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Deep-sea trace fossils from the Numidian Formation (Upper Oligocene–Lower Miocene) of the Ouarsenis Mountains, northwestern Algeria

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Trace fossils and lithofacies have been studied for the first time in the Numidian Formation (Upper Oligocene–Lower Miocene) of the Ouarsenis Mountains in Algeria to interpret their depositional environment. Twenty-two ichnogenera have been recognized in eight lithofacies of three main facies associations in four representative sections. Distribution of the trace fossils is dependent on the facies. Most trace fossils are dominated by post-depositional forms (62%) and occur in fine-grained, thin-bedded sandstones of facies F4. They belong to the *Ophiomorpha rudis, Paleodictyon* and the *Nereites* ichnosubfacies of the *Nereites* ichnofacies. The *O. rudis* ichnosubfacies is recorded in 1) medium- to very thick-bedded sandstones of the facies association FA1, interbedded with thinner sandstone beds of the facies F2 and F4 in the upper unit of the sections studied, which were deposited in channel fill and levee-overbank environments, and in 2) medium- to thin-bedded sandstones of the facies association FA2 in the lower unit of the Kef Maiz and the Ain Ghanem sections, which were deposited in isolated narrow channels within the mud-dominated part of the depositional system and occasionally fed with turbiditic sand. The *Paleodictyon* ichnosubfacies occurs in thin- to medium-bedded sandstones (FA2) of the lower units in the Ain Ghanem and Kef Maiz sections and the lowest part of the upper unit of the Kef Maiz section, which were deposited in channel margin or foremost channel-to-levee-overbank areas. The *Nereites* ichnosubfacies is recorded in thin-bedded sandstones (FA2), which were deposited in crevasse-splays or small lobes on a basin floor invaded occasionally by turbidites against a background of pelagic and hemipelagic sedimentation.

Key words: ichnology, flysch, turbidites, Atlas, Paleogene, Neogene.

INTRODUCTION

The Numidian Formation (NF) is an extensive deep-sea succession of clastic deposits, with outcrops running 2500 km along a 100 km wide belt extending from Gibraltar through Morocco, Algeria, and Tunisia to Calabria (Fig. 1). It is placed within the Maghrebian orogenic domain known as the Maghrebides (Durand-Delga and Fonboté, 1980; Wildi, 1983). The term “Numidien” was coined for the first time by Ficheur (1890) to define the Numidian stage (corresponding to the Upper Eocene), which was represented (as understood at that time) by a series of clays overlain by thick-bedded sandstones in the Algerian coastal chains to the NW of Great Kabylia. This term was introduced in Tunisia by Aubert (1891) and in Morocco by Fallot (1937). Later, the Numidian stage was transferred to the rank of “facies” to distinguish the Numidian succession composed of successions of mudstone and sandstone, at the same time when the new concept of allochthonous tectonics in the Algerian Tell was established (Glangeaud, 1932; Flandrin, 1948).

Many multidisciplinary studies on the NF deposits were made in the Mediterranean region, but very few in Algeria, where they refer mostly to the regional geology and are commonly limited to general geological data. The first detailed sedimentological study on the NF in Algeria was carried out by Hoyez (1989) and Moretti et al. (1991) in the Constantine Mountains. Much later, a brief sedimentological study was carried out in the Forêt des Cèdres outcrops of the Ouarsenis Mountains by Menzoul et al. (2019).

In this paper, trace fossils and sedimentological data from the NF in the Ouarsenis Mountains, NW Algeria, are described and interpreted. Following the work of Riahi et al. (2014) in Tunisia, this is the second modern publication on the ichnology of

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the NF outcropping in the southern Mediterranean. This allows for a comparison of ichnological features in these two areas.

There is only scattered published data on the ichnology of the NF in Algeria. Durand Delga (1955) mentioned the presence of *Tubotomaculum* (*Tubulichnium* in this paper) in varicoloured clays in the basal part of the NF in the Constantine region, NE Algeria, and interpreted it as burrow fillings lined with tiny coprolites. Mattauer (1958) reported unnamed trace fossils at the top of a sandstone bed in the Forêt des Cèdres outcrops.

GEOLOGICAL SETTING

The Numidian Formation (NF) in Algeria is composed mostly of deep sea turbiditic sandstone and mudstone deposits, which are Late Oligocene to Early Burdigalian in age (Durand Delga and Magné, 1958; Mattauer, 1958; Polvêche, 1960; Magné and Raymond, 1972; Raoult, 1974; Raymond, 1976; Bizon and Hoyez, 1979; Lahondère et al., 1979; Feinberg et al., 1981; Hoyez, 1989, Moretti et al., 1991). In this paper, the term Numidian Formation (NF) is used instead of Numidian Flysch, because the term "flysch" is considered as ambiguous in application to these deposits (Patacca et al., 1992; Guerrera et al., 1993, 2012). Deposits of the NF accumulated in the Maghrebian Flysch basin, which opened after the Pangaea breakup during the Jurassic-Cretaceous transition. They form a part of the Maghrebian domain, which is interpreted as an Alpine-type orogen resulting from closure of the Maghrebian part of the Tethys Ocean (Wildi, 1983; Bouillin, 1992). In general, sedimentation of the NF deposits ceased 16–15 Ma at the end of the Burdigalian (see Vila et al., 1994; Esteras et al., 1995) except for the Apennines and Sicily where it extended into the Langhian (Guerrera et al., 2005; Thomas et al., 2010; Pinter et al., 2018; Butler et al., 2020). Finally, the NF underwent south-verging folding and thrusting because of the Kabylides accretion to Africa, which started 15 Ma at the beginning of the Langhian (Frizon de Lamotte et al., 2000). Part of the flysch succession was detached as thrust sheets and overthrust on the external zone of the Tell deposits (Bouillin, 1977; Vila, 1980). This influenced the distribution of the NF in several, commonly isolated areas in northern Algeria (Fig. 1).

The NF occurs in three different zones (Bouillin, 1986), i.e. in (1) an internal position, superimposed on the Kabylia massifs, where the NF deposits are referred to as the North Kabylide Flysch, in (2) a relatively external position on the southern margin of the Kabylia massifs, where the NF is called the South Kabylide Flysch, and in (3) a far external position, as isolated masses floating on the Tellian succession (Paleozoic–Eocene), where they have been tectonically shifted up to a hundred kilometres to the south, and are preserved in the hinges of synclinal folds. The study area in the Ouarsenis Mountains refers to this latter zone.

The most stratigraphically complete deposits of the NF are present in the outcrops of Great Kabylia. It was subdivided for the first time by Raymond (1976) into three members: (1) a lower member (Upper Oligocene) represented by varicoloured clays with the common trace fossil "*Tubotomaculum*" (assigned to *Ophiomorpha recta* in Riahi et al., 2014 and *Tubulichnium mediterraneum* in Uchman and Wetzel, 2017); (2) a middle member (Aquitanian) represented by alternating sandstones, quartz pebble conglomerates and mudstones; this is known as the Numidian Sandstone; and (3) an upper member (Aquitanian to lower Burdigalian) formed by mudstones, marlstones and cherts ("silexites") and referred to as the supra-Numidian succession. This lithostratigraphic scheme is similar to those in other Mediterranean outcrops of the NF, i.e. in Tunisia (Glacon and Rouvier, 1967; Rouvier, 1977; Riahi et al., 2010, 2015), Sicily (Broquet, 1968; Guerrera et al., 1992; Patacca, 1992), the Apennines (La Manna et al., 1995), Spain (Didon et al., 1984; Martin Algarra, 1987; Esteras et al., 1995), and Morocco (Chalouan et al., 2008).

GENERAL OVERVIEW OF THE GEOLOGY OF THE STUDY AREA

The NF of the Ouarsenis Mountains in NW Algeria forms part of the External Zone of the Algerian Northern Belt (Fig. 1). The Ouarsenis Mountains are bordered to the north by the Chelif Plain (developed on a vast Neogene basin) and by Mount Zaccar (Djebel Zaccar), to the south by the Sersou Plateau, to the east by the Bibans Mountains (near Médéa city) and by the post-Miocene formations of the Miliana region; to the west, there is no distinct boundary, although Polvêche (1960) considered the Miocene deposits of Zemmoura as the western boundary of the Ouarsenis Mountains. The NF in the study region occurs in a complex of allochthonous units stacked above Triassic and Cretaceous deposits (Mattauer, 1958; Polvêche, 1960). It comprises two main lithological units: (1) varicoloured (greenish to dark brown) marly mudstone of the Upper Oligocene at the base (the equivalent of the lower member in Great Kabylia); and (2) alternating sandstones, quartz pebble conglomerates and bluish-grey mudstones at the top (Mattauer, 1958), which are an equivalent of the middle member in Great Kabylia. The contact between these two units is unclear (covered) in the study area; it is distinguished by a lithological change. The correlation between the lithostratigraphic divisions of the study area and the Great Kabylia is based on lithological similarities and biostratigraphic data. Mattauer (1958) found macroscopic foraminifera in the varicoloured mudstone of the study area, which dated them to the upper Oligocene, similarly to the lower member in the Great Kabylia. Investigation of foraminifers and calcareous nannoplankton in the upper unit did not give any biostratigraphic results, as with previous attempts.

The NF outcrops are scattered along several localities along the Ouarsenis Mountains. Studies for this paper were focused on (1) the Theniet El Haad region, including three main outcrops (Forêt des Cèdres, Ain Ghanem, and Kef Rzama), which are situated at 7 km, 12 km and 2.5 km north-west of Theniet El Had town, respectively, and ~50 km north-east of Tissemsilt city, and on (2) the Chlef region with one principal outcrop on the Kef Maiz mountain, which is located 4 km to the north of Ouled Ben Abdelkader town and 20 km to the south-west of Chlef city (Fig. 1).

SEDIMENTARY FACIES

The NF deposits in the studied sections consist of siliciclastic turbidites associated with hemipelagic mudstones. They are organized into two lithostratigraphic units except for the Forêt des Cèdres section which shows only the sandstone-dominated upper unit. Ten thin sections were prepared and examined under polarizing microscope in order to confirm lithological determinations in the field and obtain a brief overview of the mineralogical content. Preliminary data on the sandstone composition show a quartz-dominated mineral assemblage, with minor contributions of feldspar, muscovite and polycrystalline quartz. Dispersed heavy minerals grains include zircon, tourmaline, glauconite and opaque minerals. Based on bed thickness, sedimentary structures, grain size, texture, and petrographic content, eight distinct facies have been identified (Fig. 2).

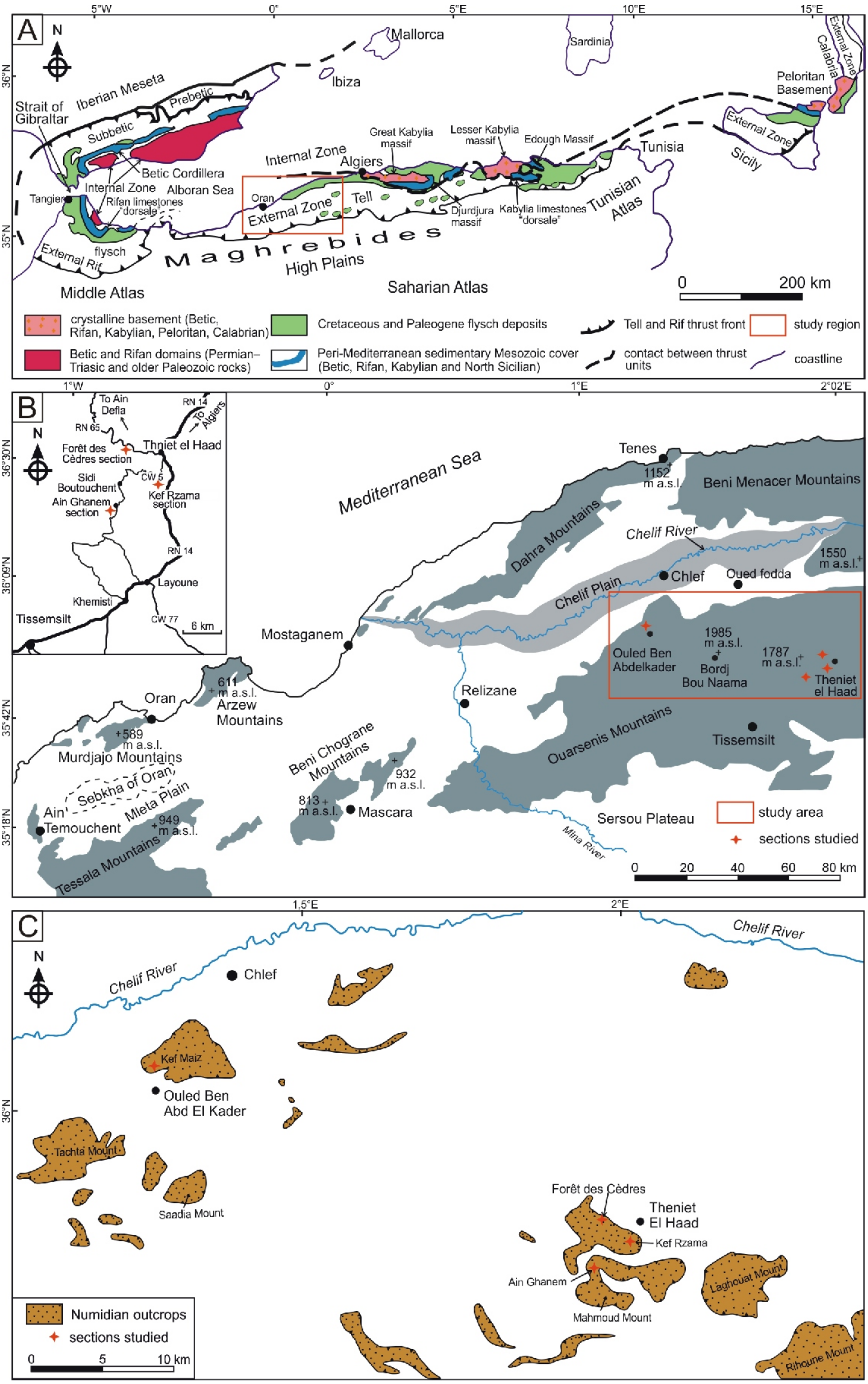

Fig. 1A – location of the study area with indication of the principal Alpine domains in the western Mediterranean (after Durand-Delga, 1969, modified); B – map showing the location of the Ouarsenis Mountains; C – map showing the distribution of the principal Numidian outcrops in the Ouarsenis Mountains

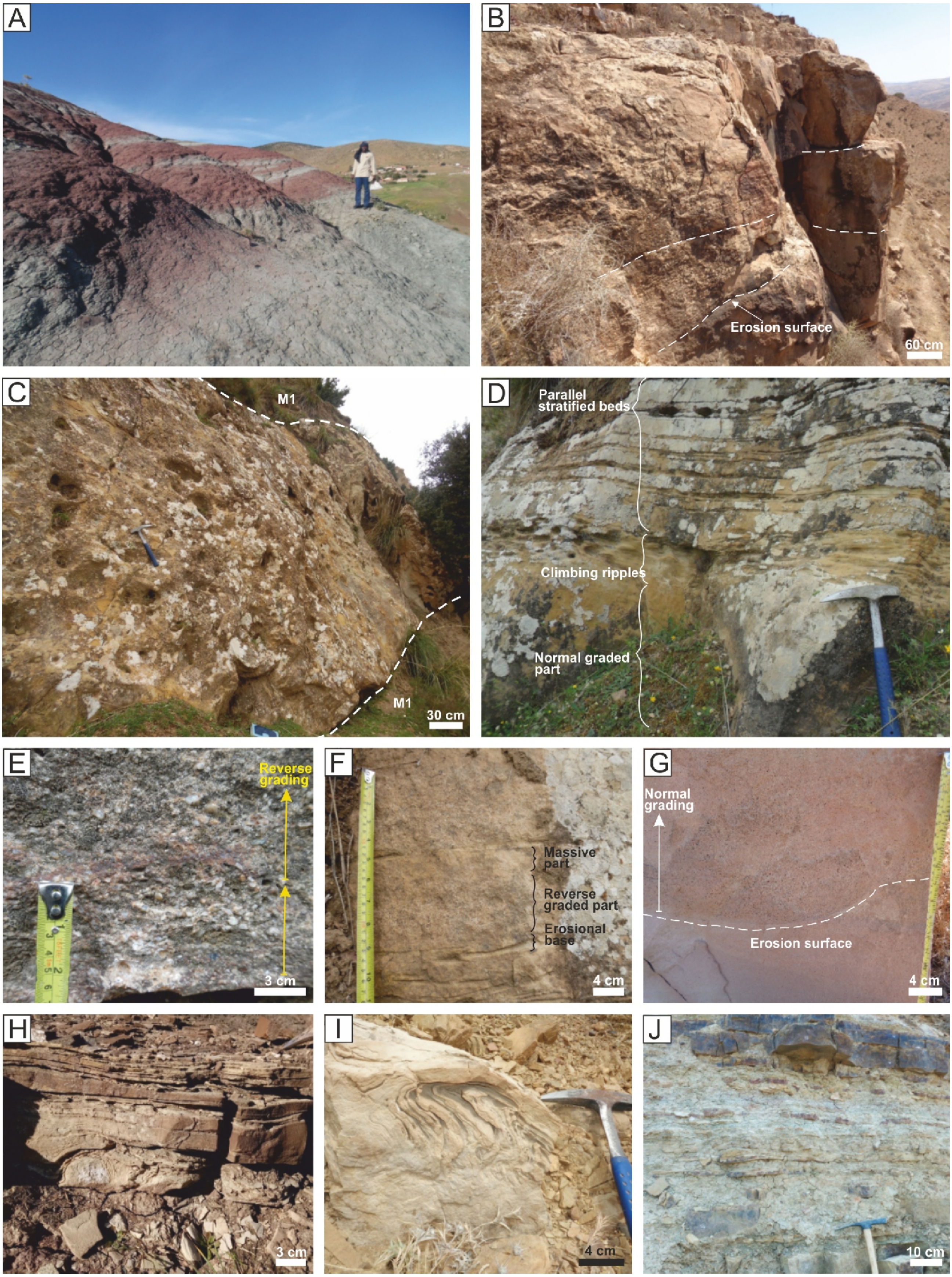

Fig. 2. Lithofacies in the field

A – varicoloured marly mudstones facies (F8) in the lower unit of the Ain Ghanem section; **B** – massive sandstone beds (F1) in the upper unit of the Kef Maiz section; **C** – mud-rich sandstone facies (F5) in the upper unit of the Kef Rzama section; **D** – package of sandstone beds showing reverse and normal grading in the lower part, capped with climbing ripples, and followed by parallel-stratified sandstone beds (F3), in the upper unit of the Kef Rzama section; **E** – detail of reverse-graded pebbly sandstone (F3) from (D); **F** – detail of parallel-stratified beds (F3) shown in (D); **G** – beds showing normal grading with amalgamation (F2), in the upper unit of the Kef Maiz section; **H** – medium- to fine-grained sandstone (F4) showing convolute lamination, in the lower unit of the Ain Ghanem section; **I** – soft-sediment deformed sandstone (F6), in the lower unit of the Kef Maiz section; **J** – mudstone alternating with siltstone and discontinuous sandstone beds, in the upper unit of the Kef Maiz section

The terminology and symbols used for the sedimentological description are after Tucker (2003) and Collinson et al. (2006). Bed thickness classification is after Ingram (1954), with laminae (<1 cm), very thin beds (1–3 cm), thin beds (3–10 cm), medium beds (10–30 cm), thick beds (30–100 cm) and very thick beds (>100 cm). The lithofacies classification is after Stow et al. (1985), Pickering et al. (1986), Mutti (1992), and Pickering and Hiscott (2015).

