Doctoral School at the University of Vienna, Austria

Planetology: From Asteroids to Impact Craters

The topic of this doctoral programme deals with aspects of planetary geology and planetary astronomy, in which we want to study minor bodies in the solar system, from their formation to the evolution of their orbits into Earth-crossing orbits to the impact of these bodies on Earth, with a particular emphasis on the impact effects and hazards. 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 planet is punctuated by mass extinction events, of which the one 65 million years ago, which marks the Cretaceous-Tertiary (K-T) boundary, is probably the best known one.

In general, a major topic of interest is the effect of impact events on the global environment and possible relations to mass extinctions in the geological history. The first physical evidence that indicated an impact event at K-T times was the discovery, by Louis and Walter Alvarez and colleagues in 1980, of a great enrichment of anomalously high platinum-group element abundances in the thin layer that marks the transition from Cretaceous to Tertiary rocks. Later shocked minerals were found, as were microscopic diamonds and other indicators of an impact event. During the 1980s a big debate was raging in the geological community – with most Earth scientists being skeptical of the claim that it was a meteorite impact that led to the extinction of the dinosaurs and more than 50 percent of all then living species of fauna and flora. Only the discovery, in the early 1990s, of the ca. 200-km-diameter Chicxulub impact structure, which is completely buried underneath younger rocks of the Yucatan Peninsula in Mexico and is thus not visible on the surface, changed the picture. Detailed studies showed that this crater is of exactly the right age, and all the chemical and petrographic characteristics of its rocks fit those of the ejecta layers around the world, confirming that Chicxulub is indeed the long-sought K-T impact structure.

At present, the Chicxulub impact structure, with a Cretaceous-Tertiary (KT) boundary age, is the only one for which a relationship to a major mass-extinction event has been established, at least with respect to the timing. To explore and demonstrate the potentially important role of meteorite impacts on biotic extinctions and subsequent evolution, it is important to find other examples of a meteorite impact that is related to a mass extinction. In addition to this biological interest, the study of meteorite impact craters also has an important economical aspect. Some of the Earth's important mineral deposits (Ni-Cu-Pt mines, Sudbury Structure, Canada) and hydrocarbon reservoirs (the giant Cantarell oil field, Chicxulub structure, Mexico – the 8th largest oil field in the world) are closely associated with large impact events.

Today astronomers and geologists have accepted that impact processes are among the most common and fundamental mechanisms that have formed and shaped the Earth and our planetary system. Impacts and related developments have changed the Earth through geological time and have been key factors in the development of life on our planet. Thus the recognition of interplanetary collisions and the formation of impact craters on planetary surfaces as a fundamental geological process led to a new paradigm in terrestrial geology: The geological and biological evolution of Earth is not only influenced by internal or superficial geological processes, but also by external, highly energetic processes. Hypervelocity impacts have produced, on a time scale of minutes, deep scars in the Earth's crust and mantle, which can be up to several thousand kilometers wide. There are certainly more craters on Earth than those known today, but the total number preserved on Earth is far less than the hundreds of thousands that would be expected from counting lunar impact craters. Unlike Earth, the unaltered ancient surface of the Moon has acted as a reliable recorder of impact processes in the inner solar system over the past 3 to 4 billion years.

The study of impact craters on Earth and the asteroids that formed them is an absolute prerequisite for the understanding of some of the most fundamental problems of Earth and planetary sciences. Mineralogical, petrographic, and geochemical methods have been used for many decades in the study of terrestrial meteorite impact craters. A clear hiatus in the history of impact-related studies was the realization that the K-T boundary bears unambiguous evidence for a large-scale catastrophic impact event (related to the formation of the 200-km-diameter Chicxulub impact structure, Mexico). Analyses of the K-T ejecta layers led to improved detection sensitivities for impact markers, allowing identification of smaller events and the study of their effects. Distal impact ejecta layers can be used to study a possible relationship between biotic changes and impact events, because it is possible to study such a relationship in the same outcrops, whereas correlation with radiometric ages of a distant impact structure is always associated with larger errors. Investigations of impact markers yield important information regarding the physical and chemical conditions of their formation, such as temperature, pressure, oxygen fugacity, and composition of the atmosphere. These data are necessary to understand the mechanisms of interaction of impact events with the environment and should ultimately lead to a better appreciation of the importance of impact events in the geological and biological evolution of the Earth. Understanding impact structures, their source objects, formation processes, and their consequences is of interest not only to astronomers and Earth and planetary scientists, but also to society in general.