cerveau, published in 1669). To the right (Fig. 4B) Descartes model on the function of the brain (criticized by Steno in Paris 1665). Accordingly to Descartes the soul would make the pineal gland (in the center of the figure) vibrate and rotate and thereby touch various parts of the inner surface of the brain. That would activate various nerves and muscles and cause the actions of man. Steno criticized Descartes' model because it did not build on observations – as Descartes' claimed – but merely tried to explain Descartes' speculations on the connection between God, soul and body.

to the muscles and other organs. By this conception Descartes so to speak reduced man to a "wonderful machine" ruled by the soul and God's unforeseeable and interfering will (Fig. 4).

Steno rejected this conception and showed, that the pineal gland is delicately, but firmly connected to the brain, and that the carefully dissected human brain is very different from the explanations given by Descartes and Willis.

In "De Solido" four years later Steno had come even farther from Descartes' Platonic view, where the soul or the ideas rule matter. Now Steno's viewpoint approaches an Aristotelian or even an Epicurean conception of "the will," where the description and understanding of observed natural changes should be independent, whatever the scientist may believe that the "moving force" is Plato's "ideas," Descartes' "soul," or otherwise an expression of God's unforeseeable will and eventual interference. Steno thought natural changes or man's changes of nature's forms should not be studied as if they have been induced by various divine powers. Scientific studies should be independent of desired results.

This viewpoint is described several places in Steno's anatomical and geological works e.g., with an allegory in the very first paragraph of "De Solido":

"While travellers in unknown territories hasten over rough mountain tracks towards a city on a mountain top, it often happens that they judge the city, at first sight, to be close to them; constantly, numerous twists and turnings along the route delay their hope of arrival to the point of weariness, for they see only the nearest peaks; in fact those things hidden by the said peaks, the heights of hills, the depths of valleys, or the levels of plains, whatever they may be, far exceed their conjectures, and they, deceiving themselves, estimate the intervening distances from their own desires."

(Translation by A.J. Pollock in Scherz [1969, p. 137).

Steno's original Latin text may be found in Scherz [1969, p. 136])

Therefore, the study of nature should be independent of the scientist's conjectures and desires, including the scientist's thoughts on God's will. Certainly, Steno believes in God as the creator and maintainer of the world, but he also believed our understanding of natural changes and man's actions should not anticipate an idea, where God's will and interference is the direct cause of all change (motion). However, before coming to this scientific point, Steno assures the readers about his belief in God's omnipotence:

"Certainly to deny this cause of power of producing results contrary to the usual course of nature is the same as denying man the power to change course of rivers, of struggling with sails against the winds, of kindling fire in places where without him fire would never be kindled, of extinguishing fire which would not otherwise vanish unless its fuel supply ceased, of grafting the shoot of one plant on the branch of another, of serving up summer fruits in mid-winter, of producing ice in the very heat of summer, and thousand other things of this kind opposed to the usual laws of Nature. For if we ourselves, who are ignorant of the structure of both our own bodies and the bodies of others, alter the determination of natural motions each day, why should not He be able to alter their determination who not only knows the whole of our structure and that of all things, but also brought them into being."

(Translation by A.J. Pollock in Scherz [1969, p. 147]. Steno's original Latin text may be found in Scherz [1969, p. 146])

Immediately after this assurance about God's omnipotence and man's capability to induce seemingly unnatural phenomena, Steno turns to our imperfect knowledge and capability of understanding, including our imperfect understanding of ourselves:

"However, in those things that Man has produced, and in those things that have been produced by Nature, to admire the genius of the freely acting Man, and to deny a free mover to things produced of Nature, appears to me to be both subtle and naïve, since Man—even when he produces the most ingenious and admirable things—only through a fog is seeing, what he has done, which organs he has been using, and what has been the moving forces of these organs."

(My translation. Steno's original text may be found in Scherz [1969, p. 146] and also A.J. Pollock's slightly different translation to English [p. 147])

Because of this imperfect capability of understanding a scientist should not anticipate any specific decision on, what the moving force (or "first cause") might be in order to produce the natural change in question. The applied scientific method should be independent of any possible result, and the necessary scientific anticipations and prerequisites should be of such reasonable or indisputable certainty, that they cannot be refuted by any scientific argument.

In "De Solido" Steno concludes on his own scientific anticipations and prerequisites about the nature of matter:

"For what I have said about matter holds everywhere, whether matter is considered to consist of atoms, or of particles which may change in thousand ways, or of the four elements, or of as many chemical elements as are needed to meet the variety of opinions among chemists. And indeed what I have proposed about the determination of motion agrees with every mover, whether you call the mover the form, or properties emanating from the form, or the Idea, or common "subtle matter," or special "subtle matter," or a particular soul, or the immediate influence of God."

(Translation by A.J. Pollock in Scherz [1969, p. 146]. Steno's original Latin text may be found in Scherz [1969, p. 147])

With this statement Steno's conception of *how to study* natural change is breaking with the Renaissance's and Descartes' theology anticipating that "God's finger" from the beyond makes "imprints" on the worldly substances without being in it. It is reasonable to suggest a parallel in the different opinions between Descartes' and Steno's conceptions of "the beyond" and "the worldly" and the almost similar disagreement between Plato's and Aristotle's conceptions of "idea" and "form." Plato's and Descartes' thoughts were occupied by the existence of "ethereal" powers—and how "the ideas" or "the soul" rules nature and man from the beyond. Aristotle and Steno on the contrary were occupied by the worldly multitude of matters and forms and how to study nature with man's imperfect capacities.

For Steno as for Aristotle—but in opposition to Descartes and Plato—nature is substance and form, i.e., that which exists in itself (per se, as Aristotle said) or in things as they are (*res ut sunt*, as Steno said). In Aristotle's and Steno's thinking the world is constituted by *matter and form*, and Plato's "idea" or Descartes' "soul" does not rule the worldly matters and forms from "the beyond" by interference. No, every changeable thing has been *created* already, and the Creation already contains *seedlings* to all possible and unpredictable changes. By nature's as well as man's freely acting capability all potential changes or deviations from "the normal" are already laid down in the worldly. Only the unchangeable does not belong to this world. Only God is unchangeable (Aristotle: *the quintessence, the 5th element,* in opposition to the 4 worldly elements earth, water, air and fire). In Steno's thinking this means that we can only approach our understanding of the unchangeable by understanding the changeable nature as it is appears now, not the opposite way around by a priori knowledge of all causes: *Religious arguments and thoughts on "the beyond" are invalid in science!*

Nature should be studied in nature, not explained by "ideas" without studies. After having come to the conclusion that even mathematical laws—which basically are metaphysical explanations—would only work sporadically in biology and geology, Steno in the first part of "De Solido" declares that the philosophical purpose of his geological project is

"to find methods, which through the study of natural solid bodies themselves will yield evidence on where and how the solid bodies have been produced [in Latin: "… in ipso corpere argumenta invenire locus et modus poductionis detergentia"].

