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Characterising Fractured Basement Reservoirs

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Summary

Following the recent discovery that the storage and flow capacity of some basement reservoirs relates to both fracture and fissure capacity, we are working towards further understanding as to how and when this paradigm shift should be applied. Our current model is based upon observations from the Rona Ridge in the UK West of Shetland. Critical questions to be addressed include: How applicable is the fissure model to other basement plays (and tight cover sequences) globally? What are the relative contributions of the fractures and fissures to storage and flow, how do they inter-relate, how can they be adequately described and how might we expect the contributions to vary in different settings?

Introduction

There has recently been a paradigm shift in understanding of the Rona Ridge fractured basement oil field reservoirs (UK, West of Shetland, Figure 1). Within core in the Lancaster and Clair oil fields, evidence has been documented to suggest there are fissures that were open to the surface, and that these were repeatedly flushed with pulses of hydrothermal fluids from below and subject to sediment ingress from above. The fissures extend across several hundred metres vertically and can have apertures that are several metres wide. They were contemporaneous with faulting, and are linked to uplift of the ridge and to oil migration (Slightam, 2012; Holdsworth et al., 2019). Oil-bearing fractures tend to occur, where present, as the youngest, dominant set of brittle fractures, typically with a predominant orientation parallel to the NE-SW ridge trend. Oil migration is believed to have coincided with fissuring, mineralisation, sediment ingress and possibly active rifting in the Late Cretaceous. The porosity and permeability of these mineralised sediment-filled fissures has significant impact on the reserves and recovery of these fields. The interaction between fractures and fissures is of major importance to predict volumes and production behaviour.

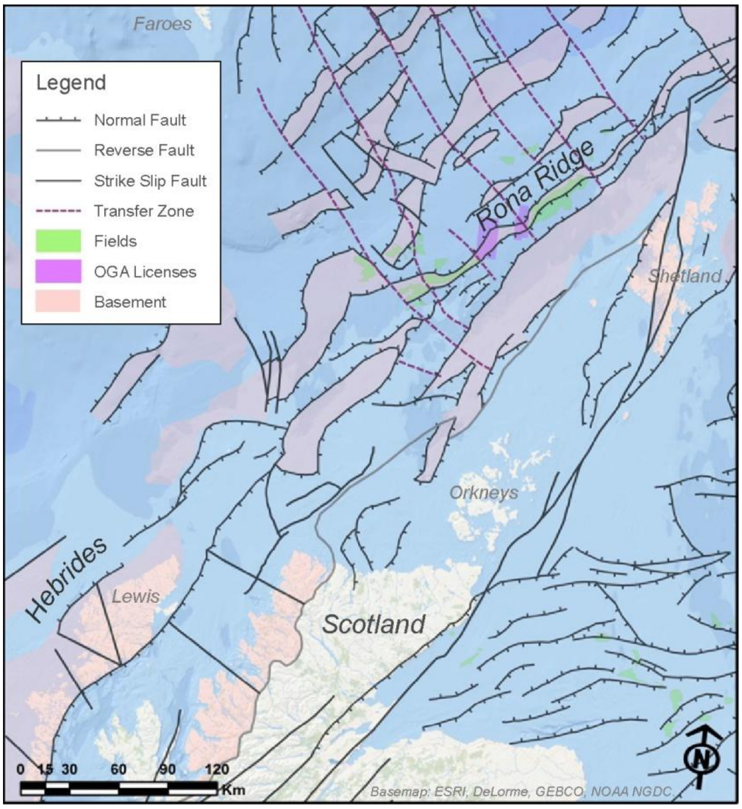

***Figure 1** Map showing the along-strike relationship between the Isle of Lewis and the Rona Ridge.*

An analogue for the Rona Ridge is the Isle of Lewis in the Outer Hebrides. The Isle of Lewis lies along the NE-SW structural trend with the Rona Ridge (Figure 1), and has comparable basement, of a similar age. The Lewisian Complex basement host typically yields NeoArchean zircon ages, and has been subject to many episodes of deformation, often concentrated along reactivated early-formed faults. Fractures, fissures are faults are all present at outcrop. Faults and fractures that are older than Mesozoic tend not to exhibit any porosity. Many of the textures seen in brittle fractures at outcrop and in the subsurface are indistinguishable. A close association between fissure-fill and faults (Figure 2) has allowed the largest fissures to have been undetected at outcrop, having been aggregated with fault rock in previous studies (e.g. Franklin 2013). Ongoing work is now characterising the fracture and fissure properties and the relationship between the two.

