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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

the scale of 'mobile sand belts' in modern shelf-margin analogues); and (2) facies architecture in a 5 x 5 km area of the field with multi-directional deviated and horizontal wells, enabling reconstruction of sub-environments at the scale of composite bar forms.

A key element to understanding reservoir architecture has been the integration of core descriptions with borehole image logs, permitting recognition and re-orientation of the main bounding surfaces, cross-bedding co-sets and individual sets. The following three sub-environments are recognized (from base to top): (1) a lower interval with isolated, mainly landward-directed (flood tidal?) planar cross-sets within burrowed packstones to grainstones. Tidal reversals become more frequent upwards. Deposition in offshore, linear mainly flood-oriented ooid sand ridges is interpreted. (2) A middle interval with amalgamated, multi-directional (mainly flood-oriented) cross-bedding interpreted as 3-D (parabolic?) ooid bars with flanking channels. (3) An upper interval dominated by low-angle stratified to massive/burrowed grainstones, possibly indicating bar exposure or back-shoal settings.

Geometries, scales of cyclicity and facies distributions indicate analogs to modern tidally-influenced ooid tidal ridges and parabolic bars. Facies architecture and impact on reservoir quality will be examined through detailed cross-sections and horizontal well transects.

Pre-Buwaib and Late Valanginian unconformities in outcrop: Inherited concepts, facts and stratigraphic consistency

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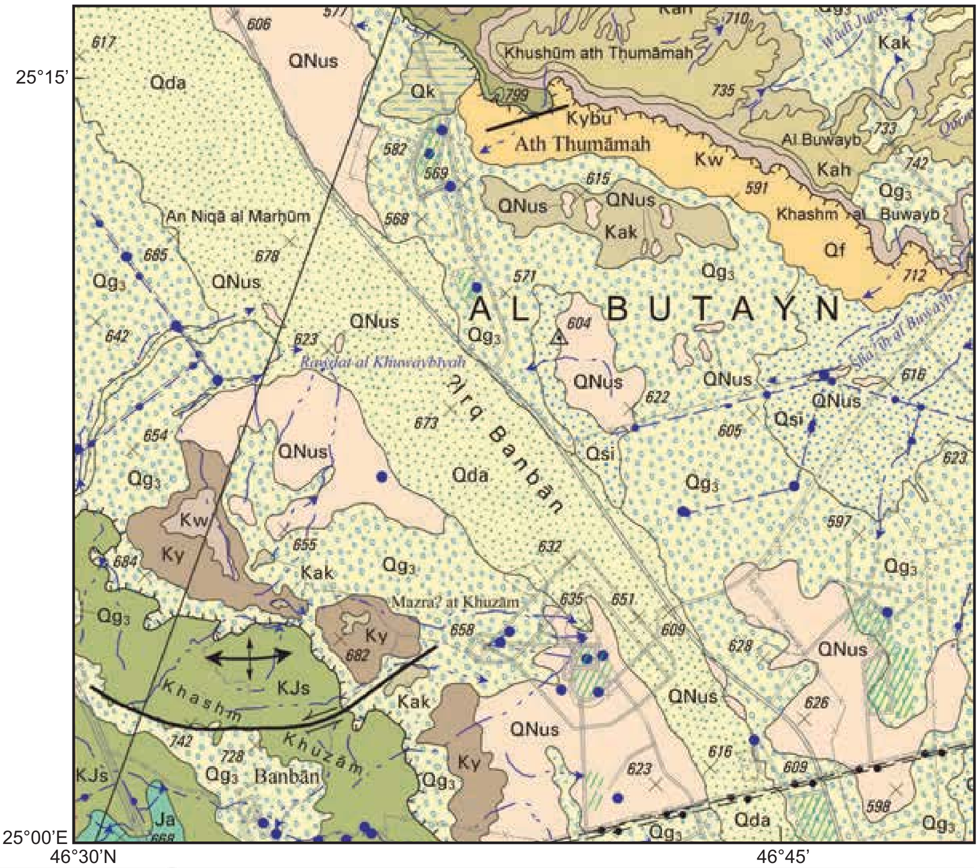
Introduction

In Saudi Arabia, the pre-Buwaib unconformity was recognized by Powers et al. (1966) and Powers (1968) on the basis of angular discordance and biostratigraphic changes. According to the Hauterivian and Valanginian ages assumed for the Buwaib and underlying Yamama formations, respectively, by Powers, this unconformity should be equivalent to the late Valanginian unconformity (Sharland et al., 2004) between the maximum flooding surfaces MFS K30 and MFS K40. Both arguments given by Powers for this unconformity have since then been questioned.

