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Deep-sea trace fossils of the Oligocene–Miocene Numidian Formation, northern Tunisia

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ABSTRACT

Twenty-two ichnogenera and thirty-one ichnospecies have been recorded in the Oligocene–Miocene Numidian Formation of northern Tunisia. Heterolithic successions of thin-bedded turbidite sandstones and interchannel mudstones contain the most diverse trace fossil assemblages. Thick- to very thick-bedded structureless sandstones and conglomerates representing the fill of channel complexes contain a low-diversity trace fossil assemblage. The ichnoassemblage in the lower part of the formation (Oligocene), which includes *Paleodictyon* isp., *Scolicia strozzii*, *Spirorhaphe* isp., ?*Cosmorhaphe* isp. and *Halopoa* isp., can be ascribed to the *Paleodictyon* ichnosubfacies of the *Nereites* ichnofacies. The ichnoassemblage in the upper part of the formation (Miocene: Aquitanian), including *Diplocraterion* cf. *habichi*, *Scolicia vertebralis* and *Ophiomorpha* isp., is interpreted as the shallower part of the *Ophiomorpha rudis* ichnosubfacies of the *Nereites* ichnofacies. The notable switch in ichnofauna between the Oligocene and lower Miocene reflects variation in environmental and depositional conditions. The common occurrence of trace fossils of the *Ophiomorpha rudis* ichnosubfacies, and *Diplocraterion* cf. *habichi* in the early Miocene, indicates an increase in energy level, greater environmental disturbance and probable shallowing. This is also confirmed by a corresponding decrease in the abundance and diversity of benthic foraminifera. The integration of ichnological, sedimentological and microfossil contents has allowed the distinction of two quite distinct geographical depositional settings within the Numidian Formation. The first domain includes the Numidian succession of the Tabarka, Cap-Negro, Cap-Serrat and Bouhertma areas, which are characterised by "distal" turbidites, showing the *Paleodictyon* ichnosubfacies that is compatible with a lower bathyal depth in the Oligocene and an upper slope depositional environment during the early Miocene.
The second domain includes the NE part of Mogod Mountain (e.g. the Ras El Korane, Jebel Gattous–Zoukar), which exhibit more proximal characteristics compatible with a probable slope canyon interpretation. The southern margin of the Kroumirie (Balta and Zouza areas) and Sejnene area shows a distal setting compared with the Ras El Korane and Jebel Gattous–Zoukar areas. It is ascribed to a mid- to upper slope depositional environment during the Oligocene to early Miocene.

1. Introduction

Analysis of ichnofacies, especially when integrated with sedimentological and palaeoecological studies, is recognised as a powerful tool in a better recognition of sedimentary environments (e.g., Buatois and Mángano, 2011). Further improvement of the current ichnofacies models includes subdivision of ichnofacies with respect to different Palaeoenvironmental parameters; e.g., the *Cruziana* ichnofacies has been subdivided into proximal, archetypal and distal parts (e.g., Pemberton et al., 2001). Similarly, the *Nereites* ichnofacies has been subdivided into the *Nereites*, *Paleodictyon* and *Ophiomorpha rudis* ichnosubfacies (e.g., Uchman, 2007c; Uchman and Wetzel, 2012). These classifications should be tested by further studies on the distribution of trace fossils in depositional environments of different ages and locations.

In this paper, we focus on trace fossils of the deep-sea, turbidite and hemipelagite sediments of the Oligocene–Miocene Numidian Formation in the northern Tunisia and their potential as tools for reconstructing depositional conditions of these deposits. Such a detailed ichnological study has not been undertaken before, although several previous studies have noted the presence of trace fossils (Gottis, 1953; Vass, 1971; Rouvier, 1977; Beaudoin et al., 1986; Yaïch, 1997). In these works the Numidian Formation depositional environment has been interpreted as shallow-water in some cases (Gottis, 1953, 1954a,b) but deep-water by others (Wezel, 1968; Parize and Beaudoin, 1988; El Maherssi, 1992; Yaïch, 1997). Recently, Belayouni et al. (2012) stated that the Numidian

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Formation of the southern margin of the Kroumirie Mountain can be considered as the shallowest deposits within the deep sea.

