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Predicting Spatial and Temporal Variations in Along-fault Fluid Flow

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SUMMARY

In June 2008 the UK Government launched the White Paper Managing Radioactive Waste Safely proposing construction of a deep Geological Disposal Facility. The GDF will be supported by an accompanying safety case that will include providing risk based estimates of the travel times for radionuclides leaving the GDF and travelling through the geosphere. This will require characterisation of the structural geological features surrounding the GDF in terms of location and associated permeability.

Faults are heterogeneous in time and space. Few data are available on which to base quantitative predictions of long-term temporal variations in along-fault flow. No published research to-date enables quantitative predictions of temporal variations in along-fault flow. Episodic fault flow has been proposed by a number of authors to explain indirect observations of fault behaviour as diverse as hydrothermal springs, temperature anomalies, cementing phases, gas-related amplitude anomalies and earthquake triggering. We present here a summary of research from an innovative range of sources to support the hypothesis that along fault flow commonly varies over both space and time. We also present the results of field investigations of faults in mudstones to explore how field data can be used to characterise along fault flow.

In June 2008 the UK Government published its strategy for geological disposal of nuclear waste. Although site selection is ongoing, the proposed Geological Disposal Facility (GDF) will be built at between 200 and 1000m depth. The GDF will be supported by accompanying safety cases, which will be made to the relevant regulators to indicate how the GDF is anticipated to perform during phases of transport or waste, GDF operations and post-closure. Part of the safety case will be to "demonstrate a clear understanding of the GDF in its geological setting" (Environment Agency, 2009), this will include geology, hydrogeology and subsurface environment of the site. The safety case will involve providing risk based estimates of the travel times for radionuclides leaving the GDF and travelling through the surrounding geosphere.

Risk-based estimates for radionuclide migration require statistical characterisation of the location and permeability of surrounding fractures and faults. In particular, because a large amount of flow can be conducted through a relatively small amount of linked faults (e.g. Evans et al. 2005), it is important to characterise large-scale faults, their ability to promote along-fault flow and the likely evolution of their permeability during the lifetime of the GDF. A key challenge is to develop an understanding of the potential for migration of radionuclides along faults, transported within liquids and gases, and to incorporate this understanding into the successful design of a GDF. Over-simplistic conceptualisations of faults, in which they are represented as uniform features with a permeability that is either higher or lower than the surrounding bedrock, may generate models that indicate unrealistically short or long travel times for groundwater and GDF-derived gases to reach the surface. Similarly, ignoring the possibility that a fault may change permeability during the design life, including post-closure life, of the GDF, for instance due to stress (e.g. Colletini and Trippetta 2007) or pore fluid pressure (e.g. Losh et al. 1999) changes, will provide inaccurate estimates of the along-fault migration risk. Hence, the development of knowledge related to evidence-based characterisation of the hydrogeological characteristics of faults is vital for future site characterisation.

Observations of faults show that they are highly heterogeneous, both in time and space. Limited research exists on quantifying spatial permeability variation within faults (e.g. Jourde et. al. 2002). Research has largely been focussed on predicting *across*-fault flow in sedimentary sequences of interest to the hydrocarbon industry. Very few data are available on which to base quantitative predictions of long-term temporal variations in along-fault flow. Direct observations of fluid flow through faults are infrequent. However, a wide range of information is available if both direct and indirect observations are integrated from a range of industries and research areas.

In this research we have collected, and pooled, indirect data on along fault flow from a highly diverse range of sources. We have combined these data where possible with a hydro-mechanical understanding of faults to estimate the magnitude and periodicity of temporal changes in along-fault flow. Periodic fault flow has been suggested by a number of authors as a mechanism to account for the complex fault behaviour found during many studies. Evidence includes:

- springs, mud mounds, and pockmark craters aligned along fault planes;
- temperature, pore water salinity or turbidity anomalies above or within fault rocks;
- fluid pressure distributions across faults;
- hydrothermal deposits, cements or spring deposits associated with faults;
- reservoir induced seismicity due to flow through faults beneath water reservoirs;
- triggering of earthquakes by static or dynamic stress changes.

The results of this data pooling allow us to develop a conceptualisation of coupled hydro-mechanical flow and fault permeability. We have tested this against field observations of faults in mudstones and sandstones. Preliminary results of fieldwork from Utah and Scotland demonstrate multiple episodes of flow along single faults (e.g. Fig 2). In these field investigations we map cements and alteration (see Eichhubl et al. 2009 for methods) and link the presence of these to past fluid flow. We then compare the mapped "flow" to the conceptualisation derived from data pooling. By combining field observations and observations from the data sources above, we can integrate observations at different time and length scales.

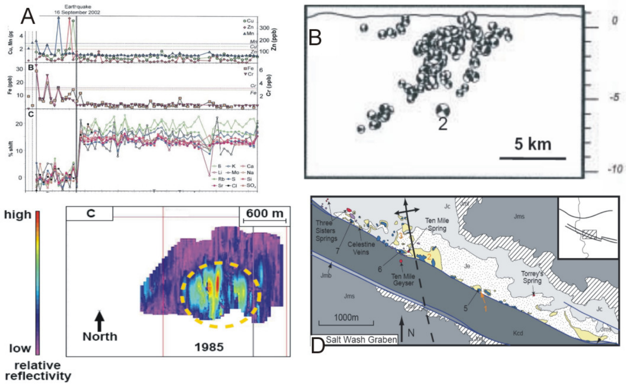

Fig. 1; Examples of temporal changes in fault permeability. A. Change of pore water composition after an earthquake in Iceland (Claesson et al. 2004) B. Aftershocks induced by CO_2 migration after the Colfiorito earthquake (Colletini and Tripetta 2007) C.Fluid pulse imaged on seismic data from Losh et al (1999). D. Migration of CO_2 -charged springs with time (Dockrill 2006).

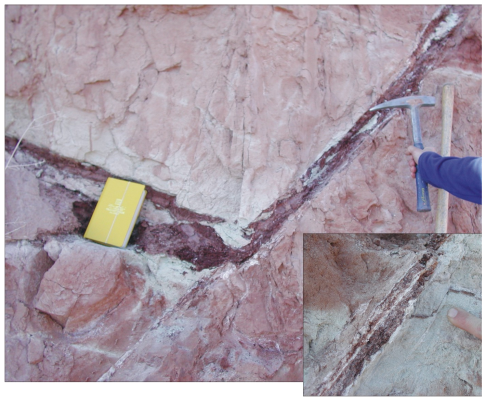

Fig. 2; This fault in Southern Utah offsets a purple mudstone by ~1 meter. Evidence for multiple episodes of fluid flow can be seen along the fault (inset); thin carbonate veins are deposited in the fault and have been cut by the fault, so flow was synchronous with fault offset.

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