**Impact Induced Crustal Differentiation: New Insights from the Sudbury Structure.**

J.R. Darling[1] and D.E. Moser[1], [1]University of Western Ontario, Department of Earth Sciences, 1151 Richmond Street N., London, ON, N6A 5B7, Canada. Email: jdarli5@uwo.ca

**Summary:** Impact melt sheets may be efficient mechanisms of crustal differentiation. Modelling predictions suggest that large volumes of silica rich crust were produced during early bombardment of inner Solar System bodies [1]. However, there has been debate over whether such differentiation is observed in the most intensively studied large impact structure on Earth. The originally ~250 km in diameter [2] Sudbury structure in Ontario, Canada, preserves a range of contemporaneous 1.85 Ga [3] igneous rock types collectively termed the Sudbury Igneous Complex (SIC). The SIC may represent a differentiated impact melt sheet several km in thickness. However, there has been significant debate over its origins, and to what extent it is comprised of impact melted target rocks.

The hafnium isotope composition of the mineral zircon offers a sensitive tracer of melt sources, and is highly resilient to post-impact metamorphism. Analysis of zircons throughout a transect of the SIC shows that all igneous units share a common crustal source. This indicates the entire SIC is derived from impact melting of locally exposed target rocks, with no significant mantle derived component. Together with the extensive available database of geochemical analyses of SIC lithologies, this allows for new insights into the effects of melt sheet formation on the composition and structure of planetary crusts.

**A Differentiated Impact Melt Sheet?** The SIC is comprised of a range of igneous units: the 2-5 km thick *Main Mass*, which is divided into a mafic Lower Unit of quartz monzogabbro, a Middle Unit of oxide- and apatite-rich quartz gabbro, and an Upper Unit of granophyres; the *Sublayer*, a discontinous sulphide- and inclusion-rich noritic unit that occurs at the Main Mass - footwall contact; quartz diorites of the radial and concentric *Offset Dykes*, which protrude from the Main Mass into the Footwall. At issue is whether the all units of the SIC share a common impact melting origin. There are currently three hypotheses regarding the origin of compositional layering in the Main Mass: (a) the Upper and Lower Units were derived from two different parent magmas, with the mafic portion originating from crustally contaminated basaltic magma derived from the mantle, and the upper granitic portion representing impact melt [4,5,6]; (b) the units are the result of differentiation of a single impact melt sheet of granodioritic composition [7,8,9] (c) the impact produced an emulsion or 'melt breccia' that underwent density segregation to form the two units [10].

**Samples:** Zircons were separated from 2 Sublayer, 5 Lower Unit and 3 Upper Unit samples, along a transect of the southern exposed limb of the melt sheet previously studied by [11]. Quartz diorites from three Offset Dykes, representing an early melt phase injected into the crater floor [12] were also analyzed. The zircons from all samples are generally equant, with long axes <300 μm, and display oscillatory zonation of varying complexity. No evidence of xenocrystic zircon is present in the traverse [11].

**Hafnium Isotope Stratigraphy:** Laser Ablation ICPMS analyses were undertaken at the University of Bristol, UK. The Main Mass and Offset Dyke samples define a narrow range of $\varepsilon Hf_{1850}$ values be (-10 to -12), with mean values that are within uncertainty (< 0.8 epsilon units, 2σ). More positive $\varepsilon Hf_{1850}$ values for the Sublayer are consistent with assimilation of local mafic target rocks, as proposed in previous studies [13].

The results demonstrate that all igneous units of the SIC share a common origin, and the highly negative $\varepsilon Hf_{1850}$ values indicate that the melts were derived from older crustal rocks (the depleted mantle at 1850 Ma has εHf of +10.5). Hafnium model ages, calculated

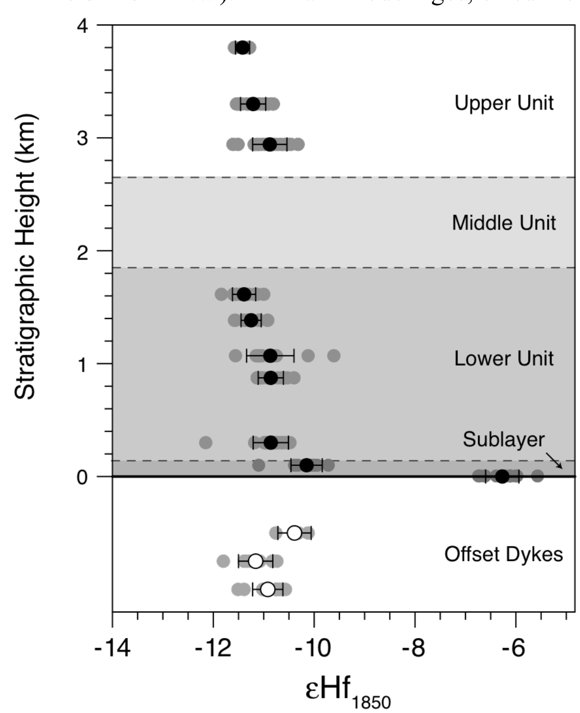


**Figure 1: Stratigraphic variations in $\varepsilon Hf_{1850}$ throughout the Sudbury Igneous Complex.** Individual analyses are shown in grey, with sample means (± 1σ) in black. Offset Dykes shown at arbitrary heights below the base of the main mass. $\varepsilon Hf_{1850} = [(^{176}Hf/^{177}Hf)_{sample}/(^{176}Hf/^{177}Hf)_{CHUR} - 1]*10^4$.

