# Cretaceous Lithostratigraphy of Eastern Jeza - Qamar Basin and its Hydrocarbon Potential, Dhofar, Oman*

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## Abstract

Jeza-Qamar Basin is a roughly east-west oriented, funnel-shaped basin which straddles across Dhofar (Oman) and Mehra (Yemen) border. The basin tapers to the WNW direction and widens ESE-ward to the coastal region of the two countries. It is filled by Jurassic and Cretaceous succession, the former being confined in the axial center in Yemen. The Cretaceous strata onlap uplifted flanks of the basin, becoming progressively younger towards the highs, the western Fartaq High margin in Yemen and the eastern Marbat High margin in Oman. In the Omani portion of the basin (Dhofar), Barremian to Maastrichtian strata that include, in an ascending order, Qishn, Kharfot, Dhalqut, Qitqawt, Samhan, and Sharwayn formations fill the basin. The lower three formations are the focus of the current project and consist of prominent intervals with promising petroleum elements. The Qishn Formation (Barremian to middle Aptian) is characterized by a 40 m-thick basal sandstone (Shabon Mb), a middle lime mudstone to packstone lithofacies and subordinate dolomudstone interbeds (Hinna Mb), and an upper bioclastic packstone to grainstone lithofacies with pervasive, sucrosic dolostone interbeds (Hasheer Mb). The latter is uncoformably overlain by the Kharfot Formation which is characterized by *Orbitolina*-rich marls that grade into bioclastic packstone to rudstone lithofacies. The Dhalqut Formation conformably overlies the Kharfot Formation. The former consists of three members, Umbaraaf, Khadrafi, and Sarfait, in ascending order. The Umbaraaf Member is characterized by *Orbitolina*-rich shales and marles interbedded with oyster- and rudist-rich biostromes and caped by storm-deposited, locally sandy, bioclastic and oolitic packstones and grainstones. The Khadrafi Member consists of bioclastic wackestone, packestone, and grainstone (locally rudistic biostromes) and *Orbitolina*-rich marls. The top of the member is marked by a thick, fine-grained, calcisphere-rich mudstone and shales. The Sarfait Member is defined by thickly to massively bedded, bioclastic wackestone to rudstone lithofacies with subordinate coarse-crystalline dolostone layers. The most attractive reservoirs in this stratigraphic succession are the Shabon sandstones ($\phi$ up to 25%) and Hasheer dolomites ($\phi$ up to 15%) and the cleaner carbonate lithofacies of the Dhalqut Formation ($\phi$ up to 15%). The late Jurassic Madbi shales and Naifa carbonates, rock units that sourced the oil in the adjacent Say'un-Al-Masila Basin, occur in the axial part (Yemen) of the Jeza-Qamar Basin. Samples collected from outcrops of the studied section show less than 1% TOC content; however, further work is needed. Structural elements associated with opening of the Gulf of Aden and lateral facies changes define significant structural and stratigraphic traps. Existence of tight mudstone, wackestones, shales, and marls (e.g., the Hinna Mb and the

Kharfot and Dhalqut formations) are considered to be potential cap rocks that could seal potential hydrocarbons in the reservoir horizons of the studied Cretaceous sequence. Further good news is a recent gas discovery in the Yemeni side of the basin; it underscores existence of a healthy petroleum system within the basin.

## Introduction

The Jeza-Qamar Basin lies across the Oman-Yemen border (Figure 1) and its Mesozoic sedimentary fill is represented by strata of Jurassic to Cretaceous age (Beydoun et al., 1996; Brennan et al., 1997). The sedimentary fill onlaps uplifted flanks of the basin, namely the Fartaq High (FH in Figure 1) to the west and the Marbat High (MH, Figure 1) to the east. In the Omani portion of the basin, no Jurassic strata are known to occur and the exposed Mesozoic section, although punctuated by unconformities, includes strata that span from Early Cretaceous (Barremian) to Late Cretaceous (Maastrichtian). These Cretaceous sequence consists of six formations that are, in an ascending order, Qishn, Kharfot, Dhalqut, Qitqawt, Samhan, and Sharwayn formations (Figure 2, Roger et al. 1987; Salad Hersi, 2011). These formations correlate with hydrocarbon-producing units in the region and the current study shows that Jeza-Qamar Basin is a frontier basin that has high hydrocarbon potential. The objectives of this study is to document the sedimentologic and stratigraphic attributes and the petroleum potential of the lower three formations (i.e., Qishn, Kharfot, and Dhalqut) in Dhofar.

