Mortar damage to heritage

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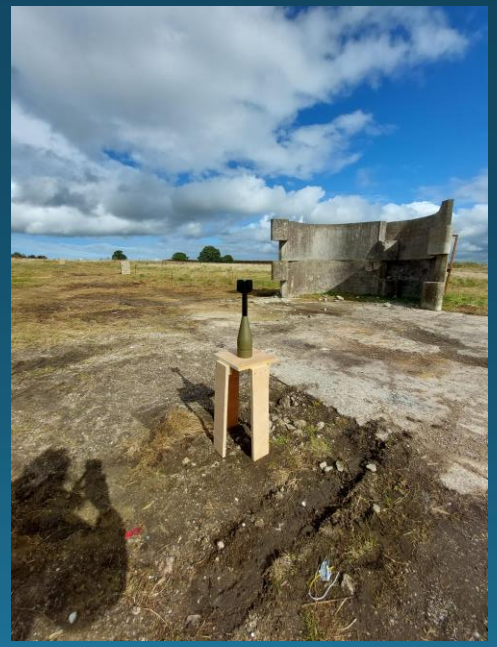
Heritage in the Crossfire project

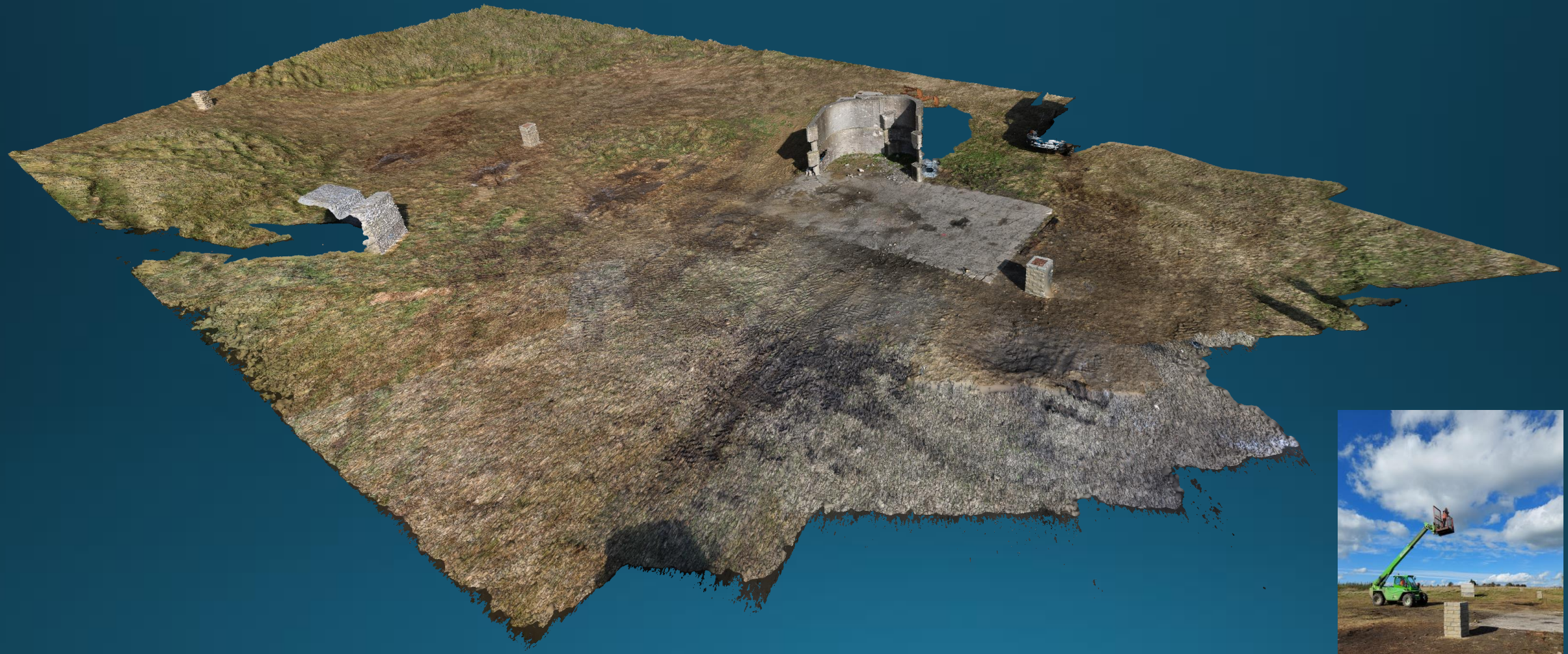
- Geoscience methodology application to conflict damaged-heritage
- Ballistic and explosive impacts are high-energy, short-duration stone deterioration events
- They inherently alter the material properties of the stone structure
- This influences long-term response to environmental stress and associated deterioration patterns

