Marine and Petroleum Geology 65 (2015) 187–197

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

The origin, type and preservation of organic matter of the Barremian–Aptian organic-rich shales in the Muglad Basin, Southern Sudan, and their relation to paleoenvironmental and paleoclimate conditions

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ARTICLE INFO

Article history:
Received 24 September 2014
Received in revised form
2 March 2015
Accepted 3 March 2015
Available online 17 April 2015

Keywords:
Organic-rich shale
Bioproductivity
OM preservation
Muglad Basin
Sudan

ABSTRACT

Barremian–Aptian organic-rich shales from Abu Gabra Formation in the Muglad Basin were analysed using geochemical and petrographic analyses. These analyses were used to define the origin, type of organic matters and the influencing factors of diagenesis, including organic matter input and preservation, and their relation to paleoenvironmental and paleoclimate conditions. The bulk geochemical characteristics indicated that the organic-rich shales were deposited in a lacustrine environment with seawater influence under suboxic conditions. Their pyrolysis hydrogen index (HI) data provide evidence for a major contribution by Type I/II kerogen with HI values of >400 mg HC/g TOC and a minor Type II/III contribution with HI values <400 mg HC/g TOC. This is confirmed by kerogen microscopy, whereby the kerogen is characterized by large amounts of structured algae (*Botryococcus*) and structureless (amorphous) with a minor terrigenous organic matter input. An enhanced biological productivity within the photic zone of the water columns is also detected. The increased biological productivity in the organic-rich shales may be related to enhanced semi-arid/humid to humid-warm climate conditions. Therefore, a high bio-productivity in combination with good organic matter preservation favoured by enhanced algae sizes are suggested as the OM enrichment mechanisms within the studied basin.

1. Introduction

Sedimentary organic matter (OM) is the major accumulation of organic carbon in the global carbon cycle (Zonneveld et al., 2010). Enrichment of organic matter is complex and known to depend on a large number of factors, including biological productivity, continental weathering, sedimentation rates, clay mineralogy, water column oxygenation levels, sea-level change, sedimentary environment influence and the total organic carbon (TOC) content in sediments (Mayer, 1994; Kennedy et al., 2002; Chen et al., 2006; Li et al., 2008; Zonneveld et al., 2010; Bechtel et al., 2012; Sun et al., 2013). However, several mechanisms controlling organic matter (OM) enrichment are input, preservation, dilution of OM (Talbot, 1988; Schwartzkopf, 1993; Carroll and Bohacs, 1999; Bohacs et al., 2000; Hofmann et al., 2000) and their interactions with each other (Tyson, 2005). The input of OM is mainly controlled by primary productivity, whereas preservation is closely related to redox conditions (Demaison and Moore, 1980; Katz, 2005; Tyson, 2005; Hakimi et al., 2012; Mohialdeen et al., 2013; Jia et al., 2013).

The area that forms the scope of this study lies in the northeastern Muglad Basin (Fig. 1). The Muglad Basin is well known as the most important hydrocarbon province, and contains a number of hydrocarbon accumulations of various sizes, the largest of which are the Heglig and Unity oilfields as shown in Figure 1 (NPA Group, 2008). Potential source rocks in the Muglad Basin occur in the Cretaceous rock units (Mohamed et al., 2002; Zhang and Qin, 2011; Lirong et al., 2013). Previous workers who studied the shales and claystones of the Abu Gabra Formation demonstrated that these sediments, deposited in a lacustrine environment are the most important source rocks (Schull, 1988; McHargue et al., 1992; Tong et al., 2004; Zhang et al., 2009; Zhang and Qin, 2011; Lirong et al., 2013; Makeen et al., 2015a). Previous studies in the basin have

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http://dx.doi.org/10.1016/j.marpetgeo.2015.03.003

