# Casualties of War: Microstructural damage to stone heritage by ballistic impacts

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## 1. Introduction

Contemporary conflicts have seen a resurgence in ideologically-driven destruction of cultural heritage, such as the sacking of Mosul and Palmyra by ISIS/Daesh[1]. The impact of ballistics on stone heritage is part of a wider spectrum of imposed damage, having serious implications for structural integrity and strength of masonry. Characterising this damage is vital for future preservation and protection of monuments as the power of small arms continues to increase. Ballistic impacts generate dynamic fracture events which require a comprehensive approach of methodology to quantify. We report our intended methods, our research directive and investigative questions. Microstructural analysis using approaches applied to meteorite impacts and endogenously deformed rocks may be applicable.

## 2. Sample Generation

15x15x7.5cm blocks of sandstone from the Huesca region of Spain were shot with a 7.62x39mm round fired from an AK-103 assault rifle at a range of 200m (Fig.1). The sandstone was selected for its suitable homogeneity in matrix distribution for preliminary observations. Future sample blocks are to be scaled up to 15x15x15cm in the hopes of fully containing internal fracture networks by preventing full perforation.

## 3. Impact Crater Morphology

- Photogrammetry will be used to generate 3D models of impact damage to quantify material loss and crater dimensions.
- Visible surface damage is the 1st stage in our comprehensive approach to quantifying damage.
- The observed fracture geometries exhibit similarities with faults and fractures associated with meteorite impact craters (Fig. 2-3).

