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Revision of the Jurassic and Cretaceous Oil-Bearing Formations in Lebanon*

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Abstract

Nader (2000) discussed the entire carbonate and marly sequences in the Nahr Ibrahim section, Northern Central Lebanon, and the following descriptions are based on his work. Other works were cited for the descriptions of the Bhanness, Salima and Chouf formations. The present work will briefly outline the hydrocarbon potential of the Mesozoic deposits in Lebanon as well as proposing a petroleum assessment for the area using up to date methods (e.g. with PetroMod – cf. Al-Ameri and Al-Musawi, 2009). In this work, the Jurassic-Cretaceous rock formations of Lebanon have been revisited with a focus on petroleum prospects (see Figure 1 for stratigraphic overview).

In Lebanon, broadly speaking petroleum exploration has begun in the late 1940s (ex. Renouard, 1955; Ukla, 1970; Beydoun, 1977, 1981; May 1991) and is currently under revision (ex. Nader, 2009, 2011 and Bowman, 2011) where several potential source rocks were defined (ex. Shaheed, 1969; Bellos 2008) and plays defined (Nader, 2011).

Review of the Mesozoic "Petroleum" Bearing Strata

Triassic to Jurassic Transition: Rhaetian to Hettangian (209.6-201.9 Ma)

The Kesrouane Formation (Figure 1) – Lower-Middle Jurassic – is subdivided into two members, the Chouane and the Nahr Ibrahim members. The Chouane Member, comprising of medium to coarse sized gray-pinkish dolostones, forms the base of the exposed Kesrouane Formation (Fm) near Nahr Ibrahim (Walley, 1997). This unit is chemically altered by high MgO content and very low concentrations of Ca and Na which is caused by its shallow-intermediate burial conditions. The Nahr Ibrahim Member, comprising massive micritic limestone strata, composes the upper part of the Kesrouane Fm. It shows high concentrations of Ca, Na, Sc, U, and Th. The original depositional environment of the Kesrouane Fm is believed to be quiet, low energy infra-tidal inner to middle shelf (Walley, 1997). The unit is characterized as a very productive aquifer/reservoir with high porosity and permeability (Nader, 2000; Hamzeh, 2000).

Late Middle Jurassic: Callovian to Oxfordian (164.9-154.1 Ma)

Overlying the Kesrouane Fm is the Bhanness Fm (Figure 1) comprising reddish to brownish volcanics including tuffs, pillow basalts, sills, dikes and columnar lavas characterized on outcrop scale by spheroidal weathering (cf. Walley, 1997). Marly intercalations baked cephalopods and gastropods are common, as well as limestone xenoliths. The top of the formation includes oxidized volcanic clasts rimmed by sparry calcite, suggesting that cementation occurred after the oxidation of the volcanics in a near-surface environment (Noujaim-Clark and Boudagher-Fadel, 2002). The Bhanness Fm is believed to have been deposited in a high-energy shallow-marine setting prevailing in the vicinity of a subaerial oxidizing environment. This unit, having low porosity/permeability, mostly acts as an aquiclude/seal (Hamzeh, 2000).

Late Jurassic: Kimmeridgian to Tithonian (154.1-144 Ma)

The Bikfaya Fm (Figure 1), like the Kesrouane Fm, is composed of fossiliferous biomicrite and biosparrudite (pelsparrudite) pale gray reefal limestones, with some dolomitic beds – was dated to the Kimmeridgian-Tithonian (Walley, 1997). The Bikfaya Fm was subdivided into biomicrite and biosparrudite reflecting infra-tidal to subtidal depositional environments (Walley, 1997; Nader., 2000). The upper part of the Bikfaya Fm includes local horizons of paleokarsts showing that it was affected by different subaerial exposures (e.g. Noujaim-Clark and Boudagher-Fadel, 2001). It was reported that those strata were deposited in a shallow open sea environment, coinciding with a relative sea level rise, since the deposition of the Bhanness Fm (e.g. Walley, 1997; Ferry et al., 2007). Due to the presence of karstic topography, this unit acts as a productive aquifer/reservoir (Hamzeh, 2000).

