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Nicolaus Steno (Niels Stensen)
and
Erasmus Bartholinus

Two 17th Century Danish Scientists and the Foundation of exact Geology and Crystallography

By

Axel Garboe.

Dansk Sammendrag.

I Kommission hos
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FR. BAGGES KGL. HOFBOGTRYKKERI
KØBENHAVN

Introduction.

To the crystallographer who works to-day with his theodolite-goniometer or in his x-ray laboratory it is an established fact that minerals and crystallized matter on the whole are built in definite patterns and that they obey definite laws.

To the petrographer or mineralogist who in his daily work is dependent on his polarizing microscope, this instrument has become so commonplace a thing that its background and development to the perfection of our days hardly ever strikes his thoughts.

The present paper by Dr. A. Garboe considers it its object to remind geologists that the statement of some very different but equally fundamental principles of modern science are due to two Danish scientists, who each published a paper, one in Firenze the other in Copenhagen, in one and the same year — 1669.

In Nicolaus Steno's time more thought had been given to the philosophy of crystals and crystal symbolism than had been given to an exact study of the crystals themselves; Steno was the first to choose another way. From analogies with crystals precipitated from watery solutions in the laboratory he came to the idea that quartz crystals in the rocks were formed in a similar way; further he was quite aware that mineral veins were formed later than the surrounding rocks. Without paying much attention to contemporary thought regarding crystals he began to study crystals as he found them in nature. Steno subjected rock-crystals to an exact investigation and succeeded in establishing certain hitherto unknown laws for the growth and form of these and other crystals. Steno observed that the size and the faces can vary, new faces, and steplike unevennesses can be found, but in spite of all differences he could always demonstrate what is to-day called Steno's Law: Regardless of size and reciprocal distances of the crystal faces the interfacial angles are constant. On reading Steno's description of his research on crystals, one cannot help feeling that behind his almost epigrammatic remarks there lies an extensive knowledge, waiting to be presented to the scientific world in the main work to which "De Solido" was only a prodromus. Alas, the main work was never published.

Also from another point of view it can only be deeply deplored that Steno's main work was never published, since it clearly appears from his studies of shark's teeth and from his "De Solido" that his aspects were purely actualistic and that in fact he marks the beginning of a new era in scientific geology. It is only necessary to mention his interpretation of the origin of mountains in order to make this clear. Steno actually recognized three types of mountains: 1) block or fault mountains, 2) volcanic mountains, and 3) mountains of erosion; he was on the very brink of discovering the folded mountains too, since he realized that the downward sloping strata on the mountain sides were in many cases "twisted into curves because their substance is tenacious".

Erasmus Bartholinus' discovery of the double refraction in minerals is perhaps less well-known, although his terms for the ordinarily refracted (ω) and the extraordinarily refracted (ε) ray are still used in all optic work with uniaxial minerals. Bartholinus acquired a number of clear calcite crystals — Icelandic spar — from the classical and now exhausted locality at Helgustaðir in East Iceland and submitted them to a series of experiments. As one result he became aware of the peculiar light refraction in the calcite, which he studied in detail and described in experiments VII to XVII in his booklet. He was surprised to find that the objects A and B when observed through his crystals appeared double, while through other transparent bodies he saw only a single image, and he came to the conclusion that the two images could only be explained by supposing a double refraction of the ray of light passing through the calcite crystals: the beam of light is divided into two differently behaving refracted rays (ω and ε). The theoretical explanation Bartholinus tried to give of the phenomena of the double refraction was not correct, since he assumed light to be a movement of corpuscula; however, C. Huygens, working on his wave theory in the 1670's, and later Isaac Newton continued the studies on the double refraction discovered by Bartholinus. His sober investigations were correct, his explanation not. In a certain way Bartholinus reminds us of his famous countryman Tycho Brahe, whose observations were outstanding, but whose interpretation was wrong; using Brahe's observations KEPPLER later on was able to formulate his famous laws and revise the Copernican conception of the universe.

Extraordinarily enough neither Steno nor Bartholinus continued his career within the geological sciences in which they had both made such remarkable progress, for Steno took Holy Orders in 1675 and died in northern Germany as a Catholic bishop, while Bartholinus became professor medicinae in Copenhagen. What characterizes both of them, however, is the fact that without paying much attention to current preconceptions they took nature's own products, investigated them soberly and critically, and described and interpreted as far as possible what they saw. It is not without a feeling of pride that we can note that milieu which the Copenhagen University offered its students and research workers 300 years ago; it was of such a quality that scientists who had received their basic education there were able to hold their own among their contemporaries —so much so that they rank high among the pioneers in the infant field of Geology.

Mineralogical-Geological Museum,
University of Copenhagen
April 1954

Arne Noe-Nygaard.

The translation has been made by

Miss M. S. Bryan

NICOLAUS STENO (NIELS STENSEN)

(1638—1686)

Nicolaus Steno
From a picture by an unknown artist, now in Galleria Uffizi, Firenze.

NICOLAUS STENO was born in Copenhagen on the eleventh of January (by the Julian calendar, the first of January), 1638[1]). His father, Sten Pedersen, a goldsmith, was a well-to-do and prominent citizen. Already as a boy, Niels must have been interested in what there was to see and learn of practical chemistry and physics in the jewelry workshop. This appears from some notes[2]) dating from his years at the University of Copenhagen. Here he was among those who heard the inspiring lectures on anatomy and medicine, given in well-phrased Latin by Prof. THOMAS BARTHOLINUS[3]); he also attended Prof. Bartholinus's dissections in the Theatrum Anatomicum, and, in all probability, he himself soon began to dissect. It also appears from the above-mentioned notes, that early he grappled with serious religious reflections. Steno's three years of study at the University of Copenhagen were made difficult by the war with Sweden, during which, in February 1659, a catastrophe nearly befell Copenhagen. The city was defended succesfully, however, by all the inhabitants, including the students on whose military service list Nicolaus Steno's name can be found.

As soon as possible after the war, in 1660, Nicolaus Steno left Denmark for several years of study abroad, as was the custom at that time. In The Netherlands he carried out independent research work in anatomy, and pursued other studies as well, i.a. mathematics, which later proved important for his crystallographical investigations. He also experienced a period of religious conflict which paved the way for his later conversion to Roman Catholicism (1667).

Step by step, Nicolaus Steno became alienated from his fatherland, where the University had no place for him as a professor, either during his stay in Copenhagen (1664) or later. And step by step, he was led away from the Lutheran confession in which he had been brought up.

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[1]) See note-references p. 43 f.

Italy, where Steno arrived in the spring of 1666, became his second fatherland. Here he lived in contact with interesting people with whom he had much in common. And both before and after his conversion in 1667, he had here the best possible working conditions, including the liberal support of the Grand Dukes of Tuscany, who favoured the arts and sciences.

In Tuscany, Steno began to study geology and mineralogy. He was led into these new studies by his investigation of the anatomy of sharks and other fishes[4]).

It happened in 1666, that an unusually large shark was caught off Livorno[5]). The Grand Duke of Tuscany, Ferdinand II, ordered its head brought to Firenze so that Steno could study it. The results of this dissection were published in 1667[6]), together with a treatise on muscle physiology and a description of the dissection of a smaller shark from the Mediterranean.

Most interesting in this connection is the study Steno made of the teeth of the larger shark, which showed a remarkable resemblance to the well-known fossil "tongue-stones", *glossopetrae,* found in especially great numbers in the rocks of Malta, where professor THOMAS BARTHOLINUS, the teacher of Nicolaus Steno, had examined them.

Opinion was divided on the origin of "tongue-stones"[7]): Were these fossils really teeth of animals that formerly had lived in the localities where the *glossopetrae* are now found? Or had the tongue-stones only a coincidental similarity to recent sharks' teeth? Steno in 1667 dared not to decide this question. Or rather: he hesitated somewhat.

Here, as everywhere in Nicolaus Steno's scientific work, we meet his caution regarding facts not yet absolutely proven, and we meet his exact investigations of nature, unbiased by opinions previously advanced by others[8]). "He asked his questions and gave his answers as a scientist of the twentieth century"[9]).

Nicolaus Steno had seen the unquestionable resemblance between the *glossopetrae* ("tongue-stones") and recent shark's teeth, and in the light of his own newly performed anatomical studies of the great shark from the Mediterranean, he now placed anew the question of the nature of the *glossopetrae* — and all other animal-like fossils — under discussion "as before a court"[10]). He would as correctly as possible present the facts, observed by himself in the strata of the earth, to the reader — and then let other "more knowing people" decide.


NICOLAI STENONIS
ELEMENTORVM
MYOLOGIÆ SPECIMEN,
SEV
Musculi descriptio Geometrica.
CVI ACCEDVNT
CANIS CARCHARIÆ DISSECTVM CAPVT,
ET
DISSECTVS PISCIS EX CANVM GENERE.
AD
SERENISSIMVM
FERDINANDVM II.
MAGNVM ETRVRIÆ DVCEM.

FLORENTIÆ,
Ex Typographia sub signo STELLÆ. MDCLXVII.
Superiorum Permissu.

Fig. 1. Title-page to Steno's description of his dissection of the shark's head (1667) and his earliest geological discussions.

NICOLAUS STENO founded this discussion of the nature of animal-like fossils on the many observations of rocks and earth strata that he had made in nature. He cautiously presented his opinions in the form of *suppositions, conjecturae.* Step by step, Steno came to the assertion (conjectura VI), that the fossils which have a resemblance to parts of animals "may be supposed in reality to be parts of animals". "And as the form of the tongue-stones resembles the recent shark's teeth as one egg another I must suppose that the scientists who declare the great tongue-stones to be the shark's teeth are not far from the truth". He built up his *conjecturae* point by point, and proposed them with the clarity and logic which is found again and again in Steno's works, both scientific and theological. This method makes his train of thought easy to follow, but hard to give in extract, as the material has already been condensed to its shortest possible form.

