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Research paper

Evolution history of transtensional pull-apart, oblique rift basin and its implication on hydrocarbon exploration: A case study from Sufyan Sub-basin, Muglad Basin, Sudan

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ABSTRACT

Sufyan Sub-basin is an East-West trending Sub-basin located in the northwestern part of the Muglad Basin (Sudan), in the eastern extension of the West and Central Africa Rift System (WCARS). The trend of the Sufyan Sub-basin (E-W) is different from the general trend of Muglad Basin (NW-SE) and similar to Baggara basin in the west of Sudan and other basins in east Chad. The unique E-W trend, suggests that this Sub-basin originated by a mechanism different from Muglad Basin that is considered more extensional in origin. Five regional seismic lines are included to illustrate the structural and stratigraphic variation across the Sub-basin. Fault polygons maps for six horizons, four isopach maps, five cross-sections, and two associated kinematic models are presented in this study. Sufyan Sub-basin is characterized by rhombic geometry with three boundary faults; two of those faults exhibit dextral strike slip movement, with two depocenters at the western and eastern segments of the southern fault. Structural interpretation of Sufyan Sub-basin based on 2D seismic data highlights the style of strike-slip related structure. Negative flower structures, en-echelon faults, and rhombic geometry all suggest a significant component of a pull-apart transtensional movement in Sufyan Sub-basin. Other alternative scenarios for evolutionary history and the forming mechanism were introduced such as the oblique extension model. The Sufyan Sub-basin is believed to be highly affected by the Central African Shear Zone (CASZ). In this study, several transtension and oblique rift related features interpreted from Bouguer gravity map and seismic data are briefly described and illustrated. Based on this study, the favorable areas for hydrocarbon accumulation are the areas of flower structure and the areas that near to the two depocenters that controlled by the southern boundary fault.

1. Introduction

The Sufyan Sub-basin is located in the northwestern part of Muglad Basin and trending E-W (Fig. 1). Muglad Basin is the largest sedimentary basin in Sudan with a total area of about 160,000 km^2 (with a width of about 200 km and a length of about 800 km). Muglad Basin is trending NW-SE and terminates in the northwestern side by the Central African Shear Zone (CASZ) (Fig. 1) (Fairhead, 1988; Schull, 1988). The formation of the Muglad Basin is believed to be a rift structure that is related to the opening of the Atlantic Ocean (Fig. 2) since the Early Cretaceous period by the right-lateral movement along the CASZ (Genik, 1993). The basin is divided into eight Sub-basins which are South Kaikang, North Kaikang, Unity, Bamboo, Fula, East Nugara, West Nugara, and Sufyan (Lirong et al., 2013; Makeen et al., 2016) (Fig. 1). These Sub-basins are occupied by Cretaceous - Tertiary non-marine sediments (Schull, 1988). Sufyan Sub-basin is a relatively independent structural unit in the Muglad Basin. It is 70 km long and 40 Km wide with total area of about 2800 km^2. The 2D and 3D seismic data coverage for the whole area is about 3718 km and 698 km^2 respectively. The Sub-basin is bounded by Tomat Uplift with boundary fault in the south and Babausa Uplift to the north and east, and connected with Nugara depression in the south east (Fig. 1).

Sufyan Sub-basin exploration results have showed the occurrence of accumulations of hydrocarbon. Source rock for this

