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Research paper

Impact of inversion tectonics on hydrocarbon entrapment in the Baggara Basin, western Sudan

Waleed Mohamed El Hassan*, Abdel-Haleem H. El Nadi

University of Khartoum, Sudan

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ABSTRACT

The Baggara Basin of Sudan is an ENE-WSW trending basin located within the West and Central Africa Rift System (WCARS) and NW of the Muglad Basin. The trend of the Baggara Basin is similar to other basins in eastern Chad, where oil has been discovered. Since there are no published studies for the Baggara Basin, the present paper represents an addition to the geology of eastern extension of the WCARS in Sudan. The 2D seismic data interpretation sheds light on the development and evolution of key regional and local structures of the basin. The Baggara Basin is characterized by graben geometry with two boundary faults, characterized by dextral strike slip movement, and a depocenter at the central part. The interpretation reveals the presence of two types of structures within the Baggara Basin; inversion tectonics restricted to the larger basin-bounding faults in the western part and en-echelon faults in the central part. The timing of inversion tectonics is during the Eocene and it is related to a brief major compressional event due to the collision of the African and Eurasian plates. Although the inversion created a four-way dip closed anticline structure, this anticline postdated the initial migration from the source rock. Accordingly, the anticline structural is unsuccessful for hydrocarbon entrapment.

1. Introduction

The West and Central African Rift System (WCARS) developed primarily during the south Atlantic opening due to the regional NE–SW extension (Binks and Fairhead, 1992). The resulting NNW-SSE oriented extensional basins developed into two extensive rift systems in Western and in East-Central Africa. Those rift systems are linked by the Central Africa Shear Zone (CASZ) dextral fault system and related transtensional basins. The combined length of these rift systems exceeds 7000 km, with sedimentary thicknesses varying from 14 km in the Termit Trough, eastern Niger, up to 7.5 km for the southern Chad Basins (Doba, Doseo, and Salamat Basins), to in excess of 13 km for the Muglad Basin, Sudan (Fairhead, 2009). The Baggara Basin of Sudan is one of the transtensional basins located within CASZ (Fig. 1). Most of the basins in the WCARS are dominated by extensional and transtensional fault geometries. Compressional structures are generally difficult to recognize but nevertheless do locally occur.

The Santonian compressional event has been reported in most of the region (e.g. Genik, 1993; Guiraud and Bosworth, 1997; Guiraud et al., 2005; Fairhead, 2009; Viola et al., 2012). It is well documented in ENE-WSW oriented basins e.g. the Salamat, Doba, and Doseo Basins due to their favourable orientation with respect to the compressional stresses. The resulting negative and positive flower structures developed numerous traps for oil and gas. The Santonian compressional event is less pronounced in the NW–SE trending basins, including Sudanese basins, due to their unfavourable orientation with respect to the compressional stresses (extensional geometries are commonly fully preserved with little evidence of compressional events). El Hassan (2012) documented the presence of Santonian compression in the Muglad Basin. El Hassan (2012) attributed the presence of oil in the lower part of the Bentiu Formation in Heglig field to be trapped in a four-way dip closed structure created by tectonic inversion; since it is difficult to trap oil due to the lack of a lateral seal, if a tilted fault block is present. However, inversion has not been documented yet in the Baggara Basin.

The aim of this paper is to investigate the presence of inversion tectonics and its impact on hydrocarbon entrapment in the Baggara Basin. The Baggara Basin is an ENE-WSW trending basin, located to the NW of the Muglad Basin (Fig. 1). Based on gravity modelling, the sedimentary fill in the basin is thought to be up to 9 km thick in the

* Corresponding author. Geology department, University of Khartoum, Sudan.
E-mail address: welhassan@hotmail.com (W.M. El Hassan).

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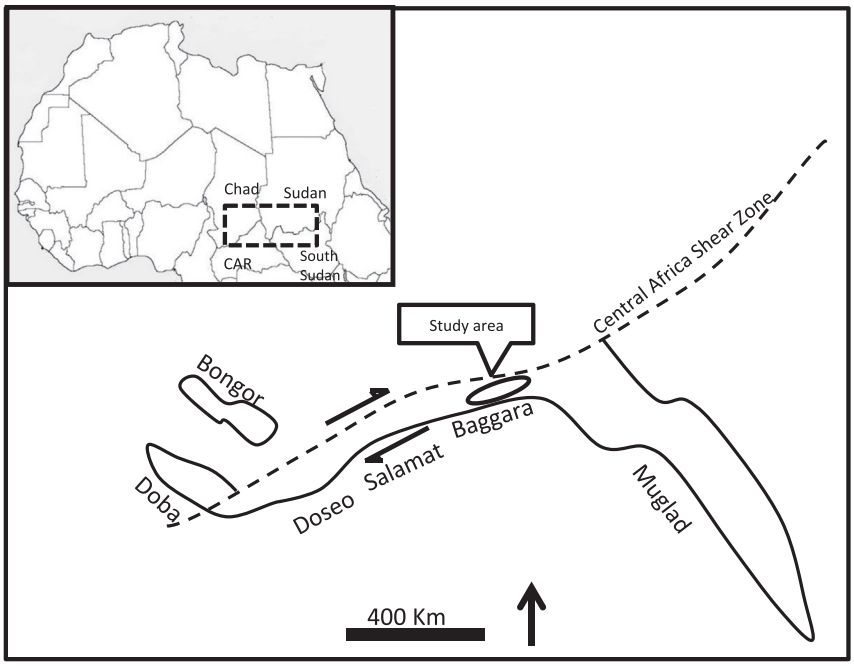