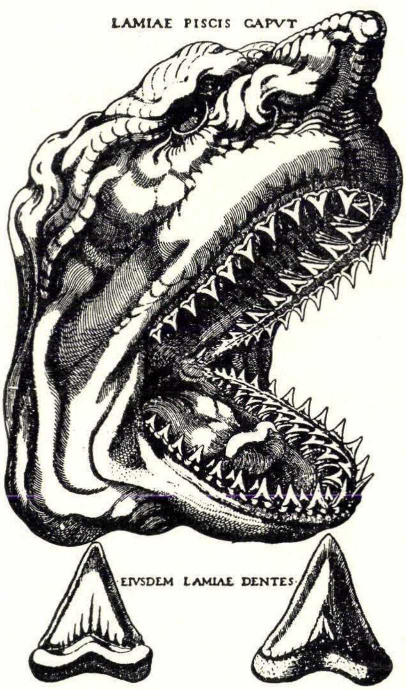


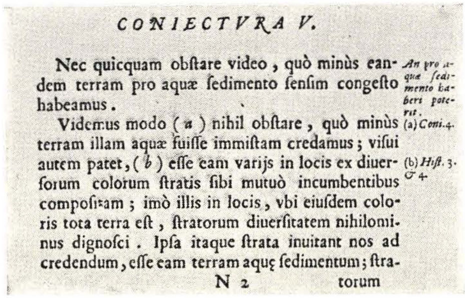
Fig. 2. STENO's figure (1667) of a shark's head and teeth. From MERCATI: Metallotheca.

Nicolaus Steno built his geological and palaeontological understanding on a long series of investigations, particularly performed in Tuscany.

He gives as an introduction to the conjecturae a short description of the different types of rocks and strata: hard stone, tuff, clay, sand, etc. and he refers to the different states of preservation of the "enclosed bodies, resembling parts of animals" found therein: while some crumbled into dust when touched, others could be studied just like the shells of living animals.

He considers the orientation of the strata, whether horizontal or inclined, and he discusses how the enclosed fossils must have come there. Without calling it *"geology"*,[10]) Steno in his *conjecturae* gives an outline of scientific earth history arrived at through inductive reasoning.

The most important principle in Steno's geological thinking, is that the strata are sediments, deposited in water, covering the earth surface, and later hardened to a greater or lesser degree (conjecturae III–V). If the sediments do not always lie in their original horizontal position, a later disturbance is responsible. The earth can have been "shaken and violently disturbed and broken, giving the strata a new position. It should not be difficult to demonstrate the effects of earth quakes."


CONIECTVRA V.

Nec quicquam obſtare video, quò minùs eandem terram pro aquæ ſedimento ſenſim congeſto habeamus. *An pro aquæ ſedimento haberi poterit.*

Videmus modo (a) nihil obſtare, quò minùs terram illam aquæ fuiſſe immiſtam credamus; viſui autem patet, (b) eſſe eam varijs in locis ex diuerſorum colorum ſtratis ſibi mutuò incumbentibus compoſitam; imò illis in locis, vbi eiuſdem coloris tota terra eſt, ſtratorum diuerſitatem nihilominus dignoſci. Ipſa itaque ſtrata inuitant nos ad credendum, eſſe eam terram aquę ſedimentum; ſtra-

(a) *Conj.* 4.
(b) *Hiſt.* 3. & 4.

N 2 torum

Fig. 3. From Nicolaus Steno's treatise about the shark's head: Fifth supposition, in which he speaks about aqueous sedimentation and stratification.

Steno's studies of both marine and fresh-water deposits led him to a consideration of the effect of the "juices" circulating in the strata of the earth (conjectura IV). He compares and illustrates the processes in the earth strata with chemical and physical processes in the laboratory and uses in this connection experiments made in the chemical laboratory of his teacher in Copenhagen, the skilled chemist Ole Borch[11]). As for the remains of plants and animals, both marine and fresh-water, which are found in the sediments, these must have become part of the sediment while it was newly deposited and still soft. Shark's teeth and other similar fossils now found high up in Malta's chalk cliffs bear witness to a geological change at an early period in the earth's history.

"Who knows the history of Malta's youth?" says Steno[12]). "Perhaps the island formerly was submerged in an ocean with sharks whose teeth after death were buried in the mud of the bottom. But suddenly an explosion of subterranean air may have altered the position of the bottom-layers which now are found as dry land on the island".

Steno's first short presentation of his beginning geological theories in the shark's-head treatise (1667) is filled with the thrill of inquiry and joy of comprehension which he experienced so fully during the short span of time — less than two decades — when he did his scientific work. He could speak from experience of[12]) "the wonderful life and work of Nature which day by day is filling us with admiration". The dissertation, in spite of its concise, almost schematic form, is so vivid that the reader can almost feel Steno's geological theories becoming clearer and clearer to himself as the treatise progresses.

At the last moment, just as the treatise was going to press, Steno added a few words about a conversation[12]) he had had with one of his learned friends, MANFREDO SETTALA[14]), of Milano, who came through Firenze and remarked, that among the rarities in his museum were many things which supported the theories of Steno.

In the dissertation on the dissection of the shark's head Nicolaus Steno gives his "geology" in a preliminary form ("verisimilitudes") "and would not blame those who had perhaps another opinion"[12]). He himself continued his geological studies in Tuscany and in the other parts of Italy to which he travelled.

After the first burst of enthusiasm, when he thought, as he himself writes[15]), that these investigations "were the work of a very short time", he came to realize that the problems were more complicated than at first supposed. He felt like a man travelling in an unknown, remote realm with a summit city as his goal. It often happens that the traveller when first he sees the city, thinks that it is very near to him, and yet manifold turnings of the way will wear his hope even to weariness. For he sees only the nearest peaks, while the things which are hidden beyond them — whether heights of hills, or depths of valleys, or level plains — far and away surpass his guesses, since he measures the intervening distances by his desire. "So, and not otherwise, it is with those who proceed to true knowledge of Nature by way of experience. As soon as a little part of the unknown truth has become clear, then he thinks that he shall at once disclose the whole matter".

Observations accumulated. It was Steno's plan to use them for a work of large dimensions, written, for the benefit of Steno's patron, the Grand Duke, in the Italian language, which the Danish scientist had mastered in an amazingly short time. The work was to have as one of its aims the exploitation of Tuscany's mineral resources; this aspect of the matter was especially emphasized to the Grand Duke by the engineer VICENTIO VIVIANI (b. 1622). Viviani was a friend of Steno's, and one with whom he could discuss both scientific and religious questions. From his travels as an engineer he had an extensive knowledge of Tuscany's geology. Undoubtedly GUSTAV SCHERZ is right in saying[16]) that Viviani had a considerable share in

NICOLAI STENONIS

DE SOLIDO

INTRA SOLIDVM NATVRALITER CONTENTO

DISSERTATIONIS PRODROMVS.

AD

SERENISSIMVM

FERDINANDVM II.

MAGNVM ETRVRIÆ DVCEM.

FLORENTIÆ

Ex Typographia ſub ſigno STELLÆ MDCLXIX.

SVPERIORVM PERMISSV.

Fig. 4. Title-page to Steno's work "De Solido" (1669).

Nicolaus Steno's geological development; as well, he had a great share in Steno's conversion to Catholicism.

Nicolaus Steno had not in any way finished his geological investigations. Special circumstances were necessary, however, to make him publish more than what he had stated provisionally in the shark's head paper.

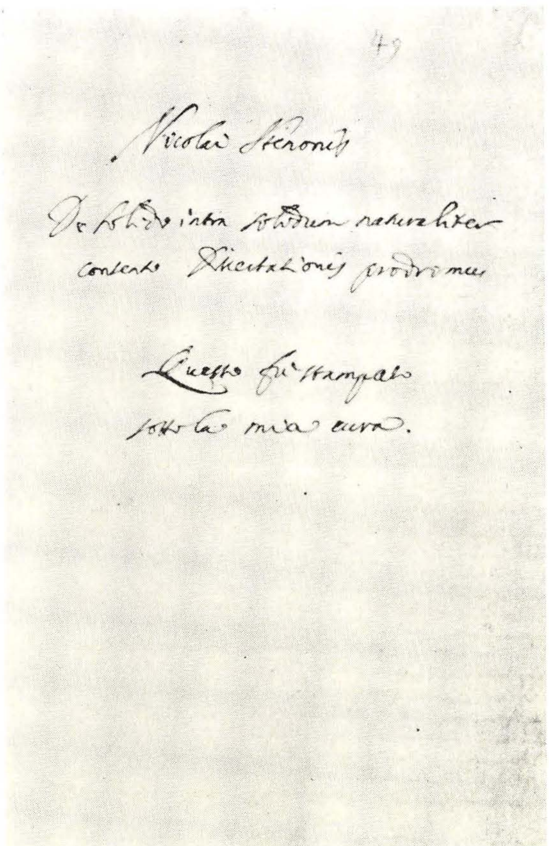
In the autumn of 1667 — the year of Steno's conversion — these circumstances arrived. Nicolaus Steno then received an official communication dated October, 1667[17]), from the Danish King, Frederik the Third, bidding him return to Denmark as "Royal anatomist", *anatomicus regius*.

Had this occured earlier, Steno would not have hesitated to comply with his King's wishes. Now, however, he felt dubious about it. The ties between Nicolaus Steno and Italy were very strong. How could he, a convert, be permitted to live in the narrow-minded, orthodox Lutheran Denmark? And how about the completion of the geological research work he had begun?

Finally, Steno decided to obey the Danish king's summons. But before he took leave of Italy, he felt himself duty-bound, both to his patron, the Grand Duke Ferdinand II of Tuscany, and to science itself, at least to publish a "forerunner", a *prodromus*, of the great geological work. This provisional treatise was to present the results Steno had attained so far in his studies of rock strata and other deposits, with their content of — so runs the title of the book — "Solid bodies enclosed by the process of nature within a solid"[18]). By this he meant, plant and animal fossils, and now, in addition, the mineral crystals to which Steno had only alluded in his dissertation of 1667. The booklet, now a classic and great rarity, is only seventy-six pages long, but filled with an enormous amount of material concerning the geological history of the earth.

Before he left Italy, Steno entrusted the manuscript to his friend Viviani, who was to supervise its publication. Viviani had, as already noted, a first-hand knowledge of the progress of Nicolaus Steno's geological investigations. It also was Viviani who, in connection with the church censor's endorsement (August 30, 1668), described the work as "having far-reaching significance for all science".

Viviani had a transcript made of De Solido for use in the printing office. This document, so interesting in respect to the history of geology, was found a few years ago by Gustav Scherz in the Biblioteca Nazionale in Firenze[16]). On the first page the manuscript has a notice (by Viviani ?) saying that De Solido was printed under his supervision. "*Questo fu stampato sotto la mia cura*"[15]). The original manuscript from Steno's own hand is not known.


