OBSERVATIONS OF THE TERRESTRIAL IMPACT CRATERING RECORD

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Introduction: The currently known terrestrial record of impact cratering stands at over 160 impact structures and several new examples are identified each year (1). The record, however, is a biased sample of an originally much larger population, favoring younger, larger structures in geologically stable areas of the Earth's continental crust. The largest and oldest known structures are limited to diameters of ~ 250-300 km and ages of < 2 Ga. Care must be taken, therefore, in making generalised statements regarding the record with respect to such time-integrated effects as variations in cratering rate, periodicities, etc. (e.g., 2). The terrestrial record, however, does provide cumulative observations of aspects of the cratering process and is the only available source of ground truth with respect to the structural and lithological results of large-scale natural impact events.

Some critical observations: Although attribution is often open to dispute, it is clear that detailed studies at a select number of terrestrial impact structures have provided important boundary constraints on aspects of cratering processes. Impact craters are three-dimensional structures and the ability to drill and recover core, to conduct multi-parameter geophysical surveys and to observe impact craters of similar size and morphology at different erosional levels is the ultimate strength of the terrestrial record. Concepts such as transient cavities formed by excavation and displacement and the collapse of transient cavity walls in simple craters have resulted (e.g., 3). Similarly, the confinement of significant excavation to only the central volume, with the structural preservation of near-surface lithologies exterior to this volume and the structural uplift of originally deeper-seated lithologies in the center of complex structures can be traced, in large part, to detailed and repeated observations of terrestrial impact craters (e.g., 4). Similarly, effects associated with shock metamorphism of various rock types and how its manifestation can differ (e.g., in porous targets) preceded and moved in parallel with shock-recovery experimentation. Observations have been particularly useful in understanding the effects of shock loading in the upper range of experimentally generated shock stresses, such as those leading to impact melting (e.g., 5).

Some less certain observations: Morphometric relations for terrestrial structures have been defined but are subject to considerable uncertainty, due to the effects of erosion and the statistics of small numbers (4). While it is only the more pristine terrestrial examples that can be used to define morphometries, the situation is exacerbated by the fact that many terrestrial impact craters have been studied in insufficient detail or without modern understanding of impact processes. In some cases, the literature is confined essentially to the "discovery" publication or dates from pre-Apollo to periods between Apollo missions, which were a major driver for the study of terrestrial impact structures. The impetus provided by the Apollo program has been replaced to some degree by economic and biosphere drivers. In the

U.S., government funding for studies at terrestrial impact structures appears to fall between the responsibilities of both NASA and NSF. This has tended to favor modelling studies at the expense of field work. It is clearly less costly to engage in modelling studies, but how can we, as a community, evaluate the veracity of the models without observational data from the field? (e.g., 6,7). Experimental data will not suffice to fill this gap, as there are problems with scale and understanding of the physical properties of the relevant materials, despite innovative procedures to compensate for them (e.g., 8). It is true, however, it is easier to connect observational data to later-time cratering processes because that is what they more closely reflect, representing as they do the end of the cratering process. Conversely, modeling has traditionally focussed on more early time processes in cratering events. Clearly, there are opportunities for closer partnerships of observational and modeling studies. The probem, however, is often that no one wants to be the bridesmaid!

Some closing thoughts on observations: We are very much prejudiced by the appearance of fresh lunar craters. It is the database with which we are most familiar regarding crater morphology. It is a fact, however, that some of the younger (fresher) complex craters on Earth (e.g., Ries, Haughton, Zhamanshin) do not have an emergent central peak, yet other, albeit buried, structures do (e.g., Boltysh, Moljnir). This begs a very fundamental question: Why? At first glance, it would appear to be a target effect, with the latter formed in crystalline targets and the former in mixed targets. There is also the question of the occurrence of ring or multi-ring basins on Earth (e.g., 9). Several structures have been "proposed" as ringed basins — Manicouagan, for instance. The question is, however, are these rings erosional artefacts? Among the larger structures is Chicxulub – again proposed as a ring structure — but it is buried and inferences rely upon (sometimes conflicting) interpretations of geophysical data (e.g., 10). Drilling at Chicxulub to date has served little to address this problem. Sudbury is also often portrayed as a terrestrial example of a multi-ring basin. There are rings of pseudotachylite, or so the limited pattern of exposed outcrops suggests (e.g., 11). If these do, in fact, exist, what is their relation to the megascarps in lunar basins? Model calculations, albeit simplistic, suggest that the high-gravity environment of Earth will not necessarily produce basins in the same size range as the large multi-ring basins of the moon, due to the increased relative proportion of impact melt to cavity volume on Earth.

References: (1) www.unb.ca/passc/ImpactDatabase. (2) R. Grieve (2001) In *Accretion of Extraterrestrial Material throughout Earth's History*, Kluwer, 379-399. (3) M. Dence *et al.* (1977) In *Impact and Explosion Cratering*, 247-276, Pergamon. (4) R. Grieve & M. Pilkington (1996) *Jour. Aust. Geol. Geophy.* **16**, 399-420. (5) J. Whitehead *et al.* (2002) *MAPS* **37**, 623-647. (6) A. Therriault *et al.* (1997) *MAPS* **32**, 71-77. (7) E. Turtle and E. Pierazzo (1998) *MAPS* **33**, 483-490. (8) K. Housen *et al.* (1999) *Nature* **402**, 155. (9) R. Grieve & A. Therriault (2000) *Ann. Rev. Earth Planet. Sci* **28**, 305-338. (10) J. Morgan *et al.* (2002) GSA Sp. Pap. 356, 39-46. (11) J. Spray & L. Thompson (1995) *Nature* **373**, 130-132.