MACRO- AND MICROSCOPIC EVIDENCE OF IMPACT METAMORPHISM IN ROCKS FROM THE CHICXULUB PEAK RING IODP-ICDP EXPEDITION 364 DRILL CORE.
L. Ferrière[1], A. S. P. Rae[2], M. Poelchau[3], C. Koeberl[1,4], and the IODP-ICDP Expedition 364 Science Party, [1]Natural History Museum, Burgring 7, A-1010 Vienna, Austria (ludovic.ferriere@univie.ac.at), [2]Department of Earth Science and Engineering, Imperial College London, SW7 2BP, UK, [3]University of Freiburg, Geology, Albertstraße 23b, 79104 Freiburg, Germany, [4]Department of Lithospheric Research, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria.

Introduction: The peak ring of the about 200 km Chicxulub impact structure (Mexico) was jointly drilled in April-May 2016 by the International Ocean Discovery Program (IODP) and International Continental Scientific Drilling Program (ICDP), providing a unique opportunity to investigate the formation mechanism of peak rings [1]. A continuous core, M0077A, 83 mm in diameter, was recovered between 505.7 and 1334.7 mbsf (meters below sea floor), and was subdivided into three main lithological units: (1) a "post-impact" section (from 505.7 to 617.3 mbsf), (2) an "upper peak ring" section of suevites and impact melt rocks (from 617.3 to 747.0 mbsf), and (3) a "lower peak ring" section mainly consisting of granitoid rocks (with aplite and pegmatite dikes) intruded by different types of sub-volcanic dikes, and intercalations of millimeter to decameter thick suevite and impact melt rock units (from 747.0 to 1334.7 mbsf).

We report here on macro- and microscopic observations of impact metamorphism features (in rocks from units 2 and 3) conducted during the onshore science party (OnSP) in Bremen (Germany) and completed with preliminary investigations of some of the samples selected for post-cruise research in Vienna (Austria).

Methods: During the OnSP, after the cores were split, the archive half cores were visually inspected (aided by the use of a hand lens and a microscope camera) for macroscopic impact metamorphism features. The occurrence of shatter cones, fracturing, brecciation, and melting were noted. In addition, petrographic observations were conducted on thin sections prepared from samples collected during the offshore science party (OffSP). A similar approach was used in Vienna on selected samples.

Results: The "upper peak ring" section consists of ~104 m of suevite (polymict lithic breccia with mm to over 25 cm in size melt clasts and lithic mineral and rock fragments) on top of ~25 m impact melt rock (dominantly clast-poor but with clast-rich intervals). The matrix of the suevite is calcitic (ranging from micritic to sparitic). Clasts include a variety of more or less shocked mineral and rock fragments (sedimentary [including isolated fossils], metamorphic, and igneous lithologies, with carbonate and granitoid being the most abundant rock types) and melt fragments with altered (green to brown in color in plane-polarized-light; clay minerals) glassy to microcrystalline textures (Fig. 1). Many of the melt fragments have flow textures and are occasionally vesicular. They often contain relic mineral clasts (dominated by feldspars and quartz) and shocked lithic rock fragments, or are, themselves, coated with an additional layer of melt. Quartz grains show planar fractures (PFs) and/or (decorated) planar deformation features (PDFs), with up to 3 sets (as seen under the optical microscope). A few toasted quartz [2] grains were noted. Silica glass, generally recrystallized, with a chert-like appearance (and with ballen silica of types II, III, IV, and V [3]) also occur. Other minerals also exhibit shock features, especially plagioclase and alkali-feldspar (with PFs and PDFs). Possible coesite was observed in a large silica-rich melt fragment during OnSP (to be confirmed by microRaman spectroscopy). The impact melt rock from the lower part of the "upper peak ring" section is green to black in color, with flow banding, and in some cases vesicular. The green and black melts are locally intermixed, forming schlieren of green material (altered impact melt?) in a black-colored melt. A large variety of clasts are present (as in suevite, with the exception of sedimentary rock clasts that were not found), in some cases so heavily shocked and/or hydrothermally altered that it was difficult to identify them. At the microscopic scale, shock features similar to those in suevite were observed in the impact melt rocks, such as PFs and PDFs in quartz, toasted quartz, and a variety of shock features in other minerals.

Fig. 1. Microphotograph (plane-polarized light) of an impact melt rock sample with tiny phenocryst laths (~25 µm) in an aphanitic groundmass. On the left side is a partly digested shocked quartz clast. Sample M0077A_93R3_51-52 (740.9 mbsf).

