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Late Triassic-early Jurassic Neotethyan evolution at Northern Gondwana (Jordan and Libya, Mediterranean region)

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ABSTRACT

The Early Mesozoic record of northern Gondwana was strongly influenced by sea level fluctuations during the opening of the Neotethys Sea. Detailed facies analysis of the Late Triassic / Early Jurassic Abu Shaybah Fm (Libya, western Mediterranean), and the Triassic Mukheiris Fm (Jordan, eastern Mediterranean) documents the transgressions and regressions that took place during the Neotethys opening. Both formations present similar facies and depositional environments, and are made up mainly by continental siliciclastic sequences and minor carbonate deposits. The facies arrangement in both zones indicates deposition in a tide-dominated environment as a part of a transgressive sequence, succeeded by a high-energy sandy fluvial deposition. In both regions the braided fluvial systems drained basinwards and impinged into the Neotethys Sea located to the north. The fluvial deposition of both formations ended abruptly due to renewed Neotethyan marine floodings that resulted in the development of carbonate shelf environments.

KEYWORDS **Triassic. Early Jurassic. Transgression. Sedimentary cycles. Neotethys. Gondwana.**

INTRODUCTION

Palaeotectonic and palaeogeographic evolution of the Tethyan realm has been a major focus of research during the last decade (Beccaletto et al., 2003). The Triassic witnessed a global palaeoceanographic change and the opening of Neotethys (Holser and Magaritz, 1987; Wignall and Hallam, 1992), when the northern margins of Gondwana were affected by sea level fluctuations causing successive marine transgressions and regressions. The southern Mediterranean Gondwanan shelf that extended from Morocco (African subplate) to Oman (Arabia subplate) was likewise affected by the opening of the Mesozoic Neotethys.

The early stage of the opening of Neotethys propagated from east to west. Triassic deposits have been reported from different areas lying along the southern Tethyan strandline, at the North African and Arabian subplates, such as those in Morocco, Libya, Egypt and Jordan, all of which indicate similar palaeoenvironmental depositional settings (Desio et al., 1963; Oujidi, 2000; Hirsch, 1986; Makhlouf, 2003a).

On the base of present-day field evidence and regional geology, this paper focuses on the middle-late-Triassic and earliest Jurassic evolution of the Neotethys Sea. This was documented by a diversity of marine and terrestrial depositional environments in the Triassic Mukheiris Fm of Jordan (Arabian Peninsula) and the Triassic Abu Shaybah Fm of Libya (northwestern Africa). The comparison of the sequence facies arrangement between both localities is a preliminary attempt to understand the palaeotectonic and the palaeogeographic evolution of the Neotethyan realm (Fig. 1).

STRATIGRAPHY

The early Triassic Mukheiris Fm of Jordan includes the sediments preserved between the underlying marine Hisban Limestone Fm and the overlying Iraq el Amir Limestone Fm (Fig. 2). This 90 m thick succession was divided by Makhlouf (2003a) into two members: tidal lower member (late Anisian) and fluvial upper member (Anisian-Ladinian; Fig. 3). The dating of this unit is based on Keegan et al. (1987), and Sadeddin (1990) who have reported the occurrence of the conodont *Pseudofurnishius priscus*. Similarly, the late Triassic-early Jurassic Abu Shaybah Fm in Libya lies over the Aziziyah Fm and under the Abu Ghaylan Fm (Fig. 3). It comprises a Carnian lower tidal carbonate member that has been dated on the base of a fossil bivalve assemblage and, to a lesser extent, the occurrence of brachiopods and cephalopods (Desio et al., 1963). The age of the upper fluvial member ranges from Norian, Rhaetian to Liassic (Christie, 1955; Desio et al., 1963; Asserto and Benelli, 1971).

FACIES ASSOCIATIONS AND SEQUENCE STRATIGRAPHY

The facies associations and stacking patterns of the Triassic succession in Jordan are identical to those in Libya, apart from age which is clearly diachronous (Fig. 2). This is concomitant with the development of the Neotethyan Sea, as it approached the eastern margin of Gondwana much later.