49

Nicolai Stenonis

De solido intra solidum naturaliter
contento Dissertationis prodromus

Questo fu stampato
sotto la mia cura.

Fig. 5. From the printers copy of Steno's treatise De solido. By kind permission of G. SCHERZ. The text runs: Nicolai Stenonis De solido intra solidum naturaliter contento Dissertationis prodromus. Questo fu stampato sotto la mia cura.

The dissertation: De Solido (1669) is a continuation and amplification of the geological parts of the treatise on the dissection of the shark's head (1667), reporting further observations and drawing far-reaching conclusions from them regarding the history of the earth.

As a beginning Steno describes[19]) again his point of departure:

whether or not the "tongue-stones", *glossopetrae*, from Malta were real shark's teeth from past time. In connection with this problem many others arose: e.g. if all other bodies "which are similar to marine bodies", and which now are found far from the sea, were once produced in the sea. And how is one to understand the bodies which are similar to bodies, produced in fresh water? Is this a coincidental resemblance? Or how else can it be explained? And the mineral crystals in rocks — how were these bodies formed? The investigation which began with the "tongue-stones", glossopetrae, from Malta eventually became a problem embracing the whole earth and its geological history. When one question was solved, others were created. "I might compare those doubts to the heads of the Lernean Hydra, since when one of them had been got rid of, numberless others were born"[21]).

Steno's basic geological assumption was expressed in De Solido (as well as in his former dissertation) in the sentence[20]): "The strata of the earth are due to deposits of a fluid".

In concise sentences he characterized sediments as opposed to other kinds of rock, e.g. lava. He also distinguished between geologically older and younger formations, and recognized that layers with enclosed fragments of other layers revealed something about the successive sedimentation. He distinguished between marine deposits (which contain a marine fauna, ship timbers and "a substance which resembles the sea floor") and fresh water sediments containing plant remains, formed for example during floods etc. Traces of volcanic activity were also recognized in the strata, and the effects of transgression and regression of the sea considered. Now there is no longer any doubt on Steno's part that the plant- and animal-like bodies in the earth-layers have an organic origin.

Nicolaus Steno arrived at these ideas through independent observation, but his studies in Copenhagen, as well as his acquaintance with the literature, must surely have brought him in contact with the geological-paleontological problems which he later was to study in Italy. Steno must, for example, have known professor Ole Worm's[22]) museum, which was one of the sights of Copenhagen in the middle of the seventeenth century. In the printed description of the museum (*Museum Wormianum*, 1655) we can find geological, palaeontological and mineralogical problems considered. Above all, it can be assumed that Steno met geological problems in the instruction given by Prof. Thomas Bartholinus, who, while in Italy for several years, discussed the problem of the nature of fossils, the past distribution of land and sea, vulcanism, mountain grottos, etc.[23]). This side of Steno's scientific life and development is still in need of careful study.

Since the strata were deposited in water, the original position, on the whole, Steno declares, must have been horizontal; the lowest stratum in the series must be the oldest, deposited and perhaps hardened before the overlying stratum was formed. Each stratum, then, except the lowest, is limited by two planes parallel to the horizon. This can be seen, for example, in open sections. The originally horizontal planes of sedimentation can be recognized, even where the stratification is now divergent from the horizontal.

The disturbed position of strata so often observed, is explained as due to the influence of different forces (underground fire, burning of subterranean gases, water) after the formation of the sediments. We must, Steno says, here think upon "the 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. Hence by reason of the diversity of the cavities and cracks the broken strata assume different positions; while some remain parallel to the horizon, others become perpendicular to it, many form oblique angles with it, and not a few are twisted into curves because their substance is tenacious. This change can take place either in all the strata overlying a cavity, or in certain lower strata only, the upper strata being left unbroken". If we take such disturbances into account, Steno continues, we have an explanation for the diversity of the earth's surface: mountains and valleys, upland lakes, high plains, lowlands, etc. These forces are not something of the past, but continue even now to change the surface of the earth.

Here Steno[24]) came to the much discussed problem of the origin of mountains.

At a time when views were based on mere speculation, rather than on observation, it was commonly thought that mountains had been formed at the time of the earth's creation, and had not changed essentially in the time which had elapsed since — a few thousand years, according to GENESIS.

But Nicolaus Steno could not agree with this. He observed the mountains of Tuscany, and of the other countries he visited on his travels. On the basis of these observations he could assert that "all present mountains did not exist from the beginning of things", and that "mountains can be overthrown . . . peaks of mountains can be raised and lowered . . . the earth can be opened and closed again".

Several different mountain types were distinguished by Nicolaus Steno in "De Solido". Some were built as the result of volcanic activity, others as a result of fluvial erosion — in which case the same strata could be found on both sides of the valleys. He had observed mountains composed of sediments where the strata were parallel to the horizon, and other mountains where the strata were inclined; and he knew of mountains where the beds were folded. Although he did not fully understand the scope of this last observation, he had thus approached the problems of mountain folding.

On the length of the geological periods in comparison with historical chronology, Steno had, of course, only the most imperfect notion, although he touched on the problem[25]). Among other things he tried to establish a connection between the (Pleistocene) elephant bones found near Arezzo in a valley of Arno, and accounts of Hannibal's march through Italy nineteen hundred years before. Furthermore Nicolaus Steno, like his contemporaries, felt himself obliged to accept the Biblical tradition about a Common Inundation in Noachian times, the Flood, "some four thousand years ago"[26]).

Nicolaus Steno did not limit himself to merely theoretical geological considerations. He made an attempt to solve a concrete problem.

The geological history of Tuscany[27]) was outlined by Steno in the light of his interpretation of geological observations. He wrote on this subject: "In what way the present condition of any thing discloses the past condition of the same thing is above all other places clearly manifest in Tuscany; inequalities of surface observed in its appearance to-day contain within themselves plain tokens of different changes". And then Nicolaus Steno presented the first attempt to understand regional geological development in the light of surface phenomena. He illustrated his interpretation with the help of some schematic drawings (Fig. 6, 20-25).

The six sketches suggest six stages in Tuscany's development. Steno gave the following legend to the figures: "Figure 25 shows the vertical section of Tuscany at the time when the rocky strata were still whole and parallel to the horizon. — Fig. 24 shows the huge cavities eaten out by the force of fires or waters while the upper strata remained unbroken. — Fig. 23 shows the mountains and valleys

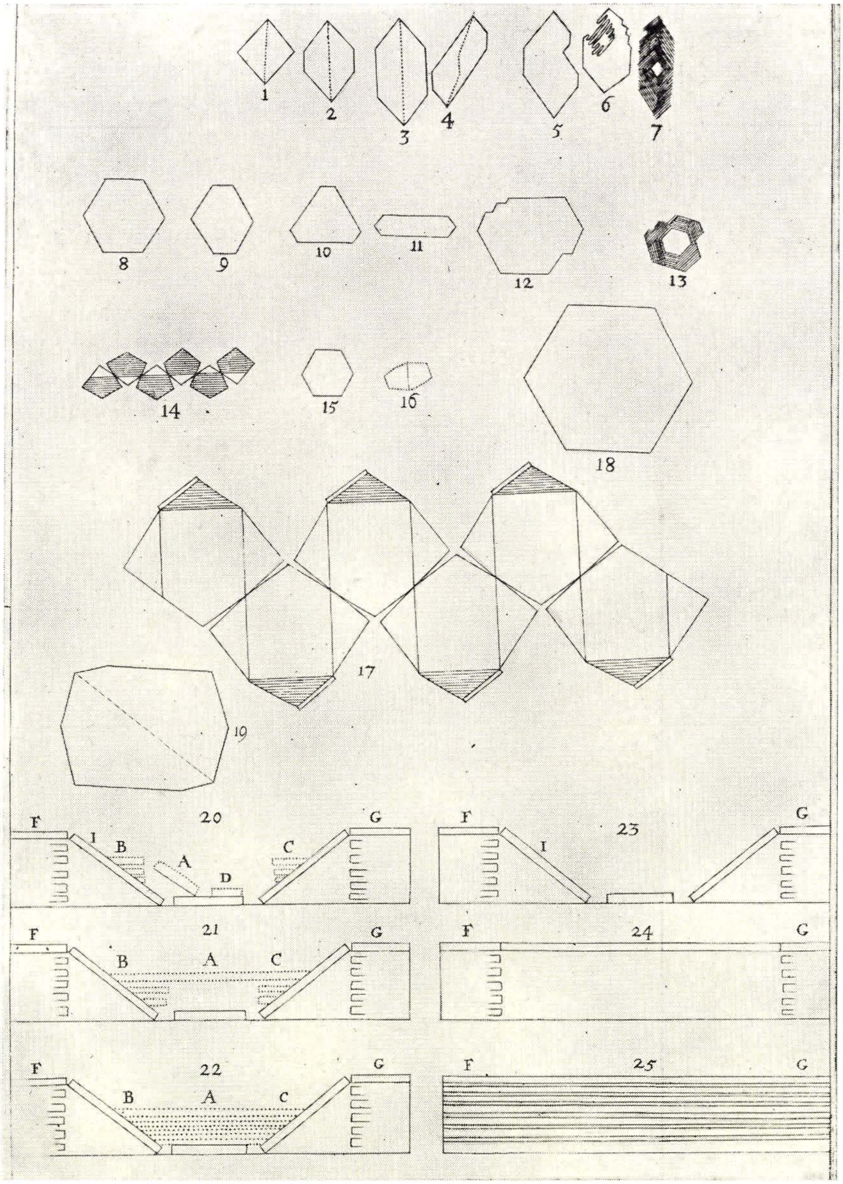


Fig. 6. Steno's illustration of his crystallographical and stratigraphical observations. For Steno's legend to the figures 1—19 see pages 26 and 45, note 36. For legend to the figures 20—25 see page 22—24.

caused by the breaking of the upper strata. — Fig. 22 shows new strata, made by the sea, in the valleys. — Fig. 21 shows a portion of the lower strata in the new beds destroyed, while the upper strata remain unbroken. — Fig. 20 shows the hills and valleys produced there by the breaking of the upper sandy strata".

In the text itself Steno explained more fully that Tuscany's surface had been covered with water twice, had twice been "even and dry", and twice "uneven". Steno tried to bring this geological history into agreement with (or least not in opposition to) the Bible. He thought that when Tuscany was covered for the second time with water it was in the days of the Flood. This was in Tuscany's "fourth stage". Later the water fell away again, carrying much sediment to the sea, where new land was formed. The sixth and last stage in the geological history of Tuscany we see going on before our eyes, with geological forces still at work changing the landscape.