The "lower peak ring" section consists mainly of pervasively deformed granitoid basement rocks (granite to syenite), overall coarse-grained, with locally cm to dm thick aplitic and pegmatitic sections. All main rock-forming minerals, i.e., alkali-feldspar, plagioclase, quartz, and biotite, show signs of shock deformation. In the case of quartz, locally PFs were even visible with the naked eye as a result of preferential hydrothermal alteration. Almost all quartz grains are shocked, with PFs, feather features (FFs), and/or (decorated) PDFs (Fig. 2; up to 4 sets of PDFs are seen under the optical microscope). Kinkbanding was also observed for some quartz grains. Similar shock features were observed in alkali-feldspar and plagioclase. Biotites and chlorites are often kinked.

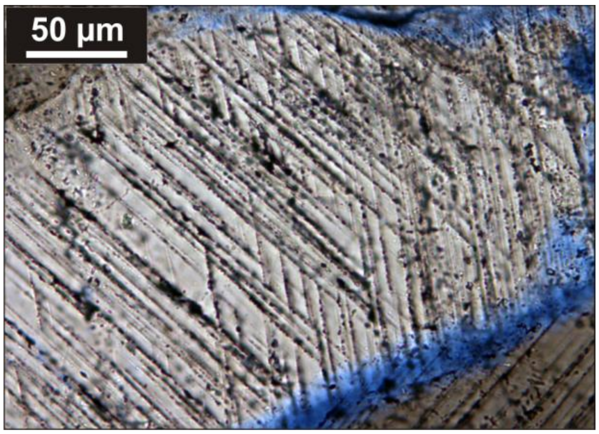

Fig. 2. Microphotograph (cross-polarized light) of a quartz grain with two sets of decorated PDFs. Granitoid sample M0077A_108R3_62-63 (783.1 mbsf).

Based on qualitative evaluation of the thin sections available during the OnSP, no noticeable shock attenuation with depth was observed. Preliminary quantitative results seem to indicate little or no shock attenuation with depth [4]. On the other hand, more data are needed and extreme care should be taken, as differences in lithology, texture, fabric, grain size, porosity, etc., as well as rheological contrasts between adjacent lithologies, can significantly influence the development of PDFs in quartz [5].

For the first time shatter cones were found at Chicxulub. They are well-developed in some of the sub-volcanic dikes intruding the granitoid basement rocks, such as in aplite at 777.2 and 777.4 mbsf and in phonotephrite dikes at 1125.1, 1131.7, 1137.5, and 1138.3 mbsf (Fig. 3). A possible poorly-developed shatter cone was also noted in a coarse-grained granitoid sample at 909.6 mbsf. Finally, suevites and impact melt rocks also occur in the "lower peak ring" section in the form of small dikes and large bodies, such as the ~100 m thick occurrence between 1215 and 1316 mbsf. Similar shock features as in suevites and impact melt rocks from the "upper peak ring" section were observed.

Fig. 3. Well-developed shatter cone in a fine-grained phonotephrite dike. Sample M0077A_239R1_121-124 (1138.3 mbsf).

Discussion: Preliminary investigations show that the rocks forming the Chicxulub peak ring are highly fractured (from the macro- to the microscopic scale) and shocked, with an average recorded shock pressure in the order of ~15 to 20 GPa, and locally >60 GPa as indicated by the occurrence of impact melt rocks. The so far most striking observations of shock related features and rock modifications, which may have contributed to their weakening, are the very high abundance of PFs (and FFs) in quartz grains (i.e., compared to other shocked granitoids previously investigated by L.F.) and the extremely low density and high porosity of these rocks.

Detailed investigations (in progress) will increase our understanding of the contribution of shock induced fractures and other impact metamorphic features on the substantial strength reduction of the rocks, which may be conducive to the formation of peak rings.

Acknowledgements: The Chicxulub drilling was funded by the IODP as Expedition 364 with co-funding from ICDP. The ECORD implemented Expedition 364, with contributions and logistical support from the Yucatán state government and Universidad Nacional Autónoma de México.

References: [1] Morgan J. V. et al. (2016) *Science, 354,* 878–882. [2] Whitehead J. et al. (2002) *Geology, 30,* 431–434. [3] Ferrière L. et al. (2009) *EJM, 21,* 203–217. [4] Rae A. S. P. et al. (this volume). [5] Ferrière L. et al. (2008) *Science, 322,*1678–1681.

Expedition 364 Scientists: E. Chenot, G. Christeson, Ph. Claeys, C. Cockell, M. J. L. Coolen, L. Ferrière, C. Gebhardt, K. Goto, S. Gulick, H. Jones, D. A. Kring, J. Lofi, L. Xiao, C. Lowery, C. Mellett, J. V. Morgan, R. Ocampo-Torres, L. Perez-Cruz, A. Pickersgill, M. Poelchau, A. S. P. Rae, C. Rasmussen, M. Rebolledo-Vieyra, U. Riller, H. Sato, J. Smit, S. Tikoo, N. Tomioka, J. Urrutia-Fucugauchi, M. Whalen, A. Wittmann, K. Yamaguchi, and W. Zylberman.