Revista Brasileira de Paleontologia, 24(4):323–335, Outubro/Dezembro 2021
A Journal of the Brazilian Society of Paleontology

doi:10.4072/rbp.2021.4.03

SHALLOW MARINE TRACE-FOSSILS FROM THE MIDDLE MIOCENE OF THE TEBESSA BASIN (NE ALGERIA) AND THEIR PALEOENVIRONMENTAL IMPLICATIONS

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ABSTRACT – The northeastern part of Algeria is characterized by Meso–Cenozoic fossiliferous deposits. All the previous studies have been focused on invertebrate and vertebrate body fossils from this region. In the present paper we provide the first ichnological study from the region of Ouenza, Tebessa Wilaya (northeastern Algeria). An ichnoassemblage composed of eight ichnotaxa, namely cf. *Archaeonassa* isp., *Arenicolites* isp., *Diplocraterion* isp., *Helminthopsis* isp., *Palaeophycus tubularis*, *Skolithos* cf. *linearis*, cf. *Taenidium* isp., and *Thalassinoides* isp., reported from the lower Langhian (Middle Miocene) of Aïn Sidi Salah locality (Tebessa Basin) is discussed. These trace-fossils belong to the *Skolithos* and proximal *Cruziana* ichnofacies indicating deposition within a shallow marine (littoral). The large size of *Thalassinoides* suggests well oxygenated setting, under moderate- to high-energy conditions, with occasional storm events.

Keywords: trace-fossils, paleoenvironments, shallow marine, Middle Miocene, Tebessa.

RESUMO – A parte nordeste da Argélia é caracterizada por depósitos fossilíferos do Meso–Cenozoico. Todos os estudos anteriores foram focados em fósseis corporais de invertebrados e vertebrados desta região. Neste artigo, apresentamos o primeiro estudo icnológico da região de Ouenza, Tebessa Wilaya (nordeste da Argélia). Discute-se aqui a associação de icnofósseis composta por oito icnotáxons, identificados como cf. *Archaeonassa* isp., *Arenicolites* isp., *Diplocraterion* isp., *Helminthopsis* isp., *Palaeophycus tubularis*, *Skolithos* cf. *linearis*, cf. *Taenidium* isp. e *Thalassinoides* isp., reportados para o Langiano inferior (Mioceno Médio) na localidade de Aïn Sidi Salah (Bacia de Tebessa). Os icnofósseis representam a Icnofácies *Skolithos* e *Cruziana* proximal, indicando uma deposição em um contexto marinho raso (litoral). O expressivo tamanho de *Thalassinoides* sugere um cenário bem oxigenado e condições de alta energia, com eventos ocasionais de tempestades.

Palavras-chave: icnofósseis, paleoambientes, mar raso, Mioceno Médio, Tebessa.

INTRODUCTION

In the west Mediterranean Miocene marginal basins, thick marine mixed siliciclastic-carbonate sediments, characterized by abundant ichnofauna, have been deposited (Naimi *et al.*, 2020a). During the last decade, these deposits have been the subject of several ichnological studies particularly in Spain and Italy (Uchman & Hanken, 2013; Monaco & Trecci, 2014; Belaústegui *et al.*, 2016). In a shallow marine settings, they contain diverse and spectacular trace-fossil assemblages. However, both bioturbation and bioerosion patterns were sparsely recorded (Doyle *et al.*, 1998; de Gibert & Robles, 2005).

During the Miocene, several basins have been individualized in the northern part of Algeria, as well as the lower Chelif (Benzina *et al.*, 2019; Naimi, 2019; Naimi *et al.*, 2020a,b; Naimi & Cherif, 2021), Tafna (Naimi *et al.*, 2021a), Tiaret (Cherif *et al.*, 2021a; Naimi *et al.*, 2021b), and Tebessa basins (Benkhedda *et al.*, 2021). In the lower Chelif, the Tafna and Tiaret Neogene basins, several studies identified Burdigalian to Messinian shallow- to deep-marine trace-fossil assemblages (Naimi *et al.*, 2020a. 2021a,b; Cherif *et al.*, 2021a; Naimi & Cherif, 2021). Unfortunately, ichnological studies have not been carried out on the Tebessa Basin.

This paper aims to present the first description of lower Langhian trace-fossils from the Ouenza area (Tébessa, eastern Algeria) in the Tebessa Basin.

LOCATION AND GEOLOGICAL BACKGROUND

The study area belongs to Tebessa Mounts, which constitute the easternmost part of the Algerian Atlasic domain, consisting of the southern part of the Algerian alpine chain (Durand-Delga, 1969; Halamski & Cherif, 2017).

Tebessa Mounts are characterized by Triassic strata, cropping out as diapirs and composed of gypsum, clays, anhydrite and dolomite (Dubourdieu, 1956). The overlying Cretaceous deposits are characterized by shallow to deep marine limestones and marls. Their infill mainly consists of the mid-Cretaceous deposits (upper Albian–Turonian), where two anoxic events were identified at the end of the Albian (OAE-1d) and the Cenomanian (OAE-2) (Ruault-Djerrab *et al.*, 2014).

The Paleocene–Eocene sediments are characterized by marls, shelly and chalky limestones rich in shark teeth and nummulites, showing phosphorite layers and silex nodules (Kechiched *et al.*, 2016). These phosphorites are rich in glauconite, which may indicate reworking processes of phosphatic particles before their deposition and final burial in a sub-oxic to sub-reduced environment (Kechiched *et al.*, 2018). Furthermore, the Eocene (Coiffait *et al.*, 1984) and Miocene (Mahboubi *et al.*, 2003; Lihoreau *et al.*, 2015) continental deposits of Bir El Ater area, located in the southern margin of the Tebessa Basin, yielded vertebrate remains belonging to proboscideans, hyracoids, rodents, primates, creodonts, insectivores, and artiodactyls. Several new species were also described in this locality. The marine Lower Miocene series is characterized by shallow marine or deltaic sediments that unconformably overlie the Cretaceous strata (Hamimed & Kowalski, 2001). During the Middle–Late Miocene, the marginal part of this basin was characterized by shallow marine siliciclastic sedimentation (Benkhedda *et al.*, 2021).

The studied outcrop is located at Aïn Sidi Salah locality, to the east of Ouenza city, in the vicinity of the Algerian-Tunisian border, in the northern part of the Tebessa Basin (Figure 1). It consists of a succession of yellowish, 2 to 11 m-thick quartz-dominated fine- to coarse-grained sandstones, with sharp erosive bases, showing low-angle cross-stratifications, parallel laminations, ripple marks and bivalve bioclasts intercalated by greyish marls (Figure 2). They contain hematite, goethite, muscovite and glauconitic grains. The sandstone beds are intercalated with greenish to grayish clayey marls, 0.5–39 m thick, represented essentially by smectite, chlorite, kaolinite and illite clay minerals (Mazouz, 2009). The Table 1 summarizes the main facies (F1–F5) with their principal lithological, sedimentological and ichnological features. This succession is underlined by Triassic claystones and gypsum, and overlain by Laghian-Serravalian conglomerates, which have been assigned previously to the Burdigalian (Dubourdieu, 1956) (Figure 3). The planktonic foraminifera identified are dominated by *Globigerina dissimilis* Cushman & Bermúdez, 1937; *Globigerinoides trilobus* (Reuss, 1850); *Globorotalia mayeri* Cushman & Ellisor, 1939; *Gyroidinoides girardanus* (Reuss, 1851) and *Planulina renzi* Cushman & Stainforth, 1945, indicating the early Langhian age.

MATERIAL AND METHODS

The analyzed material comes from a unique stratigraphic section, measured, and sampled at Aïn Sidi Salah locality, Tebessa Basin. The trace-fossil samples were studied and photographed during the bed-by-bed descriptive observation of the lithological and paleontological aspects of the exposed sequence, as well as their stratigraphic relationships pending on the specificities of the study area. The material was not collected. All photos correspond to field specimens that were not collected and were photographed *in situ*.

SYSTEMATIC ICHNOLOGY

The trace-fossil assemblage is poorly diversified, composed of eight ichnotaxa, most of them identified at the ichnogenus level. This study reveals that *Skolithos* cf. *linearis* are abundant, *Diplocraterion* isp., and *Thalassinoides* isp. are common, whereas cf. *Archaeonassa* isp., *Arenicolites* isp., *Helminthopsis* isp., *Palaeophycus tubularis* and cf. *Taenidium* isp. are rare. In addition, most of specimens are preserved as epichnia and endichnia (Table 2).

