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# Middle Jurassic *Zoophycos* and *Chondrites* from the Mélah Formation of Saharan Atlas, Algeria

Fayçal Mekki[a], Li-Jun Zhang[b], Olev Vinn[c], Ursula Toom[d], Madani Benyoucef[e], Mohamed Bendella[f], Emad Bouchemla[f], Mustapha Bensalah[a] and Mohammed Adaci[a]

[a] Research laboratory n°25, Abou Bakr Belkaid University of Tlemcen, 13000 Tlemcen, Algeria; mekkimed62@gmail.com, med.adaci@gmail.com, mus.bensalah@yahoo.fr
[b] Institute of Resources and Environment, Henan Polytechnic University, Jiaozuo 454003, P.R. China; ljzhanghpu@gmail.com
[c] Department of Geology, University of Tartu, Ravila 14A, 50411 Tartu, Estonia; olev.vinn@ut.ee
[d] Department of Geology, School of Science, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia; ursula.toom@taltech.ee
[e] Faculty of Natural and Life Sciences, Mustapha Stambouli-Mascara University, 29000 Mascara, Algeria; benyoucefmada@gmail.com
[f] Department of Geology, University of Oran 2, Mohamed Ben Ahmed, 31000 Oran, Algeria; bendellamohamed@hotmail.com, bouchemlaimad@gmail.com

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**Abstract.** The ichnogenera *Zoophycos* and *Chondrites* are described for the first time from the Middle Jurassic of Algeria. The trace fossil assemblage recovered from the Mélah Formation contains seven ichnospecies (*Chondrites targionii*, *C.* ?*intricatus*, *Zoophycos brianteus*, *Z. cauda-galli*, *Zoophycos* isp. A, *Zoophycos* isp. B and *Zoophycos* isp. C), which all represent the *Zoophycos* ichnofacies. *Chondrites* and *Zoophycos* in the Mélah Formation were made by unknown worm-like invertebrates in a deeper offshore or a shallow bathyal environment (below storm weather wave base) and may indicate oxygen depletion within the sediment.

**Key words:** trace fossils, *Zoophycos*, *Chondrites*, deep offshore, Aalenian, Bajocian, North Africa.

## INTRODUCTION

The Mesozoic deposits are widely distributed in northern Africa along the southern margin of the former Tethys Ocean. On the Algerian territory, the Jurassic has been mapped repeatedly over the past 60 years, particularly those of the Maghribides chain in the Tell Atlas and the Saharan Atlas, which links from west to east the Moroccan–Algerian and the Tunisian–Algerian basins. Only a few studies address the Jurassic of the Saharan Atlas, e.g. Flamand (1911), Cornet (1952) and unpublished theses (Bassoullet 1973; Douihasni 1976; Ait Ouali 1991). They are only available in unpublished theses (e.g. Flamand 1911; Cornet 1952; Bassoullet 1973; Douihasni 1976; Ait Ouali 1991). The most recent work goes back to the thesis of Mekahli (1995), subsequently published in the *Documents des Laboratoires de Géologie de Lyon* (Mekahli 1998).

