INFERRING THE EMPLACEMENT HISTORY OF VREDEFORT IMPACT MELT DYKES.

M. S. Huber[1], E. Kovaleva[1], M. Clark[1] and F. Fourie[2], [1]Department of Geology, University of the Free State, 205 Nelson Mandela Drive, 9300 Bloemfontein, South Africa, huberms@ufs.ac.za, [2]Institute for Groundwater Studies, University of the Free State, 205 Nelson Mandela Drive, 9300 Bloemfontein, South Africa.

Introduction: During basin-forming impact events, melted target rocks are preserved in the geological record as sheets, dykes and irregular bodies at the surface and at depth [1]. Impact melt dykes at the deeply eroded, 2.02 Ga Vredefort impact structure, referred to as "granophyre dykes", have previously been shown to have formed later than shock-related *in situ* melt (pseudotachylites) [1,2,3,4], to contain clasts of shocked target rocks [4,5], and to have a Re-Os signature indicative of a meteoritic component [6]. Based on these lines of evidence, the granophyre dykes represent remnants of the impact melt sheet that propagated downward along fractures in the basement rocks during the latest stages of post-impact modification [6,7,8,9]. The nature, mechanisms and timing of the event(s) that led to melt emplacement remain contentious.

Here, we examine granophyre dykes through geophysics, geochemistry, and petrography, as well as field relationships. Based on these data, we constrain the timing of the emplacement of granophyre dykes and possible post-emplacement deformation, with implications for the development of large impact basins on Earth, the Moon, and other rocky bodies of the solar system.

Methods: Four granophyre dykes, namely the Kopjeskraal dyke, located at the boundary between the granitic core and the metasedimentary collar of the Vredefort structure (the "core-collar boundary"), as well as the Daskop, Lesutoskraal and Holfontein North and South dykes, representing four of the total five exposed granophyre dykes in the granitic core of the structure, were investigated by electrical resistivity tomography (ERT), a non-destructive geophysical method described in [8]. Samples from these dykes were analyzed with X-ray fluorescence for bulk chemical composition, according to the methodology described in [9].

Results: *Geophysical data.* The resistivity models obtained from the ERT data for all dykes are shown in Figure 1. The resistivity of the granophyre dykes (>2000 Ωm) is significantly higher than of the host crystalline rocks, which have resistivities <1000 Ωm. The resistivity variation in the host rock is consistent with the expected compositional variation, i.e., granite to dolerite [8].

At the Kopjeskraal granophyre dyke, the highly resistive zone extends past the lowermost depth of the profile (>50 m), so that the terminus of this dyke at depth has not been determined (Fig. 1A). The core dykes, however, are distinct from the collar dyke (Fig. 1B-D). The geophysical signature of the Holfontein granophyre dyke terminates at ~5 m below the surface (Fig. 1B), and the geophysical signatures of the Daskop and Lesutoskraal granophyre dykes terminate 3 m below the surface (Fig. 1C-D).

Geochemical and petrographic data. The geochemical compositions of the core dykes are generally dacitic, in the compositional range of ~64-72 wt.% SiO_2 and 4-6 wt.% Na_2O+K_2O, in agreement with previous workers [9,10,11,12]. Petrographically, the dykes are composed of intergrowths of feldspar and orthopyroxene that are fine crystalline or spherulitic.

Unlike the core dykes, the Kopjeskraal granophyre dyke is composed of two distinct textural and geochemical phases, the Kopjeskraal granophyre A (KGA) and Kopjeskraal granophyre B (KGB). The KGA contains abundant clasts of the granite that may be locally derived. Geochemically and petrographically, the KGA is indistinguishable from the core dykes. The KGB domain is located approximately 3 m from the contact between the KGA and host granite, and strikes parallel to the strike of the dyke. The KGB is finer-grained and darker-colored than the KGA. Rounded clasts of the KGA are included within the KGB. The KGB is compositionally more mafic than any previously measured granophyre samples.

Discussion: The geophysical results demonstrate that the core dykes do not penetrate deep into the subsurface. As the same field procedures and data processing were applied to the Kopjeskraal dyke and the core dykes, but with different results, it is unlikely that the shallow penetration depths found for the core dykes are due to methodological errors. Additionally, the disappearance with depth of the high resistivity zones associated with the core dykes is unlikely to be the result of a shallow water table, as the presence of groundwater would cause a comparable decrease in the resistivity of the host rocks, which is not observed. In contrast, in some profiles increased resistivity in host rocks is documented below the dyke termination.

