ICELAND SPAR: THE HELGUSTADIR CALCITE LOCALITY AND ITS INFLUENCE ON THE DEVELOPMENT OF SCIENCE

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ABSTRACT

A site at Helgustadir, East Iceland, supplied large quantities of transparent cleavage rhombs of calcite (commonly called Iceland spar) from 1668 to 1925. These crystals played a significant role in the early development of several fields in the physical sciences including wave optics, crystallography, and crystal physics. From the mid-19th century onwards, most of the Nicol prisms which were used in petrographic microscopes, polarimeters and various other optical instruments were made of Iceland spar from the Helgustadir locality. These instruments contributed to advances in mineralogy and petrology, as well as in branches of physics, chemistry, biological sciences, and technology where polarized light was employed.

Keywords: Iceland spar - optical calcite - Helgustadir - polarized light -crystallography.

INTRODUCTION

The rock formations exposed in Iceland consist mostly of basalt lava sequences erupted from fissures or within central-volcano complexes resembling those of the British Tertiary volcanic province. Zeolite and calcite infillings are abundant in Icelandic basalts, especially in zones of alteration associated with the central volcanoes. However, the calcite rarely reaches more than a couple of centimeters in size.

One extinct central volcano (Walker, 1959), estimated to be 11 M.y. in age, crosses the fjord Reydarfjördur in East Iceland (Figure 1). The presence of large calcite crystals in cavities in the lava pile near the farm Helgustadir within the Reydarfjördur complex has been known since at least 1668. Calcite (or calc-spar, which belongs to the trigonal system of crystals) is a very common mineral worldwide, exhibiting a greater variety of forms than any other mineral: over 200 simple forms had already been reported by 1878, according to Tschermak (1894). Compared to other notable calcite deposits in Europe, the material from Helgustadir is unusual in being chemically pure and highly transparent, as well as in yielding flawless cleavage pieces of the "fundamental rhombohedron" of calcite (see Figure 2A). Moreover, the pieces are of adequate size for various experimental purposes, particularly in optical instruments.

The present paper (extracted from Kristjansson, 2001) briefly outlines the history of the Helgustadir site, and describes applications of crystals from it in various branches of the physical sciences.

EVENTS UNTIL 1800

E. Bartholinus (1669), of Copenhagen, published a booklet on crystals which he had received from Helgustadir, paying special attention to their strange double refraction. A ray of light entering such a crystal split into two rays: one obeyed Snell's law of refraction, whereas the other acted in an extraordinary manner. Even at a perpendicular incidence upon a cleavage face it was refracted away from the normal inside the crystal (Figure 2B), and when Bartholinus rotated the crystal this ray rotated with it.

Bartholinus' paper was a milestone in both crystallography and optics. His writings and the Icelandic crystals reached other scientists, so that one chapter of the important book by Huyghens (1690) describing light as undulations in a medium of "aether" is devoted to these crystals. Huyghens noted that the nature of light changed upon its passing through them. He was aware that quartz also exhibits double refraction, but to a much lesser extent. Huyghens (1690) suggested that within doubly refracting crystals, a point source of light would give rise to two wave-fronts, one being spherical and the other being ellipsoidal.

In his book *Opticks*, Isaac Newton (1704) considered light to consist of an emitted stream of particles, and subsequent editions of this book contained a brief discussion of the Icelandic crystals. He suggested that light particles might be endowed with "sides" analogous to a magnet's poles, causing them to be channeled in two different directions within such crystals. Most scientists accepted Newton's views on light until the 1820s or later, and many may have thought of double refraction as an anomalous curiosity rather than being of general significance.

In the second half of the 18th century, the Icelandic crystals were given attention in some treatises on crystallography and mineralogy. These include several works by the "father of crystallography", R.-J. Haüy of France (see for instance Haüy, 1782, 1801) where the name "spath d'Islande" appears. Judging from biographical accounts (Gratacap, 1918; Hintze, 1930), Haüy's famous law of rational proportions for crystal angles may be traced directly to his observations of Iceland spar and other calcite crystals.