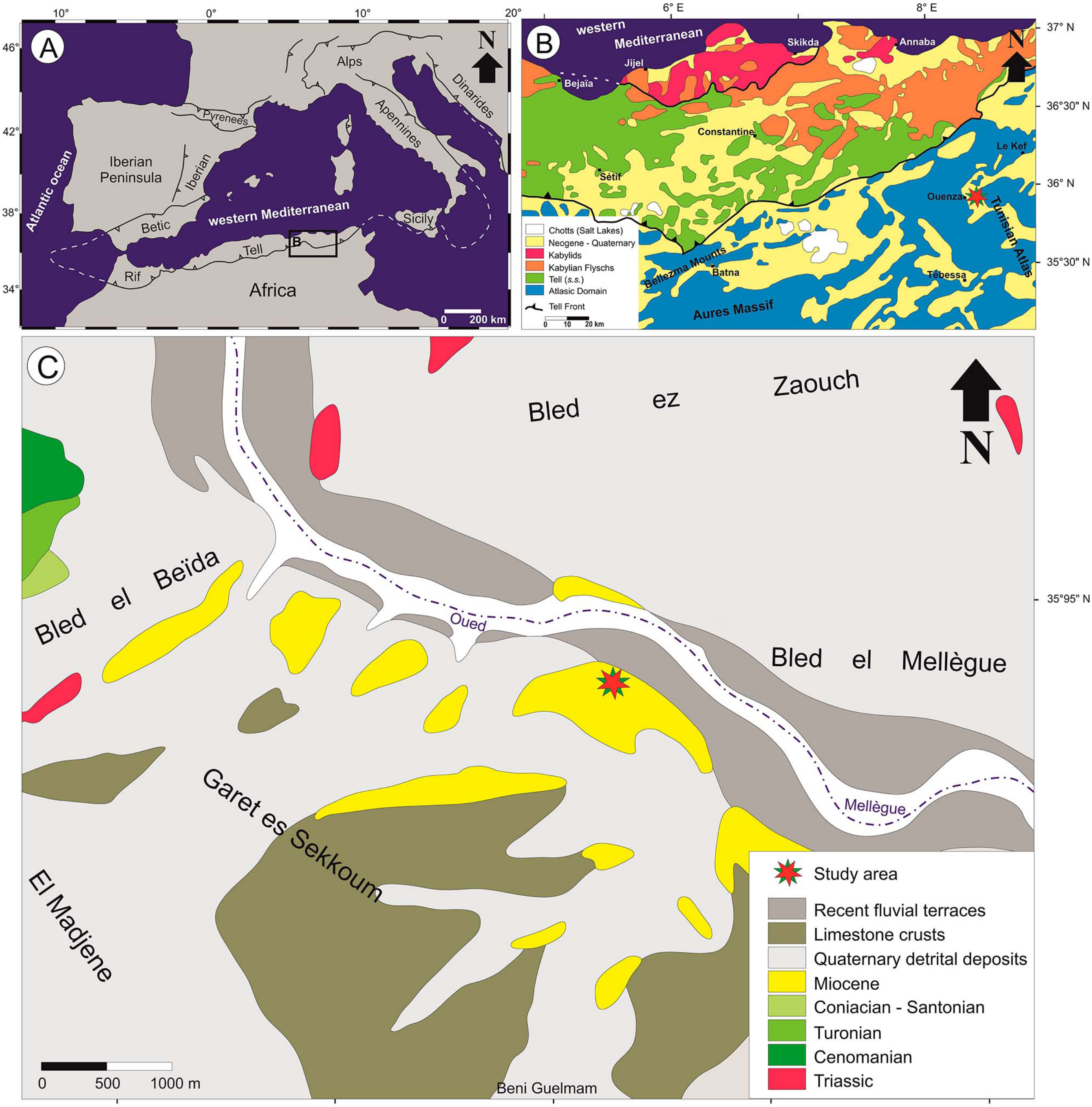

Figure 1. Location of the study area: **A,** location of northeastern Algeria in the western Mediterranean region and **B**, geological map of eastern Algeria; **C,** geological map of Aïn Sidi Salah locality.

Archaeonassa Fenton & Fenton, 1937

cf. *Archaeonassa* isp.
(Figure 4A)

Description. Subhorizontal, unbranched, cylindrical and rarely meandering trail, preserved as convex hyporelief, composed of concave central zone bounded by two convex parallel lateral ridges. It is found in the top of fine-grained sandstone with ripple marks. No evident ornamentation is seen inside the trail. The trails are 94 mm length in average, axial groove is 0.5–1 mm wide and the trail width is 3 to 5 mm.

Remarks. *Archaeonassa* is a molluscan-type trail (Netto *et al.*, 2012) ranging from the Ediacaran to the Recent (Buckman, 1994). It is considered as a crawling trail of predatory gastropods (Fenton & Fenton, 1937; Buckman, 1994; Stanley & Feldmann, 1998), crustaceans (Yochelson & Fedonkin, 1997; Mángano & Buatois, 2003), trilobites or echinoids (Buckman, 1994). Yuanyuan *et al.* (2019) also suggested nereidid polychaetes as probable trace makers. This

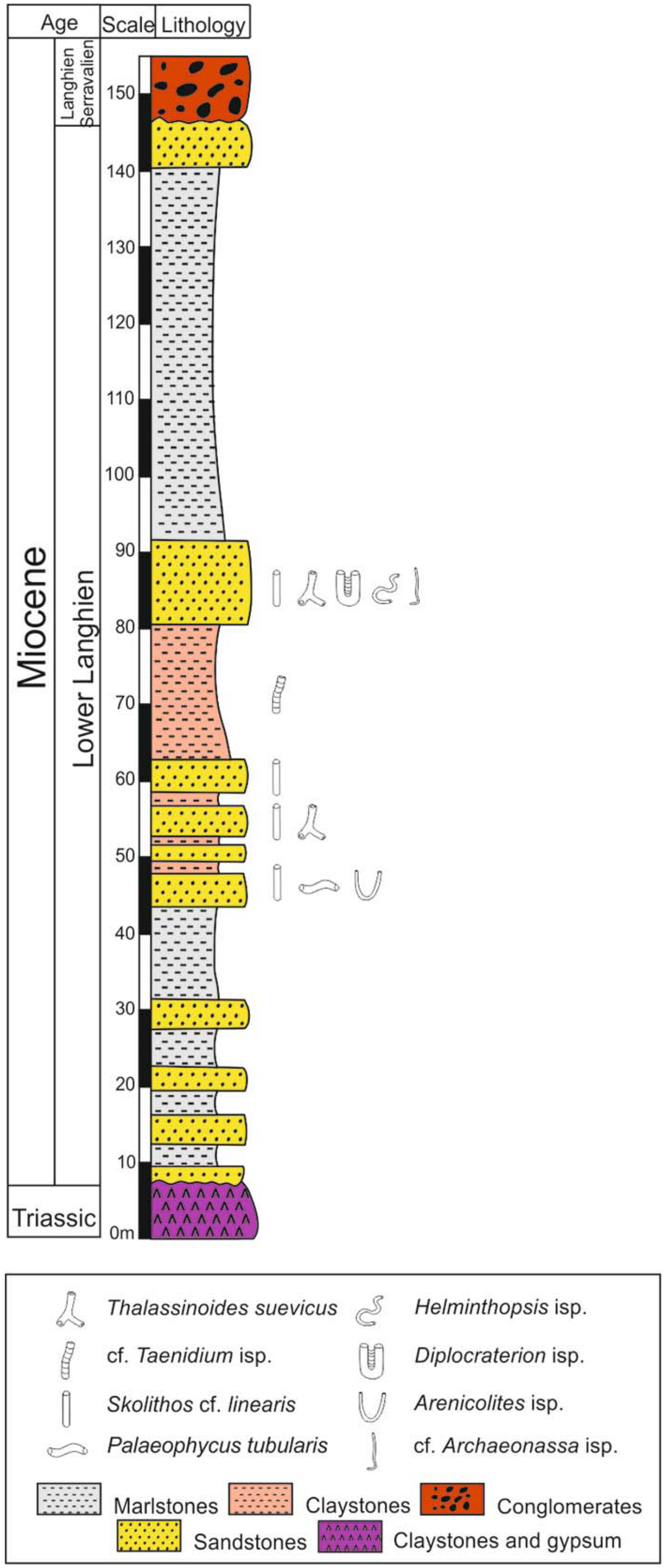

Figure 2. Stratigraphic column and trace-fossils distribution of the Aïn Sidi Salah section (Tébessa, northeastern Algeria).

Table 1. Distribution of the main facies, ichnogenera and depositional settings.

Facies	General description	Trace-fossils	Sedimentary structures	Sedimentary processes	Environment
Facies F1: Marlstones	2.5–8.3 m thick, massive, grey to green in color, containing benthic foraminifera and ostracods, with intercalations Sandstone beds (0.15 m mean)	/	/	Decantation processes mainly post-storm or tide current	Storm-dominated siliciclastic platform
Facies F2: Claystones	0.8–5.5 m thick, massive, reddish sandy claystones, intercalated by thin sandstone levels	cf. *Taenidium* isp.	/	Decantation processes and possibly related to pedogenic processes	
Facies F3: Rippled fine sandstones	Yellow to grey fine sandstones, 0.6–1.3 m thick, intercalated within marlstone facies, channelized, and showing ripple marks	cf. *Archaeonassa* isp. *Diplocraterion* isp. *Helminthopsis* isp. *Skolithos* cf. *S. linearis* *Thalassinoides* isp.	Wavy cross-laminated, wavy/ripple-marks	Weather wave or tide current in littoral zone	
Facies F4: Laminated sandstones	Brown to yellow, fine to medium-grained, 0.05–0.4 m thick, highly channelized, with sharp erosive bases	*Arenicolites* isp. *Palaeophycus tubularis* *Skolithos* cf. *S. linearis*	Horizontal and planar stratification	Deposition under high and rapid energy related to storm event	
Facies F5: Storm-dominated sandstones	Brown in color, fine to medium grained sandstone beds, 0.2–0.45 m in thickness, channelized, showing sometimes calcareous debris	*Skolithos* cf. *S. linearis* *Thalassinoides* isp.	Hummocky cross-stratification (HCS), horizontal lamination	Middle term of the tempest sequence from storm-dominated platform (middle offshore)	

Table 2. Main characteristics of the studied ichnoassemblage.

