ICELAND SPAR

THE KEY FROM EASTERN ICELAND TO MODERN CIVILISATION

BREIÐDALSSETUR

MÁLVÍSINDI – JARÐFRÆÐI – SAGAN

Scientific discoveries made with the aid of Iceland spar from Iceland directly influenced the development of modern society. Progress since its discovery in the 17th century until 1930 in various important fields of the natural sciences and technology would have been delayed by decades if Iceland spar had not been available at that time. As the sole supplier of first-class spar crystals for scientific purposes, Helgustaðir in Reyðarfjörður may therefore be considered the most valuable location in Iceland in an international context.

CARBONATES

Carbonates are minerals in which one or more metals form compounds with the carbonic acid radical CO_3. About 60 carbonate minerals are known, most of them are rare. About 4% of the Earth's crust consist of carbonates, predominantly calcium compounds. Carbonate minerals are highly important to the ecosystem of the oceans, and they have an indirect effect upon the quantity of greenhouse gases in the atmosphere. Shells of many organisms consist of carbonates, as do corals. These organisms take carbon dioxide from the sea which absorbs carbon dioxide from the atmosphere.

Carbonates are a common constituent of sedimentary rocks, especially limestone, which is formed from the shells of marine organisms. Such limestone formations make up approximately 10% of sedimentary rocks in continental regions, and form entire mountain chains, for example in the Alps (figure 2). There is no limestone in Iceland. Calcium oxide (CaO, quicklime) is the principal component in the mortar and cements of the building industry. It is obtained by heating limestone to several hundred degrees.

Carbonates are very common as secondary minerals, also in Iceland.

A third ocurrence of carbonates is magmatic form of carbonate-rich rock, called a carbonatite (> 50% carbonates). Ol Doinyo Lengai volcano in Tanzania is the only one known to have erupted carbonatite in historical time, last erupted in 2007/ 08.

CALCITE

Calcite ($CaCO_3$) is the most common carbonate on Earth: The main constituent of the sedimentary rock limestone is calcite. It also occurs as a secondary alteration mineral (cavity fillings) in the host rocks. This form of calcite is common in Iceland, most often found in the vicinity of eroded central volcanoes. The most famous example of calcite is Iceland Spar from the mine of Helgustaðir in Reyðarfjörður.

Figure 1

ICELAND SPAR SHOWING ITS DOUBLE REFRACTION EFFECT. THE WORDS TAKK FYRIR ("THANK YOU" IN ICELANDIC) APPEAR TWICE , IT IS WRITTEN ONLY ONCE BELOW THE CRYSTAL.

By Leó Kristjánsson

Figure 2

WHOLE MOUNTAIN CHAINS CONSIST OF CARBONATES, AS IN THIS EXAMPLE FROM THE SWISS ALPS, SIGRISWILERGRAT AND NIEDERHORN MOUNTAIN, BERNER OBERLAND. THE LIMESTONE ROCK IS FORMED OF MARINE CALCAREOUS ORGANISMS, SUCH AS CORALS.

By Martin Gasser.

Figure 3

THE BIGGEST STILL EXISTING ICELAND SPAR (CALCITE) IS FROM HELGUSTAÐIR MINE, REYÐARFJÖRÐUR EAST ICELAND AND HAS A WEIGHT ~300 KG. IT HAS BEEN ON DISPLAY AT THE NATURAL HISTORY MUSEUM IN LONDON, (FORMER NAME "THE BRITISH MUSEUM") SINCE IT WAS ACQUIRED IN THE 1870S.

By Peter Tandy.

ICELAND SPAR

Iceland spar is a highly transparent variant of calcite (figures 1 and 3). It can be easily split (figure 4) into rhomboids with a vitreous lustre, having angles of 105° and 75° between the sides. When one looks through a clear crystal, two images are seen due to its strong double refraction.

The Helgustaðir quarry in Reyðarfjörður, East Iceland is famous worldwide as the type locality (first discovered location) of a highly transparent variety of calcite crystals, where from around 1780, it got the name „Iceland Spar“. Its unusual properties (double refraction and more) were first described by the Danish scientist Erasmus Bartholinus on previously unknown crystals from Helgustaðir in 1669 (figure 12).