Sequence record in Jordan

The Neotethyan shoreline approached the western shoulder of Gondwana diachronously; during the middle

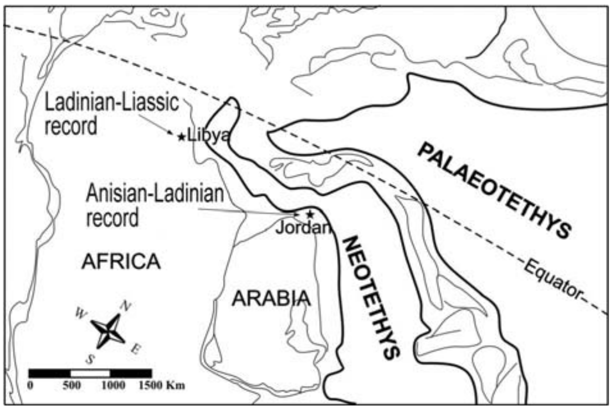

FIGURE 1 | **Permo-Triassic palaeogeographic reconstruction of the Paleotethys and Neotethys at the northern Gondwana region (modified from Stampfli and Borel, 2002a).**

Period	Epoch	Formation	
		Jordan	Libya
Jurassic		Nimr	Abu Ghaylan
			Bi'r al Ghanam
	"Lias"	Hihi	Abu Shaybah
Triassic	Rhaetian		
	Norian		
	Carnian	Abu Ruweis	
	Ladinian	Umm Tina	Azizyah
		Iraq Al Amir	Ras Hamia
		Mukheiris	
	Anisian	Hisban	
		Ain Musa	
	Scythian	Dardur	
		Ma'in	
Permian		Umm Irna	

FIGURE 2 | **Comparison between the Triassic–early Jurassic stratigraphic records in the northern Gondwana region. The proposed correlation of the lithostratigraphic units in Jordan and Libya is shown. See Figs. 3 and 4 for further detail.**

Triassic times (Anisian). Jordan was flooded by the Neotethyan Sea and, as a result of this gradual transgression, highstand (HST) conditions prevailed, leading to deposition of the shallow marine Hisban Limestone Fm After sea level reached a maximum rise and the development of a maximum flooding surface (MFS), sea level began to fall, and the shoreline shifted basinward. During this Falling Stage Systems Tract (FSST) intertidal environments developed in the area and the lower tidal member of the Mukheiris Fm was deposited (Figs. 3 and 4).

The lower member includes the lowermost 30 m of the formation, and consists of interbedded fine-grained sandstones, shales, marlstones and limestones. The clastic beds are rippled, wavy laminated, flaser bedded and bioturbated. Coarse-grained components (sandstones) and fine-grained components (siltstones) are rhythmically organized in thin fining-upward cycles, similar to the lateral persistent facies that are widespread in the tidal environments. Flaser bedding, wavy lamination and ripplemarks indicate shallow depths and low wave energy at the tidal setting. Therefore, this member was referred to as the lower tidal member.

Continued drop of sea level was responsible for the northward shift of the strandline, and the establishment of terrestrial lowstand conditions, when the fluvial member of the Mukheiris Fm was deposited. This fluvial unit includes the uppermost 80 m of the succession, and was deposited overlying a erosive sequence boundary (SB) produced by the fluvial conditions. These deposits are interpreted as a lowstand systems tract (LST) and are referred as the upper fluvial member.

The fluvial member consists of cream coloured, cross-bedded medium to coarse-grained sandstones, with subordinate siltstones and silty shales. The pebbly and granular channel lag dominates the basal part of each sandstone unit and consists of quartzitic granules and small pebbles. Drift wood is also found within the channel lag. Trough foreset azimuths (320º) indicate flow to the NW (Makhlouf, 2003a).

This member is dominated by fossil barren cross-bedded quartz arenite, subarkosic and greywacke sandstone, with subordinate silty intervals. The arrangement of the sediments into five fining-upward cycles, most of them starting with erosional channel lag base, and drift wood trunks, indicate that deposition occurred within a fluvial environment. The stacked channels with their channel lag association were developed by the rapid shifting of the active braid tracts, within a low sinuosity and highly mobile braided alluvial channel system (Collinson, 1986). The braided channel system changed gradually to a more sinuous, meandering pattern as indicated by the increased fine to coarse ratios in the uppermost two cycles (Makhlouf, 2003a).

Sequence record in Libya

As Neotethys opened, the sea approached the western shoulder of Gondwana (western Africa) diachronously, the land was submerged and the Aziziah Dolomitic Limestone Fm was deposited during late Ladinian. A similar pattern of events to that recorded in Libya occurred further east in Jordan during Carnian times (Fig. 2).

During the Carnian, the Neotethyan shoreline retreated gradually and tidal environment conditions prevailed during the deposition of the lower tidal member of the Abu Shaybah Fm (Makhlouf, 2003b; Desio et al., 1963). This member consists of 33m thick interbedded sandstones, silty shales, claystones and minor dolomitic beds. It overlies conformably the Aziziyah Dolomitic Limestone Fm These siliciclastic facies show internal structures such as ripple marks, wavy bedding, flaser bedding, lenticular bedding, parallel lamination and mudcracks. Most of the oscillatory ripple marks trend E-W (90º-270º) but other small scale, symmetrical N-S (00º-180º) trending ripple marks are superimposed at right angles. Bedding surfaces are intensely bioturbated and characterised by casts of marine fossils and bivalves (Makhlouf, 2003b).

