Fractured Reality: Lateral Variations in Fractured Shales at Outcrop, Application for Subsurface Analogues*

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Abstract

The efficiency of fracking stages in a low permeability unit can potentially be enhanced by exploitation of the natural fracture network. The use of outcrop analogue studies can be an effective strategy to provide sufficiently rich datasets to predict fracture properties away from a wellbore. Nevertheless, characteristics such as average fracture length and spacing can vary laterally across 10s of metres within a single shale bed, such that the fracture-connected distances and fracture-bound volumes vary greatly. This study describes and quantifies lateral variations in fracture parameters from an outcrop analogue for a potential UK unconventional play. Clean cliff and foreshore exposures of the Lower Jurassic Whitby Mudstone Formation (WMF), North Yorkshire, UK, have been studied to characterise the natural fractures, and, where possible, to understand the spatial variations in fracture characteristics. The WMF is a useful analogue for both the poorly exposed, time-equivalent Posidonia Shale of the Netherlands, and potential shale oil strata in Weald basin, southern England. The study focuses on shales of a single stratigraphic unit within the WMF, across a stratigraphic thickness of ~20 m and lateral extent of ~ 350m^2. Detailed fracture data have been acquired using digital and manual methods. Two systematic fracture sets with subsidiary sinuous cross joints are identified. A range of fracture properties are noted, with two end-member length distributions observed at different sample sites for one of the dominant fracture sets: one site has a significantly higher proportion of longer fractures than the other site, defining different distributions on a length-intensity plot. The positions on this plot correspond with the mean spacing / mean fracture length ratios per site, thought to be linked to the saturation of fracture system. The most saturated fractures define the upper bound of the relationship linking length and intensity. In application of analogue outcrops to subsurface data (e.g. to allow

optimal exploitation of natural fractures for a fracking stage), comparison of fracture properties observed at the well bore (e.g. fracture spacing, thus 1D intensity, and fracture interactions) with the ranges of properties observed at outcrop can be used to predict the likely fracture properties away from the wellbore. We shall discuss possible relationships that can be useful in such circumstances.

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Aims

- To demonstrate variability in shale fracture properties in a relatively homogeneous shale at an unfaulted locality
- To derive a conceptual model linking the various fracture properties
- How this could help in production from fractured shale

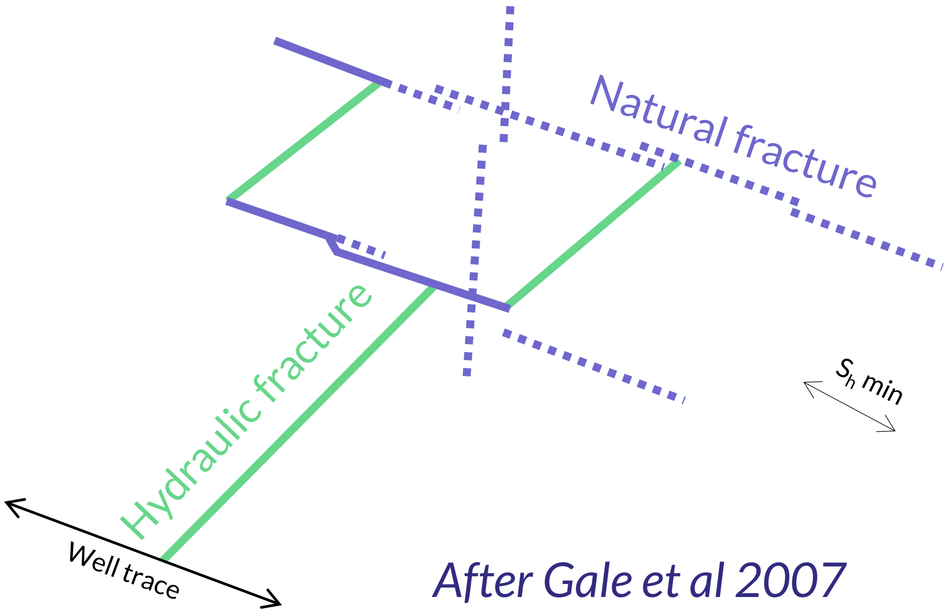
Natural Fractures & Hydraulic Stimulation

"Local knowledge on fracturing is a good starting point in any area" King, 2012

"Understanding the nature of natural fracture networks is critical", Kramer 2008

"…hydraulic frack stage placement shoulders on the need to understand the natural fracture system" Kennedy et al., 2012

"Not only do natural fractures increase the effective permeability of the reservoir, but they also affect the propagation pattern of the hydraulic fractures..." Kumar et al., 2016



After Gale et al 2007

Natural Fractures & Hydraulic Stimulation

Mayerhofer et al., 2010:

- Natural fractures & microseismic >>stimulated reservoir volume (SRV)
- Reducing spacing (increasing total fracture length) improves well performance

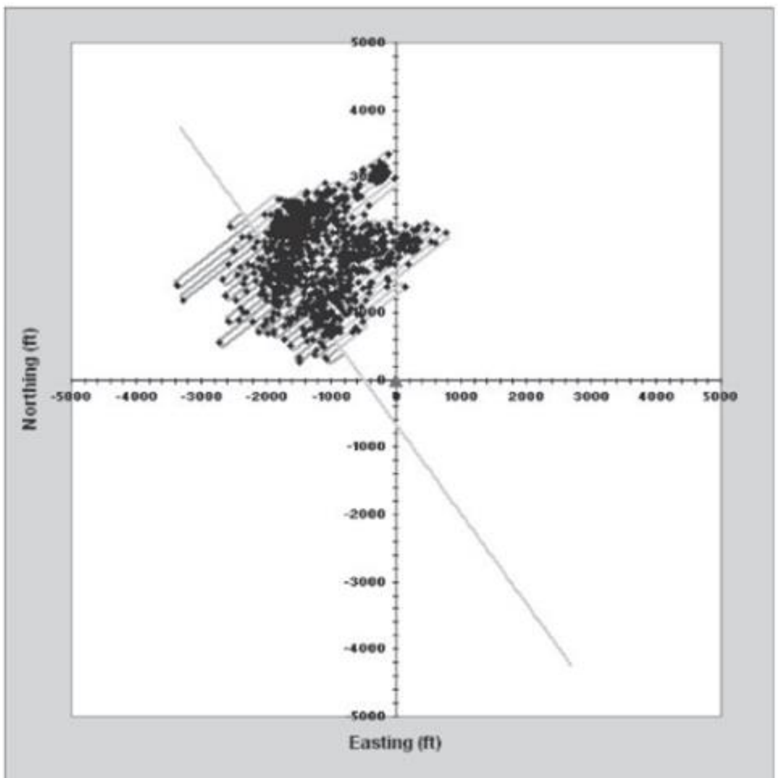
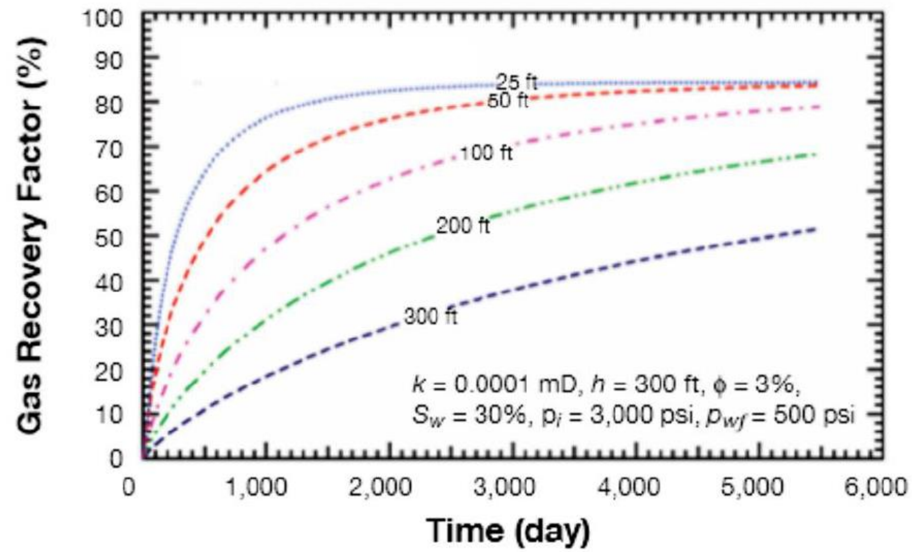


