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Research paper

Sedimentology, diagenesis and reservoir quality of the upper Abu Gabra Formation sandstones in the Fula Sub-basin, Muglad Basin, Sudan

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ABSTRACT

Successful hydrocarbon exploration of the Lower Cretaceous Abu Gabra Formation has established the need to understand the diagenesis and reservoir quality of the sandstones reservoirs in the area. Therefore, this study contains a subsurface facies analysis based on description of three conventional cores from the Moga21-2 well. Methods include wireline log analysis, a petrographic study with both thin sections and scanning electron microscope investigations, grain-size, X-ray diffraction (XRD), and heavy minerals analysis of the Abu Gabra sandstone.

Sedimentary composition and facies sequences of the well logs indicate a complex fluvial channel paleo-environment. Grain-size analysis revealed that the sandstone is a mixture of mainly sand-size (<0.01–2.00 mm) along with minor amount of silt and clay size (<0.063 mm). Alternation of coarse to medium-grained, massive to cross-bedded sandstones with fine-grained ripple laminated sandstones shows a sequence of fluvial channel fill or sand deposits of channel bars. The finer-grained facies association, predominantly mudstone and siltstone, represents overbank deposits or floodplain sediments.

Petrographically, the sandstones are classified (based on standard rock classification schemes) into, subfeldspathic arenites, and feldspathic arenite lithofacies. Quartz grains are the most abundant detrital components in the samples (both polycrystalline and monocrystalline), followed by feldspars (mainly K-feldspar), micas, and detrital and authigenic clays with carbonatic detritus. Although, lithic fragments, iron oxides and heavy minerals occur in minor amounts, presence of sillimanite, epidote and hornblende (compared to zircon, tourmaline and rutile), as well as the presence of chlorite, the dominance of polycrystalline quartz and high crystallinity of kaolinite could be responsible for the low grade metamorphism. Kaolinite is an authigenic component, while quartz overgrowths occur in variable quantity and carbonates (calcite and siderite) in a relatively minor amount. Pore types are basically primary and secondary interparticle, with few secondary intraparticle pores due to the dissolution of feldspars. Although porosity ranges from 9.20 to 31.20%, the presence of kaolinite, carbonate, and quartz overgrowth cement reduce the porosity of the samples.

Analyzed samples are characterized by poor to very good pore interconnectivity. Despite the fact that most of the sandstones display point, concavo-convex, and long contacts with poor to good compaction, few sutured grain contacts (which reflect a higher degree of compaction) still exist. XRD and SEM analyses show that kaolinite, chlorite, illite, smectite, and illite/smectite mixed layer clay are the common clay minerals in the studied samples. The presence of vermiform morphology, besides the sharp peak pattern of the kaolinite, in most of the XRD pattern indicates that part of the kaolinite was authigenically formed.

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1. Introduction

The Fula sub-basin is located in the north-eastern part of the prolific hydrocarbon Muglad Basin, Sudan (Fig. 1). The Lower Cretaceous Abu Gabra Formation is widely regarded as the predominant source rock in the Muglad Basin (Schull, 1988; Mohamed et al., 2002; Zhang and Qin, 2011; Lirong et al., 2013; Makeen et al., 2015a,b,c). In spite of this, detailed sedimentology and diagenesis investigations of the Abu Gabra Formation sandstones remain scarce or missing. Most earlier studies have focused mainly on shales/claystone as potential source rocks without thoroughly investigating the reservoir quality of the sandstone beds within the area (Lirong et al., 2013; Makeen et al., 2015a,b,c).

Successful oil exploration in the Lower Cretaceous Abu Gabra Formation sandstone, the Bentiu Formation, and sandstone of the Darfur Group further established the significance of these sandstones as hydrocarbon reservoirs in the area (Li, 2009). These reservoirs are characterized by sediments ranging from subfeldspathic arenites to feldspathic arenite and sandstones of fluvial channels, lacustrine delta-plain-distributary channels and delta-front facies (Li, 2009). Three cores (core-1, core-2 and core-3) from the Moga 21-2 well representing depth intervals of 1542.47–1550.50 m, 1550.50–1558.50 m, and 1558.98–1560.00 m, respectively, were used to study the sedimentological and petrographical characteristics of this reservoir. These cores are parts of the Lower Cretaceous Abu Gabra Formation in the Fula sub-basin.

The aim of this research is to solve issues related to oil potential, provide targets, and serve as a pathfinder to future exploration activity in the Lower Cretaceous Abu Gabra sandstone. In order to achieve this goal, a comprehensive description of sedimentological and petrographical characteristics of the cores was carried out to characterize the sedimentary facies and depositional paleo-environments and establish a facies depositional model for the studied Abu Gabra Formation. It also investigates the basin evolution, intensity of paleo-weathering, sediment transportation processes, depositional history, source rock origin, and recognizes the effects of the depositional regime and digenetic processes on the reservoir quality of the study intervals.