LITHOFACIES

F1: Structureless massive sandstone (Fig. 2B). This facies consists of fine- to medium-grained, thick- and very thick-bedded sandstones, commonly occurring as a package of amalgamated beds, 0.40–11 m thick, and <150 m in lateral extent. The beds are non-graded, showing sharp, erosional bases, sharp tops, and uneven thicknesses. They are generally structureless except for some soft sediment deformation structures, which include hydroplastic deformation, fluid-escape structures (pillar and dish structures) and load casts on bed soles. The fine-grained sandstones, which are mostly present in the upper part of the beds, are rich in muscovite and floating mud clasts. Such beds are capped in some parts with greenish mudstone intercalated with discontinuous siltstone laminae. Trace fossils are absent.

Interpretation. The product of concentrated density flows, deposited from rapidly decelerating flows (Arnott and Hand, 1989; Kneller and Branney, 1995), or from rapid mass deposition due to intergranular friction in a concentrated dispersion (Pickering and Hiscott, 2015). At small scale, these beds are comparable to division S3 in Lowe's (1982) scheme, and facies F8 of Mutti (1992).

F2: Normally-graded, medium- to very coarse-grained sandstone (Fig. 2G). This facies consists of one bed or a package of two to four beds of medium- to thick-bedded sandstones (10–80 cm thick), which show uneven thickness. The sandstones of facies F2 are medium-, coarse- to granule-grained, with normal grading. Their bases show abundant scour marks (gutter casts, flute casts, casts of obstacle scours) and tool marks (groove casts). Sedimentary structures are common, including parallel lamination and convolute lamination. In some beds, normal grading is followed by plane parallel lamination and occasionally by convolute lamination and ripple cross-lamination. Fluid escape structures are rare. Some beds show amalgamation. In this facies, the beds are often capped with silt-laminae and mudstone intervals. Floating mud clasts, greenish in colour, 0.2 to 5 cm in size, are randomly distributed in the upper part of some beds. Trace fossils are rare, including *Thalassinoides* isp. recorded within normally graded intervals and *Ophiomorpha rudis* recorded within plane parallel lamination intervals.

Interpretation. This facies is probably the result of concentrated density flows. The normally graded intervals (equivalent to Ta intervals of Bouma, 1962) were deposited grain-by-grain from suspension, with rapid burial and no significant traction transport on the bed (Pickering and Hiscott, 2015). The higher intervals Tb, Tc, and Td in the upper part of facies F2 probably resulted from continuing deposition by low-density turbidity currents characterized by occasional periods of sediment reworking or bypassing (Talling et al., 2012).

F3: Inversely-graded pebbly sandstone to parallel-stratified sandstone (Fig. 2E, F). This facies occurs only once in the Kef Rzama section as a thin package (2–2.60 m thick) of amalgamated sandstone beds. This package begins with an erosional surface. The lower part of the package shows repetitive intervals of inversely graded pebbly sandstone followed by normally graded sandstone and capped with sandstone showing climbing ripple lamination. The upper part of the package is composed of repetitive amalgamated beds of medium- to coarse-grained sandstone (10–15 cm thick). Each of these beds shows an erosional base, inverse grading in the lower part and massive sandstone in the upper part. Groove casts are frequent in the sandstone bases. The whole package is capped with mudstone alternating with siltstone.

Interpretation. The reverse grading probably resulted from the "kinetic sieve" process, whereby coarser grains rise to the top because of sheared dispersion (Middleton, 1970), or from coarser subpopulations of grains lagging behind finer subpopulations along the transport path (Hand and Ellison, 1985). It was deposited by concentrated density flows (Pickering and Hiscott, 2015) generating the climbing ripples, with some episodes of bypass (Lowe, 1982). The lower part of the reverse-graded beds corresponds to the traction carpet, similar to facies F5 of Mutti (1992) and division S2 of Lowe (1982). The overlying parallel-stratified sandstone beds were documented for the first time by Hiscott and Middleton (1979) and later referred to as "spaced stratification" by Hiscott (1994b); they are interpreted as a result of concentrated density flows, in which the lower erosional surface and the inversely graded intervals are formed by repeated burst-sweep cycles of large turbulent eddies and the overlying massive part is formed by rapid fallout from suspension. This facies does not reveal any trace fossils.

F4: Medium- to fine-grained sandstone (Fig. 2H). This facies comprises medium- to thin-bedded sandstones (3–30 cm thick), showing uneven thickness. Individual beds extend <100 m in the exposures. Some beds are structureless, whereas others are parallel and/or convolute laminated and with rare load casts on their soles. The beds are generally capped with mudstone and siltstone. Occasionally, this facies occurs as a stacked unit composed of 2 to 4 beds separated by very thin layers of mudstone. Trace fossils are very common in the thinner beds, including almost all the ichnotaxa recorded in this study, with (1) pre-depositional forms (*Spirophycus bicornis, Spirophycus* isp., *Oravaichnium* isp.*, Phycodes* isp., *Thorichnus* isp., *Squamodictyon tectiforme, Megagrapton irregulare,* ?*Arthrophycus tenuis*, *Cosmorhaphe lobata, C. sinuosa, Gordia arcuata, Helminthoidichnites* isp., *Helminthopsis* isp., *Paleomeanderon rude, Rutichnus* isp., *Paleodictyon strozzii*) and (2) post-depositional forms *(Planolites montanus, P. beverleyensis,* ?*Planolites* isp.*, Siphonichnus* isp., *Nereites* isp.*, Chondrites* isp., *Phycosiphon incertum, Taenidium* isp., *Lophoctenium* isp., ?*Scolicia vertebralis, S. strozzii, Gyrochorte* isp., *Zoophycos* isp., *Oravaichnium* isp.*, Halimedides* isp., *Ophiomorpha annulata, O. rudis, Palaeophycus tubularis*, *Palaeophycus striatus, Palaeophycus* isp., ?*Parataenidium* isp., *Thalassinoides* isp., *Tubulichnium rectum, Lockeia* isp. and *Diplocraterion* isp.). The thicker beds of this facies are poorly bioturbated. They may contain: *Thalassinoides* isp., *Diplocraterion* isp. and *Zoophycos* isp.

Interpretation. These beds were probably deposited by low-density turbidity currents. Their internal structures correspond to intervals Ta, Tc, Td, and Te of Bouma (1962).

F5: Mudclast conglomerates (Fig. 2C). This facies occurs only in the Kef Rzama section. It comprises very fine- to medium-grained, very thick-bedded, massive, muddy, pebbly sandstones, organised in bodies of variable thickness (1–4 m). The sandstones contain dispersed quartz pebbles associated with siltstone and mudstone as contorted beds or intraformational clasts ranging from 10 cm to a metre in size. The intraformational clasts are built of gently to highly folded sandstones (similar to facies F4), siltstones or mudstones, which show convolute lamination, and ball and pillow structures. The bases and tops of these beds are uneven, the whole body being lens-shaped.

Interpretation. This facies was deposited from cohesive debris flows and mudflows (Talling et al., 2012; Pickering and Hiscott, 2015 and references therein; Shanmugam, 2021).

F6: Soft-sediment deformed sandstone/siltstone (Fig. 2H, I). This facies is characterized by a multitude of soft-sediment deformation structures commonly observed within fine- to medium-grained sandstones and siltstones. The deformation structures range from centimetre-scale convolute lamination to slump folds in metre-scale thick-bedded sandstone. Convolute lamination commonly occurs within fine-grained, thin- and medium-bedded sandstone/siltstone. Fluid escape structures are common within massive sandstone beds. Load casts are common on the lower surfaces of medium- to fine-grained massive sandstone beds. The slump folds occur within fine- to medium-grained, medium- to very thick-bedded sandstone (ranging from decimetres to metres in thickness), commonly in the sand-dominated parts between undisturbed strata or as isolated units in the mud-dominated parts of some sections.

Interpretation. The features of soft sediment deformation structures are related to fluidization processes, which create gravitational instabilities (Allen, 1982; Owen, 1996). The slump folds resulted from slope-down shear stress (Allen, 1982). The triggers may have included earthquakes, sediment loading and wave action (Owen, 2008).

F7: Mudstone with siltstone and sandstone (Fig. 2J). Facies F7 consists of light green, light grey to dark grey laminated mudstones, 5 to 300 cm thick. Some parts of the mudstones contain multiple intercalations starting with thin- to very thin-bedded, parallel-laminated sandstone followed by siltstone and mudstone. The laminated siltstones and very fine-grained sandstones may occur as lenses. This facies is interbedded with all previously described facies.

Interpretation. Facies F7 shows the Bouma divisions Td, Te and/or the Stow divisions T6 and T7. It results from suspension fall-out during a final gravity flow event associated with hemipelagic sedimentation (Stow and Shanmugam, 1980; Stow and Piper, 1984).

F8: Varicoloured marly mudstone (Fig. 2A). Facies F8 constitutes the main component of the lower units of almost all the sections studied. It consists of multicoloured (greenish, reddish to dark brown, grey to dark grey) massive marly mudstones (1.11–23% $CaCO_3$), very rich in full relief trace fossils, including ?*Alcyonidiopsis* isp., and *Tubulichnium mediterraneum*. This lithofacies contains some discontinuous intercalations of siltstone and thin-bedded fine-grained sandstone, of ferruginous rusty to brownish colour, showing parallel lamination in some parts. Diagenetic septarian concretions are common. Isolated slump/slide-deformed, medium to fine-grained sandstones of facies F6 occur as rare intercalations in the mudstone. A preliminary biostratigraphic study revealed rare agglutinated foraminifera, such as *Glomospira* isp., *Ammodiscus* isp., *Paratrochamminoides* isp., *Haplophragmoides* isp., *Trochamminoides* isp., and *Recurvoides* isp.

Interpretation. The mudstone was deposited from suspension settling of a ponded mud cloud after flow cessation and from hemipelagic processes and suspension fall-out during the final gravity flow event. The rare siltstone/sandstone intercalations resulted from low-density turbidity currents (Stow and Piper, 1984; Pickering et al., 1986; Stow et al., 1996; Stow and Tabrez, 1998).

FACIES ASSOCIATIONS

The lithofacies described allowed distinction of three main facies associations (FA). Each facies association corresponds to a depositional sub-environment setting.

FA1. Sand-rich facies association (channel-fill). FA1 characterizes the upper parts of all the sections studied. It comprises mostly massive sandstones of facies F1, which occur in packages of amalgamated sandstone beds, with or without mudstone intercalations of facies F7. Facies F2, F6 and F4 are less common, and facies F5 is very rare. Facies association FA1 is 30–60 m thick and occurs in bodies that extend across <150 m, and which show a common thinning- and fining-upwards trend. These bodies are interbedded with or pass laterally into FA2. Facies F3 and F5 occur only in the upper unit of the Kef Rzama section as isolated thick beds capped with facies F7 and followed by facies F1. Trace fossils (*Thalassinoides* isp., *Ophiomorpha rudis*) occur within the thinner sandstone beds. FA1 is comparable to the massive sandstone facies, including deep-water massive sands (DWMS) described by Stow and Johansson (2000) and interpreted as the product of high-density turbidity current and sandy debris flows. This facies association has been reported from the NF of Sicily (Johansson et al., 1998) and Tunisia (Riahi et al., 2009; Riahi et al., 2021). The main characteristics of FA1, such as sand richness, erosional features, amalgamation, lateral discontinuity of beds, and fining- and thinning-upwards trends indicate a channel-fill environment (Mutti and Ricci Lucchi, 1975; Walker, 1978; Normark, 1978; Hendry, 1978; Stow and Johansson, 2000; Huneke and Mulder, 2010).

FA2. Mudstone and sandstone alternations (channel margin, channel-levee-overbank and crevasse-splays facies association, probably lobes). This facies association includes mainly facies F4 and F7 and occasionally facies F2. It is represented by fine-, medium- to coarse-grained, thin- to medium-bedded sandstone (a few centimetres to 50 cm thick) alternating with thin- to very thick-bedded mudstones and siltstones (F7). FA2 displays a lenticular shape (<50 m in lateral extent) in transverse section, reduced Bouma intervals (Tae, Tade, Tae, Tbde, Tbcde, Tcde), as well as thinning, thickening- and fining-upwards trends. This facies association is interpreted as the product of medium to low density turbidity currents interrupting hemipelagic sedimentation. FA2 occurs in three main stratigraphic positions: (1) in the lower part (Upper Oligocene) of the Ain Ghanem and Kef Maiz sections as isolated lithological units within marly mudstone (F8), (2) in the lower part of the upper unit of the Kef Maiz section, and (3) as intercalations with FA1 in the upper units of all the sections studied. These features suggest deposition within narrow isolated submarine channels and/or in a crevasse-splay setting (Mutti and Ricci Lucchi, 1975; Walker, 1978; Normark, 1978; Hendry, 1978; Stow and Johansson, 2000; Huneke and Mulder, 2010; Pickering and Hiscott, 2015 and references therein). Alternations of mudstones/siltstones of facies F7 and sandstones of facies F4, convolute lamination, folds, reduced Bouma intervals, and thinning- and fining-upwards trends suggest deposition within channel-levee, overbank or crevasse-splay settings (cf. Pickering et al., 1995; Hubbard et al., 2008; Huneke and Mulder, 2010; Pickering and Hiscott, 2015).

FA3. Mud-rich facies association (basin floor facies association). This facies association is composed mainly of facies F8 (varicoloured marly mudstone), occurring in the lower unit of all the sections studied except for the Forêt des Cèdres section. It includes isolated bodies of mudstone and sandstone alternations of facies association FA2 (F7 alternating with F2 and F4, <50 m wide), slump-slide units of medium- to fine-grained sandstones (F6), and rare, thin- to very thin-bedded sandstones isolated within mudstones. Full relief trace fossils are common in this unit, including ?*Alcyonidiopsis* isp. and *Tubulichnium mediterraneum.* The latter trace fossil was reported from deep-sea Cretaceous-Paleogene strata in the Mediterranean region, especially in mudstones of the lower part of the NF (Pautot et al., 1975).

The previous data imply that these sediments were deposited on basin-floor or slope-apron settings, which were cut by sparse, narrow channels. The channels were fed by occasional turbidites, which generated some crevasse-splays or small lobes at their terminations. The abundance of facies F6, mostly in the Kef Maiz section, suggests deposition within slope settings (cf. Stow and Johansson, 2000).

DESCRIPTION OF THE SECTIONS STUDIED

KEF RZAMA SECTION (FIG. 3)

The Kef Rzama section is 127 m thick. The beds gently dip (10–15°) to the SSW, and strike at NNW–SSE. The section comprises (1) a lower unit dominated by varicoloured mudstones (facies association FA3), very rich in full relief trace fossils *Tubulichnium mediterraneum* and rare ?*Alcyonidiopsis* isp., and (2) an upper unit, which is sand-dominated (FA1) and consists of facies F1, F2, F3, F5, and F4 (0.07–6 m thick) alternating with facies F7 (0.05–3 m thick).

AIN GHANEM SECTION (FIG. 4)

The Ain Ghanem section is 154 m thick. The beds weakly dip (10–15°) to the NNE and strike at ESE–NNW. Two main units have been distinguished: (1) a lower unit, mud-dominated (FA3), with the abundant full relief trace fossil *Tubulichnium mediterraneum,* including isolated bodies of FA2, composed of an alternation of mudstone and beds of facies F4, F2 (0.03–0.75 m), commonly deformed, and in an overturned position, showing different dip angles. The thinner beds of facies F4 are intensely bioturbated. A single thin limestone bed (0.07 m), greenish in colour, occurs within a series of thin beds of facies F4; (2) the upper unit is sand-dominated (FA1), composed of beds of facies F1 and F2 (0.05–6 m), including a few intercalations of facies F7 (0.05–3 m). The mudstone-dominated intervals (F7) include thin ferruginized beds (F4) rich in *Tubulichnium mediterraneum* and septarian concretions.

KEF MAIZ SECTION (FIGS. 5 AND 6)

The Kef Maiz section is 233 m thick. The beds are tabular in general, striking at NNE–SSW. The section includes two distinct units: (1) a lower unit which is mud-dominated (FA3) and consists of facies F8, contains isolated bodies of FA2 and alternations of mudstones and beds of F4 (3–30 cm); facies F4 is commonly deformed and very rich in trace fossils. Isolated very thin- to thin-bedded sandstones of facies F4 occur separately within the mudstones. Deformed thick-bedded sandstones (F6) (0.30–2 m) occur randomly as isolated masses within marly mudstone (F8); (2) the upper unit is sand-dominated (FA1), composed of beds of facies F1, F2, and F4 (0.05–7 m thick) alternating with facies F7 (0.07–1.10 m thick). Conglomerates are very rare and occur in thin layers within the sandstone beds (F2). The mudstone-dominated intervals (F7) contain beds of facies F4 which are rich in trace fossils. Thin to thick beds of friable (non-cemented) silty sandstones (0.07–0.80 m thick) occur between beds nos. 25 and 26.

