Conclusion

During deposition of the Jurassic and Cretaceous reservoirs, such reservoirs realized minimal amount of structural tectonic deformation. Today, these same reservoirs under current tectonic regimes are compartmentalized and detailed fault interpretation provides the understanding for the conduit (migration) and trapping of hydrocarbons.

The application and knowledge of regional tectonics is critical to the awareness of the structural complexities. Technical application such as wrench tectonics is important in finding and drilling for additional hydrocarbons and such structures are realized within the Partitioned/Divided Zone of the Kingdom of Saudi Arabia/Kuwait.

Acknowledgements

We thank the Ministry of Petroleum of Saudi Arabia, the Ministry of Oil of Kuwait, Saudi Arabia Chevron (SAC), Kuwait Gulf Oil Company (KGOC) and Chevron for permission to present this study, and Tom Heidrick who influenced and supported transtentional/transpressional tectonics (Retired, Chevron).

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Regional framework and controls on Jurassic evaporite and carbonate systems of the Arabian Plate

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The world's greatest petroleum province lies on the eastern margin of the Arabian Plate. Here in the Jurassic the depositional section was located on the southern Tethyan margin. These rocks collectively contained source rocks, reservoirs and seals that were associated with a local thermal maturation history that generated hydrocarbons and caused their migration and entrapment in the current oil and gas fields.

A detailed sequence-stratigraphic framework built progressively by Beydoun (1988), Murris (1980), Alsharhan and Nairn (1997) and Sharland et al. (2001) tracks and predicts the distribution of evolving sedimentary facies on varying spatial and temporal scales and provides an understanding of the chronostratigraphy, tectonics, climate, palaeogeography, depositional systems and diagenetic trends and petroleum systems of the region and identifies potential exploration plays. This framework is subdivided by surfaces that are the product of local low-frequency tectonic movements, associated with Wilson's (1965) cycles of tectonic plate motion (Figure 1). It is further and importantly subdivided by surfaces formed during cycles of high-frequency eustatic changes in sea level and varying rates of sediment accumulation. These were likely driven by changes in global climate caused by variations in the Earth's orbital movement proposed by Milankovitch (1941).

Hydrocarbon exploration and consequent exploitation of the southern Tethys region has established that the Jurassic section of this area has hydrocarbon potential both in conventional and unconventional plays. In the Jurassic section the world's largest fields are sequestered in shallow-water grain

