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Research paper

Origin of organic matter and paleoenvironment conditions of the Late Jurassic organic-rich shales from shabwah sub-basin (western Yemen): Constraints from petrology and biological markers

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ABSTRACT

Late Jurassic organic-rich shales from Shabwah sub-basin of western Yemen were analysed based on a combined investigations of organic geochemistry and petrology to define the origin, type of organic matter and the paleoenvironment conditions during deposition. The organic-rich shales have high total sulphur content values in the range of 1.49–4.92 wt. %, and excellent source rock potential is expected based on the high values of TOC (>7%), high extractable organic matter content and hydrocarbon yield exceeding 7000 ppm. The high total sulphur content and its relation with high organic carbon content indicate that the Late Jurassic organic-rich shales of the Shabwah sub-basin were deposited in a marine environment under suboxic-anoxic conditions. This has been evidenced from kerogen microscopy and their biomarker distributions. The kerogen microscopy investigation indicated that the Late Jurassic organic-rich shales contain an abundant liptinitic organic matter (i.e., alginite, structureless (amorphous organic matters)). The presence of alginite with morphology similar to the *lamalginite* alga and amorphous organic matter in these shale samples, further suggests a marine origin. The biomarker distributions also provide evidence for a major contribution by aquatic algae and microorganisms with a minor terrigenous organic matter input. The biomarkers are characterized by unimodal distribution of *n*-alkanes, low acyclic isoprenoids compared to normal alkanes, relatively high tricyclic terpanes compared to tetracyclic terpanes, and high proportion of C_{27} and C_{29} regular steranes compared to C_{28} regular sterane. Moreover, the suboxic to anoxic bottom water conditions as evidenced in these Late Jurassic shales is also supported based on relatively low pristane/phytane (Pr/Ph) ratios in the range of 0.80–1.14. Therefore, it is envisaged here that the high content of organic matter (TOC > 7 wt.%) in the analysed Late Jurassic shales is attributed to good organic matter (OM) preservation under suboxic to anoxic bottom water conditions during deposition.

1. Introduction

The area that forms the scope of this study lies in the Al-Uqlah oilfield of the Shabwah sub-basin, Sabatayn Basin (Fig. 1). The Sabatayn Basin is known by a variety of names, such as Sabatayn Basin, Marib-Shabwah-Hajar and contains proven commercial quantities of oil and gas (Beydoun et al., 1998), and Marib-Shabwah Basin (Brannin et al., 1999; Csato et al., 2001). The Sabatayn Basin has attracted the interest of numerous researchers, authors and oil companies. Many geochemical studies of the source rocks and crude oils and related organic matter facies and paleoenvironment conditions as well as basin modelling study had been undertaken on the Marib sub-basin of the north part in the Sabatayn Basin (e.g., Brannin et al., 1999; Csato et al., 2001; Alaug et al., 2011; Hakimi and Abdullah, 2013a, b; Hakimi et al., 2014; Hakimi and Abdullah, 2015). However, detailed organic geochemical characterisation of the organic-rich sedimentary rocks in the Shabwah sub-basin has not been investigated to date in any of the previews literature thus; there is poor knowledge on the organic facies variation and distributions. In this respect, this study focuses on the detailed

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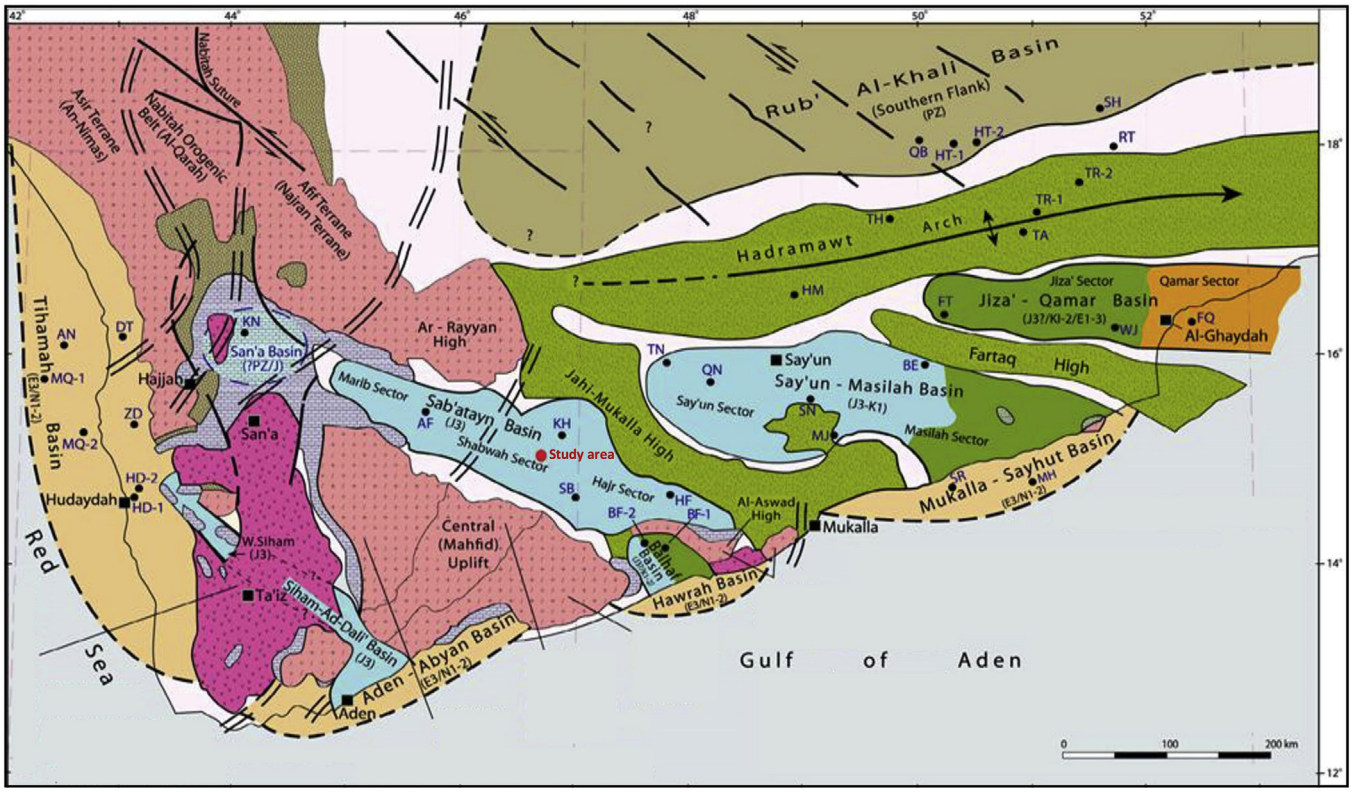

