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Facies and sequence stratigraphy of fluvio-lacustrine deposits: Cretaceous Nubian succession of the Saharan platform (SW Egypt)

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ABSTRACT

The Early to Late Cretaceous Nubian succession of the Mesaha trough (SW Egypt) records fluvial and mudflat/lacustrine deposition in an intracratonic sag. The facies architectures and sequence stratigraphic studies of this succession were carried out through detailed description and interpretation of seven lithostratigraphic sections. The development of depositional sequences in this succession reflects variation in the accommodation-to-sediment supply ratio (A/S). The depositional site of these sediments was located tens to hundred kilometers from contemporaneous shoreline and hence any possible base level effect is not ruled out. Three depositional sequences showing an overall upward fining-coarsening couplet are established. These depositional sequences are separated by regional ferricrete markers (subaerial unconformities). Sequence 1, 20–50 m thick, is characterized by amalgamated, multistory, fluvial channel deposits of proximal braidplain, defining degradational system tracts. These are capped by isolated channel deposits, 10 m thick, of distal braidplain of transitional/aggradational system tracts. Sequence 2, 12–25 m thick, is characterized by mudflat/lacustrine deposits of transitional system tracts passing upward to floodbasin and crevasse/terminal splays of aggradational system tracts. Sequence 3, up to 95 m thick, and it is represented by degradational system tracts and consist mainly of prograding braidplain sets of. Paleocurrent trends on fluvial deposits of the depositional sequences 1 and 3 show a unimodal paleoflow to the North to northeast and the source area was located to the south/southwest. Sedimentological evidences indicate humid climate with arid/semi-arid periods during the deposition of the studied Cretaceous Nubian succession.

1. Introduction

Fluvio-lacustrine deposits represent the focus of many studies owing to their significance for reconstructing tectonic, climatic, hydrologic, and other environmental conditions (Abdul Aziz et al., 2003; Ito et al., 2006; Maestro, 2008; Alonso-Zarza et al., 2009; Kempf et al., 2009; Meléndez et al., 2009; Alçiçek and Jiménez-Moreno, 2013; Scherer et al., 2015; Wanas et al., 2015; Selim et al., 2016; Wanas and Sallam, 2016). Also for understanding the nature of many petroleum reservoirs (Matthews et al., 2007; Sneider et al., 2012; Lopez and Righi, 2013). Although, the increasing current interest in understanding the sequence stratigraphic models for nonmarine successions (Miall, 1991, 1996; Schumm, 1993; Wright and Marriott, 1993; Shanley and Mccabe, 1994; Currie, 1997; Marriott, 1999; Posamentier and Allen, 1999; Martinsen et al., 1999; Boyd et al., 2000; Arnott et al., 2002; Catuneanu, 2006; Catuneanu et al., 2011; Kallini and Gierlowski-Kordesch, 2012; Beilinson et al., 2013; Amorosi et al., 2014; Scherer et al., 2015; Batezelli and Ladeira, 2016). There is a discussion about the terminology and systems tracts that build a fluvial depositional sequence, and also about the main controls on sedimentation of fluvial successions (base level, climate, tectonics). This supports the urgent need for studies that focus on the stratigraphic and sedimentary evolution of the fluvio-lacustrine successions. The Cretaceous fluvio-lacustrine deposits are widely distributed in north and central Africa and adjacent areas and are assigned by Kilian (1931) to "Continentale Intercalaire" and "Nubian Sandstone". They represent the most important hydrocarbon reservoirs and water aquifers in northern Africa, especially in Sudan, Libya, Algeria, and Egypt (Bishop, 1975; Canerot et al., 1986; Lefranc and Guiraud, 1990; Busson and Cornée, 1991; Wycisk, 1987, 1990, 1991; Mateer et al., 1992; Guiraud et al., 2005; Wood et al., 2014). These deposits are contemporaneous with active rifting episodes over vast areas that led to the break-up of the Western Gondwana and the opening of the South and Equatorial Atlantic (Fairhead 1988; Guiraud and Maurin, 1992; Guiraud et al., 2005). Subsequent Cretaceous fluvio-lacustrine sedimentation was not restricted to