FORÊT DES CÈDRES SECTION (FIG. 7)

This section is 56 m thick and well exposed in a road cut; however, only the sand-dominated facies association FA1 of the upper unit of the NF may be observed. The beds are in an overturned position, steeply dipping (60–70°) to the SW and striking at ~150° (i.e. NNE–SSW). Some faulted/folded beds show a gentler dip. This section belongs to FA1, and consists of beds of facies F1, F2, and F4 (0.15–11 m thick), alternating with facies F7 (0.10–0.30 m thick). The sandstone beds (F4) are generally rich in muscovite and contain trace fossils. Post-depositional deformation structures are common in a few beds, especially in fine- to medium-grained, non-graded sandstone beds (F1), including slump folds, load casts, and fluid escape features. The uppermost part of this section shows thicker mudstone intervals (F7) (0.05–1.50 m thick), including beds of facies F4, which are 0.10–0.15 m thick.

TRACE FOSSILS

Four sections were logged bed-by-bed with the main focus on the trace fossil content. The ichnofossils were photographed in the field. Their distribution is marked in the lithological columns whenever possible. For determination of their diversity, the terminology of Knaust (2017) is used, where: very rare refers to 1 ichnotaxon, rare – 2–6 ichnotaxa, common – 7–9, very common – 10–22, abundant – 23–41, and very abundant – >42 ichnotaxa. The trace fossils illustrated were left in the field. The occurrences and abundance of trace fossils are summarized in Table 1.

CIRCULAR AND ELLIPTICAL STRUCTURES

Lockeia James, 1879
Lockeia isp.
(Fig. 8B, C)

D e s c r i p t i o n. – A hypichnial, isolated, elongate, slightly curved, smooth, almond-shaped mound, preserved in full relief. The two specimens illustrated are 13 mm long and 8 mm wide, and 9 mm long and 4 mm wide.

R e m a r k s. – *Lockeia* is commonly interpreted as a bivalve resting trace produced by its wedge-shaped foot (Seilacher and Seilacher-Drexler, 1994). However, small crustaceans may also produce such traces (Bromley and Asgaard, 1979). *Lockeia* in general has formed in marine and non-marine environments since the ?late Cambrian (Fillion and Pickerill, 1990).

SPIRAL STRUCTURES

Spirophycus Häntzschel, 1962
Spirophycus bicornis (Heer, 1877)
(Fig. 8G, I, J)

D e s c r i p t i o n. – Hypichnial, horizontal, semi-circular ridge ending with one spiral whorl. The specimens analysed are 10–30 mm wide, at least 40–115 mm long, filled with the same material as the host sediment, smooth or occasionally covered with rare tubercles and preserved in semi-relief. The spiral whorl is 48–75 mm wide.

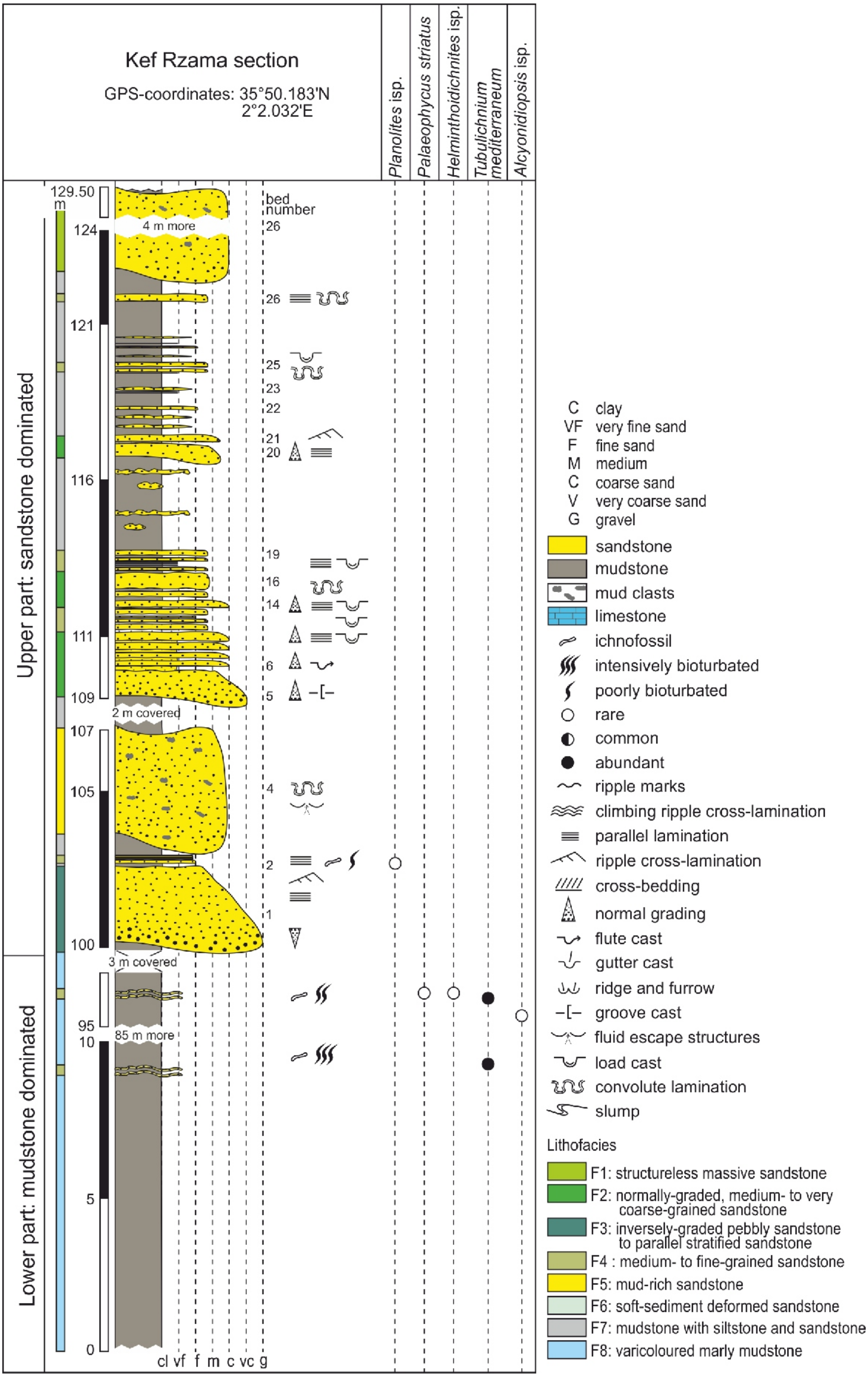

Fig. 3. Lithological column of the Kef Rzama section showing the numbering of beds, trace fossils and sedimentary structures

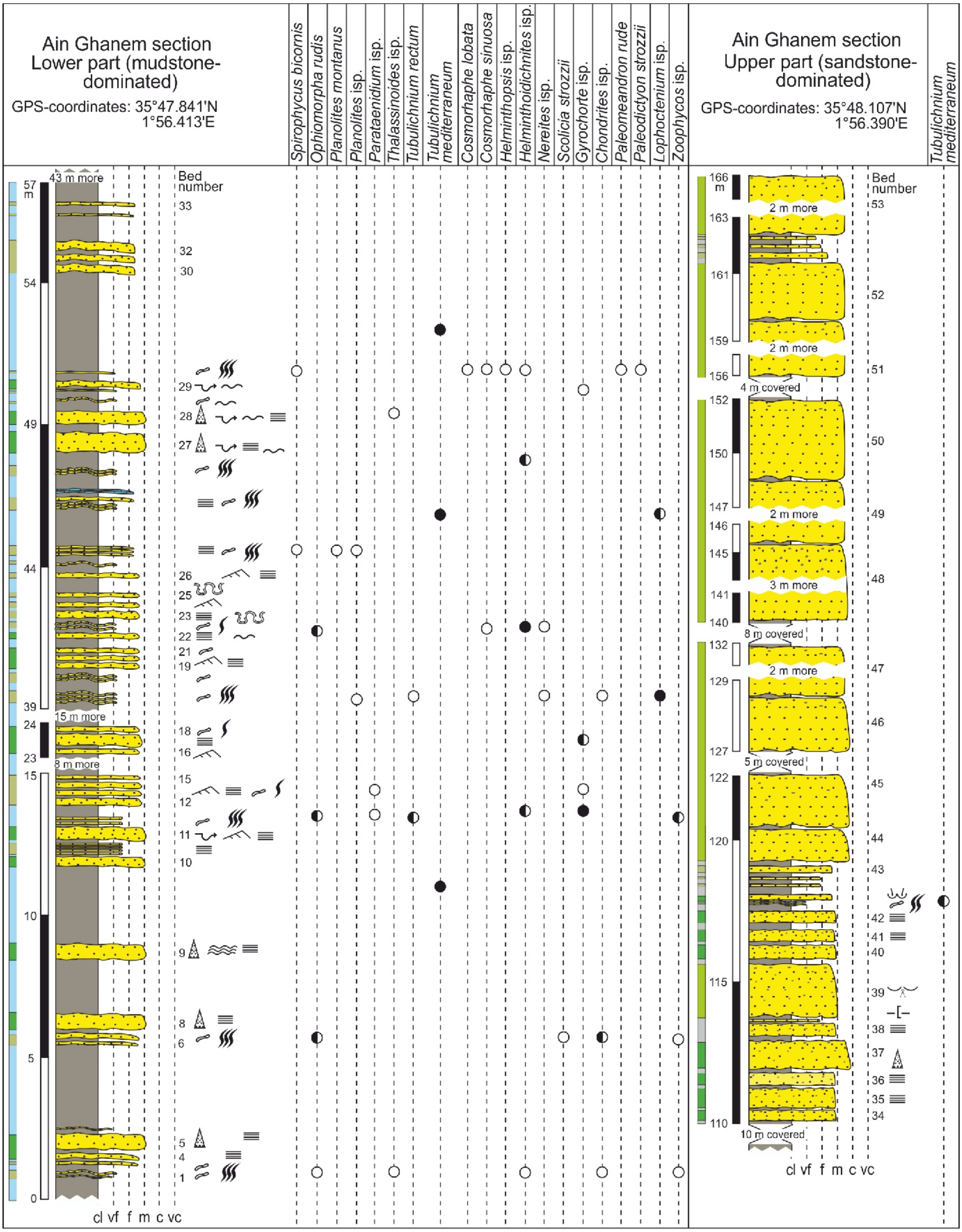

Fig. 4. Lithological column of the Ain Ghanem section showing the numbering of beds, trace fossils and sedimentary structures

Explanations as in Figure 3

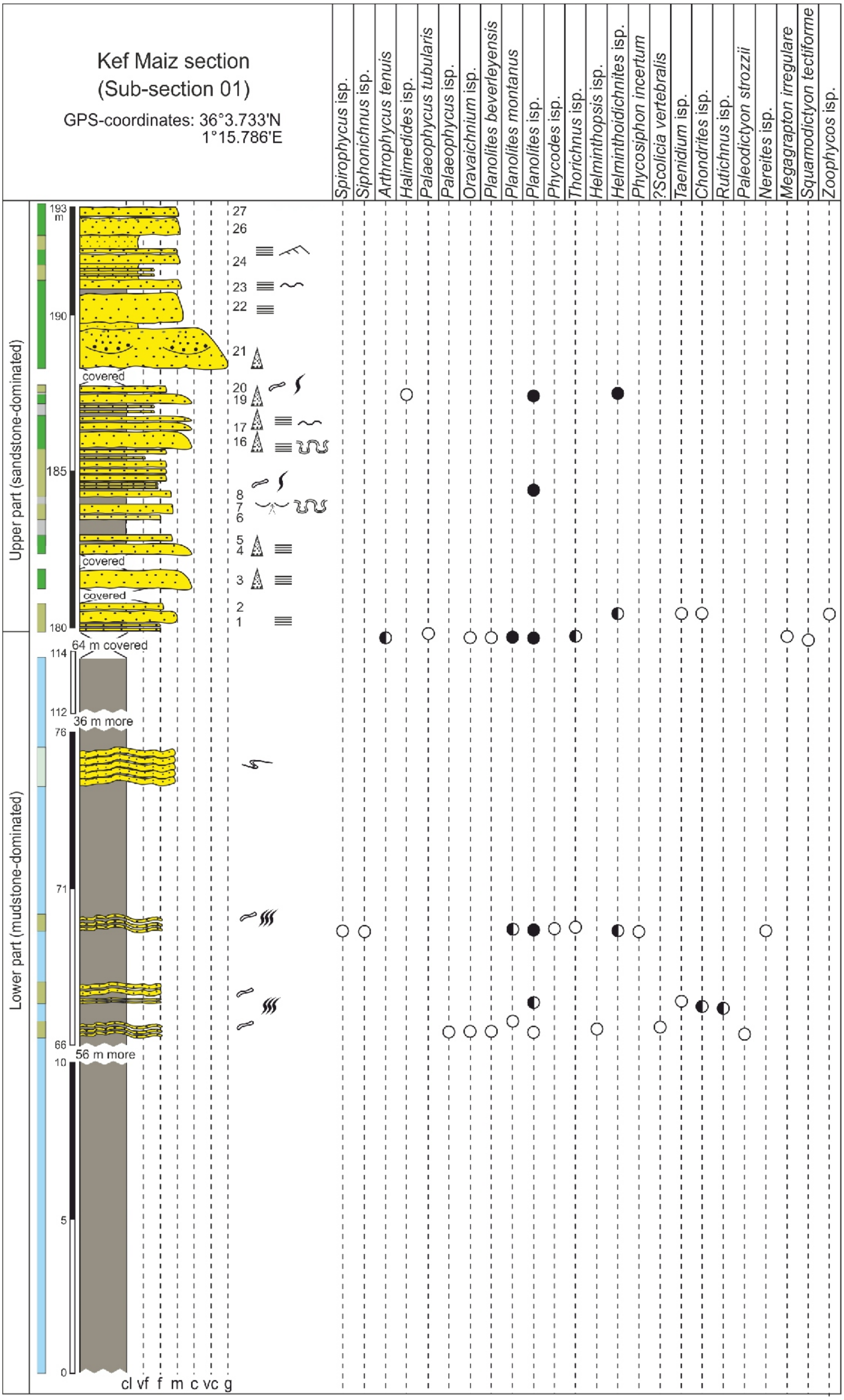

Fig. 5. Lithological column (part 01) of the Kef Maiz section showing the numbering of beds, trace fossils and sedimentary structures

Explanations as in Figure 3

R e m a r k s. – *Spirophycus* has been considered as a preservational variant of *Nereites* MacLeay (Wetzel *vide* Uchman, 1998). It is reported commonly in deep-sea turbiditic deposits (e.g., Seilacher, 2007).

Spirophycus isp.
(Fig. 8F)

D e s c r i p t i o n. – Incompletely preserved hypichnial smooth ridge with an incomplete circular whorl at the end. The ridge is 6–9 mm wide, preserved in semi-relief and filled with the same material as the host sediment. The whorl is 55 mm in diameter.

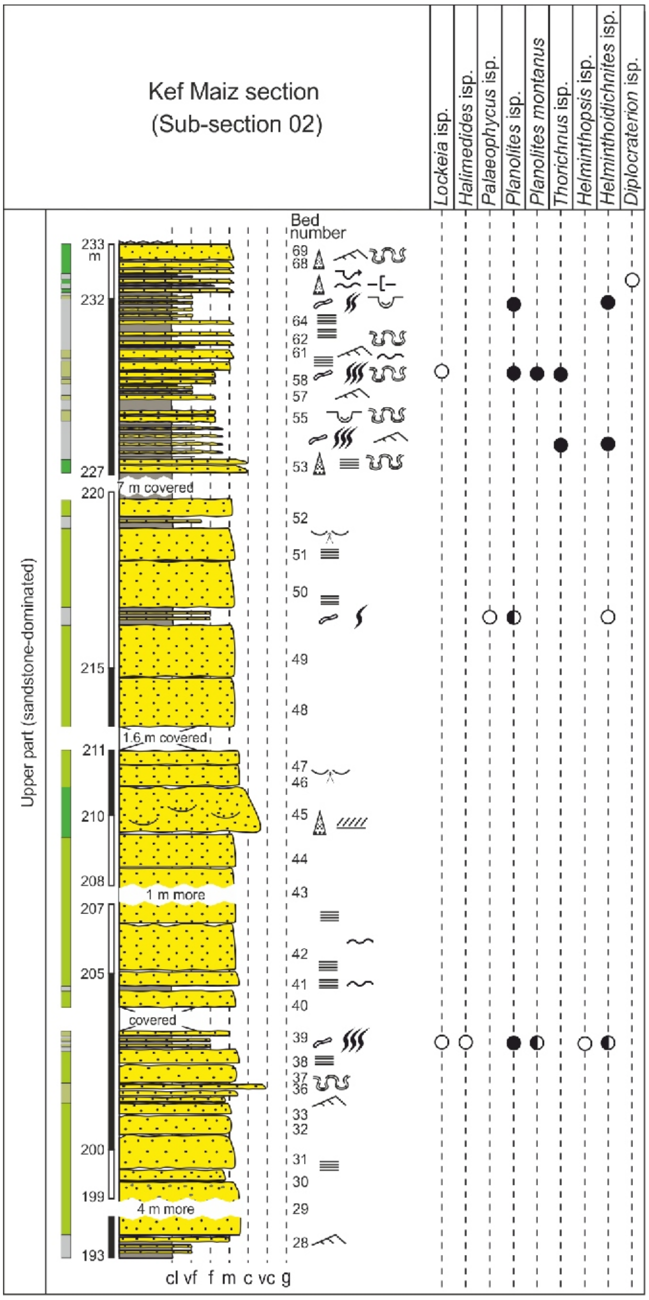

Fig. 6. Lithological column (part 02) of the Kef Maiz section showing the numbering of beds, trace fossils and sedimentary structures

