A UNIQUE OCCURRENCE OF LECHATELIERITE OR SILICA GLASS.

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Artificial silica glass or so-called quartz glass[1] is a well-known substance with remarkable physical properties now produced on a commercial scale in the electric furnace.[2]

Naturally occurring silica glass is not so well known. It is a very rare substance found in fulgurites (formed by the fusion of quartzose sand) and in quartzose inclusions of volcanic rocks. To this naturally occurring silica glass, which he considered a distinctive mineral, Lacroix[3] gave the name lechatelierite, in honor of Henry Le Chatelier, the French chemist. It is the latest of the silica minerals to be recognized. The writer[4] formerly classified lechatelierite under mineraloids with other natural glasses, but since then he has come to the conclusion that its properties are sufficiently distinctive for it to be given rank as a definite mineral.[5] W. Fischer,[6] in a recent article on fulgurites, also regards it as a distinct mineral. Lechatelierite is unique in that it is the only natural glass that has in recent times[7] been considered a mineral.

OCCURRENCE OF THE LECHATELIERITE.

The silica glass here described occurs at Meteor Crater (formerly called Coon Butte), a crater-like depression about 4,000 feet in diameter and 570 feet deep, located about twenty miles west of Winslow, Coconino County, Arizona. The only rocks in the immediate region are sandstones, shales, and limestones. The nearest igneous rocks (basalts) are about ten miles distant. The sedimentary rocks are practically horizontal except around the elevated rim of the depression where they are much disturbed, and often have very steep dips; some even have a nearly vertical attitude. The silica glass occurs at the bottom of the depression in layers which are at least six

[1] Quartz-glass is a poor name for this material, for it is no more closely related to quartz than it is to tridymite or cristobalite. It happens to be made from quartz but it might be produced from tridymite or cristobalite if either could be obtained in sufficient quantities.

[2] See paper by E. R. Berry, Smithsonian Report for 1924, pp. 213-218.

[3] Bull. Soc. Fran. de Min. 38, 182-186, 1915.

[4] Jour. Geol. 25, 526, 1917.

[5] American Mineralogist, 13, 73-92, 1927.

[6] Neues Jahr. f. Min., Geol., u. Pal., Beil. Bd. 56, *Abt. A*, 69-98, 1928.

[7] J. D. Dana, in the first edition of his *System of Mineralogy*, New Haven, 1837, p. 345, lists obsidian as a mineral species.

inches thick. As will be shown later, the silica glass is undoubtedly the result of the fusion of a saccharoidal sandstone (the Coconino sandstone of Permian age).

DESCRIPTION OF THE LECHATELIERITE.

The following description is based largely upon specimens which I collected at Meteor Crater in December, 1926. Previous to this time, a specimen of the silica glass had been given

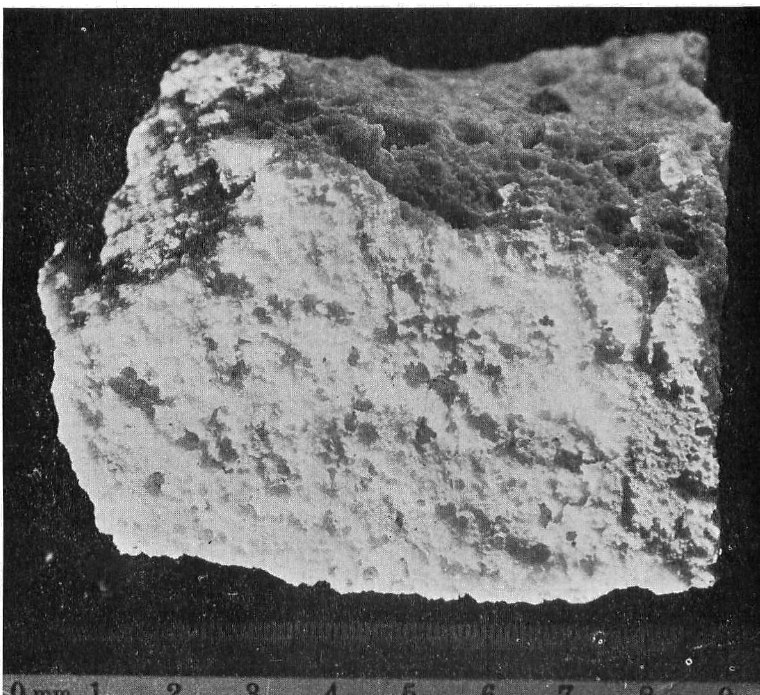

Fig. 1. Lechatelierite or silica glass from Meteor Crater, Coconino County, Arizona. (Natural size.)

to me by Dr. D. L. Webster, my colleague of the physics department. It was this specimen that aroused my interest in Meteor Crater. Mr. D. M. Barringer of Philadelphia, who has been very much interested in Meteor Crater for more than two decades, also kindly furnished me a good specimen of the silica glass, or what he called "metamorphosed sandstone B."

