WAS THE VREDEFORT MELT SHEET SIMILAR COMPOSITION TO THE SUDBURY MELT SHEET?

M. S. Huber[1] and E. Kovaleva[1], [1]Department of Geology, 205 Nelson Mandela Dr., University of the Free State, Bloemfontein, South Africa, 9300. huberms@ufs.ac.za

Introduction: The Vredefort impact crater is comparable to the Sudbury impact crater in terms of the size and age of the structures [1]. The transient cavities of the two structures were nearly identical. Both of the structures targeted crystalline rocks that were overlain by volcano-sedimentary sequences and metasediments [2,3]. Because of this, the original structural characteristics were very similar to one another. However, comparing the geochemical similarities of the structures is complicated. Because the target rocks varied between the two structures, it is not clear if the compositions of the impact melt rocks of the two structures were the same. At Sudbury, the melt sheet is fairly well preserved as the Sudbury Igneous Complex (SIC). However, at Vredefort, 8-11 km of erosion have removed primary evidence of the melt sheet composition [4]. The only remnants of the melt sheet that are preserved are intrusive dykes, known as the Vredefort Granophyre Dykes. These dykes are distributed in the core and the collar of the central uplift [5]. In order to determine the similarity between the hypothetical Vredefort impact melt sheet (VIMS) and the SIC, information must be derived indirectly from these dykes. The Vredefort Granophyre dykes are thought to be derived directly from the VIMS because the geochemical signature of the impactor is preserved in the Vredefort Granophyre [6], whereas the Sudbury Offset Dykes provide a model for how such dykes can be emplaced [7].

A direct comparison of the bulk chemistry of the Vredefort Granophyre Dykes against the Sudbury Offset Dykes shows that there are some chemical similarities, but the exact relationships are unclear. It is generally thought that the Offset Dykes were not emplaced in a singular event, but in a series of events [8]. However, the emplacement history of the Granophyre Dykes is unresolved and is a matter of contention [e.g., 9]. This work tests if the Vredefort Granophyre can form from a melt sheet of SIC composition.

Methods: In order to test the idea that the Vredefort Granophyre derived from a melt sheet similar in composition to the SIC, we performed melt modeling using the Rhyolite-MELTS program [10]. The program was set to start at a temperature of 2000ºC to simulate a superheated melt, and end at a temperature below crystallization of all major phases (700ºC). The starting composition was the average SIC [11], but we also tested average upper crustal composition (UCC) [12] and estimated lower crustal composition (LCC) [13].

Results: We found that by evolving a melt of either SIC or UCC composition at atmospheric pressure conditions, we can reproduce the composition of the Vredefort Granophyre in both bulk rock and mineralogical phases. By quenching the melt at 1025ºC, we closely match the composition of the Vredefort Granophyre for all major elements except for a depletion in Mg (Granophyre = 3.6 wt. % MgO, model = 1.6 wt. % MgO) (Fig. 1). The model shows that crystallization took place from 1150ºC to 925ºC, at which point all of the melt had solidified. The most abundant mineral phases to crystallize from the melt are feldspar and orthopyroxene, consistent with the most abundant empirically observed mineral phases in granophyre. Minor amounts of clinopyroxene and spinel also crystallized in the model, consistent with the reported phase composition of granophyre [5]. The orthopyroxene and feldspar compositions generated by the model directly overlap in composition with microprobe analyses of the same phases taken from the Holfontein Granophyre Dyke (Fig. 2) [14].

Discussion: The model results clearly show that either the SIC or a combination of UCC and LCC are reasonable source material to form the Vredefort Granophyre. This shows that a reasonable estimate of the average VIMS composition is the composition of the SIC. However, this also suggests that the VIMS was completely homogenized at the time the Vredefort Granophyre was emplaced, and moreover, this is consistent with the idea that the Sudbury Offset Dykes, which are not well reproduced by the same models, were emplaced from a differentiated melt sheet. Therefore, although the Vredefort Granophyre dykes formed by essentially the same mechanisms as the Sudbury Offset Dykes, they were emplaced at an earlier stage in the melt sheet's history, i.e., before differentiation of the Vredefort Melt Sheet took place.

The timeline of emplacement of these dykes can, therefore, be partly constrained. The emplacement processes that led to the Vredefort Granophyre Dykes and Sudbury Offset Dykes were occurring over the entire period of time that differentiation of the homogenized melt sheet was taking place. Emplacement of the granophyre dykes must have been occurring soon after the impact, at a time when the melt sheet was homogenized. Recent geophysical work has shown that at least some of the Vredefort Granophyre dykes represent the lowermost terminations of those dykes [15]. Additional work has shown that lithic clasts bearing impact-generated pseudotachylites were entrained within the Granophyre, demonstrating that the emplacement process occurred after the first pseudotachylites were formed [16].

Conclusions: This work shows that the SIC and VIMS had similar geochemical composition. Emplacement of Vredefort Granophyre Dykes occurred before differentiation of the VIMS took place. Thus, we have constraints on the stages when the Granophyre dyke emplacement occurred. We suggest that the large-scale fractures in the crater floor were forming in a very short period of time after the impact itself.

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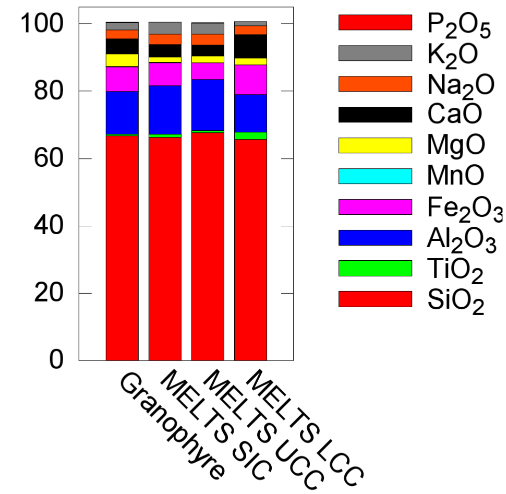

Fig. 1: MELTS model results. Input data for SIC from [11], UCC from [12], LCC from [13]. Granophyre composition determined by XRF analysis.

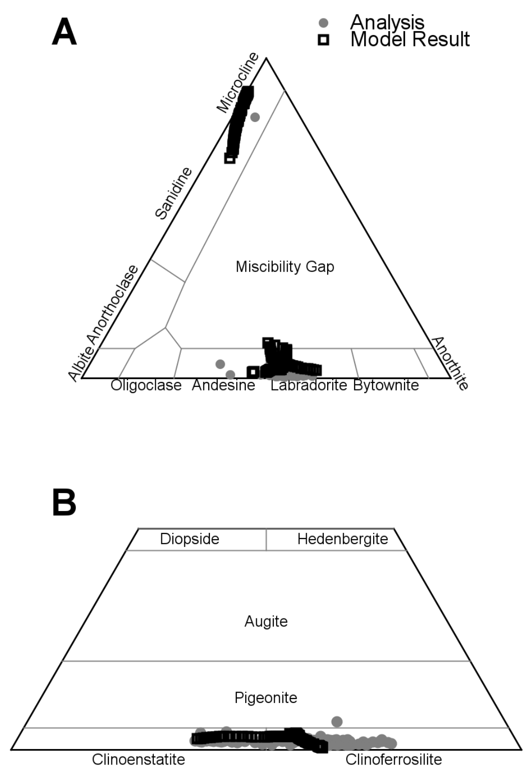

Fig 2: Mineral compositions by microprobe analysis and model result are very similar. Microprobe data from [14].