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intracratonic rifts that developed along the edges of the Arabo-Nubian block e.g. Muglad, Melut, Sirte, and Komombo (Schull, 1988; Guiraud and Maurin, 1991; Guiraud et al., 2005; Selim, 2016) but also occurred in the area with little evidence of distinct basin isolation (Wood et al., 2014). In general, sedimentary infills of these basins have been interpreted to be characterized by fluvio-lacustrine successions (Mchargue et al., 1992; Guiraud and Bosworth, 1999). The Cretaceous Nubian succession in SW Egypt has been studied by several researchers (e.g., Klitzsch, 1986, 1990; Klitzsch and Wycisk, 1987; Hendriks et al., 1987, 1990; Klitzsch and Squyres, 1990; Wycisk, 1987, 1990, 1991, 1994; Wycisk et al., 1990).

The main purpose of this research is to provide a well-constrained application of sequence stratigraphic concepts in fluvio-lacustrine successions, taking the Cretaceous succession of the Mesaha trough in the Saharan platform in SW Egypt as a case study. Hence, the objectives of the present research are: (1) to provide a detailed sedimentary lithofacies analysis and paleocurrent patterns, (2) to build a sequence stratigraphic framework through the correlation of key stratigraphic surfaces, systems tracts, and depositional sequences, and (3) to understand the stratigraphic evolution and main factors controlling sedimentation of the studied fluvio-lacustrine Cretaceous succession.

2. Geological setting and lithostratigraphy

Throughout the Early to Late Cretaceous, the North African Saharan platform was dominated by clastic deposition (Bishop, 1975; Canerot et al., 1986; Busson and Cornée, 1991; Wycisk, 1991; Mateer et al., 1992; Guiraud et al., 2005; Wood et al., 2014; Selim, 2016). Siliciclastic sediments were deposited widely across the Saharan Platform with little evidence of distinct basin isolation except in the case of the rift systems (e.g., Tenere, Sirte, Muglad, Komombo, Nuqura) that developed along the edges of the Nubian tectonic plate (Guiraud et al., 2005; Selim, 2016). The Mesaha trough is a frontier basin that covers about 5000 km^2 and is located in the East Oweinat area near the border between Egypt and Sudan (latitudes 22° 00′N and 23° 50′N and longitudes 26° 30′E and 28° 10′E, Figs. 1 B and 2). The Mesaha trough experienced rifting since the Early Paleozoic with the development of N-S to NNE-SSW grabens that are confirmed by seismic, magnetic, and drilling data (Klitzsch and Squyres, 1990). This associated with transgression and deposition of Silurian-Carboniferous fluvio-deltaic deposits. By the end of the Paleozoic, the eastern part of African Plate (Egypt and Libya) became an active E-W structural high which was subjected to extensive erosion until the Late Jurassic (Klitzsch and Squyres, 1990). The Carboniferous-Lower Jurassic has been deposited in a shallow basin extending from southern Egypt to northern Sudan and bordering areas of Chad and Libya (Klitzsch and Squyres, 1990). At the Jurassic-Cretaceous time, the Pangea break-up became associated with general sagging followed by deposition of Nubian Sandstone (Klitzsch and Squyres, 1990).

