

Origin of a Tertiary oil from El Mahafir wildcat & geochemical correlation to some Muglad source rocks, Muglad basin, Sudan



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ABSTRACT

Source rock screening analysis was performed on four stratigraphic units from the Muglad basin namely; Abu Gabra, Zarqa, Ghazal, and Baraka formations using pyrolysis and Vitrinite Reflectance (Ro). Results, integrated with the chromatographic and isotopic data from these rocks extracts and a Tertiary oil from El Mahafir-1 wild cat, were used to determine the origin of the oil.

A good organic source within the Middle Abu Gabra Formation is observed in wells El Toor-6 and Neem Deep-1 (TOC, 1.0–2.0% & S₂ 5.0–10.0 mg C/g rock), with mixed kerogens I, II, & III, and thermally mature (% Ro = 0.74–0.94). The Campanian–Early Maastrichtian sequence, i.e. Zarqa and Ghazal formations are generally poor (TOC, <0.5% & S₂ <2.5 mg C/g rock), dominated by type III kerogens, and immature at the studied locations. The Baraka shale nevertheless, is good at El Mahafir-1 well (avg. TOC 1.8% & S₂ 5.0–10.0 mg C/g rock) and fair at Timsah-1 well (Avg. TOC 0.69% & S₂ 2.5–5.0 mg C/g rock) with a Kerogen that is predominantly Sapropellic at the former, and an exclusively Humic at the later. The formation is mature at Timsah (% Ro = 0.77–1.16) and early mature at El Mahafir-1 (% Ro = 0.64–0.81).

Consistent with the pyrolysis, chromatographic data of the rock extracts confirms the mixed source nature of the Abu Gabra Formation which consists of both algal [prominent LMW n-alkanes & elevated C₂₇ steranes (36–47%)], as well as terrigenous material [higher diasterane/regular sterane ratios (0.50–0.56), abundant rearranged hopanes, & relatively high CPIs (1.22–1.9)], accumulated in an oxic to sub-oxic environment (Pr/Ph, 1.3–3.0). Abu Gabra further shows low C₂₉/C₃₀ hopanes (0.45–0.54), low C₂₈ steranes (21–26%) with high Gammacerane index (20.3). In contrast, the environment during the Late Cretaceous was strongly reducing (Pr/Ph, 0.37–1.0), associated with a wide organic diversity, both in space and time and is characterized by dominant algal input at some areas and or stratigraphic intervals [Elevated tricyclics, higher C₂₉/C₃₀ hopanes (0.5–1.14), and relatively low Gammacerane indices (4.6–14.4)], while mixed with abundant terrigenous material at others.

A direct correlation between El Mahafir oil and the Abu Gabra extracts is thus inferred based on: its mixed organic source nature, oxic to sub-oxic depositional environment (Pr/Ph 1.22), relatively low C₂₉/C₃₀ hopanes (0.54), low C₂₈ steranes (29%), and a high gammacerane index (20.5). This is largely supported by the maturity modeling results which suggest generation is only from the Abu Gabra at this location.

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1. Introduction

1.1. Background & study location

El Mahafir-1 (wild cat) was drilled in 1997 by GNPOC, with a primary objective to test and evaluate the hydrocarbon potential of

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the Late Cretaceous Baraka Formation. The well trajectory has been designed to penetrate the Baraka formation at optimal location, thereby evaluating the potential oil reservoir in the Baraka sandstones. This well, however, encountered hydrocarbon in the lower Nayil Formation (Eocene) which tested an 18.7 API (68° F PPT.) oil.

Compared to Muglad's major reservoirs (i.e. Bentiu (Aptian-Cenomanian) and Aradeiba (Santonian), which contain the majority of the oil, this relatively young oil accumulation was uncommon in the history of the basin and has been a subject of debate among GNPOC geoscientists as far as the source originator is concerned. It has been well documented that the Early Cretaceous organic rich Abu Gabra Formation is the primary source rock for all Muglad's oils (Ahmed, 1993; Miles, 1984; Schull, 1988; Hwang et al., 1994).

The well is located in the southernmost corner of GNPOC's Block-2 near the South Eastern border of Block-4 (Fig. 1). Offset wells included Amal-1, located 49 km to the NW and Kaikang-1, located 63 km to the SSW directions from ElMahafir-1 well. Other wells in Fig. 1, (i.e. Neem Deep-1, Timsah-1, Garaad-1, El Full AG-1, Grintiya-1, Faras-1, and El Toor-6) and (Shelungo-1, Haraz-1, Lol-1, & Khairat-1) are well locations for rock cuttings and oils samples data used in this study respectively. An E-W geological profile (Fig. 2) is used here to show Muglad's stratigraphic framework and the main source rocks units in the area, i.e. Abu Gabra and the Late Cretaceous (i.e. Baraka & the Darfur Group/DG).