Here we describe trace fossils from the lower Middle Jurassic Mélah Formation cropping out in the Ksour Mountains, western Saharan Atlas. Ichnofossils are an important tool for palaeoecological and palaeoenvironmental interpretations (Seilacher 2007). They are relatively poorly known in the Middle Jurassic of Algeria. However, abundant *Zoophycos* Massalongo, 1855, associated with *Chondrites* Sternberg, 1833, occur in the Mélah Formation. The earliest *Zoophycos* is known from the Cambrian strata of the Czech Republic (Doucek & Mikuláš 2014). *Zoophycos* comprises a helical spreite that marks former positions of the burrow (Häntzschel 1975; Olivero 2007; Vinn & Toom 2015). It may have a form of either simple lobes or ornate spiral structures (Häntzschel 1975; Olivero 2007; Vinn & Toom 2015) and sometimes possess a marginal tunnel (Bromley 1991; Seilacher 2007; Sappenfield et al. 2012; Vinn & Toom 2015). Spreiten of *Zoophycos* are composed of first-order lamellae, but second-order lamellae are not always present (Häntzschel 1975; Olivero 2007; Vinn & Toom 2015; Monaco et al. 2016). *Zoophycos* has been interpreted as a feeding trace of a worm-like animal (Häntzschel 1975; Olivero 2007; Seilacher 2007; Vinn & Toom 2015). It is associated with continental slope facies between the *Cruziana* and the *Nereites* ichnofacies (Osgood & Szmuc 1972) and the ichnogenus gives the name to the *Zoophycos* ichnofacies (Seilacher 1967). In the Palaeozoic, *Zoophycos* usually occurred in shallow-water environments, but from the Mesozoic it shifted mostly to deep-sea sediments (Bottjer et al. 1988; Seilacher 2007; Uchman & Wetzel 2012; Zhang et al. 2015). The macroevolution and bathymetric range of *Zoophycos* has recently been reviewed by Zhang et al. (2015). Mesozoic *Zoophycos* burrows have been described in detail by Olivero (2003).

*Chondrites* has a stratigraphic range from the Ordovician to the Pliocene. It is found in modern deep-sea muds, but also in turbidite series as well as in shallow-marine shales and even in storm sands (Seilacher 2007). Different forms of *Chondrites* share a plant-like kind of branching along bedding planes (often termed ‘fucoids’), but they also show a preference for relatively quiet and low-oxygen environments (Seilacher 2007). *Chondrites* clearly belongs to the category of feeding burrows (fodinichia), but details of the probing, feeding and backfill processes are less uniform among different ichnospecies (Seilacher 2007).

The aims of this paper are (1) to describe *Zoophycos* and *Chondrites* for the first time from the lower Middle Jurassic of Algeria and (2) to discuss their stratigraphic and environmental distribution and palaeoecology.

## GEOLOGICAL SETTING

The Saharan Atlas domain extends some 1200 km along a SW–NE direction, from the Moroccan High Atlas in the west to the Tunisian Atlas in the east. To the north, the Saharan Atlas range is juxtaposed with a platform domain of the High Plateaus. Its southern boundary is a major tectonic dislocation, which is termed the South Atlas Fault, along which the Saharan Atlas is overthrusted on the Saharan Platform. The Saharan Atlas range includes a series of subranges, from west to east: the Ksour Mountains, the Djebel Amour, the Ouled-Naïl Mountains, the Aurès Mountains, the Nememcha-Mzab Mountains and the Melegue Mountains (Fig. 1A). The studied section is located in the Ksour Mountains (Fig. 1A, B).

The Lower Jurassic deposits of the carbonate platform sealed the sediments infilling the initial Triassic rift. The Mesozoic sedimentation was initiated within small Triassic rift basins that were filled with varicoloured clays, evaporites, interrupted by occasional basaltic lava flows (e.g. diaper of Aïn Ouarka). During the Early and Middle Jurassic, marine conditions were prevailing and the Ksour Basin was then filled in with a thick sedimentary succession. The renewing of rifting processes increased the accommodation space once again in the middle Early Jurassic, and the carbonate platforms were drowned and disrupted by subsidence. Thick successions of limestones, calciturbidites (e.g. Brèche de Raknet El Kahla Formation), sandstones and marls accumulated during the Early and Middle Jurassic (Bassoullet 1973; Mekahli 1998). These sediments are overlain by a ca 3000 m thick series of mostly continental Upper Jurassic–Lower Cretaceous siliciclastics (Djara, Aissa, Tiloula and Tiout formations). The Mesozoic succession had been uplifted and deformed during the Eocene and the Oligocene (Dewey et al. 1973). Fold and fault deformations affected the Jurassic and Cretaceous deposits. Jurassic units formed ridges separated by broad synclines composed of Lower Cretaceous formations. The Cenomanian–Turonian limestone ledges (Rhoundjaïa Formation) occupy the top of synclines (Benyoucef et al. 2017).