Fig. 4—Estimating SRA from microseismic-mapping data.

Mayerhofer et al., 2010



Example calculations showing effect of **fracture spacing** in gas shale recovery.

Warpinski et al, 2009 (after Mayerhofer et al.)

Natural Fractures & Hydraulic Stimulation

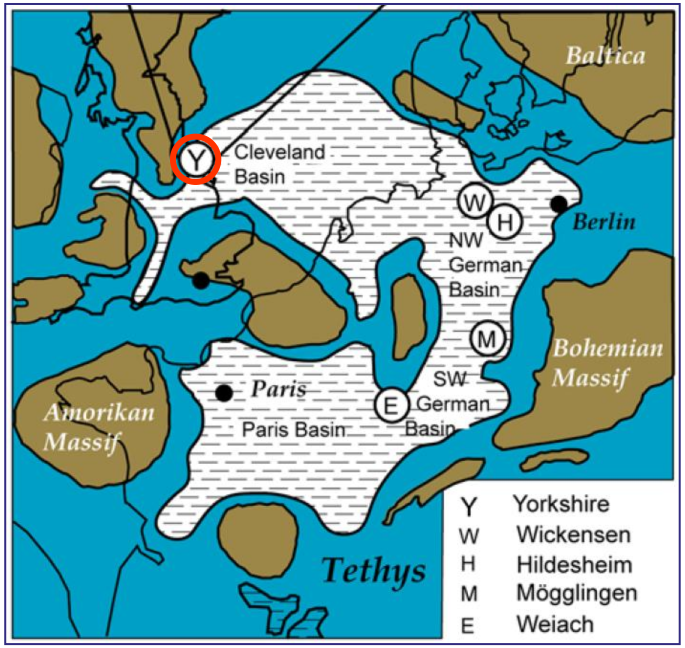
NF routinely used in

- Well orientation
- Well spacing, stimulation strategy
- Frac stage positions (efficiency!)
- To model resources and development

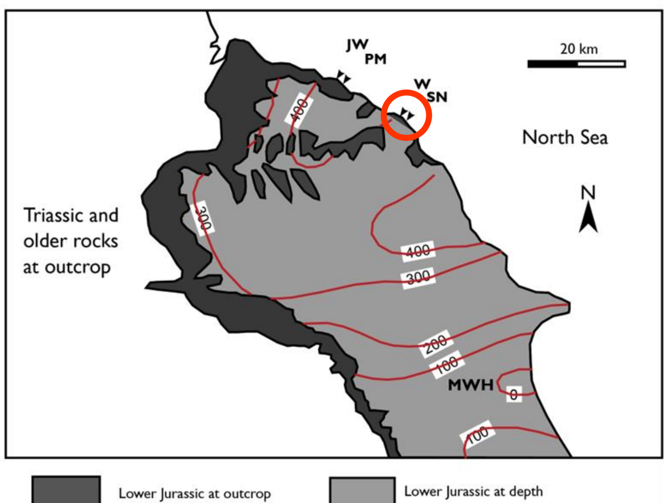
Often only subsurface data

Fracture property	well data	seismic	outcrop
Orientation	(✓)	(✓)	(✓)
Spacing	(✓)	X	✓
Length / Height	X	X	✓
Aperture	✓	X	(✓)
Connectivity (topology)	(✓)	X	✓
Physical and geomechanical properties	✓	✓	✓
Fracture maturity	(✓)	X	✓
Background fracturing	(✓)	X	✓
Fracture behaviour with proximity to structures	(✓)	(✓)	✓
Local structures	(✓)	✓	X

Case Study: Whitby Mudstone Outcrop

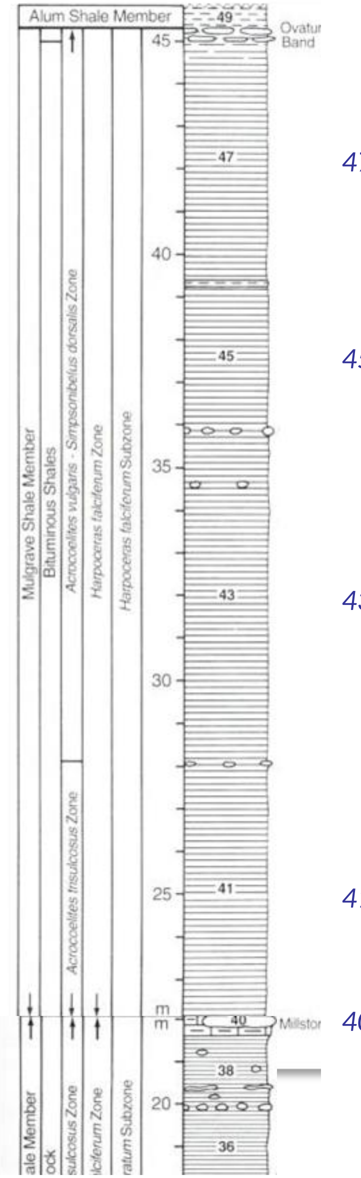


Extent of Lower Toarcian organic-rich sediments of NW Europe, McArthur et al., 2008.



