TEMPERATURE-FACILITATED PHASE TRANSFORMATIONS IN SHOCK MELT VEINS FROM THE MANICOUAGAN IMPACT STRUCTURE. R. G. Hopkins, J. G. Spray. Planetary and Space Science Centre, University of New Brunswick, 2 Bailey Drive, Fredericton, New Brunswick, E3B 5A3, Canada <rhopkins@unb.ca>

Résumé : La modélisation numérique est utilisée pour comprendre la trajectoire pression-température-temps de la formation de veines de fusion de choc dans les anorthosites de la structure d'impact de Manicouagan, Québec, Canada. La stishovite, la tissintite et la stöfflerite ont toutes été identifiées dans ou à proximité des veines de fusion de choc. Nos travaux montrent que les températures élevées introduites localement à partir des veines de fusion de choc (1850 °C) facilitent les transformations de phase des polymorphes sans avoir besoin d'excursions de pression au-delà de la pression de choc maximale.

Introduction: Within hypervelocity impact craters two distinct melt-bearing bodies can form on a localized scale via frictional heating: pseudotachylites and shock melt veins. These melt-bearing systems can share similarities, including forming planar bodies with fluidal-glassy to microcrystalline matrices, having chemical compositions derived from their wall rocks, and containing locally derived clasts suspended in their matrices. However, the two should not be conflated as pseudotachylites do not form as a product of shock wave passage (syn-shock) but rather as a product of the readjustment of the target lithology after shock wave passage (post shock). For this reason, the formation conditions of shock melt veins are more specific than those of pseudotachylites. Shock melt veins can yield high-pressure/temperature polymorphs within their matrices since they form during shock compression [1]. Shock melt veins are the primary subject of this study.

Methodology: Ten carbon-coated, polished thin sections of shock-vein bearing rock from the the Manicouagan impact structure were examined via optical microscopy and field emission scanning electron microscopy. Raman spectrometry was used to identify locations of polymorphs present within the vein systems that were identified in previous studies within the same samples [2, 3, 4, 5]. Following analysis of the sections a representative sample was chosen for numerical modelling.

Numerical modelling was performed using a function created in MathWorks MATLAB that passes a shock wave through a digitized thin section and simultaneously creates and cools the shock melt vein network via two-dimensional steady-state conduction. This function was used in previous pressure-temperature-time calculations on shock melt veins from the Vredefort impact structure [1].

Our model considers the effects of the rarefaction pressure during the cooling calculations. As a result, the shock vein cooling time will be longer than that calculated without taking the rarefaction wave into consideration. Sequentially, the shock front and rarefaction wave pass through the array. By doing so, the algorithm allows for the complete P–T–t path of shock vein formation to be tracked throughout the model runtime.

Manicouagan Impact Structure: The Manicouagan impact structure is located in Quebec, Canada. It is among the largest of the terrestrial impact structures with an apparent rim-to-rim diameter of 80-90 km (Fig. 1) [6, 7]. Manicouagan is one of three terrestrial craters in which in situ shock melt veins have been identified in a central uplift structure, along with Vredefort, South Africa [1, 8, 9, 10] and Steen River, Canada [11]. The structure is well exposed and has remained generally unaltered by post-impact tectonics, although erosion has removed the fallback breccia and the very top of the impact melt sheet [6]. It is one of the only terrestrial

