SHATTER CONES OF THE HAUGHTON IMPACT STRUCTURE, CANADA

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ABSTRACT

Despite being one of the most distinctive products of hypervelocity impact events, shatter cones remain enigmatic. Several contrasting models for their formation have been presented, none of which appear to account for all of the observations. In this preliminary study, we present an overview of the distribution and characteristics of shatter cones at the Haughton impact structure, one of the best preserved and best exposed terrestrial impact sites. Shatter cones are abundant and well developed at Haughton, due in part to the abundance of fine-grained carbonates in the target sequence. They occur in three main settings: within the central uplift, within megablocks of the ballistic ejecta blanket; and within clasts in allochthonous crater-fill impact melt breccias. Examples of shatter cones within impact breccias are rare in the terrestrial impact cratering record, yet their characteristics at Haughton provide some important insights in to the mechanism of shatter cone formation.

1. INTRODUCTION

Shatter cones are one of the most characteristic products of hypervelocity impact events and are the only shock metamorphic effect that develop on a megascopic (i.e., hand specimen to outcrop) scale [1-3]. Despite the recognition of shatter cones in dozens of terrestrial impact structures, there is still considerable uncertainty concerning their mechanism(s) of formation.

In this study, we present the preliminary results of a study of shatter cones from the Haughton impact structure, Canada. These observations are discussed with respect to the various models proposed for the formation of shatter cones.

2. FORMATION OF SHATTER CONES

Several models have been put forward for the formation of shatter cones. Johnson and Talbot [4] suggested that shatter cones form due to interaction between a propagating shock wave and heterogeneities within the target rocks. Other workers suggested that shatter cones are tensile fractures that form due to interference between the incident shock wave and reflected stress waves [5]. Two new models have also been proposed. The first model by Baratoux and Melosh [6] builds upon earlier suggestions [4] invoking heterogeneities in rocks as initiation points for shatter cone formation. These authors suggest that the interference of a scattered elastic wave by heterogeneities results in tensional stresses, which produces conical fractures. In contrast, Sagy et al. [7, 8], favour a model in which shatter cones are fractures produced by nonlinear waves that propagate along a fracture front.

3. GEOLOGICAL SETTING OF THE HAUGHTON IMPACT STRUCTURE

Haughton is a well preserved and well exposed 23 km diameter, 39 Ma complex impact structure situated on Devon Island in the Canadian Arctic Archipelago (Fig. 1) (see Osinski et al. [9] for an overview). The target sequence comprises a ~1880 m thick series of Lower Paleozoic sedimentary rocks (predominantly dolomite and limestone, with subordinate evaporate horizons and minor shales and sandstones) overlying Precambrian metamorphic basement of the Canadian Shield.

Allochthonous crater-fill impact melt breccias form a virtually continuous ~54 km^2 unit in the central area of the structure (Fig. 1) [10]. These pale grey impactites comprise variably shocked mineral and lithic clasts set within a groundmass of calcite + silicate glass ± anhydrite [10]. The groundmass phases represent a series of impact-generated melts derived from the sedimentary target sequence. The lithic clasts are typically angular and are predominantly limestone and dolomite, with subordinate sandstones, shales, and gneisses. Interaction of groundwaters with these hot impact melt breccias led to the development of a hydrothermal system within the crater following the impact event [11, 12]. This resulted in the deposition of a series of alteration products within cavities and fractures in the impact melt breccias, central uplift, and around the faulted crater rim [11, 12].

