Challenging Middle Eastern Stratigraphic Misconceptions – An Example for Creation and Infill of the Gotnia Basin

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Introduction

The Middle–Late Jurassic stratigraphy of the Middle East contains arguably the world's most economically significant petroleum system comprising of multiple, world-class source, reservoir and seal intervals. However, in a regional context, many of these petroleum significant depositional systems are not yet fully understood. This lack of clarity has led to inconsistencies in lithostratigraphic nomenclature across international boundaries, allowing long-held misinterpretations on depositional relationship and stratigraphic architectures to develop. This misunderstanding has limited the full exploration and production potential of the Middle–Late Jurassic petroleum system.

One of the stratigraphic misconceptions that exist on the Arabian Plate is the development and infill of the Late Jurassic Gotnia Basin and its relationship with the Rimthan 'Arch'. The creation and infill of the Gotnia Basin has been interpreted by many authors (e.g. Jassim and Buday, 2006; de Cabrera et al., 2019), as being largely controlled by tectonics. This model suggests that the extent and depth of the Gotnia Basin is delineated by south-west to north-east and north-west to south-east orientated lineaments, and that gradual subsidence of the Gotnia Basin would have provided the necessary accommodation space to develop the thick evaporitic sequences of the Gotnia Formation (Aqrawi et al., 2010). A recent, regional, sequence stratigraphic re-evaluation of the Middle–Late Jurassic of the eastern Arabian Plate utilizing published datasets proposes an alternative model to this long-held tectonic development and infill of the Gotnia Basin. This alternative model proposes a eustatically driven control to the development of the Rimthan 'Arch' and Gotnia Basin whereby the shallow-water carbonates of the Rimthan 'Arch' were able to keep pace with rising sea-level whilst the Gotnia Basin became a sediment starved, organic-rich intra-shelf basin.

The Application of Sequence Stratigraphy

In this recent re-evaluation, a sequence stratigraphic approach has been systematically applied to the Middle–Late Jurassic succession using the updated and globally calibrated version of the Arabian Plate Sequence Stratigraphic Model (Sharland et al. 2001; Simmons et al., 2007). This approach enables correlation between time-equivalent rock units which are constrained by biostratigraphically calibrated 3rd order depositional sequences. The consistency of these interpretations is demonstrated by the construction of laterally extensive (>2000 km) reference transects across the eastern Arabian Plate from Kurdistan (Iraq) to Oman containing key subsurface reference wells (Figure 1). Sequence stratigraphic interpretations in these key subsurface wells are tied back to the latest biostratigraphic age refinement at the Jurassic Escarpment outcrops in Saudi Arabia (Al-Mojel, 2017), as well as updates to a reference well in Kuwait (Kadar et al., 2015; de Cabrera et al., 2019). The reference transects document the main structural features, stratigraphic architectures and geometries that exist along the eastern portion of Arabian Plate. The application of the sequence stratigraphic model provides a robust framework in which published information from biostratigraphy, carbon isotope stratigraphy, sedimentology, structural geology and organic geochemistry can all be integrated.

The Importance of a Regional Datum

To fully document depositional systems across international boundaries and recognize complex architectural geometries, the identification of a regional datum on which to pin sequence stratigraphic interpretations and observations is critical. The early Callovian Uwainat Member of the Dhruma Formation is one such datum identified in early regional reviews of the Jurassic stratigraphy by Murris

(1980). This unit is a key stratigraphic horizon that has a plate-wide comparable thickness, consisting of grainy facies, locally oolitic, indicating water depths in the order of 10's of metres (Alsharhan and Whittle, 1995) and that deposition on the Arabian Plate at this time was that of a uniform, flat ramp. This unit provides a datum on which regional transects can be flattened and in which topography can be built without significant tectonic control.