(My translation. Find Steno's original Latin expression in complete context in Scherz [1969, p. 141] and also A.J. Pollock's slightly different translation [p. 141])

Thus, inspired from his studies of the glands, the muscles and the brain Steno's "De Solido" constitutes one of history's first consequent separations of scientific from religious and other kinds of metaphysical reasoning.

Steno's contribution to the initial dichotomy of deterministic and stochastic sciences

Knowing Steno's attitude to his student friend from Leiden, Baruch Spinoza (1632–77), and Steno's opinion on Spinoza's "materialistic religion" as it had been described anonymously by Spinoza in *Tractatus* (1670) it may seem difficult to connect Steno's *de facto* materialistic philosophy of science with his very critical viewpoints on Spinoza's pantheistic ideas. Steno's criticism was expressed in a letter to Spinoza well after Steno had begun his clerical career (a translation of Steno's letter from Latin to German may be found in Scherz 1963, p. 279–287, and to Danish in Larsen 1933, p. 114–125). However, in my opinion Steno wants to make it absolutely clear, that Spinoza's attempt to unite religion and science by inferring a foreseeable God ruling nature by eternal laws is a scientifically indefensible idea about the utmost "beautiful" knowledge, i.e., what we are far most ignorant about.

Certainly, it was not Steno's project to unite science and religion, but to seek the truth by both means, independently. However, after Spinoza's *Tractatus* had become broadly known to the scientific community, the idea on *the divine nature of the "eternal" mechanic laws* also became central in the "Newtonian program" (Hallam, 1988). This way of thinking soon led to the philosophy of "necessity" and to the idea that "spontaneity"—or Steno's "free mover" (see above)—is only a result of the human *feeling* of mastering a free will. This idea on necessity almost completely ruled science after Newton and Laplace until Darwin—and even later Bohr in opposition to Einstein—insisted on the reality of spontaneity. First with Charles Sanders Peirce (1839–1914), who's philosophical ideas in many aspects are comparable to Steno's philosophy of science, the idea on "necessity" and *categorical* accuracy and infinite predictability of nature's reactions was rejected on a convincing, but—until our days—unrecognized logical basis (Peirce, 1892).

In Steno's thinking—unlike Spinoza's and the upcoming Newtonian thinking—man's free will and capability to act spontaneously is just as natural as man's capability "of producing results contrary to the usual course of nature," e.g., "of grafting the shoot of one plant on the branch of another." Nature as well as man is not completely tied to "necessity." There is room for freedom. However, we will not be able to understand this capability to act freely, since man "only through a fog is seeing, what he has done, which organs he has been using, and what has been the moving forces of these organs".

For obvious reasons Steno did not know about the upcoming great conflict between the two major branches of science—i.e., the new historic (empiric-narrative) disciplines of biology and geology and the older mathematic (analytic-deterministic) disciplines of physics and chemistry. Steno simply considered Spinoza's ideas to be extremely *arrogant* by inventing a "religion of bodies" claiming a capacity to calculate everything with infinite accuracy. Although Newton's corresponding ideas and foundation of modern mechanics first appeared a few years after Steno's death, the disagreement between Steno and Spinoza should not only be seen as a theological discussion, but merely as a discussion *marking the initial philosophical separation* between the *pragmatic, diachronous* disciplines (e.g., biology, geology, thermodynamics, and genetics) and on the other hand the *categorical, achronous* disciplines (e.g., mathematics, physics, chemistry, molecular biology) (Hansen, 2000a). Spinoza prepared the philosophical basis for such a way of deterministic thinking, and Newton's mechanic laws accordingly to most 18th, 19th and early 20th Century astronomers, physicists, and chemists have followed Spinoza's vision.

However, following Steno's *geological and biological* understanding of the partly chaotic development of the Earth and living creatures' capacity to deviate from foreseeable motions a series of important scientists are "Stenonian" representatives of a diachronous (historical) and pragmatic understanding of nature. This *pragmatic lineage of thinkers* would include scientists such as Leibniz, Buffon, Hutton, Lamarck, Halley, Lyell, Darwin, Boltzmann, Gilbert, Bohr, Monod, Prigogine and Gould and philosophers such as Hume, Kant, Peirce and Popper. On the other hand and in opposition to Steno's way of thinking Spinoza's *categorical thinking* may be seen as a forerunner of a very different "Cartesian" lineage of important scientists such as Newton, Cuvier, Linnaeus, Laplace, Kelvin, Einstein, Hawking and many other influential scientists as well as many philosophers leading to the positivistic school such as Hegel, Marx, Compte, Mach, Russell and Ayer. While the "Stenonian" lineage of pragmatic scientists recognize the existence of chaotic and unforeseeable developments and the sparse capacity of human understanding, the "Cartesian," "Newtonian" and now "Einsteinian" lineage quite successfully tried to maintain a cosmology of divine order and predictability determined at the Creation (or in our days at the "Big Bang").

The "Stenonian" way of thinking cannot be described as a complete departure from the Cartesian philosophy of science (cf. Olden-Jørgensen, this volume), but merely as a revision of Cartesian philosophy. Steno does not reject reductionism, which is the core of Descartes' methodology. Steno merely considers reductionism as a necessary, but insufficient, step toward better scientific understanding. The step to follow reductionism is the understanding of how the individual parts of a complex system work *in coherence* without interference from divine powers or by inferring a "religion of bodies." Science and religion must be kept separate. A philosophy of science like Spinoza's claiming to be able to understand everything on a purely materialistic basis is just as unreasonable as Descartes' understanding of the human brain and use of speculations on interference from inexplicable divine powers.

I have argued that Steno's philosophy of science marks the onset of the dichotomy of the new historic (empiric-narrative) disciplines of biology and geology from the older mathematic (analytic-deterministic) disciplines of physics and chemistry, and that the later growth of this dichotomy is basically related to the scientist's fundamentally different field of research (Hansen 2000a). Scientists dealing with a single set or a coherent set of natural laws tend to be *determinists* believing in complete predictability, whereas scientists working on a more complex basis tend to be *stochacisists* believing in the reality of spontaneity and unforeseeable developments when systems of different origin and history interfere with each other. In terms of geology this will also explain the historic dichotomy between "hard rock" and "soft rock" geologists, i.e., scientists working mainly with endogenous and exogenous processes respectively.

In philosophical terms the problem is related to the problem of predictability, i.e., if there is a complete correspondence between the "endogenous forces" working by physical contact over short distances (chemical forces, atomic forces etc.) and the "exogenous forces" working without physical contact and over great distances (gravity, magnetism etc). In terms of the Earth's history this is basically a question, if there is a complete correspondence "from the beginning of all times" between the endogenous forces mainly defining the developments below the Earth's crust and the exogenous forces mainly defining the developments on top of and above the Earth's crust. If such a completely accurate correspondence exists it would require completely accurate correspondence between gravity and all other natural forces.

