COMPLEX POST-IMPACT EVOLUTION OF IMPACT MELT AT THE VREDEFORT IMPACT CRATER. M. S. Huber[1], E. Kovaleva[1,2] and M. Syczewski[2], [1]Department of Earth Sciences, University of the Western Cape, Bellville, South Africa; mhuber@uwc.ac.za, [2] Helmholtz Centre Potsdam, GFZ Research Centre for Geosciences, 14471 Potsdam, Telegrafenberg, Brandenburg, Germany.

Introduction: Impact melts are generated during the process of hypervelocity impact events. In the case of sufficiently large events, a voluminous melt sheet covers a newly formed crater floor, undergoing a prolonged cooling and crystallization history. For the largest impact craters, thermal activity can last up to 1 Myr [e.g., 1]. In case of the Sudbury and Vredefort impact structures, impact melt migrated into the crust below the melt sheet, forming intrusive bodies that are preserved as the Offset Dikes and the Granophyre Dikes, respectively [2]. The evolution and emplacement conditions of these dikes are not well understood.

The Sudbury Offset Dikes are complicated to study due to geochemical alteration due to economic mineralization and widespread hydrothermal overprinting of the mineralogy [3]; however, the Vredefort Granophyre Dikes are generally considered to be crystalline remnants of a dry primary impact melt [4]. Recent work has shown that the Granophyre Dikes include two phases, with a dacitic outer phase and an andesitic inner phase, which have been ascribed to either preferential assimilation [5] or multiple stages of emplacement of the dikes [6]. Despite the excellent preservation of the Granophyre Dikes, there has been little published work detailing the petrography of the dikes, especially the andesitic phase. In this study, we have examined both the dacitic and andesitic phases of the Granophyre Dikes with high-resolution field emission scanning electron microscopy, and have observed previously unreported relationships between the major and trace phases that reveal the complex evolutionary history of the impact melt.

Methods: Samples of the dacitic Lesutoskraal Granophyre Dike in the core of the central uplift of the Vredefort structure, and the andesitic portion of the Rensburgsdrift Granophyre Dike along the core-collar boundary were sampled. Polished thin sections were made at the University of the Western Cape in South Africa. Polished thin sections were analyzed at the Potsdam Imaging and Spectral Analysis (PISA) Facility at Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences. The SEM-EDS measurements and mapping were done using the FEI Quanta 3D microscope coupled with the EDAX Octane ELECT PLUS EDS detector.

Results: The high-resolution SEM images and chemical maps show the paragenetic sequence of crystallization. In both the Lesutoskraal and Rensburgsdrift samples, the order of crystallization of the major phases is as follows: 1. orthopyroxene; 2. plagioclase; 3. clinopyroxene; 4. biotite; 5. alkali feldspar and quartz. The orthopyroxene crystals are subhedral to euhedral, 50-100 μm in diameter (Fig. 1). Although skeletal habit is not observed, there are many crystals with resorption textures. In the Lesutoskraal samples, acicular orthopyroxene crystals are more common than in Rensburgsdrift. In one case, a plastically-deformed elongate orthopyroxene crystal was observed in the Lesutoskraal sample.

In both Lesutoskraal and Rensburgsdrift samples, the clinopyroxene rims surround the orthopyroxene crystals (Fig. 1). The clinopyroxene phases are minor at Lesutoskraal, but develop significant thickness in the Rensburgsdrift samples (up to 50 μm). Biotite overgrowths are found surrounding the clinopyroxene rims in samples from both sites. Plagioclase crystals likely formed simultaneously with the initial orthopyroxene (Fig. 1D).

The last stage of crystallization features simultaneous formation and intergrowth of quartz and feldspar (i.e., granophyric groundmass). Additionally, the plagioclase is frequently observed to be partially resorbed and interfingering with the alkali feldspar. Spherulitic textured quartz-feldspar intergrowths commonly have plagioclase crystals at the center of the spherulite (Fig. 2). Although the granophyric intergrowth occurs in both sets of samples, it constitutes a higher volume of the groundmass within the Lesutoskraal samples.

Accessory phases of magnetite and ilmenite are present in both sets of samples. Skeletal intergrowths of the two phases with up to 400 μm in length are observed in the Rensburgsdrift samples. In the Lesutoskraal samples, magnetite-ilmenite intergrowths are only observed up to 50 μm in diameter. Accessory chromite crystals < 10 μm in diameter are found within orthopyroxene crystals in samples from both sites, but are not observed in the groundmass. Limited amphibole rims are observed around clinopyroxene, likely representing uralitization of the pyroxene. Needles of rutile are present in the groundmass of both sets of samples. Strings of skeletal apatite crystals with individual crystal diameters of < 10 μm are found in the groundmass of both sets of samples. The rutile and apatite crystals formed prior to development of the granophyric intergrowth of feldspar and quartz.

