ON THE IMPACT ORIGIN OF THE ANOMALOUS "BLOCKHORIZONT" LAYER IN EASTERN SWITZERLAND. C. Alwmark[1], L. Ferrière[2], B. A. Hofmann[3], S. Holm-Alwmark[1], and M. M. M. Meier[4], [1]Dept. of Geology, University of Lund, Sölvegatan 12, SE-22362 Lund, Sweden (carl.alwmark@geol.lu.se), [2]Natural History Museum, Burgring 7, A-1010 Vienna, Austria, [3]Naturhistorisches Museum der Burgergemeinde Bern, Bernastrasse 15, CH-3005 Bern, Switzerland. [4]Inst. for Geochemistry and Petrology, ETH Zürich, Clausiusstrasse 25, CH-8092 Zürich, Switzerland.

Introduction: The so-called "Blockhorizont" is a 10-15 cm thick anomalous layer consisting of angular, randomly distributed, blocks and fragments (<1 mm to 20 cm in size) of upper Jurassic limestone and red mudstone, embedded in Miocene Upper Freshwater Molasse in the North Alpine foreland basin [1-4]. The age of the mudstone is unknown, but is thought to have a Triassic (Keuper) affinity [3]. So far, the layer has been documented at three different localities, all situated in outcrops along the Sitter river, in eastern Switzerland (Fig. 1). The layer was first mentioned in 1945 by [1] and was then interpreted as a volcanogenic deposit. After the finding of shatter cones in the limestone fragments, it was reinterpreted as being impact related, and a local, but unknown, impact event was suggested as the source [2]. However, the lack of evidence supporting a local impact structure directed previous authors to an origin associated with the “nearby” (~200 km) Ries impact structure in Germany [3]. Various 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 [e.g., 5, 6]. That Ries would be the culprit is further corroborated by the fact that the estimated age of the layer is ~14.5 Ma, based on dating of an overlaying bentonite [3, 7], an age more or less 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 grains within the layer [3] have been reported, although in the latter work no description or measurements of the planar deformation features (PDFs) in quartz were presented.

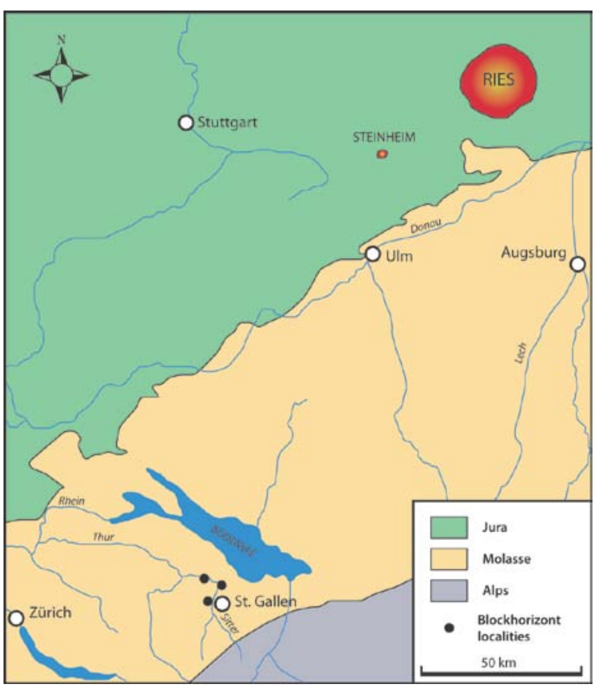

Figure 1. Location of the Blockhorizont localities and the Ries and Steinheim impact structures. The studied samples were taken at the most northern locality. Modified after [2].

The aim of our study is two-fold; 1) to confirm the presence of shocked quartz grains, by measurements and indexing of PDFs. The external morphology of the shocked material was also studied in order to draw conclusions on possible transport mechanisms; 2) to validate or disprove the causal link to the Ries impact structure, i.e., whether or not the Blockhorizont is distal Ries ejecta. This was done through comparative studies of the chemical and isotopic composition of the lithologies found in the Blockhorizont with the target lithologies of the Ries impact structure.

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; Fig.1). Thin sections of the material were prepared and searched for shock metamorphic features in quartz grains using the polarizing microscope. All quartz grains displaying PDFs were further studied using a Leitz 5-axis universal stage, following the technique described in [9]. An estimate of the abundance of shocked quartz grains in the sample was obtained by point counting. In addition, all shocked and indexed quartz grains were subjected to a roundness analysis based on the “Pettijohn scale” (e.g., [10]).

Whole rock element analysis was carried out on one sample of the red mudstone together with eight samples of Keuper clay from Gundelsheim, Oettingen, and Unterwilflingen localities within the Ries area. The concentrations of major and trace elements were determined using an ICP-ES/ICP-MS.

Three limestone clasts, two of which display shatter cones, were analyzed for their oxygen and carbon isotopic ratios using a ThermoFinnigan GasBench II linked to a Delta^{plus}XL mass spectrometer. For comparison, one shatter cones bearing limestone sample from the Ries and one sample from the Steinheim impact structure were also analyzed.

