The effect of grain size and porosity on compaction localisation in high-porosity synthetic sandstones

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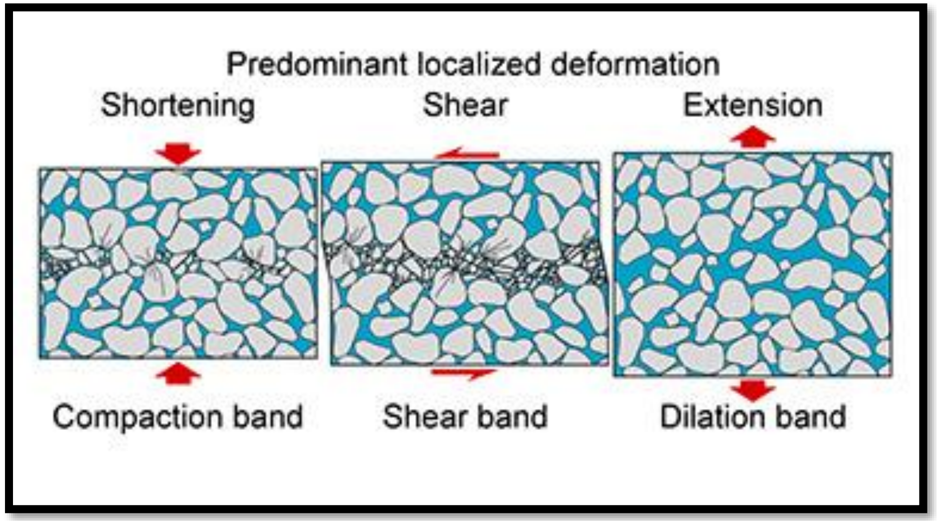
What are compaction bands?

- Localised bands of deformation, which form sub-perpendicular to the maximum principal stress orientation in the subsurface

- Generally associated with intense grain fracturing, lower porosity and several order of magnitude lower permeability than the surrounding rock

- Costly to tackle in hydrocarbon, water and CO_2 sequestration industries



Modes of localised deformation (Du Bernard et al., 2002)

Compaction bands in the Valley of Fire, Nevada

Motivation for the study

- Compaction bands are important geological structures owing to their ability to inhibit subsurface fluid flow

- However, questions still remain regarding the properties of sandstone which facilitate compaction band formation

- Although laboratory studies have examined the effect of porosity on compaction localisation, the effect of grain size has not been studied

- In this study, synthetic sandstones with controlled starting mean grain size and porosities were used to examine the effects of these properties, with particular focus on the role of grain size