The section studied herein (coordinates 33°1′6.16″N; 0°23′45.99″W) is situated about 3 km south of the national road n°6 on the southern slope of the Djebel Souiga, a 15 km long hill, close to the water source commonly known as ‘Aïn Dehara’ (Fig. 1B).

## STRATIGRAPHY AND SEDIMENTOLOGY

The southern flank of the Djebel Souiga provides well-exposed and laterally continuous outcrops to study lower Middle Jurassic marl–limestone alternations representing the Mélah Formation (Mekahli 1998). The Mélah Formation can be subdivided into two informal members (Fig. 2): *Zoophycos*-bearing marl–limestone member and marl–argillaceous limestone member.

The *Zoophycos*-bearing marl–limestone member rests on the ‘Marno-calcaires d’Aïn Beida’ Formation (Toarcian) (Fig. 2). The member is 30 m thick and is represented by regular alternation of thin- to medium-bedded (0.03–0.20 m thick) limestone and light grey marls (0.15–0.80 m). Limestone beds are bluish-grey in colour, apparently massive and contain numerous ammonites, nautiloids and belemnites. The limestone beds are commonly rich in trace fossils, represented by *Zoophycos* and *Chondrites*. The beds have sharp and slightly undulating contacts. Microscopic analysis of limestone facies documents the presence of skeletal components, including *Posidonomya*, siliceous sponge spicules and radiolarians, in addition to rare planktic foraminifers. Occasional planktic single-celled green algae (*Globochaete* sp.) are also found. Textures of the limestones range from mudstone to wackestone (Bassoullet 1973; Mekahli 1998).

The marl–argillaceous limestone member rests on the *Zoophycos*-bearing marl–limestone member and is accessible in all studied sections, either completely or partially due to a cover of younger sediments. It is up to 42 m thick (Fig. 2) and consists of irregular alternation of soft, greenish marls and blue to grey argillaceous