Figure 4
TECHNICIANS SPLITTING ICELAND SPAR CRYSTALS DOWN INTO PRISMS TO USE THEM IN OPTICAL DEVICES, PICTURE PROBABLY TAKEN IN THE BEGINNING OF THE 20TH CENTURY.
Halle, 1963.

Figure 5
WILLIAM NICOL
By Ward 1806

William Nicol
1770 –1851

was a Scottish geologist and physicist. He invented the Nicol prism (figure 6), the most effective device for obtaining plane-polarized light, in 1829, constructed from Iceland Spar. He made his prism by bisecting a parallelepiped of Iceland spar along its shortest diagonal, then cementing the two halves together with Canada balsam. Light entering the prism is refracted into two rays, one of which emerges as plane-polarized light. Nicol prisms greatly facilitated the study of refraction and polarization, and were later used to investigate molecular structures and optical activity of organic compounds. Nicol also invented making of thin sections of crystals and rocks for microscopical study. Figure 7 shows a thin section of basalt rock under cross-polarized light.

NICOL PRISM

Nicol prisms represent the prime application of Iceland spar. Thousands of these prisms were produced in the 19th century, following their invention by W. Nicol in 1829 (figure 5). They are still in production, although so-called Polaroid sheets have since 1940 replaced them in many applications. The light going through the prism is converted from unpolarized light (oscillates in 360° = all directions) into polarized light (oscillation in only one direction). In addition to converting unpolarized light into polarized light, a Nicol prism can also be used for finding the direction of oscillation in a polarized beam, and for attenuating its intensity (figure 6).

Some common examples of optical instruments which contained Nicol prisms as key components were: polarimeters, used in chemistry and biology (figure 9), petrographic microscopes, used in geology to analyze rocks (figure 10), and photometers used among others in astronomy (figure 11), including spectrophotometers (figure 12). Other functions of Iceland spar included its use as a wavelength standard in the spectroscopy of X-rays, due to its most perfect lattice structure of all natural materials.

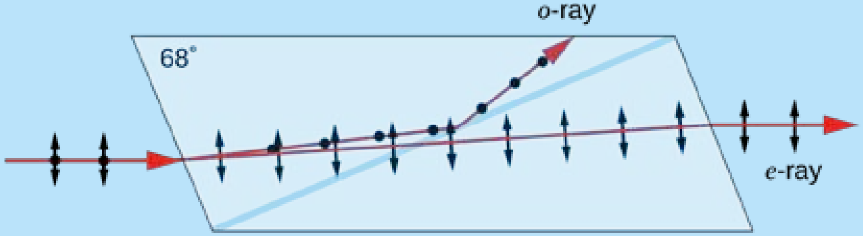
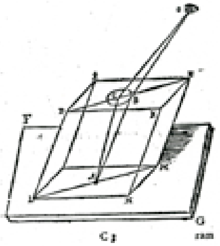
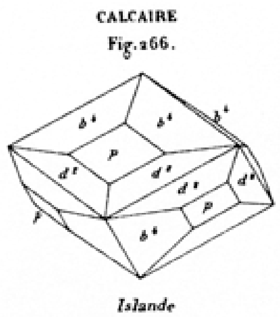
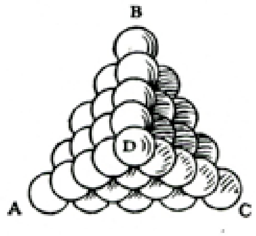


Figure 6
DRAWING SHOWING THE EFFECT ON LIGHT WHILE GOING THROUGH A NICOL PRISM THAT IS MADE FROM TWO WEDGES OF ICELAND SPAR WHICH ARE JOINED TOGETHER BY A THIN COAT OF GLUE. A WAVE OF ORDINARY LIGHT COMING FROM THE LEFT IS SPLIT INTO TWO POLARIZED RAYS ON ENTERING THE FIRST WEDGE: O-RAY AND E-RAY. THE RAY PASSING THROUGH THE GLUE (E-RAY) HAS A KNOWN DIRECTION OF OSCILLATION, WHICH CAN BE ROTATED ARBITRARILY. THE OTHER RAY IS REFLECTED FROM THE GLUE, AND IS GENERALLY NOT MADE USE OF.

Figure 7
PART OF A BASALT THIN SECTION.







MANY STUDIES USING ICELAND SPAR HAD WIDE-RANGING CONSEQUENCES, INCLUDING ACHIEVEMENTS BY WORLD-FAMOUS SCIENTISTS FROM THE 17TH TO THE BEGINNING OF THE 20TH CENTURY.

