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Shocked quartz in Sahara fulgurite

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Abstract: Comparative strain analyses were performed on quartz crystals within a Sahara fulgurite using neutron diffraction experiments. Besides, 3D-μXRCT (three-dimensional micro X-ray computed tomography) studies of the fulgurite were implemented in order to quantify the fusion behaviour, the expansion of the fulgurite as well as the distribution of the stressed quartz crystals. The study of the neutron diffraction pattern was carried out by applying an integral breadth method, more precisely a Rietveld and a LeBail strain–size evaluation with the software FullProf. The absorption contrast of the neutron diffraction pattern shows a concentration of the shocked quartz crystals in the outer shell of the Sahara fulgurite, while the inner part of the fulgurite is mostly glassy. On the basis of the diffraction results, the quartz crystals in the fulgurite can be assigned to a stage of deformation for which the causal shock pressure reaches about 25 GPa, as compared to a melting threshold pressure for quartz of about 50 GPa. Comparing the average density of the fulgurite with the average bulk density of quartz-based sand, it can be concluded that the fulgurite expanded by more than 35 % during its formation.

Key-words: fulgurite, shocked quartz, microstrain, neutron diffraction, tomography, Williamson-Hall plot.

1. Introduction

Fulgurites (Latin: *fulgur*, ''lightning'') are natural glassy and rooty tubes formed when a lightning strike terminates in rock or soil. These tubes can be several metres long and up to a couple of centimetres in diameter, like the one studied by Martín Crespo *et al.* (2009). Colour and chemical composition strongly depend on the type of rock or soil that is affected. The best-known fulgurites are found in quartz sands. In such fulgurite the extreme and rapid process of heating and cooling forms silica glass. This amorphous silica, the so-called lechatelierite, exhibits typical flow structures and vesicles. The melting threshold pressure for quartz, before lechatelierite is formed, is about 50 GPa (Stöffler & Langenhorst, 1994; French, 1998; Ferrière *et al.*, 2009).

The existence of fulgurites is known at least since 1711, when fulgurites were found in Silesia, Poland (Brocklesby, 1851). They were conclusively linked to lightning by Priestley in 1790 (*cf.* Cerveny, 2005). Even Darwin was engaged in fulgurites he found in 1832 (Darwin, 1839).

Nevertheless, there is only scarce scientific literature about fulgurites investigated by diffraction methods. The publications concentrate on geochemical analyses, as for instance Kopylova *et al.* (1988), Pavlov *et al.* (1986) or Martín Crespo *et al.* (2009). A few papers discuss the melting behaviour of minerals contained in fulgurite, such as Frenzel & Staehle (1984). Wright *et al.* (1984) analyse the glass structure of fulgurites using neutron diffraction, but they do not address microstrain in quartz crystals although, given the huge force of natural lightning, a shock-induced strain can be expected.

The shock-induced stress cannot be measured directly by neutron or X-ray diffraction (XRD), because it is an extrinsic property. However, there is a relationship between stress and measurable strain, which is material dependent.

Langenhorst (1994) reveals that the effect, which is measured, is not a residual strain linked with the quartz polymorphs and their volume difference. He points out that the dominant shock effect measured in quartz with XRD or neutron diffraction is an elastic stretching by planar deformation features. These so-called PDFs are thin amorphous SiO_2 lamellae. The threshold pressure for the incipient transformation is about 25 GPa (Langenhorst & Deutsch, 1994) and seems largely independent of temperature.

The aim of the present work is to combine the results of 3D-μXRCT (Micro X-ray Computed Tomography) and neutron diffraction to obtain information about the conditions of fulgurite formation.

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