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Organic geochemical characteristics and oil generating potential of the Upper Jurassic Safer shale sediments in the Marib-Shabowah Basin, western Yemen

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ABSTRACT

The organic rich Safer shales exposed in the north-central part of onshore Marib-Shabowah Basin are evaluated and their depositional environments are interpreted. Total organic carbon contents (TOC) of the shales range from 1.02–16.8 wt%, and yield hydrogen index (HI) values ranging from 130 to 820 mg HC/g TOC, consistent with mainly Type II with minor contributions from Type I and mixed Types II–III kerogens. The Safer shale samples have vitrinite reflectance values in the range of 0.5–1.0 R_o%, indicating early mature to peak mature stage for oil generation. T_{max} values range from 429–438 °C, which are in reasonably good agreement with vitrinite reflectance data. Kerogen microscopy shows that the Safer shales are characterized by high amounts of organic matter, consisting predominantly of yellow fluorescing amorphous organic matter and alginite of marine origin. This is supported by their high content of hydrogen rich Type II and I oil-prone kerogen.

The biomarker distributions of the Upper Jurassic Safer extracts are characterized by dominant low to medium molecular weight compounds (n-C_{14} to n-C_{20}), low Pr/Ph ratio (<1.0), high phytane/n-C_{18} ratios (0.82–2.68), and predominant regular sterane C_{27}. All biomarker parameters clearly indicate that the organic matter was derived from marine algal inputs and deposited under anoxic (reducing) conditions. Hypersaline conditions also prevailed during deposition of these sediments, as indicated by the presence of gammacerane.

1. Introduction

Yemen's main sedimentary basins are the Marib-Shabowah Basin, the Masila Basin and the Jiza'-Qamar Basin (Fig. 1; Beydoun et al., 1998). To date, only the Marib-Shabowah Basin in the western part and the Masila Basin in the eastern part of Yemen (Fig. 1) contain proven commercial quantities of oil and gas (Beydoun, 1991; Fairchild, 1992; Bosence, 1997; Maycock, 1997). 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 Madagascar plate (Redfern and Jones, 1995; Beydoun et al., 1996). Many studies concerning geology, petroleum geology, stratigraphy and tectonics of the basins have been published (e.g., Beydoun et al., 1996, 1998; Bosence, 1997; Csato et al., 2001).

The area that forms the scope of this study lies in western central Marib-Shabowah Basin (Fig. 1). The Marib-Shabowah Basin is an important hydrocarbon province in the western part of Yemen (Fig. 1) and has attracted the interest of numerous researchers, authors and oil companies for the exploration of hydrocarbons. The Marib-Shabowah Basin contains sediments of Jurassic and younger age. The Upper Jurassic organic rich shales of the Madbi Formation are considered to be the most prolific oil and gas prone source rocks in the basin (Brannin et al., 1999; Csato et al., 2001). In Yemen, Upper Jurassic shales are widespread and are found in west and east of Yemen. According to Beydoun et al. (1998), the age of the Madbi shales is Jurassic (Kimmeridgian). The Upper Jurassic clastic and evaporite sediments of the Sabatayn Formation provide the reservoir and regional seal rocks within the basin. The Alif sandstone of the Sabatayn Formation is the main producing reservoir rock in the basin. Yah, Seen and Safer members were recognized as minor reservoir units in some fields. Despite the relatively long history of oil exploration and production, few studies regarding aspects of the Marib-Shabowah Basin source rocks have been published and investigated the organic geochemical characteristics of the Madbi source rock (Brannin et al., 1999; Csato et al., 2001; Alaug et al., 2011). The aim of this work is to provide a comprehensive study on the source rock characteristics of the Safer organic rich shales in the Marib-Shabowah Basin and to investigate a potentially significant oil source and their depositional environments. The present analyses of the Upper Jurassic Safer shales are based on organic petrographic (kerogen compositions and vitrinite reflectance) and geochemical analyses (TOC and Rock–Eval pyrolysis). In addition, bitumen extraction and biomarker

