Using virtual outcrop analogues to give insight and training throughout the life cycle of a field: Examples of natural fracture characterisation in conventional and unconventional fractured reservoirs

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Abstract

Virtual outcrops allow the collection of quantitative analogue data in a quick and spatially accurate fashion, which allow repeat analysis and application of modern spatial analysis methods and machine learning algorithms. Combined with expert geological scrutiny it can provide scientific insight into challenges faced at any stage in the E&P workflow. In addition to quantitative parameters, virtual outcrops can be collated into virtual field trips or embedded into presentations to aid in the assimilation of what are often complex geological concepts. Virtual field trips allow people at any stage in their career to quickly interrogate the available analogue data in a safe and engaging manner. They are the next best thing to a real field trip but without the same budgetary and time constraints associated with going into the field.

Natural Fracture Characterisation

The characterisation of fracture networks is vital at all stages in the E&P workflow when dealing with fractured reservoirs. For instance, adequate characterisation of the fracture network is required to reduce uncertainty in volumetric calculations, flow pathway analysis, well planning for optimum recovery, prediction of (pre-)stimulated reservoir volumes, building discrete fracture networks, understating water breakthrough, and enhancing recovery (Nelson 2001). Analogues provide rich datasets that can be integrated with subsurface data to enrich understanding. An example of how virtual analogues have been used to aid in the exploration and development of conventional reservoirs comes from tight fractured carbonates of the Zagros mountain belt that runs through, Turkey, Iraq, and Iran. Cliff sections provide excellent exposure, both vertically and laterally, and by using automated identification and extraction tens of thousands of fractures can be analysed to look at the quantitative variation of fracture properties and relate these to drivers that can be extrapolated into the subsurface.

