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Research paper

Seismic inversion as a predictive tool for porosity and facies delineation in Paleocene fluvial/lacustrine reservoirs, Melut Basin, Sudan

M.I. Mahgoub [a, *], E. Padmanabhan [a], O.M. Abdullatif [b]

[a] Universiti Teknologi PETRONAS, Malaysia
[b] King Fahd University of Petroleum and Minerals, Saudi Arabia

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ABSTRACT

The Melut Basin is a rift basin in the interior Sudan linked to the Mesozoic-Cenozoic Central and Western African Rift System. The Paleocene Yabus Formation is the main reservoir deposited in heterogeneous fluvial/lacustrine environment. Delineation of channel sandstone from shale is a challenge in reservoir exploration and development. We demonstrate a detailed 3D quantitative seismic interpretation approach that integrates petrophysical properties derived from well logs analysis. A porosity transform of acoustic impedance inversion provided a link between elastic and rock properties. Thus, we used seismic porosity to discriminate between different facies with appropriate validation by well logs. At the basin scale, the results revealed lateral and vertical facies heterogeneity in the Melut Basin. Good reservoir quality is observed in the Paleocene Yabus Formation. The sand facies indicated high porosity (20%) corresponding to low acoustic impedance (20000–24000 g ft/(cm3.s)). However, lower quality reservoir is observed in the Cretaceous Melut Formation. The porosity of sand/shale facies is low (5%), corresponding to high acoustic impedance (29000–34000 g ft/(cm3.s)). This suggests that the Yabus Sandstone is potentially forming a better reservoir quality than Melut Formation. At the reservoir scale, we evaluated the facies quality of Yabus Formation subsequences using petrophysical analysis. The subsequences YB1 to YB3, YB4 to YB7 and YB8 to YB10 showed relatively similar linear regressions, respectively. The subsequence of YB4 to YB7 is considered the best reservoir with higher porosity (25%). However, subsequence YB1 to YB3 showed lower reservoir quality with higher shale volume (30%). This attributed to floodplain shale deposits in this subsequence. Similarly, the high porosity (20%) recognized in deeper subsequences YB6 to YB9 is due to clean sand facies. We learnt a lesson that appropriate seismic preconditioning, exhaustive petrophysical analysis and well log validation are important keys for improved reservoir quality prediction results in fluvial/lacustrine basins.

1. Introduction

Rift basins in the interior Sudan are linked to the Mesozoic-Cenozoic Central and Western African Rift System (CWARS). The Melut Basin is considered to be an important basin for oil exploration and production in Sudan, along with the Muglad and White Nile basins (Fig. 1). The basin is filled by channel sandstone, lacustrine claystone, and local volcanics of Late Cretaceous to Quaternary age (Schull, 1988). Extensional faults, basin thickness and tectonic subsidence are the main factors that control the sedimentary facies and reservoir quality along the basin. Significant reservoir heterogeneity that maximizes the exploration risk is the result of rift phases, erosion and deeper basement structures.

The tectonic history indicates that the Melut Basin is a Late Cretaceous to Tertiary rift basin formed as a response of the strike-slip extension with a trend NW-SE to NNW-SSE in the Central African Rift System (McHargue et al., 1992; Genik, 1993; Mann, 1989). The early evolution of the Central African strike-slip zones was probably controlled by early opening history of the South Atlantic Ocean and Benue trough during the Mesozoic.

In this paper, we have performed detailed seismic interpretation

* Corresponding author.
E-mail addresses: mahgoub75@gmail.com (M.I. Mahgoub), eswaran_padmanabhan@petronas.com.my (E. Padmanabhan), osmanabd@kfupm.edu.sa (O.M. Abdullatif).