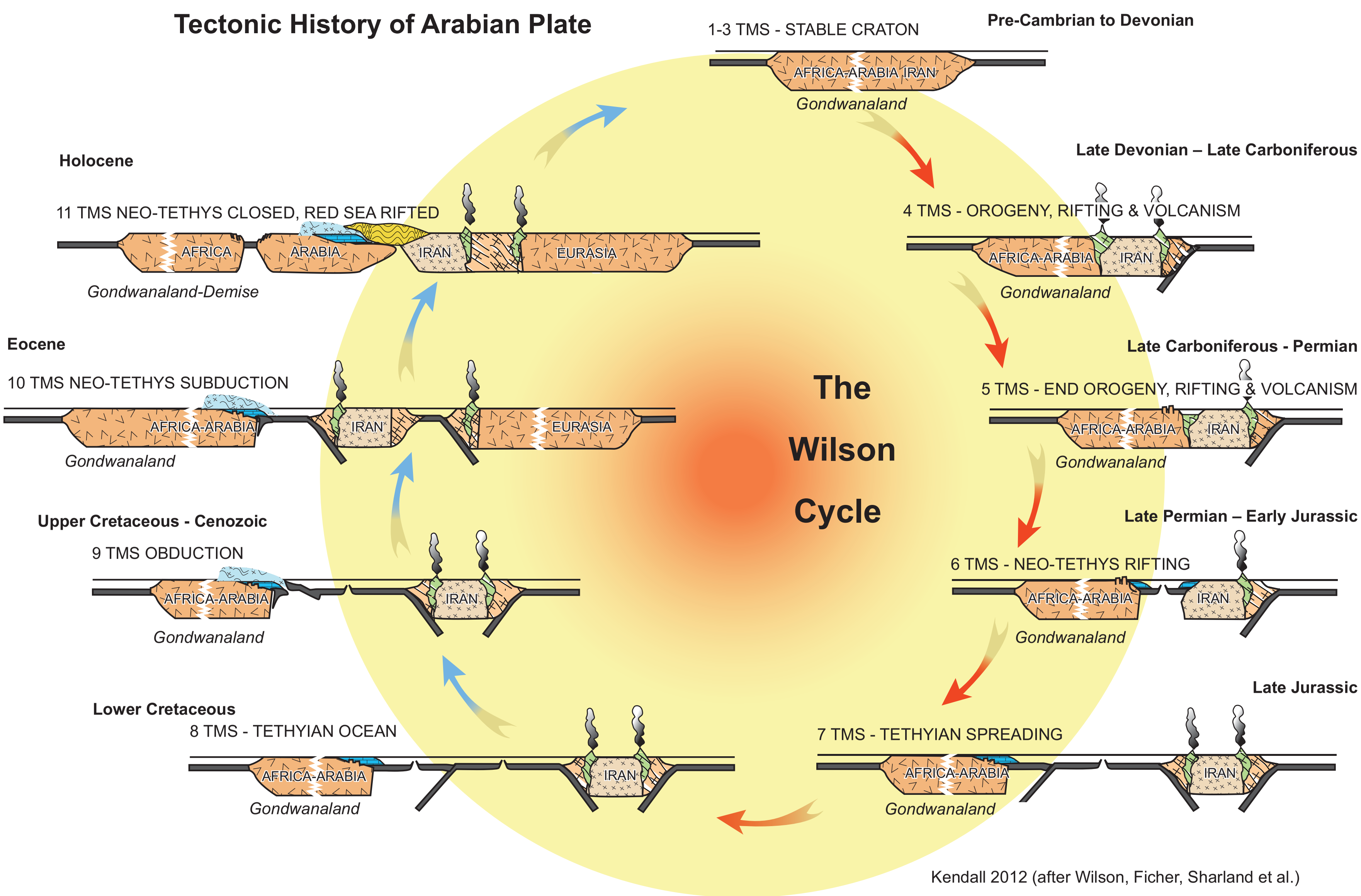

Figure 1: Note the mega tectonic sequences of Sharland et al. (2001), whose boundaries are prominent in the stratigraphic section, coincide with the major extension and collision along plate boundaries.

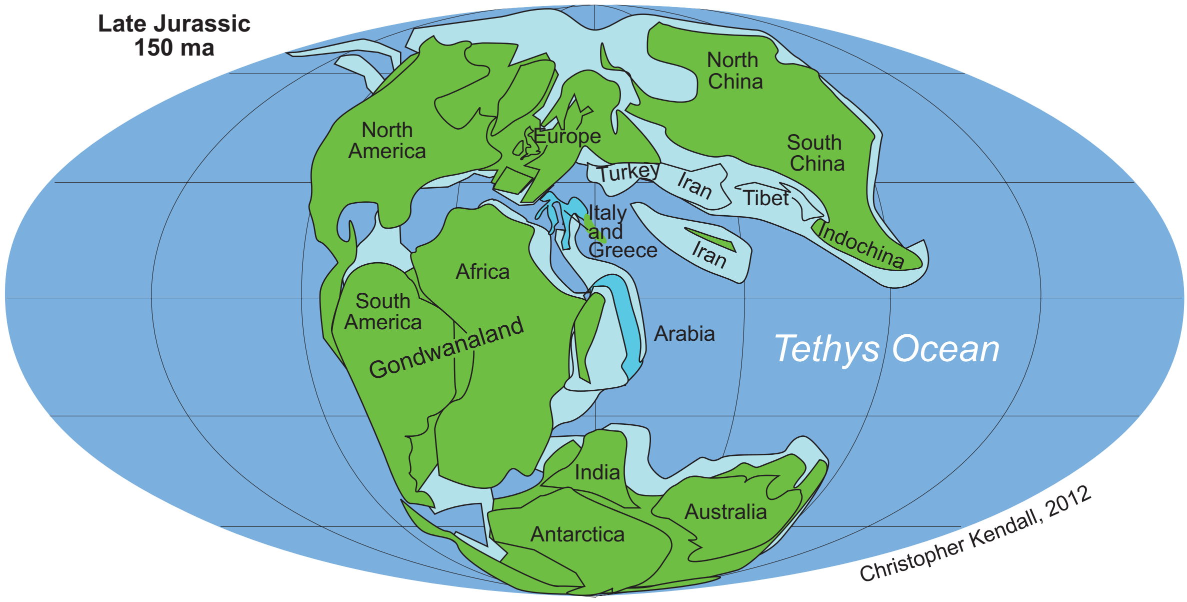

Figure 2: In the Late Jurassic the Arabian Plate was located to the east of Gondwanaland where the rain shadow caused the climate to be an arid tropical one, and matching the setting of the present-day Arabian Gulf led to the sequestration of organic matter despite the nutrient desert that existed on the eastern flank of the extensive continental mass. Evaporitic basins formed here, collecting carbonates, marls and evaporites trapped behind barriers, which were formed by the combined movement of what was once an original Hercynian horst and block terrain, and on which carbonates accumulated adjacent to the southern shore of the Tethys Ocean.

