

IMPACT MELT CLASTS FROM THE FLYNN CREEK IMPACT STRUCTURE, TENNESSEE - TEMPERATURE CONSTRAINTS FROM TITANIUM-IN-QUARTZ THERMOMETRY S. J. Jaret¹ D. T. King, Jr.², N. D. Tailby¹, M. C. Adams², and D. S. Ebel¹, ¹Department of Earth and Planetary Sciences, American Museum of Natural History, New York, New York 10024 sjaret@amnh.org, ²Department of Geosciences, Auburn University, Auburn AL 36849.

Introduction: The Flynn Creek impact structure is an ~3.8-km diameter impact structure in Jackson County, Tennessee, which formed during the Late Devonian and is situated in a very thick section of Upper Ordovician carbonate target strata of the Eastern Highland Rim physiographic subprovince [1-4]. Flynn Creek's original proof-of-impact features are shatter cones [1-2]. There are no known impact-related microstructures in quartz grains, but there is impact melt and there are impact-melt particles [5-6]. Impact melt appears to be quite limited at Flynn Creek, having only recently been identified in small cm-sized clasts in drill cores through the central uplift [5] and in graded, marine-resurge breccia deposits of the crater moat [6]. Recently, melt has been found in a sub-crater breccia zone ~ 200 m below the crater floor [7]. Another example is in drill core 77-3. Several suspected melt clasts have been found at a variety of depths between 500-600 m within an apparent breccia lens seated below the crater floor. This drill core is located between the terraced rim and the central uplift, in the north-western section of the crater moat. The clasts that have been positively identified have ranged from 0.5mm to 5 mm in size.

The melt clasts are enigmatic, and have been described as "cryptocrystalline melt" by [5]. These clasts are optically isotropic, but both micro-Raman and micro-FTIR spectroscopy indicate that these are instead crystalline quartz. These clasts are interpreted to be the result of impact melting and rapid crystallization (but not quite quenched to glass) because they do not show devitrification textures, and also have anomalously high titanium and aluminum concentrations, which would be difficult to retain during reversion or recrystallization from a glass.

Titanium-in-Quartz Barometry: Recent experimental and modeling studies of high temperature and metamorphic quartz [8-10] have shown that titanium concentration in quartz can be a robust thermobarometer. Titanium can easily substitute for silicon within the quartz lattice because titanium is also tetravalent, thereby not requiring a more complicated coupled substitution for silicon. Thus, in systems with abundant titanium (typically in rutile), the titanium activity remains fixed and the extent of this substitution will vary proportional with temperature [10]. Based on thermodynamic modeling and experiments, a temperature

calibration has been established for titanium-in-quartz, presented as TitaniQ by [10].

Methods: Aluminum, titanium, and silicon concentrations were obtained via Electron Microprobe Analysis at the American Museum of Natural History, using a Cameca SX100 electron microprobe. Analyses were done using a 15 keV accelerating voltage and a 100 nÅ beam current, following methods of [9]. Thermodynamics-based temperature calculations were done following the methods of [9-11]. A total of 26 spots on 1 thin section were analyzed.

Results: Impact melt clasts are themselves clast-rich, containing many calcite and dolomite clasts within the quartz matrix (Fig. 1).

Temperature estimations were calculated assuming surface pressures (1 bar) and activities of 0.3, 0.5, and 0.7. Calculated temperatures range from 623 °C to 950 °C. All results are shown in Table 1.