Uppermost Jurassic to Lowermost Cretaceous: Tithonian-Berriasian to Valanginian (144-132 Ma)

The Salima Fm (Tithonian-Berriasian) is preserved locally under half-grabens and comprises two main units, a shallow-water limestone component and a calcarenite (e.g. arenaceous carbonates) series of beds with diachronous boundaries, ranging from the uppermost Jurassic to the Lowermost Cretaceous (Walley, 1997; Ferry et al., 2007). The arenaceous carbonates apparently point to deep water clastics (Ghattas, 1975). The formation is mainly composed of a series of ochre brown to yellow ferruginous oölitic limestones, interbedded with yellowish brown marl, clays and sand (e.g. Ghattas, 1975; Walley, 1997; Nader, 2000). Lithologies are similar to the overlying Chouf Fm but contain the ammonite Berriasella richteri and the Balanocidaris glandifera (Walley, 1997). This unit was deposited in agitated shallow marine depositional environments, indicating a regression following the deposition of the Bikfaya Fm (e.g. Toland, 2000; Noujaim-Clark and Boudagher-Fadel, 2001). This unit, acting as an aquiclude/seal, is similar to the Sulay Fm of Arabia (e.g. Al-Ameri and Al-Musawi, 2009). We expect these formations to show similar results on PetroMod (Bellos, in Preparation).

Early Cretaceous: Wealden-Barremian to Lower Aptian (132-121 Ma)

The Chouf Fm is dated to the Hauterivian-Wealden age (e.g. Bellos, 2008, 2010, in Press, Preparation). It is mostly composed of arenites – cemented with iron oxide, calcite, and/or clays – representing immature-submature fluvio-deltaic sands, with an overall clay content of around 7%, deposited in a continental setting. The Chouf Fm has abundant lignites, which contain plant (type-III) kerogens (e.g. Bellos, 2008, 2010). The Chouf Fm acts as a semi-aquifer, with poor reservoir quantities (except in the arenite beds that show high porosity and permeability), that stores but does not transmit fluid in economical quantities (Tabet, 1978; Hamzeh, 2000; Bellos, 2008, 2010, in Preparation).The Lower-Aptian Abeih Fm (Figure 1) is a transitional from the continental Chouf Fm to the shallow marine Mdairej Fm. It is characterized by ochre fossiliferous, argillaceous marly limestone (cross-bedded sandy limestones, coquina and clays) that are known for their preserved mollusks. Oölitic and biomicritic limestone rocks (containing foraminifera and algae) characterize this formation. The algae (Charophytes) are indicative of near-shore and protected lagoonal environments, and are consistent with the mud matrix, a characteristic of low energy marine settings (e.g. Tixier 1971, 1972). It shows relatively high concentrations of Ca, Sc, U, and Th that is interpreted to represent tidal protected lagoonal to shallow storm dominated shelf depositional environments (e.g. supratidal and deltaic environments). Due to the composite nature of this unit, it mostly acts as an aquiclude (Hamzeh, 2000). Mroueh (1960) and Smirnova and Mroueh (1980) provide information about this unit, which will be re-evaluated (Bellos, 2010, in Preparation).

Late Early Cretaceous: Mid to Upper-Aptian to Albian (121-98.9 Ma)

The Mdairej Fm corresponds to the uppermost part of the Lower Aptian and is made up of light-gray fossiliferous limestone. The unit is rich in macrofossils, especially rudist and stromatoporoid reefs. Petrographically, these rocks are classified as coarse-sized biopelmictite and algal biosparrudite – enriched in Ca, Sc, U, Th, Fe, Mn, and Nb and show low REE contents – deposited in subtidal shallow-marine (with phases of current activity) depositional environments (Nader, 2000). The Mdairej Fm acts as an aquifer/reservoir, due to their high secondary porosity and permeability induced by evolved karstification (Nader, 2000; Hamzeh, 2000). Hydrocarbon potential will therefore be determined.

