PETROLOGIC ANALYSIS OF GREEN–BLACK IMPACT MELT ROCK WITH A HISTORY OF HYDROTHERMAL ALTERATION AT CHICXULUB. Stephen J. Slivicki[1,2], Martin Schmieder[1], David A. Kring[1] and the IODP–ICDP Expedition 364 Science Party, [1]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058 USA; [2]Dept. of Plant & Earth Science, University of Wisconsin River Falls, River Falls, WI 54022 USA (stephen.slivicki@my.uwrf.edu).

Introduction: With a diameter of ~180 km, the end-Cretaceous Chicxulub crater is one of the largest impact structures on Earth [1,2]. The impact occurred on a carbonate-evaporite platform on top of a complex crustal basement and generated large volumes of impact melt [1–3]. At Chicxulub, impact melt is of andesitic composition and concentrated in a central melt pool inside the peak ring, as well as in an annular trough surrounding the peak ring [1,4–6]. The crater hosted a spatially extensive post-impact hydrothermal system with an estimated lifetime of ~1.5–2.3 Myr that pervasively altered Chicxulub's impactites [3]. Evidence for this is found in borehole samples from the crater, such as Yucatán-6 (Y-6) and Yaxcopoil-1 (Yax-1) [6-10]. More recently, IODP–ICDP Expedition 364 recovered drill core M0077A from the northwestern outer flank of the peak ring, which sampled basement lithologies and impactites [2]. Of particular interest for this study is a zone of black–green impact melt rock within that core between 721 and 747 meters below sea floor (mbsf) that shows two distinct domains (Fig. 1) [2]. Our goal is to resolve whether those two domains represent (1) intermingled types of (now altered) impact melt of different original composition; (2) crystallized black impact melt juxtaposed with a domain of localized hydrothermal alteration; or perhaps a combination thereof.

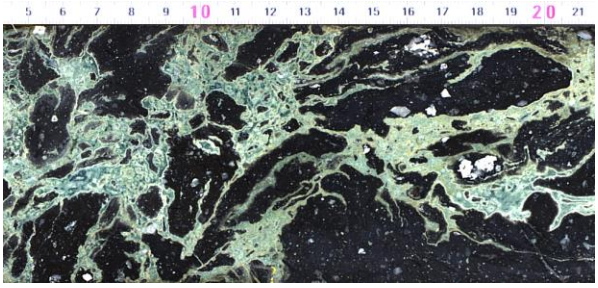

Fig. 1: Core M0077A segment 88–4 (726 mbsf) from IODP–ICDP Expedition 364 displaying both green and black domains of a hydrothermally-altered impact melt unit. Scale is in cm.

Samples and Analytical Methods: Six polished thin-section samples of the black–green melt rock interval in Expedition 364 core M0077A were examined in this study: (1) 85-1-26-28 (717 mbsf); (2) 88-3-48.5-50 (725 mbsf); (3) 89-3-13.5-15 (728 mbsf); (4) 90-3-70.5-72 (732 mbsf); (5) 89-3-39-43 (729 mbsf); and (6) 92-2-91.5-93 (737 mbsf). Samples (1)–(4) represent the 'black' melt domain while samples (5) and (6) are from the 'green' alteration domain and the boundary between the two domains (Fig. 1). Thin sections were analyzed using a Leica optical microscope at the LPI and a JEOL 5910 LV scanning electron microscope (SEM) and CAMECA SX 100 electron microprobe at the NASA Johnson Space Center.

Petrography and Geochemistry: The bulk of the black domain is a dark, aphanitic impact melt rock with target rock clasts up to several cm in size. The microcrystalline melt groundmass contains mainly feldspar, pyroxene, and opaque minerals. Groundmass feldspar is $An_{0–50}Ab_{1–70}Or_{3–99}$ (n=32). Pyroxene is augite, $Wo_{38–50}En_{22–46}Fs_{28–11}$ (n=60; FeO/MnO [wt%]=18–54). Samples (1) and (4) have a pyroxene-rich melt groundmass, while the groundmass of samples (2) and (3) contains far more feldspar; in those samples, pyroxene is mainly found in coronas surrounding quartz clasts (as in [6]). The black melt domain contains abundant mineral and rock clasts, most of which are siliceous in nature. Many siliceous clasts exhibit shock textures (e.g., PDFs in quartz, ballen quartz, and toasted quartz [11]). Vesicles are abundant in the black domain and commonly contain fillings of secondary smectite-group clay minerals (likely saponite) and locally K-feldspar (adularia), pyrite, magnetite, and sparry calcite. Vesicles and cracks, e.g., in sample (1), are commonly surrounded by halos of K-feldspar.

