Nicholas Steno's *Chaos* and the shaping of evolutionary thought in the Scientific Revolution

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ABSTRACT

Nicholas Steno (1638–1686) compiled a notebook in 1659 when he was a student at the University of Copenhagen. Titled *Chaos* by Steno, it remains unstudied in English-speaking countries, despite having been translated in 1997. *Chaos* adds important insight into geology's place in the Scientific Revolution. It shows Steno disengaging from speculations about the cosmos based on the ruling paradigms of Aristotelian metaphysics and Cartesian misconceptions in favor of an empirical model based on the new mathematics of geometry applied to all of nature, from what we now would consider the atomic level, to the human body, and to the planet. Steno thereby earns heretofore unacknowledged credit for helping to establish the geometric definition of form that makes it possible to understand the evolution of the structure of organisms as well as of the planet.

Keywords: Nicholas Steno, Scientific Revolution, history of geology, René Descartes, Francis Bacon, evolutionary theory, fractionation.

INTRODUCTION

Nicholas Steno's *Chaos* (1659) is a ''rare document revealing how a genius prepares for his task,'' to quote Jesuit scholar August Ziggelaar (1997, p. 11), who was the first to translate the manuscript into English. The document remains largely unstudied in English-speaking countries, yet it is one of the most important documents on the origin of modern geologic thought that has ever come to light.

Ziggelaar's translation of *Chaos* affords English-speaking historians of geology an unparalleled opportunity to witness Steno sifting and winnowing some of the great ideas of the period spanning the Renaissance of the fifteenth century to the Scientific Revolution of the seventeenth century, arguably the most seminal period of Western cultural history.

Chaos (Ziggelaar, p. 21) opens with a quote from Dutch physician Cornelius Schylander, who rejected the Aristotelian idea that earth, air, fire, and water are the four elements that constitute the human body: ''That man is composed of the four elements is against Holy Scripture, where Moses only mentions water and earth. For Aristotle's air nowhere appears and fire is an accident. For coal put on fire differs only accidentally from coal not on fire and bodies are only resolved into water and earth.''

In leading off with this excerpt, Nicholas Steno decisively rejected the Aristotelian thinking of the scholastics (academics) in favor of a concept of nature more consistent with Biblical scripture. Thus, *Chaos* establishes that Steno was focused in his spirituality, although, as his own subsequent history would prove, not steadfast in the religion into which he was born.

Chaos is not, however, a zealot's polemic. It shows Steno intent upon replacing Aristotelian philosophy with an empirical view of nature framed geometrically. A structured cosmos was perceived to be harmonious and evidence of God's omnipresence, an idea that had been expounded earlier by Leonardo da Vinci and other Renaissance artists (Rosenberg, 2001).

So highly did Steno value geometry that he applied it to measure the validity of all that was presumed about nature at all scales, ranging from what we would now term the molecular level to that of the cosmos. Examples include the structure and arrangement of constituents of water, air masses, organs in the body, and materials in the Earth. ''To tackle the physics of medicine without geometry is to sail over the ocean without a compass,'' Steno recorded in *Chaos* (Ziggelaar, 1997, p. 362; after anatomist Jean Pecquet): he also complained (p. 363, also after Pecquet) about scholastics whose disdain for mathematics and observation led them to Aristotelian speculations that ''never came nearer to nature.''

The reference to the ''physics of medicine'' portends Steno's renown as an anatomist. Steno discovered the parotid salivary duct, described the anatomy of the skulls of sheep, shark, and cow, understood the fine structure of muscle, and recognized that the heart is a muscle. He would also become the first ''anatomist of the earth'' (Rosenberg, 2001; Cutler, 2003) and establish the structural premise of geology in his *Prodromus* of 1669 (Winter, 1916) with his statement of superposition, original horizontality, and lateral continuity. Yet, in *Chaos*, one sees that Steno already recognized that the human body is not a microcosm for the Earth or greater cosmos. He began to understand that the Earth is a furnace whose heat boiled water, stone, and metals to the surface, an important first step to understanding fractionation, the overarching theme of modern geology. However, and in contradiction to René Descartes, he began to see the flow of blood as analogous to the flow of a river, not as emanations from a heart that is an oven warmed by the passions of the soul.