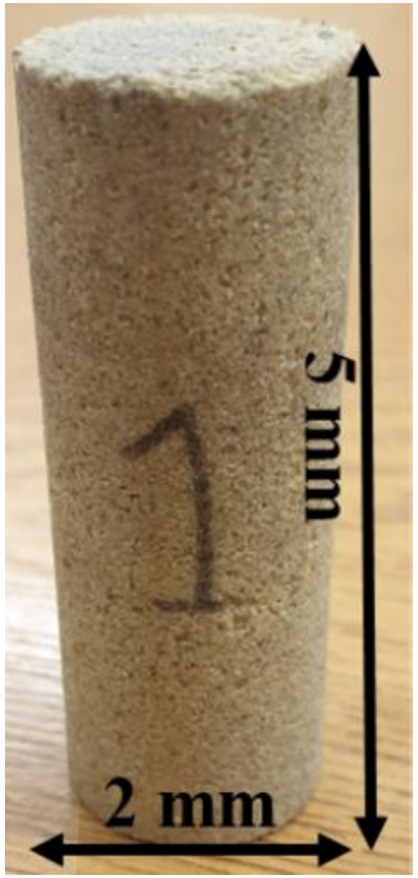
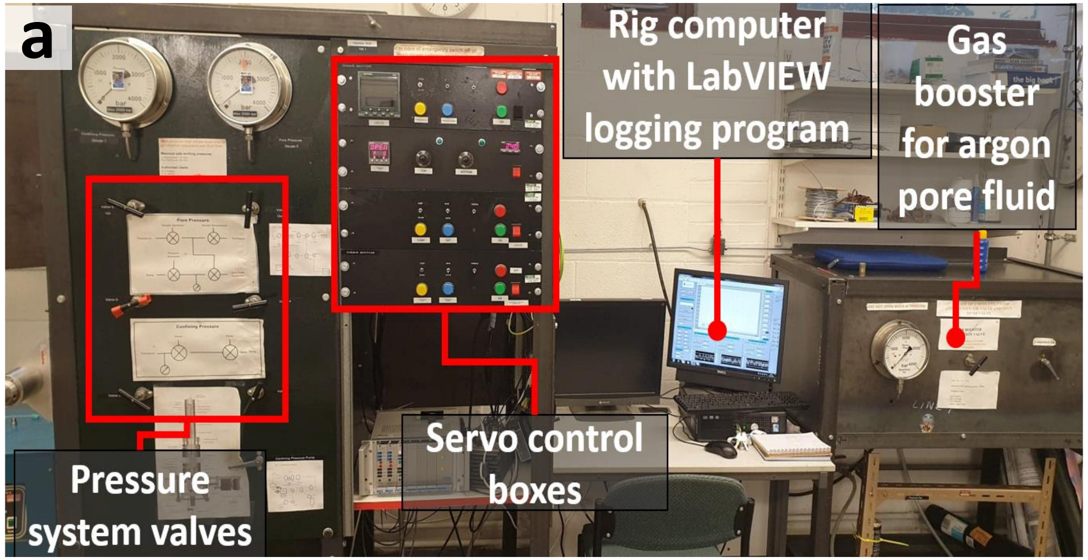


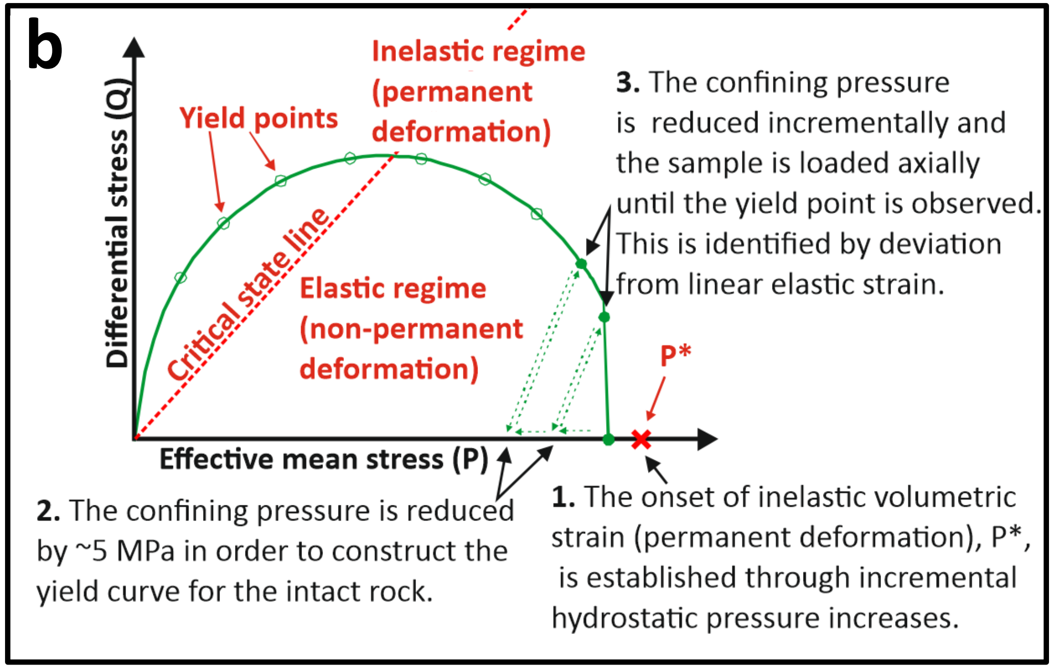
Image of one of the synthetic sandstone used in this study (Rice-Birchall et al., 2021) submitted IJRMMS

