HYPERSPECTRAL IMAGING OF DRILL CORE FROM THE STEEN RIVER IMPACT STRUCTURE: IMPLICATIONS FOR THE FORMATION OF MELT-BEARING POLYMICT IMPACT BRECCIA.

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Introduction: This study is a part of a series of projects focused on the Steen River impact structure (SRIS) in NW Alberta, Canada. The SRIS was developed in mixed target rocks, consisting of Devonian shales, carbonates, and evaporites overlying metamorphosed, crystalline rocks of the Canadian Shield. Although post-impact erosion occurred prior to burial during the Cretaceous, the SRIS maintains an elliptical raised rim, a central uplift, and a continuous, ~175 m thick sequence of crater-fill impact breccias, detected in drill core and geophysical surveys.

A model for emplacement of impact melt bearing polymict breccias at the SRIS, intersected by three continuous diamond drill cores (ST001, ST002, and ST003), has yet to be determined. There are multiple mechanisms suggested for the formation of impact melt-bearing breccias ("suevite") at other craters. This breccia type typically forms a volumetrically significant portion of the impactites in craters formed where the target includes crystalline rocks, and is observed in a range of spatial contexts within and around crater structures. The type locality of suevite is at the Ries structure, Germany, where it is subdivided into "outer suevite" and "crater suevite" [1], the latter of which is most similar to the SRIS impact breccias.

The composition of the target stratigraphy has been preserved in two main layers in the SRIS impact breccia [2, 3]. From a depth of 206 m, where the shale contacts the underlying breccia, to a depth of 242 m, the breccia is pale in colour (tan or red) with light-colored melt (pale grey or red) and a similar geochemistry to the sedimentary target materials [2]. Below 242 m, the breccia matrix is green and contains dark-colored impact melt with a composition that can be tied back to crystalline basement rock in the target sequence. Likewise, lithic clasts derived from sedimentary targets dominate in upper core units, and are effectively absent in lower breccia portions where lithic clasts are granitic [2]. The purpose of the current study is to construct detailed, hyperspectral mineralogical maps of impact breccias at the SRIS, as intersected by drill core, and to compare with other craters. The goal is to constrain the emplacement mechanism of SRIS impact breccias.

Samples and Methods: Core ST003 was collected from the edge of the SRIS central uplift and cores ST001 and ST002 from ~7 km away in the annular trough to the NNW and SSE of ST003, respectively. Two SisuRock imaging spectrometers were used to scan the impact breccia in these three SRIS cores (ST001 ~167 m, ST002 ~55 m, ST003 ~181 m) at the University of Alberta. The first scanner measures reflectance in the visible/near infrared (VNIR; Fig. 1A) and shortwave infrared (SWIR; Fig. 1B) wavelengths (400-2500 nm) and the second scanner measures thermal infrared (TIR, 8-11.5 µm; Fig. 1C). The collected reflectance data is normalized to a standard aluminum plate. The resolution of the VNIR images is ~0.2 mm/pixel. The SWIR resolution is ~0.5 mm/pixel and the TIR images are ~0.8 mm/pixel. Examples of the hyperspectral images obtained from each wavelength scan are shown in Fig. 1.

The combination of these three wavelength ranges allows identification of various silicate, carbonate, and oxide minerals; these designations are strengthened with X-ray diffraction (XRD) analyses of minerals identified as spectral endmembers. A preliminary scan of six representative boxes (total length ~10.5 m) of impact breccia from different depths in core ST003 was used to determine spectral endmembers. Homogeneous regions of these endmembers were sampled by hand, homogenized, and analyzed using XRD. Spatial subsets were made manually with ENVI software using regions of interest (ROIs) of the initial data in order to remove the cardboard box and scanner table (Fig. 1D). An endmember extraction produced 110 endmember spectra, which were grouped manually based on similar spectral features (peaks and troughs) into 13 final endmembers. These were then applied to full scans of the impact breccia in order to make a petrographic map of each core (Fig. 1E). A similar method will be employed for forthcoming processing of TIR data.

Preliminary results: Currently, only SWIR maps have been processed, and, as these do not contain the main spectral features used to identify quartz and feldspar, the results are preliminary. In the SWIR map shown in Fig. 1, orange highlights a K-Mg-Fe clay mineral that is associated with altered impact melt clasts at this depth. Green represents Na-Ca-rich minerals that dominate the matrix in the upper portion of the core. Blue pixels denote calcite, a mineral that has a very distinctive spectral peak around 2336 nm and can be identified accurately with SWIR data. Zeolite group minerals also have characteristic absorption features in this wavelength region, and have been identified in veins and vugs in these cores both petrographically and using SWIR data, although they are not present in the section of core shown in Fig. 1. The dark purple may be feldspar; this will be tested with the TIR data. Pale-purple pixels have a spectrum similar to smectite. Additional minerals identified petrographically and from microprobe data that do not appear in Fig. 1 include anhydrite, pyrite, hematite, zircon, clinopyroxene, garnet, and titanite [2, 3]. Individual, submillimeter-sized mineral grains in the breccia matrix are too small to be identified in the scanned images unless they cover a homogeneous surface area larger than the scan resolution (>1 mm). These include garnet, clinopyroxene, and other accessory minerals. Processing of the TIR data may also help identify these minerals, although the limiting factor with matrix minerals is the resolution of the scans.