Powell, 2010

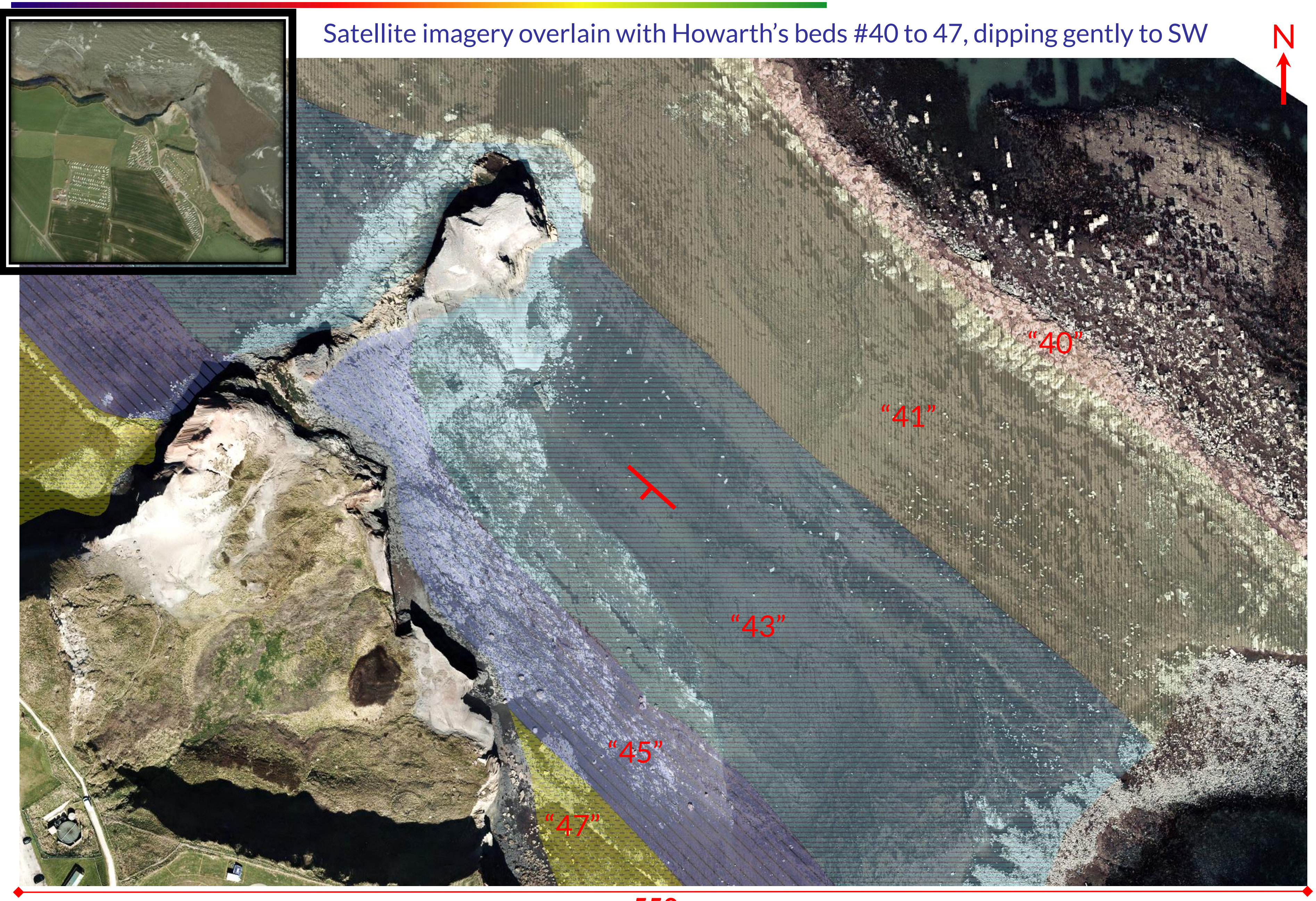
- Thick shale-dominated sequences
- Excellent coastal exposure
- Fractured but unfaulted at Saltwick Nab
- Lower Jurassic
- Whitby Mudstone Fm
- Marginally oil mature
- Potential analogue for…
  - Posidonia Shale
  - Weald
  - Bowland-Hodder Shale



Howarth's 'beds', 1962

Case Study: Whitby Mudstone Outcrop

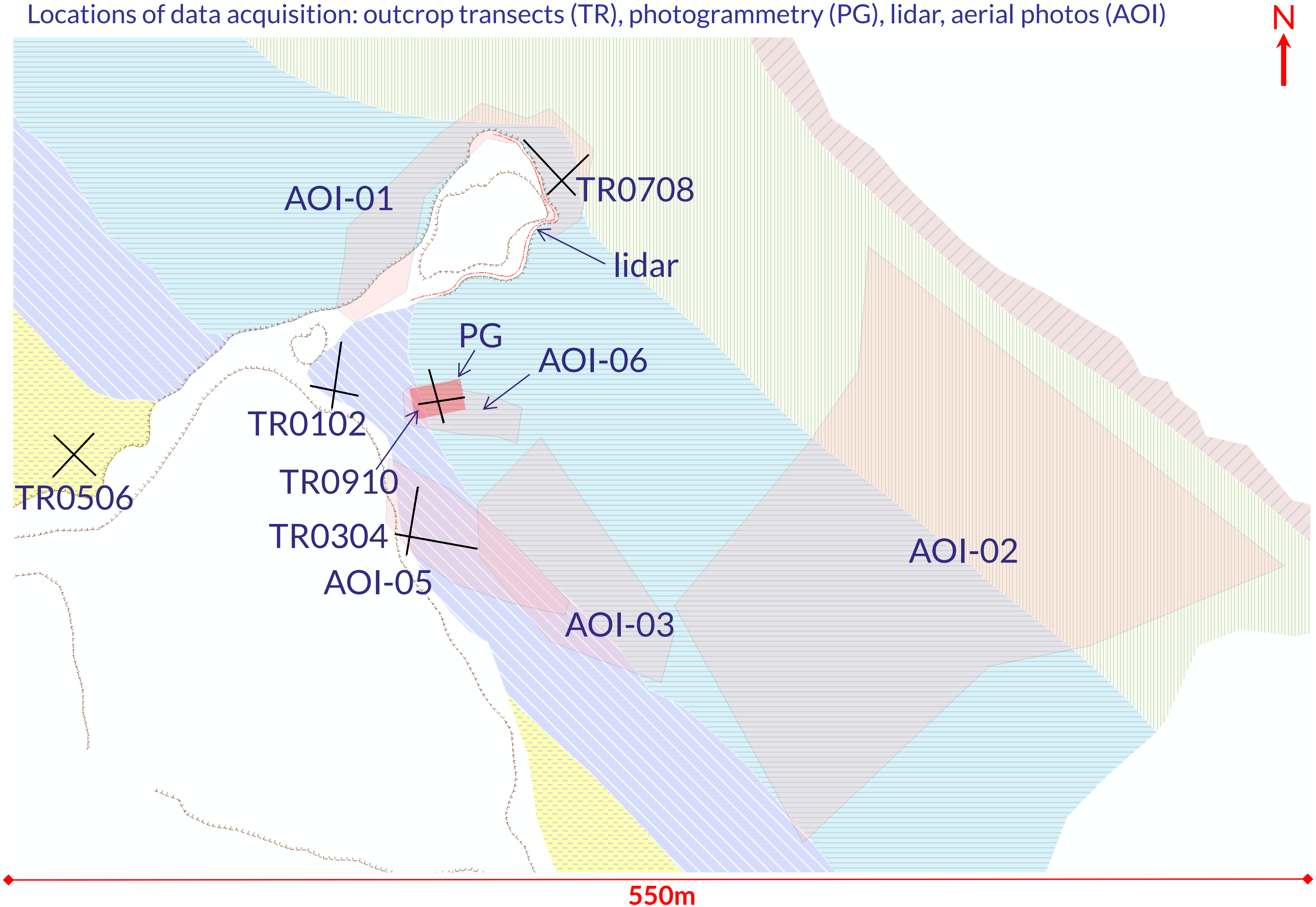
Satellite imagery overlain with Howarth's beds #40 to 47, dipping gently to SW



