# INVESTIGATION OF IMPACT MELT CLASTS IN ALLOCHTHONOUS CRATER-FILL DEPOSITS OF THE STEEN RIVER IMPACT STRUCTURE.

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**Introduction:** The Steen River impact structure (SRIS) is a buried complex crater located in northwestern Alberta that is thought to have formed around 91 ± 7 Ma [1, 5]. It is slightly elliptical with a long diameter of ~25km and a shorter axis of ~19km. The center of the crater is located at 59° 31'N and 117° 38' W [2]. The structure is buried beneath ~200 m of Cretaceous marine shales, and as such, detailed work relies on geophysical surveys and cores. The first wells were drilled in the early 1960's, which led to the initial discovery of the crater due to the occurrence of pyroclastic rocks where horizontal sedimentary units of the Western Canadian Sedimentary Basin were expected.

At the time of impact, the target rocks consisted of crystalline Precambrian basement rocks overlain by a ~1 km thick sequence of sedimentary rocks, predominantly Devonian evaporates, carbonates and shales [2, 4]. The crater-fill breccia at the SRIS has been sampled by three continuous diamond drill cores. Within this core a ~127 m thick unit of polymict impact breccia containing co-genetic clasts of impact melt was intersected. The matrix of this breccia is pale green and fine grained consisting of <1 mm size grains of clinopyroxene, quartz, feldspar, impact melt particles, calcite, garnet, titanite, zircon, iron oxides, lithic clasts and secondary alteration products, mostly clay minerals [3]. The newly formed minerals in this matrix are interpreted to have formed by subsolidus recrystallization of a fine-grained super-heated clastic matrix [3]. The goal of this study was to investigate the impact melt clasts in the SRIS breccia to determine their mechanisms of formation and emplacement.

**Samples and Methods:** The three continuous drill cores (ST001, ST002 and ST003) are located at the Mineral Core Research Facility in Edmonton, Alberta. The ST003 core was logged and sampled as part of this study, from which 72 polished thin sections were prepared. These thin sections were initially investigated using a petrographic microscope. Images collected under plane polarized light were analyzed using a commercial image-analysis program, ImageJ, to create bimodal images with black pixels assigned to melt and white pixels to the surrounding material. From these, the fractional area of melt in each thin section was calculated. This type of analysis was performed on representative thin sections from each sampled depth to constrain the amount (vol% abundance) and colour of melt as a function of depth.

The major and minor element composition of impact melt clasts were measured using a JEOL 8900R electron microprobe (EMP) at the University of Alberta (UAb) with an accelerating voltage of 15 kV and a 6-10 nA beam current. Data were corrected using a PRZ correction procedure. A defocused beam (6-10 µm) was employed to minimize beam damage to sensitive glasses. Initially, spot analyses were performed on larger impact melt clasts with a further four sections analyzed at a later date to more closely compare the composition of matrix melt (arbitrarily defined as those clasts <1 mm) and impact melt halos on granitic clasts.

The CAMECA SX100 EMP at UAb was used to map the distribution of Al, Ca, Fe, K, Mg, Na, P, S, Si and Ti within one entire thin section, sampled at a depth of 950.5′ which is representative of the impact breccia throughout the sequence. Additional X-ray elemental maps (Na, K, Fe, Ca, and Si) were acquired using the JEOL 8900R EMP to investigate the composition of melt halos and their relationship to the granitic clasts with which they are associated. Two 1024 by 1024 pixel maps were made for each of four thin sections using a current of 50 nA, a 10 ms dwell time, and a 10 µm pixel size.

**Results and Discussion:** From petrographic studies of the impact melt clasts, it is found that there is no preferred orientation of the melt blebs and that they exhibit a wide range of size (~1 mm to >15 cm), colour (clear to black), shape (circular to rectangular) and enclosed clasts (quartz, feldspar, pyroxene and zircon). The normalized results from EMP analysis of 11 thin sections covering a range of depths from 688.5' (~210 m) to 1197' (~365 m) of the ST003 core are summarized in Table 1.

A comparison of the composition of the light and dark coloured melts reveals that lighter coloured melts are Ca, Na and K-enriched compared to the dark coloured melt fragments, which are enriched in Fe and Mg. Melt with an intermediate colour falls between these two compositional end members (Fig. 2).Estimates of the total volume of breccia within the SRIS, based on a simplified model of the crater structure, resulted in a total volume of breccia ~80 km$^3$. The volume % abundance of impact melt in the crater-fill breccias, measured from bimodal images, is 18.7%. Combining the breccia volume and impact melt abundance yields an estimate of ~15 km$^3$ of impact melt within the SRIS. This volume (15 km$^3$) is 2-3 times the volume found in the Ries crater [6], despite comparable diameter and target rocks.