Steno made the first attempt to treat geological problems by inductive reasoning, and he was convinced that the history of the earth could be read from examination of the rocks. He sketched the outlines of a new, exact science: geology. The way to new fields of research was shown; new paths were opened up when Steno began to read the tale of the earth layers and their content of fossils. But it was not alone scientific paleontology and stratigraphy with their allied disciplines, that were founded by Nicolaus Steno. He also was the first scientist who made the crystals of minerals an object of exact research.

When Steno wrote or talked about "solid bodies, enclosed by the process of nature within other solids", he did not mean fossil plants and animals alone; to him the term "solid" included mineral crystals (*angulata corpora*) as well. In this field, too, his accomplishments were so extraordinary that the year 1669, when De Solido was published, has rightly been described[28]) as the date of birth of scientific crystallography. Steno must share the credit to a certain degree, however, as will be described below, with his countryman Professor Erasmus Bartholinus of Copenhagen.

In the seventeenth century, only a little was known about the technically important ores, the precious stones and other minerals used for medical and other purposes. A little was known about mineral crystals, for example the cubic crystal of pyrites. But, as it has been said[29]), in Steno's time more thought was given to the philosophy of crystals, and crystal symbolism, than was given to an exact study of the crystals themselves. Their multiplicity of forms was thought to be an incidental caprice of nature, even when attention was paid to a single noticeable crystal form.

While travelling, especially in the mountains of Tuscany, Steno often had the opportunity to observe crystallized minerals in veins, cavities, fissures etc. With his own hands he hewed the crystals from the rocks[30]), trying to find out how mineral crystals are formed, and how they get their shape.

It was a common belief in Steno's time[31]) that quartz crystals ("rock crystal", SiO_2) grow in cavities in the rock like a plant. Just as a living plant draws up nourishment from the ground through its roots, so a rock crystal on the wall of a cavity draws the juices which make it grow, from the rock substratum. The mineral particles were supposed to move up inside, by intussusception. Steno could not share this belief. From analogies with crystals precipitated from watery solutions in the laboratory he adopted the opinion that quartz crystals in the rocks were formed in a similar way — perhaps from a watery solution, perhaps from a quite different, yet unknown fluid[32]).

Steno was aware that mineral veins with their contents were formed later than the surrounding rock. "The most of the minerals for which man's labor is spent did not exist at the beginning of things", he writes[33]) He therefore rejected many of the old mining superstitions regarding the location of rich mineral deposits, their detection, etc. On the contrary, he emphasized that it is necessary to study the very rock which surrounds the mineral vein, "seeing that it is more probable that all those minerals which fill either the clefts or expanded spaces of rocks had as their matter the vapor forced from the rocks themselves"[33]).

Nicolaus Steno, unlike many of his predecessors and contemporaries, was not willing to confine himself to speculations over the primary origin of crystals[33]). Instead, he wished to study the crystals themselves as he found them.

Here again we meet Steno's desire for realities[34]). He realized the necessity of entering into close observation and diligent study of nature, and nevertheless he did not lose sight of the total picture of which the facts were part.

Steno subjected rock-crystal (quartz) to an exact investigation, and succeeded in establishing certain definite, hitherto unknown laws for the growth and form of these and other crystals.

First Steno demonstrated[35]) that the growth of a quartz crystal is not (as mentioned above) analogous with that of a plant. A crystal, he says, "grows while new crystalline matter is being added to the external planes of the crystal already formed". This accretion of material, however, is not always equal on all the faces of the crystal.

A quartz crystal's simplest form is, according to Steno, hexagonal pyramides and an intermediate prism likewise hexagonal; in reality the hexagonal dipyramid consists of two rhombohedra, but this Steno could not know. This ideal form can vary greatly during the growth of the crystal. The size of the faces can vary, and the prism may be entirely absent; new faces, and step-like unevennesses can be found, he writes, and so forth. But amid all the differences, Steno could always demonstrate this law: regardless of the size and reciprocal distance of the crystal faces, the interfacial angles are constant.

In the text of De Solido Nicolaus Steno does not formulate the law of constancy of interfacial crystal angles in definite words. He speaks of it most directly in the legend to the accompanying figures (see pag. 23). "Figures 5 and 6 belong to the class of those which I could present in countless numbers to prove that in the place of the axis both the number and the length of the sides are changed in various ways without changing the angles". And further: "Figure 13 shows how sometimes the length and number of the sides are changed in various ways without changing the angles, on the plane of the base, while new crystalline matter is being placed upon the planes of the pyramids"[33]).

If one reads carefully what Steno writes in De Solido (1669) on the morphology of different crystals, especially quartz, hematite and pyrites, time after time one will meet statements which assume the new-found law of the constancy of angles. That Nicolaus Steno did not communicate all of his observations pertaining to constancy of angles and did not pronounce it as a universal law, can be blamed on the haste with which De Solido (1669) was written. He wrote:[36]) "In as much as the brevity of my hurried writing has left not a few things insufficiently explained, especially where the treatment concerns angular bodies (i. e. crystals) and the strata of the earth, in order to afford some sort of remedy for that defect, I have decided to add . . . figures". Knowing Nicolaus Steno's cautiousness in making broad generalizations, it is easy to imagine that he had wished to study more crystals, before he pronounced the law universal. Reading Steno's description of his research on crystals, one cannot help feeling that behind his condensed remarks, there lies an extensive knowledge, waiting to be presented to the scientific world in the main work for which De Solido (1669) was only a forerunner.

Rock crystal was not the only mineral which Nicolaus Steno subjected to a crystallographical examination. One can not doubt that he had studied many others. In De Solido (1669) he communicates, for example, his results concerning the more complicated crystals of hematite from the classical iron ore mines of the island of Elba, and of the crystals of pyrites. He compared these crystals with the quartz crystals and discussed mineralogical and crystallographical problems.

Nicolaus Steno did not undertake any actual measuring of crystal angles, and in connection with this some criticism has been raised[37]) regarding his share in the finding of the law of constancy of angles.

It has been proposed[37]) that the name "Steno's Law" (the law of the constancy of interfacial angles) should be changed to: Steno-Romé de l'Isle's Law or only "Romé de l'Isle's Law", because the French mineralogist, working a hundred years after the lifetime of Nicolaus Steno, established the law's universality on the basis of a large number of measurements of crystals with his goniometer.

It must, however, he remembered that Steno actually was the first to point out the constancy of interfacial angles, directly stating it in the case of the quartz crystal and leaving it understood in his description of several other mineral crystals. We therefore must continue to assert that it is correct to speak of Steno's Law, the first of the fundamental laws of crystallography. But aside from this Nicolaus Steno occupies a distinguished place in the history of crystallography. With him began the scientific description of crystal morphology, the first step forward on the way to exact crystallography.

Unfortunately Nicolaus Steno never published the great geological-mineralogical work he had begun, and which was constantly in his thoughts[38]) in the years after the publication of De Solido. The material must, unfortunately, be regarded as lost[39]).

Nicolaus Steno, who had taken Holy Orders in 1675, died in Schwerin, Germany, in 1686, as a prominent Catholic churchman; by then he had long ceased to work with the natural sciences.

His grave is in Firenze (Basilica di San Lorenzo.)

Fig. 7. Interior of S. Lorenzo, Firenze, with the chapel of Nicolaus Steno and his sarcophagus (×).

ERASMUS BARTHOLINUS

(1625—1698)

Professor medicinæ ERASMUS BARTHOLINUS of Copenhagen.
(From FREHER: Theatrum virorum eruditione clarorum, Nürnberg 1688).

ERASMUS BARTHOLINUS' life[40]) passed in an entirely different and much more commonplace way than Steno's.

He was born (1625) in Copenhagen, the youngest son of the anatomist and theologian Professor CASPAR BARTHOLINUS (died 1629); his brother was the famous anatomist Professor THOMAS BARTHOLINUS (1616–1680) who, more than any other member of the numerous Bartholinus family, brought glory to the University of Copenhagen, and was Nicolaus Steno's teacher.

After finishing his studies at his home university, the young Erasmus traveled abroad, and studied at different foreign universities, especially the famous universities of Leiden in the Netherlands, and Padova in Italy. In the year 1654, the latter awarded him the degree of doctor of medicine; but his principal interest was always in mathematics and physics.

Personal friendships were formed in the Netherlands between Bartholinus and the learned mathematicians and scientists there, especially CHRISTIAAN HUYGENS (born 1629) with whom he continued to correspond[41]), even after he returned to Copenhagen in 1656. "Monsieur", Bartholinus wrote to Huygens 22nd November, 1656, "estant arrivé en mon pays, je n'ay pas voulu manquer, à vous faire sçavoir, comment vous conseruerez toujours pendant ma vie, un serviteur en ces pays".

In Copenhagen, ERASMUS BARTHOLINUS became attached to the University (1656) as a professor of mathematics, but he soon (1657) exchanged this position for a medical professorship. During the Swedish-Danish war he wrote a short treatise (1661) on Snow Crystals[42]), when a severely cold winter was the enemy's most dangerous ally. In this treatise he, however, presented nothing new, almost totally following RENÉ DESCARTES in his understanding of the mechanism of snow crystal building[43]).

In different ways use was made of Bartholinus' mathematical ability. In the year 1664 he was entrusted with the editing of the astronomical observations which TYCHO BRAHE had left, a difficult and more time-consuming job than he had reckoned for. As a private assistant he had a young man, OLE ROEMER (born 1644), later to become the famous Danish astronomer (discoverer of the retardation of the light, 1675), who lived in the house of Erasmus Bartholinus, and became his son-in-law[44]).