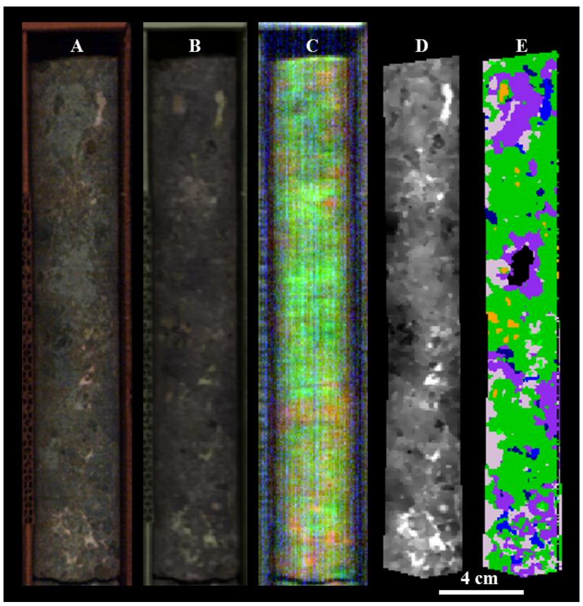

Fig. 1: A scanned section of core from ST003 at a depth of ~218 m. A) VNIR. B) SWIR. C) TIR. D) Spatial subset of (B). E) Mineral map of (D).

Discussion: Previous petrographic observations of SRIS core noted impact breccias derived from both sedimentary and crystalline target lithologies, with their pre-impact spatial relationship preserved [2, 3]. The layering is also apparent in the hyperspectral mineral maps produced in this study from scans of the three cores. Each core shows the post-impact shale overlying a Ca-Na-rich unit, which then transitions to a lower melt-rich unit with minerals that generally lack SWIR spectral features – likely quartz and feldspar. This is expected based on the impact melt compositions in core ST003; the melt in the upper 36 m of breccia is pale in color and is slightly enriched in Ca compared to the darker-colored melt in the bottom portion of the core (>242 m depth) that is enriched in Na, Mg, and Fe [2]. These SWIR maps only confirm a portion of the mineralogy, and forthcoming processing of the acquired TIR mineral maps will strengthen the interpretation of mineral variation with depth by identifying additional minerals such as quartz and feldspar. However, based on SWIR maps of all three cores, the uppermost breccia units did not mix extensively with the lower unit and, as a result, two separate compositional varieties (sedimentary overlying crystalline rock) are observed.

Conclusions: The presence of large-scale layering within the breccia and compositional similarity of impact melt clasts to the target stratigraphy at the SRIS suggests that a turbulent mechanism of emplacement could not have occurred at the scale required for whole-crater homogenization. However, the lack of a coherent impact melt sheet and the highly fragmented nature of the melt as clasts in a matrix-supported breccia seem to suggest the opposite. The layering in the pre-impact target stratigraphy is preserved in cores ST001, ST002, and ST003. This, combined with a lack of sorting implies that a fallback model from an ejecta plume cannot be invoked for the SRIS. High temperatures of deposition (> 800 ºC) and slow cooling rates [3] suggest that the crater-fill material remained heated and in place for a prolonged time after emplacement. A more representative model for the SRIS may begin with downward and outward displacement of the target during the contact / compression phase involving heating, melting, and fragmentation. The contact between the Precambrian basement and the overlying sedimentary material may have acted as a plane of weakness, allowing the sedimentary units to move laterally over the crystalline material below, rather than being compressed into and mixed with the basement material. This was likely followed by rebound of the central uplift whereby the heated and fragmented material was displaced upwards with the central uplift before flowing down and out over highly disturbed basement rocks of the crater floor. The original layering was maintained, but local turbulence and mixing similar to a pyroclastic flow caused heterogeneity in clast and melt compositions around the sedimentary / crystalline contact (~242 m depth). The breccia was deposited at temperatures >800 ºC causing the initially fine-grained matrix to undergo subsolidus recrystallization [3]. This preliminary model will be improved following forthcoming processing of the TIR maps.

References: [1] Stöffler et al. (2013) *MAPS, 48, 515-589.* [2] MacLagan E. A. et al. (submitted) *MAPS.* [3] Walton E. et al. (2017) *Geology 45(4)*, 291-294.