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The Whitehouse Shore - A Natural Laboratory for Characterizing Fault Geometry, Heterogeneity and Permeability

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SUMMARY

The Whitehouse shore intertidal exposure (Scotland) provides an excellent field site to study small scale faults in sand-shale sequences. Especially interesting is the presence of paleo fluid flow indicators, which allow us to constrain the fluid flow behaviour of the faults and fractures at depth. Combination of field study, laboratory analysis and numerical modelling allows us to collect vast amounts of data on the geometry, heterogeneity and permeability structure of fault zones. These data will ultimately form the basis of a new workflow that allows the spatial variability of fault zones to be represented in reservoir models.

Motivation

Fault permeability is a key uncertainty in hydrocarbon exploration and production. Fault architecture is heterogeneous within single fault zones, and between different faults that cut the same host rock, making deterministic prediction of fault permeability unreliable. Current practice attempts to derive deterministic relationships to estimate fault zone petrophysical properties, based on parameters that are measurable at the scale of 3D seismic data, such as fault throw and host rock properties. These relationships severely underestimate the complexity of real fault zones. This study is part of a PhD project attempting a new approach to predicting fault permeability. Fault architecture data is collected from multiple field sites. These data are then used to derive statistical relationships between seismic-scale properties measurable at depth, sub-seismic scale fault zone architectural features, and bulk fault zone permeability using both spatial and multivariate statistics. Ultimately these data will form the basis of a new workflow that allows the spatial variability of faults to be represented in reservoir models.

Field site

Intensive field data collection is being carried out in the intertidal zone of the Whitehouse shore (Girvan, SW Scotland). This well exposed site provides the opportunity to study subseismic scale fault networks in great detail. Differential erosion of the vertically tilted beds has resulted in well developed small scale relief. As a consequence many small scale faults and fractures are exposed in three dimensions. The exposure allows for very detailed mapping of fault architecture and related fracture patterns. Four large thrust faults (tens of meters of displacement) determine the overall structure of the studied area. At a smaller scale, deformation is accommodated by strike-slip faulting and small wavelength (1-5m) folding. The majority of the strike-slip faults studied have a horizontal displacement between 0.5 and 5 metres.

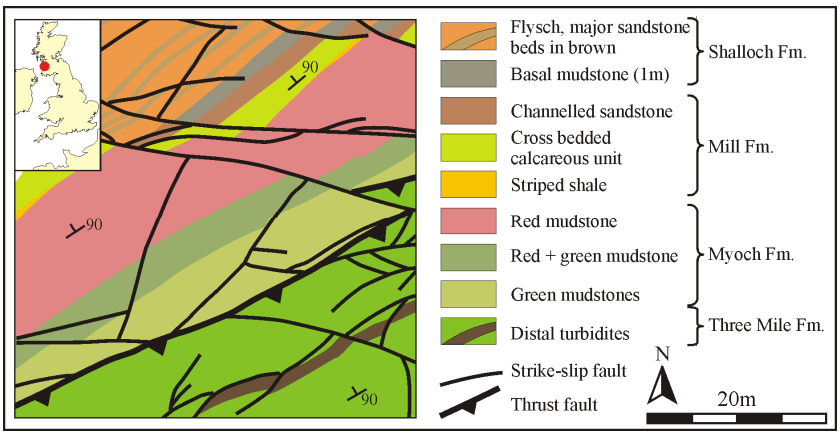

Figure 1 *Small subset of the Whitehouse shore geological map.*

The deep water clastics hosting the faults are part of the 6 km thick Mid Ordovician to Mid Silurian Girvan cover sequence (Ingham 2000), which unconformably overlies the Ballantrae ophiolite Complex. The main phase of deformation responsible for the formation of the faults is believed to be related to the Silurian terrane emplacement.

Fault architecture

Faults in mixed sandstones and shales consist of several deformation elements (Lehner & Pilaar 1997; Vrolijk & van der Pluijm 1999; van der Zee & Urai 2005). Where different lithologies are juxtaposed, low permeability features such as zones of intense grain crushing, pressure solution, cementation and shale smears, may be accompanied by fractures and breccias, which are likely to have an enhanced permeability, and slip surfaces that can have either enhanced or reduced permeability depending on whether they are open or closed. Field study and laboratory permeability measurements allow us to define key flow controls for faults of different scale and character.

Quantification of paleo fluid flow

One particularly interesting feature of the Whitehouse shore field site is the presence of fluid related alteration structures in parts of the Myoch Formation. The Myoch Formation is subdivided into three members; red mudstone, red mudstone with green bands, and green mudstone. The green bands in the middle member are localised around fractures. The green bands are interpreted to reflect alteration by fluids, probably reduction of iron oxide rich rocks by reducing fluids. We suggest that the thickness of the altered zone around a fracture is a function of the amount of fluid flow through the fracture, flow velocity and host rock permeability. Applying this assumption we use numerical models to provide order of magnitude estimates of paleo-fluid flow through the studied fracture network.

Figure 2 *Example of paleo-fluid flow related alteration of the red host mudstone. Fingers for scale.*

Upscaling of bulk fault permeability

Using flow simulations through a well-characterized fault zone at a sand-sand juxtaposition, it is shown that a number of sub-seismic architectural properties are critical to fault hydraulic behaviour (Lunn et al. 2008). A similar analysis is applied to the fault architectures mapped and measured in the Whitehouse shore sand-shale alterations. The upscaled fault permeability values calculated this way will be used to populate the small scale end of the fault permeability database that this project will ultimately develop.

Conclusions

The Whitehouse shore intertidal exposures provide an excellent opportunity to study a wide variety of small scale fault zone in sand-shale sequences. It provides a natural laboratory for collecting massive amounts of data, and also for the development of new ideas and insights into fault and fracture related fluid flow.

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References

Ingham, J.K. [2000] Scotland: the Midland Valley Terrane – Girvan. In Fortey, R. A., Harper, D. A. T., Ingham, J. K., Owen, A. W., Parkes M. A., Rushton, A. W. A., and Woodcock, N. H. *A revised correlation of Ordovician rocks in the British Isles*. Geological Society, London, Special Reports. 43-47.

Lunn R.J., Shipton Z. K. and Bright A. M. [2008] How can we improve estimates of bulk fault zone hydraulic properties? In Wibberley, C.A.J., Kurz, W., Imber, J., Holdsworth, R.E. and Collettini, C. (Eds.) *The Internal Structure of Fault Zones: Implications for Mechanical and Fluid-Flow Properties.* Geological Society, London, Special Publication 299. 231-237.

Lehner, F., Pilaar, W. [1997] The emplacement of clay smears in syn-sedimentary normal faults: inference from field observations near Frechen, Germany. In Møller-Pedersen, P., and Koestler, A.G. (Eds.), *Hydrocarbon Seals*, NPF special publication 7, 39-50.

Vrolijk P. and van der Pluijm, B.A. [1999] Clay gouge. *Journal of Structural Geology*, 21. 1039-1048.

van der Zee W. and Urai, J. L. [2005], Processes of normal fault evolution in a siliciclastic sequence: a case study from Miri, Sarawak, Malaysia. *Journal of Structural Geology*, 27, 2281-2300.