If it *could be proven* that such a correspondence *does not exist*, it would give a satisfactory explanation to the fact that the Earth's heterogeneous crust and surface appears to be partly ruled by unpredictable changes, i.e., by interference of endogenous and exogenous forces that have acted independently from "the beginning of all times." However, accordingly to the laws of logic, such a *negative* proof, on what does *positively not* exist, cannot be established. Consequently, the problem if complete predictability can exist in heterogeneous systems is comparable to the Kantian *antinomies* on the impossibility to prove the existence of man's free will and the existence of God!

Why was the philosopher and geologist, but not the anatomist, Steno almost forgotten until 1830?

On the continent Steno's anatomical achievements had brought his name to fame already before he was 25 yr old, whereas other results—including some of the most important anatomical studies—were erroneously rejected. For more than 250 yr Steno's work on muscles were considered to be among his less important—or even misleading—works, although anatomists of the latest part of the 20th Century have come to the opposite conclusion (Snorrason 1986, Kardel 1994a and b). Even the medical doctor and Steno-biographer, Harald Moe had the "old-fashioned" viewpoint on Steno's muscle-theory in his large publication on Steno in 1988, but changed it 6 yr later in the English translation from 1994. Accordingly to Kardel Steno's understanding of the anatomy and function of muscle fibers, muscle fiber bundles and muscle bundles were simply not understood before modern computer technology and modeling of the human apparatus of motion had been applied in training of sportsmen.

Nevertheless, Steno's work on the human heart had made him famous already before he went to Paris in 1665, where he argued against Descartes' and Willis' conception of the human brain. Here, invited by Melchisédec Thévenot and his learned society—a forerunner of l'Academie Royale des Sciences—the young Steno completely peeled the glamour off the renowned celebrities Descartes' and Willis' understanding of the brain's anatomy and functions. This took place in a lecture, which now is considered to be history's first realistic description of the brain (Kardel and Møllgaard 1997)—a lecture, which was also referred to with great admiration by some of the listeners, and which made Steno's name known to the head of the Medici's court, grand duke Ferdinand II.

Also Steno's geological dissertation "De Solido," in which he described the geological principles now known by all student of geology, was recognized and admired by most important contemporaneous naturalists. Already one year after "De Solido" had been published in Latin in Florence, it was translated to English by Royal Society's secretary, Henry Oldenburg, and published in London in 1670. Thus, although Robert Hooke had falsely accused Steno to have stolen some of his discoveries (Yamada 2003), Steno was known for his honesty and was highly recognized by many contemporaneous scientists. Especially, for decades and to his death Leibniz was one of Steno's great admirers as well as his personal friend (see e.g., Vad, 2000).

Reasonably, one could ask why Steno's philosophical ideas did not become better recognized and referred to during the 18th Century and early 19th Century, when many scientists had begun working accordingly to Steno's geological principles and philosophy of science, but mostly without referring to where the ideas came from?

Krogh and Maar (1902), Garboe (1948), Rodolico (1971), Vai and Cavazza (2006), and Morello (2006) emphasize the influence Steno had on his contemporaries and the powerful *but only indirect* effect Steno had on philosophy and geology after his death. After Steno's shift to a clerical career his friends Ole Borch, Thomas Bartholin, and Vincenzo Vivianni had tried to bring him back to science, and especially Leibniz had in numerous letters and otherwise called attention to Steno's work (Vad, 2000). Thus, one could wonder, why many of the most renowned geologists of the 18th Century were applying Steno's geological principles, but without connecting these principles with Steno's name.

In Germany this situation applies to Georg Christian Füchsel (1722–1773), who—building on Steno's principles of superposition and recognition of fossils—made history's first scientific geological map as well as a stratigraphy of Thuringia (see Bert Hansen, 1972). This also applies to Abraham Gottlob Werner (1749–1839), who educated several of the great names of the coming Romantic era e.g., Wolfgang von Goethe, Alexander von Humboldt, and the Dane Henrik Steffens.

In France the controversial "plutonist" Georges-Louis Buffon (1707–1788) emphasized the role of volcanism, but was nevertheless an admirer of Steno's "neptunistic" ideas emphasizing the role of water, whereas Steno to my knowledge is not mentioned by Jean Babtiste de Lamarck (1744–1829) and George de Cuvier (1769–1832), who was afraid of troubles with the church.

In England and Scotland Steno's geological works became known very early because of Henry Oldenburg's translation of "De Solido" to English, and Steno's geological ideas were known to John Ray, William Harvey, Martin Lister, Robert Hooke, William Smith, and James Hutton, whereas Steno's anatomical work and those parts of his philosophy of science, which are expressed in these works, appear to have been less known or unrecognized on the British Isles although several of his anatomical works were translated to English during the 18th Century.

As an important curiosity it should be mentioned, that the famous author Conan Doyle (1859–1930) through his geology teacher, Wyville Thomson (1830–1882) at Edinburgh University had become familiar with Steno's scientific principles and used this basis of *forensic* science intensively in his novels about "Sherlock Holmes" and in his work on "The Lost World" (Hansen 2000a).

Thus, during his own lifetime Steno's geological and most of his anatomical achievements were recognized or known in Italy, France, Germany, The Netherlands and on the British Isles. This applies to his studies of the human glands, muscles and brain and his geological studies, whereas Steno's name and achievements after his death and especially during the 18th Century and until the 1830'ies appear to have been nearly forgotten, although his methods and ideas were broadly applied—except for his extremely modern but controversial theory on muscles.

One reason for the modest recognition of Steno's philosophy of science could be, that his viewpoints to begin with were published fragmentarily; mostly in the introductions to both his anatomical and geological papers. A more comprehensive understanding of Steno's philosophy of science therefore would require scientific interest and knowledge in both anatomy and geology. Steno himself was one of history's last successful polymaths, but such a broad interest and knowledge had become rare or absent among most of his contemporaries.

First in his final scientifically published lecture "Prooemium" (1673), when he was about to shift from a scientific to clerical career, Steno gave a comprehensive and coherent explanation to his philosophy of science. At that time, it was well known, that Steno had converted from Protestantism to Catholicism. Consequently, several of his most important views were erroneously interpreted as results of his religious engagement. Moreover, during the 17th Century's attempts for counterreformations and the 18th Century's Pietism in Northern and Central Europe it was unfavorable or even dangerous to be connected with his name.

Parallel to this religious reservation another reason for the modest recognition of Steno's philosophy of science could be that Steno's previous Protestant belief and new status as a converted, but controversial, Catholic bishop had made his name and ideas difficult to handle in Southern Europe. Although Steno's distinction between science and religion is easy to understand in our days, his letter to Spinoza may illustrate how difficult it must have been to understand and explain his sharp distinctions and inclination to both religion and "godless" science during the 17th, 18th, and 19th Century (Hansen, 2007a).

Therefore, it is most likely that Steno's strictly scientific philosophy of perception and reasoning was simply not understood by most of his contemporaries, may be even deliberately misinterpreted, as a consequence of his subsequent religious career as a Roman Catholic priest and bishop.