Examples are:

Chemistry

- Fundamental knowledge of the nature of carbon's valency bonds
- The three-dimensional structure of molecules, and the nature of bonds between their atoms
- Kinetics of chemical reactions; chemical equilibria
- Initial development of new classes of materials, e.g. silicones
- Chemical analysis by light absorption in solutions (Beer's law) and by light emission in flames
- Chemistry at high temperatures monitored by optical pyrometry

Mineralogy, geology, material sciences

- For decades from ~1880, polarized-light microscopy was a prime method in research on the composition, origin and subsequent metamorphism of minerals and rocks. This furthered understanding of geological processes, facilitated the search for mineral resources, and improved recovery, as well as developing industrial materials such as cement and abrasives
- Liquid crystals, now the basis of computer and TV screens
- Deformation of engineering materials under stress (photoelasticity)

Biochemistry, biology, medicine

- Biochemical research on polysaccharides (e.g. cellulose), medicines (e.g. quinine, atropine), addictive drugs (cocaine, morphine), poisons (nicotine, strychnine), proteins, chitin, nucleic acids, colloids, hemoglobin etc.
- Research into metabolic processes (fermentation, digestion)
- Diabetes: diagnosis, symptoms, and treatment
- Research on vision, especially color blindness
- Studies with polarizing microscopes on for instance muscle and nerve fibers, bones, eyes, teeth, shells, eyes, liquid crystals (e.g. lecithine, cholesterol) in animal tissues, natural textile fibers, and so on.
- Research leading later to factory production of substances like essential oils, vanilline, starch syrup, synthetic fibers, and various medicines.

Figure 8

HIGH TECHNOLOGY TOOLS LIKE COMPUTERS AND CELL PHONES THAT ARE VERY COMMON IN THE WESTERN COUNTRIES. TOGETHER WITH ICELAND SPAR CRYSTALS: THE CONNECTION BETWEEN THE TOOLS AND CRYSTALLS IS NOT OBVIOUS, BUT THE KNOWLEDGE WE HAVE TODAY IS BUILT ON RESEARCH AND ACHIEVEMENTS WITH THE HELP OF ICELAND SPAR UNTIL THE BEGINNING OF THE 20TH CENTURY.

Physics

- The effect of magnetic fields on light discovered by M. Faraday in 1845 was a major point of support for J.C. Maxwell's electromagnetism
- The scattering of light by small particles, which among other things led to an explanation of the blue color of the sky in 1869-71
- Various experiments to measure the velocity of the Earth through the aether, both before and after A. Einstein's relativity paper of 1905
- A wide range of notable astrophysical observations and discoveries
- Tests of the application of quantum theory to atomic structure and processes (e.g. photoelectricity)
- Research into very rapid phenomena; measurements of the speed of light
- Involvement in early methods of picture transmission and television
- Development of new polarizing materials to partly replace Nicol prisms

Several Nobel prizes in the fields of physics, chemistry, astronomy, biology and medicine depended much on the use of Nicol prisms (produced from Iceland Spar from Iceland), for example the Nobel prizes to the German chemist Emil Fischer in 1902 (Synthesis of sugars and other organic compounds) or to the Swiss chemist Alfred Werner in 1913 (Coordination bonds, a new concept in chemistry).

Some instruments containing Nicol prisms (produced from Iceland spar)

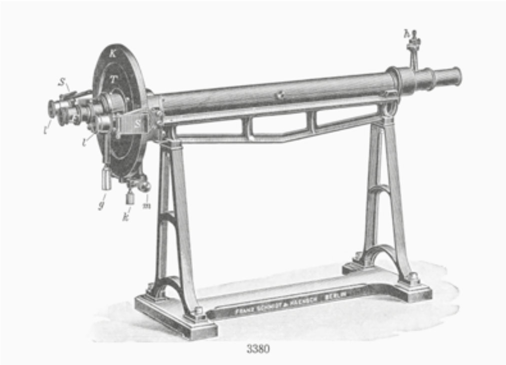


Figure 9

An accurate half-shade polarimeter for laboratory measurements of optical rotation in organic liquids, such as essential oils or solutions of sugars, alkaloids etc. This instrument, designed around 1885, contains two standard Nicol prisms made from Iceland spar, and one small one. *Struers, 1925.*