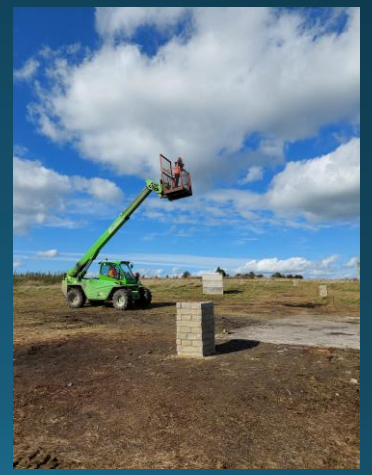
Roman theatre, Sabratha, Libya. Credit: DoA Libya

Mortar damage study

- Explosives arena trials at COTEC
- 3 Pennant Sandstone structures, chimney shaped
- Situated at 5m, 20m and 50m from the blast centre
- Mortar bomb 81mm HE L41A1 fused L127A3
- Effective kill radius 35m – expected damage zone

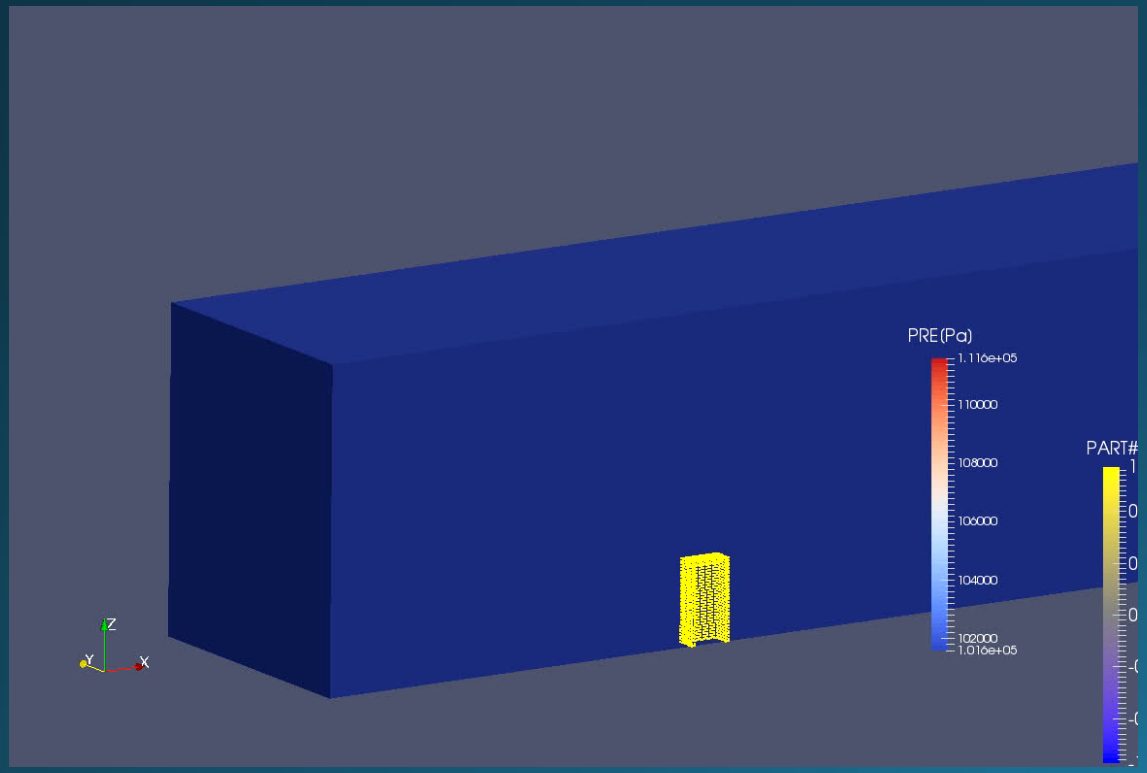




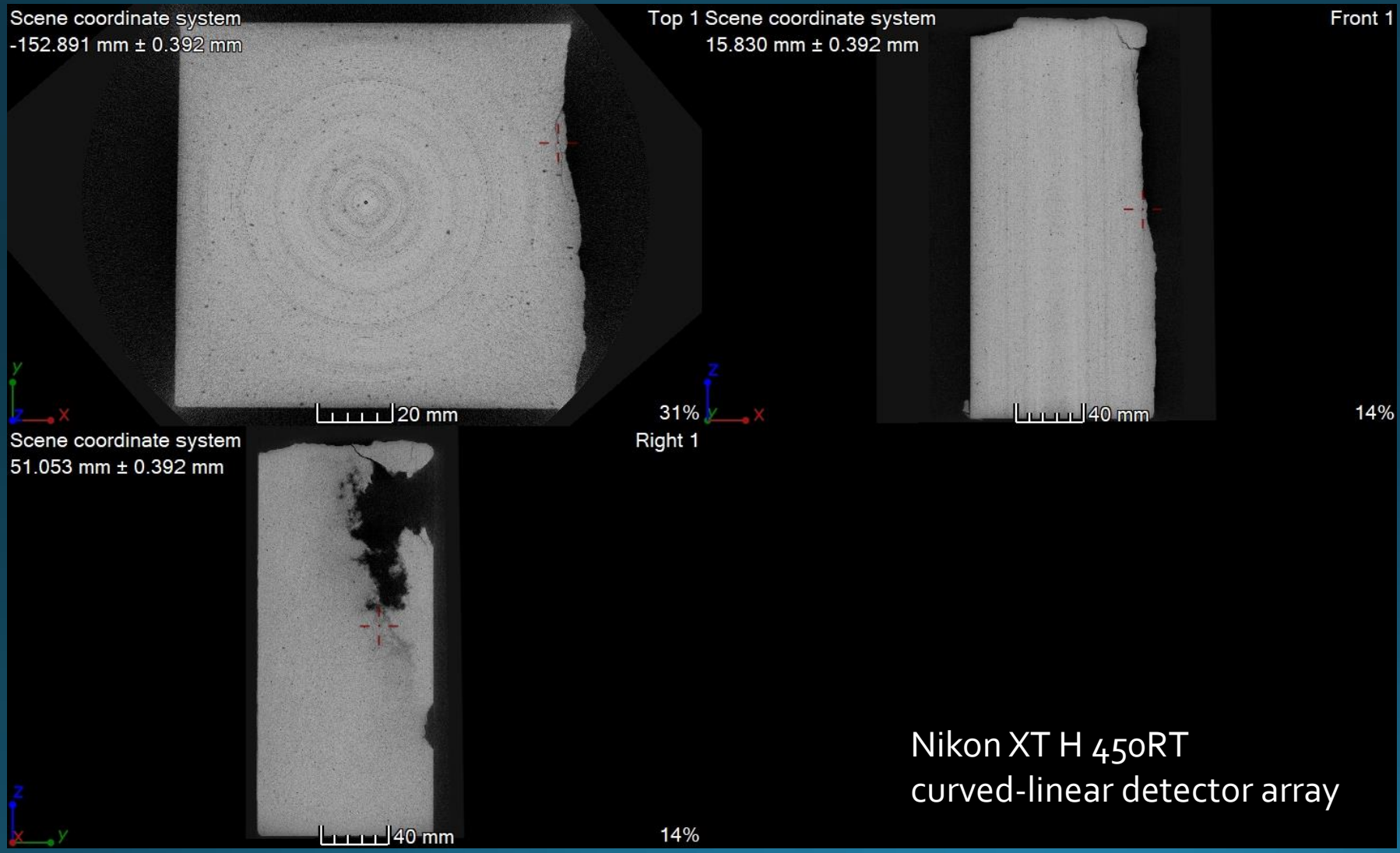


Blast impact

- Relatively few changes detected visually after the detonation
- Photogrammetry confirmed relatively few shrapnel impacts
  - Shrapnel impacts estimated to be at 219-284m/s
- Dstl blast modelling confirmed high pressure blast hit front face, then deforms and progresses