Table 1: Normalized and corrected bulk melt composition results (wt% oxides) from EMP analysis of thin sections sampled at 688.5’ – 1197’ (209.85 – 364.85 m) depth.

| Oxide | Bulk melt | Dark Melt | Light Melt |
|---|---|---|---|
| **SiO2** | 64.50 | 63.12 | 65.77 |
| **TiO2** | 0.58 | 0.79 | 0.27 |
| **Al2O3** | 19.42 | 18.89 | 19.60 |
| **MnO** | 0.03 | 0.05 | 0.01 |
| **FeO** | 2.12 | 3.80 | 0.64 |
| **ZnO** | 0.02 | 0.02 | 0.02 |
| **MgO** | 0.45 | 0.65 | 0.17 |
| **CaO** | 1.45 | 1.30 | 1.33 |
| **Na2O** | 7.55 | 8.37 | 7.46 |
| **K2O** | 3.39 | 2.62 | 4.33 |
| **P2O5** | 0.15 | 0.17 | 0.11 |
| **SO3** | 0.09 | 0.04 | 0.05 |
| **Cl** | 0.32 | 0.25 | 0.29 |
| **O=Cl** | -0.07 | -0.06 | -0.07 |
| **Total** | 100.00 | 100.00 | 100.00 |

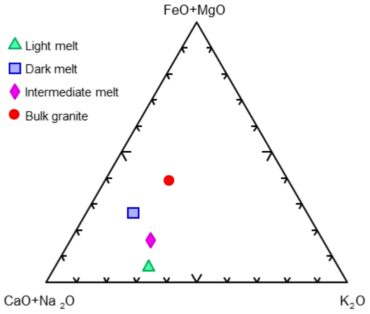

Fig. 2: Comparison of melt compositions and bulk granite composition [2, 4, 5].

Some granitic clasts located within the crater-fill breccia are enrobed in a halo of impact melt. Three types of clast-melt halo interactions are observed: 1) clasts lacking a melt halo, 2) clasts that have a melt halo completely surrounding them and 3) clasts that have a melt halo that is only partially enrobing the clast and appears to be broken off along with part of the clast. Based on the EMP results, the halos are more Na-rich adjacent to the granite clast and gradually become more K-rich away from the clast. All four sections studied showed some sort of physical incorporation into the adjacent melt. The smaller clasts within the melt halo tend to be K-rich or Na-rich with varying angularities. The grains within the larger, enrobed granitic clasts display slight zonation in three of the four sections from K-rich cores to Na-rich edges. The melt halos are weakly banded parallel to the edge of the granitic clast. (Fig. 3)

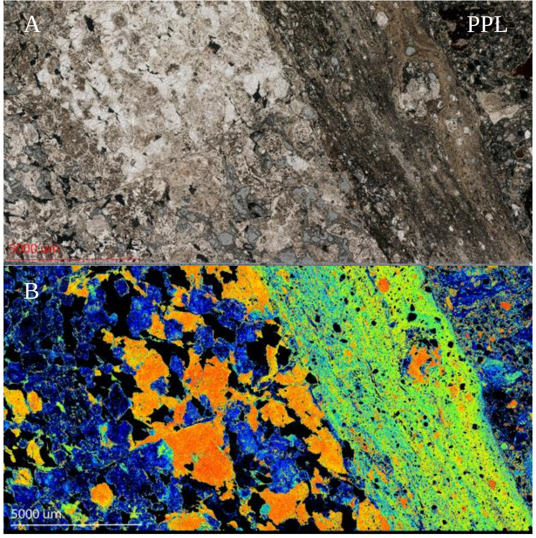

Fig. 3: A) Scan of thin section 914.5A in plane polarized light showing the “melt halo” (melt enrobing a cm-sized granitic clast, left, in polymict breccia, right). B) X-ray elemental map of K in the same thin section shown in (A).

**Conclusions:** The impact melt occurs in three main forms in the crater-fill breccias from the SRIS: matrix melt (<1 mm), melt clasts (>1 mm) and melt halos on granite clasts. The variety of colours and shapes and lack of preferred orientation implies a random deposition as opposed to cooling while airborne. The matrix clasts are likely fragments of an initial melt sheet that was disrupted by collapse of the crater or a secondary explosion, as suggested for the Ries crater [6]. The impact melt that enrobes the granitic clasts appears to be formed by the interaction of a hot matrix with clasts from the underlying basement. In this scenario, the edges of the clasts melted and were incorporated into the melt halos which may have contributed Fe and Mg from amphiboles in the granite (Table 1 & Fig. 2). The enrichment in Ca within the impact melt clasts compared to the bulk granite could be attributed to the incorporation of sedimentary units overlying basement rocks at the time of the impact. Some of these combined clast-melt fragments were then broken up after cooling, possibly during deposition or a secondary disruption.

**References:** [1] Carrigy and Short (1968) *Shock Metamorphism of Natural Materials*, pp. 367-378. [2] Molak et al. (2002) *AEUB OFR Earth Science Report 2001-04. 91p.* [3] Walton et al. (2015) *MAPS, 50, p. A376, (Abstract# 5213)* [4] McCleary (1997) *Metallic and Industrial Mineral Permits, Troymin Resources Ltd.* [5] Grieve (2006) *Impact Structures in Canada. 210p.* [6] Stöffler et al. (2013) *MAPS, 48, 515-589.*