HISTORY AND NAME OF THE NOTEBOOK

Steno wrote *Chaos* in 1659 during his last months of study at the University of Copenhagen. It contains no obvious statement of the stratigraphic principles of geology that he would publish in his *Prodromus*. It is not a diary. It is a compilation of excerpts from and references to the writings of many of the great minds of the Renaissance and Scientific Revolution as well as to their antecedents. In addition to Descartes, they include Harvey, Kepler, Paracelsus, Bacon, Borel, Kircher, Borch, Galen, and Aristotle. Steno annotated many of these, so the document offers direct insight into his thinking.

Steno named his notebook *Chaos*. The title may refer to the diverse contents and to their apparently haphazard organization, but it also refers to two ideas of Paracelsus (Ziggelaar, 1997, p. 15): first, ''chaos'' is the watery primordial matter from which God created everything and, second, ''chaos'' is the ''. . . great mystery of the world. A dead body returns to its place of origin: the chaos of the air of the higher and lower firmament.''

''Chaos'' is also the root of the word, ''gas.'' At the time ''gas'' was not yet recognized as a third state of matter and, instead, the term had metaphysical significance beyond the modern understanding of material that is neither solid nor liquid (Ziggelaar, 1997, p. 15).

Gustav Scherz discovered the document in Florence in 1946 (Ziggelaar, 1997, p. 11). He and others subsequently attempted to organize and translate it, but the English translation was completed by Ziggelaar in 1997.

CHAOS AS WUNDERKAMMER

The diverse subject matter of *Chaos* includes magnetism, the composition of gold, the Earth as chemical oven, the circulation of blood, the nature of heat, the flow of air masses, the behavior and structure of light, the dissolution of solids in water, earthquakes, the formation of mines and metals, the motion of the planets and the sun, and many others. *Chaos* also reveals Steno's interest in curiosities of nature, in

Figure 1. Bladder stone framed in silver, weighing 140 g (from Catherine Meltzerin, dated August 9, 1647, her date of death). Photo: Camilla Mordhorst, Medical Museum, University of Copenhagen.

ethics and the moral implications of nature, in artisanal objects, iatrochemistry, and alchemy. Iatrochemistry was a seventeenth century philosophy that sought analogs of physiological processes in chemical reactions then known. Although today we think of alchemy as a misguided search for the means to transform base metals into gold, by the seventeenth century it was more generally concerned with the structure and transformations that all matter undergoes and for ways to use natural substances for human benefit; in *Chaos* Steno did speculate on the constituents of gold and how they must be arranged to create gold.

Although the manifold subjects of *Chaos* seem to be unrelated today, the seventeenth century mind juxtaposed nature in all its permutations and combinations as a way of identifying commonalities underlying the entire cosmos. What constituted evidence for this unity was ill defined and metaphysical and it was held as evidence of God's design. Steno subscribed to this philosophy, as shown by his quote (Ziggelaar, 1997, p. 116) from Athanasius Kircher: ''The key of nature: there is one key of nature; only he who embraces the unity in most different matters . . . must be judged to have found it.''

All of this makes *Chaos* a wunderkammer of sorts. Translated from German, wunderkammer means room of curiosities, a room or cabinet that held an array of naturalia and/or art objects. Wunderkammer flourished through the sixteenth and seventeenth centuries and were precursors to modern museums. Because the modern geometric view of nature was not resolved in the seventeenth century and nature was still encumbered with Aristotelian preconceptions, many subjects in *Chaos* and most objects in wunderkammer conveyed multiple meanings.