Steno's philosophy of science expressed through his geological ideas

During the 17th Century's scientific revolution the foundation of geology as a discipline of science is attributed to Steno and two of his dissertations: *"Canis Carchariae Dissectum Caput"* [Dissection of a Shark's Head] from 1667 and *"De Solido intra Solidum Naturaliter Contento Dissertationis Prodromus"* [On Solids Naturally Enclosed in other Solids] from 1669. On top of that Steno wrote a comprehensive manuscript on geology in the years after 1669. This manuscript was handed over to his pupil, Holger Jacobæus, Copenhagen University's first professor of geography, but was never printed. It disappeared, probably during one of Copenhagen's devastating fires (Garboe 1948 and 1960). From their time together in Hanover Leibniz knew of the existence of this comprehensive manuscript and after Steno's death he wrote to several people, who might know where it had gone, but without any luck.

However, despite the two printed and very important dissertations Steno's name was almost forgotten among geologists from 1700 to 1830. His geological fame was first revived in the beginning of the 19th Century by Alexander von Humboldt, who rediscovered "De Solido" in 1823, and brought it to the attention of Charles Lyell and Elie de Beaumont—the founder of the first geological survey of France. Thus, at the Second International Geological Congress held in 1881 in Bologna, Steno was celebrated as a founder of geology (Vai 2004). A century later, in 1953, Steno's body was placed in a marble sarcophagus in a chapel of the San Lorenzo Cathedral in Florence.

After studies in Copenhagen, where he was born and grew up, Steno's short but highly productive scientific career began in Amsterdam with a thesis on the nature of heat ("De Thermis," 1660) and soon after doctoral theses on anatomy in Leiden. Busy as always he did not take time to wait for his doctoral celebration, but went to Paris and Montpellier. Soon Steno's studies of the glands, the lymphatic system, the brain and the muscles brought his reputation to the highest level already before he reached the age of 25 yr. On the recommendation of M. Thevenót, who had invited Steno to Paris to give a lecture on the brain, Steno's name also became known to the head of the Medici court in Tuscany, grand duke Ferdinand II. He invited Steno to Florence, where the grand duke's brother, cardinal Leopoldo, invited Steno to become a member of Accademia del Cimento.

The onset of modern geological thinking

Briefly after Steno had come to Florence a giant shark was caught off the west coast of Northern Italy and brought to Livorno. Here the giant shark caused great public attention, and came to the grand duke's knowledge. Inspired from Steno's anatomical studies Ferdinand II asked Steno to dissect the shark. During the dissections Steno noticed the resemblance between the shark's teeth and "glossopetrae" (tongue stones), i.e., solids resembling teeth from sharks, but often found in rocks far above or far away from the sea. This seemingly discrepancy between the anatomy of "glossopetrae" and their occurrence in rocks had made many scholars believe, that what we now call "fossils" were growing in the rocks.

However, Steno's combined studies of "glossopetrae" and his dissection of a giant shark's head gave him a better explanation: Solids, which in all visible aspects look like parts of living animals, but found enclosed in rocks even far above or far away from the sea, nevertheless should be regarded as remnants of former life on Earth. In order to come to this *actualistic* viewpoint Steno formulates six "conjecturae" based on refutations (Steno, 1667). As discovered by Kardel (1994a) and as discussed in Hansen (1997, 2000a and 2005) this way of reasoning is very similar to the 20th

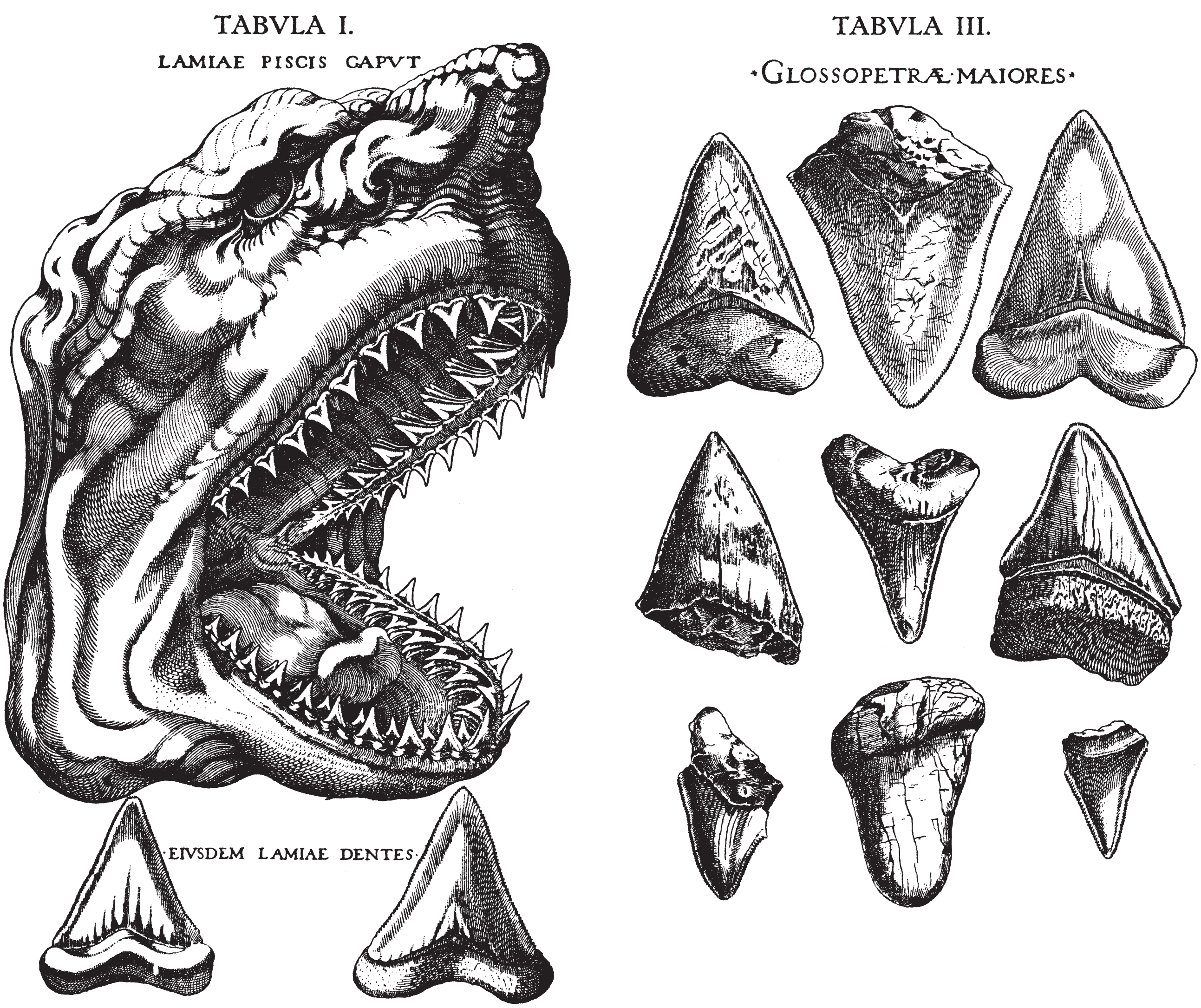

Figure 5. Drawings from Steno's Canis Carchariae Dissectum Caput (1667), where he - on the basis of the complete similarity between the teeth in the mouth of a newly caught giant shark (Fig. 5A, to the left) and "glossopetrae," i.e., "tongue stones" found in rocks far from and far above the sea (Fig. 5B to the right) – postulated that such fossils are not "growing in the rocks" but are remnants from former life in the sea. This new conception of "glossopetrae" and other marine fossils found in the mountains would anticipate that the Earth had undergone huge changes since the fossils had been deposited on the sea bottom.