Explanations as in Figure 3

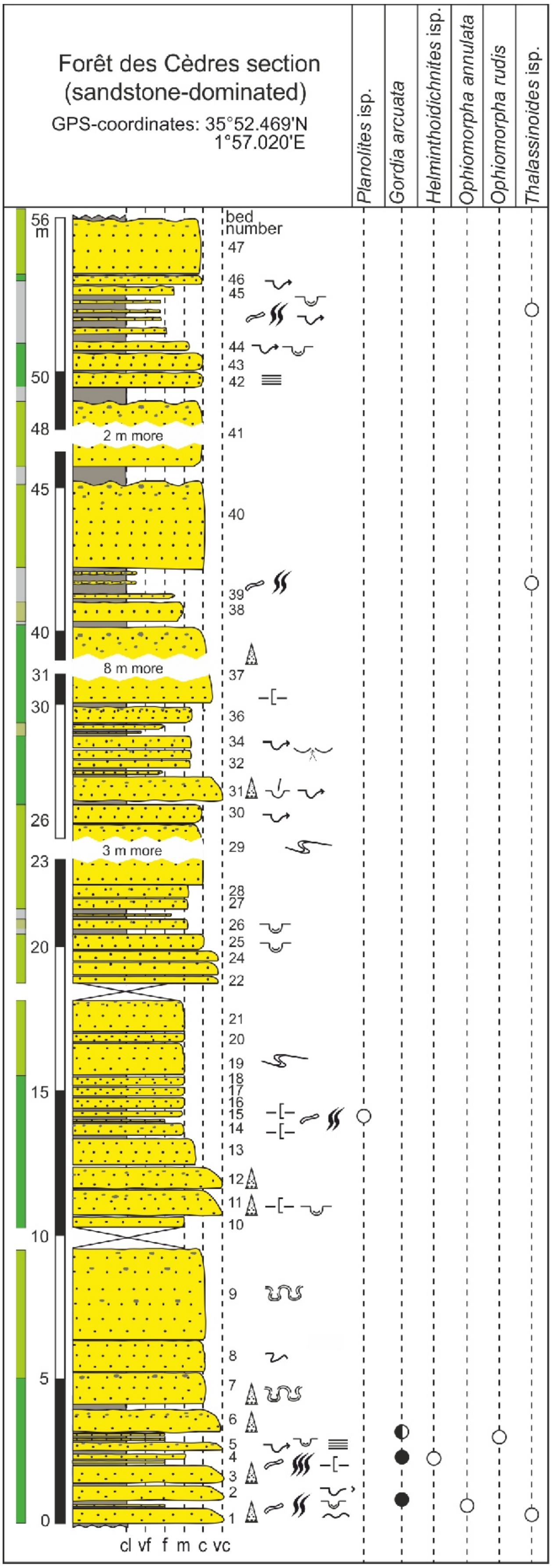

Fig. 7. Lithological column of the Forêt des Cèdres section showing the numbering of beds, trace fossils and sedimentary structures

Explanations as in Figure 3

Table 1

Distribution of trace fossils and corresponding facies in the investigated sections of the Numidian Formation in the Ouarsenis Mountains, NW Algeria

Ichnotaxon	Forêt des Cèdres section	Kef Rzama section		Ain Ghanem section		Kef Maiz section	
	upper unit	lower unit	upper unit	lower unit	upper unit	lower unit	upper unit
Lockeia isp.							R (F4)
Spirophycus bicornis				R (F4)			
Spirophycus isp.						R (F4)	
Siphonichnus isp.						R (F4)	
?*Arthrophycus tenuis*							C (F4)
Halimedides isp.							R (F4)
Ophiomorpha annulata	R (F4)						
Ophiomorpha rudis	R (F2)			C (F4)			
Oravaichnium isp.						R (F4)	R (F4)
Palaeophycus tubularis							R (F4)
Palaeophycus striatus		R (F4)					
Palaeophycus isp.						R (F4)	R (F4)
Planolites beverleyensis						R (F4)	R (F4)
Planolites montanus				R (F4)		C (F4)	C (F4)
?*Planolites* isp.	R (F4)		C (F4)	R (F4)		C (F4)	VC (F4)
?*Parataenidium* isp.				R (F4)			
Phycodes isp.						VR (F4)	
Thalassinoides isp.	R (F2, F4)			R (F2, F4)			
Thorichnus isp.						VC (F4)	VC (F4)
?*Alcyonidiopsis* isp.		R (F8)					
Tubulichnium mediterraneum		VA (F8)		VA (F8)	C(F7)		
Tubulichnium rectum				C (F4)			
Cosmorhaphe lobata				R (F4)			
Cosmorhaphe sinuosa				R (F4)			
Gordia arcuata	A (F4)						
Helminthoidichnites isp.	R (F4)	R (F4)		VC (F4)		C (F4)	VC (F4)
Helminthopsis isp.				R (F4)			VR (F4)
Nereites isp.				R (F4)		R (F4)	
?*Scolicia vertebralis*						R (F4)	
Scolicia strozzii				R (F4)			
Gyrochorte isp.				VC (F4)			
Taenidium isp.						R (F4)	R (F4)
Phycosiphon incertum						R (F4)	
Chondrites isp.				C (F4)		C (F4)	R (F4)
Megagrapton irregulare							VR (F4)
Paleomeandron rude				VR (F4)			
Rutichnus isp.						C (F4)	
Paleodictyon strozzii				C (F4)		R (F4)	
Squamodictyon tectiforme							R (F4)
Diplocraterion isp.							R (F4)
Lophoctenium isp.				VC (F4)			
Zoophycos isp.				C (F4)			R (F4)

Abundance: very rare (VR; 1 ichnotaxon), rare (R; 2–6 ichnotaxa), common (C; 7–9 ichnotaxa), very common (VC; 10–22 ichnotaxa), abundant (A; 23–41 ichnotaxa), very abundant (VA; >42 ichnotaxa)

R e m a r k s. – Radius of the whorl with respect to the ridge width is larger than in *Spirophycus bicornis*.

SIMPLE AND BRANCHED STRUCTURES

Siphonichnus Stanistreet, le Blanc Smith and Cadle, 1980
Siphonichnus isp.
(Fig. 8E)

D e s c r i p t i o n. – Hypichnial, circular, flat-top mound with steep flanks. It shows a circular depression in the centre. The mound is 4.5–5.5 mm in diameter and the central depression is 2 mm in diameter.

R e m a r k s. – The structure described represents the bedding-plane preservation of a vertical or oblique, cylindrical burrow with a median core, which can be assigned to *Siphonichnus* (for similar preservational variants see Knaust, 2015). *Siphonichnus* is interpreted as the dwelling trace of a suspension feeder (Stanistreet et al., 1980; Gingras and Bann, 2006; Gingras et al., 2008; Dashtgard, 2011) or a pascichnion of bivalves such as tellinids (Knaust, 2015). It is commonly reported from shallow-marine and marginal-marine deposits (Calver, 1968a, b; Melvin, 1986; Pollard, 1988; Rippon and Apears, 1989), often related to salinity fluctuations and freshwater influx (Knaust, 2015). Rarely, it is reported from deep-sea deposits (Krobicki et al., 2006), which is also the case reported in this paper.

Arthrophycus Hall, 1852
?*Arthrophycus tenuis* (Książkiewicz, 1977)
(Fig. 8K)

D e s c r i p t i o n. – Horizontal, subcylindrical, straight, simple ridges, covered with striations, preserved as hypichnial semi-reliefs, 0.2–1 mm in diameter and traced for a length of 10 mm.

R e m a r k s. – ?*Arthrophycus tenuis* occurs in flysch deposits from the Valanginian (Książkiewicz, 1977) to the (?) Lower Miocene (Alexandrescu and Brustur, 1981). Its assignment to *Arthrophycus* has been questioned (Mángano et al., 2005), but a possible solution of this problem requires separate study.

Halimedides Lorenz von Liburnau, 1902
Halimedides isp.
(Fig. 8H)

D e s c r i p t i o n. – Poorly preserved, hypichnial, horizontal, smooth, straight ridge, 1.5–3 mm wide with irregularly oval or crescentic chambers, each 3–8 mm wide and located symmetrically along the ridge, 8–11 mm apart. The trace fossil is preserved in semi-relief.

R e m a r k s. – The taxonomy of *Halimedides* was discussed by Uchman (1999). Lukeneder et al. (2012) distinguished the *Halimedides* Horizon within a Upper Barremian pelagic to hemipelagic succession (Southern Alps in Italy), which is characterized by stiffgrounds and firmgrounds developed below a discontinuity surface. *Halimedides* has been interpreted by Gaillard and Olivero (2009) as an agrichnion deep-sea trace fossil, probably produced by small crustaceans in stiff to firm substrates, where the chambers were used as traps and storage for food. The densely chambered specimens were considered to indicate lower oxygenation, while the sparse-chambered examples point to higher oxygenation (Gaillard and Olivero, 2009). Rodríguez-Tovar et al. (2019) emphasized the agrichnial/sequestrichnial behaviour of *Halimedides* after the Toarcian Anoxic Event in the Lusitanian Basin, Portugal, and considered it as an indicator of palaeoenvironmental change.

Ophiomorpha Lundgren, 1891
Ophiomorpha annulata (Książkiewicz, 1977)

D e s c r i p t i o n. – Cylindrical, straight or slightly curved, unbranched or rarely branched, horizontal hypichnion. It is preserved in full relief, is 3–7 mm in diameter and at least 100 mm long. Its surface is smooth or locally rough.

R e m a r k s. – *Ophiomorpha annulata* is common in turbiditic facies (Uchman, 2001). It was produced by small crustaceans (Uchman et al., 2004).

Ophiomorpha rudis (Książkiewicz, 1977)
(Figs. 9A, B, 10H and 13A)

D e s c r i p t i o n. – A hypichnial, tubular structure preserved in full relief, 2–9 mm in diameter, traced for 30–110 mm. It shows Y- and T-shaped branches. It is smooth or displays a wall covered with discoidal or ovoid pellets, which are 1–3 mm wide. The wall is smooth from the interior.

R e m a r k s. – *Ophiomorpha rudis* is the eponymous trace of the *Ophiomorpha rudis* ichnofacies, which has characterized sand-dominated flysch deposits since the Tithonian (Tchoumatchenco and Uchman, 2001; Uchman, 2009).

Oravaichnium Plička and Uhrová, 1990
Oravaichnium isp.
(Figs. 8K and 9D)

D e s c r i p t i o n. – Hypichnial, horizontal, simple, curved to irregularly meandering, smooth ridges, v-shaped in cross section, 1–8.5 mm wide, preserved in semi-relief.

R e m a r k s. – This trace fossil differs from *Oravaichnium hrabei* Plička and Uhrová, 1990 by its V-shaped cross-section. *O. hrabei* occurs in Eocene turbiditic deposits and is interpreted as a locomotion trace of wedge-footed bivalves (Uchman et al., 2011).

Palaeophycus Hall, 1847
Palaeophycus tubularis Hall, 1847
(Fig. 9F)

D e s c r i p t i o n. – Hypichnial, horizontal to subhorizontal, simple, straight to curved, unlined smooth semi-circular ridge. It is filled with the same sediment as the host

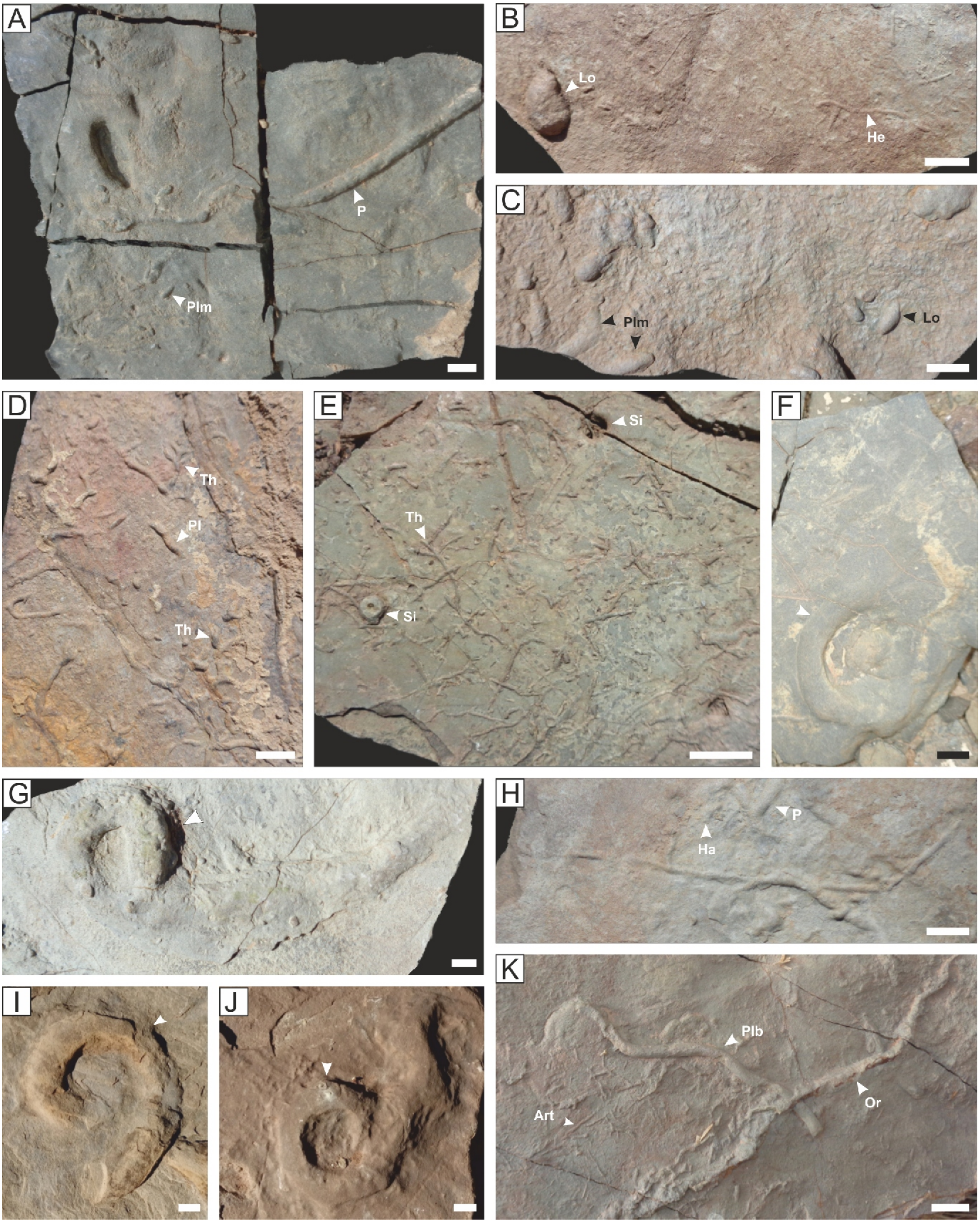

Fig. 8. Elliptical, simple and branched structures from the Numidian Formation in the Ouarsenis Mountains, NW Algeria

A – *Planolites montanus* (Plm) and ?*Palaeophycus* isp. (P), hypichnial full reliefs; **B** – *Lockeia* isp. (Lo) and *Helminthoidichnites* isp. (He), hypichnial full and semi-reliefs, respectively; **C** – *Lockeia* isp. (Lo) and *Planolites montanus* (Plm), hypichnial full reliefs; **D** – ?*Planolites* isp. (Pl) and *Thorichnus* isp. (Th), hypichnial full and semi-reliefs, respectively; **E** – *Siphonichnus* isp. (Si), full relief manifested on the lower bedding surfaces and *Thorichnus* isp. (Th), preserved in hypichnial semi-relief; **F** – *Spirophycus* isp. (arrowed), hypichnial semi-relief; **G, I, J** – *Spirophycus bicornis* (arrowed), hypichnial semi-reliefs; **H** – *Halimedides* isp. (Ha) and *Palaeophycus* isp. (P), hypichnial semi-reliefs; **K** – *Oravaichnium* isp. (Or), ?*Arthrophycus tenuis* (Art), and *Planolites beverleyensis* (Plb), hypichnial full reliefs; scale = 1 cm

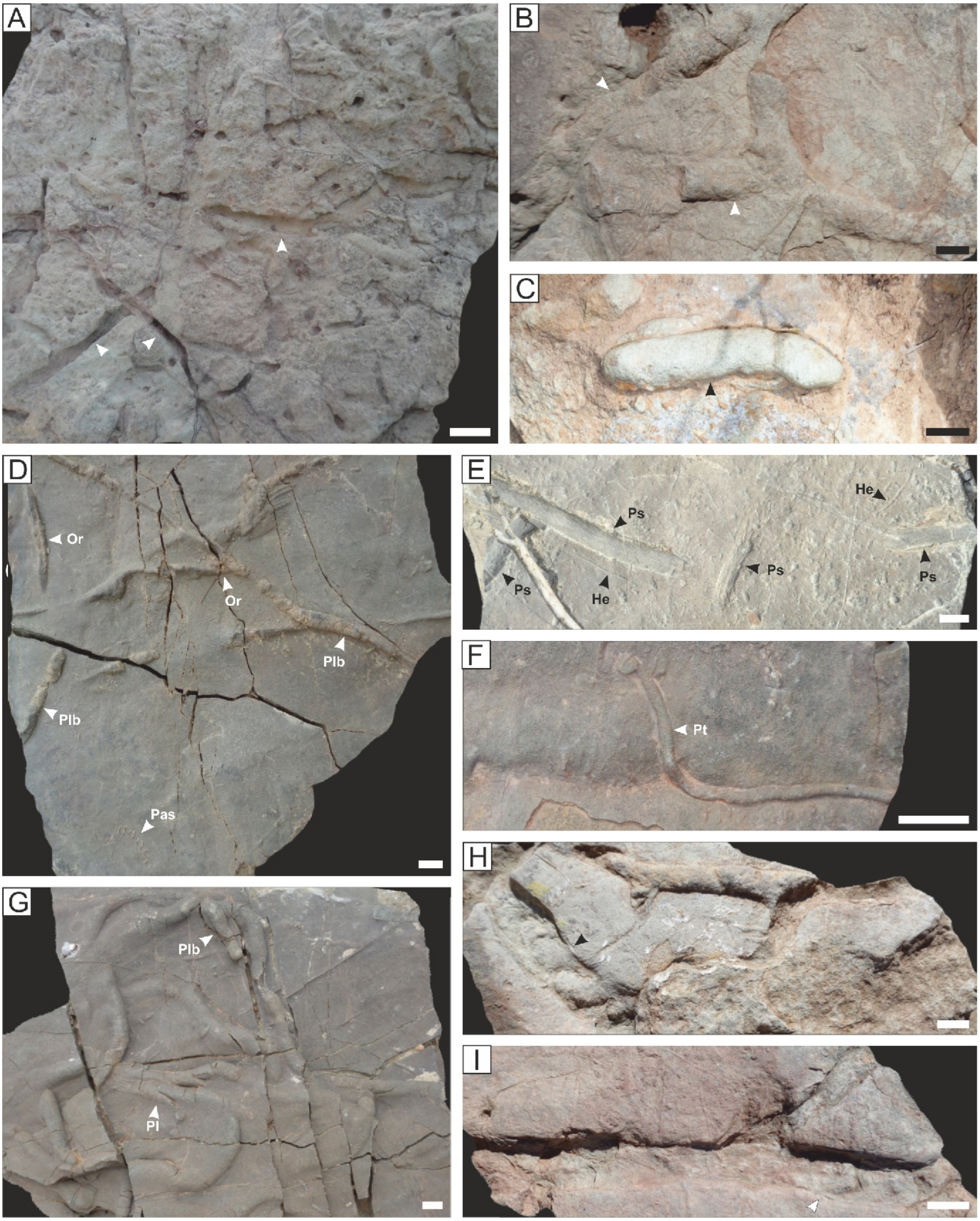

Fig. 9. Simple and branched structures, including a single ichnotaxon of network structures, from the Numidian Formation in the Ouarsenis Mountains, NW Algeria