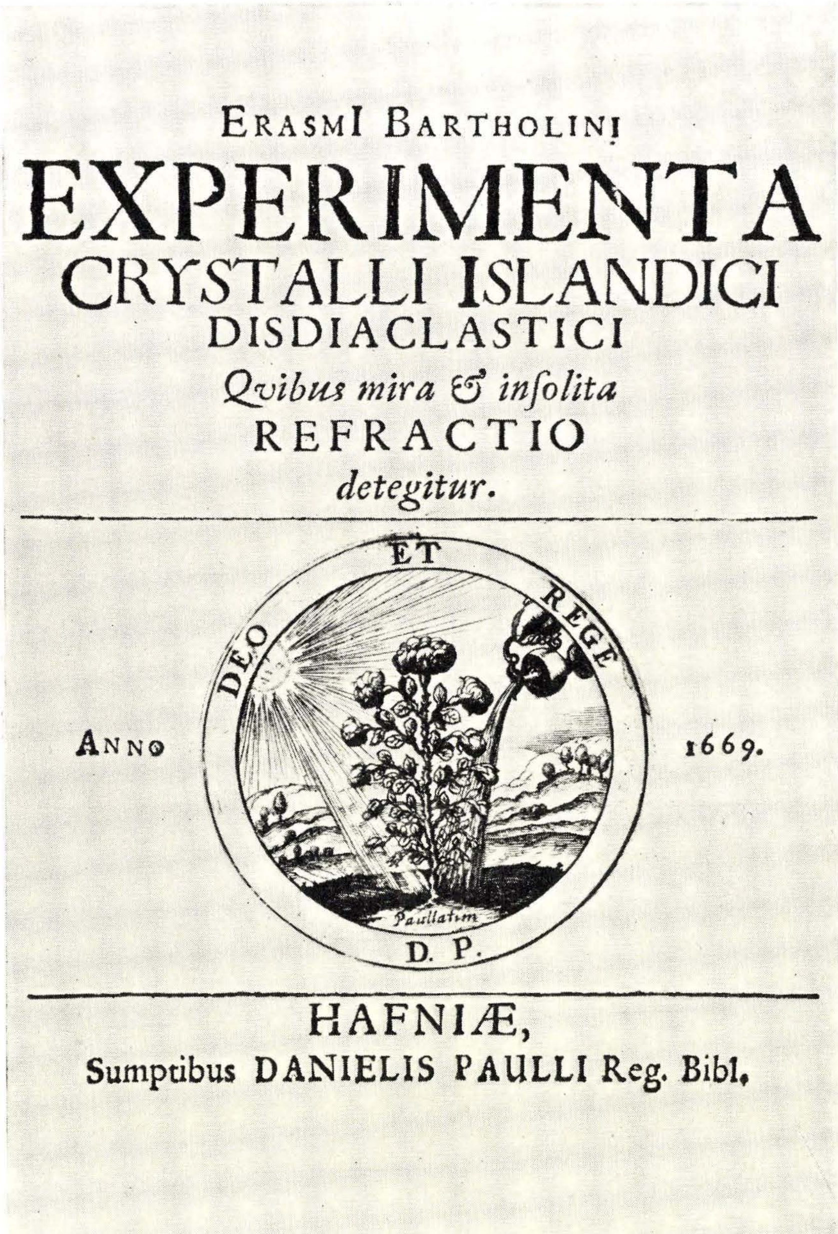
As "royal mathematician", *mathematicus regius* (from 1667), Bartholinus had to spend most of his time with practical problems. It can, therefore, be considered a piece of good luck for natural science, that ERASMUS BARTHOLINUS could publish in 1669 a little treatise[45]) on his experiments with the Icelandic calcite-crystals, in which the light-refraction (double refraction) turned out to be very unusual. *Experimenta Crystalli Islandici Disdiaclastici* is the title of the treatise (Fig. 8).

While studying abroad, Bartholinus must have heard discussions on the nature of the light. When, after his return to Denmark, he got hold of some clear Icelandic calcite-crystals ($CaCO_3$), the idea struck him that here was outstanding material for the experimental investigation of René Descartes' postulated laws of light refraction and the nature of light.

Fragments of transparent pure calcite from Iceland had been brought by trading vessels to Copenhagen, probably together with other unusual natural products from this island[46]). But a larger quantity was needed for a physical investigation. This was procured by a little expedition equipped in Copenhagen in the spring of 1668[47]). A stone-cutter and his assistant were allotted the provisions, tools and money necessary to "quarry crystal in Iceland". Timber to build a hut when the expedition reached its destination was to be delivered by the Royal Navy.

In Bartholinus' time, only one place was known where Islandic spar could be found[48]). This locality in northeast Iceland (Helgustaðir in Reyðarfjorðr) must have been the party's destination.

On a gently sloping hillside near Reyðarfjorðr, about 100 meters above sea level, lies the farm Helgustaðir (Helgestad). A brook (Fig. 9) rushes down the mountainside by the farm, flowing in a stream bed cut into the basalt rocks. In these rocks there are fissures and amygdaloidal caves which contain calcite crystals and other minerals in a claylike mass. In Icelandic the calcite crystals are called Silfurberg (Silver Stone), and the brook which washed the calcite crystals out from the clay pockets, and rolled them downwards to the coast, was named Silfurlaekur. Most of the calcite crystals at this locality



ERASMI BARTHOLINI

EXPERIMENTA
CRYSTALLI ISLANDICI
DISDIACLASTICI

Qvibus mira & insolita
REFRACTIO
detegitur.

DEO ET REGE

ANNO 1669.

Paullatim

D. P.

HAFNIÆ,
Sumptibus DANIELIS PAULLI Reg. Bibl.

Fig. 8. Title-page to Erasmus Bartholinus' treatise on the double-refracting Icelandic calcite (1669).

are non-transparent, or otherwise defective, but a few are of such purity that they could not escape notice in early time.

The expedition left Copenhagen in the spring of 1668, and procured at Reiðarfjorðr a number of clear calcite crystals of varying sizes, which Erasmus Bartholinus describes[49]) in his dissertation (1669) as "recently brought back to us from Iceland". He writes[50]) that the

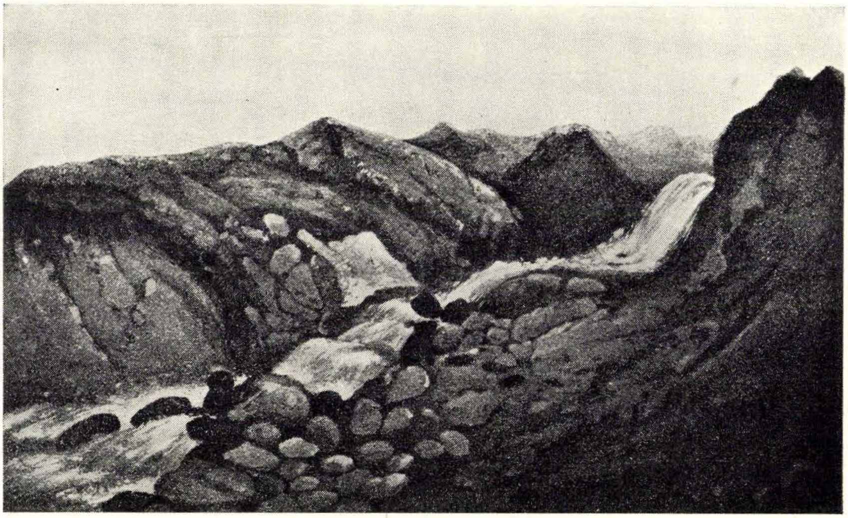
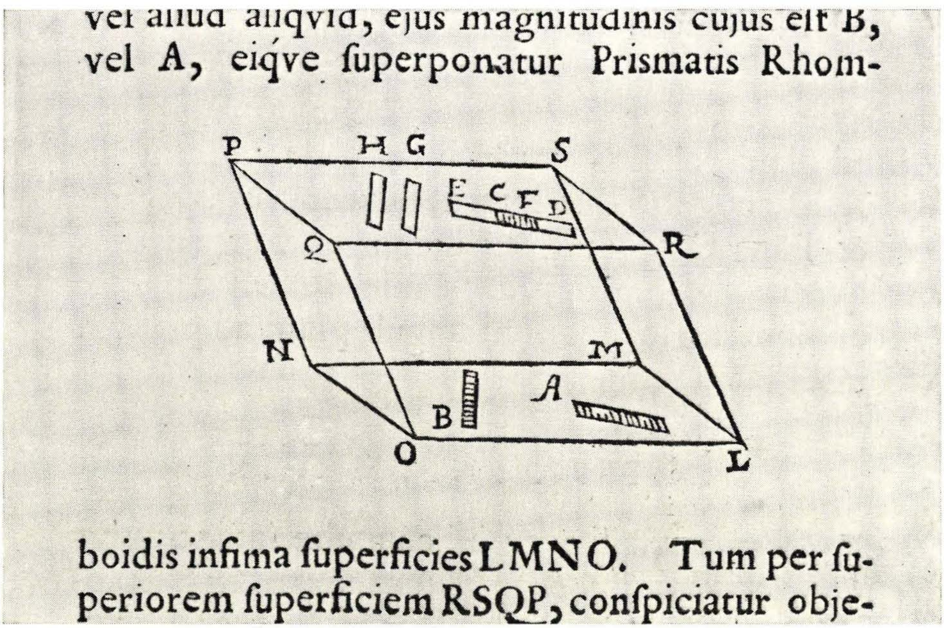


Fig. 9. The brook by the farm Helgustaðir and the double-spar locality (From Paul Gaymard: Voyage en Islande et au Groënland executé pendant les années 1835 et 1836 sur la Corvette La Recherche. Minéralogie et géologie par M. Eugène Robert. 1re partie, Paris 1840).

crystals were cut out of the rocks by means of iron tools, and that pieces of a cubic foot or more in size could be obtained. From the quarry the crystals were laboriously carried to the coast on horseback. The point of embarkation was Eskefjord (Eskifjorðr), which for this reason is often referred to in the mineralogical literature as the locality of Icelandic spar.

Some of the largest and best crystals were given, as was customary then, to King Frederick III's museum "Kunstkamret"[51]), which housed many mineralogical show-pieces, for example excellent samples of native silver from the royal silver mines at Kongsberg, Norway. Several specimens from the King's Museum of the seventeenth century can be identified in the Museums of Copenhagen today, but unfortunately the undoubtedly exquisite Icelandic calcite crystals from Erasmus Bartholinus' time are not known. The Mineralogical Museum of the University of Copenhagen, however, is in possession of a very fine collection of unusually large Icelandic calcite crystals, dating from at least the eighteenth century.

It was a strange coincidence that both Erasmus Bartholinus' treatise on the optical properties of the Icelandic calcite, and Nico-


vel aliud aliqvid, ejus magnitudinis cujus eſt B, vel A, eiqve ſuperponatur Prismatis Rhom-

boidis infima ſuperficies LMNO. Tum per ſuperiorem ſuperficiem RSQP, conſpiciatur obje-

Fig. 10. From Erasmus Bartholinus' dissertation on the double-refracting Icelandic spar.

laus Steno's dissertation "De Solido" came out in the year 1669, which was thus a decisive year in the history of crystallography. That these two scientists accomplished so much in their studies of the morphology and optics of crystals was of course due to their knowledge of mathematics.