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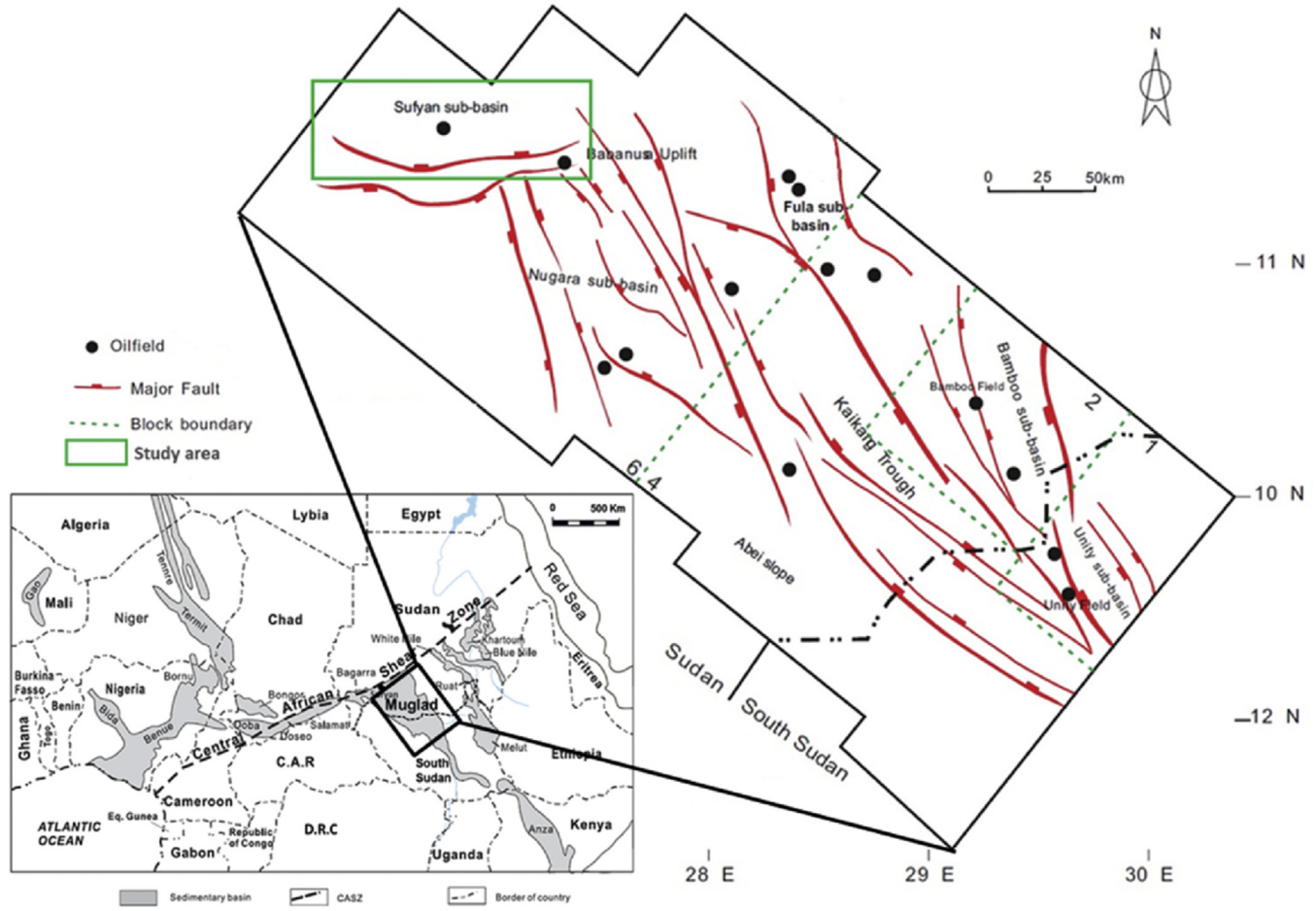

Fig. 1. Main map shows Muglad Basin structural units interpreted from seismic and gravity data (from different source of data and show only the regional faults), with location of Sufyan Sub-basin and the major discovered oilfields. The other map shows the location of Muglad Basin with relation to the West and Central Africa Rift System (WARS) (modified from Lirong et al., 2013; Makeen et al., 2016).

hydrocarbon is believed to be the lacustrine shale of the Abu Gabra Formation (Qiao et al., 2016) (Fig. 3). The TOC of Abu Gabra source rock in the area of study ranges from 1.45 to 5.15 wt % with an average of 2.84 wt % (Qiao et al., 2016). Samples with TOC more than 1.0 wt % and 2.0 wt % account for 96.92% and 60.45% of the total, respectively, and are evaluated together as good to excellent source rock (Qiao et al., 2016).

The sandstone rock within Abu Gabra Formation represents the primary reservoir (Fig. 3). The secondary reservoir rocks are the fluvial sandstones of the Bentiu Formation. The main trap style in the Sub-basin is the tilted fault blocks related to en echelon faults.

This paper discusses the tectonic evolution and structural elements of Sufyan Sub-basin. It provides evidence for describing Sufyan as a transtensional pull-apart Sub-basin and discusses implications for hydrocarbon exploration. Other alternative scenarios for evolution history and the forming mechanism are identified such as the oblique extension model.

Continental rift systems are likely to follow zigzagging routes, which are formed due to the weakness zones in the basement rocks (Daly et al., 1989; Dixon et al., 1987; McConnell, 1972; Morley et al., 2004; Smith and Mosley, 1993). The initiation of rift oblique basement lineaments during extension can yield geometries fairly similar to those formed during strike-slip (specially, transtensional) movement (Morley et al., 2004). Understanding the variation between the two structural styles and their related stress regimes is important (Morley et al., 2004). Transtension is a form of strike-slip movement; thus the intermediate principal stress is represented by the vertical principal stress (Sanderson and Marchini, 1984). On the other hand, the maximum principal stress represented by the vertical principal stress is in the oblique extension.

2. Geologic and tectonic setting of West and Central African Rift Systems

2.1. Overview

Muglad Basin represents a major part of the West and Central African Rift Systems (WCARS) (Fig. 1) and is mainly composed of discrete half and full grabens (Genik, 1993). The origin of the WCARS is believed to be related to the opening of the Atlantic Ocean (Fig. 2) (Binks and Fairhead, 1992; Fairhead and Binks, 1991; Guiraud and Maurin, 1992).

Africa is subdivided to three main sub-plates (Fig. 2); NW Africa, NE Africa, and S Africa (Fairhead et al., 2013; Genik, 1993). Geology and structure of WCARS basins were developed as a result of the African sub-plate motion's changes through time (Fairhead et al., 2013; Genik, 1993).

Basins of WCARS share similar common evolution history as they were developed in a similar tectonic setting. However, individual basins show unique histories and structure due to their locations and orientations in relation to the tectonic events. While one basin is subjected to extensional regime another basin with