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Organic geochemical characteristics and depositional environments of the Upper Cretaceous coals in the Jiza-Qamar Basin of eastern Yemen

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HIGHLIGHTS

- The Upper Cretaceous coals are high volatile B–A bituminous coal rank.
- The Upper Cretacous coals contain significant amount of oil-liptinite macerals.
- The Coals have good potential for both liquid hydrocarbons of waxy oils and condensates.
- The Upper Cretacous coals deposited in a swamp environment under relatively oxic conditions.

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ABSTRACT

This study is the first attempt which provides information regarding the organic geochemical, biomarker and petrographic characteristics of the Upper Cretaceous coals found in the in the Jiza-Qamar Basin, eastern Yemen. The geochemical and petrographic results helped us to evaluate the type of organic matter, thermal maturity, and petroleum-generation potential, as well as depositional environments of the coals. Maceral analysis shows that the coals are dominated by vitrinite, with significant amounts of liptinite, and low amounts of inertinite macerals. Liptinite present in the samples are oil-prone liptinite macerals include petroleum-like materials (exsudatinite). The Upper Cretaceous coals are high volatile B–A bituminous in rank, possessing vitrinite reflectance in the range of 0.62–0.87%R_o. This rank determination is supported by high fixed carbon and relatively low volatile matter contents, with an arithmetic mean of 54.8 wt.% and 41.9 wt.%, respectively. Upper Cretaceous coals with moderate to high oil-prone liptinite content have good liquid petroleum-generation potential. These coals have relatively high hydrogen index values in the range of 286–449 mg HC/g TOC, consistent with Type II and mixed Type II–III kerogens.

Gas chromatograms present in the coal samples are dominated by odd carbon numbered *n*-alkanes (*n*-C_{23} to *n*-C_{35}), indicating terrestrial organic matter input. The biomarker parameters obtained from mass spectrometer data on m/z 191 and m/z 217 indicate that these coals were deposited in a fluvial to deltaic environments and preserved under relatively oxic conditions.

The T_{max}, mean vitrinite reflectance and biomarker maturity data show that Upper Cretaceous coals fall into the early-mature to peak oil window.

1. Introduction

Yemen's main sedimentary basins are the Marib-Shabowah Basin, the Masila Basin, and the Jiza-Qamar Basin (Fig. 1). To date, only two onshore basins contain proven commercial quantities of oil and gas. In the western part of Yemen, oil and gas are produced from the Marib-Shabowah Basin, while in the eastern part of Yemen the Masila Basin has produced mainly oil and some gas [1–5]. These two basins formed as a rift basin during the Late Jurassic-Early Cretaceous due to the Gondwana breakup, when the African Arabian plate was separated from the Indian Madgascar plate [6,7]. The Jiza-Qamar Basin is undergoing hydrocarbon exploration and research since the significant hydrocarbon potential still poorly. The Jiza-Qamar Basin is a polyphase rift basin which lies in the Mahra province of eastern Yemen (Fig. 1). Parts of the basin have been licensed to various oil companies from the late 1970s until the present day. AGIP held an area closely corresponding to the current Nimir concession during the late 1970s and early 1980s. AGIP Oil Company carried out extensive geophysical and

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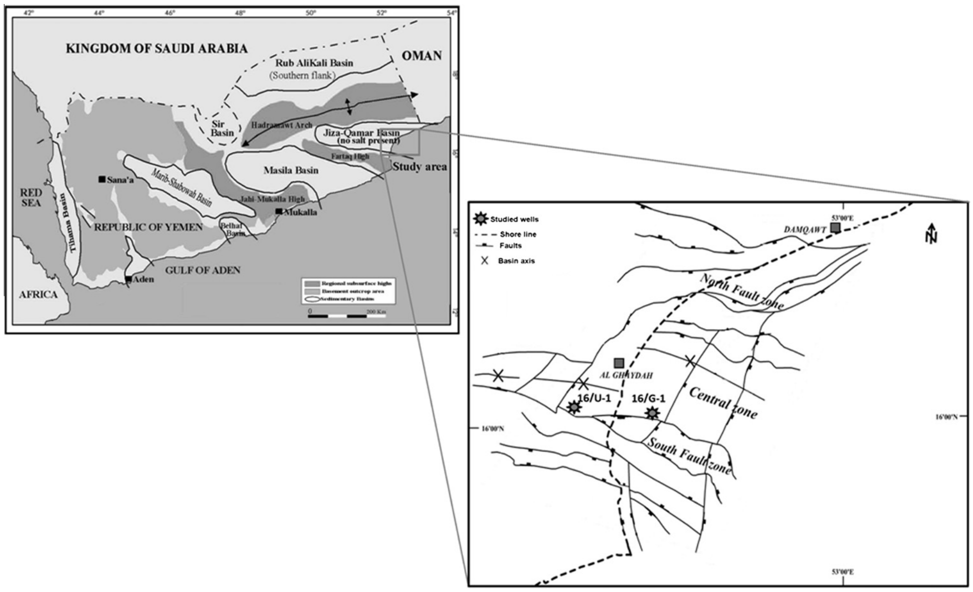