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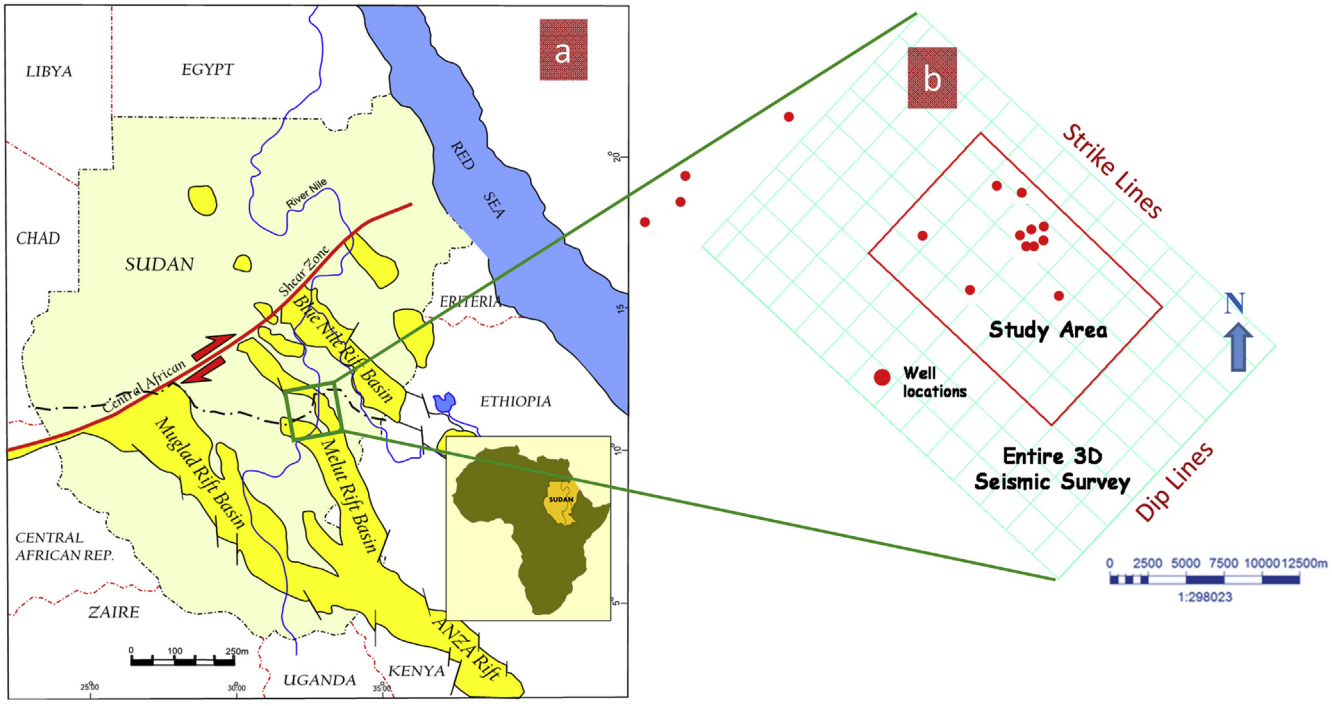

Fig. 1. (a) Location map shows Sudan rift basins and their link to CWARS (modified after Genik, 1993), the study area is located in the northern Melut Basin. (b) Selected area of 200 km^2 for seismic inversion includes 15 wells as distributed in the base map.

and acoustic impedance inversion in Abyat Field in northern part of the Melut Basin. We have used the acoustic impedance with petrophysical analysis and well data validation to produce 3D seismic porosity. The acoustic impedance and porosity results were interpreted and used for facies discrimination and reservoir prediction in the study area.

1.1. Stratigraphy

The lithostratigraphic framework of the Melut Basin includes four units separated by unconformities and three rift cycles capped by sag unit (Dou et al., 2008) (Fig. 2). This study concerned the third rift cycle's that includes Samma, Yabus and Adar formation; in addition to the Early Cretaceous Melut Formation. From the stratigraphic nomenclature, the Paleocene Samaa Formation rests unconformably upon the Late Cretaceous. The Samaa Formation represents the initial infilling of Late Cretaceous topography, with the predominance of fluvial and overbank facies. The initial deposits of the Paleocene - Lower Eocene Yabus Formation are dominated by channel sandstones, mouth bars and crevasse splay, which define the Yabus Sandstone Member that is regionally correlative. The Eocene Adar Formation represents a late rift phase characterized by reduced coarse clastics input and the prevalence of overbank, crevasse splay and floodplain facies. Lacustrine phases also became more persistent. Subaerial oxidation, however, continued to be significant during the deposition of Adar succession.

1.2. Petroleum system

Petroleum systems of the Melut Basin were reviewed based on basin-scale studies (Schull, 1988; Dou et al., 2008). The lacustrine shales of the Eocene Adar Formation has been positively identified as one of the source rock level in the basin. The second deep source rocks is series of shales of Senonian age that probably contributing to the source potential of the area (Fig. 2). All source levels might be reached maturation in Oligocene-Miocene times (Dou et al., 2008). The Paleocene sandstones of the Yabus Formation and sandstones of the uppermost part of the Senonian Samaa Formation are the only proven reservoirs in the Melut Basin (Fig. 2). Thick Upper Eocene-Oligocene shales appear to act as the main, and perhaps only, sealing horizon in the basin (Fig. 2). Structurally, the Melut Basin is essentially formed by simple extensional and tectonic regime. The Yabus Structure is a single play type that has been established from Upper Senonian-Lower Eocene terrestrially derived sandstone reservoirs. It has been charged with hydrocarbons migrating from nearby lacustrine shale sources, and capped with similar thick, lacustrine shale sequences. The accumulations are apparently held within simple, fault-modified, four-way, structural closures.

Two petroleum systems are likely to be present in the basin (Schull, 1988). The known petroleum system involves migration of oil from Upper Eocene-Oligocene shale source rocks into the main Yabus Formation reservoir (Fig. 2). The hypothetical petroleum system probably involves movement of hydrocarbons from an Upper Cretaceous (Senonian) lacustrine shale source into the underlain reservoir level. The likelihood of both systems being in operation simultaneously in late Tertiary times is considered high. Source to reservoir migration distances will have been small, with hydrocarbon movement aided by fault plane pathways. Exploration potential is apparently limited to Upper Cretaceous lacustrine sandy units, but an earlier Cretaceous section, above basement, could exist at depth. The basin is vastly under explored and remaining potential seems to be good especially in the central and eastern flank areas. These have most likely been in a favorable position to have captured hydrocarbons migrating out of the deep basin kitchen (Schull, 1988).