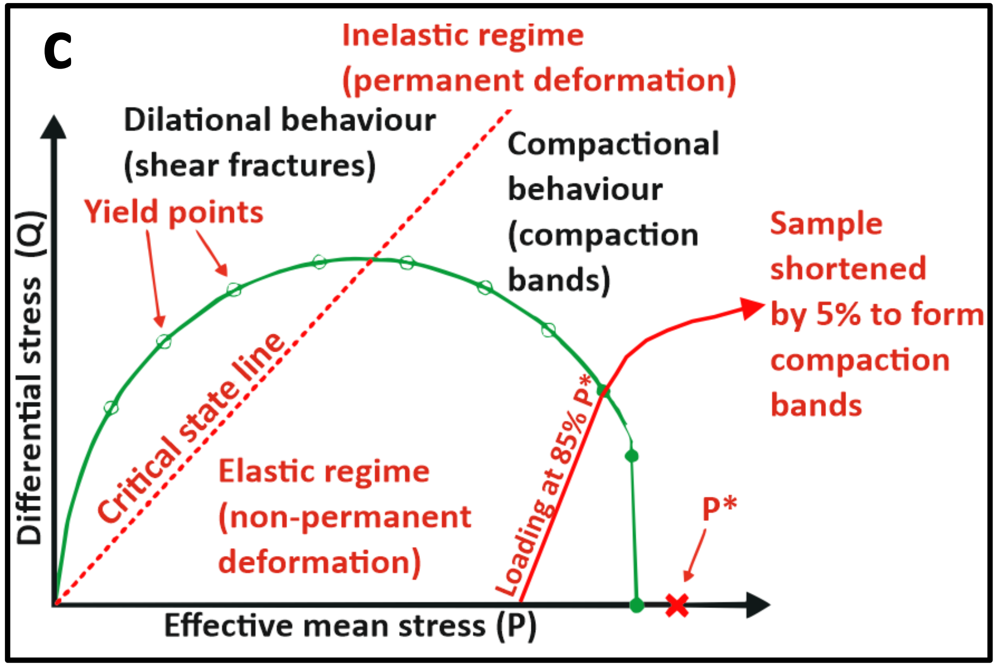
Triaxial testing methodology

- The tests were performed using a triaxial apparatus (Figure a) designed and built at the University of Liverpool (Mitchell & Faulkner., 2008)

