GEOPHYSICAL SIGNATURE OF THE FOOTWALL OF LARGE METEORITE IMPACT CRATERS.

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Background and Motivation: Through the integration of remote sensing, potential field and seismic data, exploration drilling and numerical modeling, we can constrain the size, shape and morphology of most terrestrial impact craters. New petrophysical and potential field data from the mid-to small sized Wanapitei, Bosumtwi and Monturaqui structures, as well as seismic data from Chicxulub, Ries, Sudbury and Bosumtwi demonstrate the common geophysical signatures of impacts: pronounced gravity lows, prominent magnetic anomalies and the lack of prominent reflections in the footwall of the craters. Here we investigate strain distribution in the footwall as predicted by impact modeling studies, the cooling history of the footwall and heterogeneities in the footwall as "seen" by seismic and remote sensing data.

Review of Seismic Data: Target rocks are subjected to high pressure and temperature conditions during impact, resulting in fracturing, stress-induced shearing and mixing of materials. There is typically an exponential decay in both porosity and fracture density as radial distance from the crater center increases. Fracture porosity will enhance the first-order gravity low associated with impact structures, and serve to reduce seismic parameters in the second order (velocities and densities) by increasing total porosity out to a limit where impact damage is negligible [1], [2]. In seismic profiles, areas of high brecciation appear transparent; footwall and basement structures in particular show no traceable horizons despite the sometimes large vertical contrasts observed in petrophysical logs. Analysis of physical property logs indicate that these structures have small scale lengths that describe the high degree of mixing and heterogeneity, resulting in only small amounts of seismic scattering. As a consequence of this mixing, pre-impact lithologies are typically disrupted in the vicinity of impact structures, giving rise to characteristic seismic profiles such as those over the Ries, Sudbury and Chicxulub impact structures.

Strain in the Footwall: The 200-km diameter Sudbury crater with its at least 60-km diameter melt pool was formed (compression, excavation, and modification stages) within the first 10 minutes after the impact [5], [6]. All slopes within the final crater (crater rim, peak ring) are usually less than 6-10°. This kind of slopes makes improbable further crater modification by slumping (on a large scale, while small-scale adjustment due to crater cooling and rocks' compaction is still possible). Although "visible" crater is extremely shallow, rocks beneath the floor are severely shocked (up to melting) and brecciated; radial and concentric faults propagate tens of km away from the crater (faults growing downrange are suppressed by lithostatic pressure). Temperatures at the crater floor are close to melting temperature with standard geothermal gradient at the depth of 50 km in the crater center and at the depth of 10 km near the melt pool periphery.

Melt pool differentiation and cooling: Current modeled estimates of shock melting in Sudbury vary in the range from 12, 000 km^3 [6] to 24, 000 km^3 [7] with the melt pool thickness of 3-6 km. This subsequently differentiated into the Sudbury Igneous Complex (SIC). Reconstruction of the original geometry of the structure [8] yields an estimate for the initial melt sheet thickness of at least 2.5 km with a diameter of about 60 km, and total melt volume of $(1–2.5)\times10^4$ km^3. A good correlation between models and observations is partially due to the fact that geologists estimate impact melt, i.e. shock melt plus digested rocks, while modelers estimate shock melt – rocks compressed above given pressure threshold. While part of shock melt is ejected from the crater, some rocks are additionally melted by heat conduction.

According to Zieg and Marsh [9], immediately after the impact, the SIC melt is a viscous polycompositional magma – the result of shock melting of different lithologies within the target down to the mantle. Because of different viscosities, this magma was an emulsion composed of chemically immiscible liquids (as oil and water). For reference, at 1700 ^{o}C, granophyre melt is 10-15 times more viscous than norite melt. Within a few years, this emulsion is separated into two layers: denser mafic layer at the bottom (future norite) and lighter felsic layer at the top (future granophyre). Then convection (and hence – quick mixing and cooling) is established within each layer. It ceases when temperature reaches liquidus, i.e. in 10,000 years. After that, slow conductive cooling and solidification continues for at least the next 100,000 years

The new 2D cooling model allows for more accurate definition of temperature evolution in the regions with substantial radial T-gradient (i.e. near the edges of melt pool, near the peak-ring, etc). We started with "artificial" temperature distribution correlated with realistic one, i.e. we had 1) two-layered melt pool at liquidus T; 2) preheated rocks at the central uplift (beneath the melt pool) with standard temperature at a depth of 50 km and 3) strong temperature gradient with standard temperature at the depth of 0-10 km outside the melt pool. We also varied the granophyre/norite thickness ratio from 1:1 through 3:1 to 7:1 keeping the total SIC thickness at 4 km, i.e. norite layer thickness changed from 2 km to 0.5 km – see Fig.1.