A, B – *Ophiomorpha rudis* (arrowed), hypichnial full relief; **C** – ?*Planolites* isp., hypichnial full relief; **D** – *Planolites beverleyensis* (Plb), hypichnial full relief; *Oravaichnium* isp. (Or), hypichnial semi-relief; *Paleodictyon strozzii* (Pas) hypichnial semi-relief; **E** – *Palaeophycus striatus* (Ps), hypichnial full relief; *Helminthoidichnites* isp. (He), hypichnial semi-relief; **F** – *Palaeophycus tubularis* (Pt), hypichnial full relief; **G** – *Planolites beverleyensis* (Plb), hypichnial full relief; wash-out ?*Planolites* isp. (Pl), hypichnial semi-relief; **H, I** – ?*Parataenidium* isp. (arrowed), epichnial semi-relief; scale = 1 cm

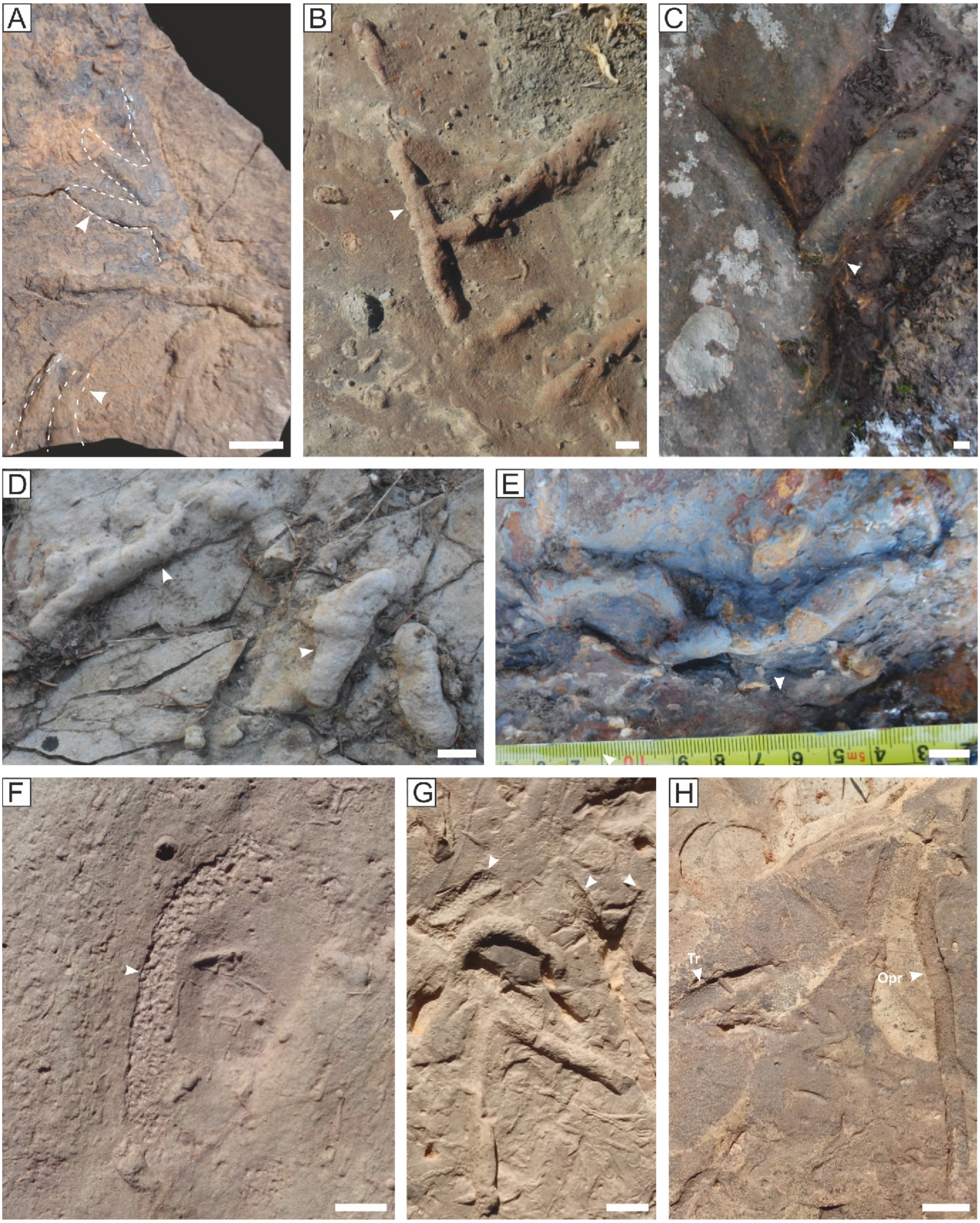

Fig. 10. Simple and branched structures from the Numidian Formation in the Ouarsenis Mountains, NW Algeria

A – *Phycodes* isp. (arrowed), hypichnial semi-relief; **B, C** – *Thalassinoides* isp. (arrowed), larger form, hypichnial semi-relief; **D, E** – *Thalassinoides* isp. (arrowed), smaller form, hypichnial full relief; **F, G, H** – *Tubulichnium rectum* (Tr) (arrowed), hypichnial semi-relief; H with *Ophiomorpha rudis* (Opr), hypichnial full relief; scale = 1 cm rock, is preserved in full relief, 5–7.5 mm wide and at least 75 mm long.

R e m a r k s. – *Palaeophycus* is commonly interpreted as a domichnion/pascichnion produced by carnivorous or omnivorous invertebrates, mostly polychaetes (Pemberton and Frey, 1982; Jensen, 1997). It occurs in a wide range of continental to marine palaeoenvironments (Knaust, 2017).

Palaeophycus striatus Hall, 1852
(Fig. 9E)

D e s c r i p t i o n. – Hypichnial**,** simple, horizontal to subhorizontal, straight to slightly curved, semicircular ridge covered partially with longitudinal wrinkles and small mounds having the same burrow orientation. This trace fossil is preserved in hypichnial full relief filled with the same sediment as the host rock, 5–6 mm in wide and 25 mm long.

?*Palaeophycus* isp.
(Figs. 8A, H and 9C)

D e s c r i p t i o n. – Hypichnial, horizontal to subhorizontal, semicircular curved to winding simple ridge, 1.5–5.5 mm wide. The ridge diminishes in width along its course and terminates with an irregular elongated swelling. It is preserved in full relief.

R e m a r k s. – Assignement of this trace to *Palaeophycus* is unsure due to the atypical change in width and a swelling at the termination.

Planolites Nicholson, 1873
Planolites beverleyensis (Billings, 1862)
(Figs. 8K and 9D, G)

D e s c r i p t i o n. – Hypichnial, horizontal to slightly inclined, simple or branched, straight to winding, smooth, cylindrical ridge, 3–7.5 mm in diameter, preserved in full relief.

R e m a r k s. – The trace fossil is ascribed to *Planolites* because of no evidence of lining. *Planolites* is interpreted as a pascichnion produced by infaunal deposit-feeding vermiform organisms (Pemberton and Frey, 1982), occurring in a wide range of palaeoenvironments, from continental and fresh water to deep-sea deposits (Keighley and Pickerill, 1995; Pemberton et al., 2001). It can be abundant in deposits of well-oxygenated as well as dysaerobic environments (Wignall, 1991: 268; Bromley, 1996).

Planolites montanus Richter, 1937
(Fig. 8A, C)

D e s c r i p t i o n. – Hypichnial, horizontal to inclined, simple, rectilinear to slightly curved, subcylindrical smooth ridge, 1–3.5 mm in diameter, preserved in full relief.

R e m a r k s. – This trace fossil is distinguished by its short length on bedding surfaces and an irregular, commonly contorted course (Pemberton and Frey, 1982).

?*Planolites* isp.
(Figs. 8D and 9G)

D e s c r i p t i o n. – A hypichnial, horizontal, unbranched, straight, curved or winding semi-cylindrical ridge, preserved in full relief or semi-relief, 5–8 mm in diameter and at least 10–30 mm long. The diameter may change along the burrow.

R e m a r k s. – The preservation in semi-relief does not permit recognition of whether the burrows are lined or not. Without that it is impossible to distinguish between *Planolites* and *Palaeophycus*. Therefore, these trace fossils are provisionally described under *Planolites*.

Parataenidium Buckman, 2001
?*Parataenidium* isp.
(Fig. 9H, I)

D e s c r i p t i o n. – Epichnial, horizontal structure composed of a basal, slightly sinuous semicylindrical burrow with meniscus-like structures at the top. The structures are 6–22 mm apart. The trace fossil is 9–24 mm wide and at least 140 mm long.

R e m a r k s. – The meniscus-like structures are interpreted as the basal part of oblique upwards protrusions. *Parataenidium* was made by an unknown organism which processed the sediment and produced the structure mainly by backfill action (Seilacher, 1990). The lower unit is attributed to locomotion and the upper part to feeding (Buckman, 2001). The taxonomy has been discussed by Uchman and Gaździcki (2006).

Phycodes Richter, 1850
Phycodes isp.
(Fig. 10A)

D e s c r i p t i o n. – Hypichnial, horizontal to subhorizontal, poorly outlined, low, flat ridges that diverge from a common stem. The ridges are straight to slightly curved, with a granulated surface. Their termination is poorly marked and welded to the bedding surface. The ridges are 2.2–4 mm wide and up to 45 mm long, preserved in semi-relief.

R e m a r k s. – *Phycodes* has been considered as a deposit-feeding trace made by annelids (Fillion and Pickerill, 1990). It has commonly been reported from shallow marine environments but has also been found in brackish and deep-sea deposits (Hakes, 1985; Fillion and Pickerill, 1990; Han and Pickerill, 1994a; Hanken et al., 2016; Jackson et al., 2016). *Phycodes* ranges from the early Cambrian to the Miocene (Crimes, 1987, 1992; Han and Pickerill, 1994a).

Thalassinoides Ehrenberg, 1944
Thalassinoides isp.
(Fig. 10B–E)

D e s c r i p t i o n. – A hypichnial, horizontal or inclined tubular, branched ridge, 15–30 mm wide, without lining. The filling is massive. The ridges are preserved in full relief, occasionally in semi-relief. Three morphotypes are distinguished: (1) larger, showing Y-shaped branches, 30 mm wide and at least 250 mm long, occurring within medium to coarse-grained sandstone beds (Fig. 10B, C), (2) smaller, with Y-shaped branches, 5 mm wide and at least 50 mm long, found in thin, fine-grained sandstone beds (Fig. 10D), and (3) forms with an unspecified branching pattern, 5–8 mm wide and 30–60 mm long, found in thin, fine-grained sandstone beds (Fig. 10E).

R e m a r k s. – *Thalassinoides* occurs in variable marine environments, commonly in shallow marine settings (Palmer, 1978; Archer and Maples, 1984; Frey et al., 1984; Mángano and Buatois, 1991; Pemberton et al., 2001), but also at greater depths (Uchman, 1995, 1998; Uchman and Tchoumatchenco, 2003; Wetzel et al., 2007). It is produced mostly by crustaceans and interpreted as domichnia and fodinichnia (Frey et al, 1978; Schlirf, 2000). *Thalassinoides* is recorded from the Ordovician to the present (Swinbanks and Luternauer, 1987).

Thorichnus Pokorný, 2017
Thorichnus isp.
(Fig. 8D, E)

D e s c r i p t i o n. – Horizontal, smooth to granulated, curved or winding, semi-circular to flattened branched ridges, 2–0.5 mm in diameter. The branches are mostly short and run obliquely or perpendicularly from the main ridge at irregular distances. Second order branching is rare. The trace fossil is preserved in hypichnial semi-relief, traced for 25 mm.

R e m a r k s. – The general morphological features fit to *Thorichnus,* which was described from Upper Miocene deep-lake turbiditic claystones and siltstones in SE Iceland and considered as a fodinichnion produced by annelids or arthropod larvae (Pokorný, 2017).

Alcyonidiopsis Massalongo, 1856
?*Alcyonidiopsis* isp.

D e s c r i p t i o n. – Simple, straight, cylindrical endichnial burrow, 9–11 mm in diameter showing elongate, randomly distributed, elongate pellets (1–3 mm in diameter) on the surface. The burrow is filled with oxidized siltstone. It is preserved in full relief.

R e m a r k s. – Probably, originally the pellets filled the whole burrow, but diagenesis obliterated their outline in the axial part of the burrow. *Alcyonidiopsis* is regarded as a polychaete feeding burrow (Chamberlain, 1977; Uchman, 1999), although there is no convincing proof of that (Rodríguez-Tovar and Uchman, 2004a, b). *Alcyonidiopsis* occurs in a wide range of environments from the Ordovician to the Miocene (Uchman, 1999).

Tubulichnium Książkiewicz, 1977
Tubulichnium mediterraneum (Garcia-Ramos, Mángano, Pińuela, Buatois and Rodríguez-Tovar, 2014)
(Fig. 11A–C)

D e s c r i p t i o n. – An endichnial tubular structure preserved in full relief, 5–20 mm diameter and 10–70 mm long, covered with elongated pellets, which are 1–2 mm long, and 0.7–1 mm wide. In some specimens, the longer axis of these pellets follows the burrow course.

R e m a r k s. – This trace fossil was re-described under the ichnogenus *Tubotomaculum* Garcia-Ramos, Mángano, Pińuela, Buatois and Rodríguez-Tovar, 2014 but it is considered as an ichnospecies of *Tubulichnium* Książkiewicz, 1977 (Uchman and Wetzel, 2017). So far, it has been found in the deep-sea Cretaceous-Paleogene deposits of the Mediterranean region, especially in mudstones of the lower part of the NF (Pautot et al., 1975), where it is abundant in the varicoloured clays (Durand Delga, 1955; Broquet, 1968; Wezel, 1968; Moretti et al., 1988).

Tubulichnium rectum (Fischer-Ooster, 1858)
(Fig. 10F, G, H)

D e s c r i p t i o n. – Oblique to horizontal, unbranched, blindly ended tube with margins densely lined with ellipsoidal muddy pellets. The trace fossil is 4–7 mm wide and 27–60 mm long. The long axis of the pellets measures 1–2 mm.

R e m a r k s. – *Tubulichnium rectum* is considered as a post-depositional structure, probably produced by vermiform organisms which fed on organic-rich sediment deposited seasonally or episodically on the sea floor (Uchman and Wetzel, 2017). It occurs commonly in muddy to fine sandy siliciclastic and marly deep-sea deposits from the Turonian to the Eocene, and possibly in the Oligocene–Miocene (Uchman and Wetzel, 2017). Here the Oligocene–Miocene age is confirmed.

WINDING AND MEANDERING STRUCTURES

Cosmorhaphe Fuchs, 1895
Cosmorhaphe lobata Seilacher, 1977
(Fig. 12C)

D e s c r i p t i o n. – Horizontal, winding, hypichnial semi-circular string, 1.5–2 mm wide, showing two-order dense meanders, higher than wider. The first and second order meanders display a wavelength of ~29 mm and ~100 mm, and their amplitude is ~24 mm and 150 mm, respectively. Single meanders have a smaller amplitude and amplitude/wavelength ratio. The string is preserved in semi-relief.

R e m a r k s. – *Cosmorhaphe* is a pre-depositional trace fossil ascribed to agrichnia. It is common, but never abundant on the soles of sandy turbidites (Książkiewicz, 1977; Uchman and Wetzel, 2012) and has been reported from recent deep-sea pelagic sediments (e.g., Rona and Merill, 1978; Ekdale and Berger, 1978; Ekdale, 1980; Gaillard, 1991).

