TEM AND XRD INVESTIGATION OF IMPACT GLASS ALTERATION PRODUCTS: AMORPHOUS MATERIALS, PHYLLOSILICATES AND EVERYTHING IN BETWEEN. S. L. Simpson[1], E . B. Rampe[1], R. Christoffersen[1,2], M. Thorpe[1,2], Z. Rahman[1,2], V. Tu[1,2], F. J. Longstaffe[3], G. R. Osinski[3], NASA Johnson Space Center, Houston, TX, 77058 (*sarah.l.simpson@nasa.gov), [2]JETS – NASA Johnson Space Center, Houston, TX, 77058, [3]The University of Western Ontario, London, Canada.

Introduction: Impact cratering is one of the most ubiquitous geologic processes shaping the surface of all solid bodies in our solar system. Impacts are also a major source of clay minerals and poorly crystalline, clay-like materials on Earth and Mars [1,2]. These phyllosilicates and related clay-like phases comprise an incredibly complex group of materials, and their characterization, even in controlled laboratory settings, remains a challenging endeavor. The nature and origin of clay minerals and amorphous materials on Mars, which form a major component (~20-70 wt %) of rock and soil samples in Gale Crater as determined by the CheMin instrument on Curiosity, have remained ambiguous [3]. These amorphous phases likely fall on a spectrum between pristine volcanic and/or impact-produced primary materials and clay minerals and related phases formed from aqueous alteration. Amorphous materials are common weathering products in terrestrial sediments, soils, and paleosols [e.g., 4,5]. Primary impact materials (glass, melt rocks) are comparable in some ways to those generated volcanically [6], and so it may be possible that an amorphous component is preserved within altered impactites. There are hundreds of thousands of impact craters on Mars, and Curiosity and *Perseverance* are currently exploring ancient impact craters. We hypothesize that the sediments and lithologies in Gale and Jezero Craters and elsewhere contain altered impact products; it is therefore important to better understand the composition and structure of these materials. Here we present the first results from a study characterizing materials produced from impact glass alteration – clay minerals, poorly crystalline/amorphous materials – in terrestrial craters using Transmission Electron Microscopy (TEM), powder X-ray diffraction (pXRD) and chemical (EDS) analysis.

Background and Methods: We analyzed altered impact melt glass preserved in the Chicxulub impact crater. In 2016, the joint International Ocean Discovery Program (IODP)-International Continental Scientific Drilling Program (ICDP) Expedition 364 recovered core from the peak-ring [7]. The main impact lithology comprises a gradational sequence of a fining upward melt-bearing breccias formed from molten-fuel coolant interaction [8,9], a process comparable to phreatomagmatic volcanism. This resulted in the formation of abundant silicate glass that was subsequently altered by the impact-generated hydrothermal system (peak temps of ~400 °C) and later, circulation of low-temperature meteoric water-dominated fluids (~20 to 50 °C) [10,11]. The peak-ring lithologies were rapidly buried under post-impact sediments; as a result, various secondary hydrated silicates (i.e. zeolites, clay minerals) including a nanocrystalline, glassy material referred to palagonite, or hydrated glass [11], are exceptionally well preserved. This Al-Si-rich phase is thought to represent an intermediate stage of alteration between pristine silicate glass and more advanced alteration products [12].

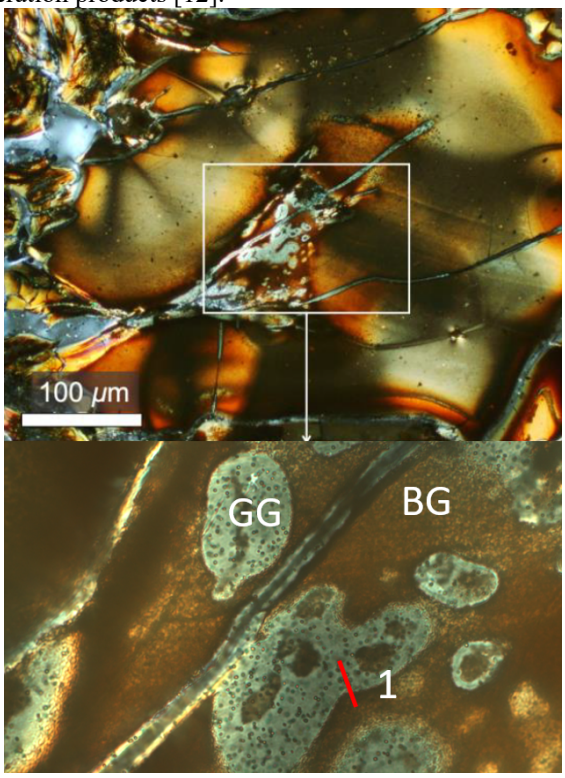

Figure 1: Transmitted light microscope image of altered impact glass clast showing two distinct colors, green glass (GG) and brown glass (BG); (1) denotes where the FIB section for TEM analysis was taken (red line).

The first sample selected for TEM analysis was a clast of altered glass from the impact melt-bearing breccia lithology (Unit 2; 658 mbsf) composed primarily of a hydrated, poorly crystalline component that, despite being altered, shows relict schlieren and possible melt immiscibility textures between two original end-member compositions. For simplicity, here two types of glass have been identified based on their color

in transmitted light: green glass (GG) and brown glass (BG) (Fig. 1). Preliminary characterization shows both types of altered glass are Mg-Fe rich, with nano-scale crystallinity and textures that are distinct from the coarser-crystalline smectite.