Figure 11

An observatory telescope c. 1890, incorporating Zöllner's astrophotometer. These instruments (and similar ones invented by E.C. Pickering) were used for decades at many observatories for measuring the magnitudes of thousands of stars. *Newcomb-Engelmann, 1921.*

Typical microscope from 1902 to study minerals and rocks. There were two Nicol prisms made of Iceland spar in a microscope like this. *Kile, 2003*

Figure 10

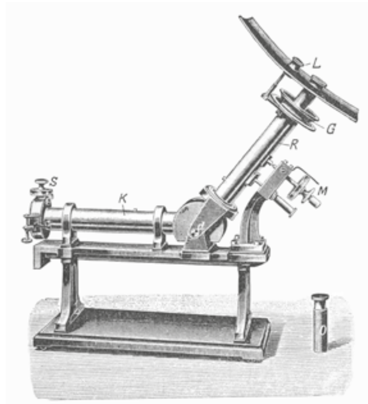


Figure 12

The König-Martens spectrophotometer was developed around 1900 and produced commercially for decades. A light beam coming from the left is dispersed by a glass prism at the bend, and the relative intensity of the various colors is measured using a Nicol prism and a Wollaston prism, both of Iceland spar. The instrument found wide use in research and industry. *Weigert, 1927.*

The most important scientists that changed the world with the help of Iceland spar

Erasmus Bartholinus
(Rasmus Bartholin)

1629-1695

Danish scientist and doctor, (portrait from 1688, unknown artist). He was the first to describe the double refraction in Iceland spar crystals from Reyðarfjörður and published an essay on this phenomenon in 1669 (below) in Latin, which was the science language at that time. Below on the right an Iceland spar drawing from Bartholinus´s essay.

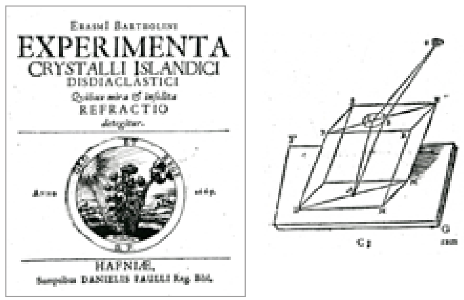


Figure 13

Christiaan Huygens

1625-1698

Dutch scientist. He was a very productive scientist who among other things argued that light was a wave (portrait from the engraving following the painting of Caspar Netscher by G. Edelinck around 1685). A chapter in his book on light "Traité de la lumière" from 1690, describes various properties of Iceland spar and presents a valid model of its double refraction (title page of the publication below). Below on the right a drawing from this thesis, showing the composition of Iceland spar in atoms.

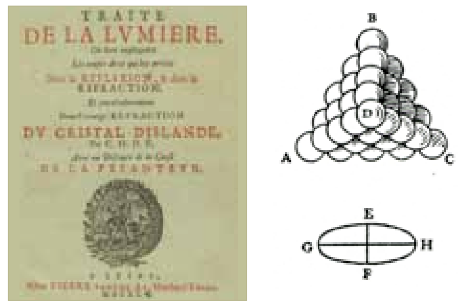
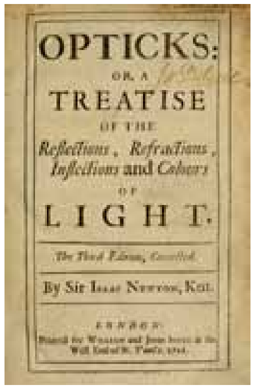


Figure 14

Isaac Newton

1642-1726

English physicist (portrait by Sir Godfrey Kneller in 1702). He made major contributions to several fields of science. The view that light was a stream of particles was presented in his book "Opticks" in 1704 (below). It was believed in by most scientists until the early 19th century, and then abandoned because it offered no credible explanation of various phenomena such as double refraction.



OPTICKS:
OR, A
TREATISE
OF THE
Reflections, Refractions, Inflections and Colours
OF
LIGHT.

By Sir Isaac Newton, Knt.

Figure 15

Augustin Fresnel

1788-1827

French engineer and physicist (portrait by A. Tardieu). He expanded Huygens' wave theory of light, especially by proving that the wave motion in a light ray is transverse to its direction of propagation. Around 1820 he derived theoretical equations governing the diffraction of light, propagation of light in crystals, reflection of light at interfaces, and other optical processes. His derivations were confirmed experimentally by himself and others, leading to the general acceptance of the wave theory by scientists.