Cosmorhaphe sinuosa (Azpeitia Moros, 1933)
(Fig. 12D)

D e s c r i p t i o n. – Hypichnial, horizontal, semi-circular string showing two-order meanders, which are mostly wider than higher. The string is 1.5–2.5 mm wide and preserved in semi-relief. The first and second order meanders have a wave-

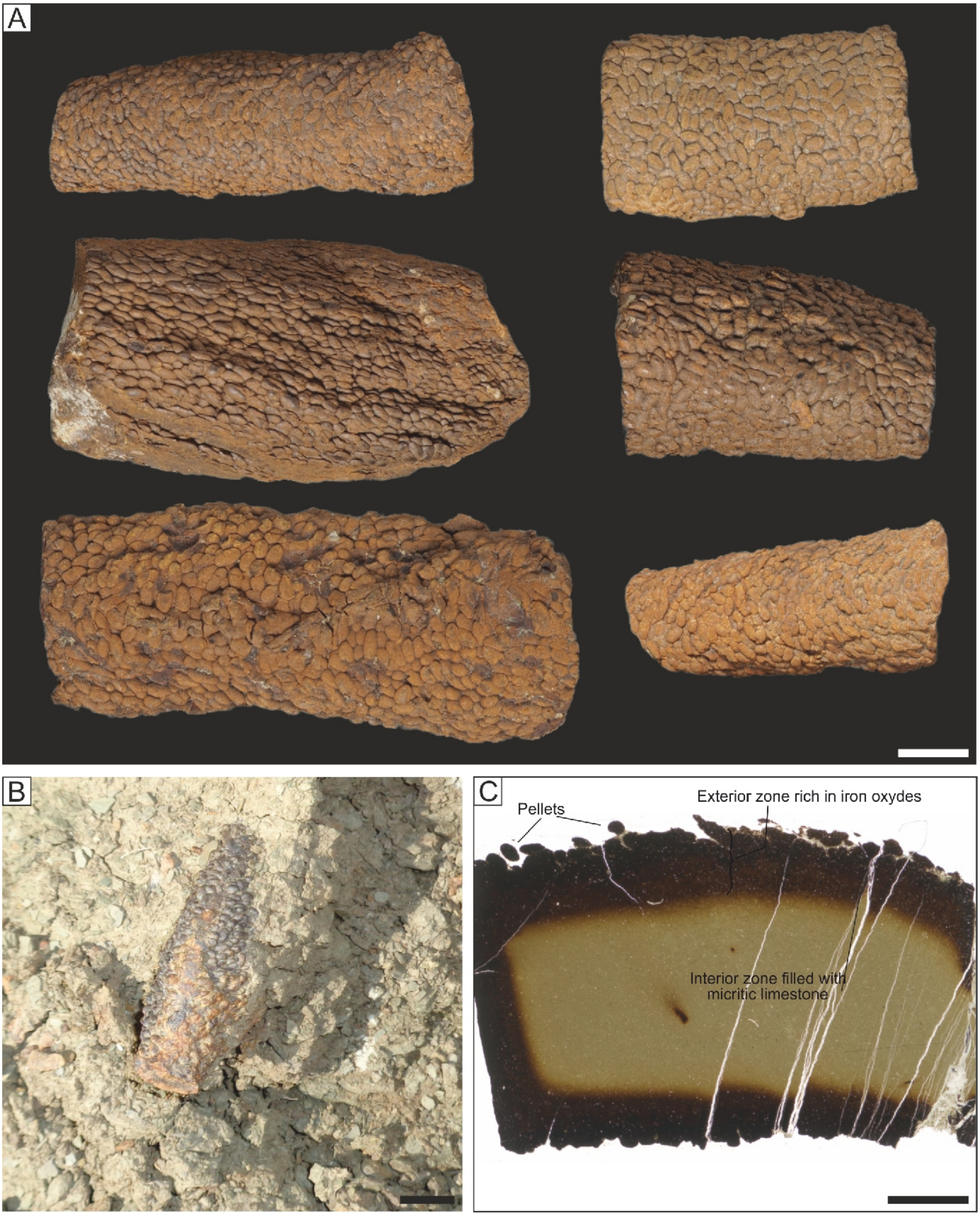

Fig. 11. Simple structures from the Numidian Formation in the Ouarsenis Mountains, NW Algeria

A – *Tubulichnium mediterraneum*, endichnial full relief; **B** – *T. mediterraneum* within marly mudstone in the lower unit of the Ain Ghanem section; **C** – micrograph showing the cross-section of the trace fossil in thin section, showing two main zones: (1) an internal zone filled with micrite, including quartz grains, some microfossils and shell fragments; (2) an external zone (envelope) made up of stacked pellets, without any internal structure, dominated by iron oxides, brown to dark brown in colour; scale = 1 cm

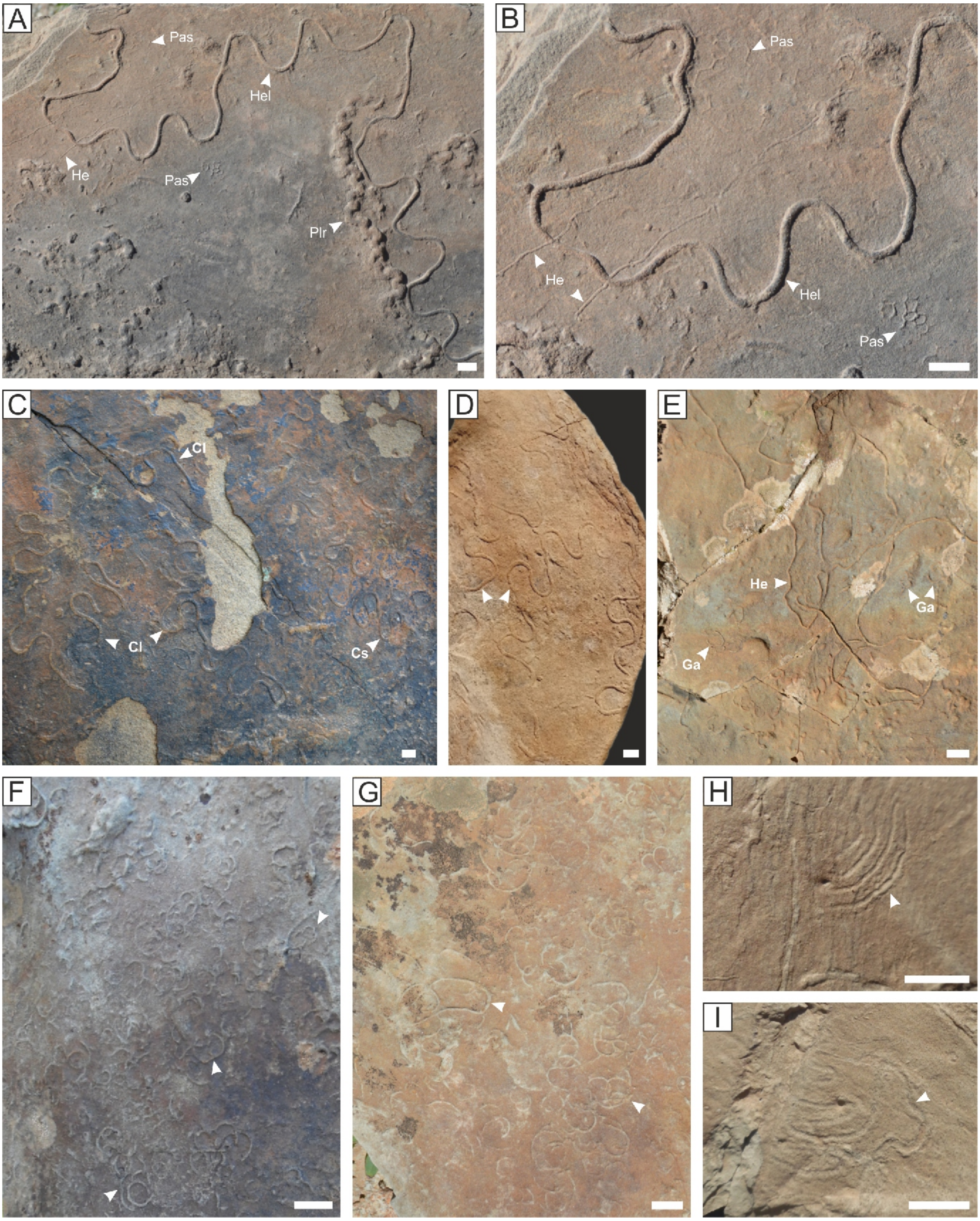

Fig. 12. Winding and meandering structures with one single network structure, from the Numidian Formation in the Ouarsenis Mountains, NW Algeria

A, B – *Helminthopsis* isp. (Hel), hypichnial semi-relief; *Paleomeanderon rude* (Plr), hypichnial semi-relief; *Paleodictyon strozzii* (Pas), hypichnial semi-relief; *Helminthoidichnites* isp. (He), hypichnial semi-relief; **C, D** – *Cosmorhaphe sinuosa* (Cs), hypichnial semi-relief: C – *C. lobata* (Cl), hypichnial semi-relief; **E** – *Helminthoidichnites* isp. (He), hypichnial semi-relief; *Gordia arcuata* (Ga), hypichnial semi-relief; **F, G** – *Gordia arcuata* (arrowed), hypichnial semi-relief; **H**, **I** – *Nereites* isp. (arrowed), epichnial semi-relief; scale = 1 cm length of ~26 mm and ~100 mm, respectively, and their amplitude is ~18 mm and ~150 mm, respectively.

Gordia Emmons, 1844
Gordia arcuata Książkiewicz, 1977
(Fig. 12E–G)

D e s c r i p t i o n. – A hypichnial, horizontal, smooth, sinuous, commonly semi-circular, unbranched ridge, 0.5–1 mm in diameter, commonly forming loops, preserved in semi-relief.

R e m a r k s. – *Gordia* is a grazing trace (pascichnion). It occurs in a variety of marine and non-marine soft, low energy deposits, e.g., in marine (e.g., Książkiewicz, 1977; Gibert et al., 2000; Trewin et al., 2002), lacustrine turbiditic (Buatois and Mángano, 1993) and varve deposits (Uchman et al., 2009).

Helminthoidichnites Fitch, 1850
Helminthoidichnites isp.
(Figs. 8B, 9E, 12A, B, E and 13A)

D e s c r i p t i o n. – Hypichnial, horizontal, semi-cylindrical, winding, smooth ridges, occasionally overcrossing, rarely forming loops, 0.4–2 mm in diameter and traced for at least 220 mm, preserved in hypichnial semi-relief. The filling of the burrow is the same as the host sediment.

R e m a r k s. – This is a non-marine and marine eurybathic trace, common also in deep-sea facies, including flysch (Chamberlain, 1971; McCann and Pickerill, 1988; Fillion and Pickerill, 1990; Uchman, 1995, 1998; Wetzel et al., 2007). *Helminthoidichnites* is common from the Precambrian (Narbonne and Aitken, 1990) to the Pleistocene (Uchman et al., 2009).

Helminthopsis Wetzel and Bromley, 1996
Helminthopsis isp.
(Fig. 12A, B)

D e s c r i p t i o n. – Hypichnial, horizontal, simple, smooth, semi-circular, irregularly meandering ridge, which is 5–22 mm wide and traced for 700 mm. It is preserved in semi-relief. The meanders are 40–70 mm wide. Their amplitude ranges from 20 to 45 mm.

R e m a r k s. – The trace fossil resembles *Cosmorhaphe*, but the meanders are less regular than in representatives of that ichnogenus. Moreover, regular second-order meanders are not obvious; rather, irregular turns of the general course are present. *Helminthopsis* is a repichnion produced probably by polychaetes or priapulids, and it is common in flysch deposits (Książkiewicz, 1977; Fillion and Pickerill, 1990; Wetzel and Bromley, 1996). It occurs from the Cambrian (Crimes, 1987) to the recent (Swinbanks and Murray, 1981; Wetzel, 1983a, b).

Nereites MacLeay in Murchison, 1839
Nereites isp.
(Fig. 12H, I)

D e s c r i p t i o n. – Hypichnial, horizontal, unbranched, winding to meandering low ridges or bands, 0.5–1.2 mm wide and traced for ~100 mm. Thy are bounded by thin levees and preserved in semi-relief. Limbs of the meanders are 2–10 mm apart and their amplitudes are 8–26 mm.

R e m a r k s. – The levees are interpreted as reworked zones bounding faecal strings (cf. Uchman, 1995). *Nereites* is a pascichnion (Mángano et al., 2000), but is also considered as a fodinichnion (Knaust, 2017). *Nereites* is a typical element of deep-sea environments, tending to occur within sediments deposited under moderate energy (Wetzel, 2002). It also occurs in slope (Callow et al., 2013; Demircan and Uchman, 2016), shelf (Knaust, 2017) and exceptionally in sandy estuarine deposits and tidal flats (Martin and Rindsberg, 2007; Neto de Carvalho and Baucon, 2010). *Nereites* ranges from the Cambrian (e.g., Aceñolaza and Alonso, 2001) to the Holocene (Wetzel, 2002).

Scolicia de Quatrefages, 1849
?*Scolicia vertebralis* Książkiewicz, 1977

D e s c r i p t i o n. – Epichnial, curved, V-shaped furrow, 3–10 mm wide, with elevated margins. The furrow bottom shows a rope-like elevation, which is 2–4 mm wide.

R e m a r k s. – *Scolicia* is interpreted as a deposit-feeding trace (e.g., Uchman, 1995; Fu and Werner, 2000), which is produced by irregular echinoids (e.g., Plaziat and Mahmoudi, 1988; Uchman, 1995, 1998). *Scolicia* occurs commonly in shallow-marine (Fu and Werner, 2000) as well as deep-sea deposits, including turbiditic successions (Uchman, 1995). *Scolicia* ranges from the Tithonian to the present (Tchoumatchenco and Uchman, 2001).

Scolicia strozzii (Savi and Meneghini, 1850)
(Fig. 13B)

D e s c r i p t i o n. – Simple, winding, smooth, bilobate ridge, 15–30 mm wide, ~5 mm high, and at least 90 mm long, preserved in hypichnial semi-relief.

Gyrochorte Heer, 1865
Gyrochorte isp.
(Figs. 13D–F and 14J)

D e s c r i p t i o n. – Epichnial, straight to curved or winding, bilobate ridge with median furrow, 0.7–1.2 mm wide and 5–130 mm long. The trace fossil shows overcrossings.

R e m a r k s. – *Gyrochorte* is interpreted as a feeding trace (e.g., Weiss, 1941; Fu and Werner, 2000; Gibert and Benner, 2002), produced by vermiform organisms, probably polychaetes (Seilacher, 2007; Fürsich et al., 2017). It has commonly been reported from nearshore and shallow-marine deposits of moderate energy (Gibert and Benner, 2002), and rarely from deep-sea settings (Uchman and Tchoumatchenco, 2003 and references therein).

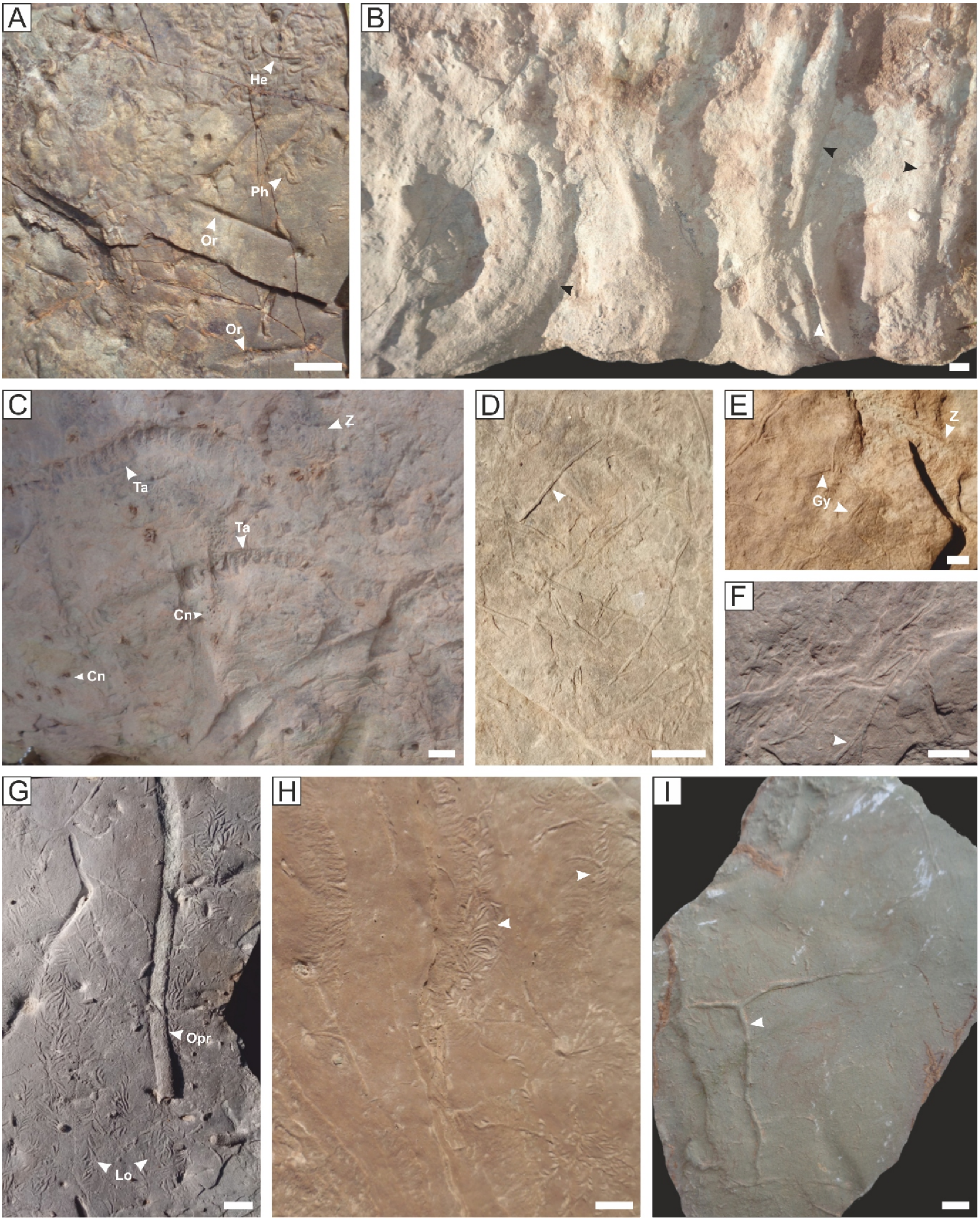

Fig. 13. Spreite, meandering, branched, and network structures from the Numidian Formation in the Ouarsenis Mountains, NW Algeria

A – *Phycosiphon incertum* (Ph), epichnial semi-relief; *Helminthoidichnites* isp. (He), hypichnial semi-relief; *Oravaichnium* isp. (Or), hypichnial semi-relief; **B** – *Scolicia strozzii,* hypichnial semi-relief; **C** – *Taenidium* isp. (Ta), epichnial semi-relief; *Chondrites* isp. (Cn), epichnial full relief; *Zoophycos* isp. (Z), epichnial semi-relief; **D–F** – *Gyrochorte* isp. (Gy), epichnial semi-relief; E – *Zoophycos* isp. (Z), epichnial semi-relief; **G, H** – *Lophoctenium* isp. (Lo), epichnial semi-relief; G – *Ophiomorpha rudis* (Opr), hypichnial full relief; **I** – *Megagrapton irregulare* (arrowed), hypichnial semi-relief; scale = 1 cm

Taenidium Heer, 1877
Taenidium isp.
(Fig. 13C)

D e s c r i p t i o n. – Epichnial, horizontal, simple, curved ribbon or low ridge, 3–9 mm wide and 3–220 mm long, showing dense meniscate structure. The menisci are 3–5 mm apart.