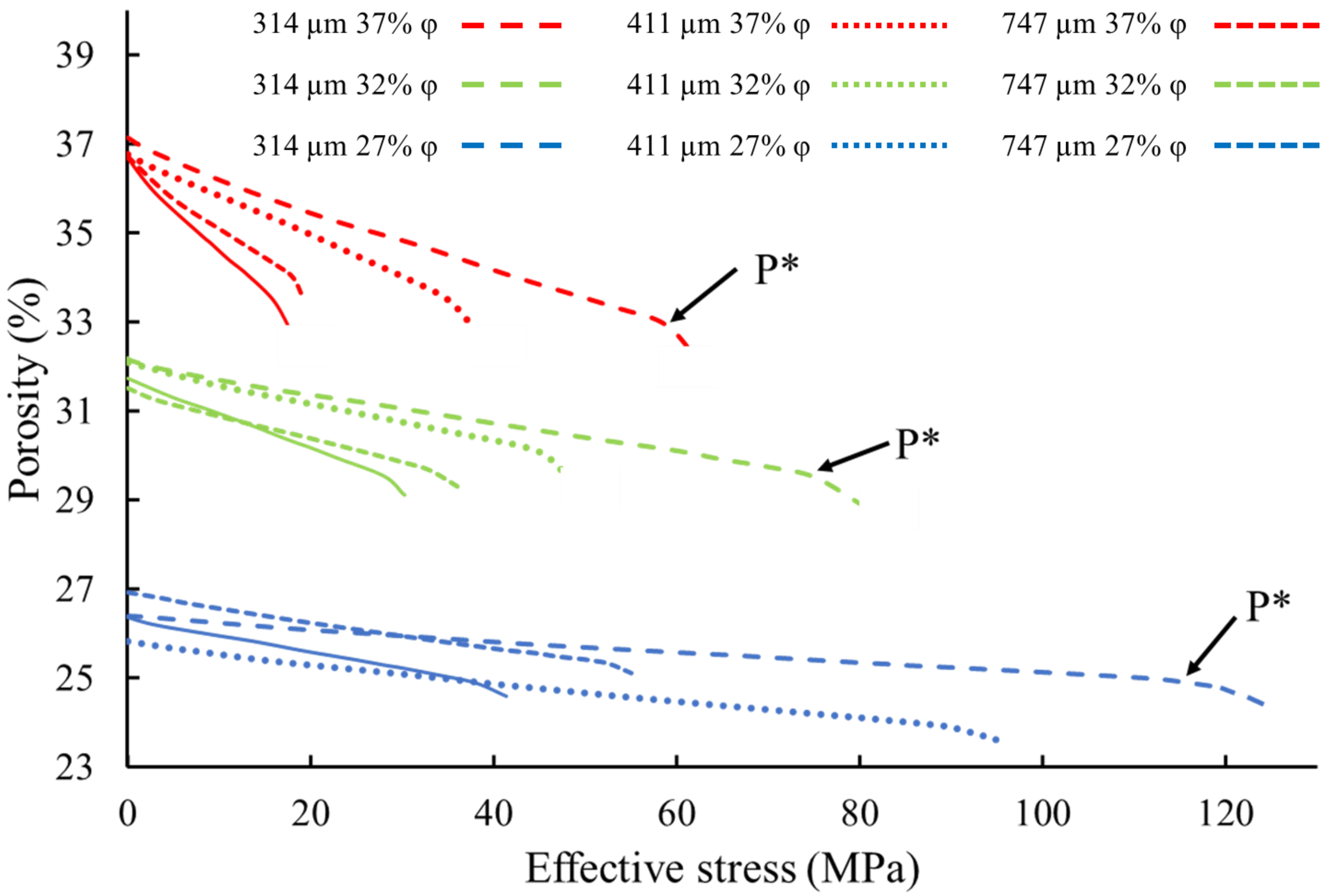
- The tests were carried out according to the hydrostatic overconsolidation technique of Bedford et al (2018) (Figures b and c)







