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Reservoir characterization of the Lower Abu Madi Formation using core analysis data: El-Wastani gas field, Egypt

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ABSTRACT

The Messinian (Upper Miocene) sandstones of the Lower Abu Madi unit are the main reservoirs of the El-Wastani (EW) gas field, located in the onshore Nile Delta of Egypt. Reservoir quality is highly variable and represents the major risk in locating new delineation and development wells in the field. Four lithofacies (F1, F2, F3 and F4) are characterized based on textural attributes and sedimentary structures. Facies F4, which is a medium to coarse-grained fluvial channel sandstone, exhibits the best reservoir rock quality. Four hydraulic flow units (*HFU 1* through *HFU 4*) were delineated in the studied wells with flow zone index (*FZI*) values indicative of a broad range of hydraulic properties. The cementation factor (m) value, was calculated from the inverse relationship between porosity and formation factor for EW-4 and EW-6 wells, agrees with the published values of clean sandstone reservoirs. The results of grain density analyses is close to the published value of grain density of quartz, and also supported by the results of petrographic study, where quartz is the dominant framework mineral. Generally, both the permeability and porosity can be linked to the two derived electrical properties (formation resistivity factor and electrical tortuosity) in the clastic reservoirs of the Lower Abu Madi unit. This correlation is particularly evident in the western and central parts of the study area at EW-4 and EW-6 wells, where facies F4 is dominant.

1. Introduction

The modern Nile Delta is not only one of the largest and best-known deltas in the world, but is also a giant gas province that has attracted attention due to estimated proven reserves of 42 TCF (Trillion cubic feet) and 50 TCF of undiscovered potential (Boucher et al., 2004). Commercial potential was established in 1966 when the Abu Madi-1 discovery well flowed gas from the late Messinian Abu Madi sandstones (Dalla et al., 1997). Exploration on the onshore Delta subsequently focused on Oligocene/Early Miocene through Pleistocene clastic reservoirs. This study focuses on the El-Wastani gas field, which is one of the most important gas fields in the onshore Nile Delta (Fig. 1).

The Nile Delta area has been affected since the Precambrian by major tectonic movements. Deep drilling has revealed a succession of clastic sedimentary rocks deposited in alluvial through deltaic to open marine environments. Jurassic coals and shales of the Lower Miocene Qantara Formation constitute the primary source rocks for the gas. Additional source rocks may be present in condensed shale intervals of Cretaceous, Oligocene and Eocene age (Boucher et al., 2004).

The type section of the Abu Madi Formation, is in the Abu Madi-1 well (31°26′17″N; 31°21′14″E), in the Nile Delta area at a depth interval of 3007–3329 m (Rizzini et al., 1978). This formation unconformably overlies the Qawasim Formation and underlies the Kafr El Sheikh Formation. The Abu Madi Formation is divided into lower and upper rock units. The Rosetta anhydrite, deposited during the Messinian salinity crisis, marks the boundary between the upper and Lower Abu Madi Formation (Douglas, 2007). The formation was first described by Rizzini et al. (1978) as a thick series of sands, in part pebbly and semi-consolidated, with interbedded thin shales which become thicker and more frequent in the upper part of the formation.

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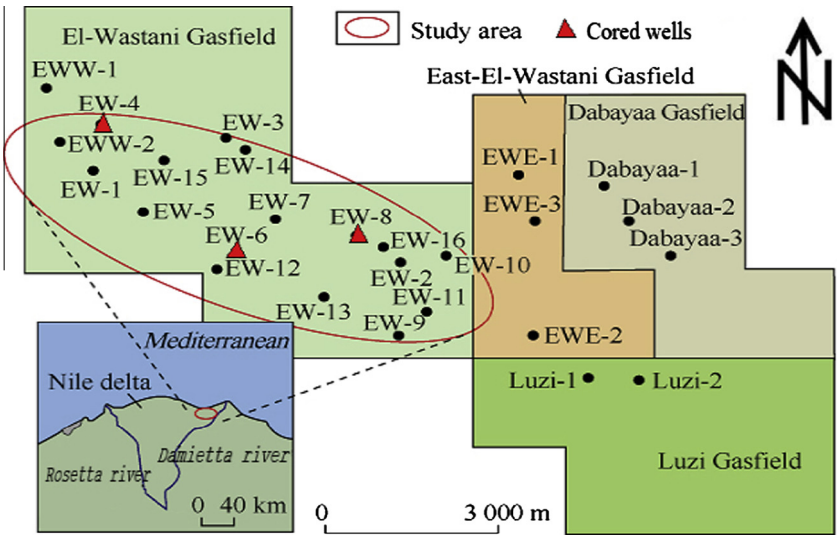

Fig. 1. Location map of the study area showing the position of the three studied wells (red triangles) in El-Wastani field at the north-eastern part of the Nile Delta, bounded to the north by the Mediterranean Sea and to the east by Damietta branch of the Nile River. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The majority of gas fields in the Nile Delta produce from the Abu Madi sandstones; the high average porosity of 21% provides excellent reservoir quality (Schlumberger, 1989).