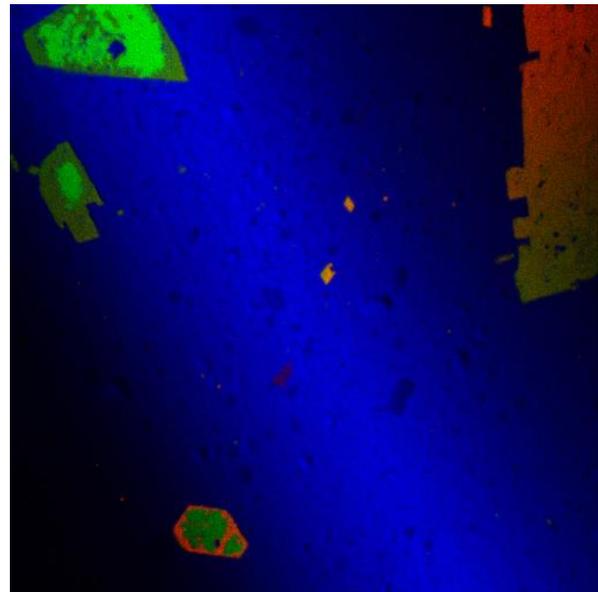


Figure 1: X-Ray elemental composite intensity map of a melt clast in the FC-77-1 drill core section. Red = Mg, Green=Ca, Blue=Si. Map area is 150 x 150 microns.

Discussion and Conclusions: The titanium concentrations provide strong evidence of a high temperature formation for these samples. Concentrations of 187-600 ppm are significantly higher than is typically

expected for either quartz precipitated within sedimentary systems or even for hydrothermal quartz. This suggests that these clasts are not derived directly from silica-rich parts of the target carbonates, but instead are products derived from impact melts.

Determining the exact formation conditions, however, is still somewhat difficult. The geothermometric calculations used here require two variables that are not easily known for Flynn Creek: pressure and titanium activity. During impact events, pressures are extremely high, but these transient pressures are not maintained for long times, and would only be achieved during the shock event. Impact melts form well after the passage of the shock wave, and therefore we assumed a pressure of 1 bar since impact melt crystallization occurred at the surface immediately post-impact. The titanium activity is harder to determine. Unlike endogenic igneous rocks, impact melts are almost certainly not in equilibrium, and so we calculated temperatures using three different titanium activities (α_{Ti}): 0.3, 0.5, and 0.7 as examples of possibilities for the α_{Ti} in this system. Using 0.7 rather than 0.3 as the activity value changes the calculated temperature by 15%. We recognize that because this system is not in equilibrium these temperatures may not represent the exact formation conditions, but are a first attempt at constraining any temperatures at Flynn Creek. Additionally, this is the first attempt at using geothermometry calculations for impact melt products.

One other consideration here must be constraining the titanium activity within the melt, which again, may differ from traditional igneous or metamorphic settings where the TitaniQ calculations were first applied. In those cases titanium activity is buffered by the presence of rutile in either the magmatic or hydrothermal setting. At Flynn Creek, that is not the case. However, titanium is still present in the system, as there are abundant titanite grains found both within the target carbonate rocks and present in the breccia deposits which contain the melt clasts.

Importantly, the temperatures presented here are crystallization temperatures for the quartz. This is therefore a minimum temperature of the impact melt itself, as quartz is one of the last minerals to crystallize from most silicate melts. The impact melt itself would have been significantly hotter, likely at or above 1,000 °C, but the exact melting temperature was not determined here. However, these values, as lower limits, are still incredibly useful as constraints on modeling efforts, such as those used by [11] in application of the iSALE hydrodynamic impact modeling code.

Table 1: Temperatures (°C) calculated for different assumed values for titanium activity (α_{Ti}) in the melt.

Analysis #	T (α_{Ti})=0.3	T (α_{Ti})=0.5	T (α_{Ti})=0.7
1	790	717	674
2	817	740	695
3	828	750	704
4	818	741	696
5	730	664	626
6	755	686	646
7	951	855	799
8	748	680	640
9	816	739	695
10	831	752	706
11	840	760	713
12	881	795	745
13	759	689	649
14	727	662	623
15	767	697	656
16	869	785	736
17	826	747	702
18	857	775	726
19	768	698	656
20	813	737	692
21	824	747	701
22	942	847	792
23	736	669	630
24	858	775	727
25	948	852	797
26	737	670	631

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