Erasmus Bartholinus begins by describing and delineating the crystal form of the clear transparent, chemically pure Icelandic calcite he had at his disposal. The faces of the crystal are, he says, that figure "which in geometry is called a rhombus or Rhomboid. The crystal shape is mostly a Rhomboid". He observes, in addition, that all the fragments of a broken calcite crystal are also rhomboidal. Next, he describes in five short chapters (Experimenta II–VI) his investigation of the physical properties of Icelandic spar.

He found that the crystals could be charged electrically so that they would attract straw and other such objects, both when they were polished and when they were heated. The hardness is described as "less than the hardness of iron". There is a strong tendency for cleavage. The crystals are not greatly affected by fire, but can be calcined. In acids they effervesce and dissolve. The crystal angles (Experimenta V–VI) were measured or calculated as correctly as possible.

How interesting this may be, it hardly compares with what Erasmus Bartholinus found concerning light refraction in calcite. He describes the results of these studies in Experimenta VII–XVII.

He was surprised to see that the objects A and B (fig. 10), when observed through a calcite crystal, appear double, while through other transparent bodies only a single image can be seen. Object A appears respectively at EF and CD, object B at H and G. The distance between the images is dependent on the thickness of the crystal. The doubled images will partly coincide if the crystal is held in a certain position (Experimentum VIII); or (as seen in Experimentum X) the images can occasionally be made to unite if the eye assumes a certain definite position. In Experimentum XI Bartholinus describes another interesting phenomenon: the image is sometimes sextupled. He explains this as due to reflection.

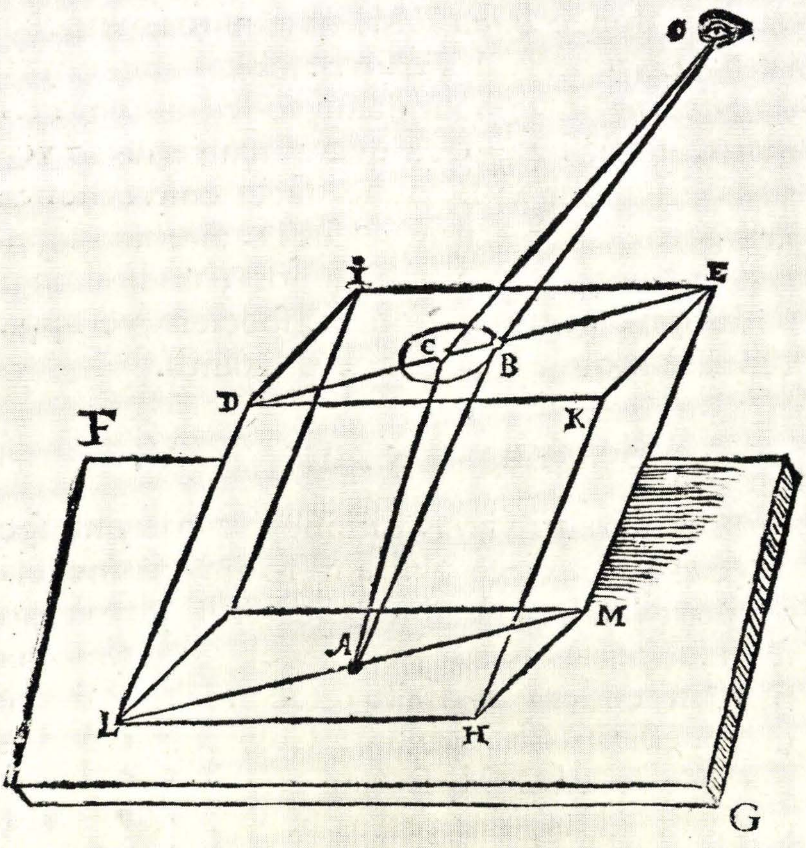
In Experimentum XIII–XV Erasmus Bartholinus also mentions the characteristic phenomenon that when a crystal lying on a paper with figures is turned, one image moves while the other remains still (fig. 11).

The next question was how this double image was formed. After a series of experiments which excluded several possibilities (Experimentum XVI), Erasmus Bartholinus came to the conclusion that the two images seen could only be explained by a double refraction of the ray of light passing through a crystal of calcite. The light beam is divided into two differently refracted rays. He called the beam which followed the ordinary refraction laws and gave the immobile image the ordinarily refracted ray, while the beam which gave the moveable image was called the extraordinarily refracted ray. "The crystal itself", Erasmus Bartholinus says, "we called disdiaclasticus, double refracting, owing to its extraordinary and unique power"[52]).

The properties of the refracted rays were investigated more closely. Bartholinus wanted especially to measure the angle of refraction. Certain technical difficulties arose, however. He could not

EXPERIMENTA CRYSTALLI ISLAND. 21

re, neqve imago in ſuperficie niſi remotione objecti vacillare; heic obſervavimus, unam ex dua-



bus imaginibus eſſe mobilem: id qvod hac ratione indagare licet. In ſchemate præcedente,

C 3 ma-

Fig. 11. Erasmus Bartholinus' figure, illustrating the moveable image.

— as in the classical dioptric experiments of Descartes — grind a prism of the crystal and use it to refract a light beam. Bartholinus therefore devised another method for measuring of the refractive index of the normally refracted light ray[53]). The extraordinarily refracted ray was not investigated in this respect.

Erasmus Bartholinus tried to give a theoretical explanation for the phenomena of the double refraction which he had discovered. He assumed[54]) light to be a movement of *corpuscula*, and thought furthermore that the Icelandic calcite crystals could be used to prove the corpuscular theory of the light. He thought the explanation was the existence of pores in different directions (cleavage directions) in the crystals and sets forth "two necessary hypotheses". But Erasmus Bartholinus was well aware that much more research work needed to be done, and he hoped that other naturalists ("more fertile spirits") would carry the work further. He therefore sent his paper to scientists in other countries, enclosing specimens of calcite[55]). Bartholinus was in contact with the Royal Society in London through its secretary, HENRY OLDENBURG, who apparently was especially interested in geology and mineralogy. It was, in fact, Henry Oldenburg, who in 1671 published an English translation of Nicolaus Steno's De Solido[56]).

There remain some letters from the correspondence between Oldenburg and Erasmus Bartholinus. One letter dated November 15, 1670, is from Oldenburg, thanking Professor Bartholinus for sending the paper (Experimenta crystalli 1669) and samples of the Icelandic crystal. Oldenburg assured him that the Royal Society would carry on the investigations[57]).

Erasmus Bartholinus himself never had the opportunity[58]) to continue his studies on the Icelandic double-refracting calcite. He was occupied with other things right up to his death in the year 1698. But other scientists in Europe worked further on the thought-provoking questions the Danish scientist had raised. Erasmus Bartholinus thought, as already quoted, that his calcite experiments and the newly detected double refraction would serve as proof for the corpuscular theory for light. The problem however, developed along other lines.

Records only recently accessible show that Bartholinus' friend from the Netherlands CHRISTIAAN HUYGENS, worked in the 1670's on his wave theory for light, trying to find proof for it in the double refraction phenomenon. Among his sketches and calculations we find Erasmus Bartholinus' figures[59]). Dated August 6th, 1677, beside the happy exclamation "Evreka" ("I have found it") stands a Latin notation that now he knew the cause for the strange double refraction in Icelandic crystal.

His light-wave theory (longitudinal waves) Huygens submitted to the French Academy the next year (1678), but he did not publish it until twelve years later[60]).

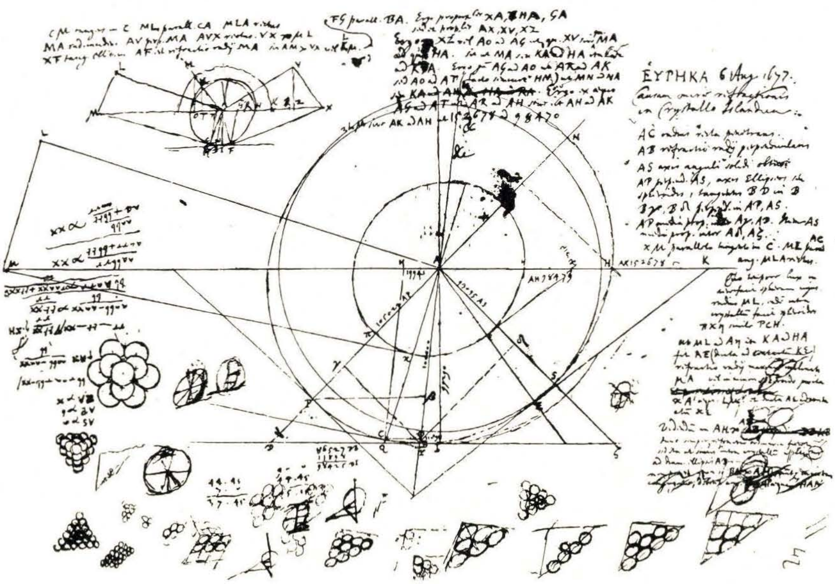


Fig. 12. A diminished reproduction of a manuscript page by HUYGENS (1677). On the right side, above, we find the date: 6. Aug. 1677 and the exclamation: ΕΥΡΗΚΑ. ("I have found it"), i. e. an explanation of the refraction in the Icelandic crystal (*Causam miræ refractionis in Crystallo Islandica*) (From CHRISTIAAN HUYGENS: Oeuvres complètes. Publ. par la Société Hollandaise des Sciences. Tome 19 (1937), the table before pag. 427).

ISAAC NEWTON, too, continued Bartholin's study of the optical properties of Icelandic calcite, and found optical peculiarities which later the French engineer, Malus, connected with his observation of the polarization of reflected light (1810), the next fundamental step forward in the history of crystal optics.

In 1669, Bartholinus wrote[61]) that the double refractive Icelandic crystal had no practical use. But how great a use, scientific and practical, has since been made of this mineral! We need only to mention Nicol's Prism.

In the history of crystallography many scientists deserve to be named. But it must not be forgotten, that it was the Danish scientist NICOLAUS STENO who in 1669 published the first scientific study of crystal morphology, and founded scientific geology, and that in the same year the Danish professor ERASMUS BARTHOLINUS published the first experimental study of crystal optics.