A final stage of mineralogical evolution is observed in both sets of samples that includes extensive rare earth element (REE) mineralization. Phases of Si-Ti-REE and Ce-silicates were observed overgrowing the earlier phases.

Discussion: The Vredefort Granophyre is a unique example of impact melt that formed during one of the Earth's largest recorded impact events and crystallized deep below the surface. By examining the paragenetic relationships between the minerals within the impact melt, the processes that were occurring in this early post-impact environment are revealed.

The temperature of impact melt has been a matter of debate, with some evidence for peak temperatures >2400°C [7], and high temperature variability [8]. In the case of the Vredefort Granophyre, the large euhedral orthopyroxene crystals indicate that the melt was fully above the liquidus temperature (i.e., not a crystal mush). The orthopyroxenes appear to have crystallized relatively slowly, preventing the formation of skeletal crystals. The resorption textures and overgrowth rims indicate that the crystallization conditions changed, but the melt did not quench. The skeletal magnetite-ilmenite intergrowths, skeletal apatite crystals, and simultaneous crystallization of quartz and feldspar indicate that the final stages of crystallization of the melt were rapid. The presence of REE-phases indicates that a late-stage hydrothermal system was active.

Therefore, we distinguish at least four stages of development of the Vredefort Granophyre: 1. slow cooling of liquid, allowing orthopyroxene to form; 2. change in chemical conditions, allowing resorption of orthopyroxene and formation of clinopyroxene and biotite rims; 3. quenching of the system, forming granophyric groundmass; 4. post-crystallization hydrothermal activity. These stages appear to have been active at both the Lesutoskraal and Rensburgsdrift sites, but the Rensburgsdrift site had a more mafic bulk composition, allowing for a greater amount of pyroxene to form and a much lower amount of felsic groundmass to develop.

The Rensburgsdrift Granophrye Dike was previously proposed to have formed as a result of assimilation of a mafic precursor phase [5]; however, the identical texture and crystallization sequence of the mafic components of the Lesutoskraal and Rensburgsdrift dikes shows that the interpretation is unlikely to be accurate. It is more probable that the impact melt experienced a multi-stage emplacement from the melt sheet, driven by post-impact crustal relaxation following the impact event [6].

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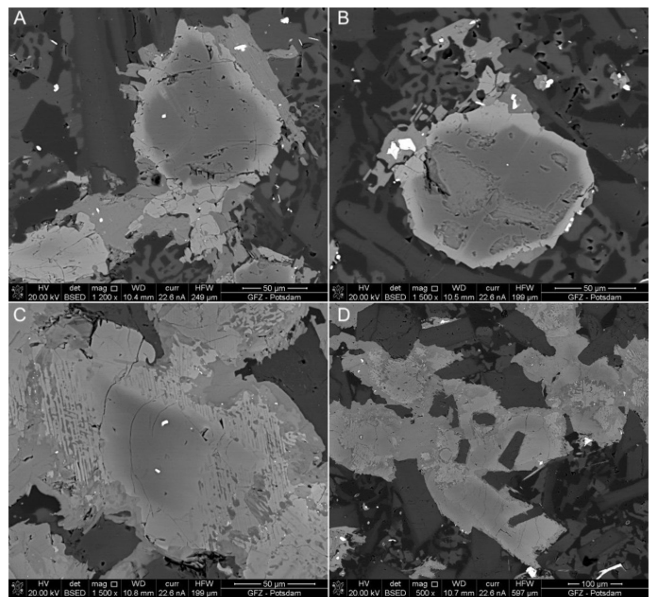

Figure 1: Orthopyroxenes with clinopyroxene rims. Bright minerals within the OPX grains are chromites. Note the overgrowth of plagioclase by clinopyroxene in D. A-B. Lesutoskraal. C-D. Rensburgsdrift.

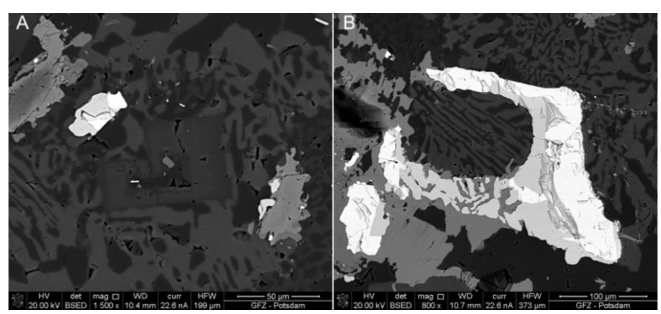

Figure 2: A. Granophyric groundmass of quartz-alkali feldspar surrounding plagioclase feldspar. Small ilmenite-magnetite intergrowth crystal is present as bright phase in top left. B. Skeletal ilmenite-magnetite intergrowth with granophyric intergrowth of quartz and feldspar.