R e m a r k s. – *Taenidium* is interpreted as a deposit-feeding trace produced by marine vermiform organisms (Gevers et al., 1971; Keighley and Pickerill, 1994; Smith et al., 2008b). It was reported from shallow-to deep-sea deposits (Keighley and Pickerill, 1994; Smith and Hasiotis, 2008; Jackson et al., 2016). *Taenidium* ranges from the Ediacaran to the recent (e.g., Crimes, 1992; Jenkins, 1995; Uchman, 1998; Jackson et al., 2016).

BRANCHED WINDING AND MEANDERING STRUCTURES

Chondrites von Sternberg, 1833
Chondrites isp.
(Fig. 13C)

D e s c r i p t i o n. – Patches of epichnial, circular to oval depressions filled with mudstone. The patches are 0.5–4 mm wide and the depressions are 0.3–1 mm wide.

R e m a r k s. – The depressions in the patches are cross-sections of downwards-spreading branched tunnels which are typical of *Chondrites* (cf. fig. 3c in Uchman, 2007). This ichnogenus is interpreted as a feeding trace (deep-tier chemichnion) of unknown vermiform organisms, which may burrow below the redox boundary (for discussion, see Uchman, 1999; Wetzel, 2008). It occurs mostly offshore and deeper, rarely in nearshore restricted environments (e.g., Knaust, 2017).

Chondrites occurs from the Cambrian (Webby, 1984) to the Holocene (Wetzel, 1981, 2008).

Paleomeandron Peruzzi, 1880
Paleomeandron rude Peruzzi, 1880
(Fig. 12A)

D e s c r i p t i o n. – Hypichnial, winding tract built of a string bent in small, densely packed, relatively shallow, irregular, second-order rectangular meanders. The trace fossil is 3–5 mm wide and can be traced for ~150 mm.

R e m a r k s. – This trace fossil is ascribed to graphoglyptids (Seilacher, 1977) and occurs in turbiditic deposits (Uchman, 1998).

Rutichnus D'Alessandro, Bromley and Stemmerik, 1987
Rutichnus isp.
(Fig. 14A)

D e s c r i p t i o n. – Hypichnial, horizontal to subhorizontal, winding, semi-circular, tubular ridges, 1–4 mm wide and 15–40 mm long, preserved in full relief. Their surface appears as a series of slightly distorted segments separated by narrow constrictions. The segments are 1–4 mm wide and 2–5 mm long. False branching is developed with tunnel overcrossings.

R e m a r k s. – *Rutichnus* is interpreted as a deposit-feeding trace produced by vermiform organisms or arthropods. It occurs in shallow-marine and deep-sea flysch deposits (D'Alessandro et al., 1987; Monaco, 2011).

SPIRALS AND NETWORKS

Megagrapton Książkiewicz, 1968
Megagrapton irregulare Książkiewicz, 1968
(Fig. 13I)

D e s c r i p t i o n. – Hypichnial, horizontal, incomplete, irregular network, composed of winding strings (1–2.5 mm wide), branching at ~90°. The meshes are at least 80 mm across.

R e m a r k s. – *Megagrapton irregulare* is interpreted as an agrichnion (Seilacher, 1977; Uchman, 1998) ranging from the Silurian (Crimes and Crossley, 1991) to the Miocene (D'Alessandro, 1982), and occurring mainly in deep-sea flysch deposits.

Paleodictyon Meneghini in Savi and Meneghini, 1850
Paleodictyon strozzii Meneghini in Savi and Meneghini, 1850
(Figs. 9D and 12A, B)

D e s c r i p t i o n. – Horizontal networks composed of regular, hexagonal meshes (2.5 mm wide; the strings are 0.2–1 mm wide) preserved in hypichnial semi-relief.

R e m a r k s. – *Paleodictyon* is interpreted as a farming trace (agrichnion) produced by unknown organisms commonly in deep-sea turbiditic deposits (Seilacher, 1977) and less frequently in shelf sediments (Fürsich et al., 2007). It ranges from the Cambrian (Crimes and Anderson, 1985) to the recent (Ekdale, 1980; Miller, 1991).

Squamodictyon Vyalov and Golev, 1960
Squamodictyon tectiforme (Sacco, 1866)
(Fig. 14B)

D e s c r i p t i o n. – Hypichnial, horizontal networks composed of irregular scale-like meshes (7.5–11 mm wide; the strings are 0.5–1 mm in diameter) preserved in semi-relief.

R e m a r k s. – *Squamodictyon tectiforme* is interpreted as a pascichnion produced by unknown organisms (Uchman, 2003). It has been reported from Cretaceous and Cenozoic flysch deposits (Seilacher, 1977).

SPREITE STRUCTURES

Phycosiphon Fischer-Ooster, 1858
Phycosiphon incertum Fischer-Ooster, 1858
(Fig. 13A)

D e s c r i p t i o n. – Epichnial, horizontal, straight to curved lobes bifurcating into two curved to winding lobes, showing marginal tubes and internal spreite. The marginal tube is 0.3–0.5 mm wide, and the lobes are up to 1–2 mm wide and 5–7 mm long.

R e m a r k s. – *Phycosiphon* is interpreted as the deposit-feeding trace of small, unknown vermiform organisms that exploit the sediment for organic-rich matter (Wetzel, 2010; Izumi, 2014). It has been reported from a wide range of palaeoenvironments, but mostly from fine-grained lower shoreface and deeper, mainly siliciclastic deposits (Goldring et al., 1991; Savrda et al., 2001; Pemberton et al., 2012; Callow et al., 2013). The tracemaker colonized freshly deposited turbidites in the sequential colonization model, when the sediment contained abundant food resources and well-oxygenated pore waters (Wetzel and Uchman, 2001).

Diplocraterion Torell, 1870
Diplocraterion isp.
(Fig. 14C, D)

D e s c r i p t i o n. – Endichnial, vertical U-shaped burrows with a marginal tunnel, concave-upwards spreite and semi-circular bottoms, preserved in full relief. Two morphotypes have been distinguished: (1) with parallel limbs, 2–3 mm in diameter, 15 mm apart and 30 mm deep; (2) with diverging-downwards limbs, 4–6 mm in diameter, 25–30 mm apart and 80 mm deep.

R e m a r k s. – *Diplocraterion* is interpreted as a suspension-feeding dwelling trace (Goldring, 1962; Ekdale and Lewis, 1991; Bromley, 1996), although deposit-feeding has been proposed as well (Leaman and McIlroy, 2016). It was produced probably by polychaetes (Arkell, 1939), although crustaceans have also been considered (Bromley, 1996).

Diplocraterion occurs mostly in shallow marine (Knaust, 2017), rarely in deep-sea (Crimes et al., 1981; Leszczyński et al., 1996) and continental deposits (Kim and Paik, 1997) from the Cambrian (Cornish, 1986; Bromley and Hanken, 1991; Mángano and Buatois, 2016) to the Holocene (Corner and Fjalstad, 1993), including recent, small incipient forms produced by amphipods (Dashtgard and Gingras, 2012).

Lophoctenium Richter 1850
Lophoctenium isp.
(Fig. 13G, H)

D e s c r i p t i o n. – Comb- and star-like traces composed of curved probes running from a main axis or centre. The probes (mm long, mm wide) are developed on both sides of the axis.

R e m a r k s. – *Lophoctenium* is interpreted as a deposit feeder trace, encountered mostly in deep water deposits (e.g., Książkiewicz, 1977). It ranges from the Ordovician (Häntzschel, 1975) to the Miocene (Uchman, 1995). It is interpreted as a product of repetitive lateral probing for feeding (Seilacher, 2007). Similar traces are produced by bivalves (Ekdale and Bromley, 2001) but they are usually only a part of a burrow system, such as *Hillichnus* (Bromley et al., 2003).

Zoophycos Massalongo, 1855
Zoophycos isp.
(Fig. 14E–J)

D e s c r i p t i o n. – Spreite-filled planar structures manifested on the bedding surface as small (Fig. 13E, F) or large whorls or lobes (Fig. 14G–J). They are part of a helical structure having similar elements in different levels of the same bed (Fig. 14I). The spreite laminae, which are mostly straight to curved, run radially from a central point. The structure is encircled by a marginal tunnel, which is 0.3–5 mm wide. The whole structure is from 30–50 mm (smaller forms) to 140 mm wide (larger forms). The margin is lobate. In some specimens, spreite-filled tongues are present. The tongues are 9–50 mm wide and 30–80 mm long. They are encircled by a marginal tunnel as in the other parts of this trace fossil.

R e m a r k s. – *Zoophycos* is interpreted as a deposit-feeding trace of vermiform organisms (Wetzel and Werner, 1981), possibly polychaetes (Bischoff, 1968; Knaust, 2009), echiurans (Kotake, 1991) or sipunculids (Wetzel and Werner, 1981; Olivero and Gaillard, 2007). *Zoophycos* ranges from the Cambrian (Alpert, 1977; Jensen, 1997) to the recent (Seilacher, 2007; Wetzel, 2008).

DISTRIBUTION OF TRACE FOSSILS (TABLE 1)

The NF in the Ouarsenis Mountains, Algeria, reveals diverse trace fossils belonging to twenty-two ichnogenera. The Ain Ghanem and Kef Maiz sections have a larger ichnodiversity (35% and 46% of all ichnotaxa, respectively) than the Kef Rzama and the Forêt des Cèdres sections (9% and 10%, respectively).

The ichnodiversity changes significantly among the facies. Facies F4 reveals almost all the trace fossils recorded in the sections studied, primarily in (1) the lower unit of the Ain Ghanem and Kef Maiz sections, (2) the lower part of the upper unit of the Kef Maiz section, and (3) when interbedded with facies F1, in the upper unit of all the sections studied.

The ichnodiversity decreases significantly in facies F2, which yields only *Ophiomorpha rudis* and *Thalassinoides* isp. in the upper unit of the Forêt des Cèdres section and *Thalassinoides* isp. in the lower unit of the Ain Ghanem section. Facies F8 yields very abundant *Tubulichnium mediterraneum* in the lower and upper units of the Ain Ghanem section, and in the lower unit of the Kef Rzama section, where it co-occurs with rare ?*Alcyonidiopsis* isp.

DISCUSSION

ICHNOFACIES AND DEPOSITIONAL SYSTEM (FIGS. 15 AND 16)

Some data about the palaeoenvironment of the NF in Algeria were given by Moretti et al. (1991), who suggested a submarine slope setting for the NF strata in the Constantine Mountains on the basis of sedimentological data, but no such interpretations were given for our study area. The trace fossil assemblages described and ichnofacies based on them, along with the sedimentary features, allow for a more precise interpreta-

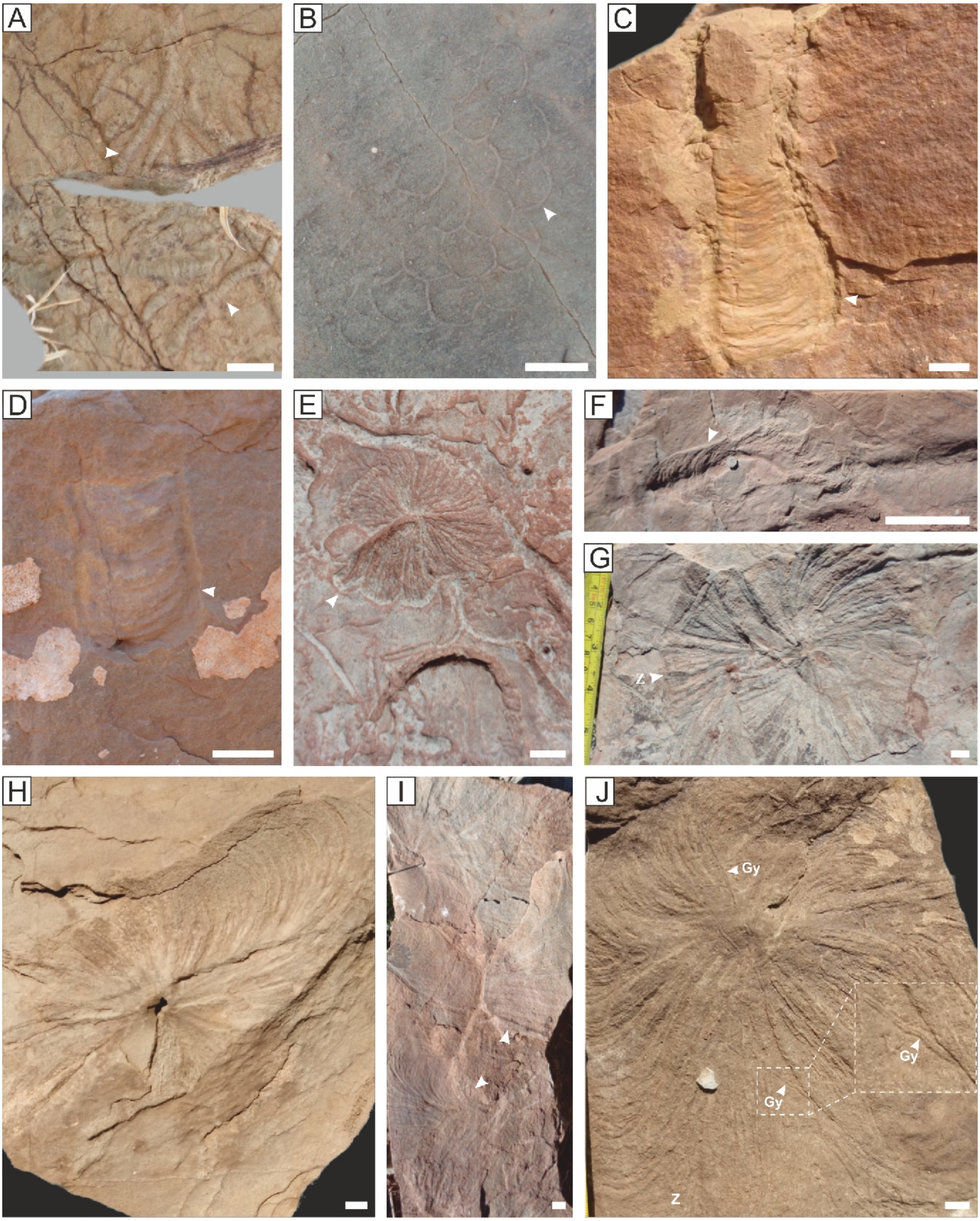

Fig. 14. Spreite, network, branched and meandering structures from the Numidian Formation in the Ouarsenis Mountains, NW Algeria

A – *Rutichnus* isp., hypichnial full relief; **B** – *Squamodictyon tectiforme*, hypichnial semi-relief; **C, D** – *Diplocraterion* isp., endichnial full relief; **E–G** – *Zoophycos* isp., small forms; **H–J** – *Zoophycos* isp. (Z), large forms: J – *Gyrochorte* isp. (Gy), epichnial semi-relief; scale = 1 cm

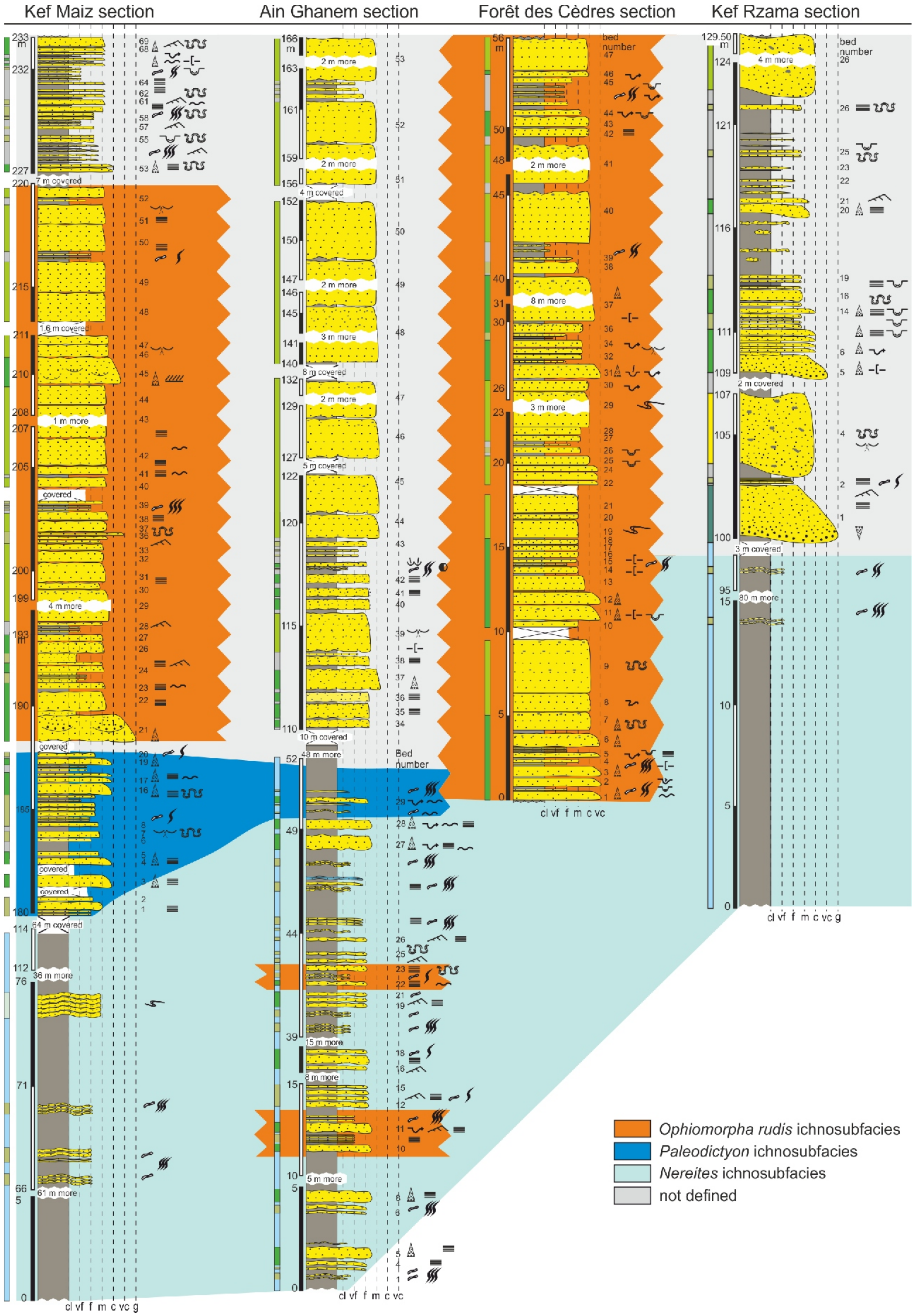

Fig. 15. Vertical distribution of the ichnofacies recognised in the sections studied with regard to lithostratigraphical subdivision (for explanation of lithofacies see Fig. 3)

