Identifying depositional units in complex clastic successions with palynology: understanding reservoir heterogeneity for CO2 storage

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Abstract

An understanding of the heterogeneity of complex continental clastic successions is vital for CO2 storage and for the extraction of oil and gas. Heterogeneity caused by very low permeability mudstone units (baffles) can cause compartmentalisation of reservoirs impeding extraction or injection. The meter(s) scale of heterogeneity caused by mudstone baffles is also often sub-seismic, and so not visible in the subsurface, and may be poorly resolved on geophysical logs.
The late Permian Umm Irna Formation outcropping along the Dead Sea shore in Jordan contains thick sandstone channels, palaeosols and mudstone units of various geometries and is an analogue for formations that are being targeted for CO2 storage in the North Sea (for example the Early Triassic Sherwood Sandstone Group), and for oil and gas bearing formations in the Middle East, for example the early Permian Gharif Formation.

Following fieldwork in December 2022, we show how chiefly palynology but also plant macrofossils and sedimentology can be used to reconstruct palaeoenvironments and geometry (thickness, lateral persistence, and form) of mudstones in the Umm Irna Formation giving rise to a 3D appreciation of the sources and character of heterogeneity. Individual mudstone units of different origins and geometries within the formation were sampled for their palynomorphs and plant fossils, and studied sedimentologically. The units revealed great variation in palynomorph assemblage type, but generally fell into two categories. The first category was found in laterally persistent argillaceous units such as migrating point bars or crevasse-splay deposits associated with the main river channels. This was high in palynological diversity, containing a wide variety of Permian pollen and spores that probably represent a regional snapshot of the vegetation on the floodplain and the higher ground around. The second category was from smaller, locally restricted argillaceous units like oxbow lake and channel plugs and was of lower diversity, but also varied almost uniquely from one unit to another with high proportions of one or two palynomorph species that appear to be related to plants growing very locally around features in the floodplain.

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Thus, it is hypothesised that using palynomorph, plant fossils, and sedimentology, it may be possible to reconstruct the origin, form, and lateral continuity of mudstone baffles in the Umm Irna Formation and other similar formations. The distribution and lateral continuity of mudstone baffles may be relatively clear in outcrop, but the key is transferring what has been learned from the outcrop to the subsurface where 3D awareness will help to guide drilling and CO2 injection or hydrocarbon extraction strategies. Our work shows that detailed palynology, palaeobotany and sedimentology, preferably on core in fairly closely spaced boreholes, could allow reconstruction of mudstone geometry.
Developing methods like these may help understanding of CO2 storage targets like the Sherwood Sandstone Group in the UK, and co-eval formations in Europe, but also other continental successions which are the targets for aquifer geothermal and carbon capture and storage. Both of these low-carbon energy techniques rely on an understanding of fluid flow for injectivity and extraction.

Keywords: palynology plant fossils Permian carbon capture and storage heterogeneity mudstone baffles