PROBING THE IMPACT-GENERATED HYDROTHERMAL SYSTEM IN THE PEAK RING OF THE CHICXULUB CRATER AND ITS POTENTIAL AS A HABITAT. David A. Kring[1,2], Martin Schmieder[1,2], Barry J. Shaulis[1,2], Ulrich Riller[3], Charles Cockell[4], Marco J. L. Coolen[5], and the IODP-ICDP Expedition 364 Science Party, [1]USRA-Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058 USA (kring@lpi.usra.edu), [2]NASA Solar System Exploration Research Virtual Institute, [3]Institut für Geologie, Universität Hamburg, Hamburg 20146 Germany, [4]School of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3FD UK, [5]Dept. Chemistry, Curtin University, Bentley WA 6102 Australia.

Introduction: Impact-generated hydrothermal alteration has been observed within core samples from the Yucatán-6 [1] and Yaxcopoil-1 (Yax-1) [2-6] boreholes, both located between the peak ring and crater rim. A thermal model of the hydrothermal system suggests it may have been active for 1.5 to 2.3 Myr [7]. The Chicxulub system is an important proxy for those that may have been produced during the Hadean, affecting the early evolution of life on Earth [8,9], and similar systems on Mars (e.g., [11-13]).

A time-spatial reconstruction of alteration in the Yax-1 borehole indicated a high-temperature phase in excess of 350 ºC [5,13]. Sodium-K metasomatic exchange for Ca in plagioclase and production of K-feldspar veins followed, also at temperatures in excess of 300 ºC, with co-precipitation of magnetite, sphene, and apatite [5]. As temperatures continued to fall from 270 to 100 ºC [14], mafic components were sequentially replaced by biotite-phlogopite, epidote, chlorite, and clay, along with hydrothermal quartz, calcite, rutile, chalcopyrite-bornite, and barite [5]. Modeling [7] suggests similar – or even more vigorous – hydrothermal activity may have persisted in the crater peak ring.

New Borehole Samples: In part to test that model, the International Ocean Discovery Program (IODP) and International Continental Scientific Drilling Program (ICDP) drilled into the peak ring at site M0077A [15]. Impactites were recovered from a depth of 617 to 1335 mbsf. The upper 130 m are composed of impact melt rock and suevite. The remaining core is dominated by granitoids, a few pre-impact intrusives, and impact-generated horizons of melt rock and suevite that were emplaced during upward and outward displacement of the peak ring [16].

We conducted an initial survey of splits from the core to evaluate alteration assemblages, their paragenesis, and implications for any co-existing biotic systems. In general, we found (i) an initially hot hydrothermal system that emerged as a potential habitat for recovering biota in a once-sterile region and (ii) subsequently as an open-network of passages and cavities for biota. The peak ring rocks are severely deformed, with shock-metamorphic features, cataclastic zones, deformation bands, and shear planes that would have enhanced fluid flow.

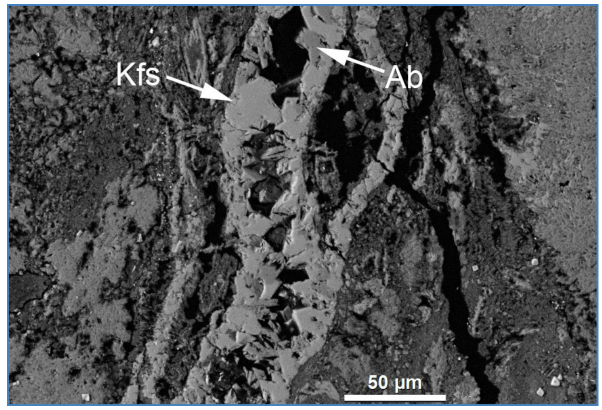

Figure 1. Vein of K-feldspar (Kfs) and albite (Ab) cutting through peak-ring granite sample 150-3-25.5-27 (887 mbsf). Scale bar is 50 µm.

High-temperature Alteration: Calcium-Na and K-metasomatism is evident along the entire core. In impact melt rock sample 85-1-26-28 (717 mbsf), a matrix of <10 µm-long laths of feldspar and rare Ca-pyroxene is overprinted with alkali feldspar alteration fronts and cross-cut by fractures with margins enriched in Ca-plagioclase. Relict quartz from the target entrained in the melt has been partially to wholly dissolved, implying a hot, Si-undersaturated fluid, and the resulting void space filled with secondary calcite, Fe-sulfide, and magnetite. Margins of vesicles in the melt are rimmed with a sheet silicate and their interiors partially filled with secondary calcite and Ba-sulfate. In addition, a K-feldspar vein cuts across granite 150-3-25.5-27 (Fig. 1). Deeper in the peak ring, adjacent to an interval of suevite, where the granite was deformed into a porous, permeable breccia, the granite (278-2, 1256 mbsf) is honeycombed with quartz dissolution cavities that may be a consequence of Ca-Na and K-metasomatism at temperatures of 300 to 400 ºC [17]. In granite sample 221-3-19-24 (1085 mbsf), secondary muscovite cross-cuts shock-metamorphic kinking of feldspar and is, thus, probably of post-impact hydrothermal origin at temperatures in excess of 350 ºC.