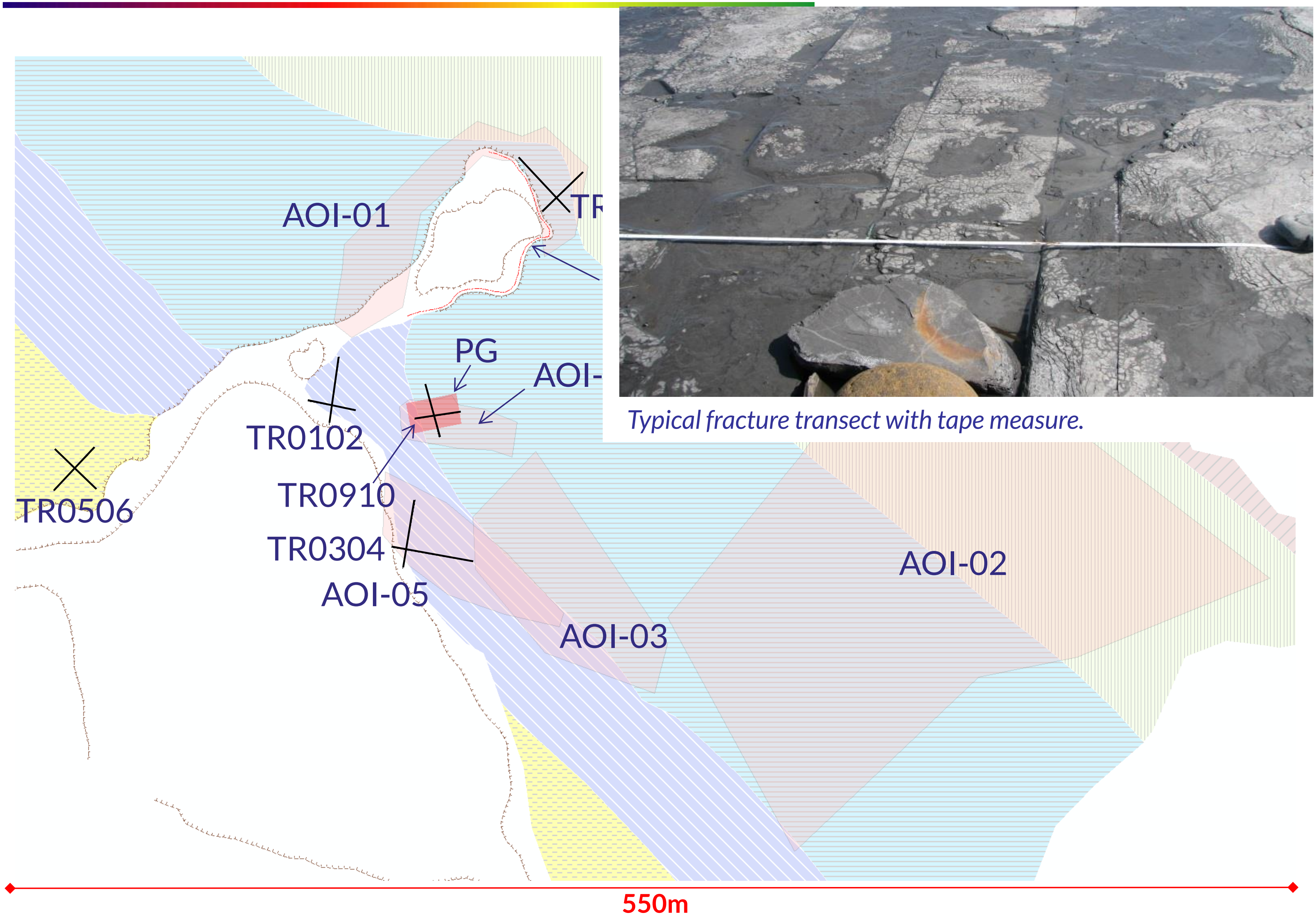
Google Earth Image © 2017 DigitalGlobe

Case Study: Whitby Mudstone Outcrop

Locations of data acquisition: outcrop transects (TR), photogrammetry (PG), lidar, aerial photos (AOI)