Carbon coated, polished thin sections were examined using a JEOL JXA-8900 L electron microprobe (EPMA). Ultra-thin sections for TEM characterization were created using focused ion beam (FIB) systems (FEI Quanta 200 3DS; Quanta 3D FEG). To protect the irradiated surface during FIB section preparation, the sample was covered with carbon and subsequently coated with a Ga ion-beam-deposited C layer. FIB sections were analyzed using a JEOL 2500SE field-emission scanning transmission electron microscope (FE-STEM). The FIB section was obtained across the red line region labeled as "1" in Fig.1. pXRD data were obtained on (unoriented) bulk, micronized glass clasts using a Panalytical X'Pert Pro MPD.

Results and Discussion: Initial TEM results show the altered glass comprises three broad categories of material: (1) a phyllosilicate component, (2) a single sheet-like component, and (3) an amorphous component that remains to be fully characterized. The green palagonite appears to be better crystallized, showing a platy texture typical of a 2:1 or possibly a 2:1:1 clay mineral, and a d(001) of ~14.3 Å (Fig. 2).

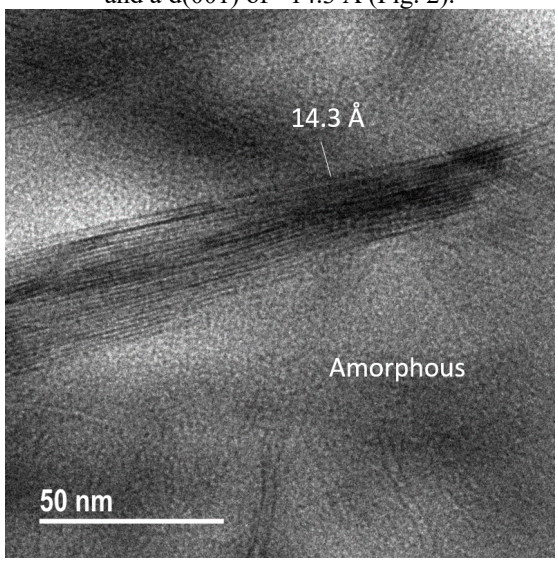

Figure 2: TEM image of hydrated green glass (Unit 2, ~658 mbsf), palagonite, showing an amorphous component and a ~14.3 Å clay mineral.

The brown palagonite, however, is texturally distinct forming a more "spongy" network of material and has a d(001) between ~4.6 to 5 Å, resembling a single layer structure. Both types of palagonite contain a significant amorphous component. Corresponding pXRD analysis of bulk (unoriented) crushed glass clasts shows a d(001) of ~14.77 Å and d(060)'s of ~1.50 and ~1.54 Å, suggesting that both a trioctahedral and dioctahedral clay mineral component is present.

Although this work is still in the early stages, these results show that the green palagonite in these samples is likely better crystallized than the brown, and can be interpreted as a smectite or possibly a chloritic clay mineral. It should be noted that previous work characterizing the Na-saturated, <0.2 μm size fraction of the same lithology in the Chicxulub peak ring also showed smectite d(001)'s of ~14.32 to 14.91 Å at 54% relative humidity (RH), which is atypical (a Na-saturated smectite should swell to ~12.5 Å in 54% RH). Those same samples also failed to collapse completely at 0% RH, a behavior attributed to weakly bound metal-hydroxylated material or possibly interlayered organics [11]. This brings to question the relationship (in particular, timing and formation conditions) among the green palagonite clay, the amorphous component and the brown palagonite single layer phase, which can be tentatively interpreted as possibly a brucite or gibbsite-like structure.

Continuing work: Continuing work will involve pXRD, TEM and EDS analysis. We will focus on determining the chemical composition and relationship of these phases to one another. We will also expand the current sample set to include other lithologies within Chicxulub as well as other terrestrial craters, representing various stages of preservation from pristine glass to highly altered, mature sediments; similar phases to those described here have been noted in impactites from the Ries crater, Germany [13]. These datasets can then be compared to those from other terrestrial environments, notably altered volcanic sediments where amorphous materials have been identified, as well as amorphous materials and phyllosilicates characterized by the CheMin instrument on the Curiosity rover in Gale Crater.

References and acknowledgements: [1] Ehlmann et al. (2012) *Space Science Reviews, 74,* 329-364. [2] Osinski et al. (2013) *Icarus*, *224*, 347-363. [3] Rampe, E. B. et al. (2020) *Geochemistry, 80*, 125605 [4] Thorpe et al. (2020) *LPSC LI, #1566*. [5] R.J. Smith & B. Horgan (2021). *JGR Planets*, *125*(5), e2020JE006769. [6] Osinski et al. (2019) *Journal of Volcanology and Geothermal Res. 353*, 25-54. [7] Morgan, J. V. et al. (2016) *Science, 354*, 878–882. [8] Gulick, S. P. S. et al. (2018) Proceedings of the IODP Vol. 364. [9] Osinski et al. (2019) *Geology, 49*, 108-112. [10] Kring et al. (2020) *Sci. Adv.* eaaz3053. [11] Simpson et al. (2022) *Chem. Geo.* 588. [12] Stroncik et al. (2002) *Intl. J. of Earth* Sci. 91. [13] Osinski (2003) *MAPS 38.* SLS is currently supported by an appointment to the NASA Postdoctoral Program at NASA Johnson Space Center.