## Lithologic Attributes

The oldest Mesozoic strata in the southern Dhofar are represented by the Qishn Formation. Older Jurassic rocks are reported to occur in the Yemeni side of the subsuraface Jiza-Qamar Basin but no outcrops are so far recognized in both Oman and Yemeni sides of the basin. Moreover, Triassic and Jurassic strata occur in the Socotra Island of Yemen; an island interpreted to be attached to southern Dhofar before the opening of the Gulf of Aden (Richardson et al., 1995; Balini et al., 2008). Thus, the possibility of having pre-Cretaceous strata in the Jeza-Qamar Basin is indeed high and attractive. This is due to the fact that most source rocks in Yemen are associated with Jurassic strata that charged Cretaceous reservoirs, including the Qishn Formation (Leckie and Rumpel, 2003).

The Cretaceous succession in Dhofar is well exposed along the mountainous region of the study area (Figure 3). The Qishn Formation (Barremian - middle Aptian) is characterized by a basal (~40 m thick) sandstone (Shabon Mb.), a middle lime mudstone to packstone lithofacies with subordinate dolomudstone interbeds (Hinna Mb.), and an upper bioclastic packstone to grainstone lithofacies with partial sucrosic dolomitization (Hasheer Mb., Salad Hersi et al., 2009a). The latter is uncoformably overlain by the Kharfot Formation which is characterized by *Orbitolina*-rich marls that grade into bioclastic packstone to rudstone lithofacies (Salad Hersi et al., 2009b). The Dhalqut Formation, conformably above Kharfot Formation, consists of three members which are, in ascending order: (i) lower Umbraf Member dominated by *Orbitolina*-rich shales and marls, oyster- and rudist-rich biostromes and subordinate storm-deposited bioclastic and/or oolitic grainstones, (ii) middle Khadrafi Member consisting of alternating thick beds of bioclastic wackestone to packstone (locally rudistic biostromes) and *Orbitolina*-rich marls, and (iii) upper Sarfait Member of thickly to massively bedded, bioclastic wackestone to rudstone lithofacies with local, subordinate dolostone interbeds. A regional unconformity lies at the top of the formation.

## Petroleum Elements

**Potential Reservoir Rocks:** There are three potential reservoir horizons in the Qishn and Dhalqut formations. In the Qishn Formation, the potential reservoirs include the Shabon Member defined by up to 25% of interconnected, intergranular porosity (Figure 4a and Figure 4b) and the carbonates of the Hasheer Member with 10 to 15% porosity in both bioclastic limestone and dolostone lithofacies (Figure 4c, Figure 4d, and Figure 4e). In the Dhalqut Formation, intervals of potential reservoir include in all members with 1 to 8 m-thick intervals of intraclastic, oolitic, and bioclastic grainstone lithofacies in the upper part of the Umbaraaf Mb characterized by 10 to 14% moldic, vuggy, and intergranular porosity which is partially filled by pyrobitumen (Figure 4f and Figure 4g), 1 to 10 m-thick intervals of rudistic rudstone and grainstones in the Khadrafi Mb and more than 50 m-thick interval of rudistic rudstones with subordinate dolostones in the Sarfait Member.

**Potential Source Rocks:** Jurassic rocks in the axial part of the basin (Yemeni side) include rock formations (e.g., Madbi Shales) known to have sourced hydrocarbon in nearby basins (Brennan et al., 1997). Existence of potential source rocks within the Cretaceous strata needs further study. TOC analysis of samples shale and lime mudstone horizons in the Qishn Formation, and mudstone/wackestone intervals in the Kharfot and Dhalqut formations showed low content of less than 1% (Salad Hersi et al., 2012).

**Potential Seals and Traps:** The Hinna Member is dominated by mudstone/wackestone lithofacies that may cap any hydrocarbons that may occur in the Shabon Member. Other sealing intervals include the *Orbitolina*-rich shales and marls of the Kharfot Formation, and Umbaraaf and Khadrafi members. Trapping mechanisms may include stratigraphic traps due to lateral facies changes and structural traps due to drape folds and faults that may juxtapose potential reservoirs and impermeable seal facies.

