Using 3D imaging to map bullet impacts in sandstone

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Introduction

Bullet impacts on heritage surfaces are increasingly a concern for conservation scientists; the escalating conflicts in the Middle East are often in the news for the deliberate targeting of heritage sites. The full destruction of sites, using large-scale force such as dynamite, has dominated the headlines over the past year. However, impacts such as bullets and shrapnel add to the wider spectrum of damage sustained during conflict but are often overlooked. As illustrated in figures 1 – 3. To understand the long-term consequences of this type of damage we need to increase our understanding of the alterations to the surface and underlying stone of building materials.

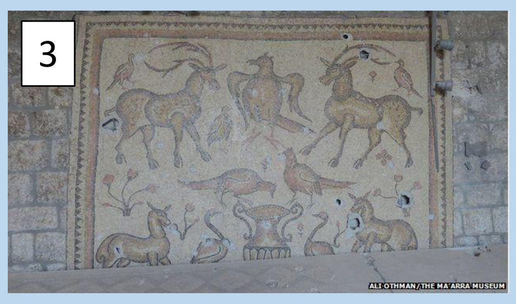


Figure 1: Bullet damage to Powick Church, ca 1640
Figure 2: Bullet damage to Hotel de Ville, Paris, ca 1871
Figure 3: Mosaic damage Ma'arram museum, Syria, ca 2015

Methodology

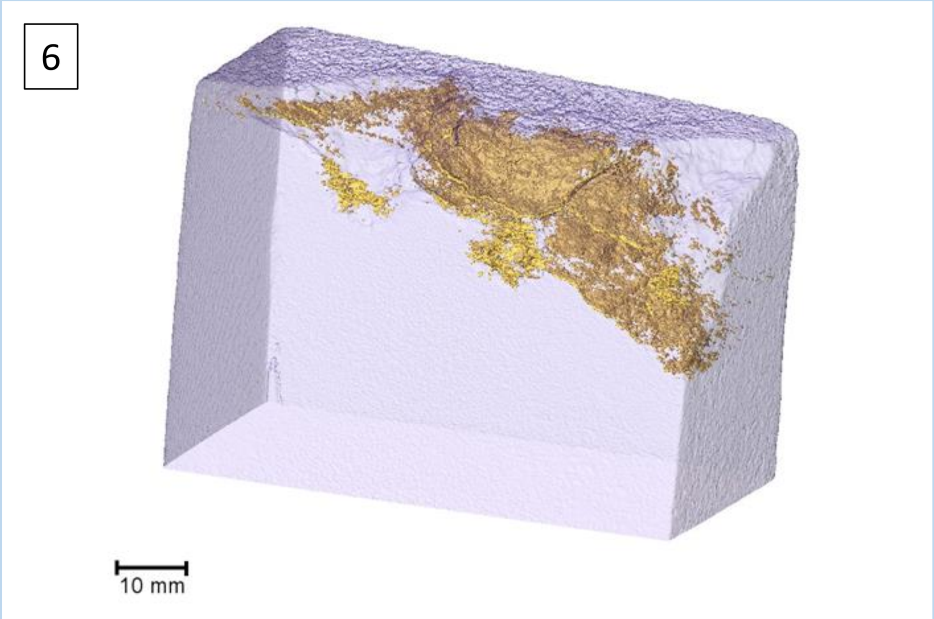
Initially sandstone samples were shot with an AK-103, which resulted in large scale fracturing of the sample (see figure 4) and rendered the samples unusable for environmental stress tests. Smaller .22 caliber lead bullets were therefore used to create contained fracture network impact sites with a Hornet rifle at 200m distance (see figure 5).
The sample was cut to encompass only the bullet impact, and to create a subsample of suitable size for micro- computed tomography (µCT) at the Manchester X-Ray Imaging Facility (MXIF), University of Manchester. The specimen was scanned in a 320/225kV Nikon XTEK bay (Nikon Metrology Ltd., Tring, UK) at 300kV and 50µA, with 1s exposure time over 3142 projections. The resulting voxel size was 0.052µm. The scan was reconstructed using the software CT Pro and imported into Avizo (FEI VSG, Bordeaux, France) for segmentation. Fractures were isolated using a top-hat transform, and compression zones segmented using a greyscale-based isosurface.

