THE PRODROMUS OF NICOLAUS STENO'S DISSERTATION CONCERNING A SOLID BODY ENCLOSED BY PROCESS OF NATURE WITHIN A SOLID, PP.170-283

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PART II. NICOLAUS STENO'S DISSERTATION CONCERNING A SOLID BODY ENCLOSED BY PROCESS OF NATURE WITHIN A SOLID

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and a half, there was no writer upon natural science before the eighteenth century that in accuracy of observation, in cogency of reasoning, or in discrimination of judgment might be compared with the "learned Dane." In some measure Steno reflected, of course, the crude notions of his time. Thus we find him adopting, though apparently with some reserve, the doctrine of the four elements, fire, earth, air, and water. In the main, however, if we exclude the prolix introduction addressed "to the Most Serene Grand Duke" and the weak conclusion intended to prove the orthodoxy of his position, the *Prodromus* with but moderate changes may be made to harmonize with the science of the twentieth century. We must attribute it largely to the closeness of his observation of Nature and to his discriminating judgment, that Steno was not lured into wild speculations, as were so many in his time. One of his statements might well be printed in large letters and placed upon the walls of our laboratories and lecture rooms, as a warning to those who undertake scientific investigation. "The nurse of doubts," says Steno, "seems to me to be the fact that in the consideration of questions relating to nature those points which cannot be definitely determined, are not distinguished from those which can be settled with certainty" (p. 213). How much trouble would be saved if to-day scholars had this point oftener in mind!

The form of Steno's essay is geometrical, and this is responsible for the almost unintelligible title and the correlation of subjects which, interpreted in the elaborate differentiation of twentieth century science, appear somewhat incongruous. As stated in the introduction, the *Prodromus* is divided into four parts. The first of these contains among other things an inquiry into the origin of fossils. The second part is stated to be: "Given a substance possessed of a certain figure, and produced according to the laws of nature, to find in the substance itself evidences disclosing the place and manner of its production." In like geometrical form the third part discusses solids which are contained within solids. The concluding portion of the essay is largely a consideration of the prehistoric geological changes which Steno was able to read in the rocks of Tuscany.

The broad outlines of the Cartesian conception of matter were adopted by Steno, who regarded a natural body as an aggregate of imperceptible particles subject to the action of forces such as proceed from a magnet, from fire, or sometimes from light. A fluid differed from a solid in having its particles in constant motion and withdrawing from their neighbors, that is to say, changing their relative positions.

Some of Steno's greatest contributions to science lie in the field of crystallography, for he studied the growth of crystals and showed that those formed in the mountains must have developed in the same manner as crystals of niter separating from solutions in water. These grow, he said, by accretions of substance upon the surface of the crystal nucleus, and not as do plants and animals.

The prevalent columnar form of crystals and the variation of their habit through the occurrence of faces of variable size, Steno explained by the addition of substance on certain sides only of the growing crystal. The force which draws the substance out of the surrounding fluid he recognized to be inherent in the crystal itself, and this crystallizing force he happily likened to what we should to-day call the lines of force about a magnet.

It is hardly to be expected that, great as Steno was, he should in his day have discovered the important fact of the orientation of the molecules of crystals, but he did point to the striking peculiarity of light refraction that distinguishes the crystal from amorphous substances, such as glass. Steno was, however, the discoverer of the fundamental law of crystallography known as the *law of constancy of interfacial angles*. As usually stated, this law affirms that ***no matter how much the faces of a crystal may vary in their size or shape, the interfacial angles remain constant, provided they are measured at the same temperature.*** The absolutely empirical verification of this law was delayed until the invention of the reflecting goniometer in 1805. Barring the refinement of temperature variations, it was amply verified by Rome de l'Isle with the simple goniometer which he invented in 1783. It is clear, however, that Steno more than a century earlier fully grasped the principle of the law, and gave it some sort of crude experimental verification. In the explanation of his figures, Steno says (p. 272):

"Figures 5 and 6 belong to the class of those crystals which I could present in countless numbers to prove that in the plane of the axis both the number and the length of the sides are changed in various ways without changing the angles."