Ichnotaxa	Toponomy	Abundance	Ethology	Main producers
cf. *Archaeonassa* isp.	Epichnia	Rare	Repichnia, praedichnia	Gastropods, crustaceans
Arenicolites isp.	Endichnia	Rare	Domichnia	Worms
Diplocraterion isp.	Epichnia	Common	Domichnia	Crustaceans, polychaetes
Helminthopsis isp.	Epichnia	Rare	Pascichnia, repichnia	Polychaetes
Palaeophycus tubularis	Epichnia	Rare	Domichnia	Worms
Skolithos cf. *S. linearis*	Endichnia	Abundant	Domichnia	Worms, crustaceans
cf. *Taenidium* isp.	Endichnia	Rare	Pascichnia	Arthropods
Thalassinoides isp.	Endichnia	Common	Domichnia	Decapod crustaceans

trace-fossil is common in the *Cruziana* ichnofacies (Knaust *et al.*, 2012) but it is also an accessory component of the *Skolithos* ichnofacies (Melchor *et al.*, 2012). Mesozoic forms occur generally in intertidal zones (Knox & Miller, 1985; Bryant & Pickerill, 1990; Buckman, 1992a,b; Chen *et al.*, 2013), offshore environments (Cherif *et al.*, 2018) and deep marine settings (Mángano & Buatois, 2016).

Arenicolites Salter, 1857

Arenicolites isp.
(Figure 4B)

Description. Incomplete unbranched U-shaped burrows, at least 125 mm long, having a pair of closely spaced circles with subvertical orientation, and preserved as endichnia. Tube diameter is 3–6 mm. The distance between the two tube parts is up from 15 mm to 45 mm. The burrow shows no spreiten. It is filled with brown-grayish fine material.

Remarks. The studied specimen closely resembles the trace-fossil *Ancorichnus* described from the Carboniferous of the Carnic Alps (Baucon & De Carvalho, 2008; Figure 4). *Arenicolites* is interpreted as resulting from the dwelling activity (domichnia) of suspension-feeding organisms (Wilson, 1971; Knaust, 2017), which correspond to holothurians, sipunculans and echiurans (Smilek & Hembree, 2012; Baucon & Felletti, 2013; Baucon *et al.*, 2014). In modern marine settings, incipient *Arenicolites* burrows have been referred to polychaete worms and amphipod crustaceans (Gingras *et al.*, 2008; Bradshaw, 2010; Baucon *et al.*, 2014). *Arenicolites* burrows are known from continental to deep-marine environments, commonly occurring in deposits of high-energy (Mángano & Buatois, 2016; Knaust, 2017). This trace-fossil constitutes with *Skolithos*, *Ophiomorpha* and *Diplocraterion*, the most common ichnogenera of the *Skolithos* ichnofacies, but can also occurs locally in the *Cruziana* ichnofacies (Knaust, 2017). Its stratigraphic

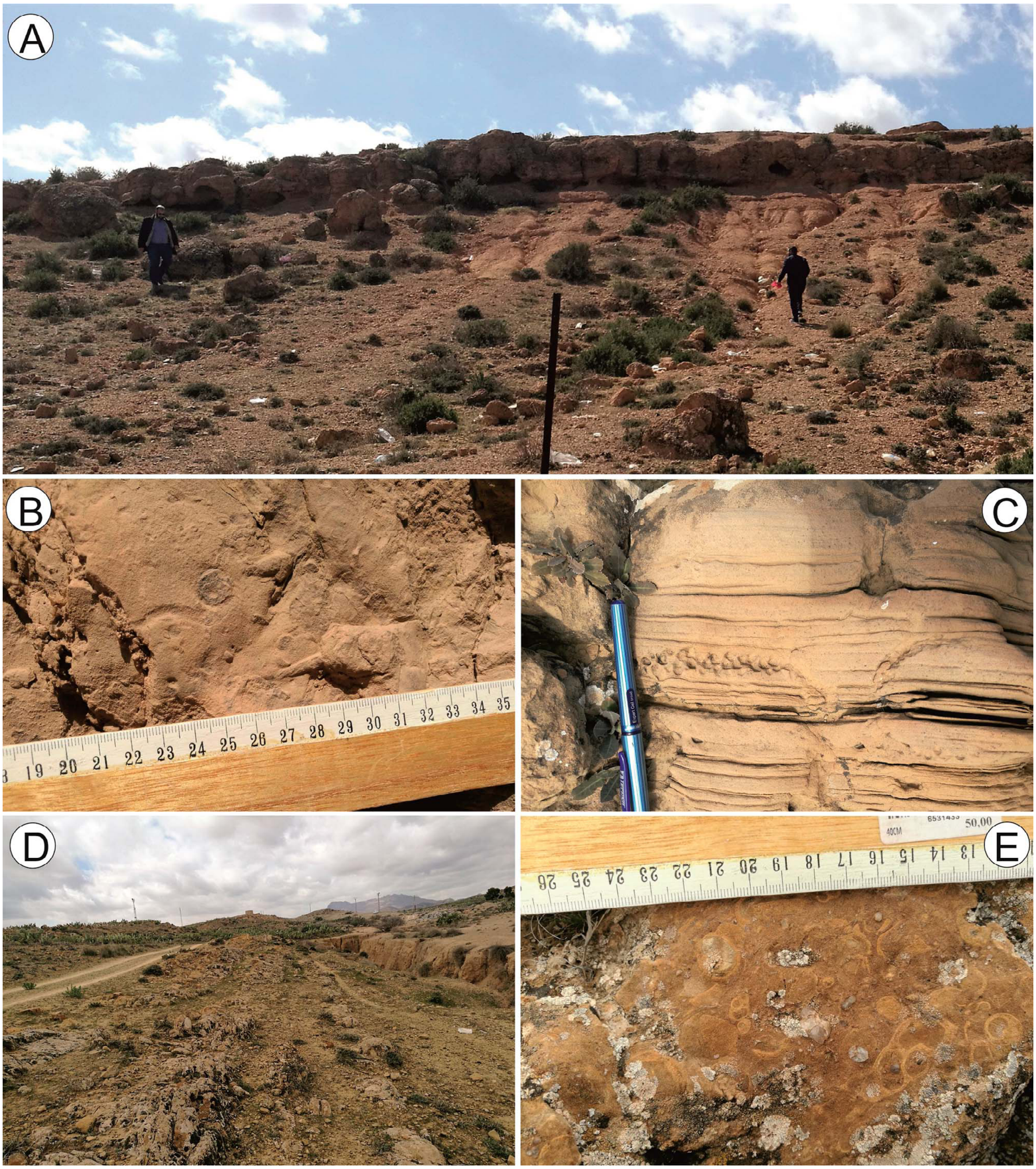

Figure 3. Sedimentary features of the Middle Miocene succession of the Aïn Sidi Salah section: **A**, field photograph of the upper part of Aïn Sidi Salah section; **B**, massive bioturbated sandstone; **C**, laminated sandstone; **D**, alternances of greyish to greenish marls with sandstone beds; **E**, massive sandstone showing numerous bioclasts.

distribution ranges from the Cambrian (Crimes *et al.*, 1977) to the Recent (Baucon & Felletti, 2013).

Diplocraterion Torell, 1870

Diplocraterion isp.
(Figures 4C, D)

Description. U-shaped, vertical burrow, preserved as epichnia at the top of fine-grained sandstone beds, and no specific characteristics are shown. The burrow diameter varies from 1.5 to 6 mm and the distance between the two limbs of the U-shaped burrow is 12–13 mm. Due to the plan view; the studied specimens closely resemble the U-shaped trace-fossils *Arenicolites* and *Tisoa*. The studied burrows were attributed to *Diplocraterion* isp. due to the presence of twin funnel-shaped craters characterizing their openings.