Figure 4: 3D scan of AK103 impact

Figure 5: .22 clibber lead bullet impacts at the Caldicot rifle range

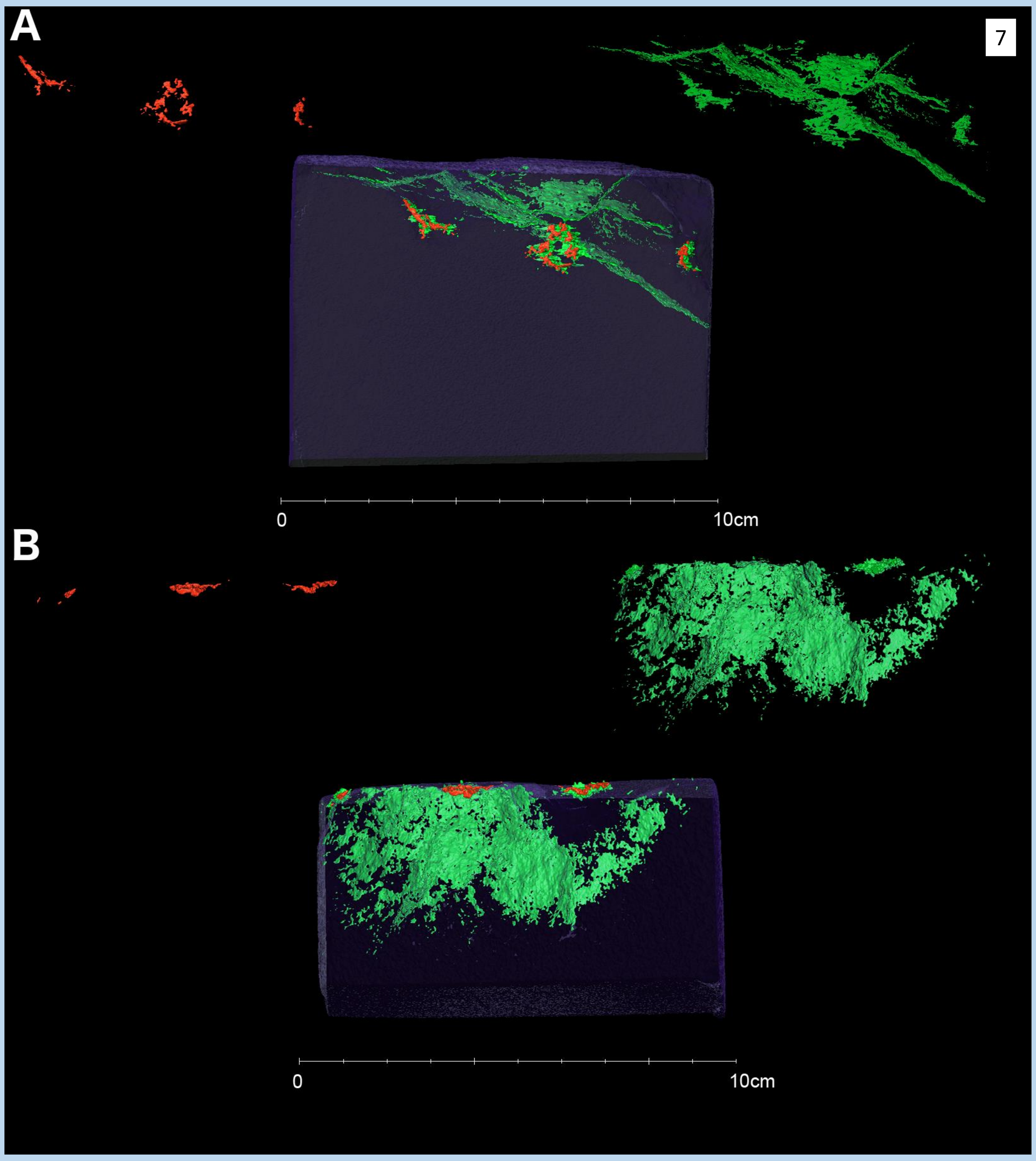
Results

These results are shown in figures 6 and 7, where the impacts coincide with compacted areas, whereas the fractured area intrudes into the surface, radiating out from underneath the impact zones. The damage appears to have been caused by stress travelling into the block as the bullet hit, towards the edges of the block while following a bedding plane within the stone sample. This exploitation of a pre-existing weakness is a commonly observed mechanism in stone under environmental stress. These results also confirm the creation of compaction areas at the site of impact which in turn effects impact site response to environmental stress and potential for long-term deterioration.



Left:
Figure 6: Initial X ray of block showing impact area

Right:
Figure 7:X-Ray of impact areas, green demarcates areas of low density (fractured) whereas red indicates areas of higher density, likely to be lead deposits. A, frontal view (line of sight parallel to travel of bullet); B, top-down view



Discussion & conclusions

While the damage on the surface may only be visible at the direct impact point, the actual weakening of the stone may be far more widespread through the material than previously thought. Formation of fracture networks due to projectile impact is not a new concept, this research places it in a new context by combining weathering and impact studies that tend to be restricted to engineering investigations, and setting it in the context of the complexity of heritage in conflict areas.

Armed warfare is becoming an increasing threat to heritage as the availability of weapons and their impact potential are increasing. These tests are based on relatively small bullet impacts with minimal the surface material loss, yet the geomorphological impact was far greater than the eye would have suspected. This research provides a small first step in understanding the effect of bullet impacts on porous stone, and the potential long-term consequences for deterioration process rates and heritage conservation.

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