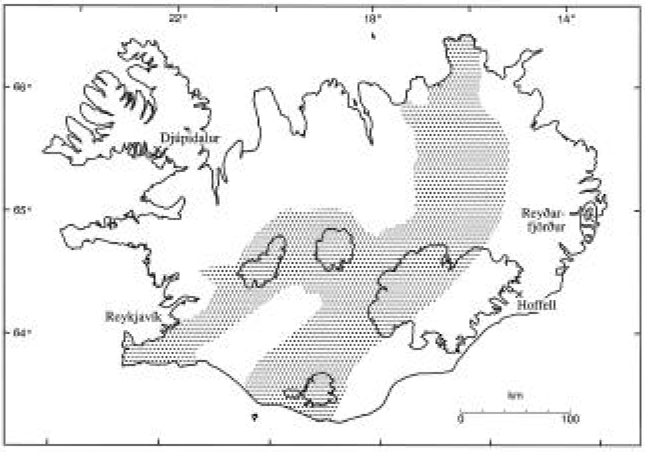

Figure 1. Iceland: the active volcanic zones are stippled. The Helgustadir quarry for Iceland spar lies within the propylitized zone (inner curve) of a central volcano remnant extending across the fjord Reydarfjördur. The location of the Iceland spar quarry at Hoffell (see text) is also shown. A calcite prospect at Djupidalur (Thoroddsen, 1891) did not yield satisfactory crystals.

EVENTS OF 1800-1850: OPTICAL PROPERTIES OF ICELAND SPAR

Haüy and others had noted by 1800 that tens of minerals exhibited double refraction. However, the phenomenon is not easy to observe in most cases (see for instance Bernhardi, 1807; Barnard, 1863) and might have gone unnoticed for many more decades if the properties of Iceland spar had not drawn attention to it. Ever since, Iceland spar has been the "type material" in textbooks for introducing the subject of double refraction and the polarization of light (Figure 2C).

In England, W.H. Wollaston constructed a new device to measure refractive indices, and applied it to various materials including Iceland spar. His results (Wollaston, 1802) regarding the direction-dependent index of the extraordinary ray agreed with Huyghens' (1690) ellipsoidal wavefront. Wollaston's paper inspired the French Academy of Sciences to announce in 1807 a prize competition on the subject of double refraction. The winner was E.L. Malus, who made thorough measurements of refraction by Iceland spar, and confirmed Wollaston's results with greatly improved accuracy. Furthermore, Malus (1808) discovered in the course of this work that the nature of a light ray reflected from any smooth surface is changed in a way similar to that caused by its passage through Iceland spar. Malus concluded that this phenomenon for which he introduced the term "polarization", related to a fundamental property of light. (The term is based on Newton's views of magnet-like light particles and refers to the reflection or refraction process selecting the particles according to their orientation.) Daumas (1987) writes in reference to the following years that "A new branch of optics was born" and "Polarization phenomena became the center of preoccupation among physicists." For instance, Bérard (1812) observed that infrared heat radiation from the Sun was similar to visible light in its polarization properties. This provided strong support for the possibility that both were of the same nature.

During the next two decades, Newton's emission theory gave way to the undulation theory, largely due to experimental evidence from interference and diffraction effects (see Buchwald, 1989). The polarization of light contributed to this evolution in thought; for example, the colors exhibited by thin crystalline plates in polarized light could be convincingly explained by wave interference (Fresnel, 1821). Brewster (1815b) and Fresnel (e.g. 1819) showed through theory and experiment that polarization was an important aspect of reflection and refraction phenomena. Fresnel (1821-22, as well as later) derived important equations that described the propagation of the extraordinary wave in doubly refracting materials. Many other scientists in Europe provided sequels to Fresnel's work, which also encouraged studies on elastic waves in matter (Whittaker, 1953).

It was noted by Bernhardi (1807) and others that crystals from the "regular" (also named isometric or cubic) system did not exhibit double refraction. Moreover, the symmetry axis of the ellipsoid of light propagation (optic axis) was found in some of the doubly refracting crystals to coincide with the symmetry axis of the basic geometrical form of the crystal. When plates from these crystals were illuminated with convergent polarized light, Brewster (1818) observed an interference pattern centered on the optic axis. He also noted that such interference patterns were different in crystals from the three least symmetric crystal systems. It turned out that the latter crystals had two optic axes and that the angle between these axes depended on the crystal as well as on the color of the light. Later, these differences in optical properties were exploited by A. Des Cloizeaux (e.g. 1857) and others in fruitful methods for investigating the structure and composition of minerals.