Remarks. This domichnion trace is produced in carbonate and siliciclastic settings, within soft- and firmgrounds, by polychaetes and crustaceans (Knaust, 2017). It is characterized

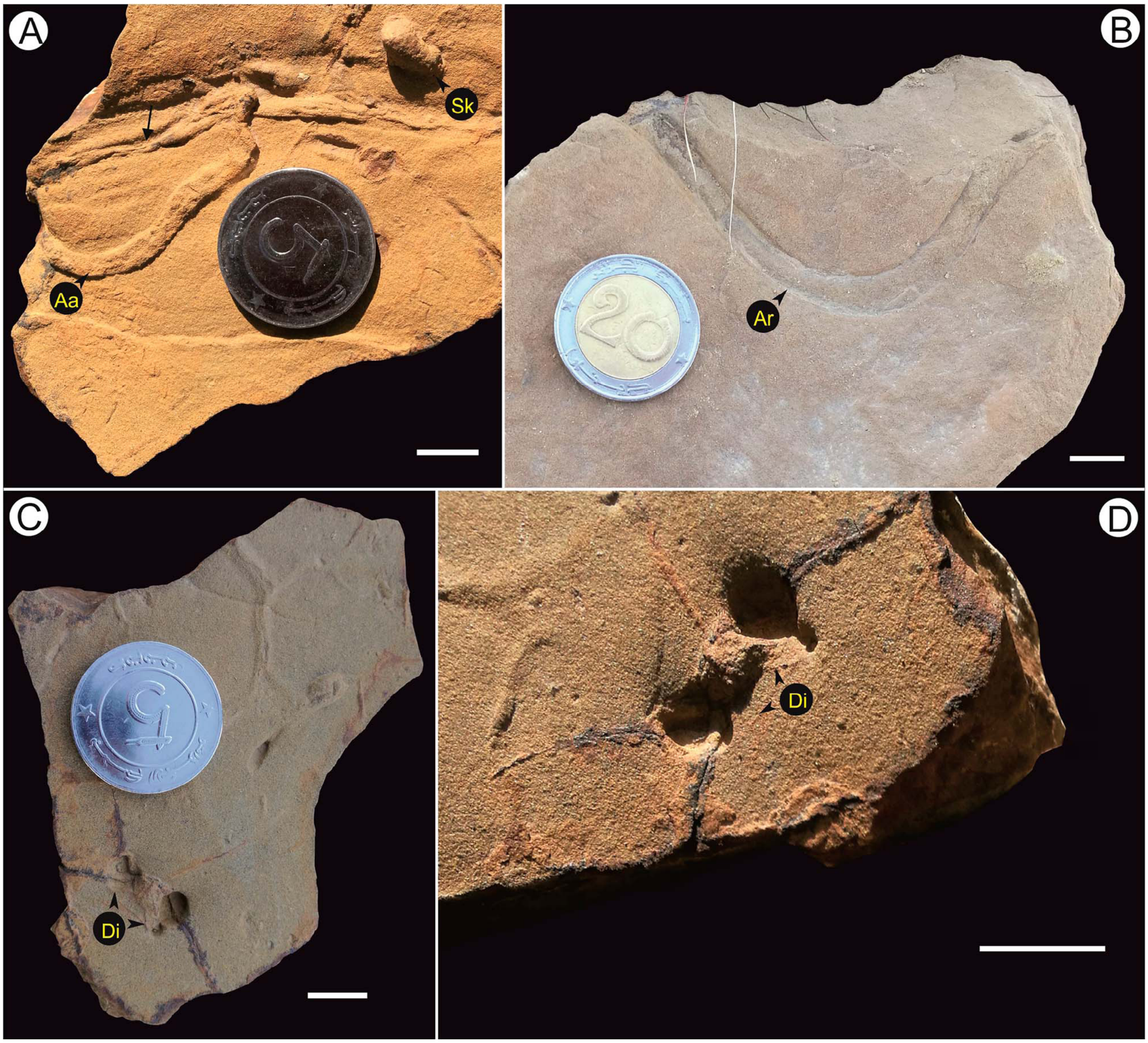

Figure 4. Trace-fossils from the lower Langhian of Aïn Sidi Salah with: **A**, cf. *Archaeonassa* isp. (**Aa**) associated with *Diplocraterion* isp. (**Di**) and *Skolithos* cf. *linearis* (**Sk**), black arrow indicates the axial groove of cf. *Archaeonassa* isp.; **B**, *Arenicolites* isp. (**Ar**) (vertical view); **C**, **D**, *Diplocraterion* isp. (**Di**). Scale bars = 1 cm.

by a spreite which can be retrusive or protrusive, or both (Goldring, 1962, 1964) and fecal pellets can be also present (Knaust, 2017). *Diplocraterion* isp., known from Cambrian to the Recent (Mángano & Buatois, 2016), is generally documented in shallow marine settings (Knaust, 2017; Palma-Ramírez *et al.*, 2019) and constitutes an important component of the *Skolithos* ichnofacies (Knaust, 2017).

Helminthopsis Heer, 1877

Helminthopsis isp.
(Figure 5A)

Description. Horizontal simple, smooth, and meandering string, 3 mm in diameter and 160 mm in length, preserved as a concave epichnial ridge in fine-grained sandstone.

Remarks. *Helminthopsis* is a pre-depositional graphoglyptid ichnotaxon, occurring within a sediment rich in nutrients of shallow and deep marine deposits (Uchman, 1995, 1998; Wetzel & Bromley, 1996; Wetzel *et al.*, 2007; Cherif *et al.*, 2021a). It is commonly interpreted as a pascichnion trace-fossil (Buatois & Mángano, 2011), probably made by grazing activity of polychaete annelids (Książkiewicz, 1977). In shallow marine setting, *Helminthopsis* ichnospecies are common in the *Cruziana* ichnofacies (MacEachern *et al.*, 2007; Belaid *et al.*, 2020). They have been recorded from Ediacaran (Narbonne & Aitken, 1990) to Recent strata (Gingras *et al.*, 2008) deposited below storm wave base.

Palaeophycus Hall, 1847

Palaeophycus tubularis Hall, 1847
(Figure 5B)

Description. Epichnial convex, simple, straight, unbranched, cylindrical to subcylindrical burrow, horizontal to bedding. Diameter is 15 mm, and the maximum length is 104 mm. The burrow lacks ornamentation and is filled with identical material to that of the host rock.
Remarks. The studied burrow has been assigned to *Palaeophycus tubularis* due to the presence of unornamented walls (Pemberton & Frey, 1982). It occurs in soft- to firmgrounds of both siliciclastic and carbonate deposits (Knaust, 2017). *Palaeophycus* ichnospecies reflect the dwelling activity (domichnion) of a predaceous or suspension-feeding animal (Pemberton & Frey, 1982). However, its tracemakers consist of vermiform animals, so other groups of organisms such as arthropods may produce it (Knaust, 2017). Modern *Palaeophycus* are produced by nereidid polychaetes (Dashtgard & Gingras, 2012; Gingras *et al.*, 2012), and the co-occurrences with large burrows, in marginal-littoral environments indicate that the tracemaker was euryhaline (Knaust, 2017). *Palaeophycus* is common in shoreface and offshore deposits of the *Cruziana* ichnofacies, and occurs subordinately in the *Skolithos*, *Zoophycos* and *Nereites* ichnofacies (Knaust, 2017). *Palaeophycus* has been reported from the Precambrian (Narbonne & Hofmann, 1987) to the Pleistocene (Dashtgard & Gingras, 2012; Gingras *et al.*, 2012).

Skolithos Haldeman, 1840

Skolithos cf. *linearis* Haldeman, 1840
(Figures 4A, 5A, C)

Description. Preserved as endichnia straight, simple, elongated, vertical to subvertical, cylindrical and unbranching tube, with lined walls and passive filling. The burrows are 55 mm long on average and 5–12 mm wide.
Remarks. In siliciclastic setting, *Skolithos* ichnospecies occur in soft- to firmgrounds (Knaust, 2017). They are domichnial (dwelling) traces, produced by suspension-feeding worms (Fenton & Fenton, 1934; Emig, 1982; Sundberg, 1983; Dashtgard & Gingras, 2012; Vinn & Wilson, 2013), crustaceans (Dashtgard & Gingras, 2012) and sea anemones in marine setting (Hertweck, 1972). *Skolithos* is the namesake for the *Skolithos* ichnofacies, commonly used as indicator of high energy conditions of shallow marine (littoral) environments (Knaust, 2017). Its stratigraphic record ranges from the Cambrian to the recent (Mángano & Buatois, 2016).

Taenidium Heer, 1877

cf. *Taenidium* isp.
(Figure 5D)

Description. cf. *Taenidium* isp. is winding, unbranched, and thinly lined burrow, vertical to the bedding plane, preserved as endichnial in sandy-claystone facies, up to 100 mm long and about 5 mm in diameter. The single specimen is moderately preserved, but in some segments, it is possible to see active meniscate-shaped filling.
Remarks. *Taenidium* is regarded as deposit-feeding, locomotion, and dwelling trace-fossil (Hembree & Hasiotis, 2008), produced probably by arthropods (Rodríguez-Tovar *et al.*, 2016). It is recorded in shallow to deep-marine deposits (D'Alessandro *et al.*, 1987), considered as characteristic element of the *Scoyenia* ichnofacies (Buatois & Mángano, 2011; Melchor *et al.*, 2012). ichnospecies of *Taenidium* occur also in the *Cruziana* ichnofacies (Bromley *et al.*, 1999; Cherif *et al.*, 2018). This trace-fossil is known from the Cambrian to the recent (Mángano & Buatois, 2016).

Thalassinoides Ehrenberg, 1944

Thalassinoides isp.
(Figure 5E)

Description. Straight or slightly curved, oblique, large, mostly with Y- to T-shaped branched burrowing network, 10–30 mm wide and 50 to 150 mm long. *Thalassinoides* isp. has been found in endichnia in the internal face of the storm-dominated sandstones (Facies F5).
Remarks. *Thalassinoides* is considered as fodinichnion-domichnion trace of decapod crustaceans (Frey *et al.*, 1984). It represents the main component of the *Cruziana* ichnofacies (Knaust, 2017) and is often documented from shallow marine to deep-sea environments (Kim *et al.*, 2002; Cherif *et al.*, 2021b), supporting high energy conditions (Cherif *et al.*, 2015), and occurring in soft- to firmgrounds, but rarely in hardgrounds (Knaust, 2017). In shallow marine setting, the abundance and the developed size of *Thalassinoides* suggest well-oxygenated deposits (Naimi *et al.*, 2020a; Naimi & Cherif, 2021). This trace-fossil is frequently reported from the Ordovician (Ekdale & Bromley, 2003) to the Holocene (Nickell & Atkinson, 1995), especially in the Mesozoic and Cenozoic deposits (El-Sabbagh *et al.*, 2017).

