### Characterising regional evaporite seal for hydrocarbon and CO2 storage — Upper Jurassic, Arab-Hith formations, Saudi Arabia

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Characterising regional evaporite seal for hydrocarbon and CO₂ storage – Upper Jurassic, Arab-Hith formations, Saudi Arabia

Introduction

One of the most important and regionally extensive seals of the Arabian Plate are the Upper Jurassic Arab and Hith formations, which consist dominantly of evaporites (Powers, 1962; Alsharhan & Kendall, 1994). Their importance for the hydrocarbon systems is self-evident since they form the seal of the world’s largest oil field (Ghawar), amongst many others. In addition, their value as a regional seal for CO₂ storage is now also recognised (Ye et al., 2022). Thus, they are of principle economic interest to the country and the region. In the East of Saudi Arabia, at the location of the Ghawar field, the Upper Jurassic section lies buried beneath approximately 2 km of overburden (Figure 1). However, towards the West, near the capital Riyadh, lies an escarpment where the Jurassic rocks outcrop. Whereas the under- and overlying carbonate strata are well preserved, the evaporites (anhidrites) of the Arab and Hith formations are mostly dissolved and represented by collapse-breccias. To better understand the stratigraphy and rock characteristics of the evaporite units a core has been taken near these outcrops, covering the Arab and Hith formations, which forms the topic of this presentation.

The Hith Formation consists of anhydrite, up to 80%, and shows a cm- to dm-scale bedding pattern. At the Dahal Hit cave, close to the drilling site of this well, the Hith Formation is characterized by nodular anhydrite facies with interbedded chicken-wire aggregates (associated with a sabkha setting) and laminated varied facies (associated with a playa setting) (Alsharan & Kendall, 1994). The base of the Hith Formation and contact with the Arab A member, is marked by dolomitized, anhydritic peloidal packstones and grainstones (Alsharan & Kendall, 1994). Conformably above the Hith Formation, lies the Sulaiy Formation (Lower Cretaceous). It forms a massive limestone, approximately 100 m thick, that signals a return to an open-marine environmental setting after the deposition of the Hith evaporites (Al-Husseine, 1997; Wolpert et al., 2015). It is water-bearing in the weathered subsurface zone (karst-type medium) and thus is of importance for agriculture use as a freshwater source (Wolpert et al., 2015).

The Arab Formation is regionally subdivided into Arab A, B, C and D carbonate reservoirs, which are separated by the A, B, C and D evaporites (Azer & Peebles, 1998). The cyclicity within the Arab and Hith formations enabled tentative sequence stratigraphic subdivisions in 3rd, 4th and possibly 5th-order (para-)sequences (Azer & Peebles, 1998).

Although both formations are recognized as important seals, they are also known to have shown seal integrity failure, causing the further upward migration of hydrocarbons (e.g. Al Shaheen Field, Qatar; van Buchem et al., 2014), which is a reason for concern when considered as seals for CO₂ storage. Since the outcrops do not provide access to the intact formations, and no core material is available for academic studies, it was decided by KAUST to take a full core throughout the Hith and Arab formations to be able to carry out an in-depth study of the sedimentology, geochemistry and rock mechanics of these formations.

Here we report the preliminary results of the coring campaign, which was successfully concluded in Fall 2022.

Methods

A 84 mm diameter well was continuously cored with a Desco SP7500SA-RC rig and reached a total depth of 390 m. Core recovery is 99% and covered the lower part of the Cretaceous Sulaiy Formation, the full Hith Formation, as well as the Arab A, B and C members of the Arab Formation. Experimental work to be performed on the core includes the following: core plugs for porosity and permeability; isotope analysis; thin sections; XRD; Wombat analysis for scratch testing, Vp/Vs and XRF measurements. In addition, wireline data of gamma-ray, sonic, density and neutron logs were acquired. Together this forms a unique dataset of core and petrophysical data.
Figure 1 The Sulaiy, Hith, and Arab formations are seen to outcrop South-East of Riyadh. The well is located approximately 35 km South-East of Riyadh on top of an escarpment. The well projection shows the lithologies drilled by the well. Adapted from Konert et al. (2001) by Ye et al. (2022)

Results
The preliminary results are:
- the obtained thicknesses measured in the cored interval are higher than predicted in the geological maps and outcrops of the area (Powers et al., 1966; Vaslet et al., 1991). The Hith Formation main anhydrite was estimated as 70-80 m thick from the Dahal Hit cave (Powers et al., 1966), and measured in the core as 78 m thick; the Arab Formation, estimated as approximately 105 m thick in outcrop (Vaslet et al., 1991), was measured in the core as 115 m thick (this only includes the Arab A and B members in full until the base of the Arab C member and is, thus, missing the Arab D member). This new data point has significant implications for the thickness trends of the regional seal.
- Sedimentology: Figure 2 shows core images from the Sulaiy, Hith and Arab formations. These images are showing: a) the intense present-day karstification that is seen in the upper section of the Cretaceous Sulaiy formation, b) light grey and brown limestone interbedding within the Sulaiy Formation, c) breccias of the Manifa Formation, and d) a dolomite interval within the evaporites of the Arab C member.

a) The present-day karstification of the Sulaiy Formation can be seen from the top of the well down to a depth of 48 m. This highly porous top section resulted in significant losses during drilling and required casing. The water table was found to be at a depth of 106 m.

b) At a depth of 197 m is a sharp contact between the Sulaiy limestone and the underlying Hith anhydrite. This depth marks the top of the Hith anhydrite in the well. The Hith is characterized by dm-scale bedding of evaporite facies that contain intercalations of cm-scale clayey wispers/partings, occasional nodular chicken-mesh aggregates and dominantly massive, laminated anhydrite.

c) The transition of the Hith anhydrite to the Arab A member limestone (top of the Arab Formation) occurs at a depth of 275 m. At this depth one can observe cm-scale brecciated limestone fragments. In outcrop it is not possible to see the contact of the Hith with the underlying Arab A formation, due to the dissolution of the Hith evaporites. The Arab Formation consists of alternating carbonates and anhydrite facies at a dm-scale. Further, cm- to mm-scale laminations of clayey intervals are visible. Brecciated and highly altered limestone layers are found on a m- to cm-scale. Halite was found in two sections where there was no core recovery (dissolution of the halite by the drilling fluid resulted in core loss). This occurred at depths of 234.45 to 237.5 m and 326 to 330 m.
Figure 2 (a) Shows the top of the Sulaiy Formation with evidence of intense karstification; (b) interbedding of light brown and grey limestone from within the Sulaiy Formation; (c) breccias that characterize the Manifa Formation (these form the transition from the Hith anhydrite to the Sulaiy limestone); (d) a 1.3m dolomite interval within the Arab C member that is interbedding the Arab C evaporites.

First results of the analytical work and a comparison with Hith and Arab wells in the region will be included in the conference presentation.

Conclusions
1. A 390 m section of core (and wireline logs) was successfully drilled in Central Saudi Arabia, that spans the Hith and Arab formations in its entirety, and a core recovery of 99% was achieved.

2. Preliminary results show that the formations are significantly thicker than predicted by the geological maps of the area (Vaslet et al., 1991), with consequences for the regional continuity of the sealing capacity.

3. Halite was found in the core in two intervals that were 3 and 4 m thick, respectively, and this is a rare if ever reported find.

Adding to the understanding of the depositional environment and sequence stratigraphic structure, this well will provide an invaluable data source for improving the regional sequence stratigraphic architectural model and improving our understanding of the characteristics of this seal unit.

References