The Late Miocene age is suggested by the occurrence of *Sphaeroidinellopsis disjuncta* in the top of the Abu Madi Formation (Ismail et al., 2010). Ward (1996) classified the Abu Madi Formation into three types (I, II, III), according to its petrology. All have inter-granular pore shapes but type III rocks are the best reservoir rocks and have enhanced porosity as a result of feldspar dissolution, very limited cement, good sorting and medium to coarse grain size.

The assessment of the hydrocarbon production potential of the Late Miocene (Abu Madi and Qawasim) clastic reservoir rocks in ten wells in the El-Wastani gas field (Fig. 1) used Neutron/Gamma-ray, Neutron/Density, and lithology-saturation cross plots to determine reservoir lithology based on wireline log characteristics (El-Din et al., 2013). El-Din et al. (2013) showed that the main lithology of the Lower Abu Madi unit is clean sandstone with occasional shale intercalations in EW-4, EW-5, EW-6, EW-12, EW-13 and EW-15 wells, with the shale content increasing in this unit in EW-7, EW-8, EW-9 and EW-10 wells. The net pay thickness of Lower Abu Madi reservoir ranges from a minimum value of three meters at EW-10 well in the eastern part of the study area, to a maximum thickness of 33 m in the central and southeastern parts of the study area. The net pay maximum defines a narrow northwesterly/southeasterly trend that bisects the study area. Consequently, the best sites for drilling new productive wells should be along this trend. The hydrocarbon pore volume map of Lower Abu Madi reservoir which represents the hydrocarbon-saturated fraction of the bulk pore volume conforms to the same trend. Generally, the combined trends of high effective porosity, high net pay thickness, low water saturation and low shale volume result in a prospective region for gas accumulation trending northwest-southeast of the study area, especially in the central part of region.

The objectives of this study are: (1) to identify genetically related lithofacies in three (EW-4, EW-6 and EW-8) wells and their respective facies associations, (2) to elucidate the internal composition of each lithofacies through a detailed petrographical analysis using thin sections and scanning electron microscope (SEM), and (3) to compare the different lithofacies associations to the results of petrophysical analyses, in order to estimate the reservoir quality of each lithofacies. The goal of this manuscript is to reduce delineation and development drilling risk through better prediction of reservoir quality of the Lower Abu Madi clastic rocks in the El-Wastani gas field.

The core analyses presented in this study support and expand on that earlier work. They offer direct evidence of the presence, distribution and deliverability of hydrocarbons and reveal variations in reservoir characteristics that are not detected through downhole logging measurements alone. Through core lithological descriptions (using standard petrographic and SEM methods) and analyses of different petrophysical parameters (i.e.: porosity, permeability, grain density, formation resistivity, water saturation, resistivity index, tortuosity, and hydraulic flow unit parameters) from core samples, we are able to fully characterize the component lithofacies.

2. Data and methodology

2.1. Lithologic and petrographic analyses

In this study, an existing sedimentological core description was used after WASCO reports, 2005. These samples have been subjected to numerous laboratory measurements at *Corex Services Limited*, located in Egypt.

The cored intervals of the Lower Abu Madi unit in EL WASTANI – 4 (EW-4) well (from 2755.00 m to 2790.80 m) and in EL WASTANI – 6 (EW-6) well (from 2746.00 m to 2788.00 m) comprise dominantly vertically stacked sequences of pebbly sandstones, argillaceous cross-laminated finer-grained sandstones and burrowed and horizontally-laminated sandy mudstones. The cored interval of the Lower Abu Madi unit in EL WASTANI – 8 (EW-8) well (from 2738.00 m to 2753.50 m) comprises an intercalation of: (a) thin beds (<2 m) of fine to very fine, argillaceous, low-angle tabular cross-stratified to massive, well-sorted, moderately-cemented grey sandstone, and (b) horizontally-laminated sandy mudstones and/or siltstones. Based on the vertical distribution and association, the identified facies are grouped into four major facies groups (F1, F2, F3 and F4). The sandy mudstone and argillaceous fine to very fine sandstone facies (F1 and F2, respectively) commonly occur between the coarser sandy facies occupying the upper part of fining-up cycles.