Based on previous work and geological mapping by BRGM-DMMR (1985, 1991), and by the Saudi Geological Survey (SGS) in the Rumah (in review) and Hawţat Banī Tamīm (2010) geological maps, we propose a review and a discussion of arguments for and against the occurrence of a pre-Buwaib unconformity in outcrop. The study will also discuss the age of the major hiatuses and point out the role of possible syn-tectonic origin for the changes observed along the outcrops.

Concerns

On the 1:2 million geological map of the Arabian Peninsula, Powers et al. (1966) represented: (1) a truncation of the Yamama Formation and Sulaiy Formation southward of 23°N and 22°N, respectively, by the Buwaib Formation. (2) The Buwaib Formation resting unconformably on the Sulaiy Formation in the Al Butayn – Wādi as Silayy depression (about 25°N), following Bramkamp and Ramirez (1958). In addition, Powers (1968) also supported the pre-Buwaib unconformity by biostratigraphic data referring to *Everticyclammina* microfauna: e.g. disappearance of *E. eccentrica* (below) and appearance of *E. greigi* and *E. hensoni* (above). In fact, although some evidence of erosion at the top of the Sulaiy and of the Yamama formations can be observed, these postulated relationships are based on arguments mostly contradicted by further work.



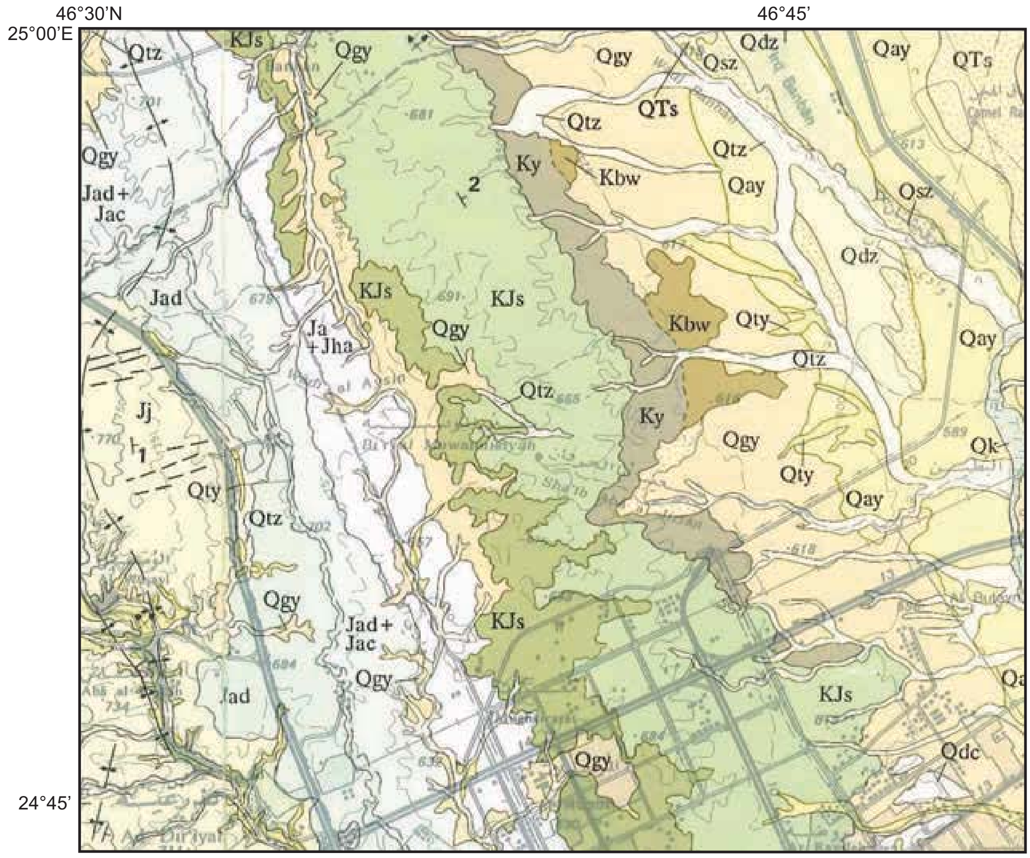


Figure 1: The Yamama (Ky) and Buwaib (Kbu or Kbw) formations in the Rumah SW (Memesh et al., 2012, upper map) and Ar Riyād NW quadrangles (Vaslet et al., 1991, lower map). © Reprinted with SGS permission. Ja: Arab Fm.; KJs: Sulaiy Fm.; Kbd: Biyadh Fm.; Kw: Wasia Fm.; Ka: Aruma Fm.