Century philosopher, Karl Popper's more general arguments for a revision of the late 19th and early 20th Century's positivistic philosophy of science. Popper (1963) proposed a revision to what has now become our time's most prominent philosophy of scientific reasoning, and what is now known as *refutation positivism*. Kardel (1994a) has pinpointed several identical expressions and rare words in both Steno's and Popper's philosophy of science. Steno's prerequisite to his "conjecture and refutation" arguments—which is most clearly expressed in his next geological dissertation—can be formulated in this way:

Similar things are produced in similar ways and in similar surrounding. The laws of nature are unequivocal and unambiguous. The laws of nature ruling the present, have also ruled the past. However, natural processes can obliterate as well as preserve evidence. Consequently, we must to some extent build scientific reasoning on conjectures and refutations by evidence.

Therefore, since "glossopetrae" in all perceivable aspects are similar to living sharks' teeth, it is a reasonable conjecture, until it may be refuted by evidence, that they have been produced as shark teeth i.e., in sharks living in the sea, and not by growing in the rocks. Moreover, since things produced in the sea may now be found far above and far from the sea, it is a reasonable conjecture that huge changes of the Earth have taken place after the Creation.

Steno's cognition criteria

In order to come from his theory of "conjecture and refutation" as expressed in *"Canis Carchariae"* to the more demanding philosophical prerequisites in *"De Solido"* Steno realized, that his findings about the huge historical changes, which the landscape of Tuscany had undergone since the Creation, would not be believed, unless he would be able to build on indisputable *cognition criteria*. In order to convince others these criteria should also create a logical basis for the geological principles on which his findings were based. I have proposed that this basis for Steno's philosophy of science and geological principles should be named *Steno's three cognition criteria* (Hansen, 2000a). Steno's cognition criteria include:

1. The chronology criterion
2. The recognition criterion
3. The preservation criterion

Chronology criterion

The chronology criterion claims, that the structural relation of two solid bodies in firm and generative contact will always reveal, which body has been formed first, and which body has been formed last. This criterion is in practice identical with Steno's geological principles of superposition (see below) by means of which it is possible to establish the chronological order of a series of geological and any other structural event. In "De Solido" the chronology criterion leads to two principles: The principle of shaping (molding) and — although not explicitly formulated — the principle of intersection. The two principles can be formulated in one sentence:

When a solid structure is in generative contact with another solid structure, is that structure youngest, which takes form from the other, or which intersects the other.

Here it should be mentioned, that Steno does not explicitly applies the word "intersection"—and thus he cannot be considered to founder of the Huttonian principle of intersection. However, Steno clearly applies the principle e.g., in the reconstruction of Tuscany's geological history. The term "fault" had not yet been invented, and Steno applies the term "broken strata" ("ruptorum stratum") when he e.g., speaks about the origin of mountains (see Scherz, 1969, p. 167).

The chronology criterion is not only valid in geology, but is omnivalid for any structural generation or change of solid material and implies, that only two possible types of generative contact relations can exist in solid material:

1. Conformity: Already existing structures shape younger structures in contact with the older structures.
2. Disconformity: Already existing structures are modified by forces creating younger structures.

These two criteria are axiomatic principles known and used by all students of geology. However, the meaning of structural conformity and disconformity is much deeper philosophically speaking.

The *conformity criterion* is practically a criterion on how to identify *growth* (see the principle of growth below), but philosophically speaking the criterion is merely an axiom saying, that it is always possible to identify *domainal change*, i.e., *effects of intrinsic forces* acting in the revealed domain of structures itself (Hansen, 2000a).

The *disconformity criterion* on the other hand is practically a criterion on how to identify reduction and modification, but philosophically speaking the criterion is merely an axiom saying, that it is always possible to identify *extra-domainal change*, i.e., *effects of external forces* acting outside the revealed domain of structures (Hansen, 2000a).

However, the philosophical importance of the chronology criterion is first and foremost, that it allows the observer *to distinguish between effects and possible causes.* Since causes always precede effects, the chronology criterion—and in practice the principles of superposition—forms a purely logical basis or, more correctly, an axiom saying, that it is possible on a purely structural basis to distinguish possible from impossible causal explanations. No empirical observation has ever contradicted Steno's chronology criterion.

Recognition criterion

Steno's recognition criterion claims, that similar things are produced in similar ways and in similar surroundings. While Steno's viewpoint on "glossopetrae" in "Canis Carchariae" was an inductive *principle of generalisation* calling for evidence by conjecture and refutation, he comes to a much deeper viewpoint on induction in "De Solido." His way of thinking is simply to pose the question, how a scientist should argue, when he is confronted with something he cannot explain without inferring a thoroughly hypothetical theory? In such cases induction by generalisation gives no meaning. Therefore, the scientist to begin with must find something in the inexplicable, *which is similar to something he knows what is*. He must *recognize* before it becomes meaningful to induce a hypothesis. Steno understands that induction is constituted by two separate cognitive forms, *recognition and generalisation*, and that recognition is a necessary prerequisite to generalisation.

But what is recognition? Steno does not explain this in a perceptive sense in "De Solido" although he four years later in "Prooemium" comes to a nearly Kantian theory on perception, where he distinguishes between things by themselves, sensing of things, and perception of things. Instead Steno takes another route of arguments, namely that nature everywhere and to all times must be ruled by the same laws. Although more or less unknown *the laws of nature are*—per se—*unequivocal and unambiguous.* And the laws now in action have also been in action in the past. Consequently, similar things are produced in similar ways and in similar surroundings. Steno concludes in "De Solido" in this way:

"If a solid body completely resembles another solid body, not only with respect to its surface, but also with respect to the arrangement of its inner parts and particles, the two bodies will also resemble each other with respect to their way of production and place of origin …"

(My translation. Steno's original text may be found in Scherz [1969, p. 150] and also A.J. Pollock's slightly different translation to English [p. 151])

I have called this axiomatic statement *Steno's recognition criterion* because it is not only relevant to fossils and other geological phenomena, but was meant by Steno as an omnivalid criterion in order to understand how nature basically works. Gould (1981) states, that this marks the beginning of *generative classification*. It means that similar things are produced in similar ways, and different things in different ways. In philosophical and cognitive terms the criterion is also an axiomatic statement defining the basic relation between recognition and generalisation, i.e., the fundamental criterion of induction (Hansen, 2000a).