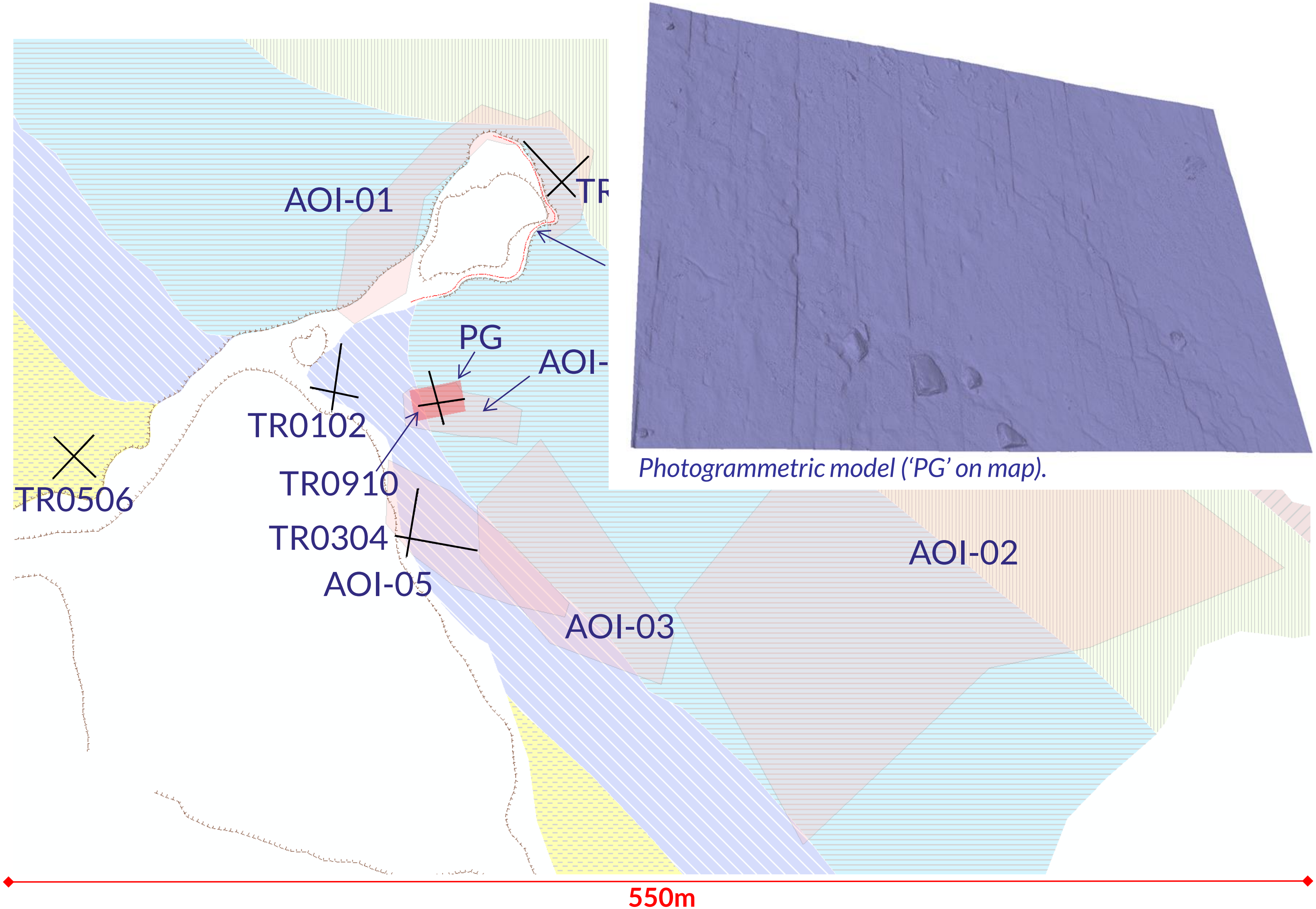


Case Study: Whitby Mudstone Outcrop



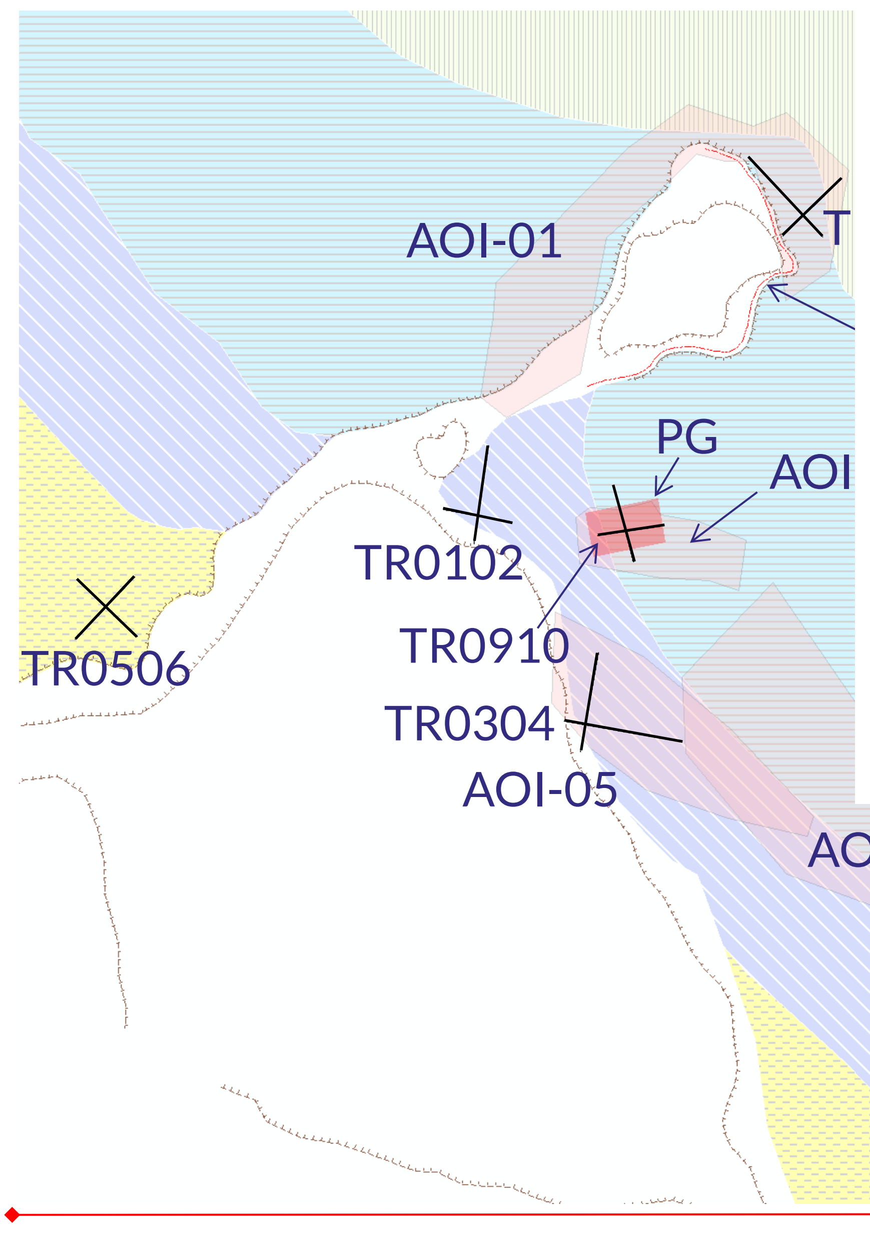
Typical fracture transect with tape measure.

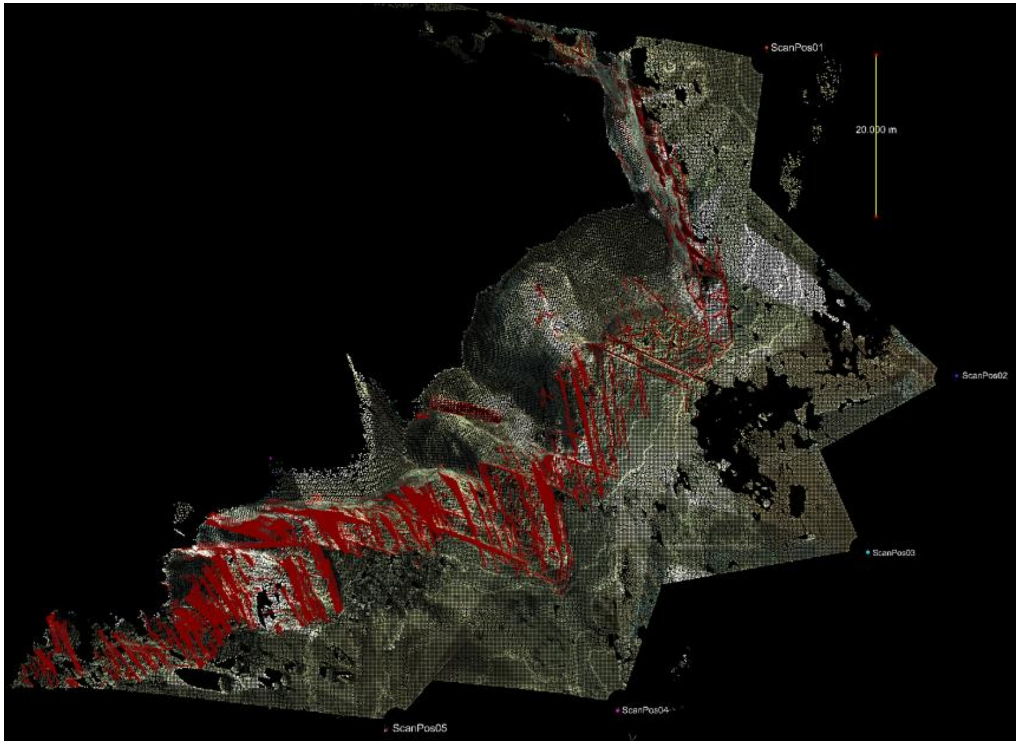
Case Study: Whitby Mudstone Outcrop



Photogrammetric model ('PG' on map).