**Maturation and Migration:** Presence of pyrobitumen in samples from the Dhalqut Formation (Umbraf Mb., Figure 4g) suggests hydrocarbon generation in the basin. Pyrobitumen is commonly associated with relatively high thermal oil-cracking process that may lead to gas generation and overmature stages. Recent gas discovery in the Yemeni side of the basin further underscores petroleum generation and its transfer from source (?Jurassic) to (Cretaceous) reservoir rocks. Like the Masila Basin in Yemen (#2 in Figure 1), if the Jurassic Madbi shales (confined in basin axial zone) are the main hydrocarbon source rocks, an updip petroleum migration (i.e., towards basin flanks) may occur, thus, potentially charging the Cretaceous reservoirs (i.e., Qishn and Dhalqut formations).

## Conclusions

The Barremian to Turonian Qishn, Kharfot, and Dhalqut formations of the Jeza-Qamar Basin in southern Oman (Dhofar) constitute a stratigraphic succession that is fairly promising for hydrocarbon exploration. The strata gets thinner eastward on the Marbat High forming the eastern margin of the basin but becomes thicker towards the international border reaching more than 1400 m at the border. Potential clastic and carbonate reservoirs occur in varies intervals of the succession. Potential source rocks are deemed to be from the Jurassic section confined in the axial zone of the basin (Yemen) but also few mudstone and shale intervals do also occur within the Cretaceous strata of the studied section. A recent gas discovery in the Yemeni side of the basin underscores existence of a healthy petroleum system in the basin. Thus, intensive exploration work is needed for this frontier basin.

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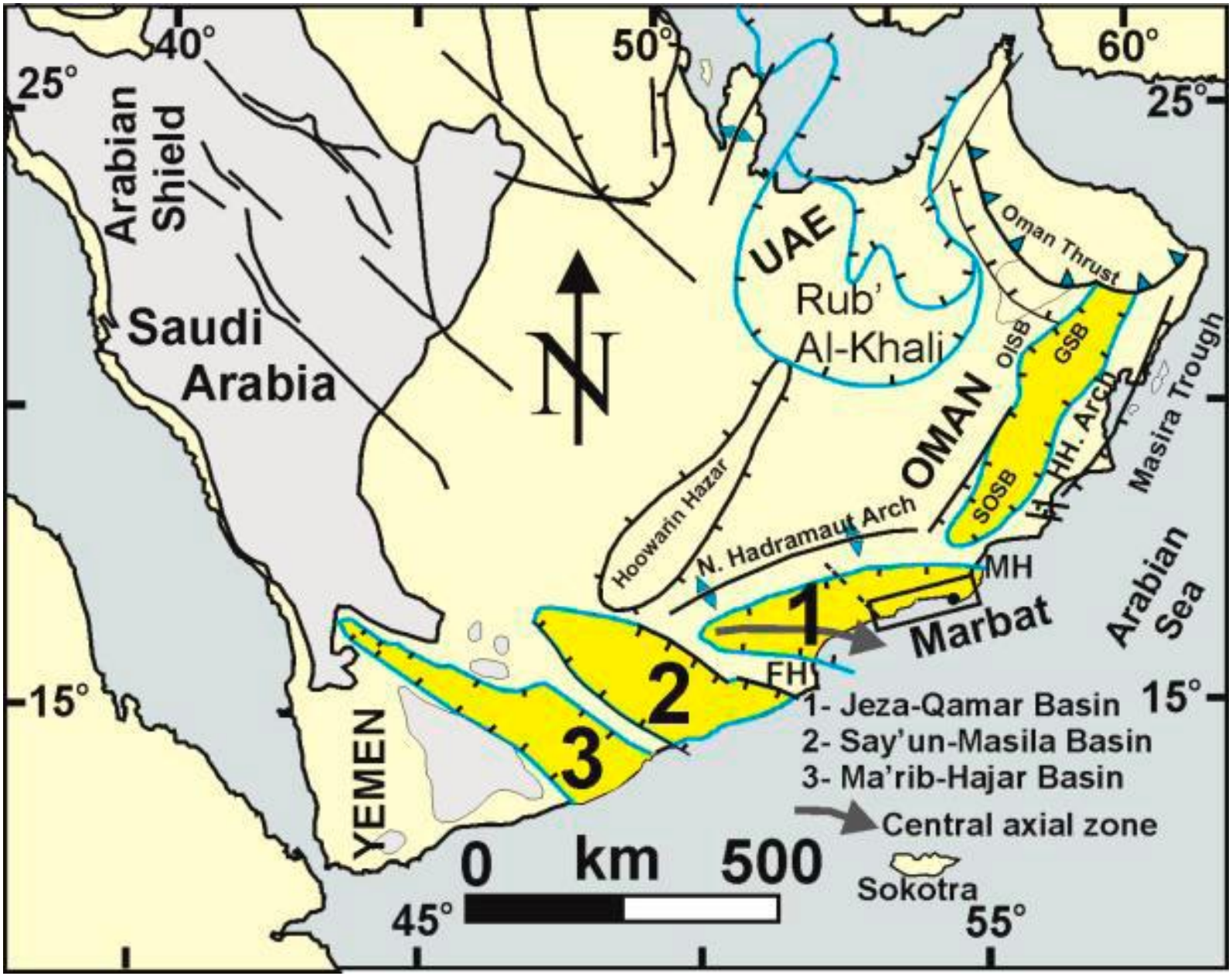


