

RELATION OF THE SHOCK FIELD HETEROGENEITY TO SHOCK PRESSURE ESTIMATIONS BASED ON PDFS CHARACTERISTICS. Anna Losiak¹ and Christian Koeberl¹², ¹Department of Lithospheric Research, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria (anna.losiak@univie.ac.at), ²Natural History Museum, Burgring 7, A-1010 Vienna, Austria (christian.koeberl@univie.ac.at).

Introduction: The most commonly used diagnostic indicators, allowing for the unambiguous identification of impact structures on Earth, are planar deformation features (PDFs) in quartz. PDFs are straight, parallel sets of planes of amorphous material that form along specific crystallographic planes in minerals and that are less than 2 μm wide and spaced 2-10 μm apart [e.g., 1]. PDFs can not only be used to demonstrate that a specific geological feature is an impact crater, but also they provide information on the shock pressure recorded in the rocks, within the range of ~5 to 35 GPa (e.g., 2, 3, 4).

The PDFs are considered a very useful and reliable shock pressure indicator because of two main reasons [e.g., 2, 5]: First, PDFs are not significantly affected by the post-shock annealing or alteration and they can be applied to very old or/and metamorphosed samples [e.g., 6, 7, 5, 8]. Second, PDFs represent a higher shock pressure range than other commonly used indicators, such as density or mean refractive index, and can be used to estimate pressure range <25 GPa [e.g., 9]. Different PDF properties can be used for shock barometry: 1) orientations of planar microstructures [e.g., 1 and references therein], 2) average number of PDF sets in a grain [e.g., 10], 3) the percentage of quartz grains that are shocked [e.g., 10]. The aim of this abstract is to discuss the validity of those estimations, especially with respect to the “average” shock pressure of the samples.

Heterogeneities in the recorded shock effects: As noted previously, but by few authors, shock effects within a sample can be distributed heterogeneously, and the same sample can include features suggestive of very different shock pressures [e.g., 7]. In case of laboratory experiments performed on a single quartz crystal, this heterogeneity is estimated to be small and ranges from half to twice in intensity when compared to the average shock pressure [11]. This heterogeneity may be a result of the intrinsic instabilities in the thermo-mechanical deformation process [12]. However, most of the observed heterogeneity of the shock effects in impactite samples is probably related to pre-shock (lithological) heterogeneity of the sample, particularly with regard to the collapse of the pore spaces due to shock wave propagation [13, 14]. The modeling of the influence of the pore collapse on the localized pressure amplification showed that for the range of pressures <15 GPa, some small areas within a porous (but other-

wise homogenous) rock can reach shock pressures 4 times the average shock pressure in this sample [15]. In a heterogeneous, multi-mineral, multi-grain and porous sample those local amplifications are probably even larger.

The shock effects are distributed heterogeneously not only between different grains (e.g., one quartz grain being not affected at all, while another was converted to diaplectic glass), but even within a single grain (Fig. 1). PDFs are rarely spaced homogeneously within a quartz grain, and often are more common in proximity to the grain rims or cracks. Additionally, some areas within a particular grain can be devoid of any indications of shock metamorphism, while another area can be so densely packed with multiple sets of PDFs that it seems amorphous under the optical microscope and can be observed only under the electron microscope (Figure 1). The transition from the apparently unshocked area to the shocked area is extremely abrupt and takes place over the scale of a few micrometers, as was also modeled by [15].

Estimation of “average” shock pressure based on characteristics of PDFs: Those observations draw attention to the question of possibility of estimating the sample’s “average” shock pressure based on the PDFs measurements. Because in most cases planar microstructures are developed in areas that locally experienced pressures higher than in the surroundings (that did not develop PDFs), using these data may lead to an overestimation of the average shock pressure within the sample.

PDF orientations: The methodological problems in using orientation of planar microstructures for the shock-pressure estimations were previously pointed out [e.g., 1, 10]. Even though this method was effective in some cases [e.g., 7, 6, 16], it did not work well with respect to samples that underwent significant amounts of recrystallization [e.g., 17], or where changes in shock pressure were potentially relatively minor [e.g., 10]. Also it was shown that lithological properties of the rock significantly influence the average pressure estimation [e.g., 18].