Samples (5) and (6) represent the black melt rock interspersed with a conspicuous green, pseudofluidal (*schlieren*-like) alteration domain that consists of ~60% sheet silicate, ~25% calcite (locally intergrown with microfibrous zeolite), ≤15% garnet, and minor opaque minerals. As revealed by SEM imaging, the sheet silicate has a fibrous to flaky microtexture and is rich in Mg, Fe, Al, and Ca, suggesting it is likely saponite, a smectite-group clay mineral [7,12-15]. Electron microprobe results suggest the green domain, vesicle-filling clays in the black domain, and clay-altered impact glass from the overlying suevite unit [2] are similar in composition (Fig. 2). Garnet in the green domain occurs in the form of euhedral, yellowish-translucent crystals, with andradite cores ($And_{62–72}Gro_{35–28}Uvt_{0–3}$) that have ≤12 wt% TiO_2 and grossular-rich rims ($Gro_{72–82}And_{28–18}$), and seems to be a pervasive hydrothermal mineral within the green domain. The green domain entrains clasts or relics of the black melt rock and, more rarely, clasts of microcrystalline-spherulitic silica and limestone. It is, overall, poorer in clasts than the black domain and the boundary between the two domains commonly appears to be relatively sharp.

Discussion: Impactites on top of the Chicxulub peak ring record a complex history of impact melt formation and hydrothermal alteration [8]. The composition of groundmass pyroxene and feldspar in the black melt domain seems to be homogeneous across samples from core M0077A and is similar to that of pyroxene in impact melt-bearing lithologies from other drill core sites at Chicxulub [6,7,9]. This suggests the composition of impact melt within the crater was relatively uniform, while cooling and alteration in different parts of the crater may have been variable. Pervasive hydrothermal alteration in the black melt domain is evidenced by K-metasomatism along cracks and vesicles [8] and secondary vesicle fillings.

The green domain, in contrast, almost entirely consists of secondary minerals that formed in a proposed post-impact crystallization sequence: garnet → smectite → calcite [8]. While hydrothermal garnet is rare in other Chicxulub core samples [16,17], it is locally a rock-forming mineral in the green-altered melt zones of core M0077A. The presence of garnet suggests minimum temperatures of ~280 to 300°C in the crater-hosted hydrothermal system [8,16–18], whereas saponite probably formed at ~100 to 150°C [19].

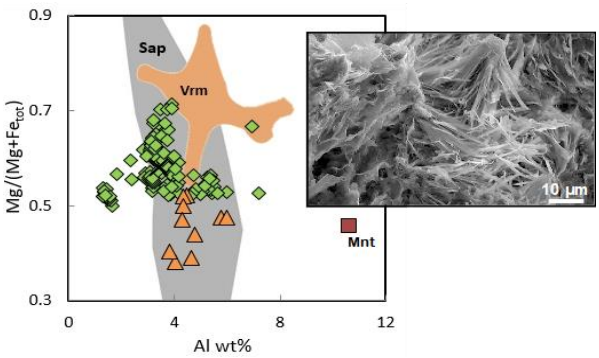

Fig. 2: Composition of mafic sheet silicates in black-green impact melt domain (green diamonds), indicating saponitic compositions (Sap; gray field). Smectite-altered impact glass in the overlying suevite unit (triangles) has a similar composition. Vermiculite (Vrm) and montmorillonite (Mnt) are shown for comparison [7,11-14]. The inset SEM image shows an example of green clay alteration in core interval 90–2 (depth 731 mbsf).

Due to pervasive hydrothermal alteration, the source 'protolith' of the green domain is not immediately obvious. The green domain may represent an alteration product of a finer-grained or glassy silicate-rich melt that was once intermingled with the surviving black crystalline impact melt. This type of subtle bimodal textural association of melt occurs in rapidly quenched volcanic melts, which may be a suitable thermal and crystallization analogue for these impact melts. This interpretation is consistent with similar saponite filling vesicles in the black melt domain and with similarly-altered, saponite clasts of once-glassy material in melt-bearing breccias elsewhere in the core (Fig. 2). Such zones of (near-)glassy schlieren within the black melt, potentially with a geochemical composition slightly different from that of the surrounding melt, may have been preferentially altered by hydrothermal fluids. The zones may have been slightly enriched in Ca, producing andradite garnet upon alteration, but not wholly carbonate melts. The clay-rich, silicate-dominated green zones have a relatively low abundance of calcite and lack typical liquid silicate–carbonate immiscibility textures (e.g., [20]) and, thus, are inconsistent with a carbonate melt-dominated origin.

The green domain may, alternatively, represent a purely hydrothermal filling of large, elongated vesicles, and/or open fractures within the black melt rock, similar to a model for saponite crystallization proposed previously for impactites in the Yax-1 core [17]. The filling of cavities and fractures would have occurred while hydrothermal fluids circulated through a permeable unit [17]. However, the presence of lithic clasts and fragments of black melt in the green domain is incompatible with that being solely the origin of those zones.

Conclusions: The intermingled green and black domains within the impact melt unit of M0077A probably represent two slightly different textural and/or compositional melts that subsequently reacted to hydrothermal fluids in different ways. The green domain was probably finer-grained, if not glassy, compared with the black domain, and, thus, more susceptible to alteration. The alteration produced a saponite matrix similar to altered glasses elsewhere in the core, augmented with a spectacular array of grossular-rimmed andradite garnet.

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