SAND INJECTITES IN SEDIMENTARY BASINS: THEIR SIGNIFICANCE IN BASIN EVOLUTION & HYDROCARBON PROSPECTIVITY

First described in 1827, the forceful injection of sand into finer grained strata, failed to attract more than casual interest in the geological community until the fortuitous recognition of sandstone intrusions as hydrocarbon reservoirs on the UKCS in the early 1990's. Several similar fortuitous discoveries were made adjacent to Harding field, but the first deliberate exploration of a sand injection complex did not take place until 2003-4, when Volund field was discovered (NCS). In the early 1990's to early 2000's, the significance of sandstone intrusions in several oil fields in development became apparent and changed field development strategy with respect to incremental reserves and their distribution and enhancing recovery by optimising well-placement. In the North Sea more than 11 bn bbls oil are known to occur in, or are associated with, sand injection complexes; in the North Sea 2 bn bbls oil occur in reservoirs where sandstone intrusions predominate.

Sandstone intrusions have varying levels of discordance with bedding, which contributes significantly to the ease of differentiating sandstone intrusions from depositional sandstones on seismic data. Individual sandstone intrusions that form significant reservoir volumes (10's m thick) often occur above, within and below biozones. Characteristics of the external geometry of sandstone intrusions includes steps, bifurcation, upward erosion of intrusion margins, preservation of fracture margins, and partial disintegration of host strata. These combine to form composite sedimentary intrusions, forming saucer-shaped intrusions, wings, sill complexes and dyke swarms, which form regionally in the subsurface and outcrop, over scales of 1000's km^2 and often >1km thick.

Examples of large sandstone intrusions from the subsurface will be shown together with similar scale outcrop examples. Comparison of these data will be used to illustrate the limitations of seismic imaging when defining the gross volume, N/G (storage capacity and reservoir quality), presence of sub-seismic reservoir, lateral and vertical connectivity and fluid contacts. Core-scale characteristics are sometimes diagnostic of sandstone intrusions and occur in core samples and outcrop, several of which record the hydrofracture of host mudstone. Angular fractures on grain surfaces and intra-crystalline micro-fracture networks are diagnostic of sandstone intrusions. Grain textures record multiple high-velocity inter-granular collisions during sand injection in which turbulent flow prevails in dilute granular suspensions.

Pore-fluid pressure (*Pf*) is requisite to the formation of sand injection complexes such that *Pf* exceeds the fracture gradient and ultimately the lithostatic gradient + the tensile strength of the seal. Absolute *Pf* is less critical than the contrast between the hydrostatic and lithostatic gradients, a contrast that is least during shallow burial sandstone intrusions (assuming a linear hydrostatic gradient). When the seal fails, hydrofractures form and propagate toward a free surface. Initially the hydrofractures are fluid filled but as they propagate fluid velocity increases, which when it exceeds the minimum fluidisation velocity for sand begins to entrain fine to medium grained grains, which form sandstone intrusions in some of the hydrofractures. There are several mechanisms by which *Pf* can create overpressure, but formation of giant injection complexes requires large volumes of fluid, likely to be derived by regional burial processes and probably most likely associated with chemical diagenesis.

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