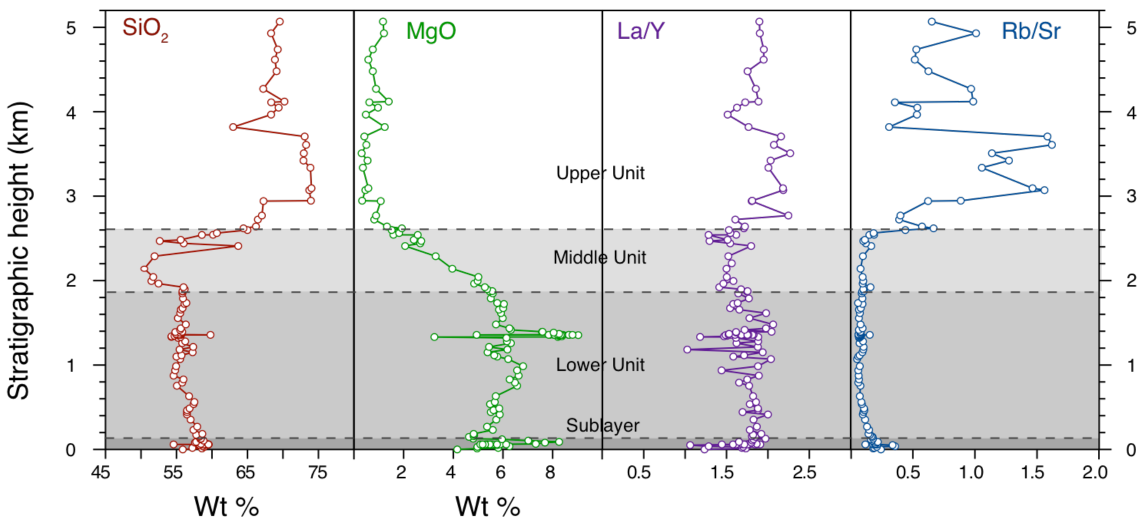


**Figure 2: Geochemical variations throughout the studied traverse of the Sudbury impact melt sheet.** Data from [14].

using the mean $^{176}Lu/^{177}Hf$ ratio of Offset Dyke quartz diorites (0.0122; n = 192) are 2.9 to 3.1 Ga, consistent with a source dominated by Superior Province gneisses and sediments derived from them (the Huronian Supergroup).

**Melt sheet differentiation:** The hafnium isotope data are consistent with a single impact melting origin for the SIC. Several studies have shown that the compositional layering of the SIC can be explained by magmatic differentiation of a single magma of granodioritic composition [7, 8, 9, 15], similar to that of the Offset Dyke quartz diorites [12,14]. Therefore, the Main Mass of the SIC is interpreted to represent a differentiated impact melt sheet.

Geochemical variations throughout the melt sheet offer insights into the effects of crustal melting by impact events. Firtsly, it is clear from lateral geochemical variations in the melt sheet that pre-existing crustal reservoirs are not completely homogenized [e.g. 16, 17]. Differentiation of the melt sheet is apparently very efficient, with an anomolously large volume of silica rich granophyre generated in comparison with other layered igneous complexes (Figure 2). This may be due to the initial superheated and crystal free conditions of the melt [10].

An important observation is that melt sheet differentiation will have significant effects on geochemical records of crustal growth and differentiation (e.g. Sm-Nd, Lu-Hf and Rb-Sr isotopes). Incompatible element ratios (e.g. La/Y, Lu/Hf, Sm/Nd) are near constant throughout the stratigraphy, whereas ratios involving more compatible elements vary greatly (e.g. Rb-Sr). As such, crustal growth curves based upon the Sm-Nd and Lu-Hf isotope systems may not be sensitive to crustal reprocessing by impact events, unless there is significant crust-mantle re-mixing. In contrast, isotopic systems such as Rb-Sr and K-Ca are likely to be very sensitive tracers of such proceeses.

**Conclusions:**

- The entire SIC is derived from impact melting of target lithologies similar to those that are locally exposed.
- Magmatic differentiation of a granodioritic impact melt sheet explains the compositional layering of the Main Mass.
- Impact melt sheets are efficient mechanisms of crustal differentiation.


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