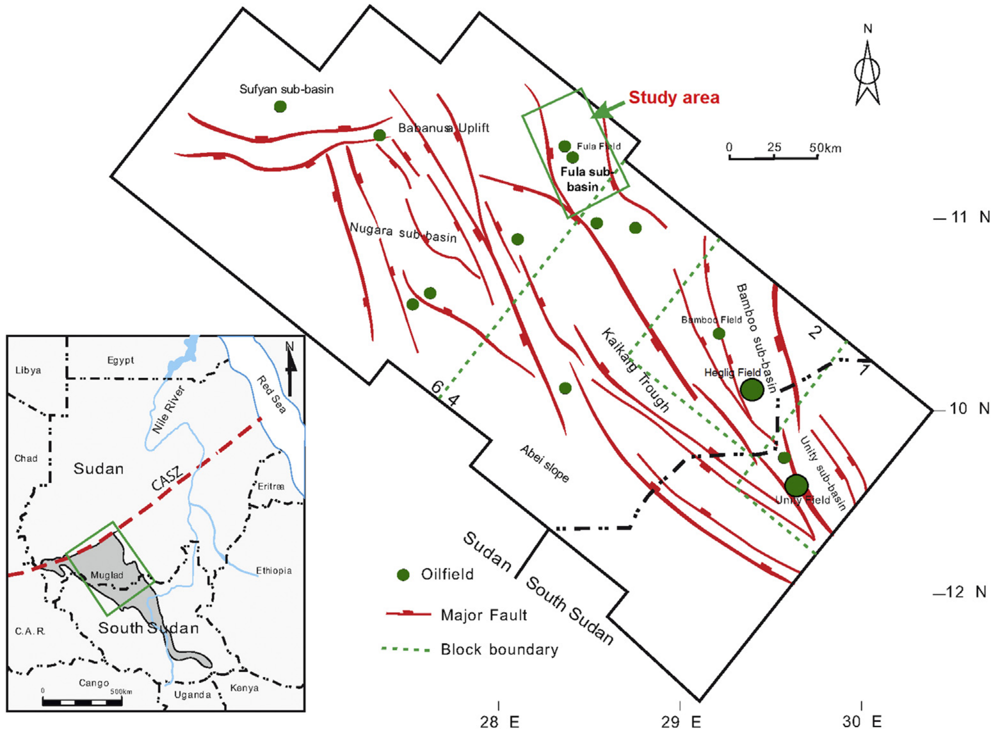

Figure 1. Location map of the oilfields in the Muglad Basin including study oilfields within the study area (Makeen et al., 2015a,b).

established the predominantly oil–prone nature of the potential source rocks in the Muglad Basin (e.g., Schull, 1988; Mohamed et al., 2002; Zhang and Qin, 2011; Lirong et al., 2013), but without adequate examination of the source organic matter input and the factors that affected their diagenesis and preservation. The integration of geochemistry and petrology has been successfully used to interpret the depositional environment conditions and the input of the organic matter preserved in the sediments (Peters and Moldowan, 1993; Peters et al., 2005). In this regard, the current study focuses on the geochemical and petrographic characteristics of the Abu Gabra organic-rich shales to provide an overview of the origin, type and the influencing factors of organic matter enrichment in them. .

2. Geologic setting

The Muglad Basin is oriented Northwest to Southeast with an area up to 200 km wide and over 800 km long, covering an area of about 120,000 km^2 (Schull, 1988; McHargue et al., 1992) (Fig. 1). The tectonic history and structural development of the basin were reported by Fairhead (1988), Guiraud and Maurin (1992), McHargue et al. (1992) and Abdelhakam and Ali (2008, 2008) concluded that the Muglad Basin is part of a trend of Cretaceous sedimentary basins of apparent rift origin, which cut across north central Africa from the Benue Trough in Nigeria, through Chad and the Central African Republic, in Sudan. Three rifting episodes occurred during the Early Cretaceous (140–95 Ma), Late Cretaceous (95–65 Ma), and early–middle Tertiary (65–30 Ma) (McHargue et al., 1992). Based on the interpretation of seismic data and the drilling of exploration wells, a 13 km thick sedimentary section consisting of three main depositional cycles was deposited in a rift-related lacustrine setting in the Muglad Basin during these episodes of extension, (Schull, 1988; McHargue et al., 1992; Lirong et al., 2013). Each cycle boundary is regionally or locally expressed by an angular unconformity (Lirong et al., 2013). A generalised stratigraphic column of the Muglad Basin is shown in Figure 2 and modified from Schull (1988), Kaska (1989). The unconformities, with slight angular discordance that terminate the cycles, probably reflect uplift due to fault block rotation, but the extent of erosion is uncertain (e.g. McHargue et al., 1992). The location of unconformities within the non-fossiliferous sections is arguable (e. g. Abdalla et al., 2001). Abdalla et al. (2001) and Abdelhakam and Ali (2008) divided the stratigraphic column of the Muglad Basin into three cycles of deposition. The first deposition cycle occurred during the Early Cretaceous (Barremian–Aptian) and consists mainly of suboxic organic-rich shales comprising the main lacustrine source beds of the Abu Gabra Formation. The Early Cretaceous (Barremian–Aptian) Abu Gabra Formation can be divided into three main intervals. The lower interval is dominated by medium-to coarse-grained fluvial sandstones which are interbedded with thin claystones, whereas the middle interval is dominated by thick organic rich laminated shales and the upper interval is dominated by interbedded sandstones and dark shales (Lirong et al., 2013). The shale and claystone sediments in the middle interval are considered to be the main source rocks in the Muglad Basin (Schull, 1988; Tong et al., 2004). The Abu Gabra Formation is overlain by a regional unconformity and the post-rift Bentiu Formation which comprises alluvial fluvial-floodplain deposits, conglomerates, and coarse-grained sandstones. The sandstones of this Formation are the most important reservoir rocks in the Muglad Basin and the mudstone in the upper Cretaceous Darfur group is the regional cap rock (Zhang and Qin, 2011; Lirong et al., 2013).

The second depositional cycle (Late Cretaceous–Paleocene) is composited by more than 4000 m of the Darfur Group, comprising fluvial and deltaic claystones at the bottom (Aradeiba Formation) and thin sandstone beds (Zarga and Ghazal formations), thickening toward the top of the section (Baraka Formation) and overlain by the coarser Amal Formation. The Amal Formation is composed of