Figure 1. The Arabian Peninsula and location of the Jeza-Qamar Basin (1) and coeval basins in Yemen (2 & 3). Rectangle in the Murbat area shows the study area. Modified from Ziegler, 2001.

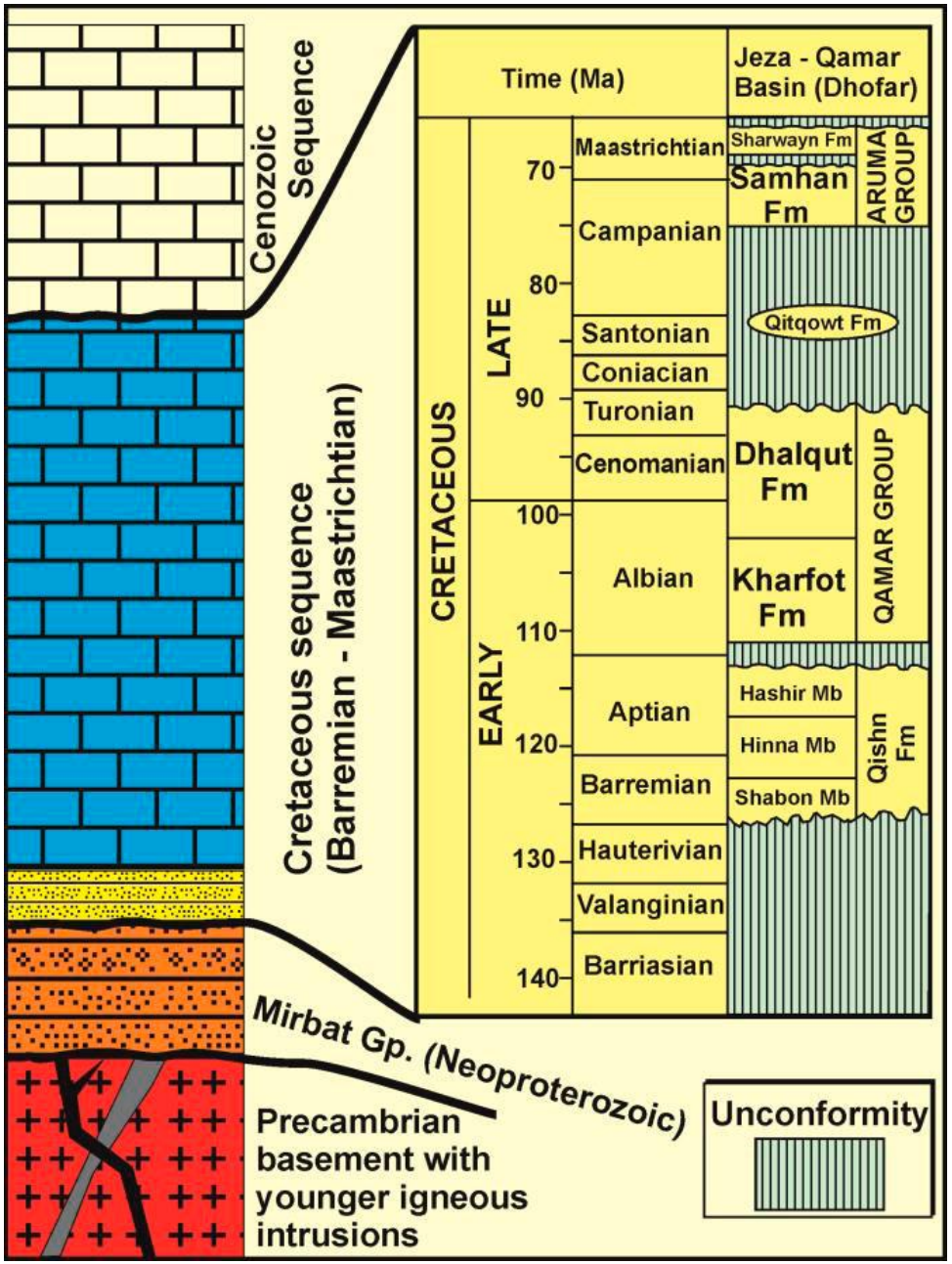


Figure 2. Stratigraphy of southern Dhofar with emphasis on the Cretaceous sequence. Compiled from Platel et al. 1987, Roger et al. 1987.


Figure 3. Outcrop section exposing the three formations discussed in this work, Jabal Dahaq O'teen, near Marbat.