Fig. 1. Main sedimentary basins in Republic of Yemen (modified after [8]) showing location map of the Jiza-Qamar Basin and the studied wells.

geological studies and drilled two offshore exploration wells. Braspetro Oil Company held a large area of the Jiza-Qamar from 1981 to 1987. They also conducted extensive surface and seismic investigations. Several wells were drilled in their acreage, the most easterly of which drilled in the onshore part of the Qamar sector. The coals currently under investigation were collected from two exploration wells (16/U-1 and 16/G-1 Wells) drilled by the Nimir Petroleum Company in the Qamar sector, Jiza-Qamar Basin, eastern Yemen (Fig. 1). However, there are few published organic geochemical and petrographic studies of the coal-bearing sediments in Yemen (Fig. 1). This may because there are few coal-bearing sediments in the region and they are extremely rare to absent from surface exposure [8]. Conventional organic geochemistry studies of the source rocks and hydrocarbon potential in the basin are limited [9,10], and their depositional environment conditions have not been conducted yet. The aim of this study is to evaluate the organic matter type, maturity and their petroleum-generation potential of the Upper Cretaceous coals in the Jiza-Qamar Basin based on organic geochemical and petrographic analyses. The evaluation petroleum-generation potential of Mukalla coals in the Jiza-Qamar Basin will greatly contributes the hydrocarbon exploration activity in the basin. In addition, various biomarkers were used to establish the maturity of the organic matter and to help identify the depositional conditions.

2. Geologic setting and regional stratigraphy

The Jiza-Qamar Basin is a Mesozoic sedimentary basin located in eastern Yemen and extending into Oman (Fig. 1). The basin was formed as a rift-basin linked to the Mesozoic breakup of Gondwanaland and the evolution of the Indian Ocean during the Jurassic and Cretaceous [6]. The main stratigraphic succession of the Jiza-Qamar Basin is presented in Fig. 2, and is dominated by a thick Mesozoic succession ranging in age from Jurassic to Paleogene. Pre-rift megasequences range in age from Proterozoic to mid-Jurassic. Sedimentation was initiated during the mid-Jurassic, producing the Kuhlan and Shuqra Formations (Fig. 2). The Kuhlan Formation represents a basal continental sandstone that grades up in the marine carbonates that comprise the Shuqra Formation.

Rifting in the Mesozoic basins of Yemen began in the Late Jurassic [6] and these basins rapidly filled with thick mixed clastic and carbonate deposits during the Late Jurassic and Early Cretaceous (Madbi, Naifa and Saar Formations). During the Kimmeridgian, syn-rift sediments of the Madbi Formation were deposited [8]. This formation is composed of organic-rich shales and limestones, which reflect an open marine environment [8]. During latest Jurassic to Early Cretaceous time, the rifting system of the Jiza-Qamar Basin continued, but the subsidence became slower. It was accompanied by the accumulation of carbonates in shallow-marine shelf deposits (Naifa Formation). Thick Early Cretaceous syn-rift carbonates and clastics of the Saar Formation were deposited within the rift whilst thin carbonates were deposited outside the basin margins [11].

The Upper Cretaceous sedimentary fill of the Jiza-Qamar Basin is considerably thicker than in other basins of Yemen [12]. In the earliest Cretaceous to Late Cretaceous, post-rift sediments accumulated in the basin producing Qishn, Fartaq, Mukalla, Fiqa and Sharwyn Formations. The Qishn Formation can be divided into two members, the Qishn Clastic Member and the Qishn Carbonate Member [8]. The Qishn Clastic Member is the main reservoir rock for some of the oilfields in the Masila Basin [13] to the south. The Qishn Carbonate Member was deposited in deep water under alternating open and closed marine conditions [8]. The Fartaq Formation is composed of light grey slightly dolomitized limestones with intercalated mudstones (Fig. 2). The Mukalla Formation is the deepest formation penetrated in the subsurface in the Jiza-Qamar Basin. The Mukalla Formation comprises white to light grey, compacted, fine grained sandstones. These sandstones are intercalated with grey siltstones, greenish grey to reddish brown shales with coal beds and carbonaceous shales (Fig. 3). The Mukalla Formation was deposited during Santonian to Early Campanian times as reported by [12,14]. The Tabut Formation conformably overlies the Mukalla Formation. Well data indicates a transitional boundary represented by a thinly interbedded interval of mudstones and limestones [12]. In the subsurface, there is a distinct lithological subdivision into a lower limestone unit and an upper clastic unit (Fig. 2). The Sharwyn Formation is composed of limestones and marls that contain a shallow marine fauna and marks the resumption of carbonate deposition in the basin [12]. The formation extends into southern Oman, where it reaches a