The Hammana Fm (subdivided into three units based on lithology, Figure 1) comprise the Dahr Baidar subgroup (Upper Aptian, actually Dahr Baidar Fm) consisting mainly of marls and biomicrites, rich in foraminifera, typical of protected lagoonal or platform environments (Walley, 1997; Ferry et al., 2007). The marls are chemically characterized by high contents of Al, Fe, K, Ti, Zr, Tb, Nb, Ga, U, Th, and REE (Nader, 2000). It is believed that they represent terrigenous deposits in protected (lagoonal-marine) environments (Walley, 1997; Nader, 2000). The Albian marls and dolomitic limestone of the Kneisseh Member (Vraconian, cf. Amédro, 2002) show mostly medium-sized skeletal micritic dolostones. The marls contain relatively high concentrations of AL, Fe, K, Rb, Ga, and REE, whereas the limestone shows enrichment in Sc, Ca, Mg, Al, Si, and K (Nader, 2000). The Hammana Fm was deposited in a hypersaline supra-tidal near-shore depositional environment, followed by a shallow burial, as evidenced in the third subgroup comprising dolostones (e.g. Doummar, 2005) that were reported to contain fossils (such as bivalves, gastropods and plant debris). This unit mostly acts as an aquiclude/seal, even though organic matter and natural hydrocarbon seeps found in the Cretaceous strata in Lebanon may have originated from these Albian strata (e.g. Doummar, 2005; and others).

Early Late Cretaceous: Cenomanian to Turonian (98.9-89 Ma)

The Sannine Fm (Upper Albian to Cenomanian) is composed of biomicrite, micritic limestone and dolostone, with dolomitic and silific diagenetic overprints. The dolostones are chemically characterized by high concentrations of Ca, Mg, and Sr, and low concentrations of Ti, Pb, U, Th, Nb, and REE (Nader, 2000). The units indicate changes of depositional environments from a reefal lagoonal inland facies to a more deep-sea coastal facies (e.g. Walley, 1997; Nader et al., 2006). Dolomitized strata reflect shallow burial. These highly karstic limestones act as very productive aquifers/reservoirs.

The Maameltain Fm (Turonian) comprises yellowish-white chalky limestone with chert nodules and bands; preserved ammonites, such as Thomasites rollandi at its base, bivalves, such as Hippuritella resectus at the top have been reported. Very fine-sized biomicrite, microsparry micrite and pelmicrite with chert inclusions characterize the Maameltain rocks, and have been subjected to silification during burial and diagenesis and exhibit relatively high contents of Fe, K, Zn, Ga and REE. A change from deep-sea to shallow-water eposition environments has been reported; the preferred depositional environment is shallow-marine and infra-tidal (Noujaim, 1977; Nader, 2000).

Late Cretaceous to Early Paleocene: Senonian to Danian (89-60.9 Ma)

The Chekka Fm caps the Cretaceous units, and extends to the Eocene (i.e. Yppresian; e.g. Dubertret, 1961, 1975; Hawi, 2000; and others). It comprises chalky limestones and marls that are very fine-sized biomicrite (chalk) also characterized by relatively high contents of P, Sr, Zn, Y, Pb, and REE with low contents of U, Zr, and Nb. It has been deposited in infra-tidal environments (deep sea, outer part of the continental shelf), thus favouring the phosphate deposits (Nader, 2000). This unit acts as an aquiclude/seal – even though asphaltites have been reported (e.g. Shaheed, 1969) – that provides an impervious base for the overlying Miocene aquifers/reservoirs. This formation will also be discussed independently at an upcoming meeting as part of the Cenozoic system in Lebanon (Bellos, in Preparation), and independently as part of another research program (Bellos in Preparation).

Current Petroleum Prospects in Lebanon

Nader (2009, 2011), Bowman (2011) presents various formations in the Levant. Whereas, Powell & Moh'd (2011) discusses related formations in Jordan.

Local reef platform structures of Miocene age - sandstone and turbidites (Cretaceous and Cenozoic) offshore northern Lebanon - especially within the southern Levant Basin, may also provide attractive reservoirs with high permeability and porosity (e.g. Nader, 2009; Bellos, in Preparation).

Recently, important discoveries of natural gas were reported from offshore Israel (Tamar and Dalit wells), and other hydrocarbons from offshore Lebanon (e.g. Nader, 2009, 2011). The present understanding of the petroleum systems in Lebanon proposes two major plays (cf. Nader, 2009):

(1) Onshore plays: The Qartaba structure (or similar anticlinal structures) - associated with the Syrian Arc Deformation, where Triassic (or pre-Jurassic) prospects that are of major interest; and

(2) Offshore plays: In northern Lebanon where various Cretaceous and Neogene formations may be charged by the Upper Cretaceous source rocks and sealed with volcanics, marl/clay, and evaporites.

