BARRINGER AWARD LECTURE. SPLIT-SECOND GEOLOGY: ATTEMPTS TO UNDERSTAND THE STRUCTURAL INVENTORY OF IMPACT CRATERS ON DIFFERENT SCALES

Thomas Kenkmann, Institut für Geo- und Umweltnaturwissenschaften, Albertstraße 23-B, Universität Freiburg, Germany, Thomas.kenkmann@geologie.uni-freiburg.de

Introduction: Impact craters display a large variety of deformation features on all scales of observation. Such micro- and macrostructures are formed under very different and rapidly changing boundary conditions. Stresses may vary from hundreds of gigapascals at the very beginning of an impact process to a few kilopascals during late stage movements [1]. Likewise strain rates change over many orders of magnitudes within the short period of an impact and cause switches in the dominant deformation mechanism of minerals. Temperatures decrease from several thousand degrees near the point of impact to ambient temperature at the crater rim. To add more complexity, both the particle path and the stress tensor related to specific material points permanently change their orientation during the subsequent stages of impact cratering and deviations from radial symmetry of the cratering flow field by oblique impacts and strain localization are the rule rather than the exception.

Objectives and vision: The framework of transient physical boundary conditions defines a complex but fascinating playground for a structural geologist working in impact craters [2]. While impact craters have many deformation features in common, each crater is also unique by itself due to specific impact conditions and target composition. Natural impact craters always show the finite end product of numerous deformation increments superimposing and partly obliterating each other. This requires that field studies are assisted by methods that allow to isolate and constrain the deformation related to each of the stages. The ideal approach to understand the kinematic and dynamic evolution of an impact event, therefore, provides the interactive combination of impact crater mapping and microstructural analysis with experimental and numerical modeling studies.

Results: In the past twenty years I tried to follow this rationale by initiating multidisciplinary projects that combine at least some of the above mentioned approaches. Here are a few general trends that characterize impact craters:

(i) Shock-induced pseudotachylites [3], shatter cones [4] and feather features [5], three important impact criteria found in many terrestrial impact structures, have in common that they are all initiated by localized mixed-mode shear failure during shock loading followed by tensile fracturing during transient unloading from a shock wave. Melt formation plays the crucial role in pseudotachylites while this is less important on shatter cones surfaces. Here the rapidly propagating fracture causes cascades of fracture bifurcations that ultimately form the shatter cone surface [6]. The characteristic morphology of feather features, in turn, is governed by the anisotropy of the quartz lattice [5] in which they form. All these shock features indicate the presence of high deviatoric stresses in shocked rocks.

(ii) In the course of an impact, the deformation develops from narrow-spaced, pervasive and delocalized deformation networks formed under high strain rates with low individual strain magnitude towards localized, relatively low strain-rate and high strain deformation during crater modification [7].

(iii) Much of the macroscopic structural complexity in impact crater targets results from non-plane strain deformation. In case of convergent flow during crater collapse space incompatibilities need to be accommodated, e.g., by the formation of radial transpression ridges [8]. It also became apparent that the structural inventory of a central uplift is at least as sensitive to impact obliquity [9] as the ejecta blanket pattern is. Target anisotropy is also critical [10].

(iv) The presence of a fluid phase in the target increases the cratering efficiency, modifies the particle trajectory field and increases the total amount and velocity of ejected masses and ultimately governs the mode of ejecta emplacement [11]. Porous lithologies such as tuff, but also non-porous carbonates effectively dampen shock waves.

Outlook: Future work may focus on: (a) Detailed mapping and structural analysis of impact craters on Earth and planetary surfaces. This provides the ground truth for understanding the kinematics and dynamics of crater formation. (b) Completion of the terrestrial crater record. Knowledge of the structural inventory of eroded craters may foster further crater discoveries. (c) Understanding the formation of shock effects such as PDFs. (d) Understanding the mechanics of dynamic fracturing. (e) Quantifying strain in natural impacts and proving modes of strength degradation.

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