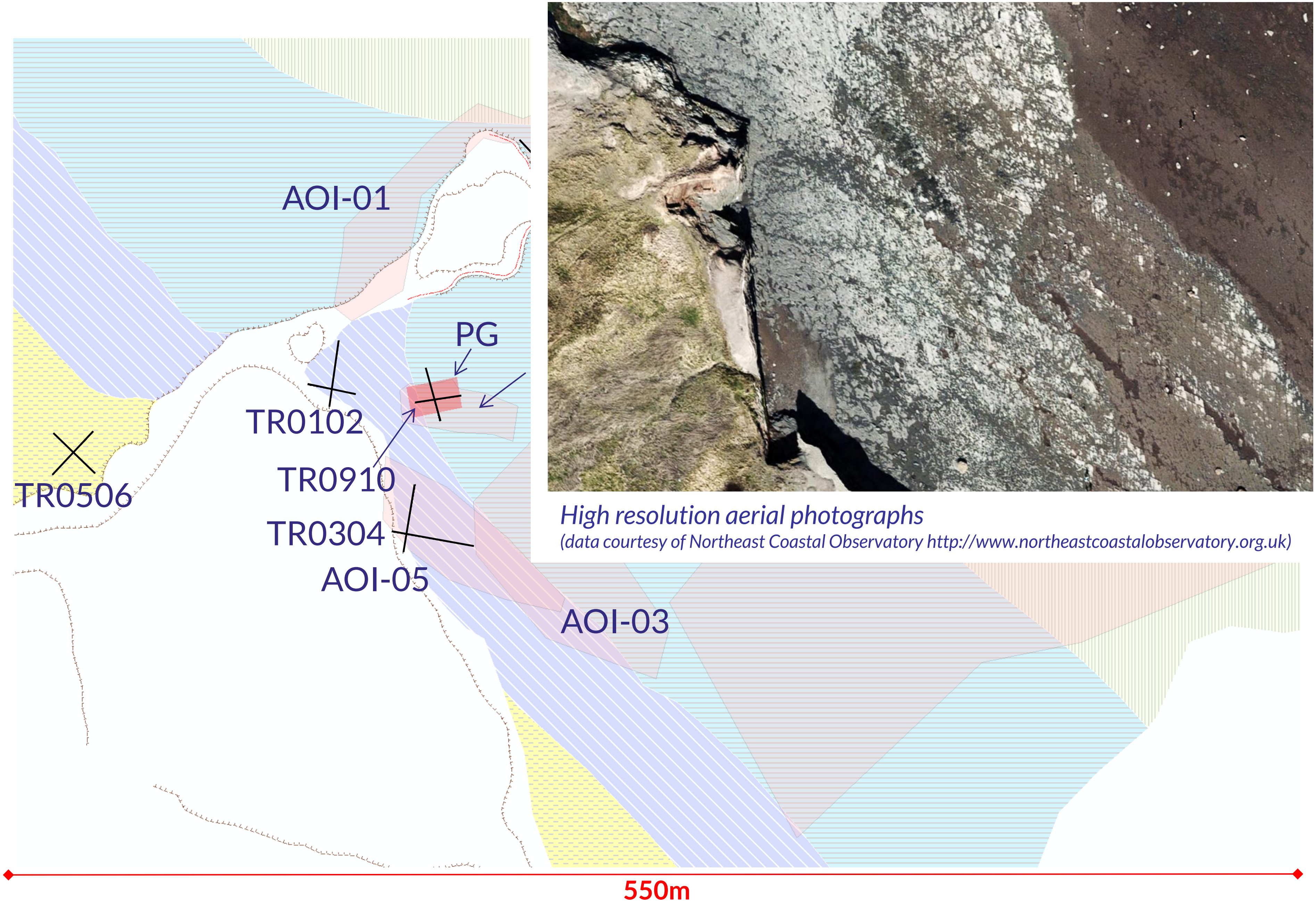
Case Study: Whitby Mudstone Outcrop





Lidar data. Aerial view looking down on top of the Nab, picked fractures shown in red.

Case Study: Whitby Mudstone Outcrop



High resolution aerial photographs

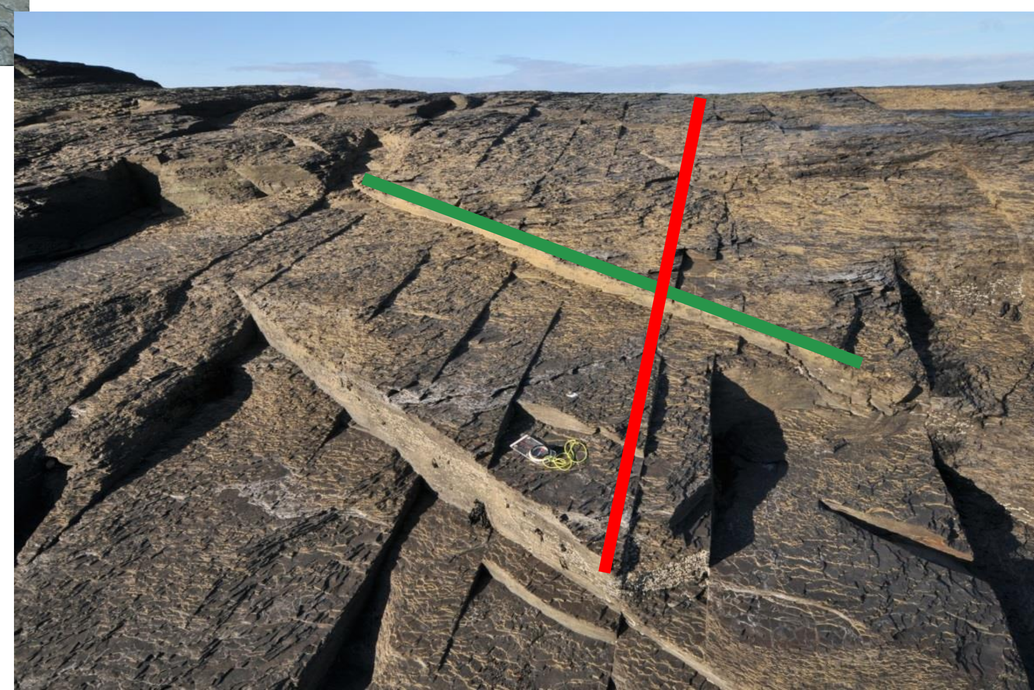
(data courtesy of Northeast Coastal Observatory http://www.northeastcoastalobservatory.org.uk)

Case Study: Whitby Mudstone Outcrop

- Lower Jurassic regional fracture sets
  - NNW-SSE – ‘R’
  - WNW-ESE – ‘G’ (secondary)
  - Systematic fractures
  - Noted across ~40km (Rawnsley,1992)
- (Also two additional sets of cross joints; sets “T” and “O”)

