FIELD STUDIES OF TERRESTRIAL IMPACT STRUCTURES.

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Introduction: The robotic and human exploration of the Solar System over the past half a century has demonstrated that impact cratering is one of the most ubiquitous and important geological processes in the Solar System [1, 2]. Scientific studies have also revealed that this impact process has played a fundamental role throughout the history of the Earth and other planetary bodies, resulting in both destructive [3] and beneficial effects [4]. Our understanding of the impact cratering process and products comes from numerical simulations, experiments, satellite and rover observations from other planetary bodies, the study of extraterrestrial samples, and the geological record of impact cratering on Earth. Despite the incompleteness of the terrestrial record and complications associated with overprinting by other terrestrial geological processes, such as erosion, tectonism, etc., the impact cratering record of Earth is critical to our understanding of the processes, products, and effects of impact events. Impact craters on Earth afford the only present opportunity to conduct fieldwork, deep drilling, detailed geophysical surveys, and obtain in situ samples, that are necessary to characterize the nature and properties of the impactites, develop ideas, test hypotheses, and refine our understanding of impact process. In this contribution, I provide an up-to-date review and synthesis of the impact cratering record on Earth, with an emphasis on the major findings related to field studies at terrestrial impact structures

The terrestrial impact record: The *Impact Earth* Database (available online at www.impactearth.com), provides an up-to-date listing and holistic view of impacts, from fireballs, to meteorite falls, to the largest crater-forming events [5]. The database currently lists 13 *impact craters* (i.e., impact sites lacking evidence for shock metamorphism) and 188 hypervelocity impact craters. Also listed are a large number of *impact deposits*, classified into four main categories: tektites, spherule layers, occurrences of other types of glass, and breccias. Of the 188 confirmed hypervelocity impact craters, 71 are exposed on the Earth's surface and are available for field study.

Recent insights from field studies of the terrestrial impact record: Below I provide three examples of how field studies of terrestrial impact sites have enhanced our understanding of the impact process.

Tectonics of complex crater formation. An important contribution of field studies of terrestrial craters is in the area of the mechanics of complex crater formation. As reviewed by Kenkmann et al. [6], structural mapping reveals that crater collapse occurs via a series of interconnected concentric listric extensional faults and radially-oriented faults and folds. With increasing depth – as revealed by the study of deeply eroded impact structures – faults give way to monoclinal folds and/or a combination of inward dipping extensional faults and monoclines. Field mapping reveals that central uplifts are structurally extremely complex, with deformation dominated by thrust faulting and radially-oriented folds formed due to constriction caused by the convergent mass flow [6].

Impact ejecta emplacement. Field studies of well-preserved terrestrial impact structures have revealed that continuous ejecta blankets comprise melt-free lithic impact breccias to melt-poor impact melt-bearing breccias, long accepted to form via ballistic sedimentation and radial flow during the excavation stage [7, 8]. Field studies also show that complex hypervelocity impact craters on Earth also preserve a second patchy layer of impact melt-bearing breccias and/or impact melt rock overlying the continuous ejecta blanket. Recent studies of the Ries [9] and Mistastin Lake [10] impact structures support the earlier idea [11] that these upper melt-rich deposits are emplaced as ground-hugging flows during a second major pulse of ejecta emplacement during the final modification stage of crater formation.

Impact craters as habitats for life. An intriguing recent idea is that impact events have beneficial effects for microbial life and may have played an important role in the origin of life on Earth (see recent review by [4]). An important contribution of field studies is that most complex impact structures on Earth resulted in the development of a hydrothermal system [12], driven by the residual heat of the impact event. Field studies have also revealed that other habitats for life are also generated, including endolithic habitats in shocked rocks [13] and impact glasses [14], and impact crater lakes [15]. This may have important implications for our understanding of the origin and evolution of early life on Earth, and possibly other planets such as Mars.

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