Results and Discussion: Shock metamorphic features in the form of PDFs are present in ~5% of the quartz grains in thin section. The orientation of PDFs were measured in 50 quartz grains, 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 grain, with an average of 3.4 sets per grain (Fig. 2). The majority of the PDF sets are oriented parallel to the $\{10\bar{1}3\}$ orientation (55%). 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, 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. The orientation pattern of the PDF population, with the majority of sets oriented along the $\{10\bar{1}3\}$ orientation, and 11% of PDFs oriented along the $\{10\bar{1}2\}$ orientation, together with the relatively high amount of sets per grain, indicates that the shock material present in the Blockhorizont was shocked to >20 GPa (see [11]). The shocked grains display clear signs of being affected by abrasion. The effect of abrasion is however somewhat limited as the average angularity of the grains according to the Pettijohn scale is 2, i.e., angular. This indicates only a modest reworking by an abrading agent, and therefore, it is very unlikely that, if the material is derived from the Ries, it was transported all the way to the present outcropping 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.

The results of the whole-rock analysis of the red mudstone show a difference in both major and trace elements chemical composition compared to the results of the Keuper samples from the Ries area, implying that the mudstone from the Blockhorizont is not of Keuper origin. It is especially the low Cs concentrations (~5 ppm) in the mudstone from the Blockhorizont that separate the samples from Ries Keuper clay ($\bar{x}$: 60 ppm). Cs is typically enriched in Triassic rocks of the region [12].

The carbon ($d^{13}C$) and oxygen ($d^{18}O$) isotopic ratios for the limestone clasts from the Blockhorizont gave values between 2.0 – 2.5 and -2.1 – -2.4, respectively. These values do not match the isotopic ratios of the shatter cones bearing limestone sample from the Ries ($d^{13}C$: -4.7; $d^{18}O$: -9.9) that was analyzed. On the other hand, the carbon ratio of the analyzed shatter cone sample from the Steinheim structure ($d^{13}C$: 2.2; $d^{18}O$: -3.9) matches the data from the Bernhardzell material. However, $d^{13}C$ and $d^{18}O$ can vary considerably with strata and facies and, thus, analysis of all the various limestone strata/facies from the Ries/Steinheim area is necessary before a definite conclusion can be drawn.

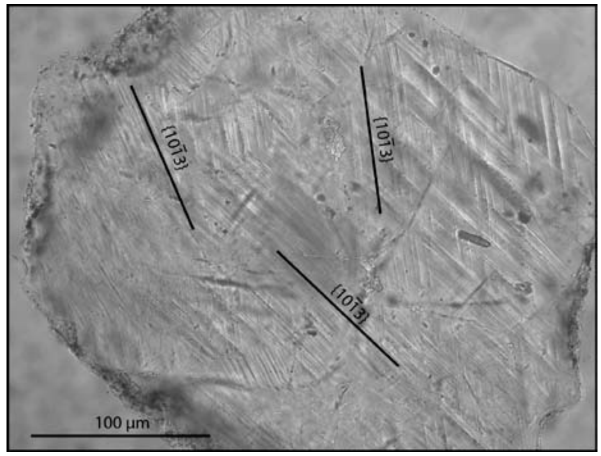

Figure 2. Thin section photomicrograph of a shocked quartz grain with three undecorated PDF sets with $\{10\bar{1}3\}$ equivalent orientations (plane-polarized light).

Conclusion: The Blockhorizont contains shocked quartz grains that have been subjected to minor reworking. A likely scenario for the formation of the horizon is ejection of material during the formation of an impact structure, and deposition at a locality at minor distance from the current sample locality, with subsequent short fluvial transportation. The geochemistry of the red mudstone is not consistent with a Keuper origin. Further studies and comparisons with other target lithologies from the Ries are needed in order to determine the source of origin. The C and O isotope analysis did not yield any definite answer to whether the shatter cones-bearing limestone clasts originate from Ries or not.

Although the Ries impact structure is the most likely source for the Blockhorizont, the studies done so far does not allow for neither a validation nor a disproval of that link.

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References: [1] Büchi U. and Hofmann F. (1945) *Eclogae geol. Helv. 38*, 337–343. [2] Hofmann F. (1973) *Eclogae geol. Helv. 66*, 83–100. [3] Hofmann B.A. and Hofmann F. (1992) *Eclogae geol. Helv. 85*, 788–789. [4] Hofmann B.A. and Gnos E. (2006) *MAPS 41*, A78. [5] Melosh J. (1989) *Impact Cratering: A Geologic Process.* Oxford Univ. 245 pp. [6] Buchner E. et al. (2007) *Icarus 191*, 360–370. [7] Fischer H. et al. (1987) Abstract *Jahrestagung der Schweiz.* Naturfor. Gesell. Luzern. [8] Buchner E. et al. (2010) *MAPS 45*, 662–674. [9] Ferrière L. et al. (2009) *MAPS 44*, 925–940. [10] Friedman G.M. et al. (1992) *Principles of sedimentary deposits: stratigraphy and sedimentology*. New York, 717 pp. [11] Stöffler D. and Langenhorst F. (1994) *Meteoritics 29*, 155–181. [12] Hofmann B.A. (1995) *Terra Nova 7*, 203.