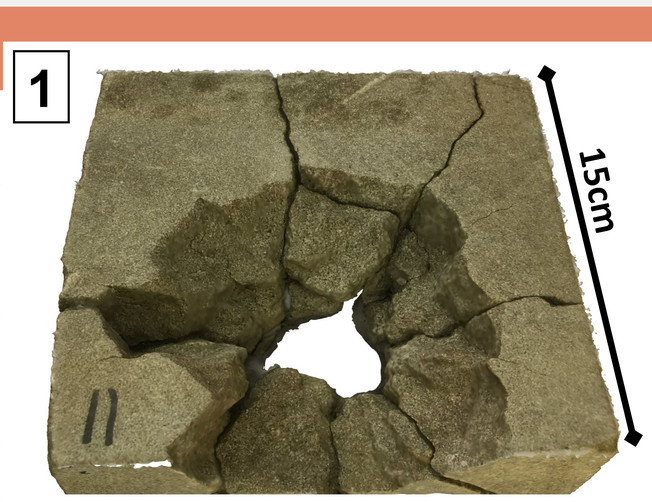



**Figure 1**: Exit cavity in a sandstone block perforated by an AK-103 rifle round.

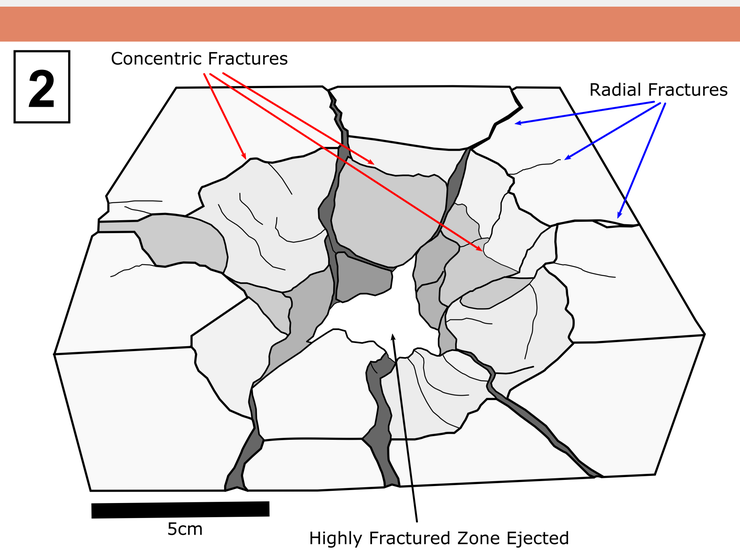



**Figure 2**: Schematic of exit cavity seen in figure 1 highlighting radial and concentric fracture geometries.

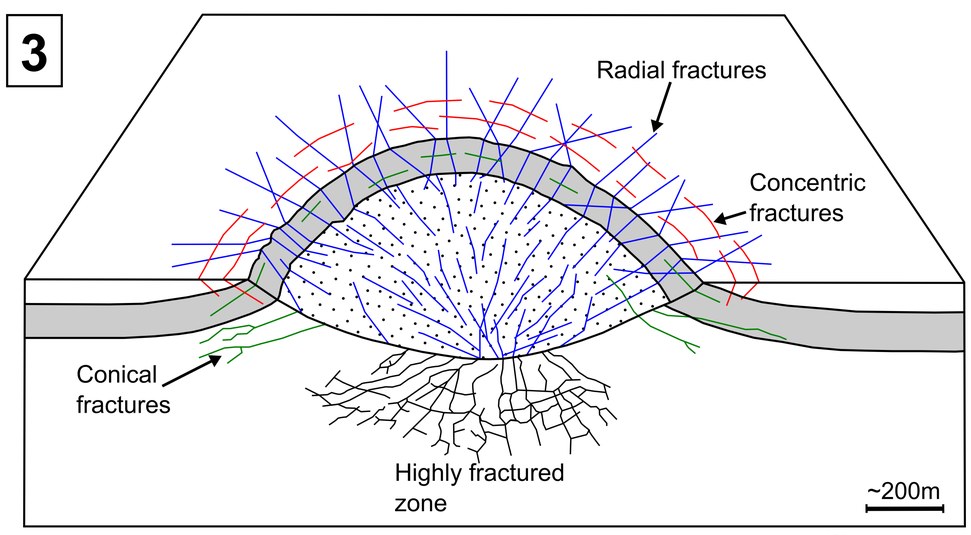
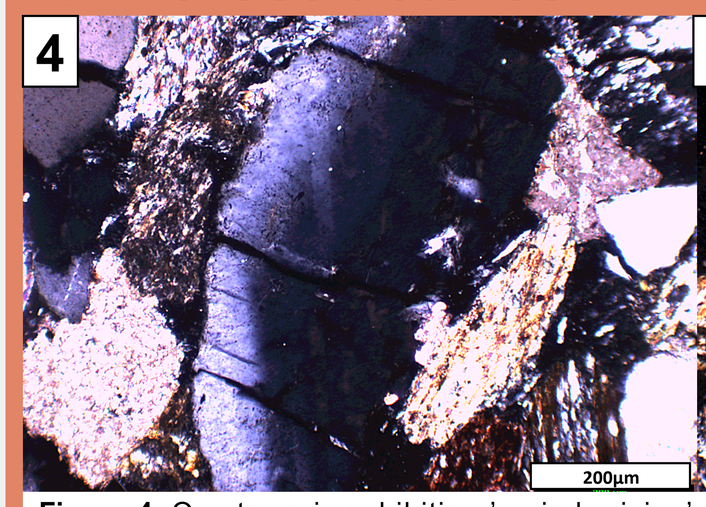



**Figure 3**: Schematic diagram of the Meteor Crater in Arizona[3]. Radial (blue), concentric (red) and conical (green) fractures centre around the point of impact.

## 4. Microstructures



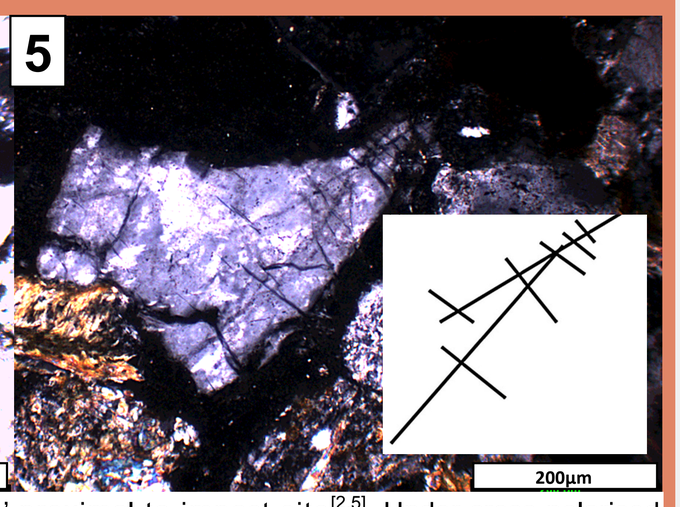




**Figure 4**: Quartz grain exhibiting 'grain bruising' proximal to impact site[2,5]. Under cross polarised light.

**Figure 5**: Microfractures in quartz grain adjacent to the impact site. Inset highlights perpendicular and parallel geometric relationship also observed in shocked quartz[2,5]. Under cross polarised light.

- Characteristic shock features such as 'grain bruising', and the geometry of microfractures found adjacent to the impact site suggest ballistic impacts may form a low-pressure end member to shock deformation microstructures[2].
- With this information we can begin to understand the damage ballistic impacts impose at the grain scale.

## 5. Fracture Analysis

- The morphology of fracture surfaces at the macro and micro-scales will inform on the mechanisms of dynamic fracture propagation.
- Combined with fracture topology, a comprehensive understanding of imposed fracture networks from ballistic impacts can be devised. In the long term, the connectivity and extent of fracture networks increases susceptibility to detrimental weathering effects [2].


**Figure 6**: Photo of planar fracture surface through a quartz grain.

## 6. Project Objectives

Through the application of the methods mentioned here, as well as the development of new ways to characterise impact damage, we seek to fulfil the following objectives:

- Characterise crater morphology in 3D.
- Quantify fracture network properties in 3D.
- Quantify fracture surface morphology and relate this to dynamic fracture processes.
- Form a comprehensive scheme of assessing ballistic damage in building stone.

## 7. Acknowledgements

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TSG Tectonic Studies Group of The Geological Society

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