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Source-rock evaluation of the Dakhla Formation black shale in Gebel Duwi, Quseir area, Egypt

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ABSTRACT

A relatively thick Upper Cretaceous–Lower Tertiary sedimentary succession is exposed in Gebel Duwi, Red Sea area, through an almost horizontal tunnel cutting the NE dipping strata from Quseir to Thebes formations. The black shale belonging to Dakhla Formation represents a real potential for future energy resource for Egypt. Dakhla Formation consists mainly of organic-rich calcareous shale to argillaceous limestone that can be considered as a good to excellent source rock potential. The total organic carbon (TOC) content ranges from 2.04% to 12.08%, and the Hydrogen Index (HI) values range from 382 to 1024 mg HC/g TOC. Samples of the Dakhla Formation contain mostly kerogen of types I and II that prone oil and oil-gas, indicating marine organic matter derived mainly from algae and phytoplankton organisms and proposing typical oil source kerogen. The average of the potential index (PI) value is 0.02 mg HC/g rock, which indicates the beginning of a considerable amount of oil generation from the Dakhla Formation. The T_{max} values range from 427 to 435 °C. Based on the T_{max} data and PI values, the studied black shale samples are immature to early mature for hydrocarbon generation in the Duwi area. The data reduction suggests four main factors covering about 91% of the total variances. The average of the calorific value (459 kcal/kg) indicates unworkable efficiency of such black shale for direct combustion use in power stations. However, selective operation of specific horizons having the highest calorific values may provide viable resources.

1. Introduction

The increased interest in black shale, all over the world during the last few decades, seems principally to be due to their importance as natural unconventional future fuel-resources. The black shale is widely distributed in Egypt in several horizons of different geologic ages, particularly in the Upper Cretaceous–Lower Tertiary formations; Duwi (phosphate-bearing), Dakhla and Esna formations in the area between Safaga and Quseir of the Red Sea region. The black shale belonging to the Dakhla Formation represents the real potential resources of Egypt. The average amount of oil yielded by Fischer assay is about 20–45 gal/ton (Robison and Tröger, 1983; Tröger, 1984). The in-place shale-oil resources in Quseir–Safaga area is 4500 * 106 bbls (Tröger, 1984). These estimations are not beyond doubt because they were calculated on the basis of measurement of surface exposures and spot samples collected from abandoned phosphorite mines (El-Kammar, 2014). The geological formations of the Upper Cretaceous–Lower Tertiary are well exposed in Gebel Duwi to the west of Quseir. It covers an area of about 112 km^2 (28 km long and 4 km wide, Fig. 1). The elevation of this ridge ranges between 450 and 545 m above sea level. The stratigraphic succession includes the formations from Nubia Formation, as the oldest sedimentary unit in the region (Cenomanian, Upper Cretaceous) to Nakheil Formation (Oligocene) with a dip of ±20°NE.

Many studies have focused on the oil potential of the black shale of the region. The first of these studies was performed by Mustafa and Ghaly (1964), followed by several others such as Tröger (1984), Ganz (1984), Khaled et al. (1987) and El-Kammar (1987, 1993, 2014). However, most of these studies focused on the geochemistry, depositional environment, stage of maturity and potential for hydrocarbon generation of the black shale of the Dakhla Formation. In addition, the organic geochemical characteristics using biomarker parameters were studied by El-Kammar (1993) in order to characterize the organic matter and its maturation. More advances have recently been projected by El-Shafeiy et al. (2014).

2. Regional geology

Geologically, Gebel Duwi area is a part of the Central Eastern Desert of Egypt that can be subdivided into two parts; the Duwi

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range and the coastal plain. The former consists of an elongate NW-trending ridge that drops precipitously to the southwest and slopes gently to the northeast. The coastal plain is generally smooth in outline, with no sharp bends or bays. It slopes gently seaward. In general, the sedimentary rocks of Gebel Duwi area are separable into two main divisions: the pre-rift Cretaceous–Eocene succession (more than 1500 m thick) and the syn-rift Oligocene and younger sediments (Fig. 1). The Cretaceous and Eocene deposits occupy the troughs of synformal-like fault-folds within the crystalline hill ranges.

The stratigraphy of Gebel Duwi area is summarized below, primarily after Said (1962). The typical stratigraphic section in the Quseir–Safaga region starts at its base with the non-fossiliferous, cross-bedded Nubia (sandstone) Formation which represents the oldest sediments in the area which unconformably overlie the basement rocks. The Nubia Formation is conformably overlain by thick multicolored shale known as Quseir (Variegated Shale) Formation. Both Nubia and Quseir formations have a pre-Campanian age. The Quseir Formation constitutes the base of black shale-bearing formations and is overlain by Duwi and Dakhla formations (Fig. 1). The black shale of both Duwi and Dakhla formations are assigned Upper Campanian to Maastrichtian age which provides a good example of major marine transgression event. The sedimentary association of that event consists of black (frequently assigned as "oil") shale, limestone, phosphorite, chert, glauconite and dolostone.