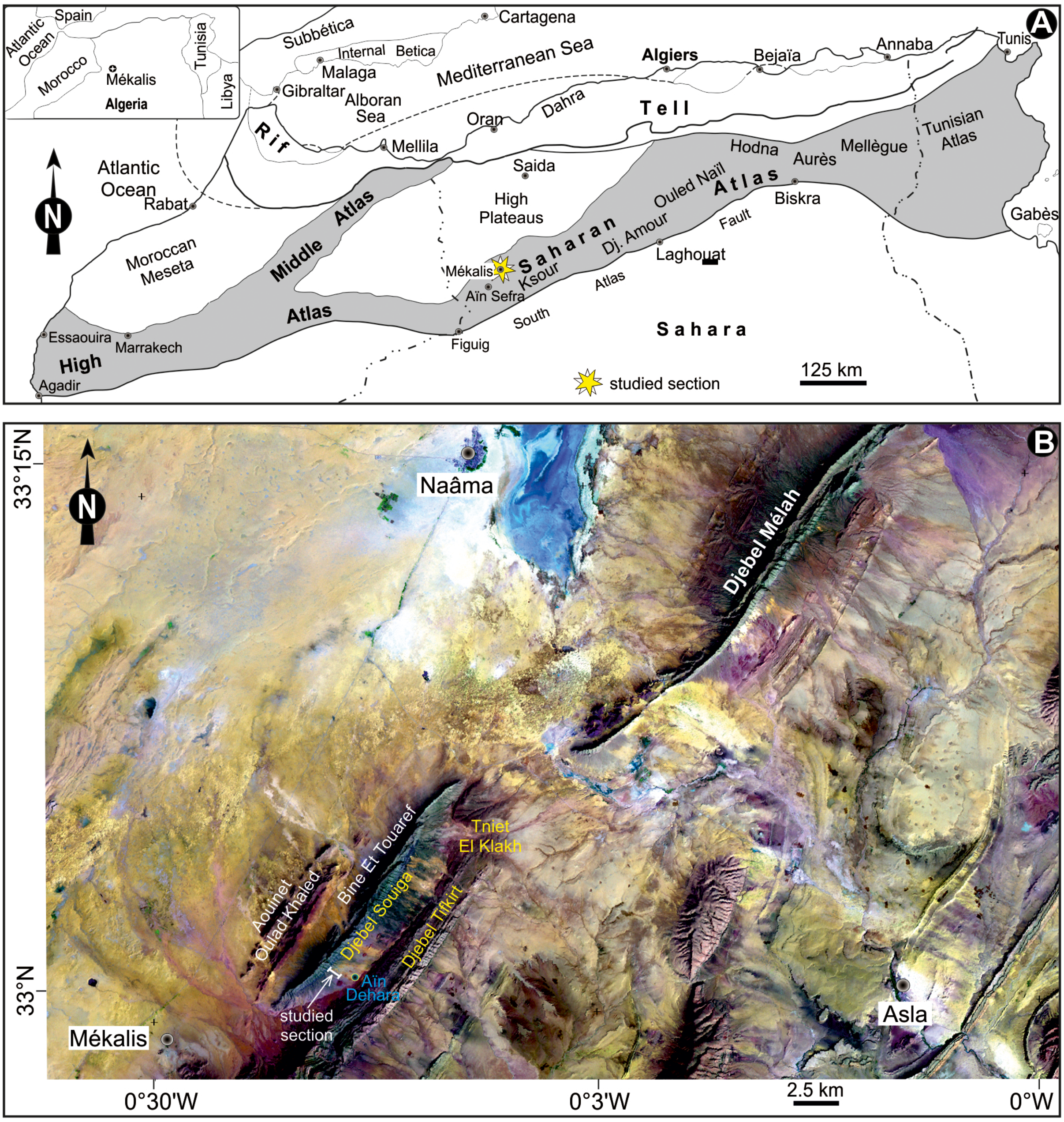
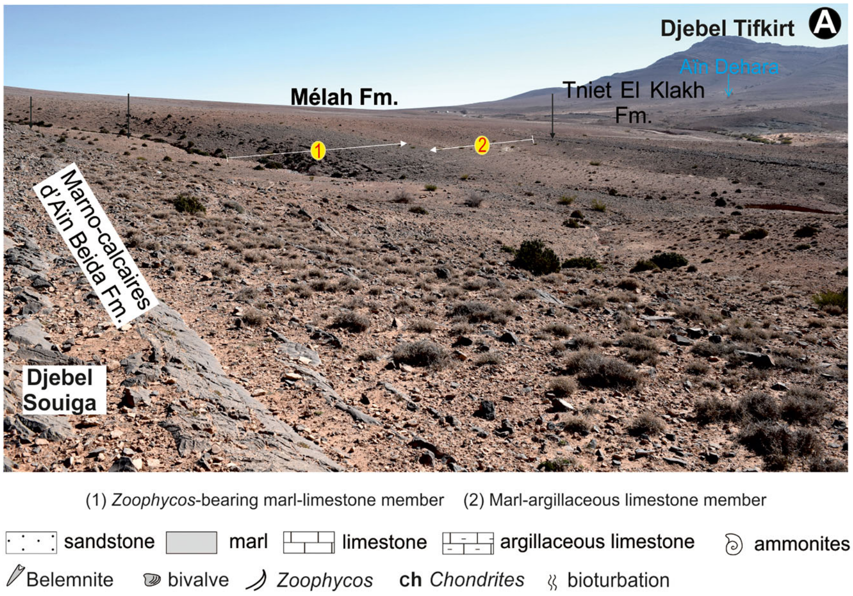