Hence, most of the later Cretaceous hydrocarbon in Lebanon and the Levant comes from earlier Triassic, Jurassic or even Cretaceous (i.e. deeper) sources (cf. Nader, 2011). This may be the cause of the later Hydrocarbon plays found (e.g. Nader, 2009, 2011 & Bowman, 2011).

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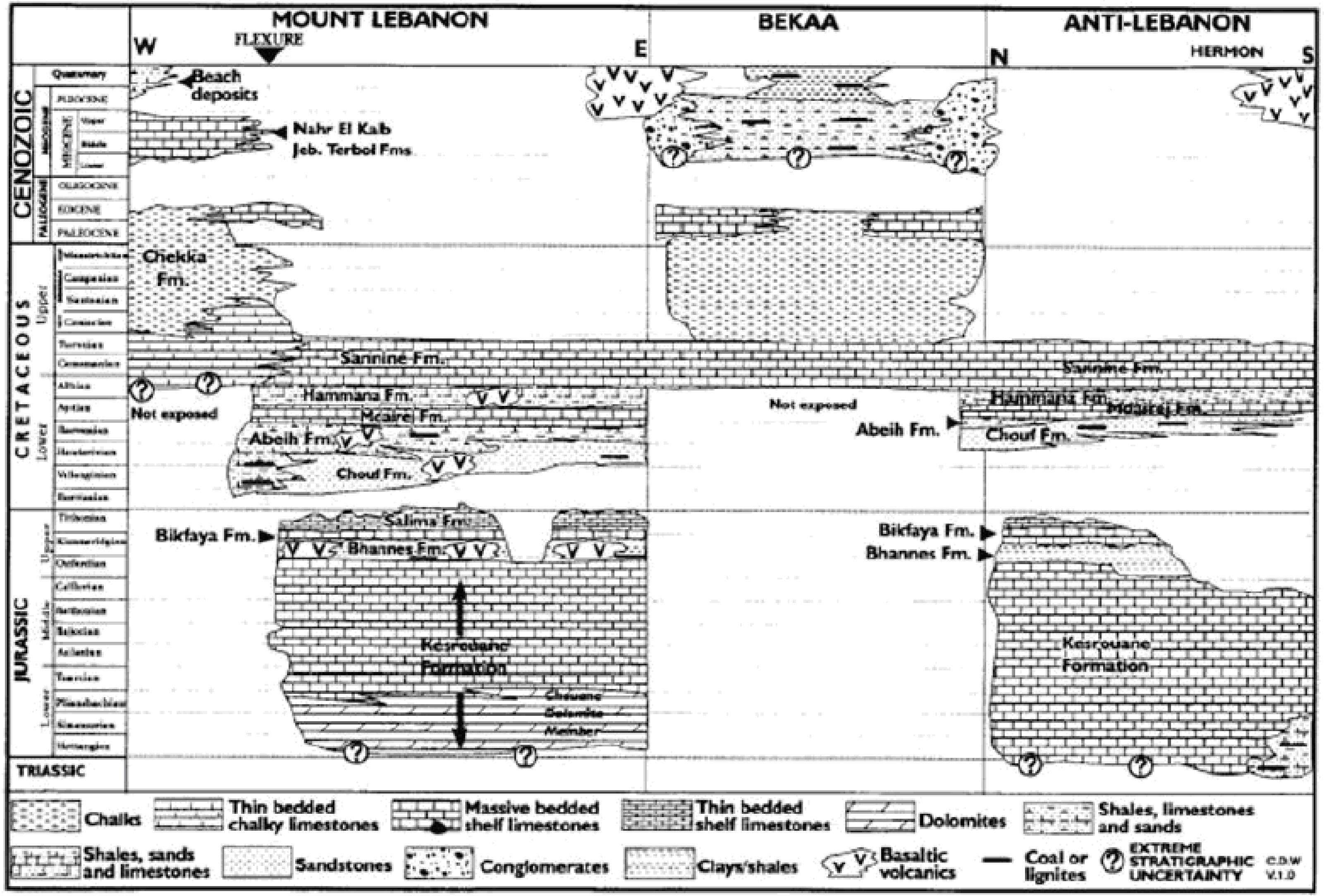

Figure 1. Detailed stratigraphic sequence of Lebanon (cf. Walley, 1997).