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Petrography, diagenesis and reservoir characteristics of the Pre-Cenomanian sandstone, Sheikh Attia area, East Central Sinai, Egypt

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ABSTRACT

The diagenetic influence on reservoir characteristics was investigated for the Pre-Cenomanian (Early Paleozoic and Early Cretaceous) sandstone sequence in the Sheikh Attia area, East Central Sinai. This sequence can be distinguished into four formations: Sarabit El-Khadim Formation (Cambrian) at the base, Abu Hamata Formation (Cambro-Ordovician), Adedia Formation (Ordovician-Silurian) and Malha Formation (Early Cretaceous) on the top. The sandstones of Pre-Cenomanian sequence in the Sheikh Attia area are dominantly quartz arenites and subarkoses, where the quartz grains constitute about 82.3–98.4% of the framework composition with an average value of approximately 94% of the framework composition. Feldspars range in abundance from 0% to14.2%, with an average value of about 3% of the framework composition. The rock fragments constitute up to 9.8% of volume percent of framework grains, with an average of about 2.7%.

Diagenetic events identified in these sandstones include compaction, cementation by calcite, quartz, clay minerals and iron oxides, dissolution and alteration of unstable clastic grains, and tectonically induced grain fracturing. Unstable clastic grains like feldspars suffered considerable alteration to kaolinite.

The Pre-Cenomanian (Early Paleozoic and Early Cretaceous) sandstones possess good reservoir characteristics because they retain sufficient porosity and permeability in some intervals. These sandstones are characterized by porosity ranges between 3.80% and 27.60%, and have a permeability range from $k \leqslant 0.03$ mD, for tight sandstones to $k \geqslant 50$ mD, for the more permeable parts. The Pre-Cenomanian sandstones can be classified into four petrophysical flow units (megaport, macroport, mesoport and microport) with varying reservoir performances and are distinguished by comparable ranges of R_{35}.

Petrographic observations showed that the Early Paleozoic sandstones are texturally immature owing to the abundance of angular grains, non-uniformity of grain size, high amounts of matrix clay mineral, and high amounts of feldspar grains. The Early Cretaceous sandstones have low amounts of rock fragments, clay minerals, and feldspars grains. Statistical analysis of the petrophysical data confirms that the reservoir quality of Early Cretaceous sandstone is higher than that of Early Paleozoic sandstones (the reservoir quality index of Early Cretaceous sandstone is 0.383 μm and for Early Paleozoic sandstones is 0.205 μm).

1. Introduction

Sinai is situated between the African and Arabian plates; the boundaries of which are defined by the Gulf of Aqaba-Dead sea rift systems. Along the Gulf of Aqaba-Dead sea, N15°E, strike-slip movement was detected with a horizontal shift of approximately 110 km. Simultaneously, right–lateral shear faulting, trending N35°W, developed along the Gulf of Suez with a horizontal displacement of the western bank estimated at 60 km minimum (Zarif, 1998).

The Pre-Cenomanian sequence in Sinai and the Gulf of Suez is of remarkable interest due to its high hydrocarbon potential. This interest is raised after the discovery of oil in the Rudies and Balayim oil fields in addition to the production from the Cretaceous reservoirs at October, Amr, Bakr and Ras Gharib fields (Hassanien et al., 1996). Its importance is due to the presence of Nubian sandstone sediments which considered to be a hosting hydrocarbon material, as well as having a wide geographical distribution in Egypt. Considerable research has previously been done on the

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petrophysical properties of Egyptian sandstone (e.g. El Sayed, 2011; Halisch et al., 2009; Weller et al., 2013).

The encouraging oil discovery of stratigraphic levels within the lower most part of Nubian (A) and (B) sandstone in West Balayim oil fields (BM-57) gave the initiative to study and evaluate the Pre-Cenomanian (Nubian sandstone) sequence. The Pre-Cenomanian faulting pattern complicated the reservoir geometry of Nubian sandstone and explained that the virgin pressure in BM-57 could be attributed to the combined effect of both the older block faulting and stratigraphic factors (El-Heiny et al., 1998).

Most of the research in clastic diagenesis and reservoir quality evaluation deal with quartzose or feldspathic sandstones from deeply buried hydrocarbon bearing basins, (McBride et al., 1987; Dutton and Land, 1988; Morad et al., 2000, 2010; Salem et al., 2000; Mansurbeg et al., 2008). However, studies of shallow sandstones provide important clues on shallow diagenesis, and the evolution pattern of early diagenetic minerals (Salem et al., 1998; Kordi et al., 2011).

Diagenetic modifications were dependent mainly on the clastic composition of sandstones, burial depth, and thrust tectonics (Umar et al., 2011). Diagentic processes that govern reservoir quality evolution include the extent of compaction, cementation (mainly by carbonates, quartz and clay minerals), and dissolution. Deposition of sandstones continuously lose porosity due to compaction and cementation, however, porosity preservation may occur due to early, partial carbonate and quartz cementation (De Ros et al., 1994) and also due to the presence of clay coating, (Moraes and De Ros, 1990; Ehrenberg, 1993).