2. Stratigraphic setting

The Fula sub-basin is a Cretaceous –Tertiary basin located in the NE of the Muglad basin, Sudan, covering an area of about 4920 km^2 (120-km long and 41-km wide). It is a fault-bounded asymmetric half graben which is separated from the northern part of the Karkang Trough by the Bahanusa uplift (Fig. 1) (Schull, 1988; Genik, 1993; Lirong et al., 2013).

The Muglad Basin is formed by extensional movement in the background of the dextral shear stress field in the Central African Shear Zone (CASZ) (Browne et al., 1983; Schull, 1988; Wu et al., 2015) and had underwent three phases of tectonic cycle evolution since Early Cretaceous (Fig. 2) (Fairhead, 1988; Lyu et al., 2001; Wang et al., 2007; Yang and Zhu, 2008; Wu et al., 2015).

Deposition of the syn-rift Barremian –Aptian Abu Gabra Formation made up of thick lacustrine and deltaic shales, claystones and sandstones form the first phase which overlies the Precambrian Basemet rocks in the area (Fig. 2) (Fairhead, 1988; Makeen et al., 2016a,b). The Abu Gabra Formation is the major source

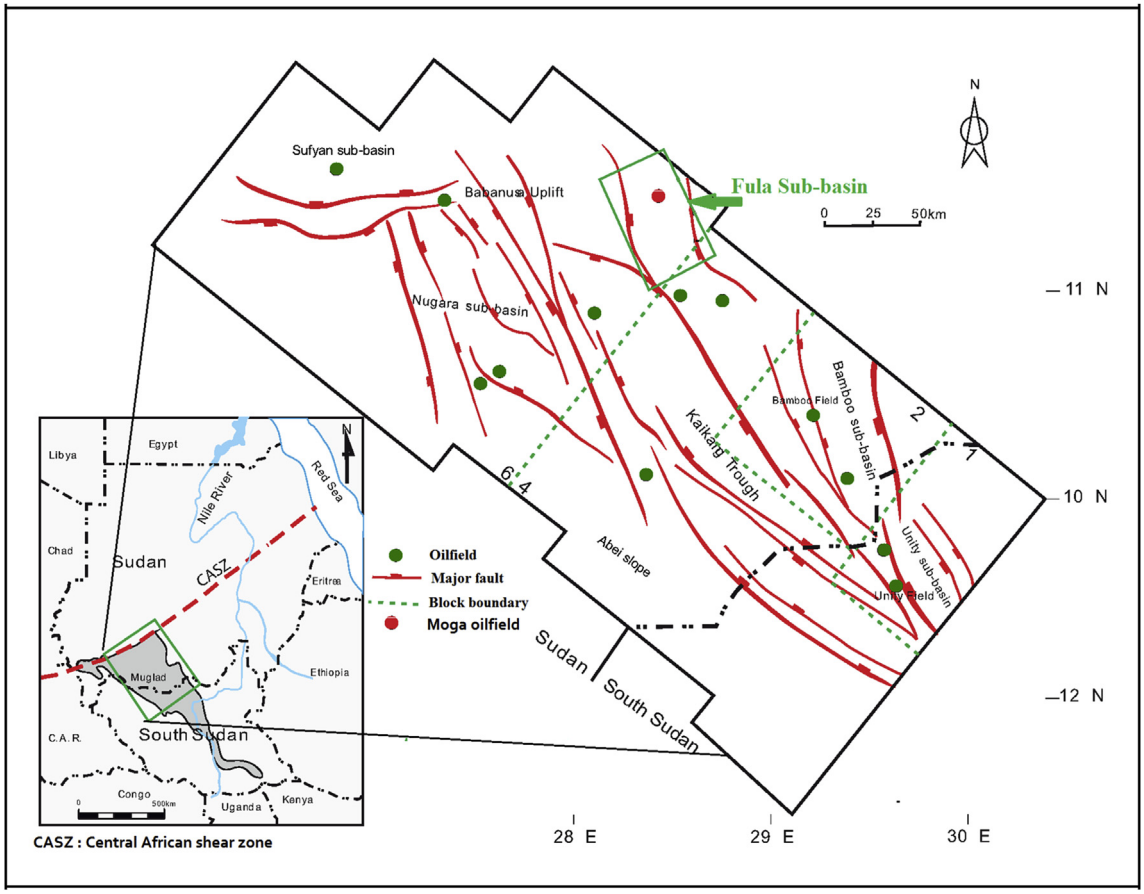

Fig. 1. Map of Sudan showing the study location and main oilfields within Muglad Basin.