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Tectono-stratigraphic evolution of the northern Levant Basin (offshore Lebanon)

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A B S T R A C T

Seismic interpretation constrained by a detailed assessment of the Levant paleogeography allowed subdividing the sedimentary infill of the northern Levant Basin (offshore Lebanon) in eight major seismic packages. Fifteen seismic facies have been identified with distinctive characteristics. The Levant Basin architecture is pre-determined by a Late Paleozoic/Early Mesozoic rift that led to the formation of a passive margin. Dominant aggrading carbonate platforms are observed along the Levant margin and deepwater mixed-settings (i.e., carbonates and siliciclastics) are suggested to prevail in the basin. The collision of Afro-Arabia with Eurasia led to the development of a flexural basin in the northernmost offshore Lebanon since the Late Cretaceous. A southward migration of this flexural depocenter in the Miocene is hindered by the change in the stress field along the Latakia Ridge and by the westward escape of the Anatolian Plate in Late Miocene and Pliocene times. Interplay between major geodynamic events as well as sea level fluctuations in the Mesozoic and Cenozoic induced important marginal uplifts and emersion. Sediments sourced from the erosion of Nubian siliciclastic material and from the exposed granitic Red Sea rift shoulders and Arabian Shield, were driven into the Levant Basin. The sediment sources diversity, the mechanisms of sediment transport through varied pathways (i.e., the Levant margin canyons, the Latakia region and the Nile Delta deep-sea cone) are expected to strongly impact the reservoir characteristics and prospectivity of the northern Levant Basin.

1. Introduction

For the past decades a focus on the link between sedimentary basins' genesis and lithospheric activity led to the proposal of basin classification schemes. Two major types of basins have been described according to (1) their type of lithospheric sub-stratum, (2) position with regards to plate boundaries as well as (3) the mode of plate motion nearest to them (e.g. Buck, 1991; Allen and Allen, 2005). The first results from extension and stretching of the lithosphere (i.e., rift-drift suite) while the second is induced by lithospheric loading/unloading and flexural deformation (e.g. foreland basins). Following plate kinematics successive types of deformations could affect a basin's architecture and its consequent sedimentary infill (Allen and Allen, 2005), as is the case of the Levant Basin that has consecutively undergone rifting, collision, and strike-slip deformations.

The Levant Basin is located in the easternmost part of the Mediterranean region, and is delimited by (1) the Cyprus and Larnaca Thrust zone to the north, (2) the Eratosthenes Seamount to the west, (3) the Nile Delta deep-sea cone to the southwest as well as (4) the Eastern Mediterranean coast (Roberts and Peace, 2007; Homberg and Bachmann, 2010) (Fig. 1). Several exploration and production projects dating back to the 1960's shed light on prolific hydrocarbon provinces found offshore Egypt (Nile Delta) (e.g. Dolson et al., 2005). Significant hydrocarbon accumulations have recently been discovered in the southern Levant Basin in Oligo-Miocene and Pliocene canyon and deepwater turbiditic systems (e.g. Noa, Mari B, Nir, Gaza Marine, Tamar, Leviathan and Aphrodite) (Gardosh et al., 2008) (Fig. 1). In contrast, the northern Levant Basin

