EAGE

Calibration of Fracture Models Using Multi-Scale Outcrop Analogues – the Importance of Mechanical Stratigraphy

Jones, R.R.[1], Kokkalas, S.[2], Long, J.J.[1], Daniels, S.E.[1], Gilment, S.R.[1], Wilkinson, M.W.[1], Oxlade, D.M.[1]

[1]. Geospatial Research Ltd., Dept. of Earth Sciences, University of Durham, UK
[2]. The Petroleum Institute (Abu Dhabi)

Summary:

Mechanical layering exerts a critical influence in the development of fracture systems within reservoir units, therefore understanding the distribution of mechanical packages, on the scale of individual beds up to entire stratigraphic formations or groups, is essential when modelling natural fracture systems.

Outcrop analogues provide critical insight into the mechanical stratigraphy that cannot readily be derived from sub-surface data alone, although image logs or core are very useful to allow outcrop-derived interpretations of the thicknesses and proportions of different mechanical packages to be suitably calibrated.

Scaling of fracture properties is important for successful prediction of reservoir properties. Fracture size distributions are critical, but require reliable data over many orders of magnitude. Combining traditional field studies with modern geospatial technologies, together with sub-surface data when available, provides reliable, robust inputs for fracture modelling.

Introduction

Naturally fractured reservoirs contain networks of fractures that range in size from microscopic (sub-mm, seen in thin section) to those visible in satellite imagery (typically 10^1-10^4m in length). Some fractures are entirely confined within single beds, while others extend across multiple bed boundaries (typically 10^{-2}-10^2m in height). Therefore in order to calibrate reservoir models we need analysis methods that can acquire data from representative outcrop analogues that span multiple scales, over large areas of exposed bedding surfaces as well as in cross-section bed-cuts.

Importance of Mechanical Stratigraphy

In many areas in the Middle East, the stratigraphic sequence consists of alternating competent carbonates (often forming highly fractured reservoirs), and less competent shales and evaporites. These stacked mechanical packages range in thickness from the size of individual beds (centimetres to metres) to the formation size (tens to hundreds of metres). In the Zagros region, the mechanical contrasts in the sequence exert a major influence on the development of fold geometries, aided by the development of multiple detachment zones within the mechanically weaker layers (e.g. Molinaro et al. 2005; Sherkati et al. 2005; Casciello et al. 2009). The mechanical layering also plays a critical role in the development of fracture systems within reservoir units (Figure 1), and is documented to exert a strong control on the intensity and height of fractures (e.g. Gross et al. 1997, Ackermann et al. 2001, Laubach et al. 2009). Therefore understanding the distribution of mechanical packages, on the scale of individual beds up to entire stratigraphic formations or groups, is critical when modelling natural fracture systems.

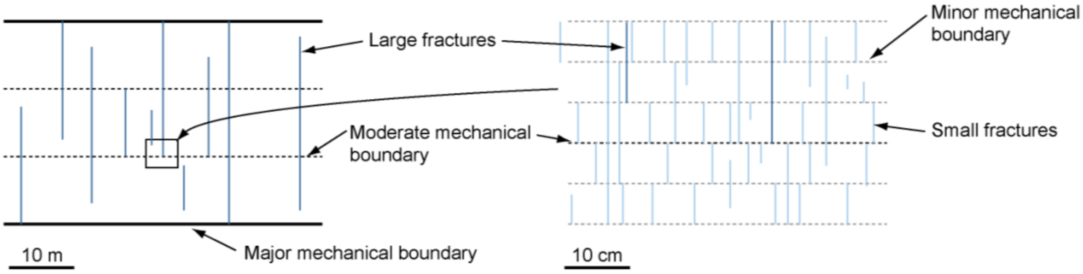

Figure 1 *Schematic diagram showing the influence of mechanical stratigraphy operating at different scales during the development of the fracture network. Major mechanical layer boundaries act as barriers to fracture propagation, even for the largest fractures, while intermediate layers act to retard most fractures, though are unable to confine the largest. The smaller fractures are confined by all mechanical boundaries.*

Multi-scale Data Acquisition

Good analogues for calibration of reservoir models should contain representative fracture properties across as wide a range of scales as possible. Extensive areas of high quality outcrops are often ideally suited to allow fracture networks to be characterised at scales from thin section and hand sample, up to many kilometres (Jones et al. 2008).