These strata represent a transitional zone between marine sediments of the Aziziyah Fm below and fluvial sediments of the Abu Shaybah upper member above. This is consistent with a gradual advance of a regressive phase in the Neotethys which took place at the end of the Aziziyah deposition. Rhythmic bedding, flaser bedding, textural components and palaeocurrent patterns suggest that they were deposited within a tide-dominated depositional environment (Harms et al., 1975). Desiccation cracks in burrowed mudstones indicate subaerial exposure of the intertidal zone (Makhlouf 2003b).

The upper member of the Abu Shaybah Fm was deposited by fluvial processes and constitutes a lowstand systems tract (LST). It consists of a 63 m thick succession of pebbly sandstones, siltstones and silty-shales. The sandstones are trough cross-bedded with locally overturned foresets. Palaeocurrent measurements show a unidirectional mode trending (N300ºW) with a 70º spread (Makhlouf, 2003b). The erosively-based nonfossiliferous,

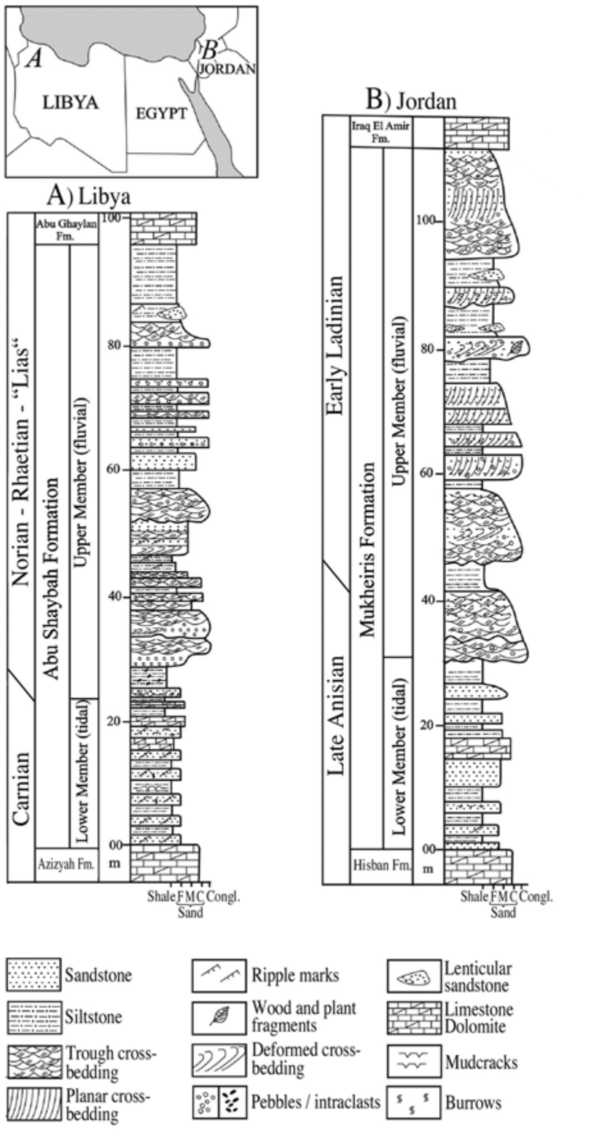

FIGURE 3 **Stratigraphic sections and comparison of the depositional records of A) Abu Shaybah Fm (Libya) and B) the Mukheiris Fm (Jordan). Modified from Makhlouf, 2003a and b.**

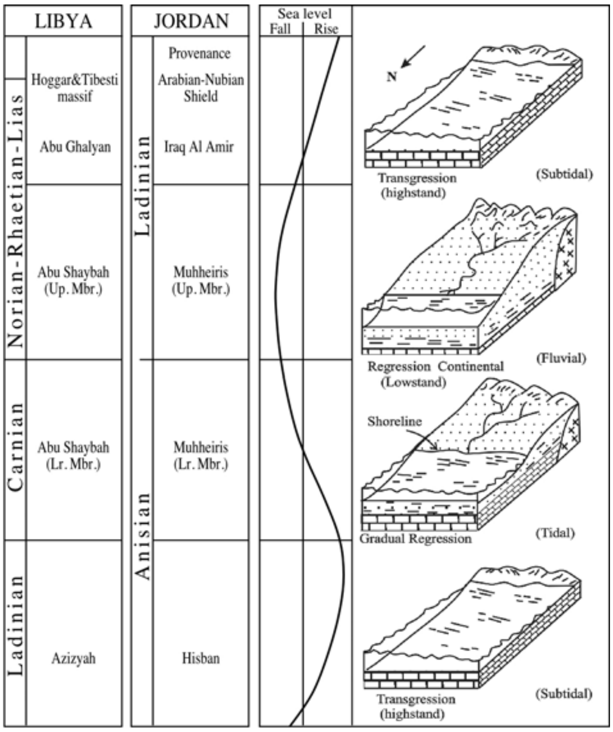

FIGURE 4 | **Schematic block diagrams showing the similar but heterochronous palaeodepositional evolution of the Mukheiris and Abu Shaybah Fms (modified from Makhlouf 2003a and b).**