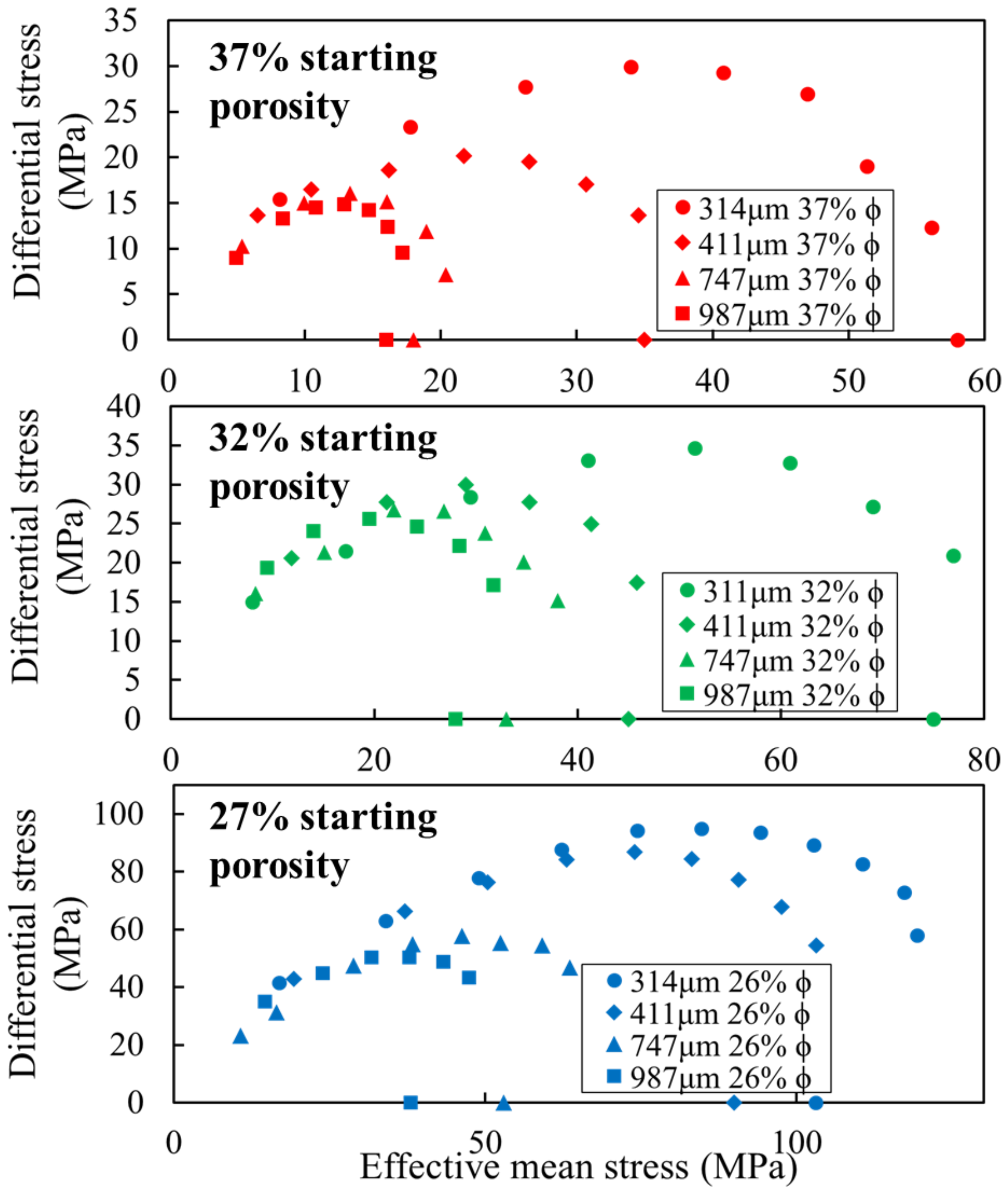
Hydrostatic loading curves



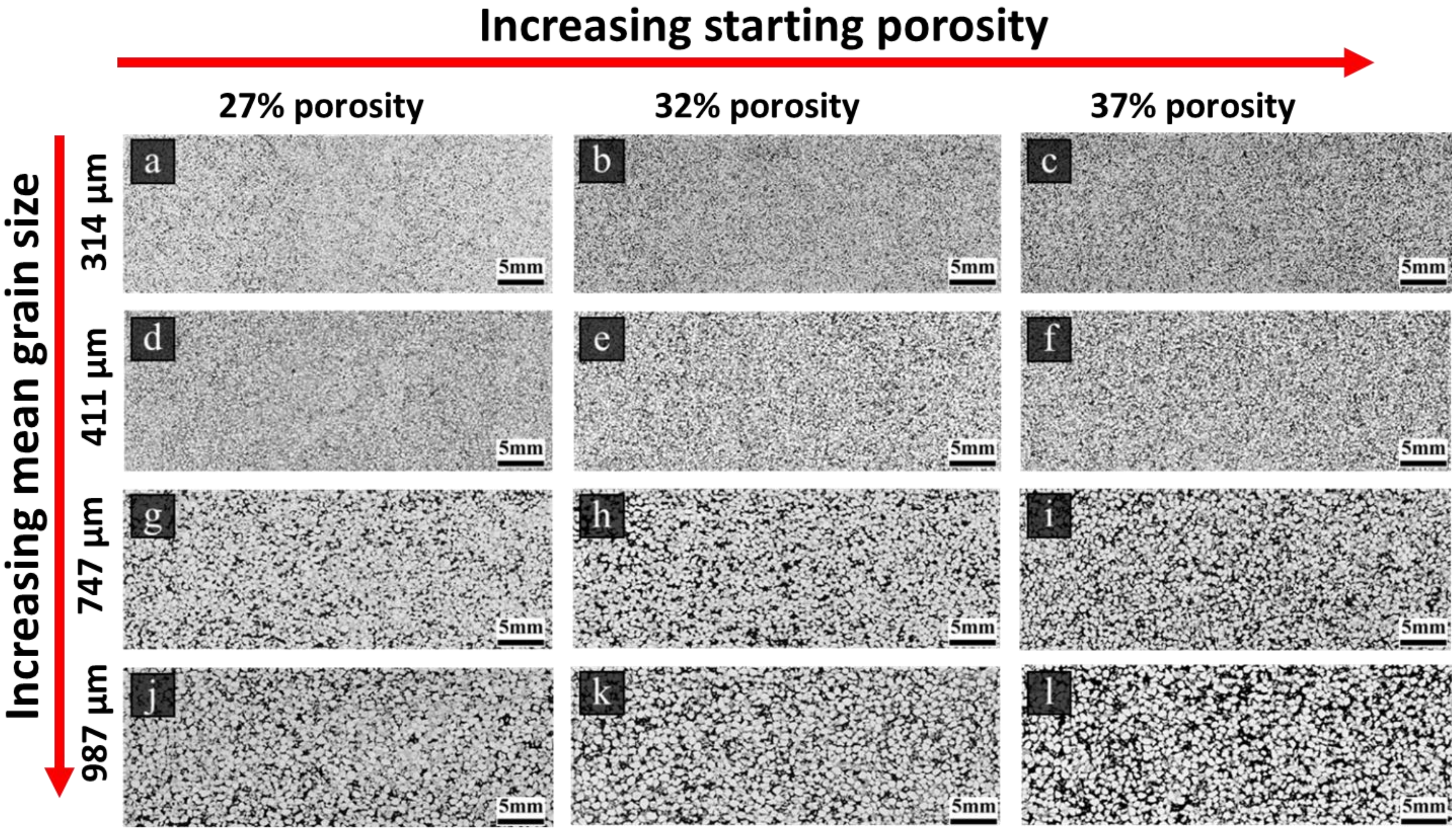
- The departure from quasi-linear elastic loading in the hydrostatic loading curves marks the onset of grain crushing and pore collapse (P*)
- Both grain size and porosity have a significant control on sandstone bulk compressibility and hydrostatic yield strength (P*)

Yield curves

- The yield curves for each of the twelve synthetic sandstones are displayed on the right
- Yield curve size and shape vary with both porosity and grain size
- At lower starting porosities the compaction limb of the yield curves appears ‘overhanging’ particularly in the larger grain sized samples