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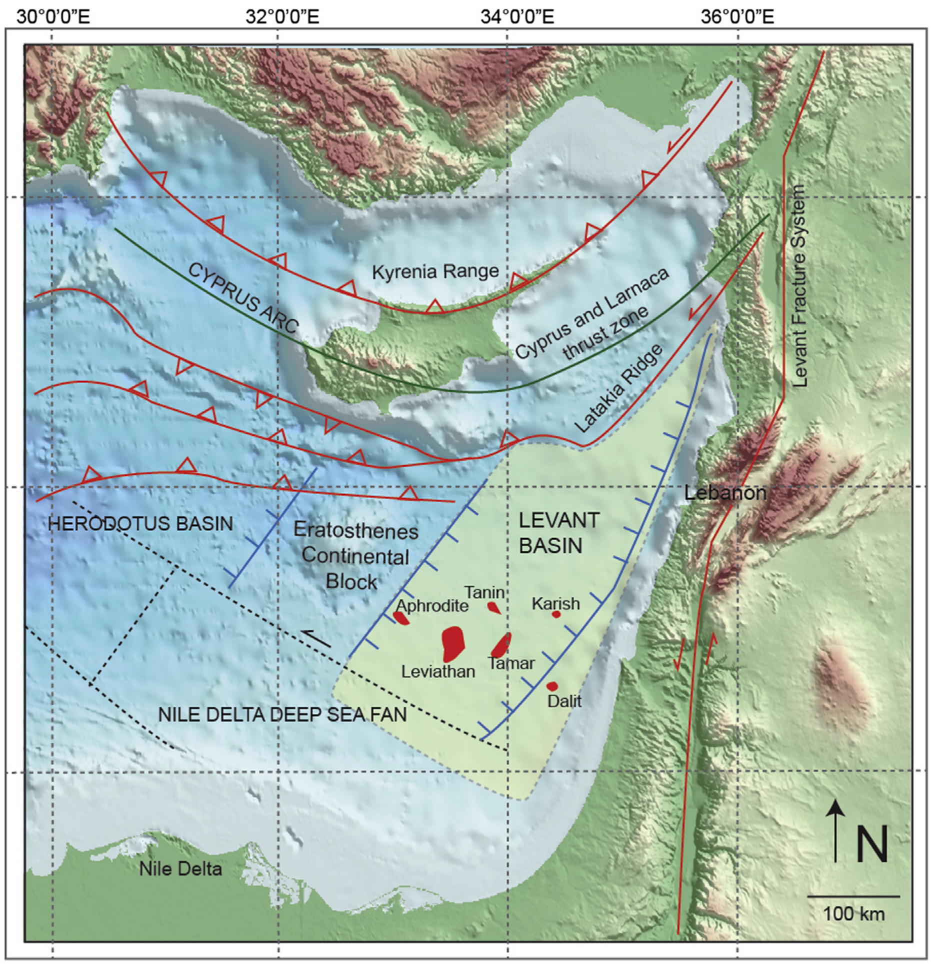

Figure 1. Location map of the study area showing the topography, bathymetry as well as the major structural elements bounding the Levant Basin. The major gas fields are colored in red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

is still considered as a frontier area given that no wells have been drilled so far offshore Lebanon and Syria (Nader and Swennen, 2004; Nader, 2011).

Recent studies provided onshore-offshore correlations for the southern Levant area (i.e., Israel) through the use of well and seismic data. A new age-constrained tectono-stratigraphic framework has been proposed revealing a thick Cenozoic unit below the Messinian evaporite cover in the Levant Basin (e.g. Beydoun and Habib, 1995; Gardosh et al., 2008, 2011; Steinberg et al., 2011). The relatively few industrial studies published for the northern Levant Basin (Lebanon) focused on depicting expected petroleum systems and plays in this frontier sector (e.g. Roberts and Peace, 2007; Lie and Trayfoot, 2009; Lie et al., 2011). Scientific investigations (e.g. Carton et al., 2009; Elias et al., 2007) using shallow coverage seismic data tackled mainly the impact of the Late Miocene and Pliocene tectonic evolution offshore Lebanon. Still, uncertainties regarding the Upper Cretaceous and Cenozoic rock unit age's subdivisions and depositional environments persist, hindering the proposal of a proper tectono-stratigraphic framework for the northern Levant margin and basin.

The aim of this paper is to investigate the architectural evolution of the northern Levant Basin offshore Lebanon, through a comprehensive analysis of regional 2D seismic profiles (Fig. 2) and partial correlations with adjacent exposed strata. The offshore depositional systems have been assessed through the application of seismic stratigraphic concepts and facies analysis (Catuneanu et al., 2009). In the light of the latest published work (Müller et al., 2010; Nader, 2011; Hawie et al., 2013), a new onshore-offshore geologic model has been proposed. It was supported by the use of well data of the coastal northern Levant margin (Lebanon: Terbol and Adloun; Beydoun, 1977, Fig. 3) as well as by publications tackling the Levant tectono-stratigraphic evolution (e.g. Brew et al., 2001; Hardenberg and Robertson, 2007; Gardosh et al., 2008; Bowman, 2011). The consequences of tectonic interactions and sea level fluctuations on the basin infill are further discussed in a paleogeographic perspective, revealing a carbonate-dominated margin and an expected mixed carbonate and siliciclastic basin. This paper also intends to highlight the diversity of sedimentary sources, pathways and reservoirs expected for the northern Levant Basin offshore Lebanon.

2. Geologic setting

Three main phases of tectonic pulses over a period of 120 Ma affected the Levant Basin with an NW–SE and NNW–SSE general extensional direction (e.g. Brew et al., 2001; Gardosh et al., 2010). The early rift phases are believed to have occurred in the Late Paleozoic/Early Mesozoic, and followed by pulses in the Middle Triassic (Sawaf et al., 2001; Gardosh et al., 2010; Yousef et al., 2010). A Triassic evaporitic sequence was intercepted by onshore wells in Syria and Israel, and reveals that a restricted depositional environment prevailed during that period along the Levant margin