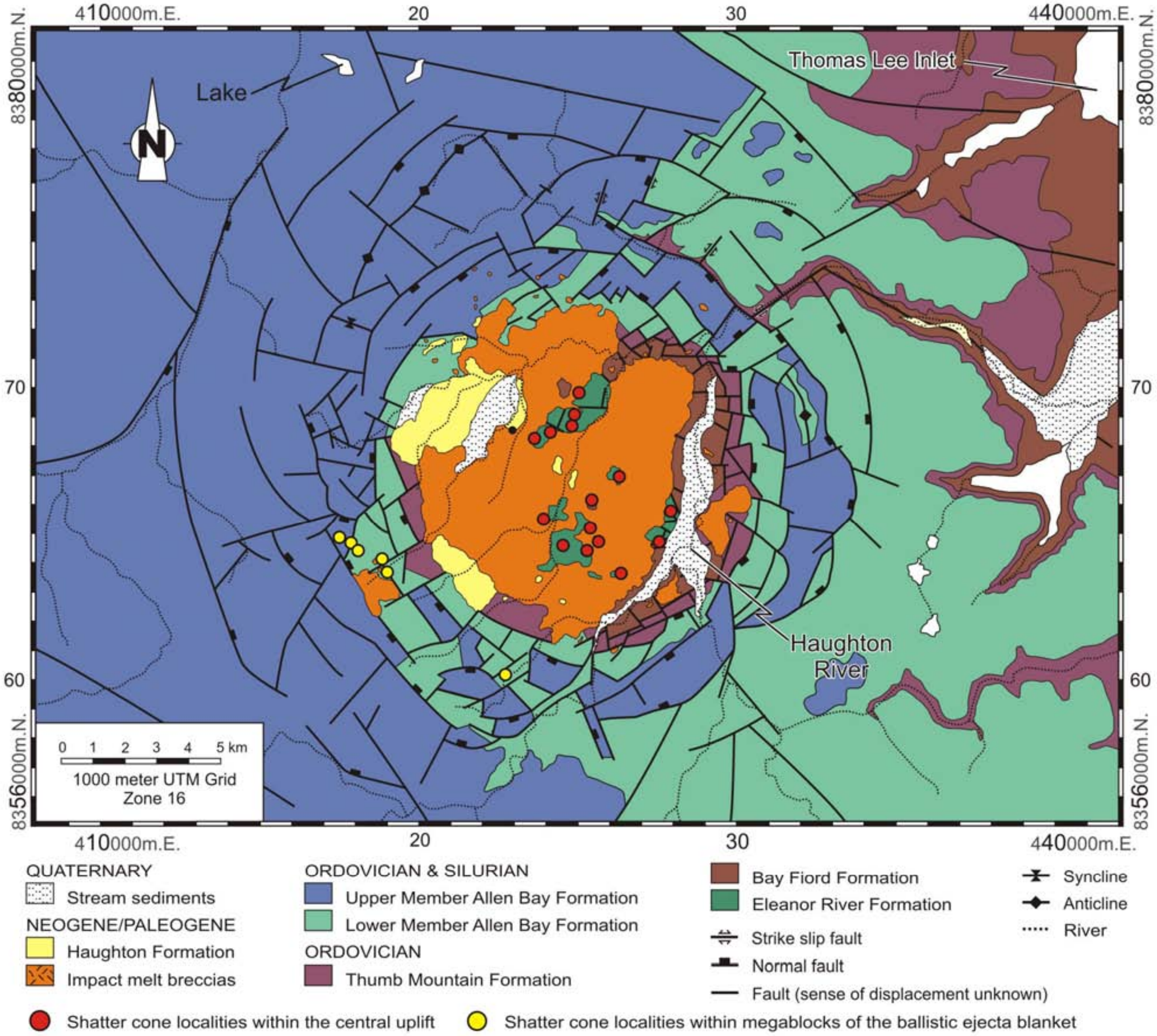

Fig. 1. Simplified geological map of the Haughton impact structure, Devon Island, Canada. Shatter cone localities within the central uplift and ballistic ejecta blanket are highlighted. Note that shatter cones are found throughout the crater-fill impact melt breccias so these localities are not shown. Modified after Osinski [13].

4. SHATTER CONES OF THE HAUGHTON IMPACT STRUCTURE

Shatter cones are common and extremely well developed at Haughton. They were first recognized by Robertson and Mason[14] and are best developed in fine-grained carbonate lithologies. The excellent preservation state and exposure at Haughton allow a detailed study of the shatter cone distribution and morphology to be conducted. Detailed mapping carried out by GRO over the course of 7 field expeditions reveals that shatter cones occur in three main settings at Haughton (Fig. 1): (1) within uplifted and rotated strata of the central uplift (Fig. 2); (2) within megablocks of the ballistic ejecta blanket (Fig. 3); and (3) within clasts in allochthonous crater-fill impact melt breccias (Figs. 4, 5). The latter are the main focus of this preliminary study.