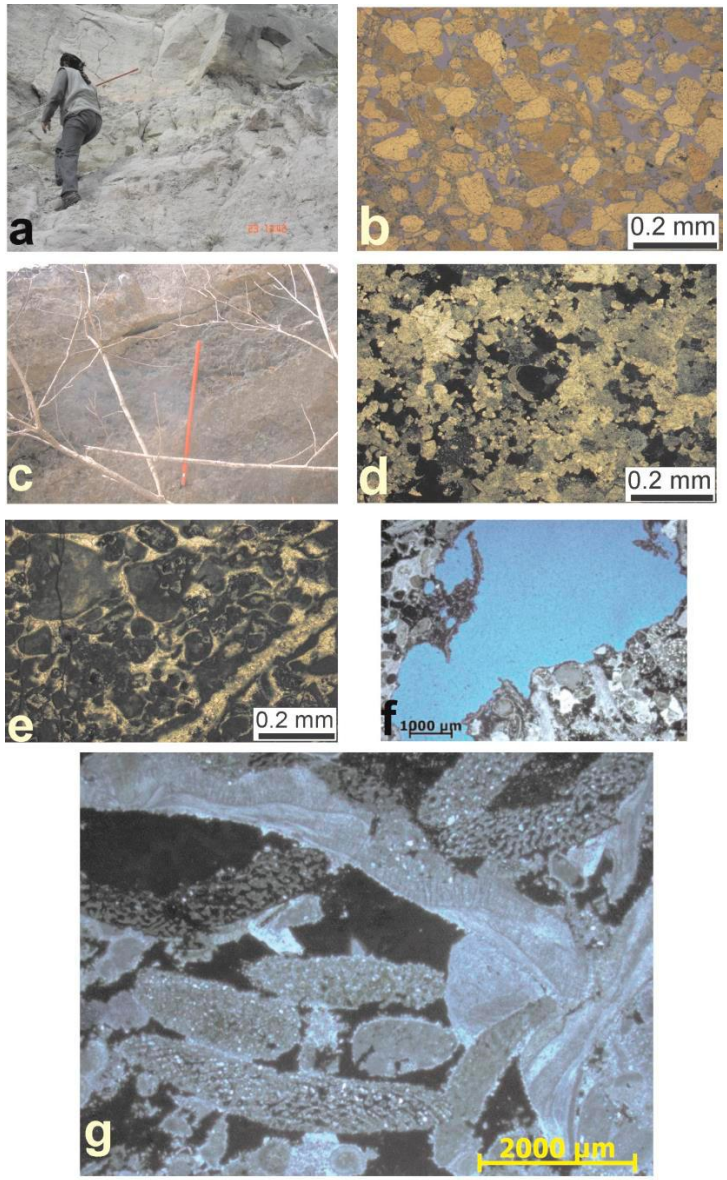


Figure 4. Field and thin section photographs showing the properties of the studied rocks. a) Loose sandstone (Shabon Mb.). b) Thin section of the porous (blue) sandstone (Shabon Mb). c) Dolostone and limestone interbeds (Hasheer Mb) and their respective thin section microphotographs showing porosities (black in d and blue in e). f) Vuggy porosity within the bioclastic grainstone facies in upper Umbraf Mb. g) Pyrobitumen (black) filling in intergranular pores, Umbaraaf Mb.