Fig. 1. Map of Yemen showing the main sedimentary basins including Shabwah basin and location of the study area.

biomarker characteristics, coupled with organic petrological study of the Late Jurassic organic-rich shales, to provide an overview of the type, source input of the organic matter and to reconstruct the paleoenvironment conditions of these the shaly sediments. The results presented in this paper may provide further insight into the subsurface rocks in the Shabwah sub-basin, especially with respect to the characteristics of the organic matter and the depositional conditions of the potential source rocks that could contribute to further exploration success and resource assessment in the whole basin.

2. Geologic setting

Yemen is located in the southwestern portion of the Arabian Peninsula, bordered by the Red Sea to the west, the Gulf of Aden to the south, and the Arabian Sea to the east. It shares a common border with Oman on the east and disputed border with Saudi Arabia on the north (Fig. 1). Yemen has ten onshore and offshore sedimentary basins and only two of them have proven commercial hydrocarbons (Klett et al., 1997). These two province basins are Sabatayn Basin in the west of Yemen and Masila Basin of the eastern Yemen (Fig. 1). The Sabatayn and Masila basin are part of a system of major rift basins, and largely separated by a structural high known as the Jahi-Mukalla High (Fig. 1). These basins also were formed as a rift-basin linked to the Mesozoic breakup of Gondwanaland and the evolution of the Indian Ocean during Late Jurassic to Early Cretaceous (Redfern and Jones, 1995).

The main stratigraphic succession of the Sabatayn Basin including Shabwah sub-basin is presented in (Fig. 2), which is shown to be dominated by a thick Mesozoic succession that ranges in age from Jurassic to Cretaceous. This succession can be classified into three tectono-stratigraphic megasequence: pre-rift (?Bathonian-Kimmeridgian), syn-rift (Kimmeridgain-Tithonian) and post-rift (Earliest lower Cretaceous-Upper Cretaceous) (Fig. 2). Pre-rift sedimentation is represented by mostly continental deposits of the Kuhlan Formation (Fig. 2), this formation includes fluvialite and arkosic redbeds that grade upward into a shallow-marine facies and represent the early transgressive phase of Late Jurassic seas. It is essentially absent of fossils; however, in the subsurface some palynomorphs have been recovered including a Middle Jurassic (Bathonian to Early Callovian) age (Beydoun et al., 1998). These continental rocks are overlain by shallow marine fossiliferous carbonates of the Shuqra Formation (Fig. 2).

The syn-rift (Kimmeridgian-Tithonian/Berriasian) sequence is characterized by horsts and nested fault blocks that were developed during Late Jurassic to Early Cretaceous time (Redfern and Jones, 1995). Initiation of rifting occurred during the early Kimmeridgian, and activity continued until the late Tithonian to early Berriasian (Fig. 2). During the Late Jurassic, commencing in the Kimmeridgian and continuing through the Tithonian, syn-rift sediments of Madbi Formation were deposited (Beydoun el at., 1998). In the Sabatayn Basin, the Madbi Formation has been divided into two members: Meem and Lam members (Oldest to youngest) (Fig. 2). The Meem member consists of turbidite sandstones, shales and claystones (Fig. 2). The upper Lam member is mostly organic-rich shale sediments (Fig. 2). The turbidite sandstones have been considered as reservoir rocks in some oilfields of the Marib-Shabwah Basin. The lithofacies of the Madbi clastic reservoirs reflects a deep marine environments setting that deposited along the flanks of grabens or half-grabens (Beydoun el at., 1998). Simultaneously continental sediments filled the grabens from the northern end of the western basin along rift margins. The organic-rich shale and claystone intervals within Lam and Meem members of the Madbi Formation are the sequences of interest for this study. During Tithonian times, late syn-rift sediments of the Sabatayn Formation were deposited during ocean circulation in the western