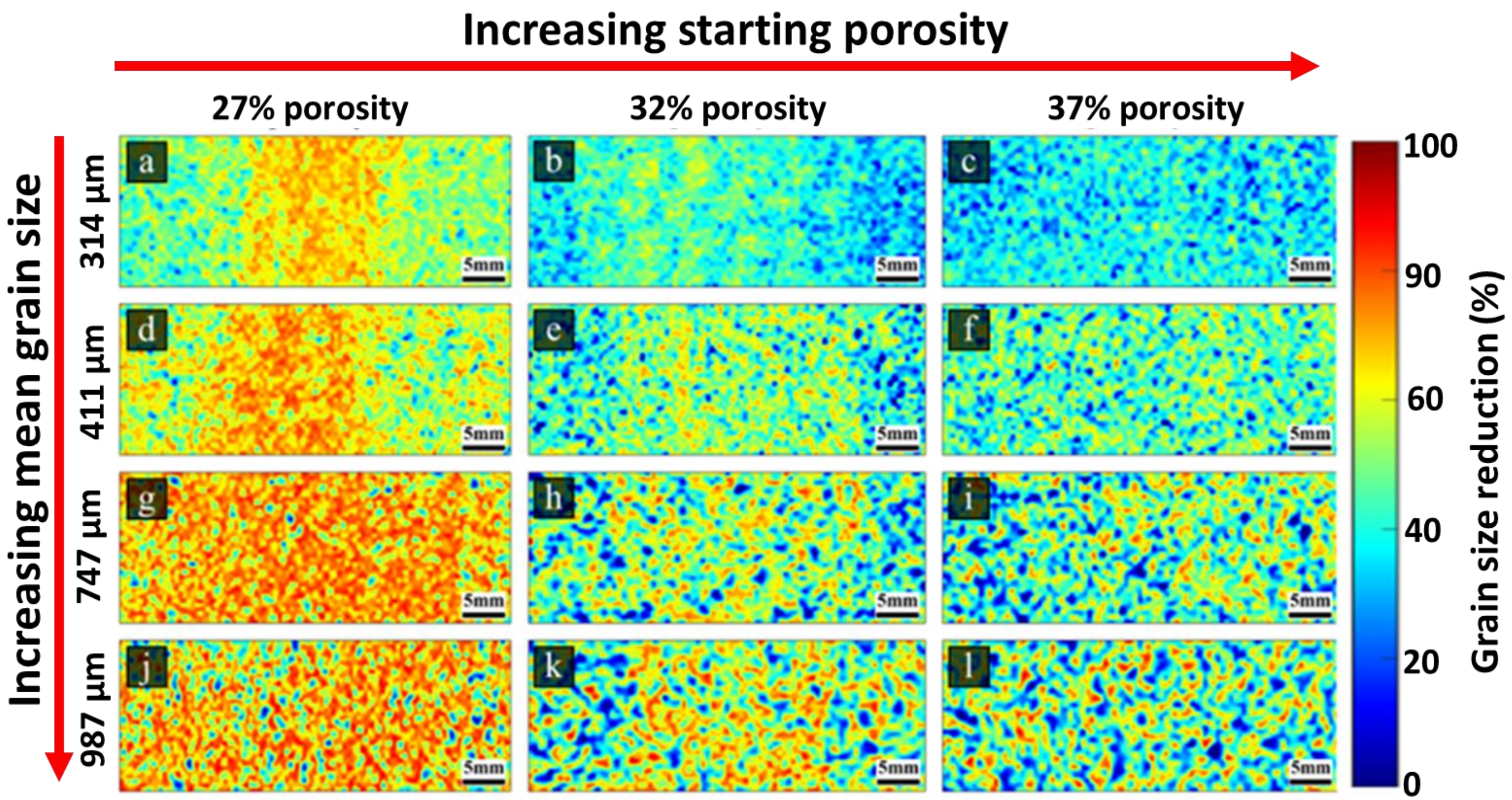


Microstructural SEM images of deformed samples



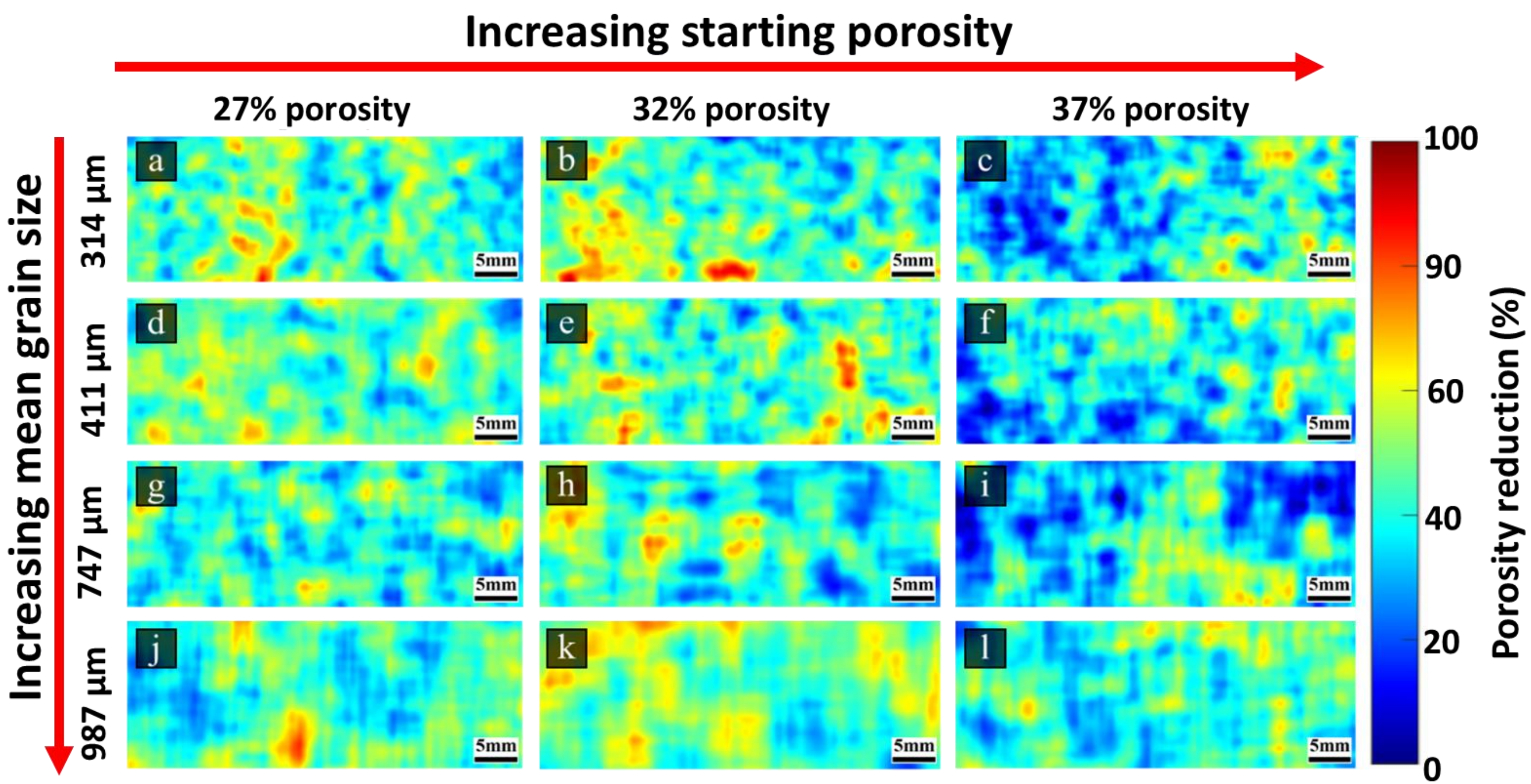
- SEM images are displayed on the left primarily to display the variation in porosity and grain size between the images
- The whole core slices were stitched together from approximately 50 separate SEM images

Grain size reduction colourmaps



- Both grain size and porosity have a significant control on grain size reduction.
- At the lowest starting porosity, deformation becomes more widespread with increasing grain size
- At medium starting porosity, deformation becomes more localised with increasing grain size
- At the highest starting porosity, deformation is relatively homogeneous

Grain size reduction colourmaps



- Unlike the grain size reduction colormaps porosity reduction shows a less clear pattern in relation to starting porosity or grain size
- Comparison with the grain size reduction map shows that grain size reduction does not necessarily relate to a porosity reduction

Conclusions

- The mechanical results indicate that grain size appears to have just as significant control as porosity on the bulk compressibility of the sandstones and their grain crushing strength (P*), while the yield curve results also indicate that these two yield properties have a significant control on yield curve size and shape

- The most localised grain fracturing was observed in the sample with the lowest porosity and smallest grain size which manifested as diffuse compaction bands

- At the lowest starting porosity (27%), with increasing grain size grain fracturing became more widespread throughout the sample. By contrast, at the intermediate starting porosity of 32% the grain fracturing appeared to become more localised with increasing grain size. At the highest starting porosity of 37% no localised grain fracturing was observed at any of the starting grain sizes.

- No such clear pattern was illustrated for porosity reduction with this being found to not necessarily relate to the regions of grain fracturing within the samples.