Case Studies

Biostratigraphy

On the one hand, Andreieff (written communication, 1989, *in* Vaslet et al., 1991), following other micropaleontologists, established that the different 'species' of *Everticyclammina* proposed by Redmond are in fact morphotypes of one single taxon and thus cannot be used for biostratigraphical purpose. On the other hand, the first author in Le Nindre et al. (1990) assigned an Early Valanginian age to the Buwaib Formation on the basis of microfauna (*Anchispirocyclina*), as for the Yamama Formation, on the basis of nannoflora (zone NC2).

Lithostratigraphy and Mapping

Ar Riyād Quadrangle (24 I): the Buwaib Formation (ca. 45 m thick) appears everywhere to lie conformably on the Yamama Formation (ca. 59 m thick). The unconformity of the Buwaib Formation over the Sulaiy Formation shown by Bramkamp and Ramirez (1958) west of the Al Butayn-Wādi as Silayy depression is incorrect, the Yamama Formation being in fact well-represented (Vaslet et al., 1991).

Rumah Quadrangle (25 I): northward, the outcrop configuration is the same as in the Riyadh Quadrangle, (Figure 1, Memesh et al., 2012). In the east of Al Thumamah, the Yamama and Buwaib formations were recognized but not mapped separately for reasons of cliff morphology or of sand sheet cover in the northwest (Kybu). In the southwest of the Al Butayn depression, the Yamama was mapped in continuity with the Riyadh Quadrangle, and then different of the 1:2 million map. In this area, the Wasia and Aruma formations rest unconformably on the Lower Cretaceous (namely Yamama Formation, Ky) with erosion of the Buwaib Formation. There is no evidence of the pre-Buwaib unconformity in this part of the map. Near Thumama, the total thickness of the section underneath the Wasia Formation does not exceed 35 m.

Sulayyimah Quadrangle (21 H): Further south, Powers et al. (1966) mapped the Buwaib Formation cutting the Lower Cretaceous up to the Upper Jurassic Arab Formation, and the Sulaiy Formation disappearing near 22°30'N (Al Aflaj Quadrangle). In fact, Vaslet et al. (1985) have identified and mapped the Sulaiy Formation (up to 95 m thick) and assigned a complex interbedded sequence to the combined Yamama and Buwaib formations (up to 40 m thick, Figure 2).

Hawţat Banī Tamīm Quadrangle (23 I): south of Riyadh, within the Hawtah Quadrangle Memesh and Dini (2012) have also identified in section and separately mapped the Buwaib and Yamama formations. They were grouped for mapping (Kybu) in the far southwest of the quandrangle (Hawtah Field) only. Therefore, in this area, the map resembles the 1:2 million map, but the interpretation differs.

Break in Sedimentation, Erosion and Cretaceous Structures

Notwithstanding the above considerations for the pre-Buwaib unconformity as previously mapped and dated, syn-sedimentary erosion and a break in sedimentation were observed and mentioned within the Riyadh Quadrangle.

(1) Near the top of the Sulaiy Formation, lithoclasts and fauna fragments reworked from a middle infralittoral environment reflect erosion of an early lithified sediment.
(2) At the base of the Buwaib Formation, large encrusted or perforated limestone pebbles (up to 15 cm) are mixed within litho- and bioclastic calcarenite of erosional channels.
(3) In the north of the quadrangle, the Yamama Formation is fairly reduced in thickness (40 m *versus* 59 m), but this reduction was interpreted by Vaslet as related more to a succession of hardgrounds rather than to regional unconformity.

At a different scale, the isopach map of the top Shu'aiba to top Aruma (Abu-Ali and Littke, 2005) shows a drastic reduction of the deposited thickness in the Rumah Quadrangle along a NS-trending