One of the most famous wunderkammer in Europe was that of Ole Worm, a Dane who ultimately sold his collection to the King of Denmark. Steno wrote (Ziggelaar, 1997, p. 179) that he saw the wunderkammer; in his travels throughout Europe he undoubtedly saw others that contributed to his development as a polymath. How Ole Worm's wunderkammer sheds light on the logic underlying the diverse contents of *Chaos* is discussed in the Appendix[1], but one example is especially relevant here. Bladder stones such as the one framed in silver in Figure 1 were common in wunderkammer and they are mentioned in *Chaos* in a quote that holds extraordinary meaning for the history of geologic thought (and for Steno's own life; he died of self-diagnosed complications from kidney stones). It exemplifies the seventeenth century analogy of human body as a microcosm of the Earth. Steno quoted Pierre Borel (Ziggelaar, 1997, p. 46): ''That seas change their beds: Singular stones of the bladder, shells turned into stone. Therefore stones in places that lie very far from the sea, it is certain that seas change their beds. In the right kidney a grey stone was observed, in the left kidney clay.'' Stones grow in the fluid of the bladder and the fluid of the kidney. Shells, too, grow in fluid. Therefore, dry sediment that contains shells and now is far from the sea must once have been covered by the sea. Steno never relinquished his belief in the universal deluge as agent of deposition, but he rejected the Aristotelian idea that plastic forces shaped shells in the Earth from the sediment that contained them. His rationale was again geometric (Rosenberg, 2001); what we now know to be fossils are not composed of the sedimentary material that surrounds them and so they must have been formed by animals living in the sea, just as they are today.

Thus, one is witness to Steno's sifting and winnowing of Aristotelian ideas through a fine geometric mesh in *Chaos*, and the process prepared him for publication of his *Prodromus*, or preface, to his planned *Dissertation Concerning A Solid Body Enclosed by Process of Nature Within a Solid.* The latter is the subtitle of *Prodromus*. What is not generally known is that Steno helped to redefine the Aristotelian concept of ''form'' with his geometric model of nature, and that this led to the establishment of more than modern geological thought in particular, but also to modern evolutionary thought in general.

CHAOS AND FORM

Scholastics of the sixteenth and seventeenth centuries concerned themselves with the Aristotelian ''form'' of objects and their classification as earth, air, fire, or water (according to which objects in wunderkammer were displayed; Appendix [see footnote 1]). Aristotelian ''form'' does not evolve, it is invisible, incorporeal, an object's God-given potential to become what God designates it to be (Collingwood, 1960). It is revealed by its movement or behavior. For example, objects that drop when released seek the center of the Aristotelian cosmos (the center of the Earth) and so are categorized as earth.

Steno pulled away from such worn ideas even when the most compelling minds of the Scientific Revolution adhered to them. Among them were Francis Bacon (1561–1626) and René Descartes (1596–1650). Bacon was one of the most influential antischolastics and a chief proponent of using the empirical or scientific method to discover new knowledge for human benefit (Zagorin, 1998). However, he did not completely break from Classical thinking. A relevant example is Bacon's attempt, with only limited success, to modernize the Aristotelian concept of form, which remained in his writings as an ill-defined causal agency that determined the distinctive being or ordered structure of things. Zagorin's (1998, p. 94) characterization of Bacon's conception of forms as ''[embracing] the unity of nature in the most dissimilar substances'' is uncannily like Kircher's statement (see preceding) that Steno quoted in *Chaos*. Steno quoted Bacon's thoughts about form, for example (Ziggelaar, 1997, p. 80): ''Natural science, speculative, either physical about nature either collected together, both because of principles which are common to all things and because of the one integral fabric of the universe, or dispersed and this either above the concrete things or the natures . . . or metaphysical, both about form and about purpose . . . ''

In contrast to Steno, Bacon distrusted mathematics and never accepted its importance (Zagorin, 1998, p. 126). Bacon was a polemicist, but Steno was an artisan who as anatomist worked with his hands and described nature in all its geometric variations. Geometry allowed him to see through the clouds of metaphysical allusions that had obscured the structure of nature since the Middle Ages. Although his position on the nascent atomic theory is unresolved in his notebook (Ziggelaar, 1997, p. 472–473), Steno understood that structure was the essence of