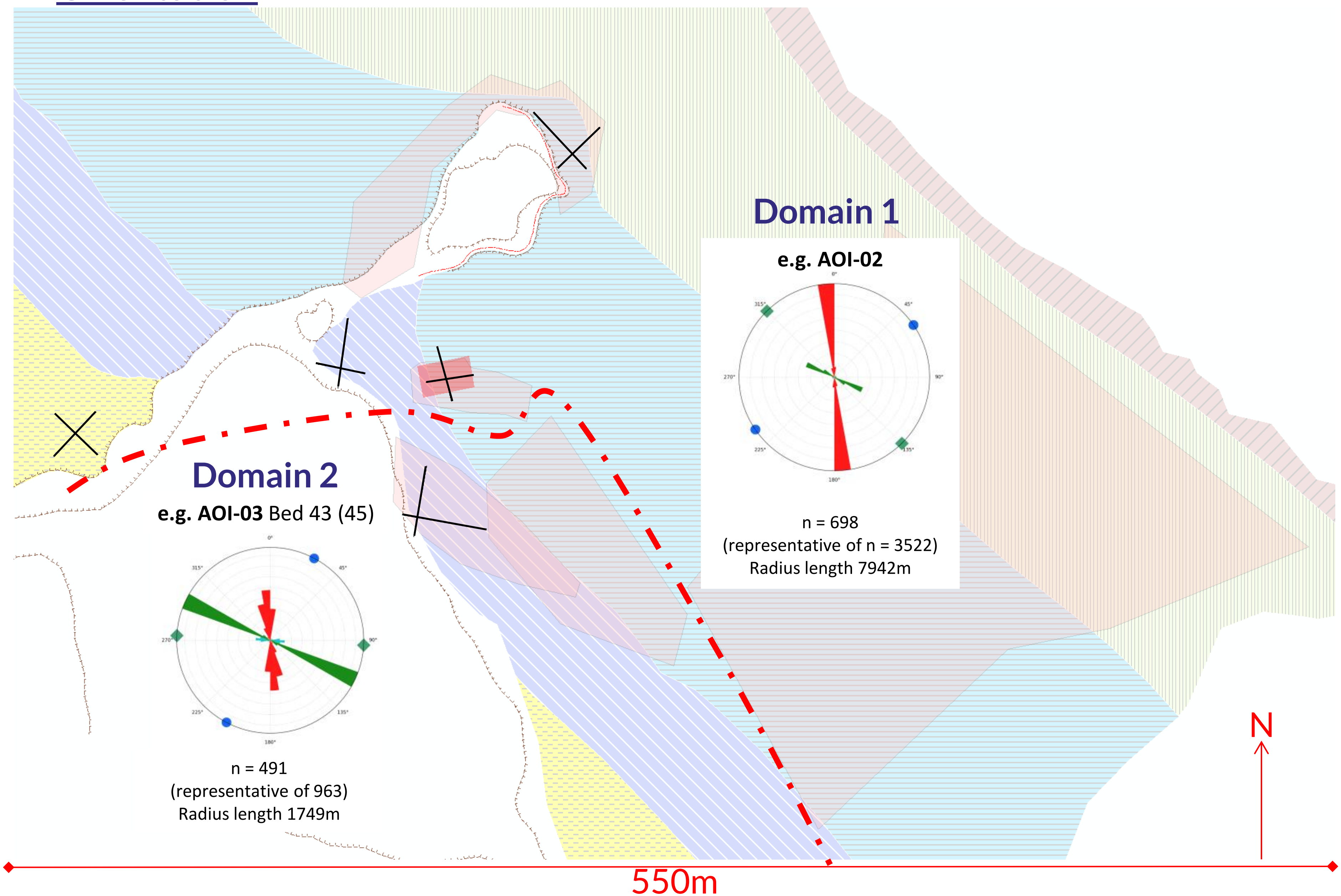
Natural hydraulic fractures

- Barren and vein filled
- Low spacing to length ratios
- Deflection around concretions
- Timing: set R oldest, rest contemporaneous
- Formed at depth