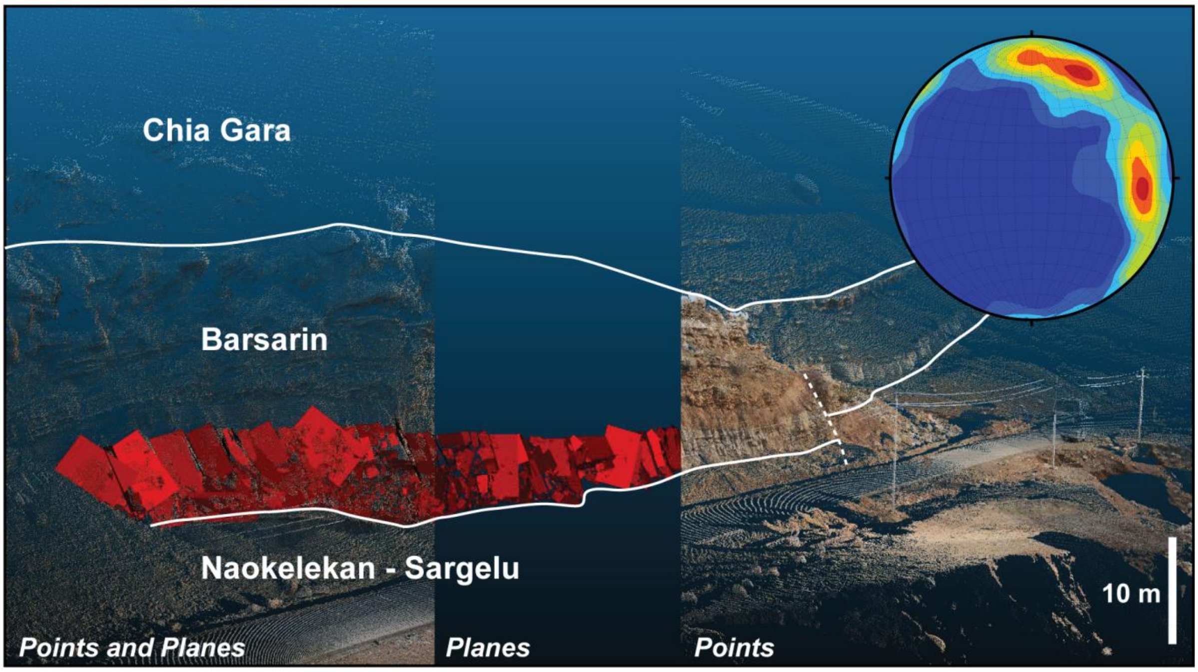

Fig. 1. 3D view of the Barsarin formation from within the core of the Makook anticline, Kurdistan (NE Iraq). The left panel shows both the outcrop point cloud and fractures, the centre panel only the fractures and the right panel only the points. Thousands of fractures (N=13,642) are interpreted from this one digital outcrop alone. Inset: Equal area lower hemisphere stereonet showing fracture orientations from the automated surface extractions algorithm and user interpretation.