[1]GSA Data Repository item 2006164, Appendix, is available online at www.geosociety.org/pubs/ft2006.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

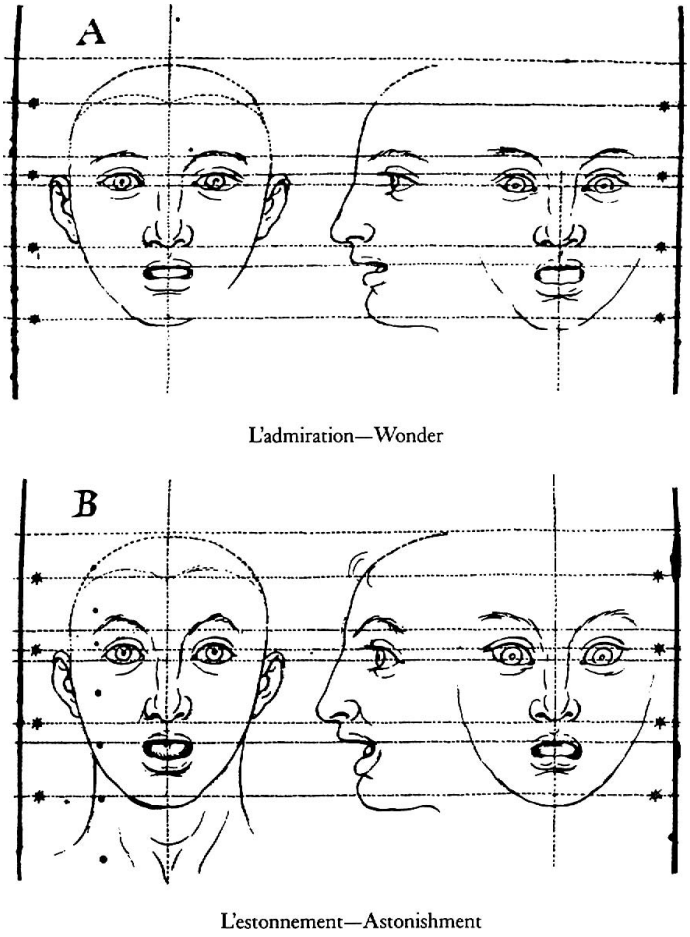

Figure 2. "Astonishment is an Excess of Wonder," from Descartes in 1649 (Voss, 1989, p. 60, Hackett Publishers).

nature from the microscopic to the cosmic scales, and in this regard he surpassed Francis Bacon.

For example, *Chaos* presages Steno's crystallography in the *Prodromus*. In quoting Ole Borch and Pierre Gassendi (Ziggelaar, 1997, p. 395–397), Steno agreed that the tiniest particles of matter will in a microscope be seen to have "very different shapes, pyramidal, pentahedral, cubic, heptahedra, trapezia, that it is quite stupendous. . . " Moreover, "not even the least visible thing is not composed of many myriads of atoms. . . " and, "Nature can distinguish more parts in a grain of millet than man can do in Caucasus, even in the whole earth globe."

Even the spaces between substances become geometric entities. In explaining how solids of different shapes dissolve in water, Steno cited anatomist Jean Pecquet, who proposed (Ziggelaar, 1997, p. 347–348) that solids fit into "Pores of water [of the same shape]. . . quadratic pores are filled by the squares of sea salt, hexagonal [pores] by the hexagonal solidity of nitreous sharpness." Although this model appears naive in light of the modern atomic theory in which dissolution of solids occurs as a result of the asymmetric shape and charge distribution of water molecules, it is nevertheless a step beyond the Aritstotelian idea that the icosahedron symbolized water, the tetrahedron represented fire, the cube earth, the octahedron air, and the dodecahedron ether.

Thus, for Steno, objects in nature ceased to have metaphysical form. They began to have geometric form, visible, material, and measurable, subject to comparison, empirical classification, and transformation, i.e., evolution. Furthermore, materials move and separate (adopt a new structure), not because they are imbued with God's potential, but because they respond to the laws of nature (Collingwood, 1960).