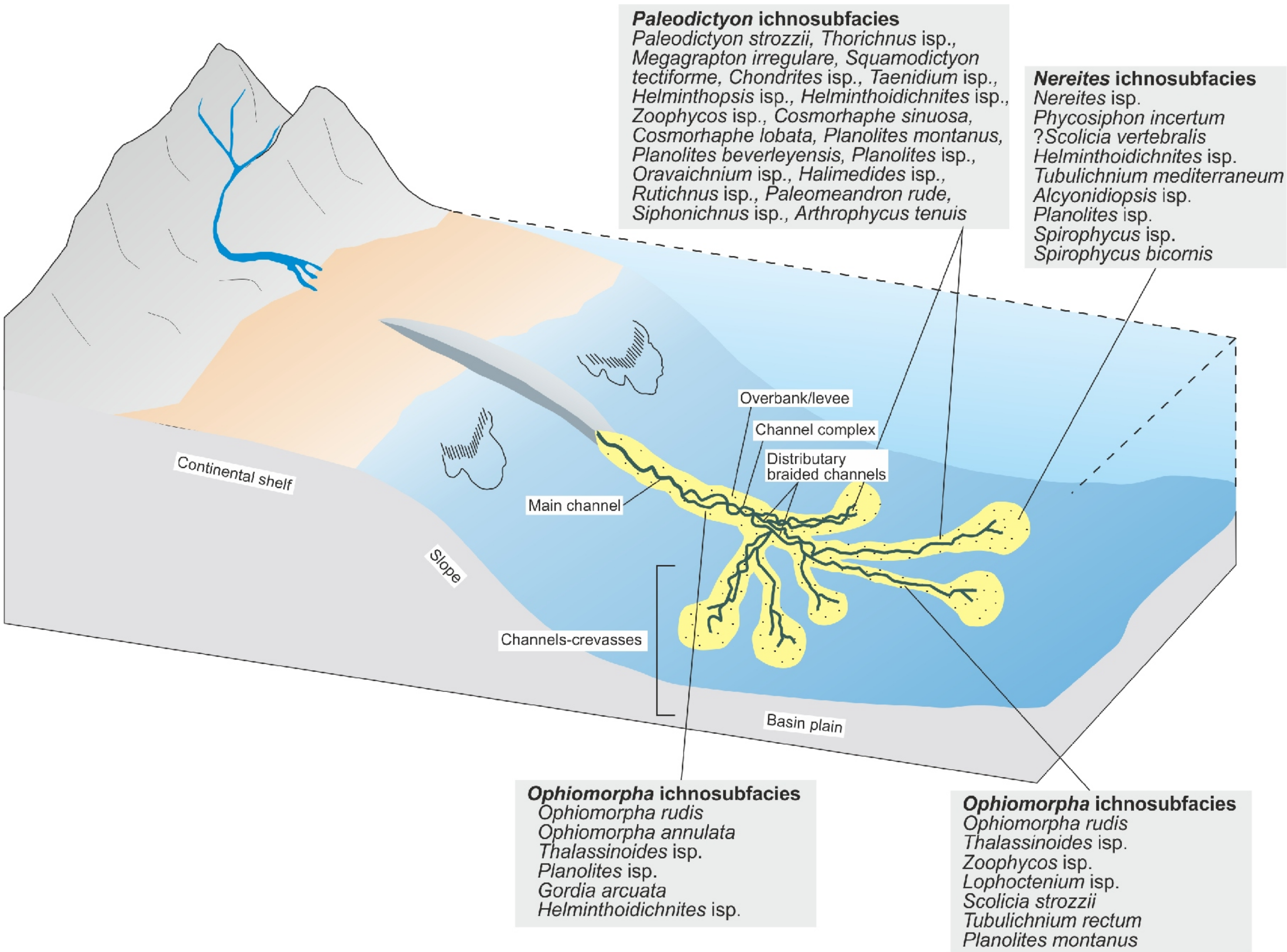

Fig. 16. Simplified schematic block diagram showing the distribution of the ichnofacies in the study area

Table 2

Distribution of trace fossils according to their ichnosubfacies

Paleodictyon ichnosubfacies	Ophiomorpha rudis ichnosubfacies	Nereites ichnosubfacies	Non-attributable trace fossils
Squamodictyon tectiforme, *Paleodictyon strozzii,* *Paleomeandron rude,* *Megagrapton irregulare*, *Chondrites* isp., *Taenidium* isp., *Helminthopsis* isp., *Helminthoidichnites* isp., *Zoophycos* isp., *Cosmorhaphe sinuosa,* *Cosmorhaphe lobata,* *Planolites montanus,* *Planolites beverleyensis,* ?*Planolites* isp., *Oravaichnium* isp., *Halimedides* isp., *Rutichnus* isp., *Thorichnus* isp., *Siphonichnus* isp., ?*Arthrophycus tenuis*	*Ophiomorpha rudis,* *Ophiomorpha annulata,* *Thalassinoides* isp., *Zoophycos* isp., *Lophoctenium* isp., *Scolicia strozzii,* *Gordia arcuata,* *Helminthoidichnites* isp., *Tubulichnium rectum,* *Planolites montanus,* ?*Planolites* isp.	*Nereites* isp., *Phycosiphon incertum*, ?*Scolicia vertebralis,* *Helminthoidichnites* isp., *Tubulichnium mediterraneum,* ?*Alcyonidiopsis* isp., ?*Planolites* isp., *Spirophycus* isp., *Spirophycus bicornis*	*Lockeia* isp., *Gyrochorte* isp., *Phycodes* isp., *Palaeophycus tubularis,* *Palaeophycus striatus*, *Palaeophycus* isp., ?*Parataenidium* isp., *Diplocraterion* isp.

tion of the NF palaeoenvironment. The trace fossil assemblage in general belongs to the deep-sea *Nereites* ichnofacies. This is indicated by the presence of graphoglyptids (*Paleodictyon, Paleomeandron, Megagrapton, Cosmorhaphe*) and other trace fossils (Table 1), which are common in this ichnofacies (see Uchman and Wetzel, 2012). The distribution of trace fossils, and differences in their composition and diversity permit distinction of the three main ichnosubfacies of the *Nereites* ichnofacies (Table 2).

The deep-sea interpretation is supported by agglutinated foraminifers, which are recorded (preliminary data) from the varicoloured marly mudstone (facies F8) in the sections studied and previously reported from the same facies in the Constantine Mountains (Hoyez, 1989; Moretti et al., 1991). The foraminifers include representatives of *Ammodiscus* isp., *Bathysiphon* isp., *Cyclammina* isp., *Hyperammina* isp., *Kalamopsis* isp., *Glomospira* isp., *Glomospirella* isp., *Haplophragmoides* isp., *Recurvoides* isp., *Trochammina* isp., and *Trochamminoides* isp. They are very similar to those recorded in the NF from Morocco (Kaminski et al., 1996) and Tunisia (Riahi et al., 2014), and from the Eocene Variegated Shale in the Carpathian Flysch of Poland (Kender et al., 2005), and correspond to lower bathyal to abyssal depths (Kaminski et al., 1996).

The *Ophiomorpha rudis* ichnosubfacies is recorded in medium- to very thick-bedded sandstones (FA1), interbedded with thinner beds of facies F2 and F4 in the upper unit of the Forêt des Cèdres and Kef Maiz sections. This ichnofacies contains abundant *Ophiomorpha rudis, O. annulata,* and *Thalassinoides* isp., which may co-occur with ?*Planolites* isp., *P. montanus*, *Gordia arcuata*, and *Helminthoidichnites* isp. Deposits representing this ichnosubfacies accumulated probably in channel and channel-levee-overbank settings. A more distal variant of the *Ophiomorpha rudis* ichnosubfacies occurs in the thick- to thin-bedded sandstones of facies F2 and F4 in the lower unit of the Ain Ghanem section. These yield *O. rudis*, *Thalassinoides* isp., *Zoophycos* isp., *Lophoctenium* isp., *Scolicia strozzii, Tubulichnium rectum,* ?*Planolites* isp. and *P. montanus.* These deposits probably accumulated in crevasse-splays generated from nearby isolated narrow channels within the mud-dominated part of the depositional system, which were occasionally fed with sandy turbiditic sediments. The channels were subject to avulsion.

The *Paleodictyon* ichnosubfacies occurs in thin- to medium-bedded sandstones of facies F4 in the lower unit of the Ain Ghanem and Kef Maiz sections and the lowest part of the upper unit in the Kef Maiz section. These deposits were probably deposited in channel-margin or channel-levee-overbank settings. Trace fossils representing this ichnosubfacies include *Paleodictyon strozzii*, *Paleomeandron rude*, *Megagrapton irregulare, Squamodictyon tectiforme, Chondrites* isp., *Taenidium* isp., *Helminthopsis* isp., *Helminthoidichnites* isp., *Zoophycos* isp., *Cosmorhaphe sinuosa*, *C. lobata,* ?*Planolites montanus,* ?*Planolites* isp., *P. beverleyensis, Oravaichnium* isp., *Halimedides* isp., *Rutichnus* isp., *Thorichnus* isp., *Siphonichnus* isp. and ?*Arthrophycus tenuis.*

The *Nereites* ichnosubfacies is recorded from thin-bedded sandstones of facies F4 in the lower unit of the Kef Maiz and Ain Ghanem sections. The sandstones were deposited on the basin floor by occasional turbidity currents in crevasse-splays (spilling over from nearby channels) or on small lobes located in the distal parts of vanishing channels or at their terminations. The turbidites interrupted the pelagic and hemipelagic sedimentation. This ichnosubfacies is represented by *Nereites* isp., *Phycosiphon incertum*, ?*Scolicia vertebralis*, *Helminthoidichnites* isp., *Tubulichnium mediterraneum*, ?*Alcyonidiopsis* isp., ?*Planolites* isp., *Spirophycus* isp. and *S. bicornis*.

The vertical distribution of trace fossils shows a general shallowing-up trend resulting mostly from the progradation of the depositional system. The succession of ichnofacies starts with the *Nereites* ichnosubfacies in the lower unit of the sections studied, and is associated with the exclusive occurrence of the *Ophiomorpha rudis* ichnosubfacies in the lower unit of the Ain Ghanem section, followed by the *Paleodictyon* ichnosubfacies in the lower unit of the Ain Ghanem section and the lowest part of the Kef Maiz section. The upper unit of the sections studied is dominated by the *Ophiomorpha rudis* ichnosubfacies, as observed mainly in the Forêt des Cèdres and Kef Maiz sections.

Diplocraterion isp. occurs in the top of the Kef Maiz section. Generally, this is a shallow-marine trace fossil of the *Skolithos* ichnofacies, but no sedimentological features of a shallow-marine setting have been noted in the section studied. Its occurrence fits to the general shallowing-up trend but is still rather in a deep-sea setting.

The shallowing-up trend recorded by the succession of ichnosubfacies is associated also with a generally decreasing-upwards abundance and diversity of the trace fossils in the sections. The high diversity of trace fossils in the lower unit is related to favourable environmental and preservational conditions. A calm environment associated with occasional turbiditic input rich in nutrients allowed for the proliferation of burrowing organisms. In contrast, the low diversity and low abundance of trace fossils in the upper unit can be caused in general by stress conditions related to high episodic turbulence, erosion of the sea floor and substrate instability (as shown by soft-sediment deformation structures), which limited the proliferation of trace makers and eroded the bioturbated sediments. In the calmer environment of the lower unit, delicate scouring and casting promoted preservation of burrows formed in mud, which are generally more abundant than burrows formed in sand in deep-sea turbiditic systems (Kern, 1980).

COMPARISONS

The trace fossil assemblages from the NF in Algeria are similar to those in Tunisia (Riahi et al., 2014) and southern Spain (Rodríguez-Tovar et al., 2016), which represent also the *Nereites* ichnofacies with the *Paleodictyon* and *Ophiomorpha rudis* ichnosubfacies. However, the fossil assemblages from the sections studied in Algeria are less diverse. Data on the ichnology of other parts of the NF (apart from Tunisia and Spain) are not available, except for incomplete data by Myron (2011), who reported some scattered trace fossils from Sicily and attributed them to the *Nereites* ichnofacies. Similarly to the Algerian sections studied, the Tunisian and Spanish sections display the highest ichnodiversity in the mudstone/sandstone alternations, which are equivalents of FA2, including the dominance of graphoglyptids in equivalents of facies F4 in this study. The medium- to very thick-bedded sandstones of facies F1 and F2 in Algeria are poorly bioturbated and show lower ichnodiversity. In contrast, some of their equivalents in Tunisia are characterized by abundant *Ophiomorpha rudis* and *Diplocraterion* cf. *habichi* (Riahi et al., 2014). Moreover, sections in southern Spain yield abundant *Ophiomorpha* and *Scolicia* (Rodríguez-Tovar et al., 2016). The mudstone or marly mudstone facies (F8) shows abundant to very abundant *Tubulichnium mediterraneum* in almost all outcrops compared in addition to rare ?*Alcyonidiopsis* isp. in Algeria, and abundant *Diplocraterion* cf. *habichi*, *Planolites montanus*, and *Chondrites* isp. in Tunisia.

When comparing with other equivalent Oligocene to Miocene turbiditic deposits of the Mediterranean region, the Grès d'Annot Basin deposits of southern France (Phillips et al., 2011) display highly abundant and low-diversity trace fossil assemblages, mostly in fine- to medium-grained sandstones (equivalent to facies F4), dominated by *Ophiomorpha*, *Phycosiphon*, *Planolites*, and *Scolicia*. In turn, the thick-bedded sandstones of France (equivalent to facies F1) show low-diversity trace fossils, dominated by *Ophiomorpha rudis* with less common *Thalassinoides suevicus*. The foredeep basins of the Northern Apennines in central Italy (Monaco et al., 2010) show more abundant and diverse trace fossils. The mud-dominated facies (equivalent to facies F8 and F7) reveals less common trace fossils dominated by *Zoophycos, Thalassinoides suevicus* and *Ophiomorpha annulata* in some parts while other places show trace fossils of the *Nereites* ichnosubfacies. The bulk of trace fossils occurs in thin- to medium-bedded sandstones (equivalent to facies F4), such as (1) interturbidites with channelized facies or (2) rhythmic beds within mudstones, including predepositional and postdepositional trace fossils with a general dominance of graphoglyptids. The thick-bedded sandstones (equivalent to facies F1 and F2) reveal scarce trace fossils, dominated by *Ophiomorpha* and *Scolicia*.

Beside the general similarities, the comparison shows that every depositional system, even if almost of the same age and region, show some differences in trace fossil composition, abundance, and distribution. This may be caused by differences in depositional processes, food abundance and other local factors, including preservational potential.

CONCLUSIONS

Ichnological and sedimentological studies of the Numidian Formation in the Ouarsenis Mountains, Algeria, allowed the determination of twenty-two ichnogenera, while distinguishing eight lithofacies grouped in three main facies associations. The trace fossils are dominated by post-depositional ichnotaxa (62%), including *Planolites montanus, P. beverleyensis,* ?*Planolites* isp., *Siphonichnus* isp., *Nereites* isp., *Chondrites* isp., *Phycosiphon incertum, Taenidium* isp., *Lophoctenium* isp., ?*Scolicia vertebralis, S. strozzii, Gyrochorte* isp., *Zoophycos* isp., *Oravaichnium* isp., *Halimedides* isp., *O. annulata, Ophiomorpha rudis, Palaeophycus tubularis*, *Palaeophycus striatus, Palaeophycus* isp., ?*Parataenidium* isp., *Thalassinoides* isp., *Tubulichnium mediterraneum,* ?*Alcyonidiopsis* isp., *Tubulichnium rectum, Lockeia* isp., and *Diplocraterion* isp., and predepositional ichnotaxa (38%), including *Spirophycus bicornis, Spirophycus* isp., *Oravaichnium* isp., *Phycodes* isp., *Thorichnus* isp., *Squamodictyon tectiforme, Megagrapton irregulare,* ?*Arthrophycus tenuis*, *Cosmorhaphe lobata, C. sinuosa, Gordia arcuata, Helminthoidichnites* isp., *Helminthopsis* isp., *Paleomeandron rude, Rutichnus* isp., and *Paleodictyon strozzii*. These commonly occur in fine-grained, thin-bedded sandstones (representing facies F4), mostly in facies associations FA2 and FA3. Ichnological analysis associated with sedimentary data indicate a deep-sea environment with typical trace fossil assemblages attributed to the *Nereites* ichnofacies, including its three main ichnosubfacies, i.e. (1) the *Ophiomorpha rudis* ichnosubfacies recorded in medium- to very thick-bedded sandstones (FA1) interbedded with thinner sandstone beds of facies F2 and F4 in the upper unit of the sections studied. These deposits probably originated in channel and levee-overbank environments. The medium to thin-bedded sandstones (FA2) in the lower units of the Kef Maiz and Ain Ghanem sections were deposited probably in isolated narrow channels in the mud-dominated part of the depositional system, which was occasionally fed with turbiditic sands. (2) The *Paleodictyon* ichnosubfacies occurs in thin- to medium-bedded sandstones (facies F4) deposited probably in channel-margin or channel-levee-overbank settings, which are recorded in the lower units of the Ain Ghanem and Kef Maiz sections, and the lower part of the upper unit in the Kef Maiz section. (3) The *Nereites* ichnosubfacies is recorded in thin-bedded sandstones (FA2), which were deposited probably in the basin-floor environment, specifically in crevasse-splays or small lobes characterized by occasional turbiditic flows associated with pelagic and hemipelagic sedimentation.

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