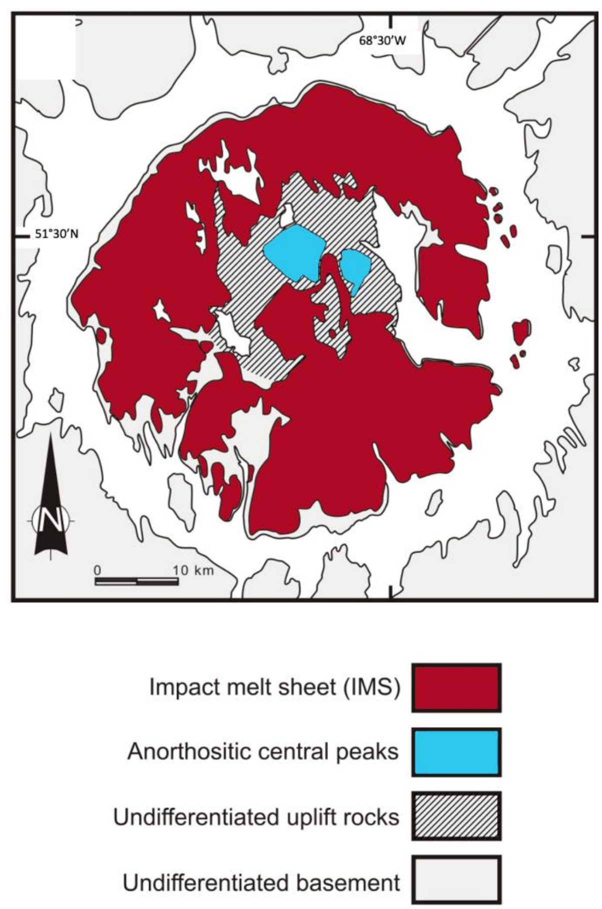

Fig. 1. *Simplified geology of the Manicouagan impact structure showing the position of the anorthositic centreal uplift (sample origin), impact melt sheet, and basement rock.*

complex impact structures that remains well exposed, reasonably accessible, and has been extensively drilled; the products of which (10 km of drill core) remain preserved and curated by the Planetary and Space Science Centre at the University of New Brunswick, Canada.

Microscopy and Spectroscopy: Shock veins appear as fluidal-textured vein systems that pervasively cross-cut the host rock. The texture of the veins varies dramatically dependant upon their thickness. In sections with an apparent width <1 mm the shock veins appear under plane polarized light as dark brown to opaque vein systems displaying signs of fluidal-glassy texture, suspended clasts, and the presence of small crystallites in, and adjacent to, the shock vein matrix. However, in some sections the shock veins are relatively wider (1-6 mm) with fluidal textures that are stratified into clear, brown, and opaque layers (under PPL). These thicker areas commonly occur at the intersection of two veins and appear to have undergone a combination of host rock melting and plastic deformation.

Three high-pressure/high-temperature polymorphs have been identified: stishovite, tissintite, and stöfflerite. Within the shock veins stishovite is present as suspended clasts with a mosaic texture. Tissintite appears lining the matrix of the veins along the inner margins. Stöfflerite is only identified immediately adjacent to (i.e., <1 mm) from the shock veins as needle-shaped crystallites growing in clusters in the outer margins.

Numerical Modelling: The shock front peak pressure was found to be 13.6 GPa at the original sample depth, which was realized within <50 ms of the shock wave arrival (signifying the beginning of shock melt vein formation). The initial temperature of the melt veins was 1850 °C (melting temperature of plagioclase at peak shock pressure) while the initial temperature of the target rock is 225 °C.

The shock vein matrix cools to the solidus (1310 °C) 623 ms after initial shock front passage. The dwell time (time above 1 GPa [12]) of the shock veins in the anorthosites at Manicouagan was determined to be 693 ms.

Discussion: The high-pressure/temperature polymorphs identified within the shock melt veins at Manicouagan are only found within the matrix or immediate outer margins of the veins; they are otherwise not present within the host rock. Given that the entire sample was subject to the same shock conditions (shock front peak pressure of 13.6 GPa and subsequent rarefaction unloading pressures) one might expect to find the polymorphs distributed throughout the entirety of the host rock. However, they are restricted to intra-vein settings. Some authors have suggested that this is due to pressure excursions beyond the peak shock pressure occurring only within the shock veins (e.g., [5]). However, pressure excursions beyond the peak shock pressure would be very short lived (<µs). Furthermore, due to the heterogeneity of the target rock and the nonuniformity of the shock front there would be no reason for these excursions to be confined specifically to shock veins and one would expect excursions to happen across the entire sample. Considering that the temperature within and adjacent host rock to the shock vein system must be elevated (due to its proximity to once-molten material identified in the vein matrices) it is more reasonable to suggest that it is temperature excursions, combined with "normal" shock pressures (i.e., not pressure excursions beyond peak shock pressures) that are facilitating these polymorph transitions.

This confinement of shock features near shock veins is also true for the presence of maskelynite within the Manicouagan samples. Plagioclase-composition glass is found both within the shock vein matrix and as an aureole around the shock vein system. The plagioclase glass within the shock veins has formed via quenching from melt as the shock veins cooled; forming the glassy texture of the matrix. The second occurrence is maskelynite (diaplectic glass), which formed via solid-state transition syn-shock. The maskelynite forms an aureole around the shock veins that transitions under cross-polarized microscopy from completely isotropic adjacent to the veins, to partially isotropic, to fully birefringent as you move further from the veins. The aureoles of maskelynite range quite dramatically in width from <1 mm to >10 mm. This variability in width likely attests to the differing angles of shock veins being viewed (i.e., not all shock veins were cut perpendicular to the plane of the thin section).

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