A strikingly similar idea on "analogic proportion" is expressed app. 200 yr later by Gilbert in 1886 (p. 287), apparently independent of Steno's "De Solido." Baker (1996) discussed Gilbert's statement in the context of modern pragmatism and thus links this basic geological principle to Peirce's semiotic philosophy of science.

Preservation criterion

What I have called Steno's preservation criterion was not explicitly described by Steno in "De Solido," but more philosophically in "Prooemium" (Hansen, 2000a). However, all of Steno's writings in "De Solido"–especially, his back-stripping of Tuscany's geological history including periods of erosion—clearly indicate that Steno from his geological studies is fully aware, that not only the geological record is incomplete, but also the human capacity to perceive the world. However, despite this deficit the human mind is often able to perceive, if something is missing—not exactly *what* is missing, but *that* something is missing. I have argued, that Steno's way of thinking builds on the fact, that

information can only be preserved as solid structures in solid material, whatever the material containing the structures are e.g. crystalline, sedimentary, biological or—in the arts and humanities—e.g. music preserved in the orientation of magnetic crystals in the tape recorder, or historical information preserved in the structure of ink on paper etc. Information will be lost for any certain cognition, when the solid material containing the solid structure is dissolved, dispersed, eroded away, disintegrated or burnt, i.e. is transformed from a solid to any other state.

The reason for this problem of preservation and imperfect possibility to know all about the past is—accordingly to Steno—that "the smallest parts" of all matter are in "inner revolt," when the matter is not in a solid state. Although in other words and more fragmentarily Steno explains, that the "smallest parts" of solid bodies may not be completely calm because of the heat, they cannot change position, or, if they change position they will immediately be substituted by other parts, so that the structure is preserved. But when a solid body melts, burns etc. all "the smallest parts" come in "inner revolt" and will constantly change positions. Consequently, solid structures—i.e., informative signs—can only exist "untouched" by later movements in solid material.

Because of this partly perfect and partly imperfect state of nature's storytelling, we cannot argue in the same way, when we deal with preserved strata and structures, and when we deal with unpreserved parts. Therefore, we have to reason (speculate, conjecture) on lost information. However, our understanding is not completely naked and speculative, when the direct information is gone. Other (always disconformable) structures show if relevant parts are missing of a more complete record. For instance, Steno's geological principle of lateral continuity (see below) shows, that pure speculation on missing parts is not allowed. Not all speculations are relevant.

This way of thinking is also the basis for Steno's conception of, what is *"far most beautiful"* (see above). In "Prooemium" four years after "De Solido" Steno finally comes to an understanding on how to approach the truth, when the information "escape the senses" i.e., is lost or is unperceivable. I repeat: "Far most beautiful—although escaping the senses—is what [nevertheless] can be approached through reasoning about what the senses have already [or elsewhere] perceived" (for context and references, see previous discussion).

Steno's principles of understanding natural change and the geological history of the earth

In "De Solido" Steno formulates a series of basic criteria for geological reasoning, now used by all students of geology. Here he goes much deeper and farther than in his first geological dissertation "Canis Carchariae." Hence, in 1669, he realizes, that his studies of Tuscany have revealed that the Earth has a complex, partly readable and partly unreadable history. Especially, the time-question is unsolved. Although he speculates on the seemingly very short time available between the ancient, pre-Roman Etruscan cultural artifacts found on top of the deposits of Volterra, which again superpose all the even older strata of Tuscany, he retreats from further speculation on the age of the Earth. Nature shows the chronology of changes, but about the time-question "nature is silent," "only the Scripture speaks."

Steno also realizes, that he might be misunderstood by others to be contradicting Genesis in the Holy Scripture, and that most likely nobody is going to believe him, unless his findings are based on uncontradictable logic reasoning, and evident empirical findings.

In his path to the fundamental criteria of cognition (see above), Steno lines up his basic ideas on how nature works. Besides the idea of nature speaking with one voice—what Lyell app. 150 yr later called the *actualistic principle*—these ideas can be summarized in two general *principles for natural change*: the principle of motion, and the principle of growth

The principle of motion

All kinds of natural motion take place by

1. *movement [location or dislocation]* (as when a ship sails or an animal runs),
2. *liquid [or gaseous] flow* (as when the water runs in a river), and
3. *[diffusion] the "hitherto unknown cause of motion"*

(My contraction of [and explanations to] Steno's original text in "De Solido." Find original expressions in the relevant contexts in Scherz (1969, p. 152–159)).

Here it should be noted, that Steno in his thesis, *De Thermis*—which had disappeared and whose content was therefore unknown to the scientific community until it was found in 1959 in Philadelphia by Gustav Scherz—had concluded, that "Heat originates from motion. Yes, certainly heat originates from motion!" (Scherz, 1960). This very early understanding of the nature of heat in combination with Steno's description of the locked motion of the "the smallest parts" in solids shows that "the third and hitherto unknown kind of motion" is what we now call diffusion. Steno's very early conception of heat also shows that he used reasoning at all spatial scales (Rosenberg, 2006). What could not be observed directly, or by "dissection," had to be understood by combination of reasoning and what elsewhere could be observed by analogy (cf. the expression "But far most beautiful—although escaping the senses—is what can be approached through reasoning about what the senses have already perceived," see above).

The principle of growth

All kinds of growth take place by superposition or increment of particles on a solid surface from a liquid (or gaseous) phase, whatever the growth concerns

1. sediments,
2. crystals, or
3. living organs.

(My contraction of Steno's original text in "De Solido." Find original expressions in relevant contexts in Scherz [1969, p. 152–159 and 172–181]).

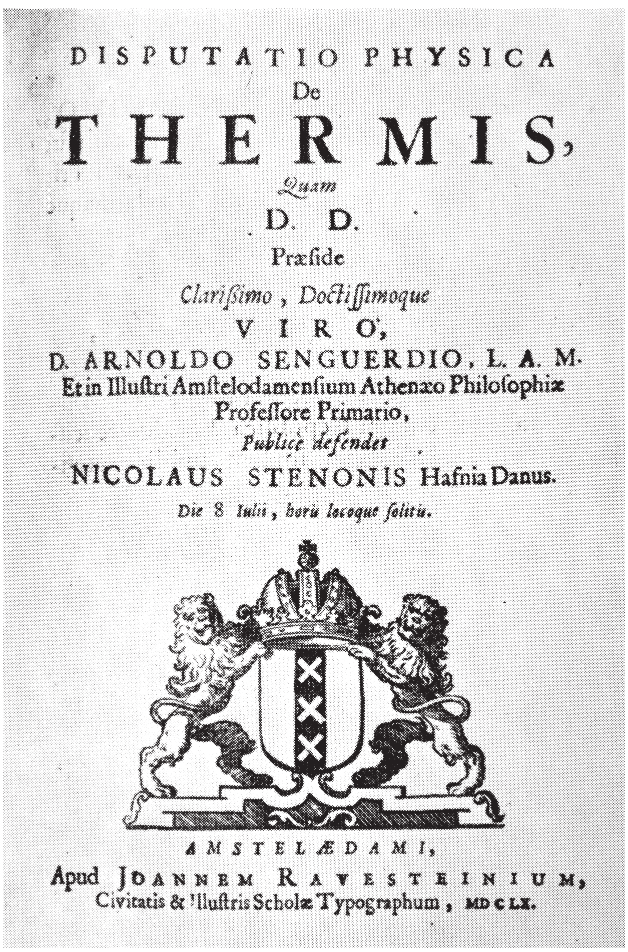
DISPUTATIO PHYSICA
De
THERMIS,
Quam
D. D.
Præside
Clarißimo, Doctißimoque
VIRO,
D. ARNOLDO SENGUERDIO, L. A. M.
Et in Illustri Amstelodamensium Athenæo Philosophiæ
Professore Primario,
Publicè defendet
NICOLAUS STENONIS Hafnia Danus.
Die 8 Iulii, horis locoque solitis.
AMSTELÆDAMI,
Apud JOANNEM RAVESTEINIUM,
Civitatis & Illustris Scholæ Typographum, MDCLX.