**Fig. 1.** **A**, position of the studied section; **B**, satellite image showing the studied section.

limestones. The limestones occur as centimetre- to decimetre-thick beds containing abundant ammonites and less common belemnites. The interbedded marls yielded abundant thin-shelled bivalves (*Bositra buchii* Roemer, 1836). The upper boundary of the member is a very sharp erosional surface. The member is followed by the Tniet El Klakh Formation, a mixed siliciclastic–carbonate unit of Bajocian–Bathonian age. Bassoullet (1973) cited in the studied section several ammonite-rich beds indicative of Upper Aalenian to Lower Bajocian age. The textural characteristics, the pronounced abundance of ammonites and pelagic microfauna such as radiolarians suggest open marine normal salinity environment. The scarcity of benthic elements, and the absence of high-energy hydrodynamic structures indicate that both members of the Mélah Formation were deposited below mean storm weather wave base. Trace fossils are not common in the marl–argillaceous limestone member, but some bioturbation occurs in its upper part (Bassoullet 1973; Mekahli 1998).



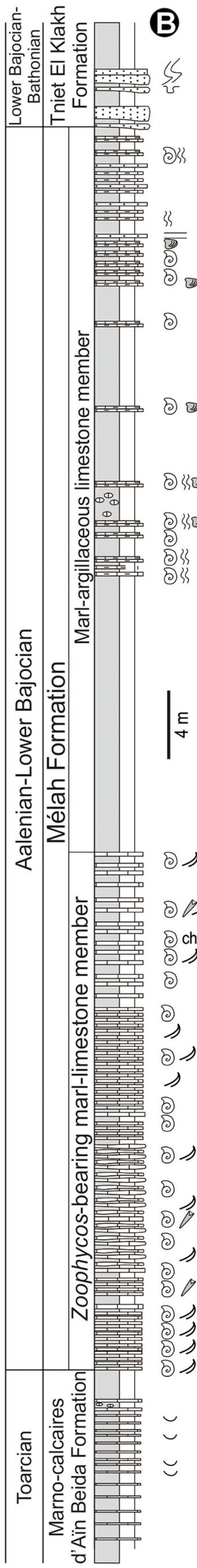




**Fig. 2.** Panoramic view (**A**) and the lithostratigraphic column (**B**) of the studied succession.

## TRACE FOSSIL DESCRIPTIONS

*Chondrites targionii* (Brongniart, 1828)
Figure 3A

*Description*. Tree-like, slightly curved, branched, flattened tunnels, with three orders of branches. Second-order branches are dominant. The angle of branching ranges from 20° to 45°. Tunnels are about 1 mm wide. The whole burrow system is about 8 cm wide. The branches are slightly curved and filled with lighter material than the host rock. The traces are preserved in concave or convex epirelief. Traces are preserved at the bedding planes.

*Discussion*. *Chondrites* systematics was revised by Fu (1991), Uchman (1999) and Uchman et al. (2012), and seven distinct ichnospecies were identified, including *C. targionii*, *C. intricatus*, *C. patulus*, *C. recurvus*, *C. stellaris*, *C. caespitosus* and *C. affinis*. The burrows here showing primary successive branching, slightly curved tunnels and mostly sharp angles of branching are diagnostic of *C. targionii* (Fu 1991; Uchman 1999; Uchman et al. 2012, fig. 5), also the size of our specimens is matching what Uchman et al. (2012, fig. 5) showed in their figure.


A
2 cm
B
10 cm
C
15 cm
D
10 cm
E
30 cm
F
ML
NL
10 cm
G
10 cm

*Chondrites* ?*intricatus* (Brongniart, 1828)
Figure 3B

*Description*. Small, tree-like branching, downward radiating, straight and short hypichnial burrows. The branches are filled with lighter material than the host rock. The width of the burrow system is smaller than 50 mm and the width of the funnel is about 1 mm.