DISCUSSION

Ichnological analysis

The trace-fossils were recorded from claystones, rippled fine sandstones, laminated sandstones and storm-dominated sandstones which show densely packed bioclast-supported shell layers. The trace-fossil assemblage is characterized by sub-horizontally to sub-vertically burrows belonging to cf. *Archaeonassa* isp., *Arenicolites* isp., *Diplocraterion* isp., *Helminthopsis* isp., *Palaeophycus tubularis*, *Skolithos* cf. *S. linearis*, cf. *Taenidium* isp., and *Thalassinoides* isp. The most abundant trace-fossil is *S.* cf. *linearis*. The low ichnodiversity observed could be the result of stress factors such as high energy (Buatois & Mángano, 2013).

The ichnoassemblage in subject is dominated by post-depositional dwelling (domichnia) traces attributed essentially to suspension- or deposit-feeding organisms (*e.g. Thalassinoides* isp.). Shallow marine trace-fossils show more ethological variations than that of other environments (Joseph *et al.*, 2020), which is the main characteristic of the

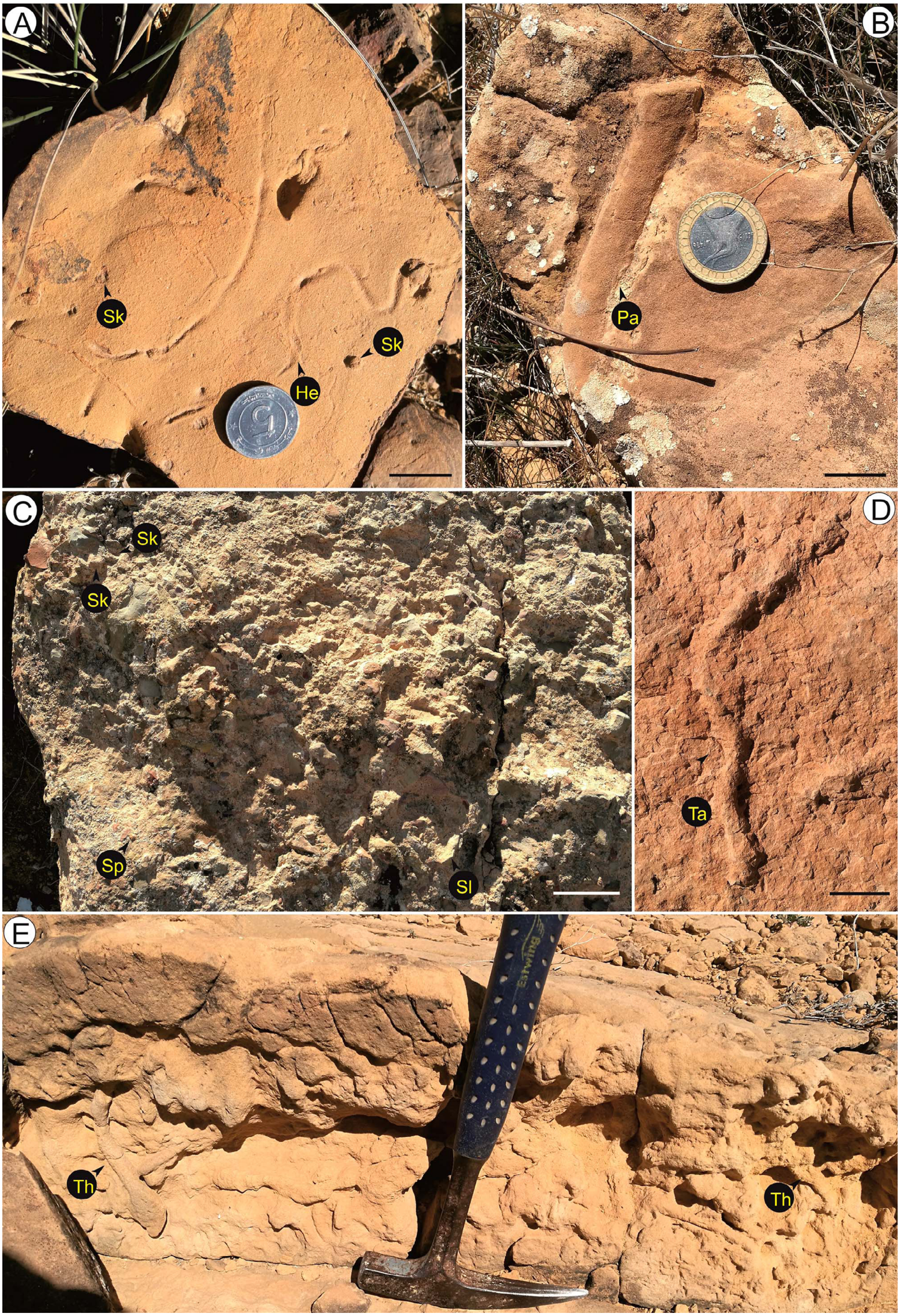

Figure 5. Trace-fossils from the lower Langhian of Aïn Sidi Salah: **A**, *Helminthopsis* isp. (**He**) associated with *Skolithos* cf. *S. linearis* (**Sk**); **B**, *Palaeophycus tubularis* (**Pa**); **C**, sandstone bed rich in *Skolithos* cf. *S. linearis* burrows (Sk), with probably pipe structures of *S.* cf. *S. linearis* burrows (**Sp**), and its lost traces (**Sl**) ; **D**, cf. *Taenidium* isp. (**Ta**) (the possible meniscate fill is indicated by white arrow); **E**, sandstone bed showing abundant *Thalassinoides suevicus* (**Th**). Scale bars: A–B = 2 cm; C = 5 cm; D = 1 cm.

proximal and archetypical *Cruziana* ichnofacies, within an upper offshore-lower shoreface environment (Pemberton *et al.*, 2001). Mazouz (2009) suggested for the Tebessa Basin a shallow marine environment under moderate to high energy conditions based on a sedimentological approach. Thereby, the occurrence of vertical structures indicates opportunistic colonization of the storm-dominated sandstones (post-event community); whereas the presence of horizontal structures (laminated sandstones) is related to fair weather conditions (Pervesler & Uchman, 2004). The preservation of the post-depositional trace-fossil *Arenicolites* and *Skolithos* in the sandstone beds could indicate a storm-related high-energy environment of the lower to middle shoreface (MacEachern *et al.*, 2012). Furthermore, the debris of bivalve shells could be related to storm events (tempestite-deposits) and suggest a shoreface depositional environment. *Thalassinoides* characterizes softgrounds (Myrow, 1995) and its co-occurrence with large and open burrows, as well as *Palaeophycus*, indicates a shallow marine environment with well-oxygenated water above the sea floor (Naimi *et al.*, 2020a; Naimi & Cherif, 2021). The worms (polychaetes and phoronids) are the most common producers of the studied trace-fossils, but crustaceans and arthropods are also probable tracemakers of these structures. The studied ichnoassemblage together with the paleontological data as well as the recorded bivalves are suggestive of adequate food resources both in substrate and water column under normal salinity conditions (Fürsich, 1973; Wilson & Rigby, 2000; Mángano *et al.*, 1999; 2005; Gurav *et al.*, 2014)

Water with relatively strong currents, irregular rates of sedimentation and a high flux of food particles is conducive to the occurrence of suspension feeders (Buatois & Mángano, 2011). Gingras *et al.* (2011) also regarded the abundance of permanent U-shaped burrows and vertical tubes as indicative of shallow-marine areas with shifting sandy substrates, moderate-to high-energy conditions and food in suspension. From an ichnological point of view, the sequence shows a shift in environmental conditions, from the nearshore to the offshore zone. The colonization occurred in fully oxygenated shallow-marine waters, in a high-energy setting.

The trace-fossil assemblage of Aïn Sidi Salah is intimately related to shallow marine ichnofacies and typically shows development of *Skolithos*, which is the diagnostic of *Skolithos* ichnofacies type conditions.

Paleogeography

During the Early–Middle Miocene, a significant marine transgression began across the expanse of epicontinental Algeria (Bessedik *et al.*, 2002). A patch reef indicating the maximum flooding has been discovered in the Langhian–Serravalian transgressive detrital strata of the Lower Chelif Basin (Belkebir *et al.*, 1994). This transgression has been recorded from the entire western Mediterranean Basin, as result of the opening of the Algero-Provençal Basin, occupying the western part of the Mediterranean Sea (de Gibert & Robles, 2005). These transgressive deposits are overlain by continental reddish detrital sediments attributed to the Serravalian (Bessedik *et al.*, 2002). The Miocene series ends by Late Miocene (Tortonian–Messinian) marine transgressive deposits (Benzina *et al.*, 2019; Naimi *et al.*, 2020a).

The attribution of the studied deposits to the lower Langhian on the basis of planktonic foraminifera allows correlating the Tebessa basin with the other marginal basins of the southwestern Mediterranean as well as the Lower Chelif Basin. The bioturbated sandstones (Facies F3–F5) have been deposited within a transgressive context related to a significant transgression recorded in the other peri-Mediterranean basins. Also, they are overlain by reddish conglomerates which are similar to that of the Lower Chelif Basin, indicating the Middle Miocene regression phase. The latter are surmounted by Upper Miocene marine siliciclastic deposits as well as in the case of the Lower Chelif and the Tafna basins (Benkhedda *et al.*, 2021). Thus, it confirms the similarities between the Tebessa and the Lower Chelif basin, which presents the reference Miocene series of Algeria.