In 1817 T. Young pointed out (in a letter to F. Arago, quoted by Verdet, 1869) that certain other interference phenomena of polarized light indicated that the elastic oscillations of the aether were (at least in part) transverse, not longitudinal as in sound waves. Distinction could accordingly be made between (i) unpolarized light, where the transverse undulations of the aether took place in random directions; (ii) plane-polarized light; and (iii) elliptically polarized light, which consisted of vibrations along two orthogonal planes, with a constant phase difference.

This recognition helped elevate light to its status as the powerful testing tool it is today. Scientists have many means of probing the nature of matter, but light is surely

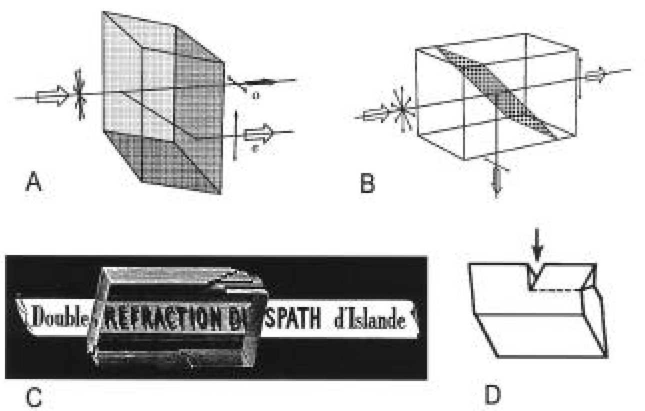

Figure 2. (A) A cleavage rhomb of Iceland spar has angles of 105°05’ and 74°55’ between its faces. The optic axis is oriented symmetrically with respect to three edges meeting at an obtuse corner. The paths taken by a light ray incident normally on a rhomb face are shown. The directions of the planes of polarization are indicated. Key: o: ordinary ray, e: extraordinary ray. In this case, the actual angle between the two rays within the crystal is about 6°. (B) Simplified diagram of one variety of a Nicol prism. Typical sizes may have been around 3 cm. The space between the two calcite halves may contain either a transparent resin or oil, or merely air. Light vibrations in one particular direction (the extraordinary ray of the crystal) are transmitted, but vibrations in the orthogonal direction suffer total reflection and were usually discarded. (C) A typical textbook illustration accompanying discussion on double refraction and the polarization of light, from Maneuvrier (1908). (D) A diagram first published by Baumhauer (1878-79), showing how an Iceland spar crystal could be permanently deformed by applying force with a knife edge. From Voigt (1910).

the most important. While engaged in such probes, one may for example adjust the tool of light regarding its wavelength (color), the intensity or duration of its pulses, and its angle of incidence. Changes in the polarization of light due to its interaction with matter furnished science with a highly sensitive testing mechanism for which ever new applications have been found.

EVENTS OF 1800-1850: CRYSTALLOGRAPHY AND CRYSTAL PHYSICS

Iceland spar was involved in the development of crystallography, crystal physics and mineralogy on more fronts than that of optics. One of the innovations was the concept of isomorphism, first discussed by E. Mitscherlich and others around 1820 (see Arzruni, 1893). This concept describes how some related compounds (in this case certain other carbonates) or even unrelated ones (such as sodium nitrate) crystallize in basic forms similar to that of calcite (Tschermak, 1881). Conversely, aragonite while belonging to a different crystal system, turned out to be pure $CaCO_3$ like calcite (Fourcroy and Vauquelin, 1804); in fact, this was one of the earliest observed cases of di- or polymorphism.