Irrespective of the G/N thickness ratio (and similar to 1D model), the hottest part of the SIC is near the crater center at the melt pool bottom and within the footwalls. Although the norite layer solidified prior to the SIC total solidification, its temperature is high enough (above 1000 K) to allow precipitation of sulphides to the footwall.

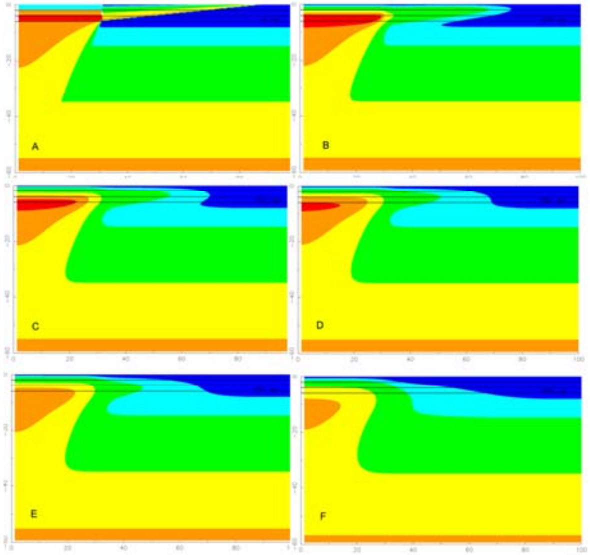

Fig. 1 *Cooling of 4-km thick SIC with G/N ratio of 1:1 (both, granophyre and norite have the same thickness of 2 km). Colors are as follows: red 1200-1500K; orange 1100-1200K; yellow 800-1100K; green 500-800K; cyan 400-500K, blue < 400K. Solidification of norite takes 350 kyr (plate D), but at this time partial melt still exists in footwalls. Total solidification (plate F) occurs after 950 kyr.*

Digital Elevation Models:

A 20 m resolution digital elevation model was collected over the entire Sudbury basin. The dataset was derived from 1;20,000 maps over the province of Ontario, Canada [10]. The data was displayed with different illumination angles to facilitate the discrimination of topographic features.

The data allows the distinction between inside-basin fabric (radial topographic lineaments) to footwall topographic fabric (radial and contact parallel lineaments). This model can be linked to the numerical modeling results on strain distribution and cooling of the SIC.

Conclusions:

For the large Sudbury impact structure cooling and solidification continued up to 1 million years, depending on the total thickness of the melt sheet and norite thickness. For any norite thickness, the hottest part of the SIC is at the melt pool/footwall contact, allowing additional melting of the footwall.

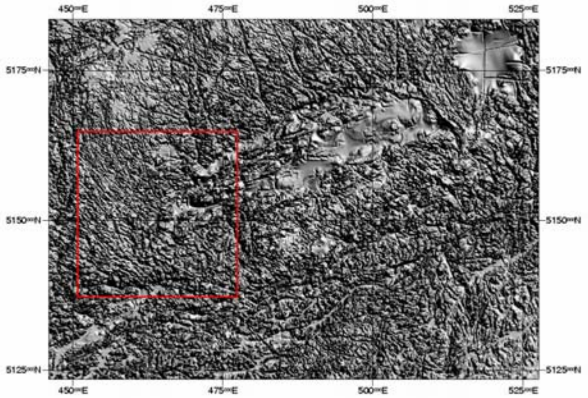

Fig. 2: *Topography over the Sudbury basin and surrounding area. Wanapitei Lake can be seen in the NE corner. The area delimited in red marks the zone of detail in Figure 3.*

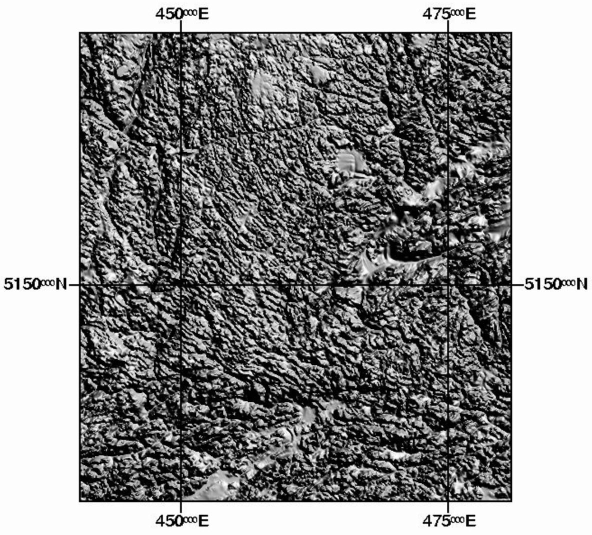

Fig. 3: *Detail of the topographic model over the West side of the Subury basin. Notice the change in fabric from the SIC-footwall contact towards the West.*

References:

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