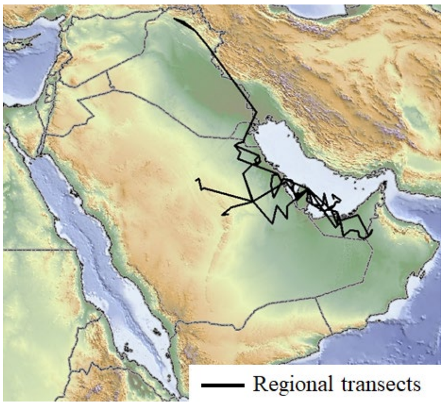

Figure 1 *Location of the regional transects with key subsurface well control for the Jurassic stratigraphy along the eastern margin of the Arabian Plate.*

The Carbonate Conceptual Model

The concept of carbonate aggradation (Figure 2) is that as some carbonates grow in-situ and can keep pace with sea-level fluctuations developing carbonate platforms, whilst others are drowned and form intra-shelf basins (e.g Schlager, 2005; Razin et al., 2010). A detailed review of facies associations, bathymetric and environmental interpretations was completed to provide extra granularity in proposing an alternative model for the creation and infill of the Late Jurassic Gotnia Basin.

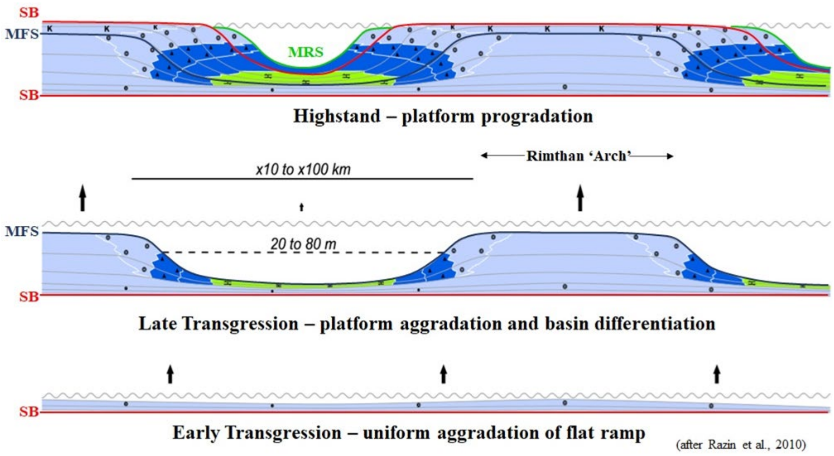

Figure 2 *Conceptual model for carbonate platform aggradation and intra-shelf basin development in response to sea-level rise. (Modified from Razin et al., 2010)*

Reviewing the latest stratigraphic literature

Several recent public domain publications from Kuwait and Saudi Arabia have shed new light on the development of the Gotnia Basin. Of particular importance to this alternative model for the creation and infill of the Gotnia Basin is a seismic stratigraphic interpretation of the Rimthan 'Arch' to the Gotnia Basin transition by Wharton (2017). This interpretation shows no structural offset along the Gotnia Basin margin but rather aggradational and progradational geometries within the Callovian–Oxfordian carbonates with time equivalent sediment starvation in the adjacent intra-shelf Gotnia Basin. The Arab cycles subsequently cover these carbonates and grade laterally into the Gotnia Formation which has a prograding wedge shape geometry.

The Evolution of the Late Jurassic Gotnia Basin

The alternative model for the creation and infill of the Gotnia Basin can be demonstrated in step-by-step evolution from a well transect that spans from the Hanifa Basin, over the Rimthan 'Arch' and terminating in the Gotnia Basin (Figure 3).

Step 1 – The early Callovian Uwainat Member represents a regional marker bed that signify a point in geological time when the depositional profile of the Arabian Plate was a reasonably flat carbonate ramp with fairly uniform water depths. Biostratigraphic age revision of the Sargelu Limestone has now recognized the continuation of the Uwainat Member into Kuwait and Iraq.

