A STUDY OF SHOCKED QUARTZ IN DISTAL RIES EJECTA FROM EASTERN SWITZERLAND.

C. Alwmark[1,2], S. Holm[1,2], M. M. M. Meier[1,2] and B. A. Hofmann[3], [1]Dept. of Geology, University of Lund, Sölvegatan 12, SE-22362 Lund, Sweden, carl.alwmark@geol.lu.se. [2]Inst. for Geochemistry and Petrology, ETH Zürich, Clausiusstrasse 25, CH-8092 Zürich, Switzerland [3]Naturhistorisches Museum der Burgergemeinde Bern, Bernastrasse 15, CH-3005 Bern, Switzerland.

Introduction: The Blockhorizont is a 10-15 cm thick anomalous layer consisting of mainly angular randomly distributed fragments (<1 mm to 20 cm in size) of upper Jurassic limestone and Triassic pelites embedded in Miocene Upper Fresh Water Molasse in the North Alpine foreland basin [1-4]. The horizon is known from three different localities, all situated in outcrops near the city of St. Gallen in eastern Switzerland, and was first recognized in 1945 by [1], which at the time interpreted the layer as volcanogenic. The finding of a shatter cone in a limestone fragment within the layer made [2] reinterpret the layer as impact derived and suggested a local but unknown impact, as the source. However, the lack of evidence supporting a local unknown impact structure somewhere in the Molasse basement directed previous authors to the "nearby" (~200 km) Ries crater [3]. Studies and simulations have shown that it is possible for ejecta to travel this far from an impact crater in the same size range as Ries [5, 6]. That Ries would be the culprit is further corroborated by the fact that the age of the layer (~14.5 Ma), based on dating of an overlaying bentonite [3, 7], is within error contemporary with the age of the Ries structure (14.6 ± 0.2 Ma [8]).

In recent years, additional findings of shatter cones [4] as well as the occurrence of shocked quartz within the layer [3] have been reported, although in the latter work no description or measurements of the planar deformation features (PDFs) were presented. Here we confirm the presence of shocked quartz within the layer, by measurements and indexing of PDFs, which also allows us to estimate the pressure range of the shocked material. We also discuss the possible transportation mechanisms of the material, through studies of morphological features of the shocked material.

Material and Methods: Material from the Blockhorizont was sampled at an outcrop along the Sitter river bed, close to the small town of Bernhardzell (9° 20.3'E, 47° 28.78'N), ca. 6 km northwest of St. Gallen. After removal of the clay fraction and larger fragments (>5 mm), through sieving, the sample was leached in HCl. From the acid resistant material, two thin sections were prepared for studies of shock metamorphic features under optical microscope. Quartz grains displaying planar fractures (PFs) and/or PDFs were further studied using a Leitz 5-axes universal stage [9] mounted on an optical microscope, and the crystallographic orientations of identified PDFs were determined according to techniques described in [10, 11]. The presence of PFs was noted, but the orientation of them was only measured in ten quartz grains, in order to get a general impression of their orientation pattern. All percentage calculations represent absolute frequencies, as defined by [10]. An estimate of the frequency of shocked quartz in the sample was obtained by point counting and comparing the number of quartz grains with and without PDFs in the thin sections.

In addition, all shocked and indexed quartz grains were subjected to a roundness analysis based on the "Pettijohn scale" (e.g., [12]) and divided into the categories; very angular (1), angular (2), sub angular (3), sub rounded (4), rounded (5) and well rounded (6).

Results: Shock metamorphic features in the form of PDFs are present in ~5% of the quartz grains in the thin sections. In total, orientations of PDFs were measured in 50 quartz crystals, rendering a total of 171 measured sets. The number of sets per grain varies from a single set to up to seven sets within a single crystal, with an average of 3.4 sets per grain. The quartz grains with PDFs commonly display strong undulose extinction and a slight brownish discoloration, in some cases bordering to toasting.

The PDFs themselves appear as straight parallel sets with spacings between individual features of 1-5 μm, usually penetrating the better part of the host grain and are usually non-decorated (Fig. 1). The majority of the PDF sets are oriented parallel to the $\{10\bar{1}3\}$ orien-

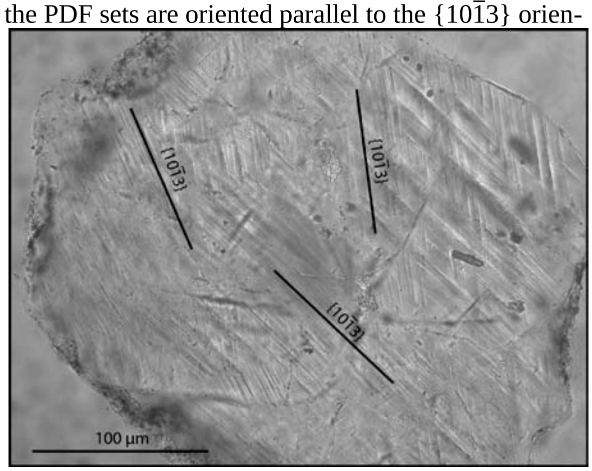

Figure 1. Thin section photomicrograph of shocked quartz grain displaying three undecorated PDF sets with $\{10\bar{1}3\}$ equivalent orientations (uncrossed polars).