CONCLUSIONS

Ichnological analysis of the Aïn Sidi Salah lower Langhian sequence revealed low ichnodiversity represented by sub-horizontally to sub-vertically oriented burrows belonging to eight ichnotaxa of *Skolithos* and proximal *Cruziana* Ichnofacies. Thus, these trace-fossils are cf. *Archaeonassa* isp., *Arenicolites* isp., *Diplocraterion* isp., *Helminthopsis* isp., *Palaeophycus tubularis*, *Skolithos* cf. *linearis*, cf. *Taenidium* isp., and *Thalassinoides* isp. The *Skolithos* ichnofacies suggests high hydrodynamic energy reflecting foreshore-shoreface environment with occasional storm events, while proximal *Cruziana* ichnofacies represents moderate energy condition of shoreface. This ichnoassemblage suggests that suspension- or deposit- feeding organisms, represented essentially by worms (polychaetes and phoronids), crustaceans and arthropods, occurred within these deposits, despite the absence of their body fossils.

ACKNOWLEDGMENTS

This paper is a part of the PhD thesis of Abdelhakim Benkhedda. We thank the associated Editor of Revista Brasileira de Paleontologia, M.N. Ritter, and the three reviewers, H. Francischini, J. Villegas-Martín and D. Sedorko, for the comments on early drafts of this manuscript.

REFERENCES

Baucon, A. & De Carvalho, C.N. 2008. From the river to the sea: Pramollo, a new ichnolagerstätte from the Carnic Alps (Carboniferous, Italy-Austria). *Studi Trentini di Scienze Naturali, Acta Geologica*, **83**:87–114.

Baucon, A. & Felletti, F. 2013. Neoichnology of a barrier-island system: the Mula di Muggia (Grado lagoon, Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **375**:112–124. *doi:10.1016/j.palaeo.2013.02.011*

Baucon, A; Ronchi, A. & Felletti F. 2014. Evolution of crustaceans at the edge of the end-Permian crisis: ichnonet work analysis of the fluvial succession of Nurra (Permian–Triassic, Sardinia, Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **410**:74–103. *doi:10.1016/j.palaeo.2014.05.034*

Belaid, M.; Cherif, A.; Vinn, O. & Naimi, M.N. 2020. First record of trace-fossils from the Oxfordian Argiles rouges de Kheneg Formation (Tiaret, northwestern Algeria). *Geologia Croatica*, **73**:85–94. *doi:10.4154/gc.2020.10*

Belaústegui, Z.; Ekdale, A.A.; Domènech, R. & Martinell, J. 2016. Paleobiology of firmground burrowers and cryptobionts at a Miocene omission surface, Alcoi, SE Spain. *Journal of Paleontology*, **90**:721–733. *doi:10.1017/jpa.2016.84*

Belkebir, L.; Mansour, B.; Bessedik, M.; Saint Martin, J.P.; Belarbi, M. & Chaix, C. 1994. Présence d'une construction récifale corallienne à Djebel Chott (Dahra occidental, Algérie): témoin du maximum transgressif du Miocène moyen en Méditerranée. *Géologie Méditerranéenne*, **21**:1–7.

Benkhedda, A.; Defaflia, N.; Cherif, A.; Benzina, M.; Kechiched, R.; Naimi, M.N. & Djerrab-Ruault, M. 2021. Upper Miocene deposits from El Ma Labiod (Tébessa, Northeastern Algeria): sedimentology, micropaleontology and paleoenvironmental implications. *Russian Journal of Earth Sciences*, **22**:ES1002. *doi:10.2205/2021ES000768*

Benzina, M.; Hebib, H. & Bensalah, M. 2019. New insights in late Miocene lower Chelif basin biostratigraphy based on planktonic foraminifera (Algeria). *Revue de Micropaléontologie*, **62**:9–24. *doi:10.1016/j.revmic.2018.10.005*

Bessedik, M.; Belkebir, L. & Mansour, B. 2002. Révision de l'âge Miocène inférieur (au sens des anciens auteurs) des dépôts du bassin du Bas Chélif (Oran, Algérie): conséquences biostratigraphiques et géodynamiques. *Mémoires du Service Géologique de l'Algérie*, **11**:167–186.

Bradshaw, M.A. 2010. Devonian trace-fossils of the Horlick Formation, Ohio Range, Antarctica: systematic description and palaeoenvironmental interpretation. *Ichnos*, **17**:58–114. *doi:10.1080/10420941003659329*

Bromley, R.G.; Ekdale, A.A. & Richter, B. 1999. New Taenidium (trace-fossil) in the Upper Cretaceous chalk of northwestern Europe. *Bulletin of the Geological Society of Denmark*, **46**:47–51.

Bryant, I.D. & Pickerill, R.K. 1990. Lower Cambrian trace-fossils from the Buen Formation of central North Greenland: preliminary observations. *Grønlands Geologiske Undersøgelse, Rapport*, **147**:44–62.

Buatois, L.A. & Mángano, M.G. 2011. *Ichnology. Organism-substrate interactions in space and time*. Cambridge, Cambridge University Press, 347 p.

Buatois, L.A. & Mángano, M.G. 2013. Ichnodiversity and ichnodisparity: significance and caveats. *Lethaia*, **46**:281–292. *doi:10.1111/let.12018*

Buckman, J.O. 1992a. Palaeoenvironment of a Lower Carboniferous sandstone succession northwest Ireland: ichnological and sedimentological studies. *In*: J. Parnell (ed.) *Basins on the Atlantic Seaboard: Petroleum Sedimentology and Basin Evolution*, Geological Society Special Publication, vol. 62, p. 217–241. *doi:10.1144/GSL.SP.1992.062.01.19*

Buckman, J.O. 1992b. *Lower Carboniferous Trace-fossils from northwest Ireland*. Queen's University, Ph.D. Thesis, 356 p.

Buckman, J.O. 1994. *Archaeonassa* Fenton and Fenton 1937 reviewed. *Ichnos*, **3**:185–192. *doi:10.1080/10420949409386387*

Chen, Z.; Zhou, C.; Meyer, M.; Xiang, K.; Schiffbauer, J.D.; Yuan, X. & Xiao, S. 2013. Trace-fossil evidence for Ediacaran bilaterian animals with complex behaviors. *Precambrian Research*, **224**:690–701. *doi:10.1016/j.precamres.2012.11.004*

Cherif, A.; Benyoucef, M.; Ferré, B. & Benhamou, M. 2018. Etude sédimentologique et ichnologique de la Formation des Argiles de Saïda (Jurassique supérieur) dans les monts de Frenda (Algérie nord-occidentale). *Revue de Paléobiologie*, **37**:121–135. *doi:10.5281/zenodo.1315455*

Cherif, A.; Bert, D.; Benhamou, M. & Benyoucef, M. 2015. La Formation des Argiles de Saïda (Jurassique supérieur) dans le domaine tlemcenien oriental (Takhemaret, Algérie): données biostratigraphiques, ichnologiques et sédimentologiques. *Revue de Paléobiologie*, **34**:363–384. *doi:10.5281/zenodo.34344*

Cherif, A.; Naimi, M.N. & Belaid, M. 2021a. Deep-sea trace-fossils and depositional model from the lower Miocene Tiaret Marls Formation (northwestern Algeria). *Journal of African Earth Sciences*, **175**:104115. *doi:10.1016/j.jafrearsci.2021.104115*

Coiffait, P.E.; Coiffait, B.; Jaeger, J.J. & Mahboubi, M. 1984. Un nouveau gisement à mammifères fossiles d'âge Eocène supérieur sur le versant sud des Nementcha (Algérie orientale): découverte des plus anciens rongeurs d'Afrique. *Comptes Rendus de l'Académie des Sciences*, **299**:893–898.

Crimes, T.P.; Legg, I. & Marcos, A. 1977. ?Late Precambrian-low Lower Cambrian trace-fossils from Spain. *In*: T.P. Crimes & J.C. Harper (eds.) Trace-fossil*s 2*, Geological Journal, Special Issue, vol. 9, p. 91–138.

D'Alessandro, A.; Bromley, R.G. & Stemmerik, L. 1987. *Rutichnus*: a new ichnogenus for branched, walled, meniscate trace-fossils. *Journal of Paleontology*, **61**:1112–1119. *doi:10.1017/S0022336000029498*

Dashtgard, S.E. & Gingras, M.K. 2012. Marine invertebrate neoichnology. *In*: D. Knaust & R.G. Bromley (eds.) Trace-fossil*s as indicators of Sedimentary environments*, Elsevier, p. 273–295. *doi:10.1016/B978-0-444-53813-0.00004-6*

de Gibert, J.M. & Robles, J.M. 2005. Firmground ichnofacies recording high-frequency marine flooding events (Langhian transgression, Vallès-Penedès Basin, Spain). *Geologica Acta*, **3**:295–305. *doi:10.1344/105.000001397*

Doyle, P.; Bennett, M.R. & Cocks, F.M. 1998. Borings in a boulder substrate from the Miocene of southern Spain. *Ichnos*, **5**:277–286. *doi:10.1080/10420949809386426*

Dubourdieu, G. 1956. Etude géologique de la région de l'Ouenza (confins algéro-tunisiens). *Publications du Service de la Carte Géologique de l'Algérie*, **10**:1–659.