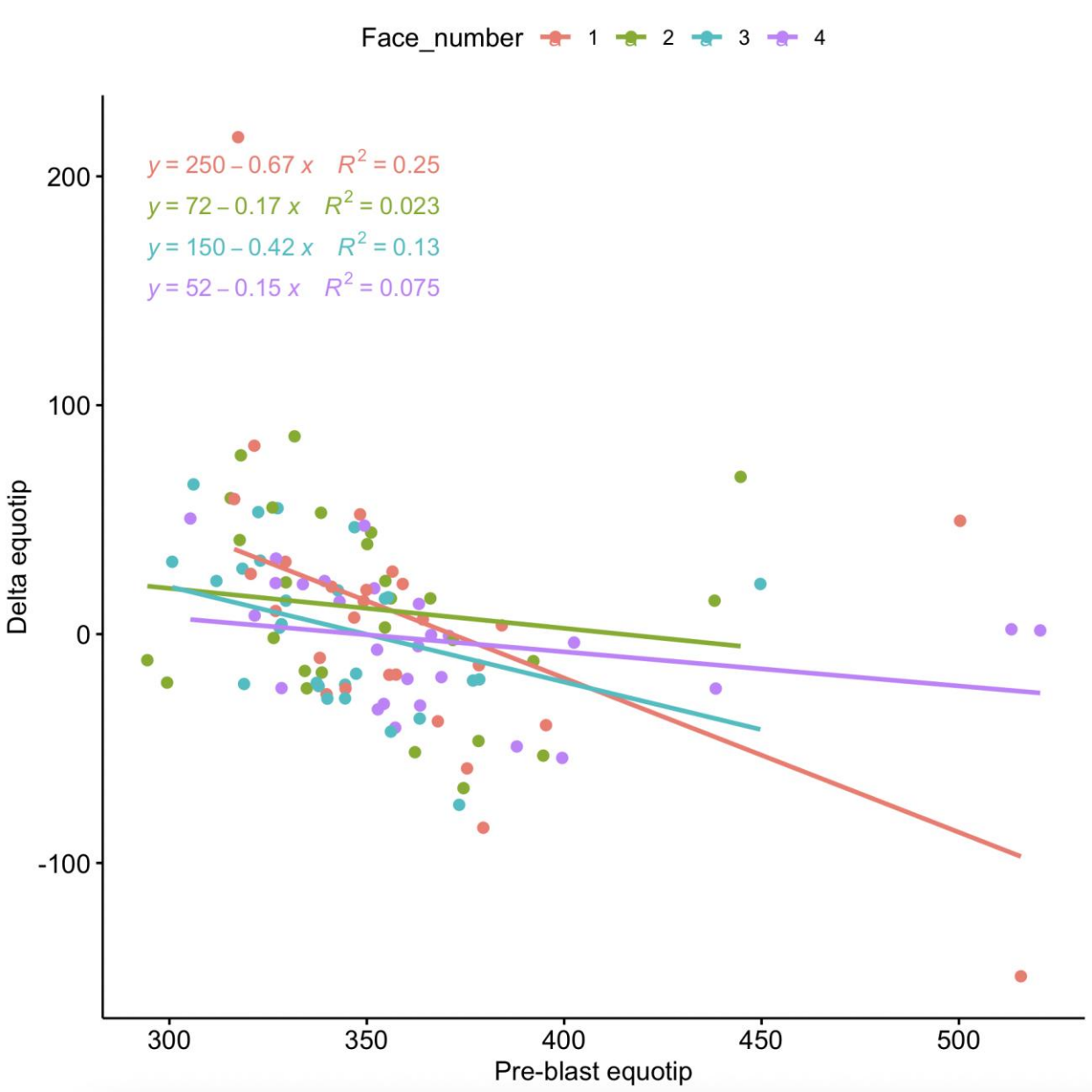


Internal changes – CLDA scan



Rock surface hardness changes

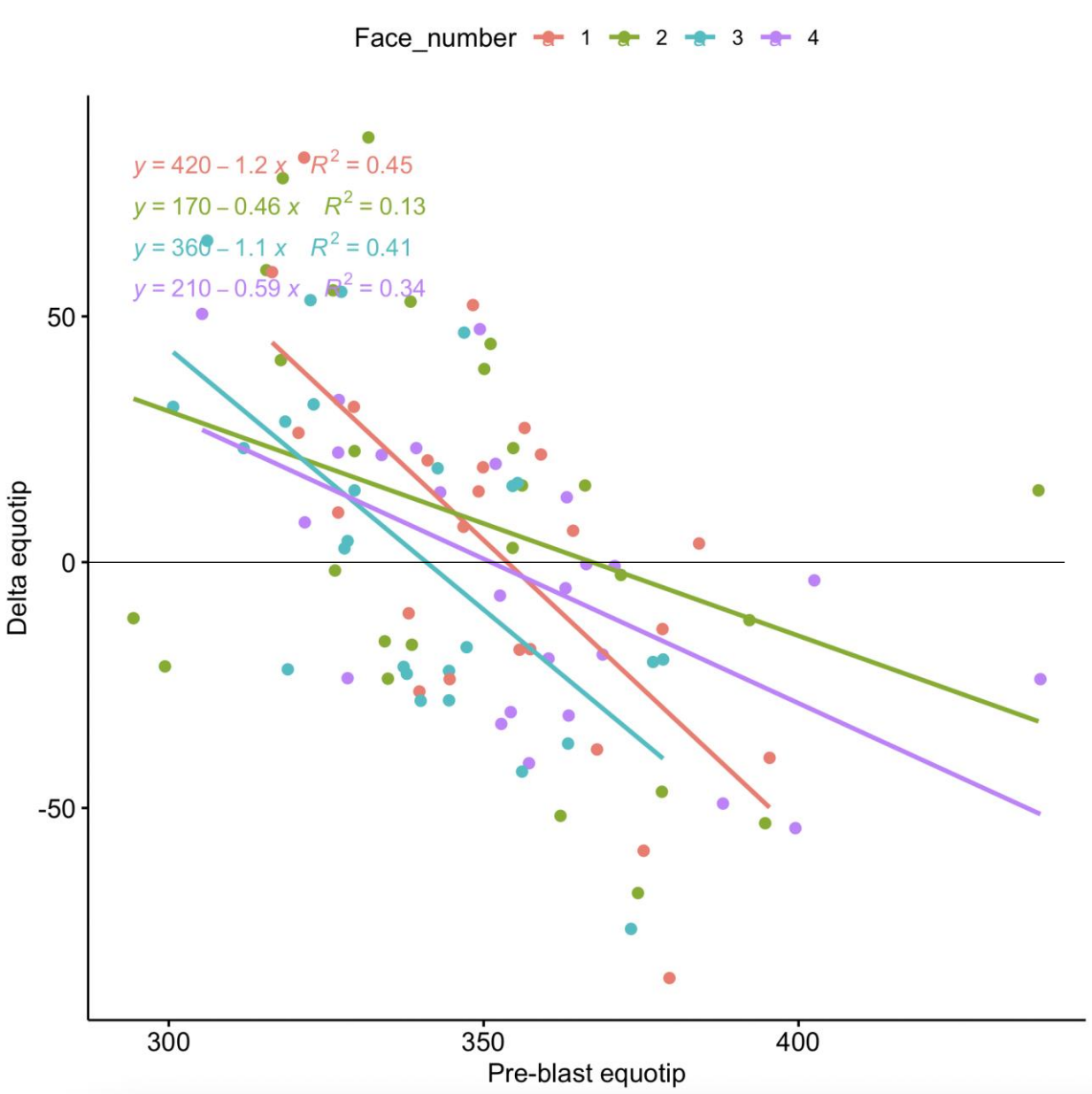
- 2160 equotip measurements on wall 1 (4 faces x 27 bricks per face x 10 measurements per brick x before/after damage)
- **Delta** values calculated as post blast equotip values – pre blast values on a 'per brick' basis
- Hypothesis:
  - Bricks initially characterized by **high** values of hardness will experience **-ve** delta i.e. become less hard



Our hypothesis would predict negative slopes i.e. harder regions show brittle failure behaviour and become less hard after blast, softer regions show plastic failure behaviour, becoming compacted (harder) after a blast)

Graph **pre-outlier removal**

Data does not pass tests for normality or homogeneity of variances



Outliers identified via cooks.distance in R (7 points identified and removed)

Significant negative slopes (as per hypothesis) for all 4 faces

ANCOVA to test for differences in slope between faces

Pre-tests
Pruned data passes shapiro test:

- No evidence of non-normality (W=0.99, p=0.54)

Pruned data passes Levene test (F=2.59, p=0.04)

After adjustment for pre-blast hardness, delta hardness was **not significantly difference** between the faces, F(3,96)=0.82, p=0.49

No pairwise comparisons of slopes are significant (p>0.30)

This means that **all** measured stones were affected by the blast pressure, even those at the back of the structures and outside of the direct blast progression

How do we apply this?

- Current field applications:
  - Royal Garrison Church, Portsmouth UK (historic blast damage)
  - The Stock Exchange, Bath UK (historic blast damage)
  - Sabratha, Libya (contemporary conflict)
  - National Preserve Kyiv-Pechersk Lavra, Ukraine (preparation for blast damage)
  - Remote sensing applications – supporting colleagues in active war zones

Al-Qahira Castle, Taiz, Yemen 5 June 2015
Source: Washington Post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42 m
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Thank you for your attention

Any questions, please contact me: lisa.mol@uwe.ac.uk

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