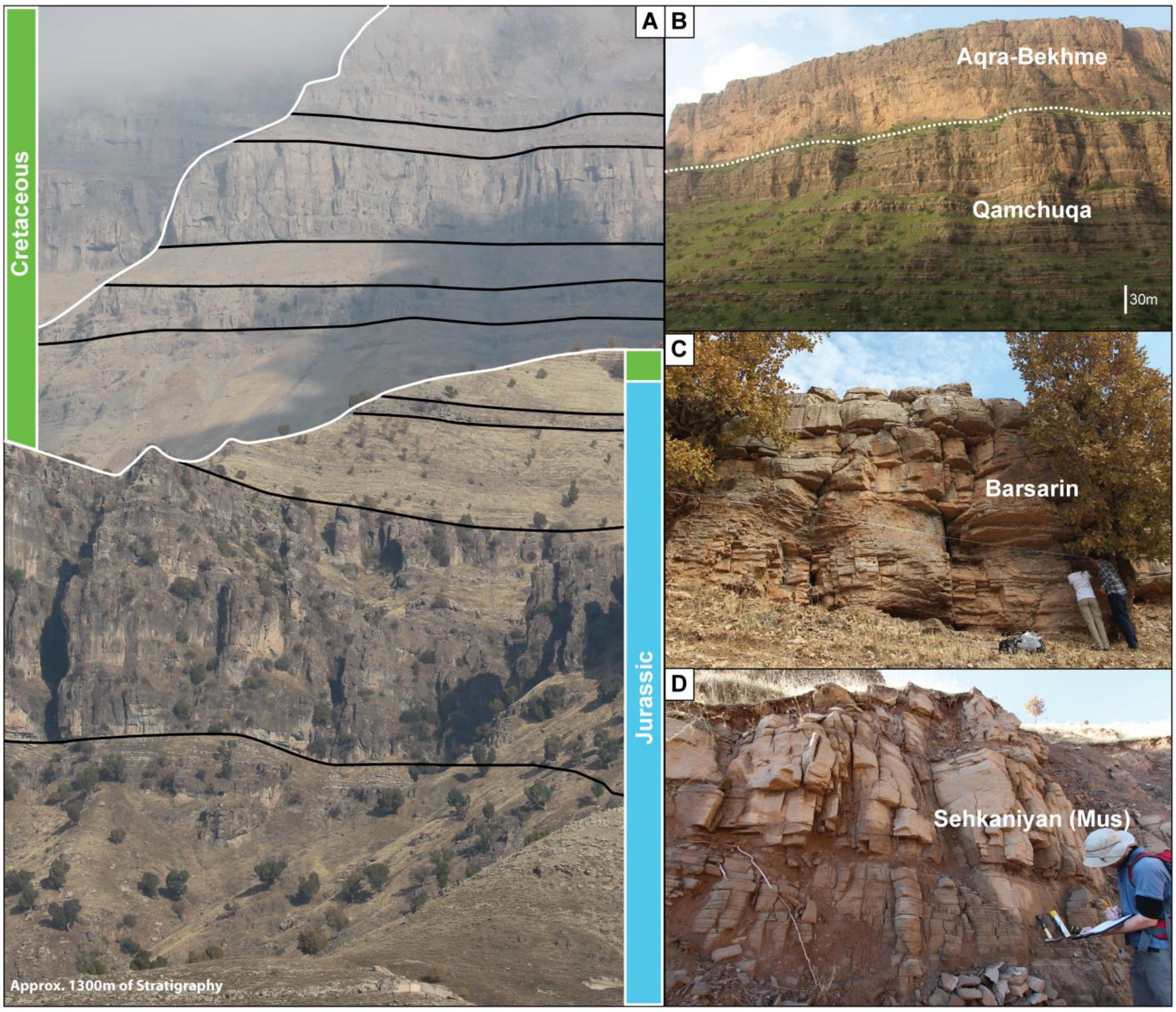

Fig. 2. A) Large scale mechanical layering separates fractured carbonate reservoirs throughout the Jurassic and Cretaceous stratigraphy of Kurdistan, NE Iraq. B) Clos-up of the Aqra-Bekhme and Qamchuqa formations from Bradost, Kurdistan. Note the difference in internal mechanical layering with the Qamchuqa having a layered profile. C) and D) examples of the Barsarin and Sehkaniyan showing bed scale mechanical unit variations and its associated control on fracture geometry and spatial location.

For instance in Kurdistan mechanical layering segments the fracture network into layer bound sections. From detailed logging and analysis of digital analogues the mechanical packages can be defined, their fracture properties calculated and correlated with the subsurface, which enables the targeting of highly permeable zones within the reservoir. In addition, information on likely fracture heights can be used to inform the optimum stand-off from the water contact, which is highly significant for production performance.

An example of virtual outcrop with significance for E&P of unconventional shale plays comes from the Whitby Mudstone Fm., North Yorkshire, UK. WMF has high TOC, is marginally oil mature and is a time equivalent of the Posidonia Shale (an oil shale in Netherlands and Germany) and the Dunlin Group of the Northern North Sea. Using high resolution UAV data, ortho-rectified aerial photos and field work we are able to map the natural fracture network around a wave cut platform. Two systematic fracture sets occur with subsidiary sinuous cross joints.

By understanding the behaviour of the existing natural fracture network at outcrop, we can better predict fracture extents in the subsurface away from the well bore and fracture spacing encountered by the wellbore, key factors in devising optimal well and stimulation strategies and predicting field performance. Observations of scale-dependent behaviours can inform flow model parameters for equivalent fracture sets in the subsurface (for example, longer fractures with a particular strike tend to be made up of several closely spaced smaller fractures, which would impact along-strike flow rates).Topological analysis indicates the whole fracture network creates well-connected pathways, which would further extend the reach of stimulation fluids away from a well bore in a comparative reservoir.