Pervasive Alteration: Other examples of alteration at temperatures ≤300 ºC include replacement by a variety of Mg-Fe and Na-K sheet silicates. Melt fragments in the suevite are altered to saponite-like and montmorillonite-like smectite-group minerals with significant chemical zoning and variable nH_2O. In granite 150-3-25.5-27, Ti-rich biotite is being replaced by chlorite and epidote is present. Where a 2-cm-wide melt vein cuts through granite sample 206-3-54-56 (1039 mbsf), the melt is enriched in Mg and K relative to the granite and contains distributed particles of Fe-sulfide. The adjacent granite, with albite ($An_1Ab_{97}Or_2$), K-feldspar ($An_1Ab_4Or_{95}$), and quartz, is crosscut with several types of veins consisting of quartz; muscovite; a mafic aluminosilicate; calcite with sphene and galena; and Ti-oxide with zircon and calcite. Isolated precipitates of galena are associated with chalcopyrite in impact-generated fracture pore spaces. A cm-wide vein of epidote cuts through the lowermost core section (303-3-1.5-3.5, 1334 mbsf). Some alteration in the core is due, however, to pre-impact processes, such as alteration halos along the margins of dolerite intrusions.

Lower-temperature Filling of Vugs and Open Fractures: Cavities are filled with secondary quartz (*var.* amethyst), epidote, calcite, barite, at least two Fe-sulfide minerals, halite, and co-existing analcime and Na-dachiardite (Fig. 2a), sometimes with heulandite. The paragenesis of dachiardite is still poorly understood, but has been produced experimentally at 250 ºC [18]. Analcime can be produced from albite and water when temperatures cool below 200 ºC [19].

Venting at the Surface: Venting is implied by vertical alteration channels and partially- to wholly-filled pockets with sparry calcite in the uppermost suevitic cores (#40-41). Similar features, albeit much less obvious, were noted while logging cores 43 and 46.

Habitats and Energy Sources: Hydrothermal alteration is notoriously heterogeneous, but the inferred high temperatures would have been locally sterilizing. We are still assessing potential energy sources, but sulfide framboids in several veins of 63-2-69.5-72 (Fig. 2b), which is a low-temperature and, thus, biologically-compatible mineral assemblage, imply sulfate reduction was one viable energy source for microorganisms. If the model of [7] is correct, conditions for thermophilic and hyperthermophilic life may have existed in this part of the peak ring for 10^4 to 10^5 years.

Conclusions: We have identified high- and low-temperature elements of an evolving hydrothermal system in the peak-ring of the Chicxulub impact crater. As anticipated, fluids were as hot as those that affected Yax-1 samples in the crater trough, but more study will be needed to map out the full paragenetic sequence as in Yax-1 (Fig. 9 of [5]) and the longevity of that system. Potentially, the hydrothermal system was hotter and persisted longer in the vicinity of the peak ring [7] where the M0077A borehole is located.

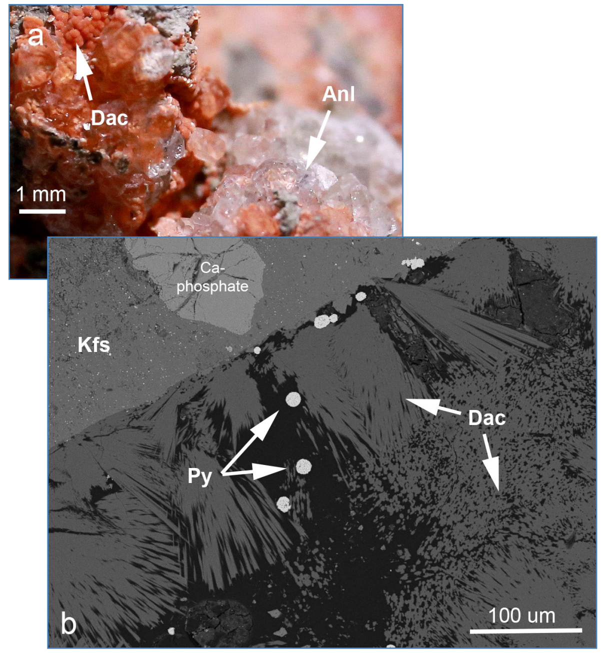

Figure 2. (a) Transparent analcime (Anl) and red Na-dachiardite (Dac) in open cavities within suevite sample 60-1-90-92 (678 mbsf). Analcime also occurs at the base of the 1335 m-deep borehole. Scale bar is 1 mm. (b) Sheaves of Na-dachiardite with framboids of pyrite (Py) growing into an open fracture adjacent to K-feldspar (Kfs) with a Ca-phosphate crystal in sample 63-2-69.5-72 (685 mbsf). The pyrite framboids may be reduction products after sulfate. Backscattered-electron image. Scale bar is 100 µm.

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