The best outcrop analogues to constrain mechanical stratigraphy are well exposed areas with high topographic relief, so that sufficient lateral variability can be studied for a thick stratigraphic sequence. Small outcrops are often situated within a single mechanical package, so high outcrops are best in order to see the larger mechanical boundaries, and to quantify the parameters of vertically persistent fractures that are most likely to support high fluid flow rates.

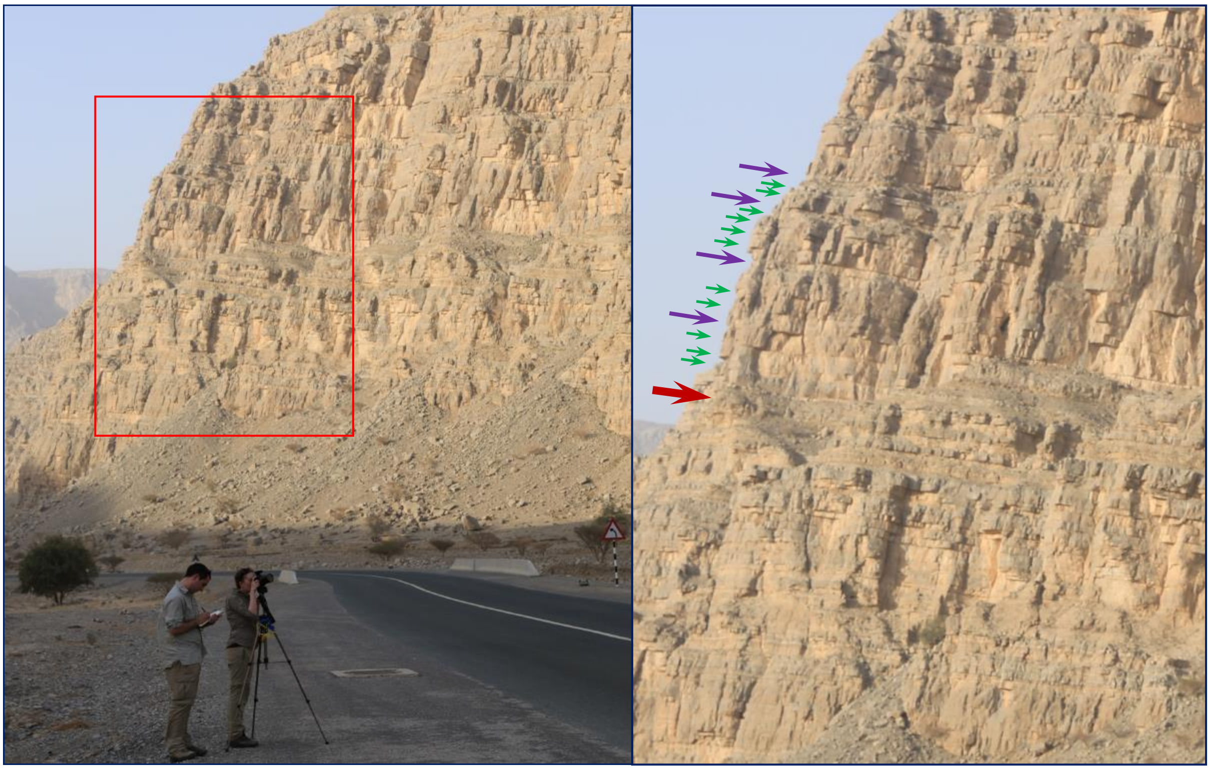

Figure 2 *[Left] Acquisition of photogrammetric data for analysis of mechanical stratigraphy from the Musandam 2 Fm. in Wadi Bih, near Ras Al-Khaimah, UAE. Red rectangle shows area of inset [Right]. Red arrow: larger mechanical boundary, which few fractures cross; purple and green arrows: examples of intermediate and smaller mechanical boundaries, respectively.*