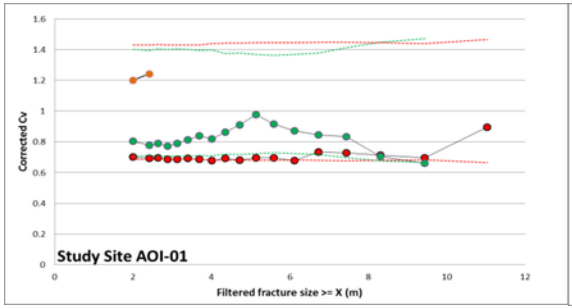


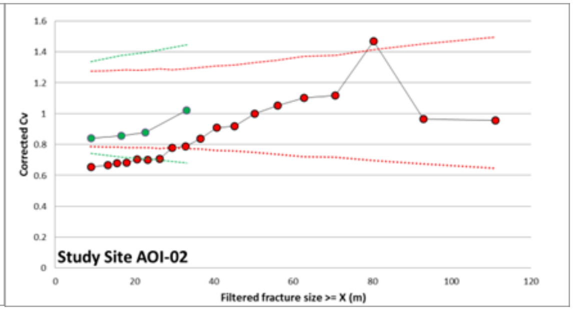
Case Study: Fracture Properties

Orientation

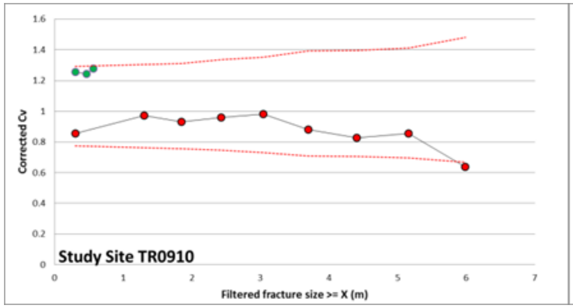


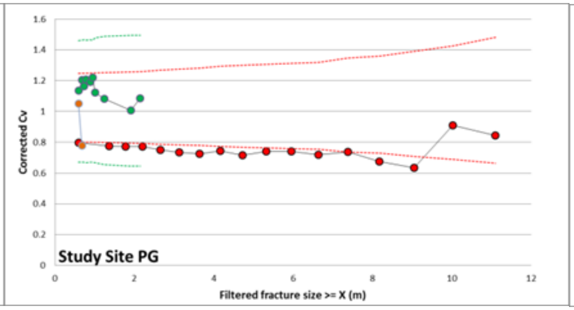
Case Study: Fracture Properties

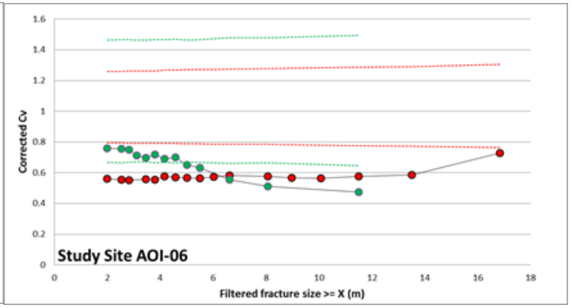


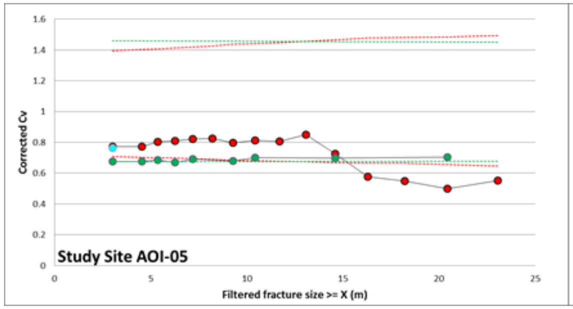


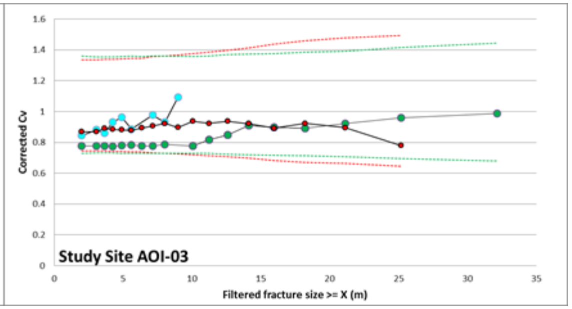
Fracture spacing

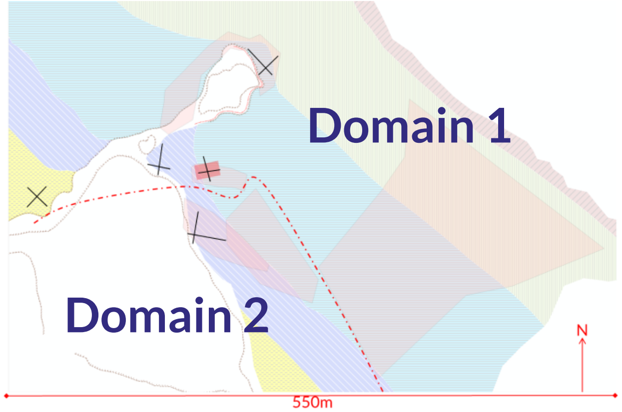






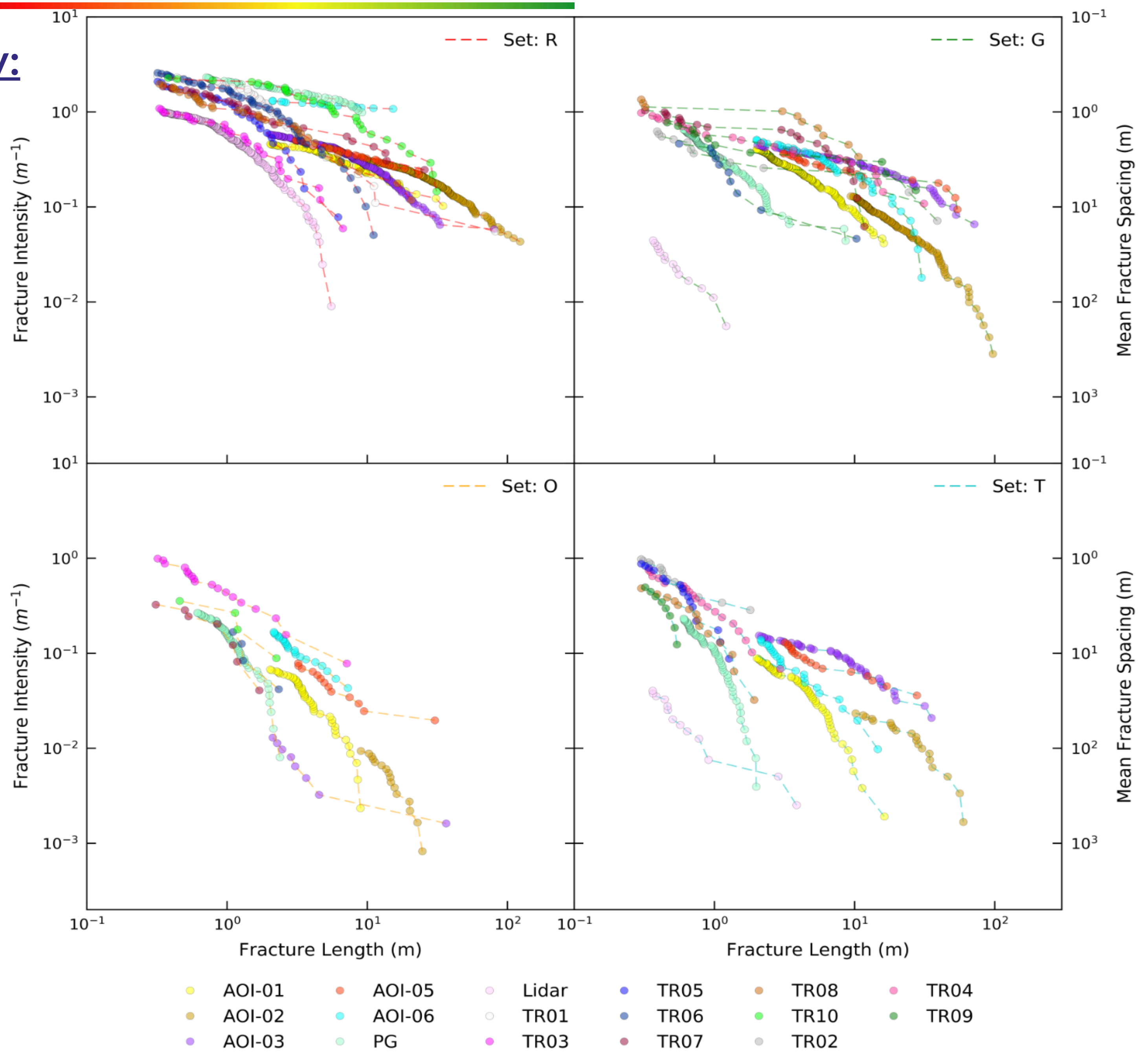






Case Study: Fracture Properties

Length vs intensity: Whitby Mudstone



Case Study: Fracture Properties

In Summary

Sets	R	G	O / T
	Increasing fracture development ←		
Avg Spacing/ Length	*0.17*	*0.35*	*1.86*
Spacing (C_V)	*55% regular*	*27% regular*	*100% random*

Fracture spacing / length ratio rough proxy for maturity of fracture system

- Set R most mature
- Within set R the most mature sites >> regularly spaced fractures
- Set G less mature, three sites have regularly spaced fractures
- Sets T and O immature
- At maturity tend to have regularly spaced fractures
- *Consistent with an intermediate subcritical crack index*

Case Study: Story So Far

- Lateral variations in fracture development
  - 2 domains
- Quantified ranges of properties
- Tend to regularly spaced fracturing
- Could inform
  - Development plans
  - Improved fracture modelling
  - Improved prediction of well performance, based on natural fracturing,
- Degree of similarity with subsurface? (compare with well data, histories, mineralogy, succession to decide level of applicability)

Summary

Outcrop characterisation of fractures

- More data earlier
- Potential to predict fracture properties away from the wellbore
- Relatively cheap
- Predicting fracture-connected distances and fracture-bound volumes
- Better predictions of well performance and better well performance?