The circumstance that Iceland spar could be split easily into large rhombs having exceptionally flat, clean surfaces, made it popular for various experiments during the 19th century (see Hintze, 1930). Using accurate equipment in a series of measurements on the angles between the sides of such a rhomb, Mitscherlich (1825) noted that these angles changed with the ambient temperature. The geometry of this unexpected deformation was closely connected to the optic axis of the crystal. Mitscherlich’s findings prompted research on the directional associations of various physical properties of Iceland spar and other crystals: their hardness, elasticity, thermal conduction, and response to magnetic and electric fields. The results were largely qualitative and sometimes obscured by other effects (such as iron-rich impurities affecting magnetic properties); nevertheless, they paved the way to understanding the concept of anisotropy in the mid-19th century.

EVENTS OF 1800-1850:INSTRUMENTATION

Until 1829, there were three methods of producing plane-polarized light and of finding its direction of polarization: by inclined glass plates which reflected or transmitted one polarization component more than the other; by plates of so-called dichroic materials (chiefly tourmaline) which preferentially absorbed one component; and by doubly refracting crystals, especially Iceland spar.

When a narrow beam of light has travelled through a cleavage rhombohedron of Iceland spar, the two rays are separated by about one-tenth the thickness of the crystal (Figure 2A). For a broad beam, the two images overlap (Figure 2C). W. Nicol (1829) of Edinburgh found a way that one of the images could be eliminated, by making the “ordinary” ray suffer total internal reflection at an inclined interface between the crystal and a material with a lower refractive index. For this purpose, Nicol sliced a rhomb of Iceland spar diagonally and glued the resulting halves together with resin (Figure 2B). These “Nicol prisms” were widely known by 1840, and the following decades saw the introduction of many modifications of Nicol’s original design. Wedges of Iceland spar or quartz (Rochon prisms, Wollaston prisms, etc.) were preferred for some applications to Nicol prisms.

Two main types of instruments named polariscopes (Figure 3A) were in common use by the late 1840s. One type measured a progressive rotation of the plane in plane-polarized light which occurs as it passes through

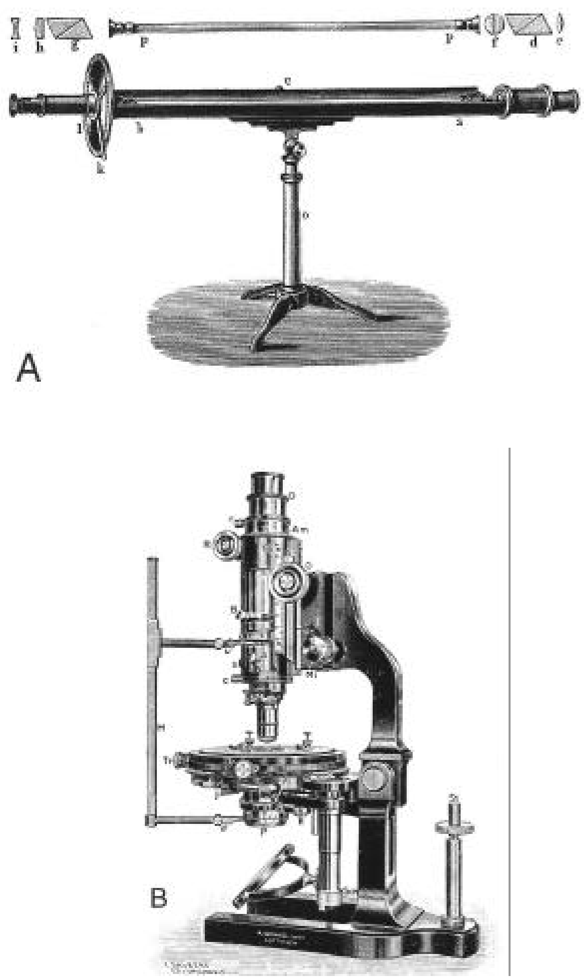

Figure 3. (A) A polariscope from around 1850, for measuring optical activity in liquids. Light admitted by the right-hand Nicol prism, d, is plane-polarized. The left-hand prism, g, is used to measure the rotation angle of the plane of polarization within a liquid sample in the tube, PP. From Landolt (1898). (B) A petrographic microscope designed in 1918, containing two rotatable Nicol prisms (connected by the bar, H). From Leiss (1925).

