The Meteoritical Society

Meteoritics & Planetary Science 42, Nr 11, 1859–1860 (2007)
http://meteoritics.org

Proceedings of the Workshop on Impact Craters as Indicators for Planetary Environmental Evolution and Astrobiology

This issue of *Meteoritics & Planetary Science* contains 13 papers that emerged from contributions presented at the Workshop on Impact Craters as Indicators for Planetary Environmental Evolution and Astrobiology, held at Östersund, Sweden, in June 2006. It was the aim of the organizers (Hans Rickman, Maurits Lindström, Jens Ormö, and Jesus Martinez-Frias) to stimulate discussions between the "field people" (e.g., geologists, geophysicists) and modelers, experimentalists, astronomers, and astrobiologists. Only such a multidisciplinary approach will strengthen our knowledge on how the target properties influence the morphology and geology of the resulting crater, and how these relations can be used to reconstruct present or past environments on planets and natural satellites in the solar system. The workshop was attended by 72 participants from 17 nations, and included a two-day field trip to the nearby Lockne crater that served as an excellent example of how target properties may influence the final crater. In the case of the Lockne impact, a layer of seawater approximately as deep as the diameter of the projectile (~600 m) constituted a weak layer above the more resistant target rocks. The influence from the marine target environment at Lockne was not only restricted to the crater excavation phase, but also to the early modification of the crater (i.e., water resurge erosion and deposition), as well as to post-cratering processes such as crater-induced variations in sedimentation and biological colonization of the new habitat.

The papers in this proceedings volume reflect the topics discussed during the workshop. In the first paper, Patrick Michel and Alessandro Morbidelli give a résumé of the frequency of impact events in the solar system and the impact process from an astronomical point of view. A set of papers then discusses how impact craters and impact-related materials can provide information about past environments. Jane Wigforss-Lange et al. describe the provenance of the material in different distal ejecta units from the Chicxulub crater and find evidence supporting a single-impact scenario for this impact event at the Cretaceous-Paleogene boundary, for which both a single and multiple impacts have been proposed. Another example of how distal ejecta can provide more precise stratigraphic correlation of an impact event, and thus better link the event to biological and geochemical changes, is presented by Andrew Hill et al. They study the potential local and regional influences of the Acraman impact event in Australia. Even relatively small impacts may affect the environment at great distances from the impact site when they occur at sea, where some of the kinetic energy can be transferred into tsunami waves. However, Kai Wünnemann et al. show with numerical simulation that the propagation of these waves depends strongly on the relative water depth. In the most frequent deep-ocean impacts, the waves decay more rapidly than previously assumed, and thus the hazard for populated coastal areas may have been overestimated.

The oceans' layer of water has also a preventive effect on the cratering, thus causing only a fraction of the impacts to form detectable craters in the seafloor. The protective effect of the seawater is studied by Emily Baldwin et al. using high-velocity impact experiments. They also note differences in crater diameter/depth ratio related to the porosity and saturation of the target. Thomas Davison and Gareth Collins have used numerical simulation of a large number of hypothetical impacts at different water depths to analyze how the protective effect of the ocean water has affected the crater size-frequency distribution for Earth during the last 100 million years. They also show that many past impact events would today only be visible as disturbances of the seafloor sediments by forceful resurge movements. Deposits from such resurge movements may form significant parts of the infill of a crater and represent strong evidence of an impact that occurred in an aquatic setting. Such evidence needs to show that the water movements occurred in direct connection with the impact (i.e., the collapse of the cavity formed in the water layer). Good representatives for this situation are the Lockne and Tvären craters. The sea in which these craters were formed about 455 million years ago no longer exists. Thus, the resurge deposits give valuable information on the environment at the time of the impacts. Jens Ormö et al. have found certain sedimentological features that indicate the dynamics of the resurge flow using clast frequency and lithology analysis of resurge sediments in drill cores from these two craters. These features depend on the amount of available water and thus give information on the paleo-water depth in this past sea.

The Haughton impact structure in the Canadian Arctic provides much information on impacts into sedimentary targets. Gordon Osinski determines the shock levels in target sandstones and uses this information to establish the shock pressure at which the calcite component in the sandstones begins to melt. This information may, in turn, be used to calculate the amount of melt and CO_2 that is generated from impacts into carbonate targets. The target can affect a crater even long after the termination of the direct cratering

processes. Paula Lindgren et al. discuss the influences of an organic- and uranium-rich target on the subsequent concentration of carbon in impact craters using the Lockne crater as an example. The polymerization of the bitumen around radioactive minerals occurred at Lockne in combination with a hydrocarbon flow, which was aided by the impact-generated heat and the fractured target rocks. However, the authors emphasize that similar processes may have been active on Mars causing carbon concentrations at impact craters, and thus having astrobiological implications. Hypervelocity impact events not only change the environment, but they also create new local habitats. Åsa Frisk and Jens Ormö describe sediment- and bio-facies variations in post-impact marine sediments at the Lockne and Tvären craters and how these facies variations are influenced by the impact-generated bathymetry. Likewise, an impact can change the habitat also for microorganisms living within or on rocks. Charles Cockell and Gordon Osinski have experimentally analyzed how impact-induced changes in rock pore space, either increased by for instance fracturing or decreased by thermal annealing and recrystallization, affect the distribution of certain lithophytic microbes.

The last two papers discuss the changes that a crater may undergo long after its formation. Thomas Kenkmann et al. use sandbox experiments and structural geological analysis to estimate how much post-impact tectonic influence has occurred on the Lockne crater. They argue that the previously described resurge gullies that cross the rim of the crater are not primary features, but instead are gentle synclines in the crystalline basement. In addition to tectonic movements, the overburden weight from thick stacks of post-impact sediments may deform a crater by causing subsidence and differential compaction. Filippos Tsikalas and Jan Inge Faleide show that this can have a substantial influence on the final crater morphology, affecting the construction of scaling laws and estimates on impact-generated consequences. The papers in this volume show that the workshop succeeded in its goal of bringing together scientists from different fields to further our knowledge on the impact cratering process, how cratering is influenced by various processes including the environment, and how it affects the biosphere of a planet.

Finally, we want to acknowledge the sponsors of the workshop, the Swedish National Space Board, the Royal Swedish Academy of Science, the Swedish Research Council, Centro de Astrobiología (INTA/CSIC), Spain, the City of Östersund, the Storsjöbygdens Golfklubb, and the invaluable help of the people form the Östersund Tourist & Convention Bureau. The papers in this volume provide evidence for a successful workshop; publishing would not have been possible without the efficient help of the reviewers and the editorial staff of *Meteoritics & Planetary Science*.

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