The lechatelierite is a nearly colorless, porous material of low specific gravity which occurs in thin slabs that are usually from

1 to 2 or 3 cm. in thickness. Some of the larger masses in Mr. Barringer's museum collection in the office of the mining company on the rim of the Crater are at least 15 cm. thick and show only a faint banded structure. These larger specimens are highly vesicular and may be recognized at sight as a glass of some kind. (Fig. 1 gives a very good idea of the highly vesicular glass.) The vesicular character of the other specimens is apparent with a hand lens. Threads of glass may be observed occasionally.

The lechatelierite varies from clear colorless to subtranslucent white. It has about the same hardness as quartz. Before the mouth blowpipe it is infusible, and gives no water in the closed tube. It is insoluble in a sodium metaphosphate bead, and when heated with a sodium carbonate bead it causes effervescence. It is insoluble in nitric and hydrochloric acids, but is readily soluble in hydrofluoric acid.

The silica glass is dark between crossed nicols and has a rather high relief in Canada balsam. The index of refraction is 1.460 ± .001. This was determined by the indirect immersion method; a Wratten E 22 screen was used as an approximation to monochromatic (orange-yellow) light. The index of refraction is a trifle greater than that for pure artificial silica glass, which is 1.4584 for sodium light.

A specific gravity determination made with about a gram of the powdered mineral gave 2.10. This value is low (the true value for silica glass is 2.20), on account of minute air bubbles which cannot be entirely eliminated.

Photographs of thin sections of the Meteor Crater lechatelierite are reproduced in Figs. 2, 3, 4, and 5. The vesicular character is apparent in all of them. Some of the specimens show a well-defined flow structure (see Fig. 4). The dark areas are due to numerous minute bubbles which make the glass opaque. The vesicular structure is doubtless due largely to entrapped air. It is the entrapped air that makes so difficult the production of clear silica glass free from bubbles on a commercial scale. It is probable that moisture originally present on conversion to steam was also in part responsible for the production of the vesicles.

The only associated minerals found in the thin sections of lechatelierite are grains of quartz (see Figs. 8 and 9), which are clearly residual, and occasionally a small amount of cristobalite (Fig. 5) which is recognized by its very weak double refraction, very low relief, and peculiar curved fracture. The cristobalite from the specimen which furnished the thin section of Fig. 5 has an index of refraction of 1.483 ± .003.

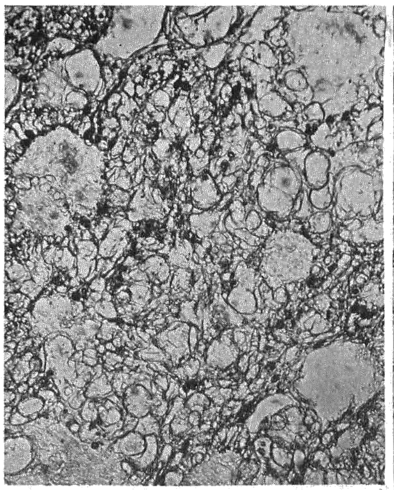

Fig 2

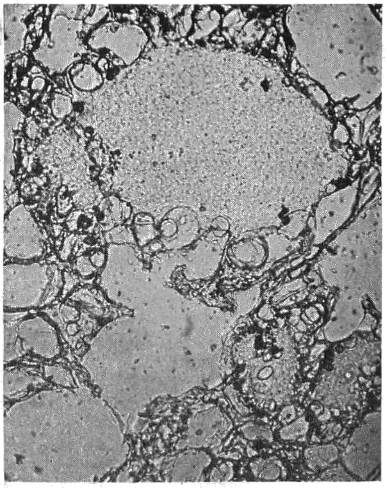

Fig 3

Fig 4

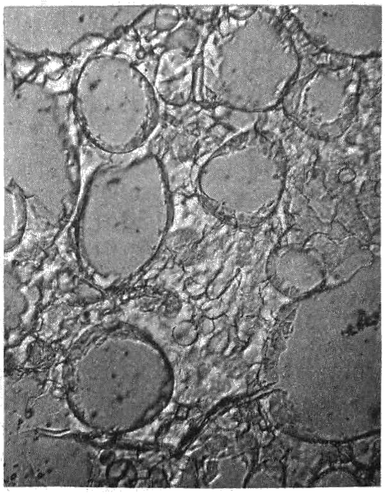

Fig 5

Fig. 2. Silica glass retaining somewhat the structure of the sandstone from which it was formed. (x 83 diameters.)