Figure 6. Front page of Steno's first - and least known - dissertation De Thermis (a student work from 1660).The dissertation had disappeared and its content was therefore unknown to the scientific community until it was rediscovered in 1959 in Philadelphia in USA by Gustav Scherz. In De Thermis Steno concluded, that "Heat originates from motion. Yes, certainly heat originates from motion!" which statement in the present author's opinion clearly relates to Steno's new fundamental ideas on motion as expressed in De Solido nine years later: Heat is the "third and hitherto unknown cause of motion" and may result in what we now would call diffusion.

Introducing the principle of growth Steno explains: "Additions made directly to a solid from external fluid sometimes fall to the bottom because of their own weight, as is the case with sediments; sometimes the additions are made from a penetrating fluid that directs material to the solid on all sides, as is the case of incrustations, or only to certain parts of the solid, as is the case of those bodies that show tread-like forms, branches, and angular bodies [crystals]" (Translation by Pollock in Scherz [1969, p. 153]. My explanation in brackets).

The third statement is also remarkable. In a *geological* dissertation Steno makes a series of anatomical statements inspired from his geological findings. First Steno explains his new finding on the threefold compartment of the living body's liquids: (1) liquids in "outer" rooms such as the digestive system, (2) liquids in vessels such as the veins and the lymphatic system, and (3) interstitial liquids. On the basis of this anatomical knowledge Steno explains about the nature of growth, that many parts of the human body—which may appear to be "inner" or even the "innermost" parts of the living body—in reality consist of "outer surfaces," which are connected to the outer world directly or through "filters." This applies e.g., to the digestive system, the lungs, the glands, the kidneys, the blood vessels, and the lymph system. Therefore, *even growth of the "innermost" parts at the very end is caused by addition of originally external substances to a pre-existing surface.*

Basic principles for geological interpretation

Having explained these general and breathtakingly clear prerequisites for a natural conception of biological and geological change Steno has finally come to formulate the *geological principles* known and applied by any later student of geology. Steno's five principles for geological interpretation are all *purely structural*. They explain how to interpret the structural *"signs"* laid down by natural processes in solid material (crystals, rocks, strata, sequences of strata, landscapes, mountains etc.), where these "signs" on contemporaneous processes or later changes have been preserved. Thus, Steno's geological principles may be considered to be history's first stringent contribution to structural interpretation at all scales or a general *"geo-semiology."*

Steno's geological principles consist of five general statements forming his basis for geological reasoning. These five principles can be described in this way:

1. *The principle of horizontal layering:* Geological strata have originally been deposited horizontally or nearly horizontally. Strata in other positions have been tilted

or otherwise deformed by later events.

2. *The principle of lateral continuity:* Similar geological strata on either side of a valley or another disrupting structure were originally coherent and continuous.

3. *The principle of superposition:* In a series of strata the lowermost strata are the oldest and the uppermost strata are the youngest.

a. *The principles of shaping (or molding):* A geological body shaping another body is older than the body it shapes. A geological body, which takes shape from another body, is younger than the body it takes shape from.

b. *The principle of stratigraphical up and down:* When strata are inclined, vertical or folded the original order of deposition can be found by the help of the principle of intersection (se below).

4. *Application of the (later) Huttonian principle of intersection:* Any geological structure cutting through another geological structure is younger than the structure it is cutting through. Any geological change or changing agent is younger than what has been changed. Steno does not formulate this principle explicitly. However, the principle—as well as the principle of stratigraphical up and down—follows implicitly from the *principle of shaping* if we, e.g., consider that a fault or any other penetrating geological structure actually shapes pre-existing strata and structures. Steno's application of a principle of intersection is particularly clear in his formulation of the principle of reconstruction (see below).

5. *The principle of reconstruction (or back-stripping):* Nature's geological history can be described by stripping off the youngest strata and events and thereby reconstruct the original state of the next youngest geological strata and events. Having reconstructed the next youngest strata and events the original state of the third youngest strata and events can be reconstructed. By such continuous "back-stripping" the original state of the oldest strata can be reconstructed. Now, by knowing the original states of an area's strata, the area's geological history can be reconstructed in chronological order of cause and effect.

Besides these general principles for geological reasoning Steno's drawings show the *law of angular constancy of crystals* (known as Steno's law). This law—which in my opinion merely should be understood as a principle of crystal growth (see above)—to some extent may be inspired from Erasmus Bartholin's (father to the anatomist Thomas Bartholin) work on double refraction in Icelandic calcite and Kepler's little paper on hexagonal snow flakes. However, Steno understands in opposition to Erasmus Bartholin and Kepler, that "the smallest undividable parts"—the atoms—may belong to many different kinds with respect to size or shape or forces of attraction (cf. Schneer, 1971), since crystals are not only hexagonal, trigonal or cubic as they should be, if crystals are formed only by identical atoms. Steno's drawing shows, that crystals also can be less symmetric i.e., rhombic, monoclinic and triclinic, which should only be possible if atoms are of several different categories.

