**DIFFERENTIAL SCALING OF CRATER PARAMETERS: IMPLICATIONS FOR THE OBSERVED TERRESTRIAL RECORD**; R.A.F. Grieve[1] and M.J. Cintala.[2] [1]Geol. Surv. Canada, Ottawa, Ontario K1A0Y3 [2]Code SN21, NASA JSC, Houston, TX 77058

Model calculations indicate that, above some minimum impact velocity, the volume of impact melt relative to the volume of the transient cavity is a function of both impact velocity and the magnitude of the impact event.[1] Simply, for fixed impactor and target types, higher velocity impacts produce more melt and vapor than lower velocity impacts and, for a fixed velocity, larger impacts produce more melt relative to the size of the crater than smaller impacts. While these are not entirely new conclusions,[2,3] they have implications and predictions for the cratering record that have not been explicitly explored previously:

**(i)** As the volume of melt produced and the depth of melting relative to depth of excavation increases with size, relatively more impact melt will occur within larger impact craters. Observed melt volumes as a function of crater diameter are generally consistent with this prediction, with observed melt volumes paralleling those predicted from model calculations.[1] Observed melt volumes are, in fact, smaller than those predicted by model calculations. This is believed to be a function of the scaling relation used to determine model cavity diameters. A fuller explanation of the implications of this apparent paradox for scaling large craters can be found elsewhere in this volume.[1]

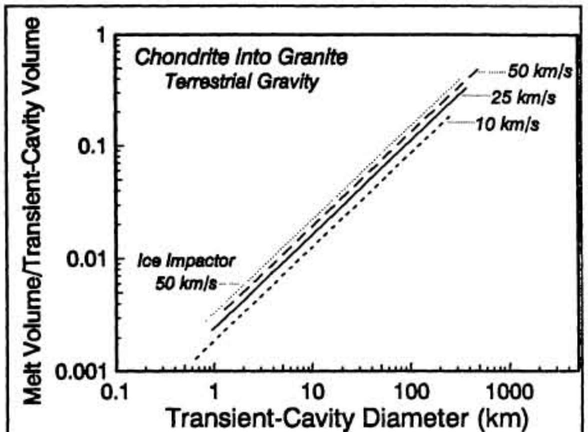


**Figure 1.** Total volume of impact melt as a fraction of the transient cavity's volume as a function of the diameter of the transient cavity. The transient-cavity dimensions were determined through use of the scaling relationship proposed in ref. *1*.

**(ii)** As the melt occupies a greater percentage of the volume of the transient cavity (Fig. 1), there will be less clastic material available for incorporation in the melt. The clast content of the basal lens of impact melt at Brent (D=3.8 km) has been estimated to be 25-50%.[4] We calculate that clastic debris presently represents ≤7 and ≤4% of the impact melt sheets at W. Clearwater[5] (32 km) and Manicouagan[6] (100 km), respectively. These observations are generally consistent with implications of the model calculations. The impact melt at Popigay (100 km), however, is described as containing 10-15% clastic inclusions.[7] At this time, therefore, there are insufficient detailed studies to determine unequivocally whether or not the prediction of clast content variations is borne out.

**(iii)** In principle, variations in melt volume could be used to differentiate between "small, fast" and "large, slow" impacts resulting in similar-sized craters. We have demonstrated previously the methodology of using crater and melt scaling to determine impact velocity.[8] The melt-volume to cavity-volume ratio increases by ~30%, as impact velocities increase from 15 to 50 km/s (Fig. 1); unfortunately, this is unlikely to be detected given the accuracy of melt-volume estimates. If melt rocks are well exposed, so that their present volume is easy to estimate, there will be an uncertainty due to erosion. If the original melt volumes are protected from erosion by burial, the accuracy of melt volume estimates will suffer, as they will be based on drilling data. Velocity estimates based on comparisons of melt volumes require a knowledge of the impactor type at the level of stone, iron, or cometary body. This information is not known for all craters. Finally, variations in relative melt volumes between cometary and asteroidal impacts resulting in equivalent-sized cavities (Fig. 1) are also too small to be detected easily at the level of currently available observational data.