4.1 Observations

Carbonate clasts within the allochthonous crater-fill impact melt breccias at Haughton show abundant and well-developed shatter cones (Fig. 4). Point counting of clasts at 4 separate locations showed that 50–60 % displayed shatter cones. Weathering in the prevailing polar desert environment tends to break down the fine-grained groundmass of the impact melt breccias so that the more resistant clasts are available for study on talus slopes. This affords an exceptional opportunity to study the 3-D nature of shatter cones.

The important results of our observations of shatter cones from the Haughton structure are summarized below:

- Apical angles range up to 120°.
- While many shatter cones display curved, oblate, spoon-like surfaces (cf., [7]), many are also conical (Figs. 5a, b).
- Apices often point in opposite directions (Figs. 5b–d).
- Complete cones are present in ~5–10 % of the samples studied (Figs. 5a,b).

Fig. 2. Shatter cones developed in fine-grained limestones of the central uplift of the Haughton impact structure, Canada. The height of the image is 18 cm.

Fig. 3. Field photograph of shatter cones in a limestone megablock from the ballistic ejecta blanket, near the eroded southern rim of the Haughton structure. 35 cm long rock hammer for scale.

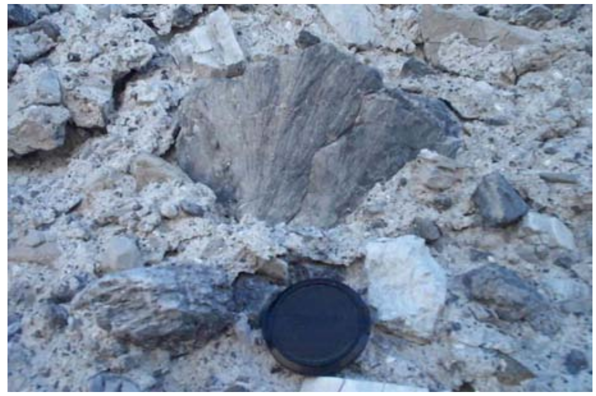

Fig. 4. Field photograph of a large carbonate clast (above 6 cm diameter lens cap) with well-developed shatter cones included within crater-fill impact melt breccias. All the clasts in this image are carbonates.

5. DISCUSSION

Shatter cones within central uplifts have been documented at many complex terrestrial impact structures, and have been studied in detail at a few sites (e.g., Beaverhead, USA [15]; Kentland, USA [7]; Sudbury, Canada [16]; Vredefort, South Africa [17]). In this study, we have presented the first detailed observations of shatter cones from allochthonous crater-fill deposits at a terrestrial impact site. These results have some important implications for the currently proposed models for the origin of shatter cones.

The Haughton shatter cones display many of the characteristics typical of shatter cones from other impact sites (e.g., striated surfaces, horsetail structures). The formation of such features can be explained by the models of Baratoux and Melosh [6] and Sagy et al. [7, 8]. However, the presence of shatter cones with complete cones and apices pointing in opposite directions is not explained by the model of Sagy et al. [7] in which shatter cones are "branched, rapid fractures formed by shock impact". These authors also concluded that shatter cones "are intrinsically not conical", which is at odds with our observations from Haughton.

In the model of Baratoux and Melosh [6], conical, complete cones result from conical tensile fractures that are produced by the interference of a scattered elastic wave by heterogeneities in the target rock. However, shatter cones with apices pointing in different directions, as noted at Haughton (this study) and Vredefort [17] were not produced in the numerical simulations of Baratoux and Melosh [6]. This may, however, be due to the simplified nature of the target in these numerical models. Thus, neither of the currently proposed models for shatter cone formation can explain all the features of shatter cones from terrestrial impact structures.

The abundance of shatter cones within the crater-fill deposits at Haughton is also interesting. Shatter cones form a plane of weakness along which a rock may break apart. The presence of shatter cones within crater-fill deposits at Haughton also indicates that they form early in the cratering process (i.e., during the contact and compression stage). Thus, the target will be pervaded by shatter cones during the opening up of the transient cavity during the subsequent excavation stage. We suggest that shatter cones may, therefore, play a role in weakening the target prior to collapse during the modification stage, which appears to be necessary to form complex impact structures [18].