carbonates and dolomites, mostly in Saudi Arabia, with others in Kuwait, Qatar, the United Arab Emirates (UAE) and Yemen. Now exploration is switching to horizontal drilling of deeper euxinic settings flanking and enclosing the traditional shallow banks. Most of these Arabian Jurassic fields are found within the crests of large, approximately NS-trending, anticlinal folds but many are found to be stratigraphic traps within and flanking these structural features.

The highly productive Permian through Cenozoic petroleum systems of the Arabian Plate are within successions of carbonate and evaporite sediments associated with high rates of organic production. The successions accumulated in the arid, rain-shadow of the lee shores of the equatorial seaway flanking the eastern margin of Gondwanaland and the consequent restricted basins confined behind structural and/or depositional barriers that formed over Hercynian structural highs (Kendall et al., 2003, 2007). This is particularly true of the Late Jurassic (Figure 2).

The current Arabian Gulf and the underlying Upper Mesozoic to Cenozoic of the area (Murris, 1980) and the Fars of Iran (Kashfi, 1980; Aqrawi, 1993) are stratigraphic sections that represent prime examples of a linearly depressed intercontinental compressional zone that has a history punctuated by limited access to the sea and repeated desert climates (Figure 2). This sea represents an isolated linear belt of interior drainage with a restricted entrance to the open ocean. Regional drainage tends to flow into the Arabian Gulf and the air system is that of the arid tropics. There is a wide envelope formed by the surrounding subcontinents of Arabia and Asia Minor.

Here the ancient arid climate is evidenced in the geologic record of thick sections of evaporites (anhydrite, gypsum and halite) that have accumulated in the marine settings that flanked the margins of the pulled-apart continental plates of Gondwanaland from the Permian through Jurassic. Later in the Late Cretaceous and Cenozoic the compressional terrains of colliding margins of Arabia and Indo-Iranian plates were areas of local tectonic uplift or sediment accumulation that have isolated standing bodies of water from the sea.