**(iv)** As the relative depth of melting increases with respect to the base of the transient cavity at larger structures (Fig.2), the peak shock stresses recorded in the parautochthonous rocks of the crater floor will increase. The peak shock stresses recorded in the true crater floor at Brent (3.8 km) are estimated to be 25 GPa, based on orientations of planar features,[9] although there is a 16-m zone of thermally recrystallized basement above this, where shock features are annealed. Peak shock stresses in the crystalline basement of the Ries (24 km) have been estimated at 16 GPa,[10] which appears to be at variance with the trend above. The basement, however, is described as a megablock zone and the significance of this estimate is not known. At Boltysh (25 km), maskelynite and diaplectic quartz glass, suggesting peak stresses of ~40 GPa, are developed in the center of the central uplift.[7] At Popigay (100 km), partially melted crystalline rocks, suggesting recorded peak stresses of ~55 GPa, are reported beneath the impact melt in the center of the structure.[7] Other structures where peak stress recorded in crystalline ("granitic") rocks in

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the crater floor have been estimated (*e.g.*, Charlevoix, 17 GPa; Manicouagan, 40 GPa; Slate Islands, 20 GPa) have all suffered erosion.

(v) For terrestrial conditions, the depth of melting is greater than the depth of the transient cavity at diameters >50-80 km (Fig. 2). Using the scaling relation of Croft,[11] this corresponds to final crater diameters of >80 km. The melted cavity floor will be uplifted during transient-cavity modification; as the melted cavity floor will have little to no strength, the formation of topographic central peaks will be inhibited. Examining the record of essentially uneroded structures, we note that Boltysh (25 km) and Kara (65 km) have central peaks; Puchezh-Katunki (80 km) has a 20-km wide central peak but with a 600 m-deep, 5-km diameter central depression;[12] and Popigay (100 km) has a ring structure, with no central peak. At more eroded structures, Sudbury (175-200 km)[13] has no central peak and Manicouagan (100 km) has been compared morphologically to a transitional structure between a central uplift crater and a ringed basin.[14] It has a topographic peak 5-10 km north of the center. This peak is, however, a well-defined horst of anorthosite, suggesting some lithologic control, and may have been covered originally with impact melt and fallback breccia.[15] W. Clearwater (32 km), which has been cited as a ring structure, has a central peak of basement almost completely submerged by the infilling lake.

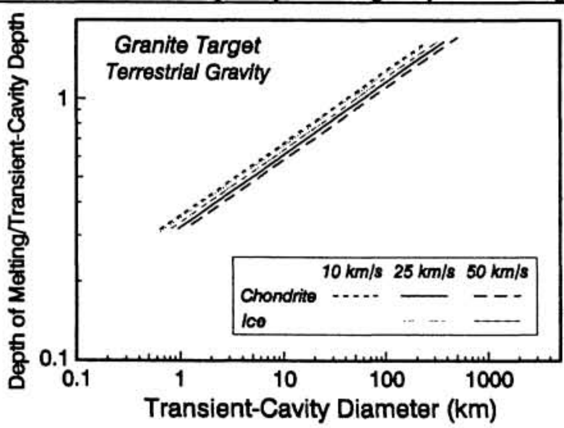


**Figure 2.** Depth of melting relative to the depth of the transient cavity as a function of transient-cavity depth. The scaling relationship used here[1] imposes a depth/diameter ratio for the transient cavity of 0.33, a value determined from terrestrial craters.[18] Shallower transient cavities will result in downward displacement of the set of curves. Consequently, the depth of melting will exceed the depth of the transient cavity at smaller cavity diameters.

(vi) At the largest structures, the volume of melt will represent a substantial fraction of the volume of the transient cavity (Fig.1). This begs the question as to the appearance of large, terrestrial impact-basins. They would not have central, topographic uplifted features, and subsolidus shock effects would be generally absent at the surface in the center. The structure would have the form of a melt pool in a depression and the melt would be relatively clast-free, texturally mirroring an endogenous melt more than our common concept of an impact melt. This may be the case for such controversial structures such as Sudbury, where the Sudbury Igneous Complex may represent an impact melt sheet,[13] or the Bushveld. In the case of the Bushveld, it has been suggested that the 300,000 km$^3$ Rooiberg felsite is an impact melt,[16] requiring a transient cavity at least 150-200 km in diameter, according to the model calculations. Unlike Sudbury, however, searches for subsolidus shock effects at the Bushveld have not been successful. Similarly, in the case of the putative impacts associated with Archean spherule beds,[17] the source craters of these events, even if still present, may never be clearly recognizable as impact craters in the terrestrial record.

**Concluding Remarks:** In summary, the observational data are not inconsistent with model predictions. In several cases (*e.g.*, clast contents and peak shock-stresses recorded in central structures), data quality and quantity need improvement before unequivocally stating that the model predictions and observations are in agreement. We have noted previously the lack of detailed studies in testing models with observational data.[18] Given the importance of impact as a planetary process and that the terrestrial record presents the best case for testing many model predictions, this is a lamentable situation. While identifying new additions to the terrestrial record has merit, more energies need to be focussed on detailed studies of known structures, in order to address first- and second-order problems in impact phenomena.

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