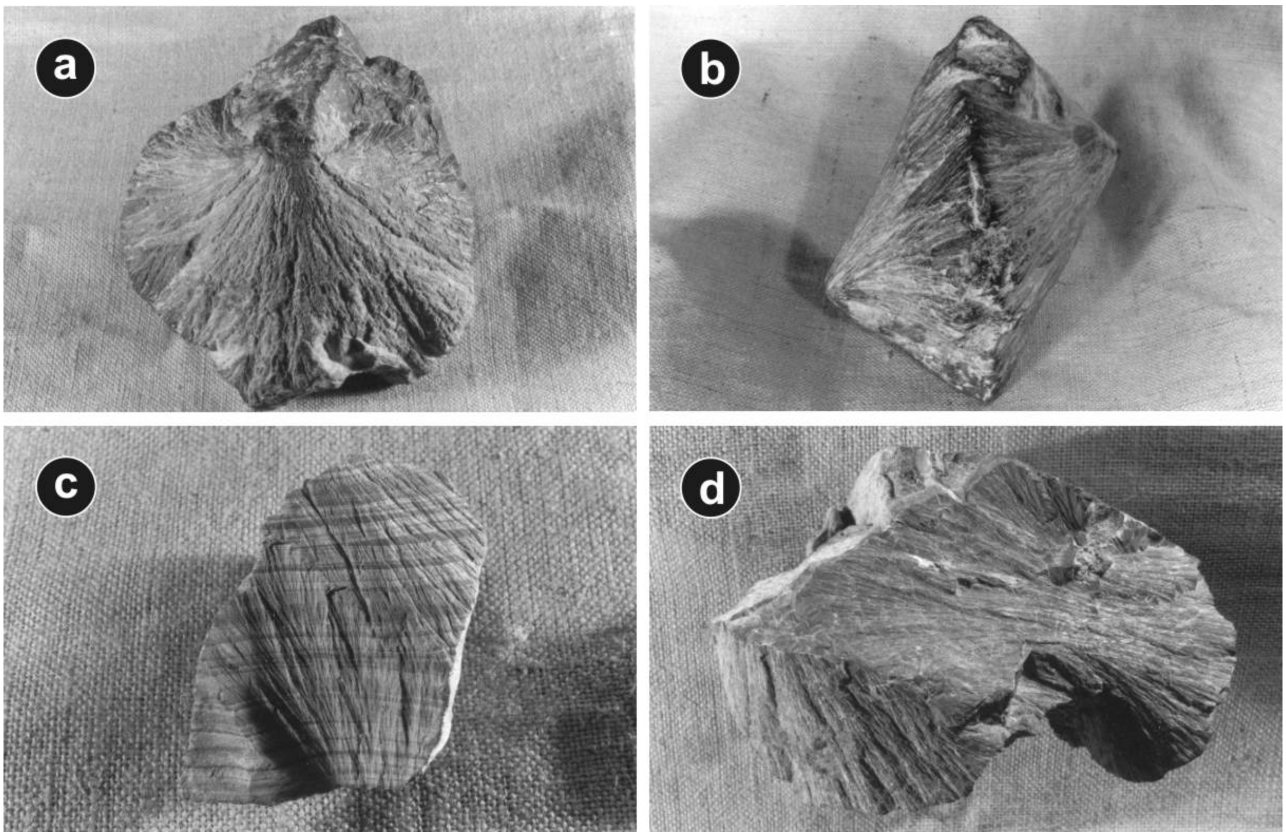

Fig. 5. Hand specimen photographs of carbonate clasts with well-developed shatter cones from the Haughton impact structure. (a) A well-developed shatter cone ~14 cm in diameter. (b) Two complete cones pointing in opposite directions. The specimen is ~13 cm across. (c) Shatter cones with apices pointing in opposite directions. Note the faint horizontal bedding. Specimen is ~6 cm across. (d) Several shatter cones are present in this clast. Note that the striations on the large face converge and then diverge (i.e., these are two shatter cones whose apices meet).

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