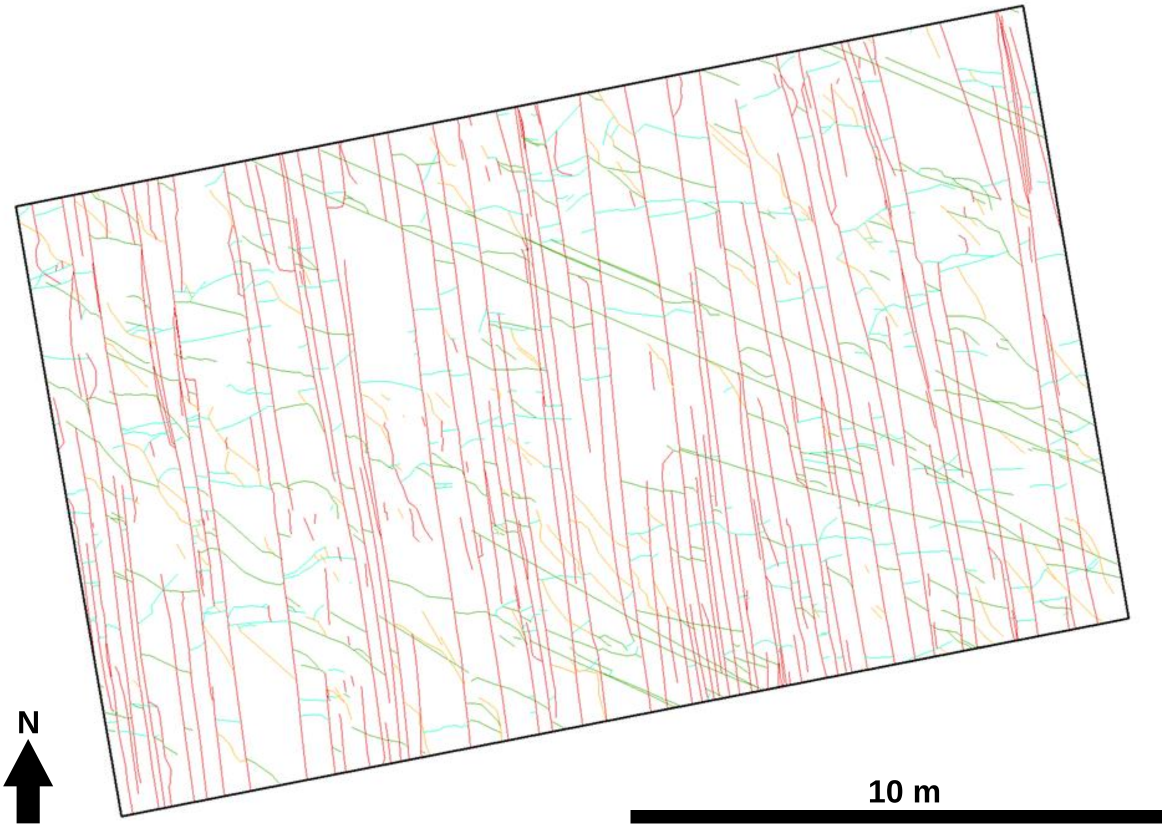

Fig. 3. Interpreted UAV aerial imagery from the Whitby Mudstone Fm. along the North Yorkshire coast. Using UAV imagery fractures of length between 0.1 m and >10 m can be measured in a single location. Fractures are coloured by set, which are classified on the assessment of orientation, topology, length and timing.

When integrating insights gleaned from outcrop analogues to the subsurface reservoir it is vital they are robustly and cautiously applied, considering factors such as basin histories, fracture generation timings, and sampling biases. Simplistically, a hypothetical well drilled parallel to a fracture set would under-sample the set, whilst a well orientated perpendicular would be more representative. Awareness of any such sampling bias is important during comparison. Understanding relative (and ideally absolute) timing and interactions of the separate fracture sets is also critical. Direct comparison of topological behaviour in image logs and core can also be used to evaluate the comparison and level of applicability of such interpretation.

Conclusions

Analogues provide rich insights into often under-sampled subsurface units. The proliferation of digital outcrop analogues has enabled the explosion of data in this field of geology. Correct understanding and application of this rich dataset is critical as it can bring insight to allow efficient development at all stages in the life cycle of a field. Virtual analogues can provide quantitate parameters that can be integrated with their subsurface equivalent..

Virtual field trips can also be used to provide an enriching training environment, enabling the immersive 3D content to be wrapped together with insightful interpretations and knowledge into a single platform for the effective collaboration of ideas between all members of the E&P team. Virtual fieldtrips and outcrop analogues can be accessed remotely or navigated together in groups to facilitate learning, discussion and the exchange of ideas. The interactive nature of such a training platform could allow users to improve the content and preserve specific knowledge within an organisation.

Regarding natural fracture networks mechanical laying is readily identified using digital outcrops over 100's m from cliff sections. Likewise map view datasets enable the detailed analysis of fracture networks in the horizontal plane. In the examples used we can see the value of understanding fracture networks for the planning of wells in exploration and development for both conventional and unconventional reservoirs.

References

1. *Nelson, R., 2001. Geologic analysis of naturally fractured reservoirs. Gulf Professional Publishing.*

Presenter Biography

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Susie has worked in the oil and gas industry for 16 years. This began with ExxonMobil (or Mobil North Sea Ltd as it was when she joined) where she worked on UK and Norwegian exploration and production assets.

For the last 11 years Susie has worked for Geospatial Research Ltd, a spin out company from Durham University. GRL are a technology savvy consultancy using structural geology, regional tectonic and global geodynamic studies to solve exploration and production issues. She has particular expertise in fracture characterisation.