Dynamic Fault Weakening and the Formation of Large Impact Craters

Laurel E. Senft and Sarah T. Stewart

Supplemental Online Material

Pressure Dependence on the Threshold Slip Distance

Theoretical work on frictional melt formation shows that the threshold slip distance, s_*, depends inversely on the square of the pressure (P); thus s_* will increase towards the surface (Melosh, 2005). To test the effect of this pressure dependence on our results, we implemented a pressure dependence to s_* of the form:

$$s_* = \frac{A}{P^2} + B,$$

where A and B are constants. We chose $A=6\times10^{16}$ $(\text{dynes/cm}^2)^2$ and $B=3\times10^2$ cm based on slip-weakening data from Hirose and Shimamoto (2005) and Mizoguchi et al. (2007). For the large craters studied here, the effect was negligible. However, the effect may be significant for smaller complex craters, which will be studied in future work.

Center line artifact on Symmetry Boundary

We conducted simulations where strain-rate weakening was prohibited along the center line to assess the significance of artifacts that arise from the cylindrical symmetry boundary. The process of crater collapse and the final crater dimensions (depth and diameter) are similar with and without strain-rate weakening on the center line (Figure S1).

Note on the Term "Psuedotachylitic Breccia"

There has been confusion and controversy in the literature regarding the use of the term pseudotachylite, which was first introduced by Shand (1916) to describe breccias with a black aphanitic groundmass in the Vredefort dome. Earthquake geologists typically reserve the term pseudotachylite (Sibson, 1975) for unambiguous friction-induced melts, while impact geologists have generally used the term based on textural appearance in the field (of a dense, dark colored and fine-grained rock), as opposed to genetic origin (which is often difficult to determine). As a result, some documented pseudotachylites may actually be products of other processes, e.g., shock melting or melt injection. Thus, following the suggestion by Reimold (1995), we use the generic term pseudotachylitic breccias to refer to melt-rich veins instead of pseudotachylites.

Animations of Simulations (QuickTime files)

Movie #1: Simulation presented in Figure 2: a 10-km diameter projectile impacting a basalt half space at 17 km/s under Earth gravity, resulting in a ~100 km diameter crater. Left shows locations where the criteria for frictional melting are satisfied (dark color) and right shows integrated effective plastic shear strain. Vapor is removed for computational efficiency (the projectile is vaporized). Time is scaled by a factor of 1/7.5.

Movie #2: Simulation the Chicxulub-forming impact presented in Figure 6: a 16-km diameter projectile impacting at 17 km/s onto 3 km of sediments, overlying 32 km of granite (the crust), overlying dunite (the mantle). Left shows materials (colors) and stratigraphy (lines) and right shows integrated effective plastic shear strain. Black lines are rows of initially horizontal Lagrangian tracers; the thicker black lines correspond to the boundaries between the upper/mid/lower crust, sediments, and mantle. Vapor is removed for computational efficiency (the projectile is vaporized). Time is scaled by a factor of 1/7.5. Note that the values for the effective plastic strain scale are larger compared to movie #1, and strain-localization behind the shock front is present but not emphasized by the color scale.

References

Hirose, T., Shimamoto, T., 2005. Growth of molten zone as a mechanism of slip weakening of simulated faults in gabbro during frictional melting. J. Geophys. Res. 110, B05202, doi: 05210.01029/02004JB003207.

Melosh, H.J., 2005. The mechanics of pseudotachylite formation in impact events, in: Koeberl, C., Henkel, H. (Eds), Impact Tectonics. Springer Berlin Heidelberg, Berlin, Germany, pp. 55-80.

Mizoguchi, K., Hirose, T., Shimamoto, T., Fukuyama, E., 2007. Reconstruction of seismic faulting by high-velocity friction experiments: an example of the 1995 Kobe earthquake. Geophys. Res. Lett. 34, L01308, doi:01310.01029/02006GL027931.

Reimold, W.U., 1995. Pseudotachylite in impact structures - generation by friction melting and shock brecciation?: A review and discussion. Earth Sci. Rev. 39, 247-265.

Shand, S.J., 1916. The pseudotachylite of Parijs (Orange Free State), and its relation to "trap-shotten gneiss" and "flinty crush-rock". Geol. Soc. London Quart. 72, 198-221.

Sibson, R.H., 1975. Generation of pseudotachylyte by ancient seismic faulting. Geophys. J. Royal Astro. Soc. 43, 775-794.

FIGURE CAPTION

Figure S1. Time steps from a two-dimensional simulation of a 10-km diameter basalt projectile impacting a basalt half space at 17 km/s under Earth gravity, resulting in a ~100 km diameter crater. The center line is on the left of each panel. Dark color indicates locations where strain-rate weakening criteria are satisfied and the coefficient of friction is reduced. The target resolution is 250 m per cell. Top row: strain-rate weakening is allowed everywhere. Bottom row: strain-rate weakening is prohibited from 0 to 5-km distance from the center line.