certain materials, most notably quartz (Biot, 1812) and various organic liquids such as sugar solutions. These materials were termed "optically active". The other type, incorporating an additional device (usually made of quartz but sometimes of calcite, mica or gypsum) for phase compensation, measured the shape and orientation of the vibration ellipse in elliptically polarized light. The latter instruments were applied in varied research, for example on light from the sky; the emission, reflection, refraction and absorption of light by materials; and the double refraction induced in isotropic solids by pressure (discovered by Brewster, 1815a). Polariscopes soon contained two Nicol prisms each, as glass-plate and dichroic polarizers proved unsuitable for studying light quantitatively.

ESPECIALLY MOMENTOUS EVENTS: 1840-1850

In the late 1840s, the use of polariscopes (later called polarimeters) spurred new discoveries. One was Faraday's (1846) observation that substances such as glass exhibited measureable optical activity when subjected to strong magnetic fields. This demonstrated for the first time a connection between light and electric or magnetic fields, and drew considerable attention.

Also in the late 1840s, an Edinburgh student named J.C. Maxwell was given a pair of Nicol prisms by W. Nicol himself. Maxwell experimented with polarized light (e.g. Maxwell, 1853), subsequently completed his university education, and then turned his attention toward other fields of physics for a while. When he later introduced his theories of electromagnetism (Maxwell, 1863), which provided a new theoretical foundation for the existence of light waves, he was well acquainted with the work by Faraday and others on the magneto-optic effect. In Maxwell's writings on magnetism, Iceland spar was discussed as an example of an anisotropic material.

Meanwhile L. Pasteur, a young chemist in France, was studying crystals of tartaric acid and its salts, whose optical activity in aqueous solutions had puzzled previous investigators. He found (Pasteur, 1848) that such a solution rotated the plane of polarization of light clockwise or anticlockwise in accordance with the "handedness" of the respective crystals, since they existed in two mirror-image modifications. From the results of Pasteur and others, it was later concluded (Hoff, 1874) that the four chemical bonds of carbon were three-dimensional. This new concept of stereochemistry revolutionized the understanding of organic chemistry and of biochemical processes.

THE HELGUSTADIR SITE, 1800-1895

Up to the 1850s, crystals of Iceland spar found their way from Helgustadir to Europe by various routes (Kristjansson, 2001): freight vessels serving nearby trading posts, fishing boats from abroad (mostly French) after 1815, and travelers including local and foreign scientists. The amounts involved are difficult to estimate, but one expedition from the continent in the 1830s was later claimed to have removed 30-40 tonnes of crystals.

Quarrying at Helgustadir on a significant scale was first organized in 1855-1860, to be greatly intensified in 1863-1872 (Kristjansson, 2001). The operators were merchants at a nearby village. They paid an annual fee to the Danish state which Iceland belonged to at that time and which incidentally owned one-fourth of the Helgustadir property. The exported quantity is estimated to

