Meteorite impact cratering on Earth: Hazards, and geological and biological consequences

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Impact is a unique, short-time, high-energy geological process. Craters are a fundamental and common topographic form on the surfaces of planets, satellites, and asteroids. On large planetary bodies, of the size of the Moon and larger, craters can form in a variety of processes, including volcanism, impact, subsidence, secondary impact, and collapse. The two most important processes are volcanism and impact. On smaller bodies (e.g., of the size of minor planets), impact may be the only process that can form craters (as shown, for example, by the numerous craters that pockmark the surfaces of asteroids). In the explanation of terrestrial crater-like structures, the interpretation as volcanic features and related structures (such as calderas, maars, cinder cones) has traditionally dominated over impact-related interpretations.

The importance of impact cratering on terrestrial planets (Mercury, Venus, Mars) is obvious. Our Moon (Fig. 1), and the satellites of the outer planets, are pockmarked with a large number of craters on their surfaces. On most bodies of the solar system that have a solid surface, impact cratering is the most important surface-modifying process even today. On Earth, active geological processes rapidly obliterate the cratering record. To date only about 170 impact structures have been recognized on the Earth's surface. The come in various forms, shapes and sizes, from 300 km to less than 100 m in diameter, from Recent to 2 billion years in age. Mineralogical, petrographic, and geochemical criteria are used to identify the impact origin of such structures or related ejecta layers. The two most important criteria are the presence of shock metamorphic effects in mineral and rock inclusions in breccias and melt rocks, as well as the demonstration, by geochemical techniques, that these rocks contain a minor extraterrestrial component. In impact studies there is now a trend towards the use of interdisciplinary and multi-technique approaches to solve open questions (e.g., Koeberl 2002).

Impact cratering is a high-energy event that occurs at more or less irregular intervals (although over long periods of time, an average cratering rate can be established). Part of the problem regarding recognition of the remnants of impact events is the fact that terrestrial processes (sedimentation, erosion, plate tectonics, etc.) either cover or erase the surface expression of impact structures on Earth. Many impact structures are covered by younger (i.e., post-impact) sediments and are not visible on the surface. Others were mostly (or entirely) destroyed by erosion. In some cases, ejecta have been found far from any possible impact structure. The study of these ejecta has led, in some cases, to the discovery of the source impact craters. Important witnesses for the characteristics of the impact process are the affected rocks. As described in more detail by, e.g., Melosh (1989), crater structures are filled with melted, shocked, and brecciated rocks. Some of these are in situ, others have been transported, in some cases considerable distances, from the source crater, representing so-called ejecta. Some of the ejecta material can fall back directly into the crater, and most of the ejecta end up close to the crater ($<$ 5 crater radii; these are called proximal ejecta), but a small fraction may travel much greater distances and is then considered distal ejecta (e.g., Montanari and Koeberl 2000).

An aspect of impact cratering that may be underestimated is the influence of impacts on the geological and biological evolution of our own planet. Even the impact of relatively small asteroids or comets can have disastrous consequences for our civilization. There is a 1 in 10,000 chance that a large asteroid or comet 2 km in diameter (corresponding to a crater of about 25–50 km in diameter) may collide with the Earth during the next century, severely disrupting the ecosphere and annihilating a large percentage of the Earth's population. The biological evolution of our planets is punctuated by mass extinction events, of which the one 65 million years ago, which

Fig. 1. Densely cratered part of the surface of the moon. Apollo 17 image no. 155-237907.

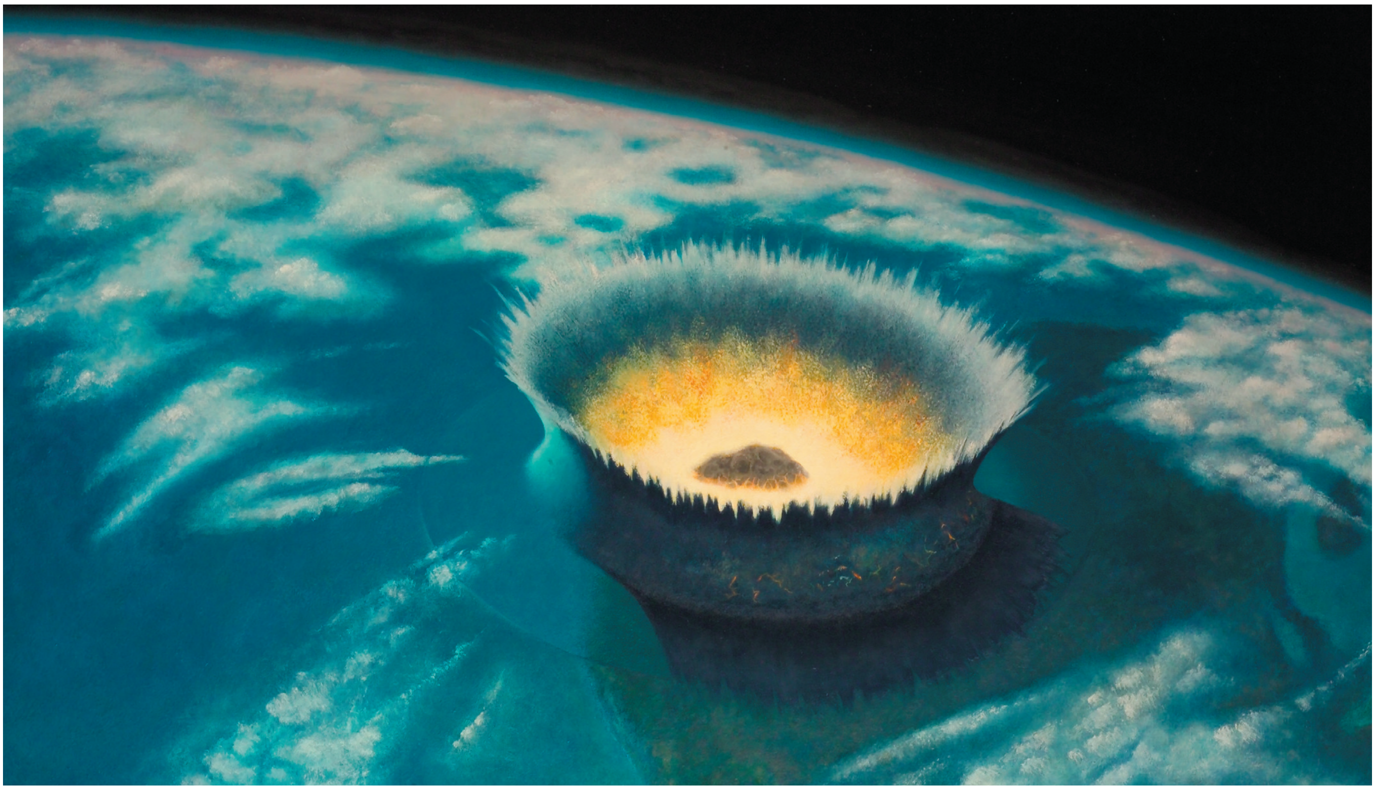

Fig. 2. The first seconds of the K-T asteroid impact event at the site of present-day Yucatan in Mexico. Painting by D. Jalufka

marks the Cretaceous-Tertiary boundary, is probably the best known one (Fig. 2). Abundant impact debris marks this boundary, providing a clear link with a major impact event. The Chicxulub impact structure in Mexico, about 200 km in diameter, which resulted from the impact of an about 10-km-diameter asteroidal body, has been identified as the culprit. Understanding of impact structures, their formation processes, and their consequences should be of interest not only to earth and planetary scientists, but also to society in general.

References

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