A Model of Localized Shear Heating with Implications for the Morphology and Paleomagnetism of Complex Craters.

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Introduction: The need for a dynamic weakening mechanism to facilitate the collapse of a transient cavity to produce the complex crater shape has been well documented. Several have been proposed: acoustic fluidization [1], thermal softening due to shock melting [2] and frictional melting along fault planes [3]. Several studies have stressed the potential importance of frictional melting during the impact process [4-8]. In the present work, we develop a numerical model of shear failure and frictional heating within faults and demonstrate how this model can play a role in explaining complex crater morphology and in the acquisition of remnant magnetization.

Model: Our starting point is the damage model of Collins et al. [9], where the yield strength of fully damaged material follows a Coulomb friction law and thermal softening of bulk material occurs approaching the melting point. We extended the model by estimating statistical crack spacing based on strain rate, a determination of shear heating within cracks and heat loss via conduction away from cracks. With this extension, thermal softening can occur as the temperature within a crack approaches the melt temperature. The model has been added to CTH [10] as the Brittle Damage with Localized Thermal Softening (BDL) model.

Discussion: The BDL model is dependent on estimates of crack spacing. In the examples shown in Figs. 1-2, we've chosen crack spacing (L) to follow a power law, $L=L_0\dot{\varepsilon}^{-n}$, where $\dot{\varepsilon}$ is strain rate. We've chosen values of L_0 and n to produce crack spacing of 2-7 m for terrestrial crater diameters of 1–280 km. With EOS, strength and conductivity properties appropriate for granite, the BDL model predicts thermal crack widths of 0.3-3 cm and characteristic cooling times of 10-1000 s. over the size range studied. Frictional heating within each crack is proportional to $\mu L \dot{\varepsilon} P$, where μ is the friction coefficient (which decreases with temperature) and P is pressure. With the crack spacing and widths in these examples, 0.1-1% of rock volume is affected by this process.

Implication 1: As shown in Fig. 1, temperatures within cracks approach the melting point of granite (~2000 K) and persist for a period of time dependent on crater scale. For simple craters, the characteristic cooling time of cracks is significantly smaller than the crater formation time ($T_c << T_f$) so there is little time for thermal softening to influence crater development. For central peak craters T_c is comparable to T_f so thermal softening can influence the development of a central peak but decay rapidly enough to "freeze" the peak at the end of crater formation. For larger craters, thermal softening persists long enough for central peak overshoot to occur with implications for peak ring and multi-ring basin development.

Implication 2: The high temperatures acquired by some fault materials in this model would allow magnetic carriers to acquire thermal remanence of the magnetic field present at the time. If the cooling time is rapid enough, as it seems here for simple and central-peak craters, the acquired remanence may be of an impact-generated field [11] or the ambient field distorted by the presence of impact-generated plasma.

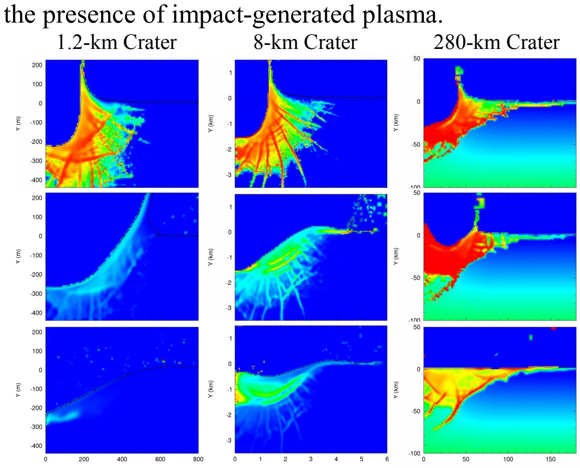

Fig. 1. Fault temperature using the BDL model for three simulated terrestrial craters at three representative times (top→bottom is beginning→end of crater formation). Blue ≤ 350 °K, Green = 1175 °K, Red ≥ 2000 °K.

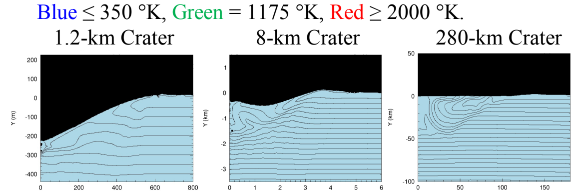

Fig. 2. Predicted final crater cross-sections after motion has ceased. The 1.2- and 8-km simulations straddle the simple-to-complex transition which occurs at 2-5 km.

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