New geospatial technologies such as terrestrial lidar and photogrammetry (ground-based or from unmanned aerial vehicles; i.e. 'UAVs' or 'drones') are particularly well suited for capture of the detailed 3D geometry of the outcrop surface, from which quantitative measurements can be derived. This allows rapid acquisition of extensive areas of outcrop data, even from large areas of steep exposure that are unsafe or impractical to access directly (Figure 2).

Calibration and Utilisation

Interpretation of mechanical stratigraphy from outcrop analogues provides important constraints needed for Discrete Fracture Network (DFN) modelling. Large-scale outcrops such as Wadi Bih (Figure 2) give valuable insights into the multi-scale mechanical makeup of layered carbonates sequences, in terms of the representative thicknesses of different scales of mechanical packages and how they vary through a formation, both vertically and laterally. Note that this input is usually unfeasible to derive in a robust way from subsurface data alone, emphasising the importance of suitable outcrop analogues. Where borehole data are available, image logs or core are very useful to allow outcrop-derived interpretations of the thicknesses and proportions of different mechanical packages to be calibrated and refined.

Field Examples

We illustrate these concepts with field examples from the following areas:

- Musandam 2 Fm. from Wadi Bih, near Ras Al-Khaimah, UAE.
- Dammam and Rus Formations from the Jebel Hafeet anticline near Al Ain, UAE.
- Mesozoic reservoir units from the Kurdistan Region of Iraq.

Acknowledgements

Fieldwork in the UAE was carried out with support from RIFP project no. 15312 funded by Petroleum Institute (Abu Dhabi). We thank colleagues in GRL and University of Durham for ongoing collaboration in research into fracture systems.

References

Ackermann, R.V., Schlische, R.W., and Withjack, M.O. [2001]. The geometric and statistical evolution of normal fault systems: an experimental study of the effects of mechanical layer thickness on scaling laws. Journal of Structural Geology, **23**, 1803-1819.

Casciello, E., Vergés, J., Saura, E., Casini, G., Fernández, N., Blanc, E., Homke, S., and Hunt, D.W. [2009]. Fold patterns and multilayer rheology of the Lurestan Province, Zagros Simply Folded Belt (Iran). Journal of the Geological Society, London, **166**, 947-959.

Gross, M.R. Gutierrez-Alonso, G., Bai, T., Wacker, M.A., and Collinsworth, K.B. [1997]. Influence of mechanical stratigraphy and kinematics on fault scaling relations. Journal of Structural Geology, **19**, 171-183.

Jones, R.R., McCaffrey, K.J.W., Imber, J., Wightman, R., Smith, S.A.F., Holdsworth, R.E., Clegg, P., De Paola, N., Healy, D. and Wilson, R.W. [2008]. Calibration and validation of reservoir models: the importance of high resolution, quantitative outcrop analogues. In: Robinson, A., Griffiths, P., Price, S., Hegre, J., and Muggeridge, A., [Eds.] The Future of Geological Modelling in Hydrocarbon Development. Geological Society, London, Special Publication 309, 87-98.

Laubach, S.E., J.E. Olson, and M.R. Gross. [2009]. Mechanical and fracture stratigraphy. AAPG Bulletin, **93**, 1413-1426.

Molinaro, M., Leturmy, P., Guezou, J.-C., and Frizon de Lamotte, D. [2005]. The structure and kinematics of the southeastern Zagros fold-thrust belt, Iran: From thin-skinned to thick-skinned tectonics. Tectonics, **24**, TC3007, doi:10.1029/2004TC001633.

Sherkati, S., Molinaro, M., Frizon de Lamotte, D., and Letouzey, J. [2005]. Detachment folding in the Central and Eastern Zagros fold-belt (Iran): salt mobility, multiple detachments and late basement control. Journal of Structural Geology **27**, 1680-1696.