tation (55%; Fig. 2). Some 56% of the poles of these PDF planes are oriented at an angle to the c-axis of between approximately 18 and 23 degrees, meaning that they are overlapping the $\{10\bar{1}4\}$ orientation (see template in [11]). These planes are considered as $\{10\bar{1}3\}$ orientations, as recommended by [11]. The second most abundant orientations are $\{10\bar{1}4\}$ and $\{10\bar{1}2\}$, constituting 12% and 11% of the total population of PDFs, respectively. In addition to these dominating sets, planes parallel to (0001), $\{11\bar{2}2\}$, $\{10\bar{1}1\}$, $\{11\bar{2}1\}$, $\{21\bar{3}1\}$, $\{22\bar{4}1\}$, $\{40\bar{4}1\}$ and $\{51\bar{6}1\}$ occur in minor amounts (each between 0.6% and 6% of the total measured PDFs). Approximately 7% of the measured planes could not be indexed. PFs, appearing as closed fractures usually spaced more than ~20 µm apart, are common in the grains displaying PDFs. The PFs are oriented either along the basal plane (0001) or in the $\{10\bar{1}1\}$ orientation.

The size of the quartz crystals with observable PDFs ranges from 140 to 630 µm (average 280 µm). The grains are typically angular, but display clear signs of being affected by abrasion. The effect of abrasion is limited as the average angularity of the grains according to the Pettijohn scale is 2, i.e., angular.

Discussion and Conclusions: With the presence of numerous quartz grains displaying multiple sets of PDFs oriented along crystallographic planes typical for shock metamorphosed quartz within the sample from the Bernhardzell locality, we provide unambiguous evidence that the Blockhorizont is indeed impact related. The orientation pattern of the PDF population, with the majority of sets along the $\{10\bar{1}3\}$ orientation, and 11% of PDFs oriented in the $\{10\bar{1}2\}$ orientation, together with the high amount of sets per grain (average 3.4), indicates that the material present in the horizon was shocked to >20 GPa during impact (see [13] for discussion about assigning shock pressures based on PDFs in quartz). The pressure range of the material described here indicates ejection from zones of target rock that were proximal to the point of impact.

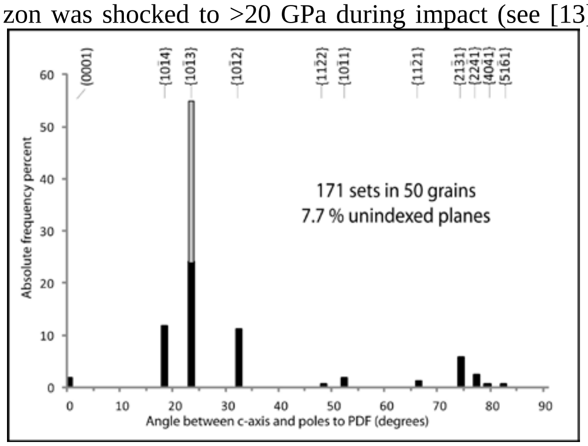

Figure 2. Histogram of the absolute frequency percent of indexed PDFs in quartz from the Bernhardzell locality. PDFs that plot in the overlapping zone between the $\{10\bar{1}4\}$ and $\{10\bar{1}3\}$ crystallographic orientations are plotted in grey on top of the uniquely indexed $\{10\bar{1}3\}$ planes.

The angularity of the shocked quartz grains indicates only little reworking by an abrading agent, and therefore it is unlikely that, if the material comes from Ries, it was transported all the way to the present locality by fluvial processes. This is corroborated by the fact that quartz grains displaying PDFs are common in the material. If the grains were fluvially transported for 200 km it is improbable that the concentration would be as high as observed. Furthermore, the presence of previously described shatter cones [3], up to 15 cm in size, together with the minute quartz grains directly contradicts fluvial transport, which naturally separates material based on grain size. In addition, the adjacent lithologies (the Molasse) represent material deposited on a large alluvial fan ("the Hörnli-fan") consisting of material derived from the south, i.e., the Alps [14].

To conclude, the Blockhorizont contains shock-metamorphosed quartz grains that have been subjected to minor reworking by an abrading agent. A likely scenario for the formation of the horizon is ejection of material during the formation of an impact structure (most likely Ries, as it is the closest verified large impact structure which also is coeval in age), and deposition at a locality at minor distance from the sample locality, with subsequent short fluvial transportation.

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