As a corollary to his deductions concerning the growth of crystals, Steno showed that so-called "phantom crystals" are no product of the action of the larger crystal, but existed first and were enveloped through continued growth of the crystal nucleus.

In the realm of geology we owe to Steno the first clear enunciation of some of those great principles which to-day we assume to be axiomatic only because so much has been built upon them as a foundation. That rocks in the main result from sedimentation in water is thus expressed in the *Prodromus* (p. 219):

" The strata of the earth, as regards the manner and place of production, agree with those strata which turbid water deposits."

The reasons for this belief are most cogent: "The strata of the earth are due to the deposits of a fluid, (1) because the comminuted matter of the strata could not have been reduced to that form unless, having been mixed with some fluid and then falling from its own weight, it had been spread out by the movement of the same superincumbent fluid; (2) because the larger bodies contained in these same strata obey, for the most part, the laws of gravity, not only with respect to the position of any substance by itself, but also with respect to the relative position of different bodies to each other" (p. 227).

It is further clearly shown how marine deposits may be distinguished by their character from those deposits which are laid down in fresh water upon the continents, as well as from the ejectamenta of volcanoes. The origin of variation in the character of strata from place to place, and of the alternation of layers of different characters, are all discussed with a clear understanding of the actual conditions. The great principle that the order of superposition of beds determines the age of formations, is given its first expression (p. 230):

" At the time when any given stratum was being formed, all the matter resting upon it was fluid, and, therefore, at the time the lowest stratum was being formed, none of the upper strata existed."

Likewise it is pointed out that sedimentary formations were either laid down in definite basins of deposition or were universal in their extent. The original horizontality of sedimentary formations is now regarded as one of the great fundamental principles of geology. Steno says of the strata " that the upper surface was parallel to the horizon, so far as possible; and that all strata, therefore, except the lowest, were bounded by two planes parallel to the horizon. Hence it follows that strata either perpendicular to the horizon or inclined toward it, were at another time parallel to the horizon" (p. 230).

If strata are no longer in a horizontal position, it indicates, says Steno, subsequent disturbance of them; and this may be due either to uplift "by violent thrusting up of the strata," or "spontaneous slipping or downfall of the upper strata after they have begun to form cracks, in consequence of the withdrawal of the underlying substance, or foundation" (p. 231).

These changes in position of the strata are according to Steno the chief cause of mountains, and he pretty clearly distinguishes three of the more important mountain types; namely, (1) block or fault mountains, (2) volcanic mountains, and (3) mountains of erosion. The relation of earthquakes to the formation of mountains is indicated with a much nearer approach to present beliefs than is to be found in any save Robert Hooke and comparatively recent writers.

The fissures which form in the strata were recognized by Steno to be the passageways or channels for the movement of underground water, and for subterranean gases as well. These crevices are thus the places where veins of mineral are formed. The storehouses of the precious metals being brought about by natural processes, the foolishness of those who employ the divining rod for the locating of them is pointed out. An imperfect notion of the manner of replacement of one mineral by another seems to have been gained by Steno from his studies.

In the description of the figures — a most important part of the essay — a clear conception is revealed of the relative order of age of strata, of the alternation of transgression and recession of the sea over the same places, and of the nature of a structural unconformity, whereby one set of strata comes to overlie another from which it differs in its lesser angle of inclination. Here Steno gives us the results of his careful field observations in the vicinity of Florence. His figures may, therefore, be regarded as the earliest geological sections ever prepared.

Over the origin of fossils war had long been waged in Steno's time. Like Leonardo, a century and a half before, Steno declared that fossils were petrified remains of plants and animals which had once existed.

Steno's activity in biological studies is brought out in his elaborate examination of the structure of the shells of mollusks. His description of the subdivisions of the shells and the division of these into