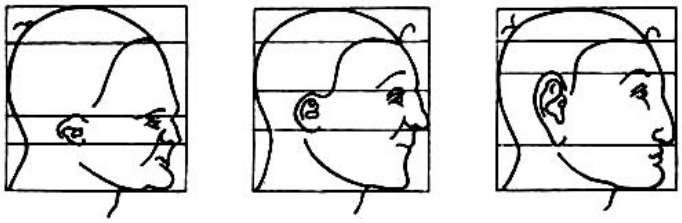

Figure 3. Proportions of human head after Albrecht Dürer (Thompson, 1961, p. 290, Cambridge University Press).

Steno's growing understanding of the structure of the human body evident in *Chaos* caused him to disengage from one of René Descartes' most important philosophies, that the heart is a furnace warmed by the passions of the soul. At the same time, Steno began to comprehend the Earth as an oven whose materials separated due to heat, a first step toward understanding that grand theme of modern geoscience, the fractionation of the planet.

Several passages in *Chaos* refer to the separation of substances in nature based on weight, as in Bernhard Varen's reference to Archimedes, who (Ziggelaar, 1997, p. 261) ". . . presupposes there is a center for the spherical earth . . . that heavy bodies tend towards it." By itself, this statement is consistent with the Aristotelian idea that substances that sink represent the element earth. But note also the passage from Athanasius Kircher (Ziggelaar, 1997, p. 126), ". . . that water is lifted up not only out of the sea in the chemical oven of the . . . earth . . . but that there is one and the same source of metals, stones, and other substances . . . found in hills and on flat countryside."

Steno also cited Kircher on the separation of the Aristotelian elements (Ziggelaar, 1997, p. 121), "Expulsion and attraction of the elements is not . . . due to magnetism. . . . The four elements shut up in a vessel will found a new centre . . . because of gravity . . . because of qualities . . . inside the things . . . according to which everything acquires its proper place in the universe . . . "

Inherent qualities are Aristotelian qualities. But, from Jean Pecquet (Ziggelaar, 1997, p. 357), "Such separation by weight does not occur in the body." Also from Pecquet (Ziggelaar, 1997, p. 351), "When the roots of the portal vein in the . . . liver are obstructed, a thicker sediment of slow blood is retained (see an example in the narrowness of the bed of a river where sometimes dirt is collected until obstruction . . .)." Elsewhere in *Chaos* (again after Pecquet; Ziggelaar, 1997, p. 334, 361) Steno considered and rejected both gravity and heat as causes of movement of blood through the body.

The growing realization that the Earth is an oven, the body is not, brought Steno into direct conflict with Cartesian metaphysics. Descartes believed that the soul mediates emanations from the pineal gland, through the nerves to the heart, where the passions of the soul boil them along with the blood through the body. To prove this, Descartes had to demonstrate the materiality of the soul or at least its ability to affect materiality. As the founder of analytic geometry, Descartes sought evidence with geometry. In *The Passions of the Soul,* Descartes (1649; translated by Voss, 1989) superimposed a common geometric grid over facial expressions of all of the emotions to prove that a common underlying entity—the soul—produced them. For example, Figure 2 shows Descartes' portrayal of "wonder" and "astonishment." This follows the tradition of Renaissance artists such as Albrecht Dürer, who used geometric grids to study facial proportions and the shape of the head, particularly with changes in perspective (Fig. 3, after Thompson [1961], who cited Dürer in his studies of relative growth).