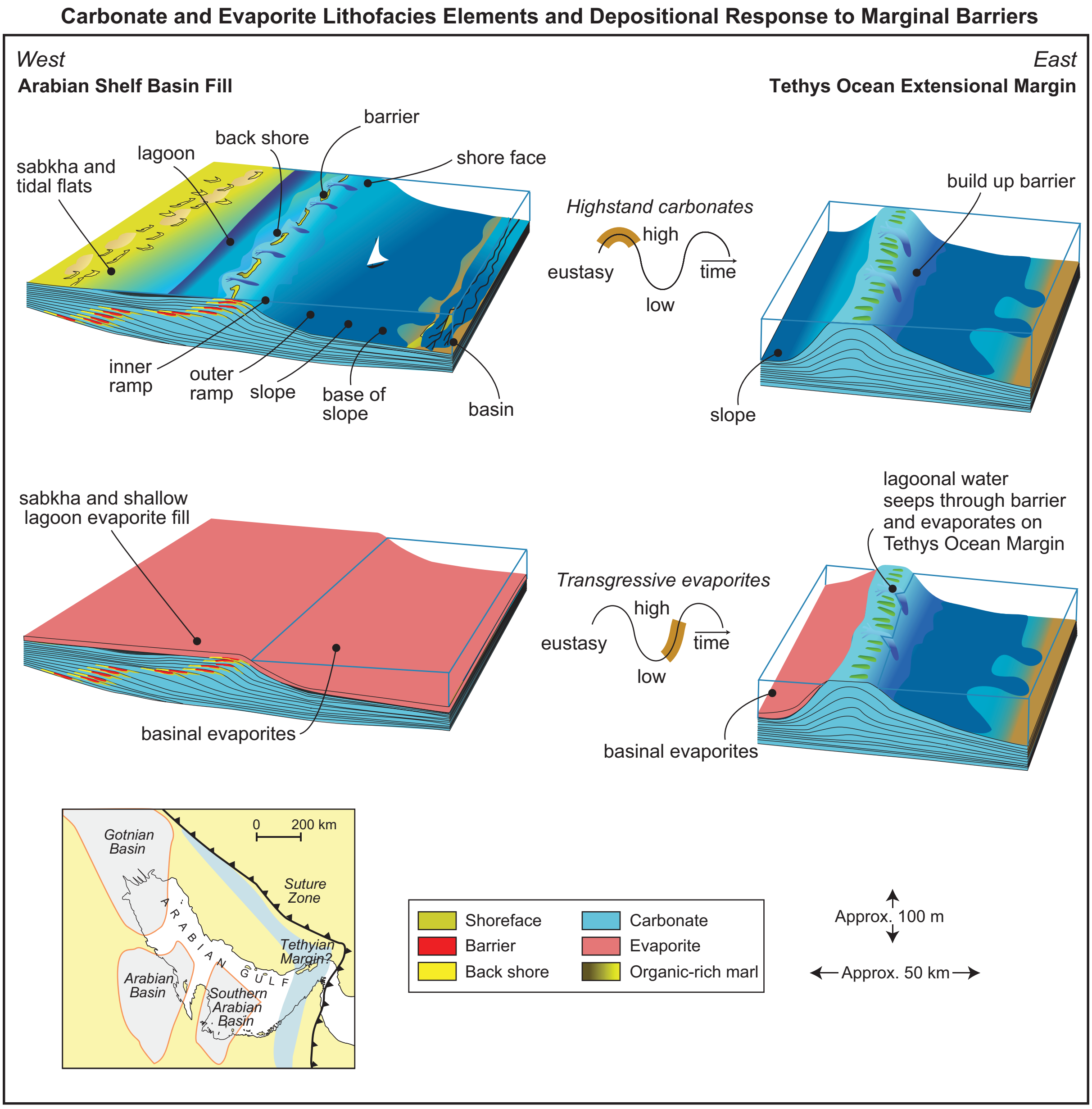

Figure 3: In the Kimmeridgian through Portlandian the Arabian Plate was located to the east of Gondwanaland. As introduced in Figure 2 original Hercynian horst and block terrain and carbonate accumulation limited access to the sea, and punctuated the geological record with evaporites, as during the transgression associated with the accumulation of the Hith Anhydrite (J 150.7 of Sharland et al., 2001).

These linear belts of evaporitic rocks can be directly related to rain shadow caused by: (1) aerial extent of adjacent enveloping continental plates; (2) occurrence of uplifted crust marginal to linear belts of depressed crust; (3) occurrence of linear belts of depressed crust, with surfaces that are often below sea level; (4) occurrence of internal drainage and/or limited access to open ocean waters; and (5) location within a climatic belt already characterized by low rainfall.

Other examples of evaporite generation in depressed extensional basins belong to the Mesozoic sedimentary section of the North and South Atlantic margins: the Mesozoic of the northern Gulf of Mexico; the Mesozoic of the Yemen rift belt; the Mesozoic and Cenozoic of Eritrea; the East African Rift; the Dead Sea, and so on (Kendall et al., 2003).

Evaporites form stratigraphic marker horizons and "sequence-stratigraphic" boundaries to the Upper Jurassic section and their bounding surfaces can be used to subdivide the framework; namely: upper surfaces of updip supratidal sabkha evaporite cycles, and the upper surfaces of downdip restricted playas and basin evaporites formed during marine transgressions. In the Jurassic section common shallow-water carbonate play elements are tied to platform evaporite depositional settings that are comprised of sabkha, salina, and mudflats; and now subaqueous evaporative lagoons or salterns of the shallow or deeper basin center (ca. 100 m) evaporite plays are a new potential focus (Figure 3). The reservoir and seal are enhanced by concomitant organic-matter accumulation, concentrated and preserved where there was low rainfall and low siliciclastic influx. This enabled the products of algal and cyanobacterial blooms, and limited in-fauna to collect under conditions of lower levels of oxygen and elevated salinities and accounts for the extensive petroleum regime.

Carbonate reservoirs ranging in age from Permian to Cenozoic contain most of the 675 billion barrels of Arabian Gulf hydrocarbon reserves (Kendall et al., 2007). Two major Holocene organic sources serve as probable models: whitings that turn part of the Arabian Gulf milky white; and cyanobacteria forming mats on intertidal areas. The mud and cyanobacteria is quickly sequestered into the sedimentary section in the axial trough of the Gulf and extensive tidal flats that rim it.