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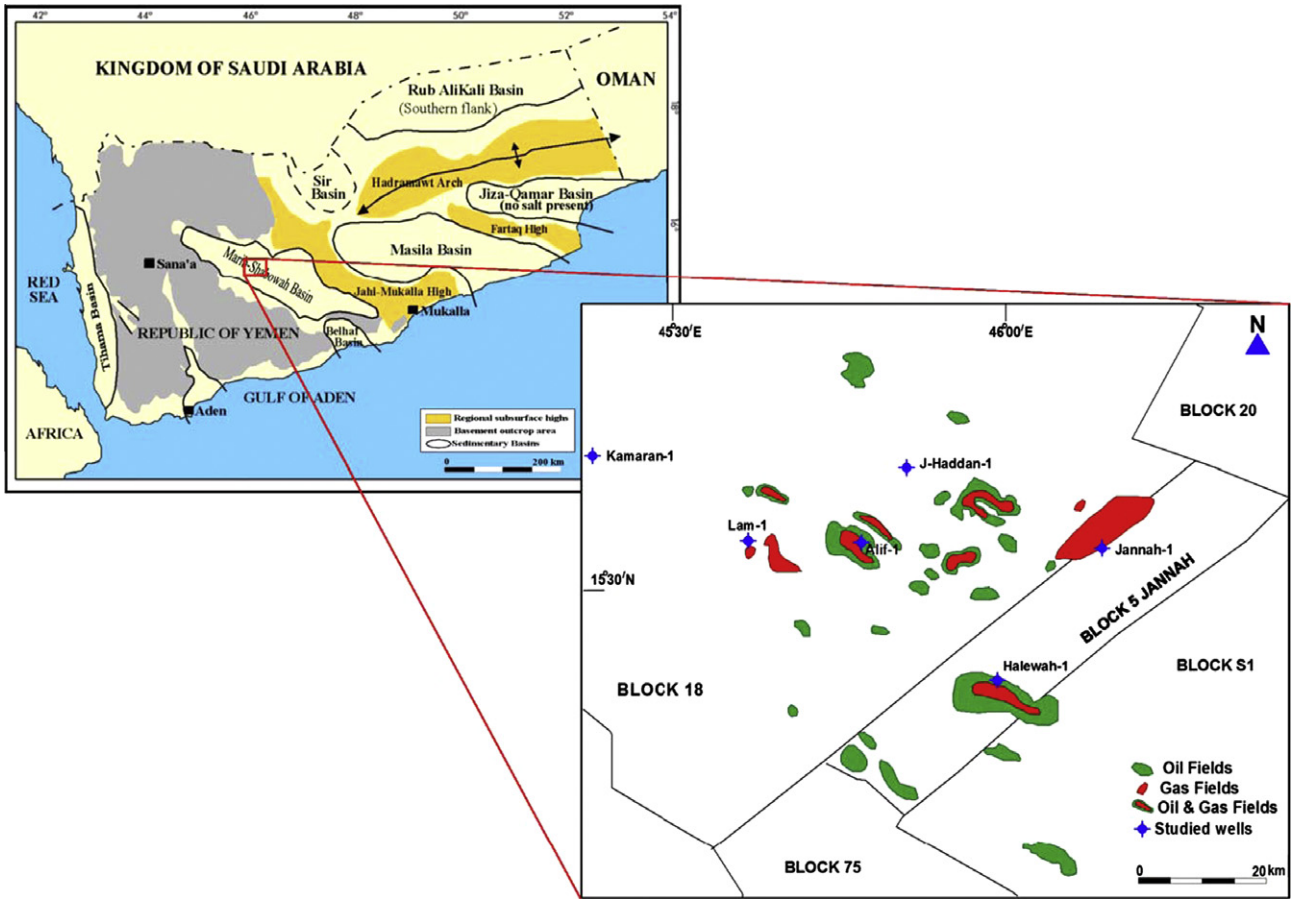

Fig. 1. Main sedimentary basins in Republic of Yemen (modified after Beydoun et al., 1998) showing location map of the fields in the Marib-Shabowah Basin including studied wells.

distributions were used to further discern thermal maturity and depositional conditions.

2. Geological setting

The geological evolution of Yemen was driven by the plate motions that broke southern Gondwana apart in the Mesozoic and formed the Gulf of Aden and Red Sea in the Cenozoic (Redfern and Jones, 1995; Beydoun et al., 1998; Csato et al., 2001). Petroleum occurs in two rift basins in Yemen. In western Yemen, petroleum is generated and produced in the Marib-Shabowah Basin, and in eastern Yemen in the Masila Basin. These eastern and western basins are largely separated by a structural high known as the Jahi-Mukalla High (Fig. 1). The Marib-Shabowah Basin was initiated during the Jurassic and was related to rifting of the Arabian plate from the Gondwana supercontinent. The stratigraphic section in the Marib-Shabowah Basin is dominated by a thick Mesozoic succession and ranges in age from Jurassic to Cretaceous and can be classified into three megasequences: pre-rift (Proterozoic to mid-Jurassic), syn-rift (mid-Jurassic to earliest Cretaceous) and post-rift (earliest Cretaceous to Upper Cretaceous; Fig. 2).

Pre-rift megasequence ranges in age from Proterozoic to mid-Jurassic (Fig. 2). The basement of the Marib-Shabowah Basin consists mostly of igneous and metamorphic complex rocks of complex rocks of Proterozoic to early Cambrian age. Pre-rift sedimentation is represented by mostly continental deposits of the Kuhlan Formation (Fig. 2); this formation includes fluviatile and arkosic red beds that grade upward into a shallow-marine facies and represents the early transgressive phases of the Late Jurassic seas (Beydoun et al., 1998). These continental rocks are overlain by shallow marine fossiliferous carbonates such as the Shuqra Formation of the Amran Group (Fig. 2). The Upper Jurassic Shuqra Formation conformably overlies the Kuhlan Formation with a gradational contact. It conformably underlies the Madbi Formation (Fig. 2). The Shuqra Formation is a neritic limestone with richly fossiliferous marls and does not contain potential source beds (Beydoun et al., 1998).

The syn-rift sequence is characterized by horsts and nested fault blocks that were developed during Late Jurassic to Lower Cretaceous time (Redfern and Jones, 1995). During the Late Jurassic commencing in the Kimmeridgian, syn-rift sediments of the Madbi Formation were deposited (Beydoun et al., 1998). This formation is divided into two members. The lower member (Meem Member) consists of clastic turbidites and shales that are important source rock as well as reservoirs in the western basin. The Upper Lam Member is mostly composed of laminated organic rich shales and considered to be the most prolific oil prone source rock in the basin (Brannin et al., 1999; Csato et al., 2001). The lithofacies of the Madbi Formation reflects marine environments (Beydoun et al., 1998). During Tithonian time, late syn-rift sediments of the Sabatayn Formation were deposited (Beydoun et al., 1998). This formation consists of thick sequence of clastic and evaporite sediments (Fig. 2). The Sabatayn Formation is divided into four members named Safer, Alif, Seen and Yah members (Fig. 2). The Alif Member is considered the main reservoir in the Marib-Shabowah Basin and comprises over 90% of recoverable oil in the basin (JNOC, 2000 "unpublished results"). The Safer Member constitutes an