Step 2 – During the Callovian and Oxfordian transgressions, local carbonate aggradation led to the development of the roughly east-west trending, shallow-water carbonate Rimthan 'Arch' close to the Saudi Arabia-Kuwait border. Either side of the Rimthan 'Arch', two sediment starved intra-shelf basins developed: the Gotnia Basin to the north, with the condensed, organic-rich facies of the Naokelekan Formation and the organic-rich mudstones of the Hanifa Formation in the Hanifa Basin to the south. In the Hanifa Basin, prograding, grainy highstand facies of the Hanifa Formation represent stratigraphic potential sealed by organic-lean, micritic transgressive facies.

Step 3 – At the Oxfordian–Kimmeridgian boundary, sea-level fell exposing the Rimthan 'Arch' and surrounding carbonate platforms, causing karstification. In the adjacent intra-shelf basins, early Kimmeridgian lowstands were deposited forming the Najmah Limestone stratigraphic pinch-out against the Rimthan 'Arch' and subtle trap potential within the interbedded carbonates within the anhydrites and organic-ich facies of the Diyab Formation in the Hanifa Basin.

Step 4 – In the succeeding sea-level rise, the Hanifa Basin was infilled by shallow-water carbonates whilst sedimentation in the Gotnia Basin was minimal, condensed and organic-rich, leaving the basin underfilled.

Step 5 – In the Late Jurassic the final infill of the Hanifa Basin consists of vertically stacked, aggrading and flat bedded shallow-water carbonates and evaporites of the Arab A-C cycles with the overlying Hith Formation that extended over the Rimthan 'Arch'. The Gotnia Basin continued to be underfilled at this time with increasing water depths. Four cyclic successions of anhydrites and salts of the Gotnia Formation were deposited as thick shelf margin wedges that first onlapped and then offlapped the Rimthan 'Arch'.

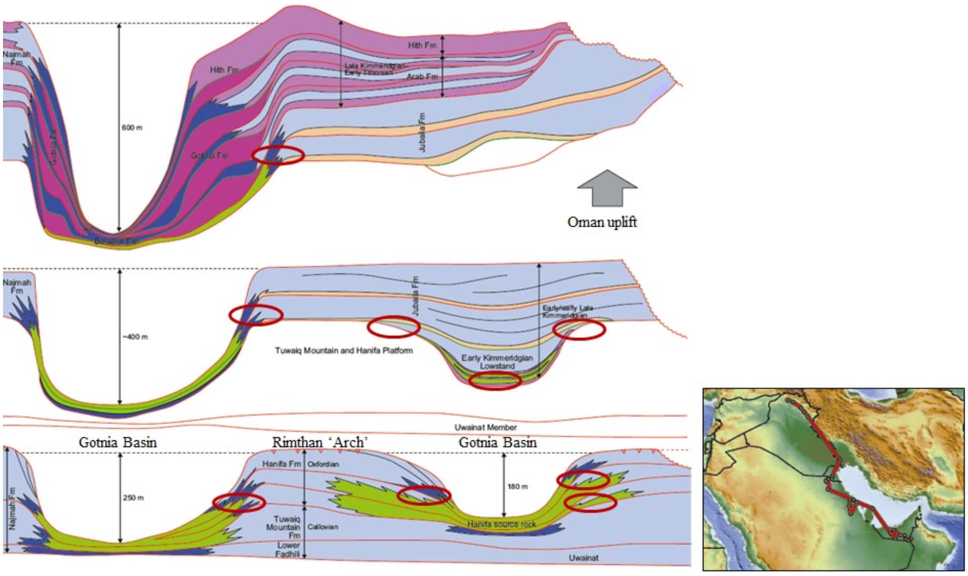

Figure 3 *A cross section showing the step-by-step evolution of the Gotnia Basin and Rimthan 'Arch'. Red circles highlight stratigraphic trap potential within the Gotnia and Hanifa basins.*