Fig. 3. Silica glass with lechatelierite pseudomorph after a sand grain. (x 77.)

Fig. 4. Silica glass showing flow structure. (x 71.)

Fig. 5. Cristobalite aggregate embedded in silica glass. The rounded areas are sections of air bubbles. (x 165.)

In several thin sections there are a few spots of lechatelierite which show a structure like that of twinned tridymite. These suggest that tridymite was formed first and was afterwards converted into lechatelierite. This, however, has not been definitely established.

The only mineral that is apt to be confused with lechatelierite is opal. Opal, however, is a comparatively low-temperature mineral of colloidal origin and always contains water.

ORIGIN OF THE LECHATELIERITE.

There is convincing evidence that the silica glass was produced by the fusion of the Coconino sandstone. This is a white to pale gray, loosely consolidated saccharoidal sandstone made up almost entirely of fairly well rounded grains of quartz, which often show secondary enlargements. Fig. 6 is a photomicrograph of a thin section of the sandstone. One hundred grains in five different thin sections gave as the arithmetic mean of the longest dimension 0.405 mm., with the extremes varying from 0.10 to 0.74 mm.

One of the main arguments in support of the above mentioned origin is the presence of gradations between specimens made up entirely of quartz and those made up entirely of lechatelierite. Fig. 7 represents a thin section with most of the quartz grains still intact, but with some interstitial glass. In this particular specimen the interstitial glass is probably not pure silica glass, for its index of refraction is about 1.470. It seems probable that slight impurities between the sand grains have produced an impure silica glass which would have a somewhat higher index of refraction. Narrow tongues of glass extend into the quartz grains, and here we see the incipient change of the quartz to lechatelierite. The quartz grains of this and similar specimens show rhombohedral cleavage or parting. This is probably the result of the inversion of low quartz to high quartz.[8] According to the most recent determination,[9] this inversion takes place at $573 \pm 1^{\circ}C$.

In other specimens the lechatelierite predominates, but appreciable amounts of quartz are present and these are clearly residual. Fig. 8, for example, shows four rounded areas which were originally sand grains. The smallest one, which measures 0.23 mm. in the longest dimension, is practically converted into lechatelierite. (Note its rather high relief.) The

[8] Wright and Larsen, this Jour. 37, 433, 1909.
[9] Bates and Phelps, Physical Review, 18, 115-116, 1921.

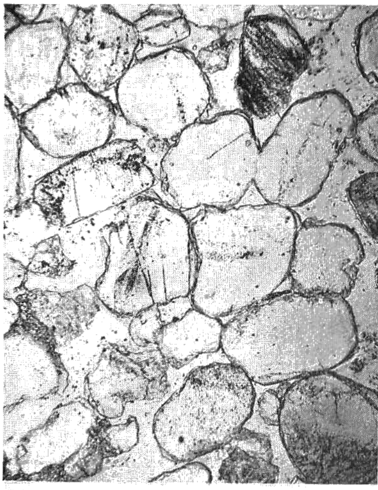

Fig 6

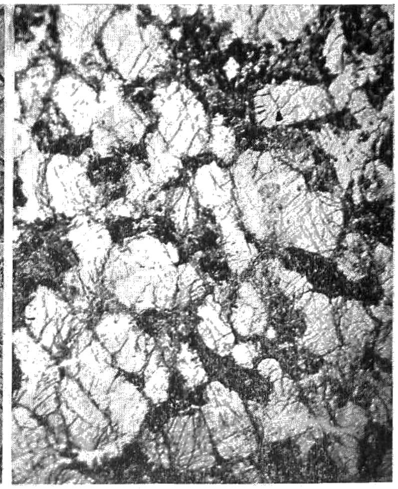

Fig 7

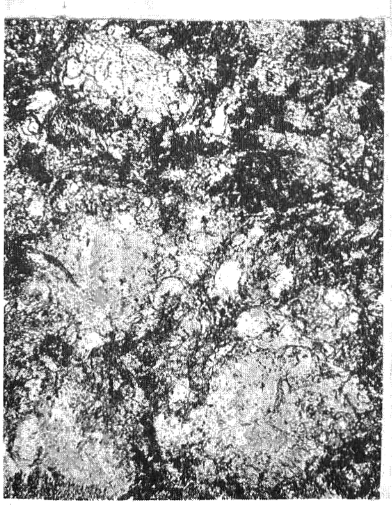

Fig 8

Fig 9

Fig. 6. Original saccharoidal sandstone from which the lechatelierite was formed. (x 34.)