Figure 2 *Outcrop at Seisadar, Isle of Lewis, showing two small filled fissures (arrowed) with a well-developed network of natural fractures between. A full characterisation of the fracture and fissure properties and their inter-relationship is necessary to be able to adequately predict reservoir volumes, recovery factors and production behaviour.*

It is now understood that there are three potential components that contribute to porosity and permeability within fractured basement reservoirs: fractures, filled fissures and weathered host rock. To begin to predict the reservoir distribution within a fractured reservoir prospect or field requires insight as to how to apply these three components to model the fractured basement reservoir, and to which aspects in the geological history the parameters relate. An interesting question remains as to how relevant this finding is for other fractured basement reservoirs globally.

Discussion

Data compilation of global fractured basement fields/ prospects show fractured basement production can be found in varied tectonic settings (Figure 3). Fractured basement reservoirs are often conceptually described as a 'buried hill play' (e.g. the Bach ho Field in Vietnam as described by Cuong et al., 2009, or the Penglai 9-1 oilfield in China, Hu et al., 2017). Within this model the fractured basement reservoir is level with or structurally higher than a mature source rock. The basement has undergone some uplift relative to the basin (within which a source rock was deposited and matured), which for some time is exposed prior to deposition of a blanketing sequence of mudstones, for example, that provide a seal. The uplift could have been caused by footwall uplift associated with a normal fault, or hanging wall uplift in a reverse fault. As the basin filled, the structurally high basement will also have undergone weathering if it was at surface.

Whilst not a recognised component of the buried hill model, if faulting occurred while the basement was at or near surface, fissures might also have formed. Van Gent et al. (2010) demonstrate the effects of rotation of principal stresses in an extensional setting, along a fault from depth to surface, as the reduction in confining stress prompts a transition in sense of movement from shear through hybrid to dilation in the upper parts of a normal fault. They also mention a real-world example of equivalent dilation observed along a shallowly dipping oblique-reverse fault, indicating this feature might be a common component regardless of the fault kinematics, rather being related to fault activity whilst exposed at surface. Uysal et al, 2007, constrained the generation of travertine deposits within fissures to have been co-seismic.

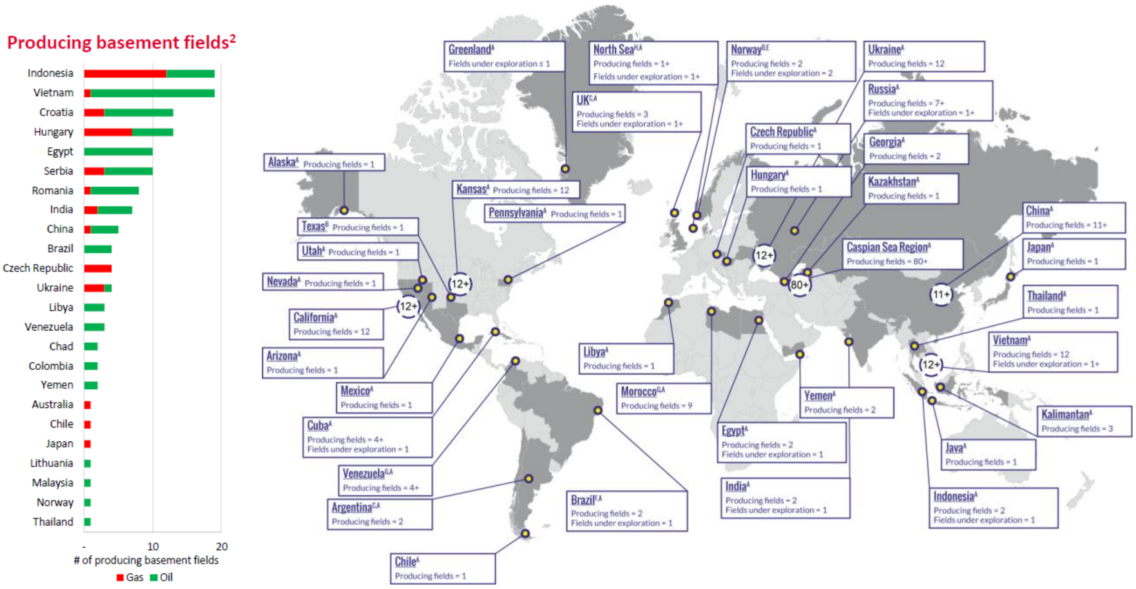

Figure 3 *Global producing basement fields and active prospects (after Hurricane Energy).*