1.2. Previous work

The lacustrine Barremian-Neocomian shales/mudstones succession of the Abu Gabra formation represents the effective source rock in the Muglad basin. All discovered oils have been correlated to this source interval (Ahmed, 1993; Miles, 1984; Schull, 1988; Hwang et al., 1994; Waples, 1997; Moffat, 2000; Fadul & Mohamed, 2007). Next in importance comes the Eocene-Miocene Tendi & Nayil formations which, like the Abu Gabra Formation, are of lacustrine origin. However, the generation potential of this source interval is hindered due to immaturity (Moffat, 2000).

As stated above, previous workers consistently agree that all discovered Muglad's oils are sourced from the Abu Gabra Formation. The minor dissimilarities in these oils have always been

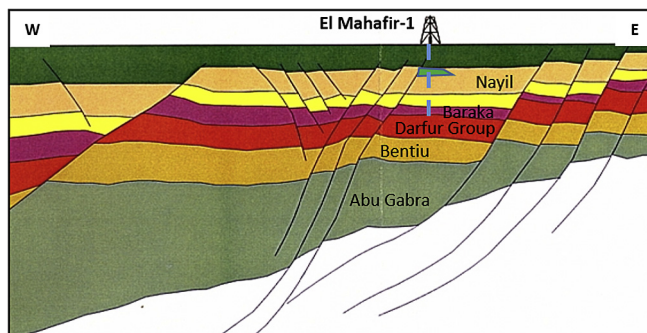


Fig. 2. An E-W geological profile (seismic interpretation) across El Mahafir-1 location showing the Nayil oil accumulation, the potential source rocks (i.e. the Early Cretaceous (Abu Gabra) and the Late Cretaceous (Baraka & Darfur Group) rocks).

attributed to facies variations within the Abu Gabra itself rather than to any different source (Waples, 1997; Fadul & Mohamed, 2007). Two organic facies units have previously been identified within the Abu Gabra formation based on Omer and Ahmed's work on some sixty Muglad's crude oils; a deep-water algal-rich lacustrine and a shallow-water terrigenous lacustrine suite (Fadul & Mohamed, 2007).

The majority of Muglad's oils were entrapped within Cretaceous sandstones reservoirs. The recent discovery of some oils in Tertiary reservoirs (e.g. Chevron's Kaikang-1, GNPOC's El Mahafir-1, Diffra, & Haraz-Suttaib oils) ignited a debate among GNPOC geoscientists on whether a new source rock could be contributing to charge these reservoirs. We conducted this study in order to determine the origin of the oil in El Mahafir-1 well.

1.3. Objectives of this study

The objective of this study is to identify and fully characterize hydrocarbon potential source rocks in the area, geochemically characterize the oil in El Mahafir well, and investigate its genetic relationship to potential source rocks. This work attempts to answer the long debated origin of such unusual oil. This is

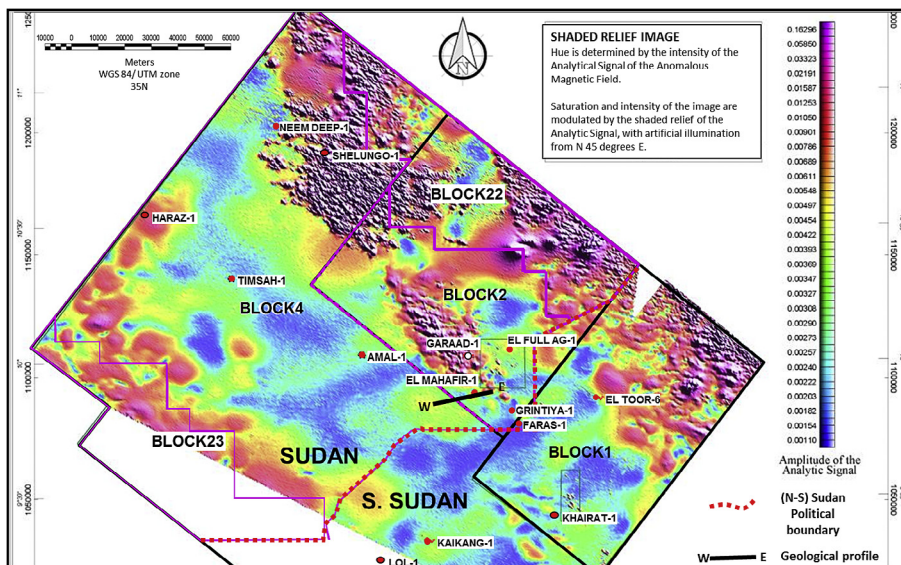


Fig. 1. Location map for the study area superimposed on an "Analytic Signal" background, (after Salley, 2001), showing the location of the study wells, structural highs and lows, and an E-W seismic interpretation section across the area.

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