Fig. 7. Metamorphosed sandstone showing quartz grains with cleavage and interstitial glass. (x 33.)

Fig. 8. Partially fused sandstone. Lechatelierite predominates over quartz. (x 75.)

Fig. 9. The same as Fig. 8 but taken with crossed nicols. The light-colored areas are residual quartz grains. (x 72.)

largest area in the lower right corner is about 0.31 mm. in longest dimension. These dimensions are within the size-range of the sand grains of the original saccharoidal sandstone. The three larger rounded areas of Fig. 8, when examined with crossed nicols (Fig. 9), show very much corroded fragments of quartz, which extinguish together over areas corresponding to the rounded areas of Fig. 8. The quartz in this specimen is undoubtedly a residual mineral.

The typical, more or less vesicular specimens of lechatelierite contain no visible quartz, but thin sections show rounded areas which are undoubtedly lechatelierite pseudomorphs after quartz grains. A number of these can be seen in Fig. 2. An especially good example of these pseudomorphs is shown in Fig. 3, which is from a different specimen. Here the longest dimension of the elliptical area of solid lechatelierite is 0.54 mm., a common size of the sand grains of the sandstone. Out of 50 sand grains in a thin section of one of the sandstones, ten had a length of 0.54 mm.

The facts mentioned in the last three paragraphs make it certain that the silica glass or lechatelierite was produced by the fusion of the saccharoidal sandstone. This confirms the work of Merrill.[10]

The question that now presents itself is: how was this fusion of the sandstone brought about? A temperature of somewhere between 1400 and 1800° was required to accomplish the fusion. The melting point of quartz, according to Sosman,[11] is in the neighborhood of 1400° C. But it is possible that the quartz was first converted into cristobalite, the melting point of which is 1710° C. A little cristobalite is present in some of the silica glass, but it may be the result of devitrification of the glass.

Most of the natural occurrences of silica glass are in the form of fulgurites, but it is certain that lightning was not responsible for the formation of the silica glass of Meteor Crater. The comparatively large pieces of lechatelierite could not possibly have been produced in this way.

Since lavas or igneous rocks of any kind are not found at Meteor Crater, it seems hardly probable that volcanic activity of the usual kind caused the fusion of the sandstone.

It seems certain that the production of the crater-like depression and the fusion of the sandstone were brought about by

[10] Smithsonian Misc. Collections 50, 461-498, 1907.
[11] Paper read before the American Iron and Steel Institute, New York, May 24, 1929, p. 3.

the same geological agent. All who have discussed the subject, I believe, agree upon this point.

A number of writers, including Guild, T. C. Chamberlin, Darton, and Thurmond, assign the formation of Meteor Crater to a volcanic steam explosion of some kind. They cite the occurrence of similar topographic features in other parts of the world apparently produced by what is called cryptovolcanic activity. One would expect a steam explosion to produce rock alteration of some sort but, in addition to ordinary superficial weathering the only evidences of rock alteration at Meteor Crater are the melting of some of the sandstone and the shattering of other portions to produce a finely comminuted rock flour composed of quartz grains. It seems impossible that silica glass could have been produced by a steam explosion. An inconceivable amount of superheating would have been required. No silica glass has ever been described from any of the cryptovolcanic regions. There are no field or laboratory evidences of the effect of any kind of vulcanicity at Meteor Crater.

There is, however, another geological agent of an unusual kind which is in all probability responsible for the fusion of the sandstone to form silica glass and for the production of the peculiar topographic feature known as Meteor Crater. I refer to the impact of a huge meteorite. In the immediate region of Meteor Crater, but not within the Crater itself, hundreds and even thousands of iron meteorites have been found. These are known as Canyon Diablo meteorites. The impact of an iron meteorite with a diameter of 500 feet or so would probably produce a cavity of the size of Meteor Crater, and there would probably result, from friction, a temperature sufficiently high to melt quartz. This hypothesis of the origin of Meteor Crater was first advanced by D. M. Barringer.[12]

A recent writer[13] gives G. K. Gilbert the credit for the meteoritic hypothesis of origin but Gilbert[14] simply mentions this hypothesis along with a number of others.

The only reasonable explanation of the origin of the silica glass and the production of Meteor Crater that I can find is the impact of an immense meteorite. This conclusion is based upon a combined laboratory and field study.

[12] "Meteor Crater in Northern Central Arizona," paper read before the National Academy of Science in 1909 and printed privately.

[13] W. D. Boutwell, Nat. Geogr. Mag. 53, 720-730, June, 1928.

[14] *Science* 3, 1-13, 1896.

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