Major marine transgression during the Late Cretaceous–Early Tertiary times covered most of the Egyptian territory southwards up to latitude of Aswan (24°N). It was interrupted by minor mild regressive, and some tectonic, pulses associated with uplifting (Issawi, 1968; Said, 1990; El-Sabbagh et al., 2011). The marine depositional conditions during the transgression maintained favorable conditions for accumulation and preservation of organic-rich sediments that were deposited in two main conformable geological formations, namely; Duwi and Dakhla formations. The former is mostly Campanian to early Maastrichtian in age and it includes the economic phosphate deposits of Egypt. The Dakhla Formation was deposited in near shore to deep marine environments during Maastrichtian to Early Paleocene as indicated by the presence of dinoflagellates, nannoplanktons, planktonic foraminifera and palynology (Abdel-Malik, 1982; Schrank, 1984, 1987; El-Kammar et al., 2013).

In the Quseir–Safaga district, the Dakhla Formation reaches its maximum thickness in Gebel Duwi (175 m) and can be subdivided into two members; lower Hamama (Marl) Member (Maastrichtian) and upper Beida (Shale) Member (Paleocene). The latter is composed of gray shale and unconformably overlies the Hamama Member (Masters, 1984). El-Kammar (1987) reported a remarkable feature in the Quseir and Safaga phosphate mines where the capping black shale caught fire by self-ignition being rich in hydrocarbons and pyrite.

3. Materials and methods

The Dakhla Formation, consisting of thick black shale strata, was systematically sampled from a tunnel that was excavated in the early 1930s almost horizontally to cut the NE dipping sedimentary strata starting from Quseir Formation (old) to Thebes Formation (young). The tunnel starts at the south-western flank of the Duwi range, near to Beida mine (at longitude 34°05′02″E and latitude 26°09′00″N) and terminates in Wadi El-Nakeil (at longitude 34°05′58″E and latitude 26°06′39″N). It was dug by an Italian phosphate company to provide systematic profiling and sampling of the Upper Cretaceous–Lower Tertiary sedimentary sequence, in general, and phosphorites in particular (Fig. 1). The tunnel runs almost

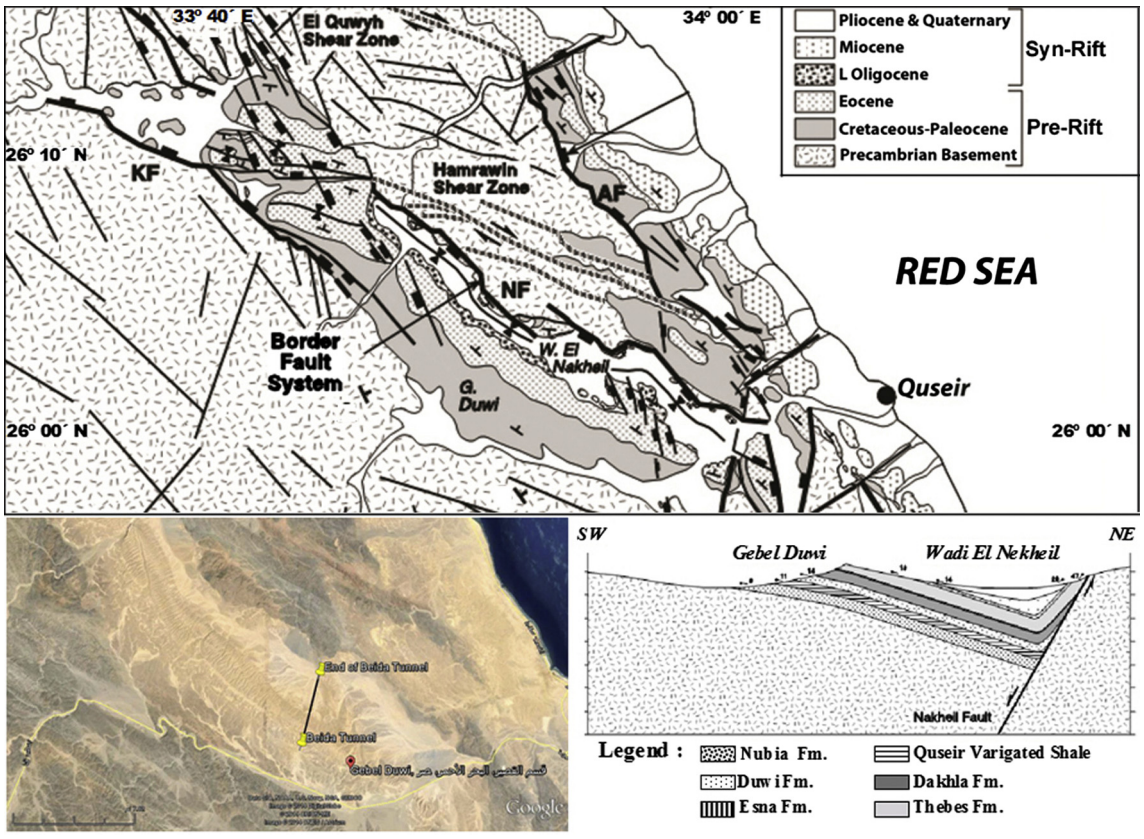

Fig. 1. Geologic map of the Gebel Duwi showing the different stratigraphical units of the study area (modified after Khalil and McClay (2002)).