An unbroken line can be followed from these men and their studies to the theoretical physics of our twentieth century.

REFERENCES

Nicolaus Steno (Niels Stensen)

[1]) The Steno-literature is rather extensive. H. EHRENCRON-MÜLLER (Forfatterlexikon VIII (1930), 11 f.) and Dansk biografisk Lexikon XXII (1942), 562 f. give exhaustive lists up to the years of their publication. In Danish literature A. D. JØRGENSEN: Nils Stensen. Et mindeskrift (1884) is still the classic Steno-biography. — Two German biographies are: W. PLENKERS: Der Däne Niels Stensen (1884), and J. B. METZLER: Nicolaus Steno. Aus dem Leben eines nordischen Gelehrten und Bischofs (1911). GUSTAV SCHERZ in his edition of Nicolai Stenonis Epistolae I–II (1952) contributes (in German language) solid biographical material, in great part new on Nicolaus Steno. — An English biography of Nicolaus Steno is to be found in: VILHELM MAAR's edition of NICOLAI STENONIS Opera philosophica (i. e. scientific works) volume I (1910) p. I–XXVIII. See also: The prodromus of Nicolaus Steno's Dissertation concerning a solid body enclosed by process of nature within a solid. An English version with an introduction and explanatory notes by JOHN GARRETT WINTER (New York 1916). With biography p. 175–187. — An Italian biography is R. CIONI: Niccolò Stenone. Scienziato e vescovo (1953).

[2]) The "Chaos"-manuscript, published by GUSTAV SCHERZ in: Nicolai Stenonis Epistolae vol. II (1952), 907 f.

[3]) AXEL GARBOE: Thomas Bartholin vol. II (Acta historica scientiarum naturalium et medicinalium. Edidit Bibliotheca Universitatis Hafniensis. Vol. VI (1950), 18 f.)

[4]) Nicolai Stenonis Opera philosophica. Edited by VILHELM MAAR vol. I (1910), XXI f.

[5]) It was *Carcharodon Rondeletii Müll.* (*Carcharodon Lamia, Bonaparte*). NICOLAI STENONIS Opera philosophica vol. II (1910), 323. — R. SPÄRCK and AUGUST KROGH: Nicolaus Steno. Dissektion af et Hajhoved, in Stenoniana. Edited by VALD. MEISEN and KNUD LARSEN vol. I (1923), 50 f. — Axel Garboe: Niels Stensens (Stenos) geologiske Arbejdes Skæbne. With an English Summary (1948), 4 f. (Danmarks Geologiske Undersøgelse. IV. series vol. 3, no. 4).

[6]) NICOLAUS STENO: Elementorum myologiae specimen, seu musculi descriptio geometrica. Cui accedunt Canis Carchariae dissectum caput, et dissectus piscis ex Canum genere (Firenze 1667). Edited with notes by VILHELM MAAR in: Nic. Stenonis Opera philosophica vol. II (1910), 61 f., 319 f.

[7]) K. A. VON ZITTEL: Geschichte der Geologie und Palaeontologie (1899), 13 f., 22 f. — FRANK DAWSON ADAMS: The Birth and Development of the Geological Sciences (1938), 90 f., 115 f.

[8]) Nicolaus Steno as a Scientist at work is discussed by VILHELM MAAR (Steno's Opera philosophica volume I (1910), XII f. and HILMAR ØDUM in the Danish journal "Naturens Verden" (1938), 49 f.

[9]) VILHELM MAAR in his introduction to Nic. Stenonis Opera philosophica volume I (1910), XII.

[10]) FRANK DAWSON ADAMS: Earliest use of the term Geology (Bull. Geol. Soc. of America vol. 23 (1932), 121 f. and vol. 24 (1933), 821 f. — ARNE NOE-NYGAARD:

Om den første Brug af Ordet Geologi (Meddelelser fra Dansk Geologisk Forening vol. XI (1947), 220 f.)

[11]) OLE BORCH, Olaus Borrichius (1626–1690), medical botanical and chemical professor at the University of Copenhagen. Founder of the still existing Borchs Kollegium for students.

[12]) NICOLAUS STENO: Elementorum myologiae specimen (conjectura VI).

[13]) NICOLAUS STENO: Elementorum myologiae specimen (conjectura VI).

[14]) MANFREDO SETTALA (1600–1680) was in possession of a famous "Museum", a collection of natural and artificial products of many sorts. A description of the Museum Septalianum was published in 1664 (MICHAUD: Biographie universelle vol. 39, 176).

[15]) NICOLAUS STENO: De solido (1669), 3 (see note 18).

[16]) Nic. Stenonis Epistolae vol. I (1952), 29.

[17]) Sjællandske Tegnelser (1667), folio 258, Rigsarkivet (The Danish State Archives), København.

[18]) N. STENO: De solido intra solidum naturaliter contento Dissertationis prodromus. Ad serenissimum Ferdinandum II Magnum Etruriæ Ducem (1669). — A Danish translation with introduction and notes was published (1902) by AUGUST KROGH and VILHELM MAAR (NICOLAUS STENO: Foreløbig Meddelelse til en Afhandling om faste Legemer, der findes naturlig indlejrede i andre faste Legemer). — The modern English translation by JOHN GARRETT WINTER (1916) see Note 1. — German translation with notes was published (1923) by KARL MIELEITNER (volume 209 in the series OSTWALD's Klassiker der exakten Wissenschaften). — An Italian translation came in 1928 (NIC. STENONE: Prodromo di una dissertazione sui corpi solidi naturalmente inclusi in altri corpi solidi. Tradotto dal Latino con prefazione e note a cura di GIUSEPPE MONTALENTI . . . Roma 1928).

[19]) NICOLAUS STENO: De solido, 2, 8.

[20]) NICOLAUS STENO: De solido, 26 f.

[21]) NICOLAUS STENO: De solido, 3.

[22]) OLE WORM (Olaus Wormius) 1588–1654, medical professor in Copenhagen, famous for his excellent museum and for his epochmaking archæological studies (the Runic Stones).

[23]) AXEL GARBOE: Thomas Bartholin vol. I (1949), 64 f.

[24]) NICOLAUS STENO: De solido, 32 f.

[25]) NICOLAUS STENO: De solido, 63.

[26]) NICOLAUS STENO: De solido, 62.

[27]) NICOLAUS STENO: De solido, 67 f.

[28]) KARL MIELEITNER: Die Anfänge der Theorien über die Struktur der Kristalle (Fortschritte der Mineralogie etc. 8 (1923), 199). — A. JOHNSEN: Die Geschichte einer kristall-morphologischen Erkenntnis (Sitzungsberichte d. k. preuss. Akademie der Wissenschaften. Phys.-math. Klasse. Jahrg. 1932, p. 404–415).

[29]) FRANTZ V. KOBELL: Geschichte der Mineralogie von 1650–1860 (1864), 3.

[30]) NICOLAUS STENO: De solido, 50.

[31]) NICOLAUS STENO: De solido, 39.

[32]) NICOLAUS STENO: De solido, 17.

[33]) NICOLAUS STENO: De solido, 36.

[34]) HILMAR ØDUM: Niels Stensens geologiske Syn og videnskabelige Tankesæt (Naturens Verden (1938), 49 f).

[35]) NICOLAUS STENO: De solido, 39 f.

[36]) Nicolaus Steno: De solido. Explanation of the figures. Here Steno writes: "The first thirteen figures, intended to illustrate the angular bodies of crystal, fall into two classes. The first class contains seven varieties of a plane in which the axis of a crystal lies. In figures 1, 2 and 3, the axes of the parts, of which the body of the crystal is composed, form a straight line; but there is an intermediate prism, which is lacking in Figure 1, appears rather short in 2, longer in 3. In Figure 4, the axes of the parts which make up the body of the crystal do not form a straight line [here follows the explanation of Figures 5 and 6]. The second class contains six varieties of base of planes. In Figures 8, 9, 10 and 11, there are only six sides; with this difference, nevertheless, that in Figure 8 all the sides are equal, while in Figures 9 and 11 not all, but only the opposite sides, are equal; in Figure 10, any given opposite sides are unequal. In Figure 12 the plane of the base, which ought to be a hexagon, is bounded by twelve sides. Figure 13 shows how sometimes the length and number of the sides are changed in various ways without changing the angles, on the plane of the base, while new crystalline matter is being placed upon the planes of the pyramids".

The figures 14–19 shall illustrate Steno's studies of hematite crystals. "Figures 14, 15, 16 serve to illustrate those angular bodies of iron which are enclosed by twelve planes. Fig. 14, in fact, shows all the twelve planes spread out into a single plane, six of these being triangular and brilliant, the remaining six pentagonal and striated. Figure 15 is the plane of the base of the same body. Figure 16 is the plane of the axis of the same body. Figures 17, 18 and 19 serve to illustrate those angular bodies of iron which are bounded by thirty planes. Figure 17 shows the thirty planes spread out into a single plane; of these six planes are pentagonal and brillant. twelve triangular and also brilliant, six triangular and striated, six oblong quadrilaterals and brilliant. Figure 18 is the plane of the base of the same body. Figure 19 is the plane of the axis of the same body" (Garrett Winter's translation).

[37]) A. Johnsen: Die Geschichte einer kristall-morphologischen Erkenntnis (Sitzungsberichte d. preuss. Akad. d. Wiss. Jahrg. (1932), 404 f.), — R. Hooykaas: De oudste Kristallografie (Chemisch Weekblad. Orgaan der Nederlandse Chemische Vereniging (1950), 438 f.) — R. Hooykaas: De Kristallografie van F. B. Romé de l'Isle 1783 (Chemisch Weekblad (1951), 848 f.).

[38]) Nicolai Stenonis Epistolae. Ed. Gustav Scherz, volume I (1952), 210, 212 (Letter from Steno to Marcello Malpighi, okt. 27. 1669 about the mines in Hungary which Steno had studied). See also Epistolae volume I p. 219, 247. — In 1671 Nicolaus Steno studied two alpine grottos for the problem of antiperistasis. See Epistolae volume I (1952) 245. Cfr. Axel Garboe: Niels Stensen's Grotto Letters (1671). An Episode in the Life of the young Niels Stensen (Steno) in: Hilsen til J. Christian Bay paa Firsaarsdagen (1951), 13. — Epistolae volume I (1952), 268 f. (Amber, in the earth at Kopenhagen 1672). — Epistolae I (1952), 278 f. (Professor Willum Worm presents (1672) Nicolaus Steno a Norwegian stone containing fossil fishes).