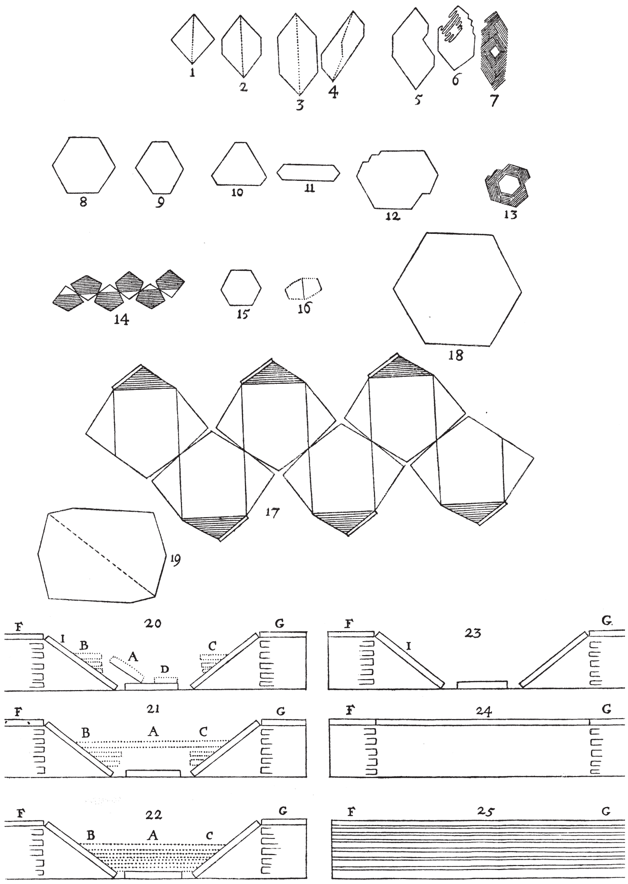

Figure 7. Steno's drawings from De Solido (1669), where he in the upper part of the figure illustrates the angular constancy of quartz and haematite crystals as well as growth lines in crystals (no. 7 and 13). In the lower part of the figure Steno illustrates his principle of reconstruction by "back-stripping" (no. 20–25). The present stage is represented by no. 20. By use of the geological principles he just has described and by careful studies of the actual structural relations one can identify the youngest event that has led to the present stage. By stripping the youngest event off one can reconstruct the next youngest situation (no. 21). By continuing this procedure one can peel off still older events (no. 22–24) and reconstruct the original situation (no. 25). Having done all this by careful structural studies of the present situation one can reconstruct the history beginning with the oldest known stage (no. 25) and continue through all the younger known stages (no. 24–21) and end with a historic understanding of the present (no. 20).

Conclusion: oblivion, revival, and misunderstandings of Steno's philosophy and geology

Steno's modern philosophy of science—often most elegantly described in his anatomical works—is an important basis for his geological achievements. His philosophy of science should be considered to be among the earliest, clearest and most stringent contributions to the onset of the rationalistic, historic and perceptionalistic way of thinking as it contemporaneously evolved from Steno's friend and admirer, G.W. Leibniz, as it evolved 80 yr later from Immanuel Kant in the 18th Century, and some 200 yr later from Charles S. Peirce in the 19th and 20th Century and 250 yr later from Karl Popper in the 20th Century.

However, in most modern literature on the history of geology and on the philosophy of science Steno's name and importance is hardly mentioned nor recognized. Some of this oblivion may be explained with Steno's nationality as born in a declining and small country (Denmark-Norway) and by his career in ascending and more important countries (The Netherlands, France and above all Italy). This contrast between nationality and career did not make his name useful in the scientific competition between the new upcoming national states of Europe during the coming two centuries.

Moreover, all of Steno's scientific writings are—with one exception—in Latin, which language already was losing power less than 50 yr after Steno's time. Larsen (1933) and Kragelund (1976) mentions that Steno's Latin language is of great beauty and poetic value, and that translations to other languages cannot give justice to Steno's texts. Translations therefore, may have seemed too difficult to most Latin philologists. Whatever the reasons were, only few of Steno's scientific works were translated to "modern" languages before during the 20th Century, when Latin had become unreadable to most scientists. Thus, one might say, that there is a "hiatus" of up to 200 yr, where Steno's writings were inaccessible to most scientists, and especially to students of natural history.

In England on the other hand Steno's "De Solido" was translated immediately from Latin to English by Henry Oldenburg, secretary of the newly created Royal Society. However, Oldenburg was falsely accused by Robert Hooke to have stolen Hooke's geological ideas and given Steno the credit. This absurd conflict to some extent has given rise to some unreasonable doubt on Steno's merits in the English speaking world.

Consequently, the national pride which has brought many names of less brilliant scientists to greater fame did not apply to Steno. Nevertheless, Steno's geology, methodology and philosophy of science was broadly applied in Italy, England, France and Germany, and his geological principles are in daily use by all of present days' students of geology. But contemporary and younger scientists did not know, refer to, or dare to mention, where their geological methods came from until Humboldt, Lyell, and Elie de Beaumont drew attention to Steno's name in the beginning of the 19th Century. Soon after Steno was celebrated as the founder of geology under the Second International Geological Congress in Italy.

However, the most important reason to the oblivion of Steno's geology until 130 yr after his death could be his religious conversion as it may also be the case for his philosophy of science. During the counterreformations of the 17th Century, Steno's conversion from Protestantism to Catholicism could even endanger or discredit users of his geology and philosophy of science just by referring to his name in Northern Europe—certainly in Protestant controlled parts of Germany and in Denmark-Norway. And in Italy, France and Catholic parts of Germany Steno's conversion to Catholicism and status as a former Protestant also made his name somewhat dubious. Thus, it should be understood, that some fear of religious consequences may have been related to the use of Steno's name in Protestant as well as in Catholic parts of Europe. This certainly applies to Steno's short scientific career in Denmark, where he for formal religious reasons could not become professor at the university, and where the king instead appointed Steno as "royal anatomist" *(anatomicus regius)* from 1673 until Steno definitively left science two years later.

When Steno in 1675 became a Catholic priest and from 1677 titular bishop of the no more existing city, Titiopolis of the fallen East Roman Empire, many contemporary and younger scientists have misinterpreted Steno's departure from a scientific career as a rejection of science. That is a widespread misunderstanding. To his death Steno considered *scientific knowledge to be the highest praise to God*, and he claimed that religious speculations should not have authority above scientific arguments. Leibniz deeply regretted Steno's change of career and urged him several times without luck to reconsider his decision. Leibniz wrote many letters to influential persons in order to make them convince Steno that he should return to science. However, among scientists of the 18th Century this interference from Leibniz, and Steno's insisting on his new religious career, may also have contributed to the misunderstanding, that Steno had rejected science.

Finally, it should be mentioned that two of Steno's most learned biographers, the Protestant priest and historian of Danish geology, Axel Garboe, and the philologist Knud Larsen nevertheless interpreted Steno's most cited expression on the threefold levels of knowledge ("Beautiful is what we see" etc.) as a ladder from scientific to religious understanding. Steno's own explanation of this famous maxim was given by himself in 1673 and separates clearly his modern philosophy of science from religious arguments.

The misleading viewpoint on Steno's ladder of knowledge may also be caused by misunderstanding of the Danish philosopher, Anthon Thomsen (1877–1915). Thomsen (1910) saw a parallel *personal* development in Steno's change of curriculum with another famous Dane, the psychology- and moral-philosopher Søren Kierkegaard (1813–1855). Through their lives they both became more and more inclined to a religious-existential way of living, and they both died before the age of 50 after they both had reached outstanding scientific results. However, a juxtaposition of Steno's and Kierkegaard's ladders is unreasonable and misleading. The two ladders do not at all deal with the same matter. Steno's ladder describes three levels of perception and scientific reasoning, whereas Kierkegaard's ladder describes three stages in a person's psychological development: *an aesthetical, an ethical, and a religious stage*.

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