The spiral structure of quartz, suggested by Fresnel in order to explain its optical activity and confirmed by X-ray studies more than a century later, Wahlstrom 1969.

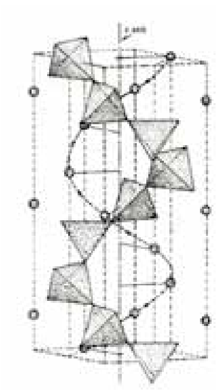
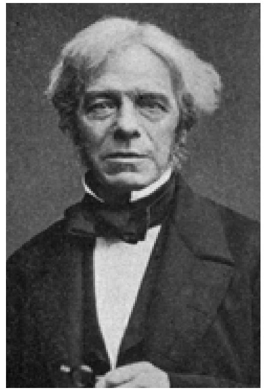


Figure 16

Michael Faraday

1791-1867



English chemist and physicist. He investigated important aspects of the magnetic properties of Iceland spar. In 1845 he found with the aid of Iceland spar prisms that magnetic fields affected the passage of light through materials.

Replication of Faraday's experiment of 1845, as illustrated in Handbuch der Physik, vol. 16, 1936. Equipment for studying the Faraday magneto-optic effect (1845), i.e. rotation of the plane of polarization of light in materials placed in a magnetic field. Light from the flame on the left is made linearly polarized with a Nicol prism inside b. It then passes through a glass rod surrounded by the current coils N and M. Another Nicol prism at a measures the resulting angle of rotation of the plane of polarization.

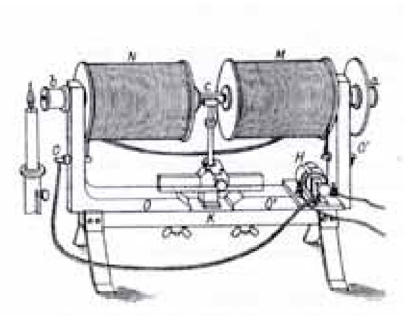


Figure 17

Louis Pasteur

1822-1895

French biochemist. His first major scientific discovery concerned the changes in polarized light produced by aqueous solutions of certain organic compounds. This led to a new understanding of the nature of carbon compounds. He demonstrated in 1848 that aqueous solutions of mirror-image tartrate rotated the polarization direction of light respectively to the left and to the right. Subsequently, Hoff and LeBel suggested in 1874 that three-dimensional chemical bonds of carbon could form mirror-image molecules. In this case it is the amino acid alanine (below).

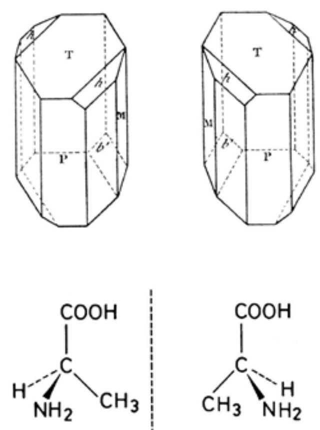
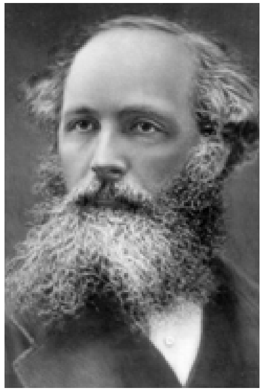


Figure 18

James Clerk Maxwell

1831-1879



Scottish physicist. He proposed in 1862-65 that light waves consist of electrical and magnetic oscillations. This idea was in part based on experiments with polarized light and Iceland spar by himself and M. Faraday. It gained support gradually during the next quarter-century, to some extent due to observational evidence involving Iceland spar. The electromagnetic theory forms the basis for modern physics and for a wide range of major technical achievements in the 20th century.

Maxwell's theory about the characteristics of light: Electric (E) and magnetic (B) fields in an electromagnetic wave in free space. The wave is travelling in the direction of the z axis.