The Nubian Sandstone (Early-Late Cretaceous) in the Mesaha trough is overlain by the Late Cenomanian Maghrabi Formation at the top and rest unconformably above the Paleozoic/basement. The Nubian Sandstone has been subdivided into three formations (Fig. 3): a lower (regressive) Six Hills, a middle (transgressive) Abu Ballas, and an upper (regressive) Sabaya Formation (Wycisk, 1991; Van Houten et al.,1984). All these three formations are siliciclastic-dominated. The Six Hills Formation (the Basal Clastics of Klitzsch, 1978 and Klitzsch et al., 1979) is composed of, 30–60 m thick, fluvial sandstone successions which are conglomeratic in part, comprising fining-upward cycles with some paleosol horizons (Wycisk, 1991). The Six Hills Formation was assigned to be of a Late Jurassic-Early Cretaceous age (Klitzsch et al., 1979; Klitzsch and Squyres, 1990) based on different species of ferns, such as *Cladophlebis oblanga, C. aff. patagonica, Phlebopteris muensteri,* and *Weichselia reticulate.* Wycisk (1994) proposed a Barremian age for this formation based on the plant remains recognized in the coeval stratigraphy of NW Sudan. It is laterally almost correlated with Gilf Kiber Formation at Gilf El Kiber Plateau (Wycisk, 1990). Additionally, palynological investigations by Schrank (1987) from the E1 Masara Well support this age (i.e., Barremian). The overlying Abu Ballas Formation (Barthel and Böttcher, 1978) is composed of varicolored mudstone and sandstone. It represents a distinctive marker bed with an average thickness of about 30 m. It unconformably overlies and underlies Six Hills and Sabaya formations, respectively (Wycisk, 1994). The Sabaya Formation (Barthel and Böttcher, 1978) is composed of fluvial deposits of a channel-dominated alluvial plain. Mottled, truncated paleosols are repeated all over the Formation (Wycisk, 1991). It is previously named as Desert Rose (Klitzsch, 1978) and Desert Rose unit (Klitzsch et al., 1979). It unconformably overlies the Abu Ballas Formation. The studied Cretaceous fluvio-lacustrine succession in the Mesaha trough are age-equivalent to the Alam El Bueib, Alamain, Dahab, and Burg Al Arab formations over 1000 km to the north in the Abu Gharadig and Alamian basins of the north Western Desert (Wycisk, 1994). The deposits in this distal location (north western Desert) are dominated by deltaic and shallow marine deposits, while that of the proximal location (south Western Desert) are dominated by fluvio-lacustrine deposits.

3. Methodology and data sets

The data sets used for the present study were primarily collected through detailed field description and interpretation of seven composite stratigraphic sections throughout the area of study (Fig. 2). Detailed sedimentary successions were described to define the sedimentary lithofacies and facies associations of the Lower to Upper Cretaceous fluvio-lacustrine succession in the Mesaha trough, SW Egypt. Sedimentary lithofacies were described based on grain-size, lithology, sedimentary structures, color, and bounding surfaces, following Miall's schemes (1978 and 2006). The sedimentary lithofacies were grouped into facies associations, which represent genetically-related sedimentary packages that reflect the dominant depositional systems (Collinson, 1996 and Dalrymple, 2010). Paleocurrent data were obtained to reconstruct sediment provenance, paleoflow pathways, and paleogeography. Paleocurrent directions were measured mainly from the planar and trough cross-stratification. Stratigraphic key surfaces, systems tracts, and depositional sequences were identified and correlated between the studied sedimentary sections. Fifteen hand-specimen samples were collected for palynological analysis, although returned negative results.

4. Results

4.1. Sedimentary lithofacies

Ten sedimentary lithofacies types are recorded within the fluvio-lacustrine Cretaceous succession of the Mesaha trough, south-western Egypt. The description and interpretation of these lithofacies are outlined in Table 1 and illustrated in Fig. 4. These sedimentary lithofacies are grouped into five sedimentary facies associations (FA 1–5). Such associations are (Fig. 5): (1) proximal braidplain; (2) distal braidplain; (3) terminal/crevasse splay, (4) floodbasin/floodplain; and (5) mudflat/lacustrine.

4.1.1. Proximal braidplain (FA 1)

4.1.1.1. Description. This facies association is mainly composed of medium to coarse-grained and pebbly sandstones with stratified to massive and cross-stratified conglomerate (Gs, Gp). It attains a

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