In addition, we have paid special attention to the relationship between the distribution of trace fossils and architectural elements (e.g. sheet sands, channel-fill, and channel-lobe transition) as determined by a separate sedimentological study (Riahi, 2011). Detailed age determination is on the basis of planktonic foraminiferal studies (Riahi, 2004, 2011; Riahi et al., 2010). Careful analysis is also made of foraminiferal ratios, benthic/planktonic (B/P) and deep-water agglutinated foraminifera/calcareous foraminifera (DWAF/C). This work has broader implications: (1) as the basis for interpretation of the Numidian Formation elsewhere in the western Mediterranean area (e.g., Algeria, Morocco, Italy and Spain); and (2) as a case study that informs our understanding of slope-system, turbidite ichnology in general.

2. Geological background

The Numidian Formation of northern Tunisia is mainly latest Oligocene to early Miocene in age and contains a series of deep-marine turbiditic sandstones and mudstones. It is closely linked with the much more extensive Numidian succession that outcrops discontinuously along the southern Mediterranean coast from the Gibraltar Arc in the west to Sicily and southern Italy in the east. This orogenic belt is approximately 2500 km long and up to 100 km wide (Fig. 1A). It represents an extensive mud-rich, slope-apron system characterised by a mature to ultramature, quartz-rich petrofacies (Johansson et al., 1998; Stow et al., 2009; Fildes et al., 2010; Riahi, 2011). The uses of the term "flysch" for this Formation has been widely discussed in the literature; Patacca et al. (1992) and Guerrera et al. (1993, 2012) considered it to be ambiguous and therefore proposed abandonment of the term. Furthermore the vast regional extent of this formation (~2500 km) has led some authors to promote it as a 'facies' rather than a single formation (Magné and Raymond, 1972; Giunta, 1985; Moretti et al., 1991). Whereas much of the past literature and recent papers still refers to "Numidian Flysch", we prefer to use the term 'Numidian Formation'.

The Numidian Formation and its correlative deposits (e.g. Oligocene–Miocene of Kabyle and La Galite Flysch) were formed in a compressional tectonic setting during the Alpine tectogenesis (Durand Delga, 1980; Guerrera et al., 2005; Frizon de Lamotte et al., 2006), which produced a foreland basin in the late Eocene, to Miocene (Fig. 1B). The basin was bounded on the north by an active margin composed of a southward-verging accretionary prism underlain by the European crustal blocks, while to the south it is bounded by the African margin represented by the passive margin of the Maghrebian Flysch Basin (Fig. 1B).

By the Oligocene to early Burdigalian, a significant change in facies was caused by a diversification of the tectonic regime in response to Mediterranean deformation events. This change is signalled by the relatively abrupt termination of carbonate sedimentation, and the equally sudden influx of quartz-rich clastic sediments throughout the Numidian basins offshore as well as the correlative continental deposits onshore in Northern Africa. During this period the geodynamic history of the region is dominated by: (1) Kabylides migration towards the south and the counterclockwise rifting of Corsica and Sardinia from Europe, and the opening to their north of the Algerian back-arc basin (Frizon de Lamotte et al., 2009); and (2) formation of the foreland basin accommodated by various early Oligocene to mid-Miocene flysch (Oligocene–Miocene of Kabyle, La Galite Flysch and the Numidian Formation) dominated by turbidites. This also shows a progressive migration southeastward.