Similar features are observed in breccias within carbonates: specifically, fissure fills with cockade textures indicative of long-lived fluid pathways containing occasional sand grains, presumably entrained from above are described in Daniels et al. (in review). This example is not linked to active tectonic faulting but active collapse following dissolution of 100+m of anhydrite. Van Gent et al., 2010, describe equivalent dilational features in carbonates at Jebel Hafeet, UAE (with a rim of precipitated calcite between the wall rock and unconsolidated stratified sediments, equivalent to fissure fill).

Conclusions

Our discussion leads to a conclusion that fissures *could* be a common theme in fractured basement plays, but does not prove this is always the case. Further work is required to evaluate producing fractured basement fields to see whether the presence of fissures could account for so many weathered or karstified features in many fractured basement play models (e.g. Fig 9 from Hu et al, 2017, indicating horizontal karst zones).

Furthermore the scaling, spatial and connectivity relationships between the fissures, fractures and faults need definition to understand how they might interrelate. Figure 4 shows a schematic of the various fracture and fissure parameters necessary to characterise their networks. The spatial relationship between fissures and fractures is a critical characteristic to understand. The permeability within fissure-fill may resemble a matrix reservoir; understanding the relative contributions of the porosity and permeability components is critical to predict overall performance.

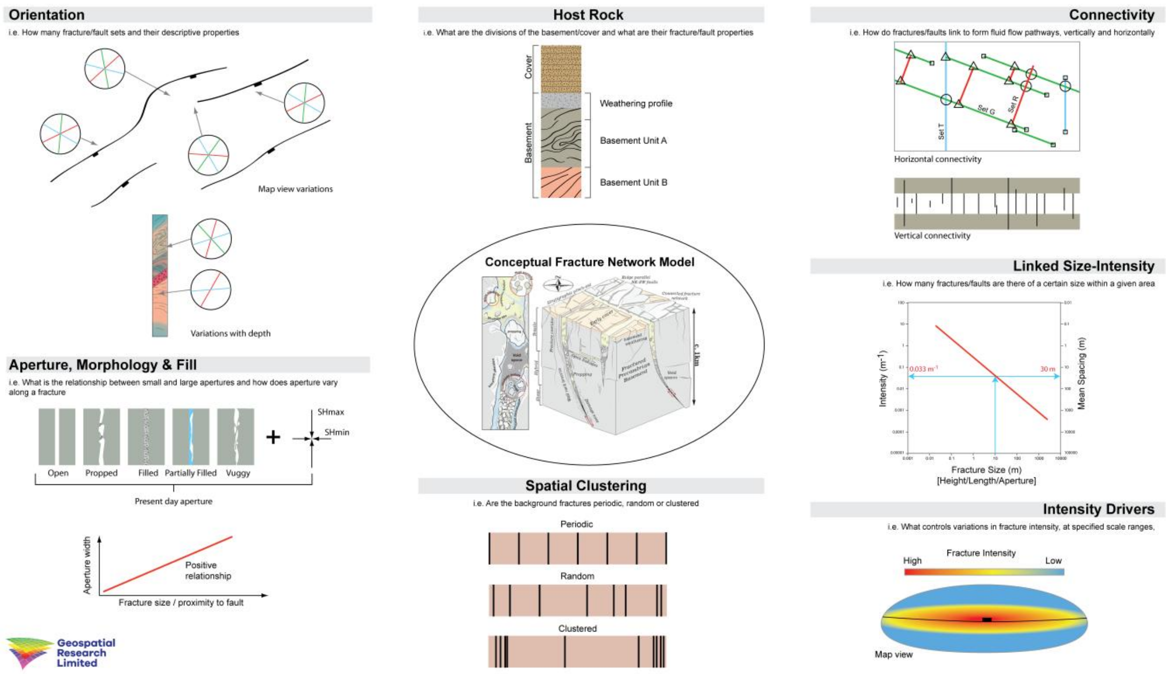

***Figure 4** Schematic of fracture characteristics in a fractured basement reservoir. Conceptual Fracture Network Model after Kit Hardman.*

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