Durand-Delga, M. 1969. Mise au point sur la structure du Nord-Est de la Berbérie. *Publications du Service Géologique de l'Algérie*, **39**:89–131.

Ekdale, A.A. & Bromley, R.G. 2003. Paleoethologic interpretation of complex *Thalassinoides* in shallow-marine limestones, Lower Ordovician, southern Sweden. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **192**:221–227. *doi:10.1016/S0031-0182(02)00686-7*

El-Sabbagh, A.; El-Hedeny, M. & Al Farraj, S. 2017. *Thalassinoides* in the Middle Miocene succession at Siwa Oasis, northwestern Egypt. *Proceedings of the Geologists' Association*, **128**:222–233. *doi:10.1016/j.pgeola.2017.01.001*

Emig, C.C. 1982. The biology of Phoronida. *Advances in Marine Biology*, **19**:1–89.

Fenton, M.A. & Fenton, C.L. 1934. *Scolithus* as a fossil phoronid. *Pan-American Geologist*, **61**:341–348.

Fenton, C.L. & Fenton, M.A. 1937. *Archaeonassa*, Cambrian snail trails and burrows. *American Midland Naturalist*, **18**:454–456.

Frey, R.W.; Pemberton, S.G. & Fagerstrom, J.A. 1984. Morphological, ethological, and environmental significance of the ichnogenera *Scoyenia* and *Ancorichnus*. *Journal of Paleontology*, **58**:511–528.

Fürsich, F.T. 1973. A revision of the trace-fossils *Spongeliomorpha*, *Ophiomorpha* and *Thalassinoides*. *Neues Jahrbuch für Geologie und Paläontologie*, **1973**:719–735.

Gingras, M.K.; Baniak, G.; Gordon, J.; Hovikoski, J.; Konhauser, K.O.; La Croix, A.; Lemiski, R.; Mendoza, C.; Pemberton, G.S.; Polo, C. & Zonneveld, J.-P. 2012. Estuaries. *In*: D. Knaust & R.G. Bromley (eds.) Trace-fossil*s as indicators of sedimentary environments*, Elsevier, p. 463–505. *doi:10.1016/B978-0-444-53813-0.00004-6*

Gingras, M.K.; Dashtgard, S.E.; MacEachern, J.A. & Pemberton, S.G. 2008. Biology of shallow marine ichnology: a modern perspective. *Aquatic Biology*, **2**:255–268. *doi:10.3354/ab00055*

Gingras, M.K.; MacEachern, J.A. & Dashtgard, S.E. 2011. Process ichnology and the elucidation of physico-chemical stress. *Sedimentary Geology*, **237**:115–134. *doi:10.1016/j.sedgeo.2011.02.006*

Goldring, R. 1962. The trace-fossils of the Baggy Beds (Upper Devonian) of North Devon, England. *Paläontologische Zeitschrift*, **36**:232–251.

Goldring, R. 1964. Trace-fossils and the sedimentary surface in shallow water marine sediments. *Developments in Sedimentology*, **1**:136–143. *doi:10.1016/S0070-4571(08)70478-3*

Gurav, S.S.; Kulkarni, K.G.; Paranjape, A.R. & Borkar, V.D. 2014. Palaeoenvironmental implications of Middle Jurassic trace-fossils from the Jaisalmer Formation, India, with emphasis on the ichnogenus *Asteriacites*. *Annales Societatis Geologorum Poloniae*, **84**:249–257.

Halamski, A.T. & Cherif, A. 2017. Oxfordian brachiopods from the Saïda and Frenda mountains (Tlemcenian Domain, north-western Algeria). *Annales Societatis Geologorum Poloniae*, **87**:141–156. *doi:10.14241/asgp.2017.006*

Hamimed, M. & Kowalski, W.M. 2001. Sedimentological analysis and paleogeography of the Miocene sediments (Langhian-Serravalian) of the surroundings of Tebessa (North-East of Algeria). *Bulletin of the Geological Service of Algeria*, **12**:49–75.

Hembree, D.I. & Hasiotis, S.T. 2008. Miocene vertebrate and invertebrate burrows defining compound paleosols in the Pawnee Creek Formation, Colorado, U.S.A. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **270**:349–365. *doi:10.1016/j.palaeo.2008.07.019*

Hertweck, G. 1972. Georgia coastal region, Sapelo Island, U.S.A.: sedimentology and biology V. Distribution and environmental significance of lebensspuren and in-situ skeletal remains. *Senckenbergiana Maritima*, **4**:125–167.

Joseph, J.K.; Patel, S.J.; Darngawn, J.L. & Shitole, A.D. 2020. Ichnological analysis of Jurassic shallow to marginal marine deposits: example from Wagad Highland, Western India. *Ichnos*, **27**:35–63. *doi:10.1080/10420940.2019.1612390*

Kechiched, R.; Laouar, R.; Bruguier, O.; Laouar-Salmi, S.; Ameur-Zaimeche, O. & Foufou, A. 2016. Preliminary data of REE in Algerian phosphorites: a comparative study and paleo-redox insights. *Procedia Engineering*, **138**:19–29. *doi:10.1016/j.proeng.2016.02.048*

Kechiched, R.; Laouar, R.; Bruguier, O.; Salmi-Laouar, S.; Kocsis, L.; Bosch, D.; Foufou, A.; Ameur-Zaimeche, O. & Larit, H. 2018. Glauconite-bearing sedimentary phosphorites from the Tébessa region (eastern Algeria): evidence of REE enrichment and geochemical constraints of their origin. *Journal of African Earth Sciences*, **145**:190–200. *doi:10.1016/j.jafrearsci.2018.05.018*

Kim, J.Y.; Kim, K.S. & Pickerill, R.K. 2002. Cretaceous Nonmarine Trace-fossils from the Hasandong and Jinju Formations of the Namhae Area, Kyongsangnamdo, Southeast Korea. *Ichnos*, **9**:41–60. *doi:10.1080/10420940190034076*

Knaust, D. 2017. *Atlas of trace-fossils in well core: appearance, taxonomy and interpretation*. Stavanger, Springer, 209 p.

Knaust, D.; Curran, H.A. & Dronov, A.V. 2012. Shallow-Marine Carbonates. *In*: D. Knaust & R.G. Bromley (eds.) Trace-fossil*s as Indicators of Sedimentary Environments*, Elsevier, p. 705–750. *doi:10.1016/B978-0-444-53813-0.00004-6*

Knox, L.W. & Miller, M.E. 1985. Environmental control of trace-fossil morphology. *In*: H.A. Curran (ed.) *Biogenic structures: their use in interpreting depositional environments*, The Society of Economic Paleontologists and Mineralogists, Special Publications, vol. 35, p. 167–176.

Książkiewicz, M. 1977. Trace-fossils in the Flysch of the Polish Carpathians. *Palaeontologia Polonica*, **36**:1–208.

Lihoreau, F.; Hautier, L. & Mahboubi, M. 2015. The new Algerian locality of Bir el Ater: validity of *Libycosaurus algeriensis* (Mammalia, Hippopotamoidea) and the age of the Nementcha Formation. *Palaeovertebrata*, **39**:e1. *doi:10.18563/pv.39.2.e1*

MacEachern, J.A.; Pemberton, S.G.; Gingras, M.K.; Bann, K.L. 2007. The ichnofacies paradigm: a fifty-year retrospective. *In*: W. Miller, III (ed.) Trace-fossil*s: concepts, problems, prospects*, Elsevier, p. 52–77.

MacEachern, J.A.; Dashtgard, S.E.; Knaust, D.; Catuneanu, O.; Bann}and, K.L. & Pemberton, S.G. 2012. Sequence stratigraphy. In: D. Knaust & R.G. Bromley (eds.) D*evelopments in Sedimentology*, **64**:157–194. *doi:10.1016/B978-0-444-53813-0.00006-X*

Mahboubi, M.; Tabuce, R.; Mebrouk, F.; Coiffait, B.; Coiffait, P.E. & Jaeger J.J. 2003. L'Eocène continental à vertébrés de la bordure sud des monts des Nementcha (Atlas saharien oriental, Algérie). Précisions stratigraphiques et implications paléobiogéographiques. *Bulletin du Service Géologique de l'Algérie*, **14**:27–35.

Mángano, M.G. & Buatois, L.A. 2003. Trace-fossils. *In*: J.L. Benedetto (ed.) *Ordovician Fossils of Argentina*, Universidad Nacional de Córdoba, Secretaría de Cienciay Tecnología, p. 507–553.

Mángano, M.G. & Buatois, L.A. 2016. *The trace-fossil record of major evolutionary events. Volume 2: Mesozoic and Cenozoic*. Dordrecht, Springer, 485 p. *doi:10.1007/978-94-017-9597-5*

Mángano, M.G.; Buatois, L.A. & Muniz-Guinea, F. 2005. Ichnology of the Alfarcito Member (Santa Rosita Formation) of northwestern Argentina: animal-substrate interactions in a lower Paleozoic wave-dominated shallow sea. *Ameghiniana*, **42**:641–668.

