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On the depth of crater excavation and melting during the Sudbury impact: geochemical evidence from chilled impact melt dykes

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The 1.85 Ga Sudbury Igneous Complex, Canada, is the remnant of a ~3 km thick impact-generated crustal melt sheet, caused by a 10-15 km large chondritic asteroid or comet that had left behind an impact structure of ~200 km prior to tectonic deformation und subsequent erosion. However, less is known about how deep the impactor penetrated the continental crust and where the source of the impact melt was. Mixing models including radioisotopes and trace elements on locally exposed country rocks have been used to evaluate their relative contribution to the impact melt. Based on this, Darling et al. (2010) have argued for shallow melting of the upper crust (UCC) only, either due to an oblique impact and/or a low-density bolide (comet). In contrast, the abundance of siderophile elements in impact melt-rocks was taken as evidence of a lower crustal source (Mungall et al. 2004), i.e. overlying rocks of the middle and upper crust must have been removed during the crater excavation stage. U-Pb age data on zircon xenocrysts also point to the involvement of rock types not exposed on surface (Petrus et al. 2016) in agreement with theoretical simulations, which have predicted a >20 km deep but unstable transient cavity (Ivanov & Deutsch 1999).

Large-scale (10s of km) and well-exposed impact melt dykes are a unique feature of Sudbury. The dykes are of granodioritic/quartz dioritic composition and are interpreted as clast-laden melt injections into the basement instantaneously after the impact (Pilles et al. 2018). Their vitric margins and distal extremities should therefore approximate the undifferentiated bulk composition of the Sudbury Igneous Complex prior to sulfide saturation. A compilation of published and new geochemical data of these dykes reveal a remarkably strong affinity (r^2 >0.989) to the average middle continental crust (MCC) as given by Rudnick & Gao (2014), especially in terms of major elements and fluid-immobile transition metals (Th, Zr, Hf, Nb, Ta, Ti, Sc, REE). The dykes are, however, significantly enriched in Ni, Cu and Cr, and to a lesser extent in V, Co and P relative to the typical UCC and MCC. A systematic loss of volatiles (Tl, Cd, Sn, Zn, Pb, Ag, Cs, Rb, Na, K, Ga, As) compared to either crustal model is not evident. These new observations favour a scenario in which the impactor and supracrustal rocks in the target area became vaporized and ejected. Shock melting affected predominantly the middle crust of the Canadian Shield. We also propose that the rocks that contributed to the impact melt were, on average, more mafic than the typical UCC and MCC. This is consistent with the report of exotic mafic-ultramafic xenoliths within

the Sudbury Igneous Complex (Wang et al. 2018) and its anomalously high PGE concentrations (Mungall et al. 2004). (Ultra-)mafic rocks hidden at mid-crustal depth were a likely source of Ni-Cu-PGE-Co and gave rise to world class ore deposits presently mined at Sudbury. Such (ultra-)mafic intrabasement body might also explain the 1200 km^2 Temagami magnetic anomaly in the eastern vicinity of the Sudbury Complex.