Conclusion

The application of sequence stratigraphy in a regional geological context is a powerful tool to help resolve complex subsurface stratigraphic architecture across international boundaries. Using a geological time-based approach, identifying key flattening horizons and a combination of carbonate sedimentological and sequence stratigraphic concepts have challenged one of the long-held stratigraphic misconceptions over the development of the Gotnia Basin and Rimthan 'Arch' – this being that the creation and infill of the Gotnia Basin was tectonically controlled. This approach has demonstrated the carbonate factories response to eustatic sea-level fluctuation has provided an alternative model to explain the creation and infill of the Gotnia Basin in the absence of tectonic control. This new insight has impacted the prediction and distribution of source, reservoir and seal facies, and the presence of stratigraphic traps. The creation of the Gotnia Basin by the carbonate factories response to sea-level change has resulted in a complex, asymmetrical sediment infill between the Gotnia Basin and adjacent Hanifa Basin separated by the Rimthan 'Arch'. For example, during Oxfordian–Kimmeridigian sea-level fall, grainy facies of the Najmah Limestone prograded leading to stratigraphic pinch-out against the Rimthan 'Arch' sealed by transgressive facies. Whilst time equivalent, in the Hanifa Basin, interbedded carbonates within the anhydrites and organic-rich facies of the Diyab Formation may also have formed some stratigraphic potential.

References

Al-Mojel, A. [2017]. *Sedimentology and sequence stratigraphy of the Jurassic, Jabal Tuwaiq, Central Saudi Arabia.* Université de Bordeaux.

Alsharhan, A.S. and Whittle G.L. [1995]. Carbonate-evaporite sequences of the Late Jurassic, southern and southwestern Arabian Gulf. *AAPG Bulletin*, **79**(11), 1608-1630.

Aqrawi, A.A.M., J.C. Goff, A.D. Horbury and Sadooni F.N. [2010]. *The Petroleum Geology of Iraq*. Scientific Press Ltd (Wiley-Blackwell).

de Cabrera, S.C., T. De Keyser, G. Al-Sahlan, A. Hajar, A.P. Kadar and Karam K.A. [2019]. Middle and upper Jurassic strata of the Gotnia Basin, Onshore Kuwait: Sedimentology, sequence stratigraphy, integrated biostratigraphy and paleoenvironments, part 1. *Stratigraphy*, **16**(3), 165-193.

Jassim, S.Z. and Buday T. [2006]. Tectonic framework. In S.Z. Jassim and J.C. Goff (Eds.), *Geology of Iraq*, 45-56.

Kadar, A.P., T. De Keyser, N. Neog and Karam K.A. [2015]. Calcareous nannofossil zonation and sequence stratigraphy of the Jurassic System, onshore Kuwait. *GeoArabia*, **20**(4), 125-180.

Murris, R.J. [1980]. Hydrocarbon Habitat of the Middle East. In A.D. Miall (Eds.), Facts and Principles of World Petroleum Occurrence. *Canadian Society of Petroleum Geologists – Memoir, **6***, 765-800.

Razin, P., Taati, F., van Buchem, F. [2010]. Sequence stratigraphy of Cenomanian-Turonian carbonate platform margins (Sarvak Formation) in the High Zagros, S.W. Iran: an outcrop reference model for the Arabian Plate. *Geological Society of London Special Publication,* **329**, 187-218.

Schlager, W. [2005]. Carbonate Sedimentology and Sequence Stratigraphy. SEPM - Concepts in Sedimentology and Paleontology no. 8, *SEPM Society for Sedimentary Geology (Formerly Society of Economic Paleontologists and Mineralogists)*, 1-200.

Sharland, P.R., R. Archer, D.M. Casey, R.B. Davies, S. Hall, A. Heward, A. Horbury and Simmons, M.D. [2001]. *Arabian Plate Sequence Stratigraphy*. GeoArabia Special Publication, **2**, Gulf PetroLink

Simmons, M.D., Sharland, P.R., Casey, D.M., Davies, R.B., Sutcliffe, O.E. [2007]. Arabian Plate sequence stratigraphy: Potential implications for global chronostratigraphy. *GeoArabia*, **12**, 101-130.

Wharton, S.R. [2017]. The Rimthan Arch, basin architecture, and stratigraphic trap potential in Saudi Arabia. *Interpretation*, **5**(4), 563-578.