Mángano, M.G.; Buatois, L.A.; West, R.R. & Maples, C.G. 1999. The origin and paleoecologic significance of the trace-fossil *Astericites* in the Pennsylvanian of Kansas and Missouri. *Lethaia*, **32**:17–30. *doi:10.1111/j.1502-3931.1999.tb00577.x*

Mazouz, E.H. 2009. *Étude sédimentologique, stratigraphique et pétro minéralogique des affleurements miocènes aux environs d'Aïn Sidi Salah et de Fedj El Behim (Ouenza – Confins algéro-tunisiens)*. Université de Tebessa, M.Sc. thesis, 89 p.

Melchor, R.N.; Genise, J.F.; Buatois, L.A. & Umazano, A.M. 2012. Fluvial environments. *In*: D. Knaust & R.G. Bromley (eds.) Trace-fossil*s as indicators of sedimentary environments*, Elsevier, p. 329–378. *doi:10.1016/B978-0-444-53813-0.00004-6*

Monaco, P. & Trecci T. 2014. Ichnocoenoses in the Macigno turbidite basin system, Lower Miocene, Trasimeno (Umbrian Apennines, Italy). *Italian Journal of Geoscience*, **133**:116–130. *doi:10.3301/IJG.2013.18*

Myrow, P.M. 1995.*Thalassinoides* and the enigma of early Paleozoic open-framework burrow systems. *Palaios*, **10**:58–74. *doi:10.3301/IJG.2013.18*

Naimi, M.N. 2019. *La plate-forme carbonate messinienne du Djebel Aoud Sma (Monts des Ouled Ali, Bassin du Bas Chélif): sédimentologie et géochimie*. University of Oran 2, M.Sc. thesis, 53 p.

Naimi, M.N. & Cherif, A. 2021. Ichnological analysis of the late Miocene shallow marine diatomaceous deposits of the Lower Chelif basin (northwestern Algeria): paleoenvironmental insights and comparison with deep diatomites. *Journal of African Earth Sciences*, **180**:104239. *doi:10.1016/j.afrearsci.2021.104239*

Naimi, M.N.; Cherif, A. & Belaid, M. 2021b. The trace-fossil *Cardioichnus planus* from the lower Miocene of Algeria: the first record from Africa and a probable endemic tracemaker. *Geologia Croatica*, **74**:121–126. *doi:10.4154/gc.2021.09*

Naimi, M.N.; Mansour, B. & Cherif, A. 2020b. First record of the *Halimeda*-rich beds from the Tessala – Beni Chougrane Messinian carbonate platform (Lower Chelif basin, NW Algeria). *In*: GEOCONVENTION, 2020. *Abstracts*, Calgary, p. 1–5.

Naimi, M.N.; Mansour, B.; Cherif, A.; Chekkali, M.C.; Benkhedda, A. & Belaid, M. 2020a. Lithostratigraphie et paléoenvironnements des dépôts messiniens du Djebel Aoud Sma (bassin du Bas Chélif, Algérie nord-occidentale). *Revue de Paléobiologie*, **39**:467–483.

Naimi, M.N.; Vinn, O. & Cherif, A. 2021a. Bioerosion in *Ostrea lamellosa* shells from the Messinian of the Tafna basin (NW Algeria). *Carnets de Géologie*, **21**:127–135. *doi:10.2110/carnets.2021.2105*

Narbonne, G.M. & Aitken, J.D. 1990. Ediacaran fossils from the Sekwi Brook area Mackenzie Mountains, northwestern Canada. *Palaeontology*, **33**:945– 980.

Narbonne, G.M. & Hofmann, H.J. 1987. Ediacaran biota of the Wernecke Mountains, Yukon, Canada. *Palaeontology*, **30**:647–676.

Netto, R.G.; Benner, J.S.; Buatois, L.A.; Uchman, A.; Mángano, M.G.; Ridge, J.C.; Kazakauskas, V. & Gaigalas, A. 2012. Glacial Environments. *In*: D. Knaust & R.G. Bromley (eds.) Trace-fossil*s as Indicators of Sedimentary Environments*, Elsevier, p. 299–327. *doi:10.1016/B978-0-444-53813-0.00004-6*

Nickel, L.A. & Atkinson, R.J.A. 1995. Functional morphology of burrows and trophic modes of three thalassinidean shrimp species, and a new approach to the classification of thalassinidean burrow morphology. *Marine Ecology Progress Series*, **128**:181–197.

Palma-Ramírez, A.; Maldonado-Sarabia, R.C. & Stimson, M.R. 2019. Marginal marine trace-fossils from the Cárdenas Formation (Maastrichtian), Rayón municipality, San Luis Potosí, central Mexico. *Revista Brasileira de Paleontologia*, **22**:89–96. *doi:10.4072/rbp.2019.2.01*

Pemberton, S.G. & Frey, R.W. 1982. Trace-fossil nomenclature and the *Planolites-Palaeophycus* dilemma. *Journal of Paleontology*, **56**:843–881.

Pemberton, S.G.; Spila, M.; Pulham, A.J.; Saunders, T.; MacEachern, J.A.; Robbins, D. & Sinclair, I.K. 2001. *Ben Nevis & Avalon Reservoirs, Jeanne d'Arc Basin*. St. John's, Geological Association of Canada, Short Course Notes 15, 343 p. *doi:10.1669/0883-1351(2003)018<0471: IASOST>2.0.CO;2*

Pervesler, P. & Uchman, A. 2004. Ichnofossils from the type area of the ground formation (Miocene, Lower Badenian) in Northern Lower Austria (Molasse Basin). *Geologica Carpathica*, **55**:103–110.

Rodríguez-Tovar, F.J.; Alcalá, L. & Cobos, A. 2016. *Taenidium* at the lower Barremian El Hoyo dinosaur tracksite (Teruel, Spain): assessing palaeoenvironmental conditions for the invertebrate community. *Cretaceous Research*, **65**:48–58. *doi:10.1016/j.cretres.2016.04.013*

Ruault-Djerrab, M.; Kechid-Benkherouf, F. & Djerrab, A. 2014. Données paléoenvironnementales sur le Vraconnien/Cénomanien de la région de Tébessa (Atlas Saharien, nord-est Algérie). Caractérisation de l'OAE2. *Annales de Paléontologie*, **100**:343–359. *doi:10.1016/j.annpal.2014.03.002*

Smilek, K.R. & Hembree, D.I. 2012. Neoichnology of *Thyonellagemmata*: a case study for understanding holothurian ichnofossils. *The Open Paleontology Journal*, **4**:1–10. *doi:10.2174/1874425701204010001*

Stanley, T.M. & Feldmann, R.M. 1998. Significance of nearshore trace- fossil assemblages of the Cambro-Ordovician Deadwood Formation and Aladdin Sandstone, South Dakota. *Annals of Carnegie Museum*, **67**:1–51.

Sundberg, F.A. 1983. *Skolithos linearis* Haldeman from the Carrara Formation (Cambrian) of California. *Journal of Paleontology*, **57**:145–149.

Uchman, A. 1995. Taxonomy and palaeoecology of flysch trace-fossils: the Marnoso-arenacea Formation and associated facies (Miocene, Northern Apennines, Italy). *Beringeria*, **15**:3–115.

Uchman, A. 1998. Taxonomy and ethology of flysch trace-fossils: a revision of the Marian Książkiewicz collection and studies of complementary material. *Annales Societatis Geologorum Poloniae*, **68**:105–218.

Uchman, A. & Hanken, N.M. 2013. The New Trace-fossil *Gyrolitheslorcaensis* isp. n. from the Miocene of SE Spain and a Critical Review of the *Gyrolithes* Ichnospecies. *Stratigraphy and Geological Correlation*, **21**:312–322. *doi:10.1134/S0869593813030088*

Vinn, O. & Wilson, M.A. 2013. An event bed with abundant *Skolithos* burrows from the late Pridoli (Silurian) of Saaremaa (Estonia). *Carnets de Géologie*, **13**:83–87.

Wetzel, A.; Blechschmidt, I.; Uchman, A. & Matter, A. 2007. A highly diverse ichnofauna in Late Triassic deep-sea fan deposits of Oman. *Palaios*, **22**:567–576. *doi:10.2110/palo. 2006.p06-98r*

Wetzel, A. & Bromley, R.G. 1996. Re-evaluation of the ichnogenus *Helminthopsis*-a new look at the type material. *Palaeontology*, **39**:1–19.

Wilson, E.O. 1971. *The insect societies*. Cambridge, Belknap Press, 548 p.

Wilson, M.A. & Rigby, J.K. 2000. *Asteriacites lumbricalis* von Schlotheim 1820: ophiuroid trace-fossils from the Lower Triassic Thaynes Formation, central Utah. *Ichnos*, 7:43–49. *doi:10.1080/10420940009380145*

Yochelson, E.L. & Fedonkin, M.A. 1997. The type specimens (Middle Cambrian) of the trace-fossil Archaeonassa Fenton & Fenton. *Canadian Journal of Earth Sciences*, **34**:1210–1219. *doi:10.1139/e17-097*

Yuanyuan, W.; Xueqin, W.; Uchman, A.; Bin, H. & Huibo, S. 2019. Burrows of the polychaete *Perinereis aibuhiutensis* on a tidal flat of the yellow river delta in China: implications for the ichnofossils *Polykladichnus* and *Archaeonassa*. *Palaios*, **34**:271–279. *doi:10.2110/palo.2018.105*

Received in 01 January, 2021; accepted in 02 June, 2021.