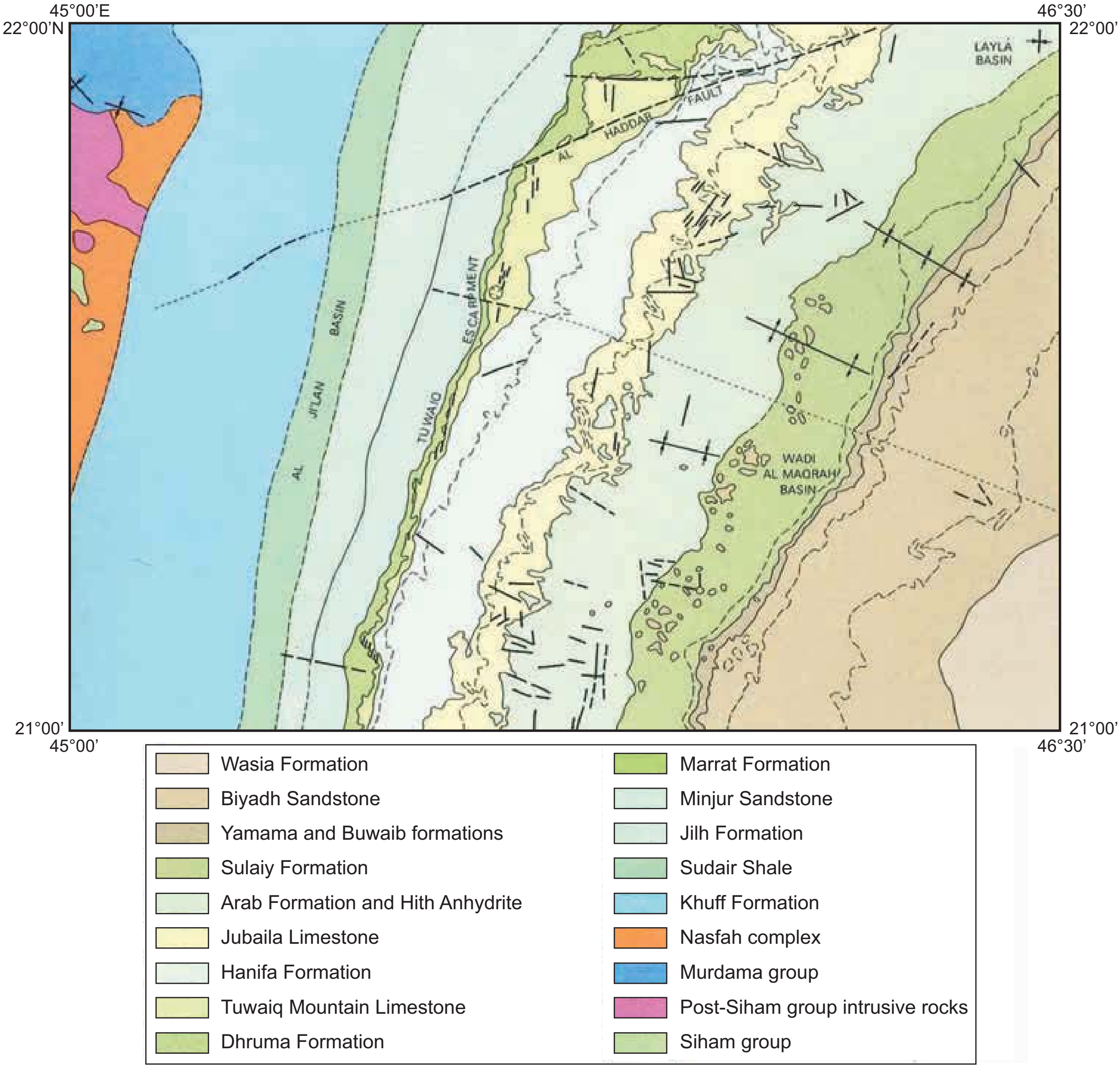


Figure 2: Structural sketch map of the Sulayyimah Quadrangle showing the pre-Biyadh unconformity and the Yamama-Buwaib formations overlying the Sulaiy Formation. © Reprinted with SGS permission.

uplifted region. Particular erosion and thickness reductions in this area from the end of the Jurassic until the Campanian (Aruma Formation) could be related to a persistent tectonic growth of this structure.

Conclusions

According to the above facts, we come to the following conclusions. In spite of the proven quality of the pioneer geologists Powers, Bramkamp, Ramirez and Redmond, the geological mapping performed since the 1980s in central Arabia did not confirm the inherited concept of the pre-Buwaib unconformity in outcrop. Notwithstanding this statement, hardgrounds, erosional structures and lithified lag deposits in the Sulaiy, Yamama, and Buwaib formations reflect at least breaks in sedimentation. However, subsurface data may prove the occurrence of the unconformity above particular structures (Khurais Field, Alsharhan and Nairn, 1997).

The age of the Buwaib Formation is most likely Early Valanginian. For this reason, and also based on sedimentary content, it has been associated by Le Nindre et al. (1990) to the Yamama Formation in the same depositional cycle: GSS K30. Therefore, tying the Late Hauterivian K40 MFS to the Buwaib Formation (Shebel and Alsharhan, 1994 *in* Sharland et al., 2001; Alsharhan and Nairn, 1997–2003) is questionable for several reasons: age and geometric contradictions.

The Late Valanginian unconformity (Sharland et al., 2004) separates the Biyadh Formation (in correspondence with the Zubair delta in Kuwait) from the Buwaib Formation, and is identified as the pre-Biyadh unconformity. Uplifts and syn-sedimentary tectonism may be the origin of the first Cretaceous clastic influx and of sedimentation reduction in the Yamama Formation.

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