*Discussion*. *Chondrites* ?*intricatus* and *C. targionii* co-occur in the Mélah Formation (Fig. 3B). The larger *C. targionii* cross-cut the smaller *C.* ?*intricatus*. The smaller *Chondrites* deserves a separate name as there seems to be a size break between smaller and larger *Chondrites* specimens in our sample. The described specimens are assigned only tentatively to *C. intricatus* due to their rather poor preservation.

*Zoophycos brianteus* Massalongo, 1855
Figure 3C, E

*Description*. Preserved in full relief, endichnial, horizontal to inclined, spiralling, probably helicoidal J-shaped spreiten burrows. The specimens are more than 30 cm wide. Primary and secondary lamellae are distinguishable. Primary lamellae are 1–2 mm wide; they start from a central tube and bend slightly towards the external part of the spreite.

*Discussion*. *Zoophycos* is a complex and still enigmatic trace fossil because of its variable morphology (Bromley & Hanken 2003; Olivero 2003; Knaust 2009; Zhang 2014). *Zoophycos* was initially named as a plant genus by Massalongo (1855). Olivero (2007) reviewed the specimens Massalango used to establish *Zoophycos* and proposed a paralectotype for the ichnogenus. The specimens described here are similar to *Zoophycos brianteus* and we found no obvious morphological differences between the studied material and the type material (Massalongo 1855, pp. 51–52, pl. 3, figs 1,2; Olivero 2007, fig. 13.10). *Zoophycos* is considered as a feeding burrow of worm-like deposit feeders (Bottjer et al. 1988; Olivero 2003).

*Zoophycos cauda-galli* (Vanuxem, 1842)
Figure 3D

*Description*. Endichnial, full relief, U-shaped helicoidal spreiten burrows. The outline is cock-tail shape and the primary and secondary lamellae are distinct. The specimens are more than 30 cm wide. Primary lamellae are 3–4 mm wide.

*Discussion*. Trace fossil morphology classified today as *Zoophycos cauda-galli* was first found in calcareous and clay-rich sandstone of the Devonian Hamilton Group in New York and Ohio, USA and described under the name *Fucoides cauda-galli* (Vanuxem 1842). It was later described as fossil seaweed under the name *Spirophyton cauda-galli* (Hall 1863). The specimens studied here are similar to *Z. cauda-galli* in the overall shape, dimensions of the spreite and primary lamellae, and the described ichnospecies does not exhibit any obvious morphological differences from the type material (Vanuxem 1842, pp. 128–129, fig. 30).

*Zoophycos* isp. A
Figure 3E

*Description*. Hypichinial, horizontal, flat, arcuate U-shaped spreiten burrows with a visible marginal tunnel. The marginal tunnel is less than 1 cm wide. The primary and secondary lamellae are not easily distinguishable. The maximum width of the specimens is 8.6 cm.

*Discussion*. The specimens described here should be referred to U-shaped *Zoophycos*. Their traces are quite abundant and diverse on the sole surfaces of marly limestone from the Mélah Formation (Fig. 3E). The morphology is treated in open nomenclature because of the poor state of preservation and limited number of specimens.

*Zoophycos* isp. B
Figures 3F, 4

*Description*. Endichnial, horizontal, spiralling, J-shaped spreiten burrows. The outline is cock-tail shape and the primary and secondary lamellae are visible. The primary lamellae are 3–5 mm apart. The burrow system diameter is about 30 cm.

*Discussion*. The lobes resembling the tail of a cock are diagnostic for *Z. cauda-galli*, but *Zoophycos* isp. B differs from that ichnospecies in having J-shaped spreiten, a slightly smaller diameter of the burrow system and a larger maximal diameter of primary lamellae. The morphology is treated in open nomenclature because of the poor state of preservation and limited number of specimens.