Fig. 1. Generalized map shows a part of the West and Central Africa Rift System and the location of the Baggara Basin.

deepest part, and to be mainly composed of fluvial and lacustrine sediments. To date, only a single well, Khadari-1, has been drilled in the basin. The data used in this study of the Baggara Basin was acquired by the Chevron Overseas Petroleum Inc. during the late 1970s and early 1980s in the previously unexplored interior basins of Sudan. The data includes 2D seismic lines, a gravity survey, and an exploration well.

2. Objective

Several studies on the basins in the West and Central African Rift System (WCARS) have been conducted including the Muglad, Doba, Doseo, and Salamat Basins, where the presence of source, reservoir, and seal rocks favoured the generation, migration, and entrapment of hydrocarbons. This study endeavours to describe the structural elements in the Baggara Basin, and to discuss the impact on its hydrocarbon potential. The database for this study consists of 2D seismic lines and one well (Khadri-1) (Fig. 2).

3. Regional tectonic setting and stratigraphy

The origin of the WCARS is attributed to the extensional tectonics, which resulted in the break-up of Gondwana in the Early Cretaceous time (Fairhead and Binks, 1991). Movement along the major faults continued intermittently into the Miocene. Many authors (e.g Bumby and Guiraud, 2005; Fairhead et al., 2013) relate the rifting process to the gradual opening of the Central and South Atlantic, which uses the Central Africa Shear Zone as a failed arm of a triple junction, to strike-slip movements dissipated into extensional basins. The extension resulted in the formation of several basins and inter-basinal highs in Niger, Chad, Sudan, and Kenya (e.g Burke, 1976; Browne and Fairhead, 1983; Popoff, 1988; Gaina et al., 2013).

The presence of frequent hiatuses in the sedimentary succession in the Late Santonian, associated with angular unconformities, reflects the occurrence of a tectonic event which is considered to be compressional (Guiraud et al., 1987). The Late Santonian compression caused folding and basin inversion in the Benue, Yola, and Bornu Basins (Popoff et al., 1983; Benkhelil, 1988; Avbovbo et al., 1986). Genik (1993) believed that the Doba, Doseo, and Salamat Basins, which until the late Santonian had effectively been a single basin, were separated into three discrete basins by dextral strike slip movements. This late Santonian episode of deformation is considered to be plate scale event, that resulted in inversion and/or folding of most of the E–W to ENE–WSW trending basins. This deformation also, affected Eurasia and resulted from a change in plate motions around 84 Ma (Guiraud and Bosworth, 1997; Ziegler et al., 2001; Fairhead et al., 2003).

The stratigraphic column of the Baggara Basin resembles that generalized for the Muglad Basin (Fig. 3). The huge amount of data acquired (including gravity and seismic data) showed that structural high separates the Baggara Basin from the Muglad Basin.

Based on the Khadari-1 well in the Baggara Basin, all sedimentary rocks penetrated are of nonmarine origin. The deepest sedimentary unit penetrated is the Abu Gabra Formation which is dominated by lacustrine shales. The lakes were sufficient for the accumulation and preservation of organic-rich shales that are the source rocks for the oil shows detected in Khadari-1 well. Overlain by a predominantly sand sequence of the Bentiu Formation of fluvial origin. This unit shows good reservoir quality (it represents the primary reservoirs of Heglig field in the Muglad Basin). Followed by deposition of a cycle of fine to coarse-grained sediments of Darfur Group (Aradeiba, Zarqa, Ghazal and Baraka formations). The Darfur Group is overlain by a coarser grained sediments of Amal Formation. Followed by deposition of Kordofan Group. The Nayil and Tendi formations are of fine-grained sediments, while Adok and Zeraf formations are sand-rich sediments.

4. Hydrocarbon system elements

Although oil shows were encountered in Khadari-1 well hydrocarbon exploration has not discovered a commercial oil discovery in the Baggara Basin to date. Whilst in the adjacent Muglad