Short-lived isotopes in the Bahama banks support the instantaneous character of whiting precipitation. Source-rock analysis of the Gulf carbonate mud/cyanobacterial deposits demonstrates that these sediments are future source beds for hydrocarbons. 25% of the 1.3 million metric tons precipitated and suspended each year in the Bahamas is organic matter, dropping to 1.8% of the surface sediment. The Bahamian Bank whitings and associated organic matter covering more limited areas is swept off the bank into deep water. Cores through Neogene western platform slope sediments preserve 1% TOC up to 4%. Cyanobacteria may contribute more hydrocarbons than previously thought. Organic matter associated with whiting blooms is believed to be dispersed in the lime muds of the ancient Arabian Gulf section and may have generated large volumes of its oil. Cyanobacterial membranes liquefy at low-threshold temperatures. A short time interval burst of oil generation could produce transient overpressures liberating oil by microfracturing and in some cases long-range migration. Rapid accumulation of large volumes of oil in a short time-span would provide the collective buoyancy necessary to drive large-scale migration. It is proposed that whitings of the modern Arabian Gulf are the key to the origin of the vast petroleum reserves of this region.

Conclusions

The hydrocarbon potential of the Middle East can be better exploited if it is recognized that this province has been in the rain shadow of Gondwanaland and its evolution to the North African Plate. The stratigraphic section and so hydrocarbon reservoirs, source and seals will be better defined by a framework of sequence-stratigraphic surfaces that recognize the importance of evaporites as stratigraphic markers associated with major transgressions.

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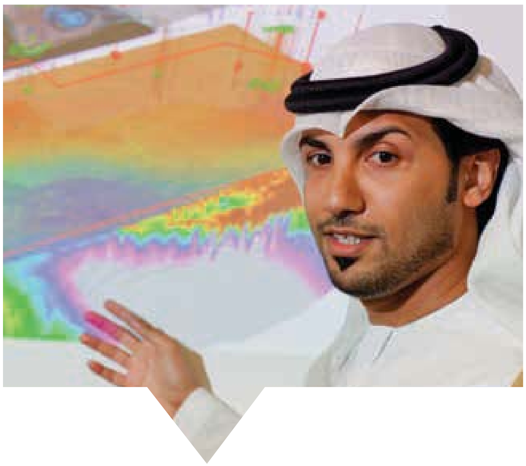

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The relation between regional (palaeo-) stress engines, sand machines, and carbonate factories in the Middle East region

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Relative sea-level fluctuations exert primary control on patterns of sediment dispersal and differential erosion. Generally subtle, but locally significant lateral variations of “carbonate factories” and “sand machines”, are critically controlled by the combined effects of the global eustacy record and regional-scale structural evolution of the Arabian Plate. It is generally accepted that regional-scale structural development is related to plate-boundary forces, associated with plate-tectonic models of Neo-Tethys, throughout its Mesozoic history. An assessment of the main driving forces (“stress engines”) involved may contribute to better-constrain structural framework models for the Mesozoic Middle East region, including the Late Jurassic–Early Cretaceous time period.

Reconstruction of Late Jurassic oolite shoal paleoenvironments in a giant gas field, onshore United Arab Emirates

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The Late Jurassic Arab Formation is being developed in a major gas accumulation located onshore in southern region of the United Arab Emirates (UAE). The reservoir intervals form a large-scale shallowing-upward cycle capped by the widespread Hith anhydrite topseal. The lower part of the Arab Formation consists of wackestones to mudstones of mid-ramp to basinal setting (Arab D Member) overlain by foreshoal and oolitic grainstone shoal deposits of the Arab C Member. The succeeding upper part of the Arab Formation (A and B members) comprises alternations of dolomitic limestone and anhydrite of restricted lagoon to backshoal and sabkha/salina origin.

The main Arab C interval comprises skeletal and ooid-rich wackestones and packstones grading upwards into oolitic grainstones (25–30 m thick package) interpreted as the progradation of foreshoal to ooid shoal environments. It has proven difficult to identify smaller-scale (amalgamated) cycles at the scale of individual shoal bodies. Conceptual facies models in such environments are qualitative and of little value in predicting reservoir heterogeneities. However, literature reviews, outcrop studies and analogues from producing fields demonstrate that reconstruction of oolite shoal sub-environments is fundamental to understanding initial depositional fabric, near-surface diagenesis and modification by later burial diagenesis.

This presentation examines the depositional architecture of oolite shoals at two different scales: (1) field-wide correlation of facies stacking patterns linked to seismic response over tens of kilometers (at