The sedimentation of the Numidian Formation ceased by the end of the Burdigalian (16–15 Ma) except for the Numidian succession of Sicily and the Apennines, which are thought to extend into the Langhian (Guerrera et al., 2005; Thomas et al., 2010). At about 15 Ma (Langhian), the docking of the Kabylides against the continental African margin achieved the flexural stage (Frizon de Lamotte et al., 2006). This accretion of a continental terrane along the margin was accompanied by the propagation of thrust faults within the African domain forming the external Tell system with general uplift of the coastal range, which started during the late Miocene (post-11 Ma) and is interpreted by Benaouali-Mebarek et al. (2006) and Frizon de Lamotte et al. (2009) as the result of a rebound following detachment of the subducting slab. Evidence for this process is given by the type of the post-collisional magmatic activity and by seismic tomography imaging (Frizon de Lamotte et al., 2000). Since the beginning of the Pleistocene, the whole orogenic domain has been affected by diffuse compressive activity, mainly concentrated in the coastal areas, both onshore and offshore.

3. Study area and outcrops

The Numidian succession of northern Tunisia represents a complex allochthonous unit (Rouvier, 1977; El Euchi et al., 2004; Riahi et al., 2010) occupying the highest structural position in Kroumirie and Mogod mountains (Fig. 1C) and consists of approximately 2000–2500 m of alternating sandstones, quartz pebble conglomerates and mudstones of turbiditic affinity. Nappes of the Numidian Formation are stacked above the deformed upper Cretaceous limestones, Palaeocene marls and Ypresian limestones of the Boudabbous Formation. The Numidian Formation overlies the Oligocene–Miocene Bejaoua Group (e.g. Nefza Window, Ain Jantoura) and is intruded by Triassic salt diapiric structures (e.g. in the Jebel Zouza and Jebel Ouled El Mejri in the Sejnene area) and, in some cases, by felsic plugs and mafic dikes, sills and basaltic flows (e.g. in Galeb Saad Moun in the Sejnene area) of late Miocene and Pliocene age (Laridhi Ouazzaa, 1994; Jallouli et al., 2003; Talbi et al., 2008).

On la Galite Island (60 km north of Cap-Serrat), the Numidian Formation crops out along with contemporaneous deposits of the La Galite Flysch, which is dated as early Miocene in age (Yaich, 1992; Rekhiss, 2007; Belayouni et al., 2010). These deposits are formed by immature, micaceous turbidites that may be interbedded with mature, to ultramature quartz-rich Numidian Formation sandstones.

For this study we have investigated a series of coastal outcrops, at Tabarka, Cap-Serrat and Ras El Korane, and inland sections at Bouhertma, Gassa–Msid, Sidi Shaieb, Ben Metir and Sejnene (Fig. 1C). In each case we have followed an integrated approach including: (1) bed-by-bed logging; (2) detailed survey of trace fossils; (3) carbonate content ($CaCO_3$); and (4) foraminiferal analysis with special emphasis on P/B and DWAF/C ratio variation. This work builds on previous detailed sedimentological and biostratigraphic work by the authors, and careful regional correlation between sections.

4. Stratigraphy and major lithofacies of the Numidian Formation

Based on biostratigraphic dating (Riahi et al., in press) and detailed sedimentary logging of several sections located in the southern margins of Kroumirie and Mogod mountains and fringing the coastline, the Numidian Formation can be subdivided into: (1) the lower part or Zouza Member (Oligocene succession), which is mainly mud-rich, with

Fig. 1. Geographic distribution and geodynamic context of the Numidian Formation. A. Location map showing the distribution of the Numidian Formation across the Western Mediterranean region (Hoyez, 1989). B. Oligocene (Rupelian) palaeogeographic map of the western Mediterranean highlighting the Numidian Formation at time of deposition and its time equivalent deposits. Map redrawn from Meulenkamp and Sissingh (2003). The AlKaPeCa block is redrawn from Thomas (2012). Abbreviations: B — Betic, R — Riff, Cs — Corsica, Sa — Sardinia, Ca/P — Calabria and Peloritan, G — Galite Block, Pka — Petit Kabylie, Gka — Grand Kabylie. C. Distribution of the Numidian Formation in northern Tunisia (Rouvier, 1977). The zones with red circles correspond to the main areas in which the trace fossils were recorded.