[39]) Axel Garboe: Niels Stensens (Steno's) geologiske Arbejdes Skæbne. With an English Summary (Danmarks Geologiske Undersøgelse 4. series volume 3 No 4, 1948).

Erasmus Bartholinus

[40]) Kirstine Meyer f. Bjerrum: Erasmus Bartholin. Et Tidsbillede (1933). — Kirstine Meyer f. Bjerrum: Erasmus Bartholin (in: Prominent Danish Scientists through the Ages. Edited by V. Meisen (1932), 29–32).

[41]) CHRISTIAAN HUYGENS: Oeuvres complètes. Tome I (1888), 515 f.

[42]) THOMAS BARTHOLINUS: De nivis usu medico observationes varia. Accessit D. Erasmi Bartholini de figura nivis dissertatio (Hafniae 1661).

[43]) DORTOUS DE MAIRAN: Dissertation sur la glace, ou: explication physique de la formation de la glace, & de ses divers phénomènes (Paris 1749), 164.

[44]) AXEL V. NIELSEN: Ole Römer. En Skildring af hans Liv og Gerning. Udgivet i 300-Aaret for hans Fødsel af Ole Römer-Observatoriet i Aarhus (1944).

[45]) ERASMUS BARTHOLINUS: Experimenta crystalli Islandici disdiaclastici, quibus mira et insolita refractio detegitur (1669). An edition (reprint) 1670. — A German translation was published by KARL MIELEITNER in OSTWALD'S Klassiker der exakten Wissenschaften No. 205. (Versuche mit dem doppeltbrechenden islandischen Kristall, die zur Entdeckung einer wunderbaren und aussergewöhnlichen Brechung führten).

[46]) The correspondence of the learned naturalist, professor OLE WORM, proprietor of the famous *Museum Wormianum*, bears witness to the lively naval traffic between Denmark and Iceland in the seventeenth Century (Olai Wormii et ad eum doctorum virorum epistolae volumes 1–2, 1751).

[47]) Rigsarkivet (The Danish State Archives), København (sjællandske Tegnelser XXXVIII no. 297–298, 11. april 1668).

[48]) TH. THORODDSEN: Nogle Bemærkninger om de islandske Findesteder for Dobbelspath (Geologiska Föreningens i Stockholm Förhandlingar vol. 12 (1890), 247 f. — cfr. (Danish) Geografisk Tidsskrift vol. 7 (1884), 104 f. — See also Helgi H. Eiriksson: Silfurbergsnáman á Helgustöðum (Timarit Verkfræðingafjelags Islands 7. arg. (1922), 62–67), with summary: The Iceland Spar mine at Helgustaðir.

[49]) ERASMUS BARTHOLINUS: Experimenta crystalli, 1.

[50]) ERASMUS BARTHOLINUS: Experimenta, 60.

[51]) HOLGER JACOBÆUS: Museum Regium seu Catalogus rerum tam naturalium quam artificialium etc. (1696), 35.

[52]) ERASMUS BARTHOLINUS: Experimenta crystalli, 29: Hinc, crystallum ipsum, a duplices istius refractionis præcipia et singulari gloria vocamus Disdiaclasticum.

[53]) ERASMUS BARTHOLINUS: Experimenta crystalli, 36.

[54]) ERASMUS BARTHOLINUS: Experimenta crystalli, 42 f.

[55]) In the scientific journal, Miscellanea curiosa medico-physica Academiæ naturæ curiosum, annus secundus (1671), 267, ERASMUS BARTHOLINUS expressed the wish that other scientists would investigate the properties of the Icelandic double-spar.

[56]) I. B. WOODWORTH: A 1671 English version of Nicolaus Steno's *De solido intra solidum naturaliter contento*. By H. O. (Science New series vol. 25. (1907), 738).

[57]) Den Böllingske Brevsamling, Det kgl. Bibliotek, (The Royal Library), København (U. 4°; 730).

[58]) In his University lectures (1674) ERASMUS BARTHOLINUS mentions crystallographical questions (De naturæ mirabilibus qvæstiones academicæ 1674; De figuris corporum qvæstio prima).

[59]) CHRISTIAAN HUYGENS: Oeuvres complètes, tome 19 (1937), 409, e. g. fig. 131.

[60]) CHRISTIAAN HUYGENS: Traité de la lumière. Ou sont expliquées les causes de ce qui luy arrive dans la reflexion, & dans la refraction, et particulièrement dans l'étrange refraction du Cristal d'Islande (Leiden 1690).

[61]) ERASMUS BARTHOLINUS: Experimenta crystalli, 34.

DANSK SAMMENDRAG

Den betydning, de to danske naturforskere i 1600-tallet NIELS STENSEN (STENO) og ERASMUS BARTHOLIN har for grundlæggelsen af geologien og mineralogien som eksakte videnskaber, er emnet for denne afhandling.

Niels Stensen (NICOLAUS STENONIS, STENO) blev født i København 1638 som søn af en guldsmed af skånsk præsteslægt. Efter en kort, men betydningsfuld videnskabelig, især anatomisk, virksomhed, der dog aldrig skaffede Steno en varig lærervirksomhed ved Københavns universitet, blev denne mand, der i 1667 gik over til den romersk-katolske kirke, mere og mere optaget af sit arbejde i kirkens tjeneste. Han døde allerede i 1686 i Schwerin som katholsk biskop og ligger begravet i San Lorenzo kirken i Firenze.

ERASMUS BARTHOLIN var også københavner, født 1625. Han tilhørte den dygtige og indflydelsesrige lærde slægt Bartholin og fik som flere af denne slægts medlemmer en livslang virksomhed som professor ved Københavns universitet.

Niels Stensen (Steno) publicerede i 1667 (figur 1) det første forsøg på at forstå jordskorpens bygning og dens udviklingshistorie ad de eksakte undersøgelsers vej: det var anatomiske undersøgelser af hajer, især en meget stor haj fra middelhavet, der førte Niels Stensen ind på geologiske overvejelser og studier. Især trængte det spørgsmål sig på, om de dengang meget omdiskuterede »Tungestene«, *glossopetræ*, var af organisk oprindelse (fossile hajtænder). — Det foreløbige resultat af sine geologiske studier »i marken« fremsatte Niels Stensen (1667) i en række »formodninger«, *conjecturæ*, hvori han i virkeligheden giver et første eksakt grundrids af jordens udviklingshistorie, og det var hans hensigt at skrive et større, udførligt værk herom. Dette skete desværre aldrig. Men noget af sit materiale fremlagde Niels Stensen i sit arbejde (1669) »Om faste legemer, der findes naturligt indlejrede i andre faste legemer«, De solido intra solidum naturaliter contento Dissertationis prodromus (fig. 4–6). En dansk oversættelse heraf udsendtes (1902) af AUGUST KROGH og VILHELM MAAR. I dette skrift, som Niels Stensen selv kalder »en foreløbig meddelelse«, *prodromus*, skrevet i hast under opbrud fra Italien, er Niels Stensen klar over »forsteningernes« organiske oprindelse med de deraf følgende vidtrækkende palæontologiske og geologiske konsekvenser, selvom han naturligvis kun glimtvis kunne overskue disse. Han fremsætter som sin geologiske grundopfattelse, at jordlagene er sedimenter, hvis oprindelige vandrette lagstilling dog ofte er forstyrret under indflydelse af underjordisk ild og vandets virksomhed. Han diskuterede bl. a. bjergdannelsen og gjorde dette udfra iagttagelser på rejser i Italien, ikke som hans samtidige under udfoldelse af rene fantasier. Og tilsidst gav han, som den første af alle, en skitse af et bestemt områdes (Toscana's) geologiske udviklingshistorie (fig. 6). Stensens betegnelse »faste legemer, naturligt indelejrede i andre faste legemer«, omfatter også mineral-krystaller. Han studerede mineralforekomster (gangdannelser o. a.) og krystaller (især bjergkrystal, jernglans og svovlkis) på eksakt måde (»som en naturforsker i det 20. århundrede«) og kunne fastslå, at krystaller vokser ved pålejring af stof på krystalfladerne, ligesom han var den første, der opdagede loven om kantvinklernes konstans. Med rette benævnes, trods rejst kritik, denne lov »Steno's lov«.

Samme år som Niels Stensen publicerede sit længe glemte, men nu klassiske arbejde »om faste legemer &c.« (1669) offentliggjorde Erasmus Bartholin et eksperimentelt arbejde, hvori han meddelte den første krystal-optiske undersøgelse og derved ledte forskningen ind på områder, der skulle vise sig af meget stor vigtighed for forståelsen af lysets natur og give forskerne uundværlige tekniske hjælpemidler (Nicol); skridt for skridt førte dette frem til nutidens opfattelse af krystallers atom-gitterstruktur.

Erasmus Bartholins undersøgelsesmateriale var vandklare, store kalkspatkrystaller fra en øst-islandsk lokalitet i basaltklipperne ved gården Helgustaðir nær handelspladsen Eskifjorðr. I et bækleje (fig. 9) havde man fundet de første klare kalkspatkrystaller. Nu fremskaffede en lille dansk ekspedition, som udsendtes fra København i foråret 1668, et større parti deraf.

Erasmus Bartholin beskriver i afhandlingen »Undersøgelser over den islandske, dobbeltbrydende krystal«, experimenta crystalli Islandici disdiaclastici (1669) (titelblad fig. 8) disse kalkspatkrystallers krystallografiske og fysiske forhold, især det dengang ganske nye og opsigtsvækkende fænomen, at en indfaldende lysstråle deler sig i to, den ordinært brudte stråle, som brydes på sædvanlig måde, og den extraordinært brudte stråle. Han søgte at give en teoretisk forklaring ud fra antagelsen af »porer« i krystallen og lyset som corpuscula. Men Christiaan Huygens, som var iblandt dem, der arbejdede videre med fænomenet, udarbejdede i tilslutning til Erasmus Bartholins undersøgelser sin lysbølgeteori.

I Huygens' efterladte papirer finder man tegninger af Erasmus Bartholins islandske krystaller og beregninger over lysets gang derigennem (fig. 12), således som han allerede i 1678 kunne forelægge det for videnskabernes akademi i Paris.

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KØBENHAVN