**Fig. 3. A**, *Chondrites targionii*, convex epirelief, Mélah Formation; **B**, small (*C.* ?*intricatus*, black arrow) and large (*C. targionii*, white arrow) *Chondrites* together, Mélah Formation; **C**, *Zoophycos brianteus*, endichnial, Mélah Formation; **D**, *Zoophycos cauda-galli*, endichnial, Mélah Formation; **E**, two forms of *Zoophycos* together, *Z. brianteus* (white arrow) and *Zoophycos* isp. A (black arrow), hypichnial, Mélah Formation; **F**, *Zoophycos* isp. B, J-shaped form with primary lamellae (ML) and secondary lamellae (NL), endichnial, Mélah Formation; **G**, *Zoophycos* isp. C, arcuate U-shaped form, hypichnial, Mélah Formation.

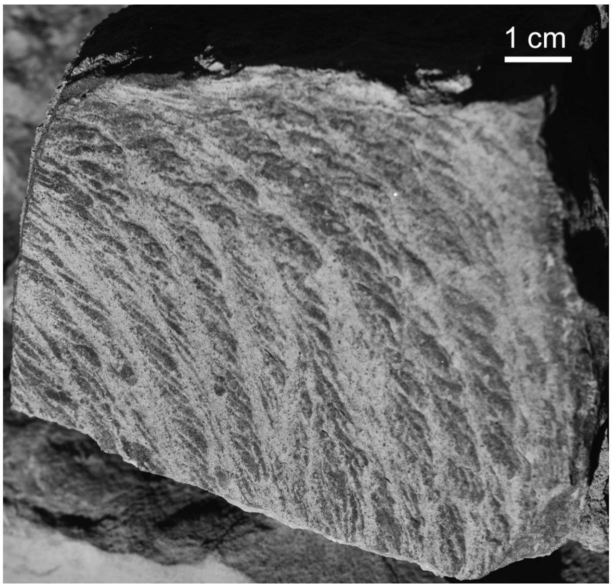



**Fig. 4.** Detailed view of second-order lamellae in *Zoophycos* from the Mélah Formation.

*Zoophycos* isp. C
Figure 3G

*Description*. Hypichnial, horizontal, helicoidal, arcuate U-shaped spreiten burrows. The spreite lamina are arranged around a central point. The primary and secondary lamellae are clearly distinguished. The burrow system diameter is about 30 cm. The primary lamellae are 8–9 mm apart.

*Discussion*. *Zoophycos* isp. C resembles *Zoophycos cauda-galli* in having a similarly U-shaped spreiten burrow, but differs from the latter ichnospecies in much thicker primary lamellae. It differs from the other described *Zoophycos* ichnospecies also in much thicker primary lamellae. The morphology is treated in open nomenclature because of the poor state of preservation and limited number of specimens.

## DISCUSSION AND CONCLUSIONS

The trace fossil assemblage from the Middle Jurassic Mélah Formation of the western Saharan Atlas contains two ichnogenera and probably up to seven ichnospecies which represent the *Zoophycos* ichnofacies. The described *Zoophycos* traces show variable morphologies (*Z. brianteus* is most common); some were left in open nomenclature (*Zoophycos* isp. A, *Zoophycos* isp. B and *Zoophycos* isp. C). The observed morphological variation may in some instances reflect various section views of the trace fossil rather than true morphological differences. Moreover, as it has been demonstrated in *Zoophycos rhodensis* (Bromley & Hanken 2003) and in *Zoophycos* described by Pervesler & Uchman (2004), the morphologies typical of distinct ichnospecies (e.g. *Z. brianteus* and *Z. insignis*) may meet in one structure. The *Zoophycos* observed during our study is indicating a relatively quiet, nutrient-rich, offshore environment (Seilacher 2007; Zhang et al. 2015). Similarly to the Mélah Formation, *Zoophycos* is characteristic of certain Jurassic and Cretaceous basinal deposits of southeastern France (Olivero 1996, 2003). In contrast to the Mélah Formation, trace fossils are more diverse (e.g. common *Chondrites*, *Planolites*, *Zoophycos*, *Teichichnus* and *Thalassinoides*; Uchman & Jach 2017) in the Middle Jurassic facies of spotted limestones of the High Tatra Mts (Jach & Reháková 2019). In general, the assemblage is not diverse in comparison with shallower marine Middle Jurassic strata such as spotted limestones of the High Tatra Mts. *Zoophycos* dominates the association, whereas *Z. brianteus* is the dominant ichnospecies. All the morphotypes of *Zoophycos* occur in the same facies. The observed variation of burrow systems assigned to *Zoophycos* is documented herein with five morphologies: two ichnospecies and three more morphologies left in open nomenclature. The differences in observed morphologies may result from (1) the action of different tracemakers, (2) various behaviours of the same tracemaker or (3) ontogenetic changes in the tracemaker population.