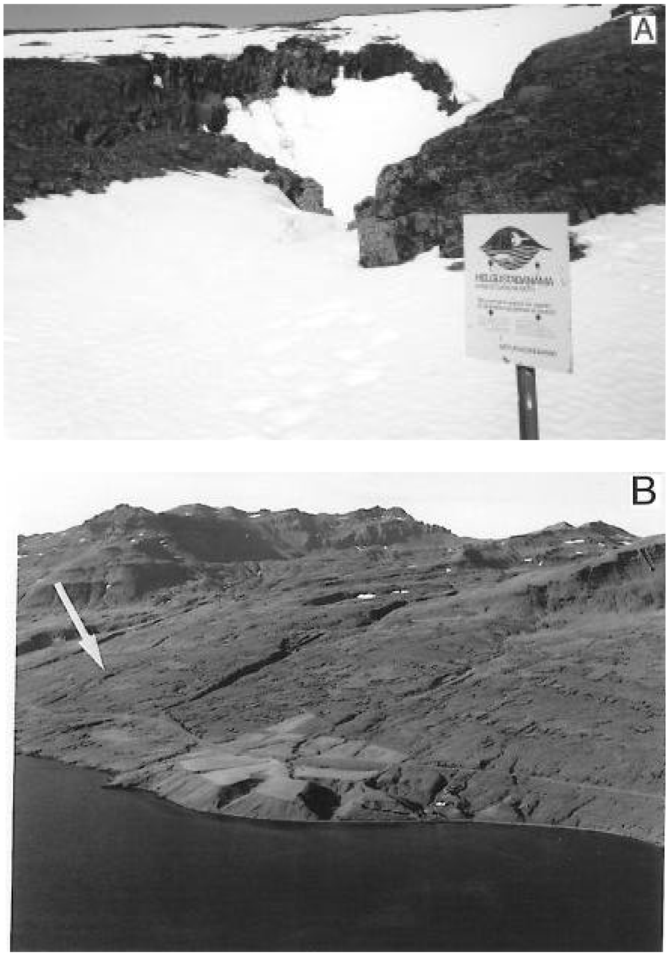

Figure 4. (A) The Helgustadir quarry, as seen half full of snow in April, 2001. Its diameter is about 30 m. (B) Aerial photo of the north coast of Reydarfjördur. The Helgustadir quarry is at the tip of the arrow. Photo copyright Mats Wibe Lund www.iceimage.com, Reykjavik.

have exceeded 300 tonnes, but much of this must have been low-grade material intended for various industrial purposes. Optical-quality crystals were presumably distributed by dealers to private collectors, museums, scientists, and manufacturers of instruments (Hessenberg, 1866).

In late 1872 the government shut down the quarry, on account of fears that its rate of exploitation might depress the market for Iceland spar and damage the site. Until the early 1880s the expanding demand for fine crystals seems to have been met (at least in part) by stockpiles from the 1863-1872 operations. The quarry was wholly state-owned from 1879 on. Following minor extraction in 1882 and 1885 (Thoroddsen, 1891), it lay idle till 1895.

PETROGRAPHIC MICROSCOPES, POLARIMETERS, AND THE DISCOVERIES OF 1850-1880

Studies of crystals through microscopes employing polarized light date from around 1840. In the 1850s as mentioned above, A. Des Cloizeaux pointed out the potential of this field, investigating the birefringence properties of hundreds of minerals (Des Cloizeaux, 1862, 1874). After H.C. Sorby (1858) succeeded in making sections of common rocks thin enough to be transparent, F. Zirkel (1863) and others developed techniques for observing such sections microscopically. Petrographic microscopes featuring built-in Nicol prisms (Figure 3B) for identifying minerals by their interference colors were being produced commercially by 1875 or even earlier. Several manufacturers entered this market in the following decades, during which period various specialized mineralogical devices incorporating Nicol prisms were also developed. The importance of methods utilizing polarized light can hardly be overestimated in the general development of earth science research, as well as in economic geology, materials science, and many other applications.

Polarimeters improved greatly from 1850 to 1880 and found extensive use for analysing organic compounds in diverse fields from industry to medicine. A common type of polarimeter named a saccharimeter was calibrated directly in terms of the sugar content in aqueous solutions. For over a century, photometers employing Nicol prisms were also widely used in the measurement of light intensity: an example of these is F. Zöllner's astrophotometer from the 1860s (see illustration in Herrmann, 1981).

Discoveries in 1850-1880 which depended to some extent on polarimeters and other applications of Nicol prisms include the following: the law of mass action in chemistry (see Heys, 1952); the recognition of double refraction induced by strong electric fields (Kerr, 1875); the findings of J. Tyndall and others on the scattering of light by small particles (see Strutt, 1871); and the description of flow birefringence in liquids (Maxwell, 1873).

CRYSTALLOGRAPHY AND CRYSTAL PHYSICS, 1850-1880

Iceland spar and rock salt were the first minerals in which the generation under pressure of artificial twinning and slip planes was observed (by Reusch, 1867; Baumhauer, 1878-79, and others); see Figure 2D. Such observations probably contributed to an improved understanding of tectonic deformations. Crystals of these two minerals were also the first whose elastic parameters were measured in detail, i.e. in 1874 (see Voigt, 1910). Tschermak (1881) praised Iceland spar as "this incomparable mineral, the cornerstone of our knowledge of crystal physics." The hypotheses of

Huyghens (1690) and Fresnel (1821-22) concerning the shape of light-wave fronts in crystals were confirmed by increasingly accurate measurements of refraction and reflection in various minerals, particularly Iceland spar (Glazebrook, 1880, and many others).

