ALWAYS IN STYLE – SHOCKED QUARTZ PAST, PRESENT, AND BEYOND.

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Background: To recognize a hypervelocity impact structure, or its ejecta, on Earth, the identification of either unambiguous evidence of shock-deformation or traces of extraterrestrial matter is mandatory (e.g., [1,2]). Quartz has been the go-to mineral for the recognition of hypervelocity impact structures (and ejecta), and for studying the process of impact cratering, ever since the first impact structures were confirmed on Earth (e.g., [3,4]). The uniqueness of shocked quartz as a diagnostic indicator of shock metamorphism results from a combination of factors, including the relative abundance of quartz in terrestrial crustal rocks, its resistance to alteration, its ability to record shock metamorphic features over a wide range of pressures, and also its rather simple optical characteristics, making it relatively easy to study. Shock-induced deformations and transformations of quartz include: irregular fractures (which are not impact diagnostic), planar fractures (PFs), Brazil twins (basal "PDFs"), feather features, planar deformation features (PDFs), mosaicism, high-pressure mineral polymorphs (coesite and stishovite), diaplectic quartz glass, lechatelierite, and ballen silica (e.g., [1-4]). When speaking of "shocked quartz", and using it as the "smoking gun", quartz grains with PDFs is what is generally referred to, as PDFs are the most straight-forward diagnostic feature of impact. PDFs are parallel, thin, straight, closely-spaced (originally glassy) planes that only form by shock. They are oriented along rational crystallographic planes, such as c(0001), a$\{10\bar{1}4\}$, ω$\{10\bar{1}3\}$, and π$\{10\bar{1}2\}$ [5,6]. PDF orientations in quartz grains from a given sample are related to the shock pressure that the rock was exposed to, thus, shocked quartz can be used as a shock pressure indicator. Depending of a number of rock properties, in particular the porosity (see [7,8]), deformations and transformations of quartz form over a wide range of shock pressures, from ~5 to 35 GPa [2].

Using shocked quartz as diagnostic evidence of impact can be complicated by the occurrence of more or less planar microstructures formed by endogenic geological processes (see discussion in [1]). Because these features have been commonly misinterpreted as PDFs, it is important to describe and characterize detected planar microstructures in quartz following recommendations from e.g., [3,5,6]. This includes universal stage (or spindle stage) measurements to determine the angles between c-axis and poles to PDF planes and, then, indexing them using a standard stereographic projection template (or alternatively, transmission electron microscopy (TEM) can also be used).

Much of the knowledge of quartz behavior under shock compression comes from experimental works that started ~60 years ago (see e.g., papers in [9]), which has led not only to the understanding that PDFs in quartz are (in nature) uniquely formed during hypervelocity impact, but also to an understanding of how PDF orientations can be used to establish shock barometry schemes at impact structures and, more generally, how shock waves behave and interact with target rocks. These important findings are not without flaws though, as questions about how exactly shock experiments translate to the natural impact environment remain. For example, experiments suffer from short pulse duration (<1 µs compared to ~1 s in natural impact) and most of them were not conducted on polycrystalline samples.

Outlook: Shocked quartz remains the "little black dress" of studies of terrestrial impact structures and their ejecta, and while we know much especially about the response to shock compression of quartz in non-porous crystalline rocks, there are a number of important aspects that remains to be (further) investigated. These include e.g., detailed PDF orientation analysis of variations between porous and non-porous lithologies, and understanding the reasons for the differences in PDF populations between different target materials. We also need to expand our knowledge about quartz response to shock compression in the low-pressure regime, including how the timing of PDF and PF formation relate to each other (e.g., [10]). As we learn more about shock metamorphic features in quartz-lacking lithologies, onset pressure for such features can be constrained by PDF orientations in quartz in samples where those minerals occur together with quartz. PDF orientations in quartz will remain the standard method for generating statistically significant datasets for evaluating shock barometry, because it is relatively easy to be completed and rather inexpensive. As a final remark, we would like to emphasize that the mechanisms behind PDF formation are still not well understood (e.g., [11]), and that further experimental work is needed to resolve this outstanding question.

References: [1] French B. M. and Koeberl C. (2010) *Earth-Science Reviews* 98:123–170. [2] Stöffler D. et al. (2018) *Meteoritics & Planetary Science* 53:5–49. [3] Stöffler D. and Langenhorst F. (1994) *Meteoritics & Planetary Science* 29:155–181. [4] French B. M. (1998) *Traces of Catastrophe*, LPI Contribution 954, 120 p. [5] Engelhardt W. v. and Bertsch W. (1969) *Contributions to Mineralogy and Petrology* 20:203–234. [6] Ferrière L. et al. (2009) *Meteoritics & Planetary Science* 44:925–940. [7] Kieffer S. W. et al. (1976) *Contributions to Mineralogy and Petrology* 59:41–93. [8] Kowitz A. et al. (2016) *Meteoritics & Planetary Science* 51:1741–1761. [9] French B. M. and Short N. M. (eds; 1968) *Shock metamorphism of natural materials*, Mono Book Corp. Baltimore, 644p. [10] Poelchau M. H. and Kenkmann T. (2011) *Journal of Geophysical Research* 116:B02201. [11] Goltrant O. et al. (1992) *Physics of the Earth and Planetary Interiors* 74:219–240.