fining-upward sequences, unidirectional palaeocurrents and the presence of silicified wood fragments indicate a continental depositional environment (Allen, 1965; Makhlouf, 2003b). The high proportion of siltstone and silty-shale compares closely with the meandering stream model of Allen (1970). The transgression of the Neotethyan Sea was then reestablished, and a transgressive system tract (TST) was responsible for the deposition of the shallow marine Abu Ghaylan Fm during a highstand systems tract (HST).

DISCUSSION AND CONCLUDING REMARKS

The collision of northwestern Gondwana with Laurasia during Permo-Carboniferous times resulted in the Pangaea supercontinent assembly. Subsequently, the Palaeotethys Sea was initiated and its shoreline periodically invaded the northern margins of the Gondwana in a series of transgressions and regressions during the early Triassic. According to the reconstruction of Dietz and Holden (1970) the Mediterranean Sea is a remnant of the Neotethys Sea that was a large triangular bight on the east, separating Eurasia from Africa.

The shallow late-Permian Palaeozoic Tethys became rejuvenated by the opening of a new Mesozoic Tethyan seaway (Neotethys) that was initiated in the late early Triassic (late Scythian; Stampfli et al., 1998). This is documented by the deposition of the Scythian marine deposits of the Ma'in, Dardur and Ain Musa Formations in Jordan (Bandel and Khoury, 1981; Makhlouf et al., 1990; Makhlouf, 1998; Makhlouf, 2000). Marine transgressions were periodically interrupted by fluvial episodes. The continental intervals were responsible for the deposition of the late Scythian-early Anisian Ain Musa Fm of Jordan, which consists of a fluvial unit in the middle part of the succession bounded by two marine units at the top and bottom (Makhlouf, 1998).

The subtidal Hisban Limestone Fm indicates a major transgressive phase in Jordan during the Anisian times (Bandel and Khoury, 1981). Gradual shallowing conditions continued and led to the deposition of the carbonate deposits recorded at the bottom of the Mukheiris Fm (Lower Member). The regressive phase continued, giving way to fluvial conditions and deposition of the fluvial unit (Upper Member), until the early Ladinian when a major transgression took place, and carbonates of the Iraq el Amir Fm were deposited. During the regressive phase the Neotethyan strandline prograded to the north and northeast (Figs. 3 and 4).

Further shallowing of the Tethyan realm during the early late Triassic (Carnian) was responsible for the development of evaporitic conditions in Jordan, as evidenced by the thick gypsum and anhydrite sequences of the Abu Ruweis Fm (Bandel and Khoury, 1981). This evaporitic event was possibly connected to the early opening of the proto-Atlantic ocean when the Neotethyan sea level was lowered because of the loss of large volumes of water transferred to the proto-Atlantic ocean, as a result of continuous subsequent regression.

Similar depositional events took place in Libya during the late Triassic-early Jurassic times. Sea level changes in a shallow shelf sea (Neotethys) to the north gave rise to a major regressive event initiating subtidal Aziziyah deposits, then intertidal depositional environments at the beginning of the Abu Shaybah times, when the lower tidal member was deposited (Figs. 3 and 4). This records the seaward progradation of the tidal flat environment. This process was followed by the establishment of fluvial conditions during the deposition of the upper fluvial member, in response to late Triassic/ early Jurassic episodes of relative sea level fall (Makhlouf, 2003b).

Further to the west Morocco was part of the southern Neotethyan platform domain in the northern area of the African Craton during the Triassic. The structural and biostratigraphic setting of the Oujda Mountains are consistent with the first late Ladinian/early Carnian transgression that reached the northeastern Moroccan margins from the Neotethys domain (Oujidi, 2000).

A precise timing for the initiation of the Neotethys spreading has been a long-lasting controversial issue (Langhi et al., 2003). The opening of Neotethys is regarded as the result of the strong slab-pull effect of the subducting Palaeotethys Ocean-floor plate. The Neotethys opening detached the Cimmerian terrane from Gondwana which gently collided with the Eurasian margin in late Triassic times (Rosselet et al., 2003). An agreement is now emerging about the Permo-Triassic age of the Eastern Mediterranean-Ionian sea floor, and its direct connection with Neotethys (Stampfli and Borel, 2002a, b).

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