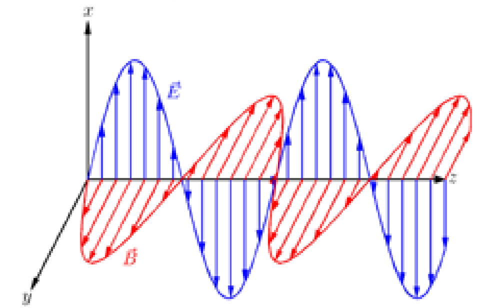


Figure 19

Otto Lehmann

1855-1922

German chemist who discovered the peculiar optical properties of so-called liquid crystals in 1889 and carried out comprehensive investigations on them for 30 years. Polarized light was quite essential in this research, which has for instance resulted in the development of flat TV screens and displays.

Strange patterns exhibited by liquid crystal specimens, when viewed in a polarizing microscope under varying conditions.

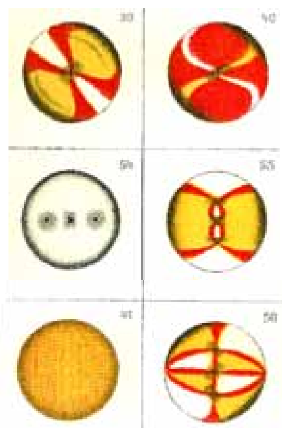
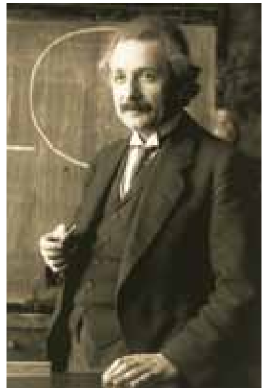


Figure 20

Albert Einstein

1879-1955



German, Swiss and US physicist. He proposed alternative theoretical foundations for various physical phenomena where previous theories had not accounted satisfactorily for observational results. Some of these observations had involved Iceland spar; it was also used in many experiments aimed at verifying Einstein's predictions and at applying them to new situations in physics.

Equipment used in 1915-20 for verifying one prediction of Einstein's quantum theory of radiation. X-rays are generated in the glass bulb at the top. They are then reflected by the crystal C (often Iceland spar) to the detector I. The change in direction of the rays is a measure of their energy.

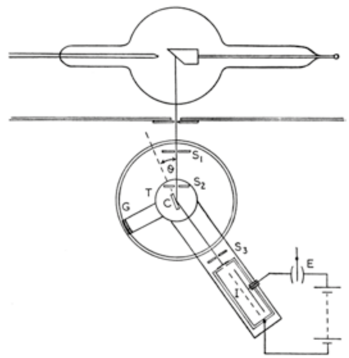


Figure 21

SUNSTONE AND ICELAND SPAR

Around 1968 it was suggested that seamen in the North Atlantic during the Viking age could, by looking upwards through crystals of Iceland spar or of certain other minerals, find the direction to the sun, even if it was hidden in clouds or below horizon. This method was supposed to have aided in estimating the course of a vessel and/or its location. The idea is that the light from a clear sky is to some extent polarized in such a way, that the direction of the oscillation in light arriving to an observer from the zenith is related to the direction from him to the Sun. The arguments produced so far in support of this „sunstone“ theory and the potential usefulness of the method in Viking navigation are rather inconclusive.

ICELAND SPAR MINING

The Helgustaðir quarry in Reyðarfjörður is famous worldwide as the type locality (first discovered location) of a highly transparent variety of calcite crystals. The quarry (figures 23 and 25) is an open pit in a formation of altered basalt lavas, about 30 m wide at 90-100 m above sea level. A small brook called Silfurlækur (Silver stream) runs beside the pit. The glistening crystals carried down the hillside by the brook probably caught the attention of passers-by centuries ago.

Organized mining of crystals for export began in 1855 (on a small scale a few years earlier), and different operators were mining until 1914. After a mining break of around 6 years the state sponsored in 1920 renewed activities at Helgustaðir in Reyðarfjörður, including the digging of an 80-m long tunnel to below the quarry pit. Some tons of crystals were recovered up to 1924, partly from this tunnel. Operations then ceased, apparently due to the arrival on the market of Iceland spar crystals from South Africa. Leftovers were then used in the 1930s and later for coatings on buildings in Iceland. (A detailed operator list is on figure 22).