Hessenberg (1866, 1872, 1874), who described several crystal forms from Helgustadir, pointed out that comparatively little crystallographic work had been carried out on calcite from this site. Strangely enough, only a few papers on the crystallography of Helgustadir calcite seem subsequently to have appeared.

PROGRESS AND EXTRACTION DURING 1880-1925: THE "SPAR FAMINE"

By the early 1880s, a shortage of Iceland spar in Europe is mentioned in contemporary documents (see Kristjansson, 2001), a situation which seems to have lasted till at least the mid-1920s. Four examples will be given here:

(i) The physicist G.G. Stokes (1886), then President of the Royal Society, wrote to the Minister for Iceland in the Danish government, that some years ago large blocks of Iceland spar were freely available, "... But I hear on all sides ... of the impossibility of procuring the material now, ...". In his letter (reproduced in Kristjansson, 2001), Prof. Stokes urged the minister to resume operation of the Helgustadir quarry.

(ii) Tschermak (1894) stated that the Helgustadir quarry "... is the only deposit of large transparent crystals, and it therefore provides all material for optical purposes."

(iii) Dammer and Tietze (1913) lamented that ".... instrument makers are almost wholly dependent on using doubly refracting calcite from Iceland, which has often been very difficult to acquire in adequate quantity and quality." However, these authors mention that occasional shipments of suitable calcite had been received from Crimea, and that individual crystals from other areas were finding use in less demanding applications. In the U.S. before 1918, a few localities in Montana and California managed to supply some Iceland spar of optical quality (Parsons, 1918; Hughes, 1937).

(iv) Stöber (1924) confirmed that "... the Icelandic calcite mines, the only ones supplying crystals of sufficient quality for optical equipment, have been almost exhausted for many years now." Stöber´s own research on growing large sodium nitrate crystals was part of the extensive but not too successful efforts to develop substitutes for Iceland spar.

Quarrying at Helgustadir was resumed in 1895-1914, but less and less material of acceptable quality was recovered. In some years no crystals were extracted at all, in spite of explosives being used to dislodge basalt from promising points in the quarry. A rather inaccessible calcite deposit at Hoffell in southeast Iceland (Figure 1) was worked at intermittently from 1911 to about 1938. From the 1880s into the 1920s, the gap between Iceland spar production and demand may have been bridged by some manufacturers with stocks built up earlier, or through the purchase of crystals from private and public collections.

Before WW I, German firms were the chief suppliers of optical glass and optical instruments, including those employing polarized light. As an example of the industrial importance of such instruments, Skinner (1923) states: "Had the Bureau of Standards not undertaken the repair of polarimeters ... [during the war] ... it is difficult to estimate what would have been the consequences of the resultant paralysis to the [U.S. sugar] industry."

In 1920 the Icelandic government had a tunnel excavated under the Helgustadir quarry, and some tons of crystals were recovered for export in the next few years. However, by 1925 better or cheaper material from South Africa (Hughes, 1937) had appeared on the market, and the quarry was closed again.

ADVANCES OF 1880-1925

From 1840 or earlier, because of its purity (> 99.9% $CaCO_3$), Iceland spar was used as a raw material in various chemical studies. Around 1900, these included precise determinations of the atomic weight of calcium (e.g. Hinrichsen, 1901). A further role emerged when X-ray diffraction studies on crystals began (e.g. Bragg, 1914) because the best crystals of Iceland spar from Helgustadir and elsewhere were second only to diamond in their structural regularity. They therefore found use at least into the 1950s as a standard "meter stick" for X-ray wavelengths. Comparisons between the isomorphous series of metal carbonates (including calcite) were also valuable in the early interpretations of X-ray diffraction spectra and other physical properties of minerals.