In a quote from Ismael Boulliau (Ziggelaar, 1997, p. 371), Steno

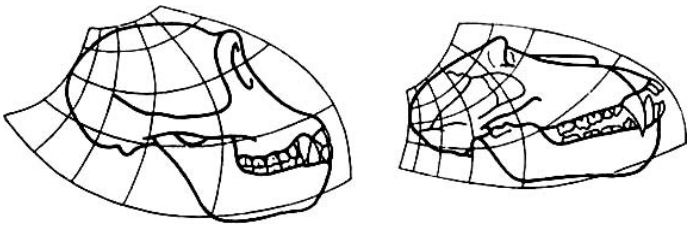

Figure 4. Allometric relationship of skull of chimpanzee (left) and baboon (right), from Thompson (1961, p. 319, Cambridge University Press).

showed his concern with the corporeal-incorporeal dichotomy: ''As matter is corporeal but form is incorporeal, for reconciling them one needs a mean proportional having something in common with both. Such a bond in all things is light; but when . . . it has freed itself from matter, the combination is dissolved. One could object that substantial forms are nothing else than participated light . . . ''

Yet Pecquet's influence prevailed, as Steno's later accomplishments prove. He rejected Descartes' misapplication of geometry to rationalize the existence of something that was intangible. In 1664, Steno wrote (Walsh, 1961) that his dissections proved that the heart is not a furnace, but that it is a muscle like any other and that it works like a pump (Kardel, 1994). This quashed Descartes' claim that the soul was an entity that persisted after the body died, an idea that the Church opposed because it challenged transubstantiation. If the soul was a material or even metaphysically conceptual object that separated from the body upon death, then it would be unlikely that both the body and spirit of Christ could be present together at communion. For Steno, the discovery was decisive and caused his conversion to Catholicism; he abandoned veneration of human authority in general and Descartes in particular, because Descartes' metaphysical soul obscured the true nature of the heart as a muscle and mystery of creation (Sobiech, 2004).

Nicholas Steno's studies advanced the tradition of description of the body started by Renaissance artists such as Dürer because they added details to the body's geometry. Thompson (1961) used Dürer's work to develop his concept of allometry, which states that related species differ in form as a result of proportional variations in growth rate along common geometric coordinates (Fig. 4). His implicit debt is to Steno and his contemporaries whose anatomical analyses defined organisms as dimensional, and thus whose transformations could be observed through time.

CONCLUSIONS

Nicholas Steno disdained scholastics for viewing nature through a fog of Aristotelian vaporizations. He believed that geometry could reveal the true structure of nature beneath that haze, and that geometry, not metaphysical associations of diverse objects in a room of curiosities, was the true unity of the cosmos. His ''crystalline'' model of nature gave new meaning to the concept of ''form,'' which was once a murky Aristotelian concept that the likes of Bacon had trouble understanding. Even Descartes had misapplied his own analytic geometry in a vain attempt to prove the existence of a dimensionless soul. In contrast, Steno and his contemporaries brought form into focus as structure and shape, which can be visualized and measured, and which was requisite for understanding evolution (Hansen, 2000; Rosenberg, 2002).

Steno began to envision an evolving Earth in *Chaos*. For Steno, neither the Earth's interior nor the surface was static. Kidney stones were produced within the body by fluids, and similarly shells found in dry sediment were once bathed by seawater when it covered the land. Steno accepted that Earth materials separated according to their weight just as substances in a vessel do. The Earth was an oven that cooked metals, water, and stones to the surface, the beginnings of the modern concept of fractionation. Steno believed in the universal flood throughout his life, and he rejected the Aristotelian categories of nature because they were not consistent with Biblical scripture, but it was geometry that gave shape to all that Steno believed about God as much as about nature. The structure of the heart proved that it was a muscle, not an oven, and that blood flowed through the circulatory system like a river. The heart did not spread emanations warmed by the passions of the soul.

There is a lesson here for contemporary creationists: Nicholas Steno's spirituality only strengthened as his understanding of the structure of nature grew, even though it meant rejecting an assertion of God's immanence in nature. Stated a little differently, Nicholas Steno's aphorism, ''Beautiful is what we see, more beautiful is what we understand, most beautiful is what we do not comprehend,'' signifies Steno's appreciation of the geometric design of nature as proof of the mystery of God's transcendence (Sobiech, 2004, p. 154), not as trivial evidence of God's material presence or influence.

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