The shallow penetration depth of the core dykes may either be interpreted as the lowermost penetration depth of the dykes [8], or as a representation that the dykes have experienced post-emplacement faulting, offsetting the dykes either laterally or vertically. As the dykes were emplaced in the late stages of development of the impact basin [8], the difference in dyke preservation suggests that the central part of the impact structure experienced distinct post-shock processes compared to the core-collar boundary.

By contrast, the geochemical compositions of the core dykes and KGA are indistinguishable, suggesting that they were derived from the same melt source and experienced the same geochemical evolution. The KGB was clearly emplaced later, after the KGA had solidified, and as a result the KGB has a significantly different geochemical composition. Thus, the granophyre emplacement process must have occurred in a minimum of two discrete phases over an extended timeframe, allowing time for the melt to differentiate [13]. It is not clear if the more mafic composition was only present at the core-collar boundary, or if it was also present in the core of the structure, as the mafic composition has not been found in the core of the structure.

We infer that the following series of events must have taken place: 1) Shock melting of rocks at the surface generated the melt sheet that would later serve as a source of the granophyre melt. 2) After the formation of the impact basin, the core dykes and KGA intruded into the crust. Although we do not know the timescale in which this took place, it had to occur while the melt sheet was still molten, i.e., within ca 10^4 years [13]. 3) After the KGA had already crystallized, the KGB intruded. The compositional difference between the KGA and KGB suggests that the source of the melt had a different composition, which may have been caused by differentiation of the melt sheet. 4) Uplift of the core of the impact basin resulted in distinct preservation of the core and collar dykes.

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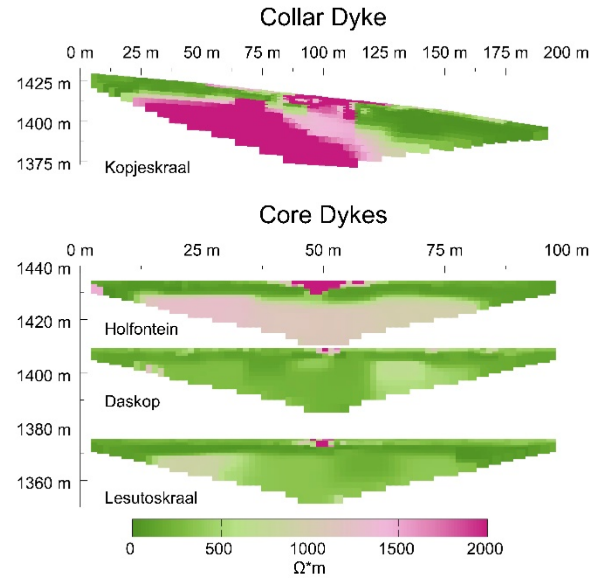

Fig. 1: Resistivity profiles of the granophyre dykes examined in this study, with elevation indicated. Highly resistive material (interpreted as granophyre) is shown in pink and the host rocks are shown in green.

References: [1] Dence M. R. (1971) *J. Geophys. Res.*, 76, 5552-5565. [2] Bisschoff A. A. (1988) *S. Afr. J. Sci.*, 84, 413-417. [3] Dietz R. S. (1961) *J. Geol.*, 69, 499-516. [4] Kovaleva E. et al. (2019) *Geology*, 47, 691-694. [5] Buchanan P. C. and Reimold W. U. (2002) *Meteoritics & Planet. Sci.*, 37, 807-822. [6] Koeberl C. et al. (1996) *Geology*, 24, 913-916. [7] French B. M. et al. (1989) LPS XIX, 733-744. [8] Fourie F. D. et al. (2019) *Meteoritics & Planet. Sci.*, 54, 1579-1593. [9] Kovaleva E. et al. (2018) *S. Afr. J. Geol.*, 121, 383-402. [10] French B. and Nielsen R. (1990) *Tectonophysics*, 171, 119-138. [11] Therriault A. et al. (1997) *S. Afr. J. Geol.*, 100, 115-122. [12] Lieger D. and Riller U. (2012) *Icarus*, 219, 168-180. [13] Zeig M. and Marsh B. (2005) *Geol. Soc. Am. Bull.*, 117, 1427-1450.