Percentage of PDF-bearing quartz grains: In some cases estimation of the relative shock-pressure differences was based on the percentage of shocked quartz grains and/or the average number of PDF sets in a grain [e.g., 10]. However, re-examination of one of the samples measured previously by [10] (KR8-29: a

coarse grained meta-greywacke from the Bosumtwi impact structure from a depth of 271.4 m in LB-08A drill core) showed that the measured percentage of shocked quartz grains is strongly dependent on the method used (U-stage vs. “normal” optical microscope) and/or time devoted to every sample. Ferrière et al. [10] found that planar features (not indexed, observation under optical microscope) are present in 58% of all quartz grains, whereas re-examination revealed PDFs present in 78% of the grains (only indexed features, observation with U-stage).

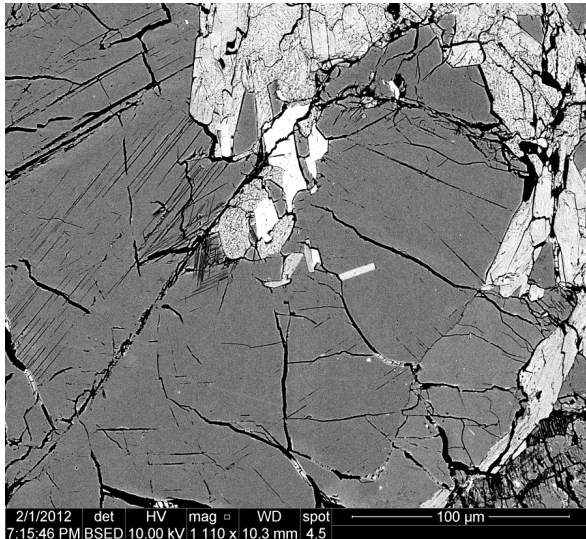


Figure 1. SEM photomicrograph of the fragment of a quartz grain from a sample KR8-29 (a coarse grained meta-greywacke) from the Bosumtwi impact structure, analyzed previously by [10]. The gray grains in the central and left part of the figure are quartz with planar deformation features. Most of the quartz includes widely spaced PDFs or no planar features at all. The area in the center includes densely spaced PDFs (two or more sets in the same place). This may illustrate a local maximum within the heterogeneous stress field produced by shock wave propagation through a heterogeneous sample.

The average grain size in the sample potentially also has an influence on the percentage of shocked quartz grains present in the sample. It is known [e.g., 19, confirmed by this study] that larger grains tend to have more PDFs present. Because of that, the same number of planar features developed in coarse-grained samples will result in a higher percentage of shocked grains than those that developed in fine-grained samples. This makes (even relative) comparisons of shock levels between lithologically different samples a very challenging task. Even if the percentage of the shocked grains is normalized to the average grain size present in the sample, this will not be sufficient because different PDF-bearing grains can be shocked to very different degree. For example, two similarly sized grains – the first with a very small number of PDFs belonging to a single orientation in very small fragment of the grain,

and the second one fully covered with dense net of PDFs belonging to multiple orientations – are very clearly not shocked to the same extent.

Number of PDF sets in a quartz grain: Similar limitations are related to the estimations of the shock level in the sample based on the average number of PDF sets in a grain. Additionally, it is necessary to consider if a grain with two not-crosscutting PDF sets (located in different areas within the grain) should be classified in the same way as a grain with two crosscutting sets of planar features. Especially as in some cases, the development of two different PDF orientations is clearly a result of Dauphiné twinning existing in the quartz grain before it was shocked. It might be better to measure the average number of crosscutting PDF sets in the grain instead of measuring the average number of PDF sets in a grain. However, the most highly shocked areas (Fig. 1), characterized by a high number of crosscutting PDF orientations, are often not clearly visible under an optical microscope because of the high density of planar features and the highly distorted crystal lattice (which may lead to underestimating the average shock level). There is a need for an alternative method of estimation of shock barometry in highly heterogeneous, multigrain, multiminerale, porous samples. This method should 1) appropriately represent full spatial variability of the shock pressures, 2) be relatively independent of lithological differences, and 3) preferably not be more time consuming than the currently used methods.

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