New methods in science and technology appearing from 1880 to the 1920s which involved the use of Nicol prisms include reflected-light microscopes for studying anisotropic ore minerals and metals, ellipsometric methods of investigating thin films, Kerr electro-optic cells for long-distance picture transmission and light-speed measurements, magneto-optical studies of molecular structure, and liquid crystal research. The previously mentioned pressure-induced birefringence in isotropic solids gave rise to a valuable technique (photoelasticity) for research on mechanical stresses in engineering materials. Furthermore, polarization experiments contributed to fresh investigations into various properties of light following the general acceptance of Maxwell's electromagnetic theory (e.g. Wiener, 1890).

Last but not least, some discoveries rewarded with Nobel prizes in the period 1901-1925 relied to a significant extent on the application of polarimeters containing Nicol prisms. Worth mentioning is the work of H.A. Lorentz and P. Zeeman (Physics 1902, effects of magnetic fields on light emission), E. Fischer (Chemistry 1902, synthesis of sugars and purines), A. Werner (Chemistry 1913, atomic bonds in inorganic molecules), and J. Stark (Physics 1919, effects of electric fields on light emission).

DEVELOPMENTS AFTER 1925

Dichroic crystals of the organic compound herapathite, especially in the form of "Polaroid" sheets patented in 1933 (see McElheny, 1998), greatly reduced during the next 20-30 years dependence on Iceland spar for many manufacturing applications. Demand for Nicol prisms probably increased again later, for instance with the advent of laser techniques in the 1960s. On the other hand, optical-quality calcite has in later decades been mined in several countries.

It seems that the only collection of calcite from the Helgustadir quarry after 1925 was from tailings: this waste material was crushed for use in the Icelandic building industry into the 1960s. Since then, both the quarry itself (Figure 4A) and its history have been rather neglected. According to local sources, the walls of the quarry have partially collapsed, covering any outcrops of calcite. However, in 1975 the site was declared a "natural monument" by the Icelandic Ministry of Education, and a postage stamp showing crystals from Helgustadir was issued in 1999. The present author understands that preparations are proceeding to improve access to the site which lies close to a local road (Figure 4B).

CONCLUSIONS AND NOTES ON EDUCATIONAL ASPECTS

Tschermak (1894, p. 433) declared: "From the point of view of Science, calcite is the most important mineral species." and "The history of calcite is the history of mineralogy." The present paper attempts to illuminate some of the grounds for his statements. One reason may be that calcite offered excellent opportunitities for studying how anisotropic crystals differ fundamentally from isotropic solids such as cubic crystals, glass or polycrystalline solids. Another reason may be the fact that calcite crystals were used in a large variety of experimental situations, especially in optical instruments. In both cases, Iceland spar from the Helgustadir quarry was the material of choice over a long period of time. Although the reference literature on the quarry and its product assembled by the author since 1995 (Kristjansson, 2001 and unpublished data) and summarized here is still rather fragmentary, it should be evident that few if any other individual geological sites have exerted a comparable influence on the overall advance of knowledge in the physical sciences.

In historical works treating scientific and technological progress, the steps in this progress are often attributed to persons, institutions, particular ideas, publications, new equipment and so forth. However, geoscientists should not forget that sometimes these steps might not have been achieved without contributions from the Earth itself, even from what is literally a "hole in the ground" in a remote region.

Books on general physics for secondary schools or for self-study a century ago (e.g. Paulsen, 1893, 1895; Maneuvrier, 1908), commonly contained a chapter of respectable size on polarized light and double refraction. However, this topic has been one of those squeezed by subsequent progress, particularly in modern physics: for instance, the current official syllabus for the secondary school level in Iceland does not mention polarized light at all. This development may be unfortunate for students aiming at further studies in science, as polarization continues to be an outstanding aspect of light and other waves, in the geosciences as elsewhere. Experiments with polarized light such as that of Malus (1808) can also be fascinating, as testified to in his later years by Edwin H. Land, inventor of "Polaroid" dichroic polarizers and founder of the Polaroid Corporation (quoted in McElheny, 1998): "I am here .... because when I was a kid some teacher showed me a Nicol prism taking the reflection off a table top."

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