The roles of partial cementation and over pressuring are important in limiting compaction, whereas the clay coatings are effective in preventing quartz cementation and thus preserving porosity. The emplacement of oil has been suggested to inhibit diagenesis by limiting both cementation and chemical compaction (Robinson and Gluyas, 1992).

Enhancement of secondary porosity in sandstones occurs due to the dissolution of framework grains and cements (Siebert et al., 1984; Burley and Kantorowicz, 1986).

The Pre-Cenomanian sequence was selected for this study because of its wide occurrence in Egypt and for the recent oil discoveries found in the Cretaceous rocks in Egyptian sedimentary basins, as in the Gulf of Suez, Sinai and Western Desert.

This work aims to study the Pre-Cenomanian (Early Paleozoic and Early Cretaceous) clastic sequences of the Sheikh Attia area, East Central Sinai (Fig. 1) in terms of lithostratigraphy, petrography, petrophysics, diagenesis, and depositional environment of the two separate clastic sequences to reveal their diagenetic history and reservoir characteristics by using some surface samples that helped in the better understanding of the best reservoir quality in their analogous subsurface units.

The studied area is traversed by a number of faults slicing the basement rocks into elongated blocks in a SSW-NNE direction and tilted towards the Gulf of Aqaba. The wrenching along the Gulf of Aqaba is in the form of strike-slip faults cutting through basement rocks and overlying sedimentary section with both sinistral and dextral displacements. Folds are developed with strong wrenching deformation and associated with faults of different trends. They are in the form of doubly-plunging asymmetric anticlines that are commonly aligned in an en echelon arrangement.

2. Sampling and measuring techniques

The Pre-Cenomanian (Early Paleozoic and Early Cretaceous) succession at Shikh Attia area, East Central Sinai, unconformably overlies the granitic massive of basement complex. Both the basement and sedimentary rocks are well exposed in the area and exhibit a series of elongated ridges running parallel to the Gulf of Aqaba.

The measured succession at Shikh Attia area reaches about 185 m in thickness and is composed mainly of sandstone that is conformably overlain by well defined, diversified marine strata. The sequence can be distinguished into four formations from base to top: Sarabit El-Khadim Formation (Cambrian), Abu Hamata Formation (Cambro-Ordovician), Adedia Formation (Ordovician-Silurian) and Malha Formation (Eraly Cretaceous). Abu Hamata Formation (Cambro-Ordovician) subdivided into two members (Ras El-Naqab and Nasib).

A total of 78 representative samples were obtained out of the hand specimens for the petrographical and petrophysical studies. The description of primary and authigenic mineralogy of the sandstones is based on point counting petrography of 78 thin sections, scanning electron microscope (SEM) and X-ray diffraction analyses (XRD).

Thin section preparation involved vacuum impregnation with blue resin (blue-dyed epoxy) to facilitate the recognition of porosity. Each thin section was point-counted (400 points). Special attention was paid to the types of porosity (intergranular, intera-granular and oversized pores) due to their significance in the reservoir quality evaluation. Staining methods (Dickson, 1965) with a mixed Alizarin Red-S and Potassium Ferri Cyanide solution, to identify the carbonate minerals, were applied to the studied samples. In addition, samples were stained with a Sodium Cobalt Nitrate solution to aid in the recognition of alkali feldspars.

Scanning electron microscope (SEM) was carried out using a SEM Model Jeol 5300 JSM, Japan at Egyptian Petroleum Research Institute (EPRI). XRD of sandstones and their clay separates was carried out in the Egyptian Geological Survey and Mining Authority (Central Laboratories Sector), using a Philips X-ray diffractometer with Ni-filtered copper radiation at 40 KV and 30 MA and scanning speed of 0.02 °/s.

Petrophysical measurements were preformed under ambient conditions at a constant temperature of about 20 °C. To determine the standard parameters for reservoir characterization of the twenty eight (28) representative sandstones, cylindrical samples with a length up to 3 cm and a diameter of 2.5 cm were drilled from the hand specimens and dried in an electric oven for 10 h at a temperature not more than 95 °C to avoid clay deformation and alteration by heating.

The bulk density (σ_b) of rock samples was measured using direct methods for geometrical shapes (cylindrical plugs) and dry weight of the core samples. The rock porosity ($\O$) was determined by a helium porosimeter instrument; serial no. A – 8222, Model 3020 – 062, Dallas. Texas, U.S.A.

The grain density (σ_g) was determined by product of porosity measurements. Permeability (K) was determined by a Core Lab permeameter (model is 3021–38, Dallas, Texas, U.S.A and serial no. A – 3148) using air as flowing fluid.

The apparent electrical resistivity (Ωm) of the samples was measured twice in two successive brine saturation cycles (very low of concentration at 600 ppm and very high of concentration at 60000 ppm) using a two-electrode A–C bridge and a Hassler type core holder with two copper electrodes, at a surrounding laboratory temperature and current frequency (f) = 1000 Hz. to minimize the pre-electrode effects. Formation resistivity factor was calculated according to Archie's equation (1942). Electrical tortuosity (t) on the other side can be calculated according to Gür (1976).

3. Results and discussion

3.1. Lithology

The stratigraphic sequence of the studied area was investigated in the field in where, the Early Paleozoic strata rest unconformably