From 1930 and onward, a technique in building industry was developed that allowed fine-grained minerals and rocks to be utilized as outer wall coating. In lack of good paint, this technique soon became popular. Several buildings in Reykjavík are still coated like this. The most famous buildings are the University of Iceland (main building) and the National Theatre. The first named was refitted with a new roughcast in 1995 with calcite from northwest Iceland, the latter underwent the same process 2006/2007 with calcite from Breiðdalur valley, Eastern Iceland. Both locations do not contain Iceland spar of any noteworthy quality. See also map, figure 26.

In 1975 the Helgustaðir quarry and its immediate surroundings were listed by the Ministry of Education as a protected site. Since then, removal of any crystals from there has been prohibited.

Figure 22

Operators of the Helgustaðir quarry

Thomsen kaupmaður - merchant, Seyðisfjörður: ~1850

Svendsen kaupmaður - merchant, Eskifjörður: 1855-60, Iversen ~1862

Carl D. Tulinius kaupmaður - merchant, Eskifjörður: 1863-72

The State: 1882 (supervision: Þorvaldur Thoroddsen)

The State: 1885 (supervision: Tryggvi Gunnarsson)

Carl D. & Thor E. Tulinius - Eskifjörður/Copenhagen: leased 1895-1910

French entrepreneurs*): contract 1910-20, stopped after 1914

The State: 1920-24 (supervision: Helgi H. Eiríksson)

Research Council: 1946-47 (minor yield)

Various operators: 1933-60 (calcite from tailings)

*) The lease was awarded to two Reykjavik businessmen, whose contract was soon transferred to a French company directed by Consul-general J.P. Brillouin.

Figure 23

VIEW FROM HELGUSTAÐIR QUARRY TO THE WEST INTO THE FJORDS OF REYÐARFJÖRÐUR (LEFT) AND ESKIFJÖRÐUR (RIGHT).

Figure 24

FRENCH SAILORS (COMPANY MATELOTS) OF THE VESSEL „INDRE“ IN HELGUSTAÐIR MINE IN 1886. AFTER SIGURJÓNSDÓTTIR 2000, *by Henry Labonne.*

In 1910 the farmer of Hoffell farm, close to Höfn in Southeastern Iceland, discovered a site yielding good Iceland spar crystals, at 500 m altitude on a mountainside. This is the only other known locality with high quality Iceland spar in Iceland. A quantity of spar was recovered there in the following years and exported, however access to both the site itself and transportation facilities was much more difficult than at Helgustaðir, Reyðarfjörður. The exporting of spar from Hoffell was discontinued during World War I but then resumed from 1921. No mining has taken place at Hoffell since 1925, except calcite for the coatings of the National Theatre around 1933 and 1938-39 to provide materials for the main building of the University of Iceland.

Small amounts of optical-quality Iceland spar crystals were mined sporadically in 1900-1940 outside Iceland, for instance in the Crimean peninsula, in California, Montana and New Mexico of the U.S., in the Harz mountains of Germany, and in Spain. For a couple of decades from about 1920, shipments from the Kenhardt district of South Africa dominated the market, leading to discontinuation of operations at Helgustaðir. Other deposits of Iceland spar were later discovered in various locations worldwide, such as in the Chihuahua area of Northern Mexico which has been a significant supplier since 1942.

The importance of Iceland spar was primarily due to its unique optical properties. In this respect, it could not be replaced adequately by any other natural or man-made materials. However, so-called Polaroid sheets which were invented in the early 1930s, have with subsequent improvements served as a practical substitute for Iceland spar components in a range of applications.

Figure 25

THE QUARRY OF HELGUSTAÐIR MINE IN JULY 2015, *by Rolf Tschumper.*

Figure 26

GEOLOGY AND ICELAND SPAR/CALCITE MINING LOCATIONS IN ICELAND

by Martin Gasser:

Blue: Late tertiary, bedrock older than 3,3 mio years.
Green: Late Pliocene/Early Pleistocene, bedrock 0,8-3,3 mio years old.
Pink: Active volcanic belt, bedrock younger than 0,8 mio years.

Calcite and Iceland spar mines are marked on the map.
The biggest ones are **Helgustaðir (He)** and **Hoffellsdalur (Ho)**, in other locations where some amounts of impure calcite: **Djúpidalur (Dd), Akrar (Ak), Mógilsá (Mg)** and **Höskuldsstadasel (Hs).**

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Iceland spar and its influence on the development of science & technology in the period 1780-1930.
Notes and References. Report JH-02-2015,
University of Iceland.

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