Deposits of the *Zoophycos*-bearing marl–limestone member of the Mélah Formation are moderately bioturbated (authors' field observations). *Chondrites* and *Zoophycos* represent deep tier traces among the trace fossil associations of the Middle Jurassic (Bromley 1990; Zhang et al. 2015). *Zoophycos* indicates that the sediments forming the seafloor could have been slightly dysoxic or, alternatively, *Zoophycos* could have occurred in oxic deposits but in deep tier (Ekdale 1992). *Chondrites* has also often been considered to be an indicator of anoxia in sediments (Bromley & Ekdale 1984; Gong & Droser 2001). This could suggest oxygen deficiency in the sediments during the deposition of the *Zoophycos*-bearing member of the Mélah Formation.

*Zoophycos* occurs usually in deep-sea sediments since the Jurassic (Bromley 1990; Seilacher 2007; Zhang et al. 2015), but is also present in shallower marine deposits in the German Triassic (Knaust 2004). The abundance of ammonites and pelagic microfauna and the scarcity of benthic faunal elements suggest that *Zoophycos*-bearing marl–limestone member of the Mélah Formation could be deposited in offshore, normal sea salinity settings. The ichnospecies of *Zoophycos* from the Mélah Formation are also similar in morphology to those described from the deep-sea environments (Zhang et al. 2015) and do not resemble nearshore representatives of *Zoophycos* (Knaust 2004).

It is accepted that *Zoophycos* and *Chondrites* are more related to the oxygen level within the substrate than to bathymetry. What seems to be most important here is that *Zoophycos* and *Chondrites* are the only trace fossils in the formation, all shallower traces are missing and sedimentary structures are well preserved (i.e. primary lamination). When shallow tier trace fossils are missing and the sedimentary structures are preserved, the redox boundary could be close to the sediment–water interface and therefore any colonization by oxygen-dependent burrowers would be excluded. Hence, the settings could be deep as the oxygen level was low. Alternatively, this may suggest weak ventilation, infrequent storms, or no storms and no normal weather wave action, but any geological structures prohibiting normal wave activity are unknown from the study region.

Most likely the studied trace fossils were made by unknown worm-like invertebrates in a deeper offshore or a shallower bathyal environment (Zhang et al. 2015). *Chondrites* is likely a feeding system of unknown tracemakers related to infaunal deposit-feeders such as sipunculoids and/or annelids (Osgood 1970). This is in agreement with the other available palaeontological data, indicating a relatively deep-water environment for the lower, *Zoophycos*-bearing member of the Mélah Formation.

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## REFERENCES

Ait Ouali, R. 1991. *Le rifting des Monts des Ksour au Lias: Organisation des bassins, diagénèse des assises carbonatées, place dans les ouvertures mésozoïques du Maghreb*. Thèse de Doctorat es Sciences, Université d'Alger, 297 pp.

Bassoullet, J. P. 1973. *Contribution à l'étude stratigraphique du Mésozoïque de l'Atlas Saharien occidental (Algérie)*. Thèse de Doctorat d'État, Sciences Naturelles. Université de Paris VI, 497 pp.

Benyoucef, M., Mebarki, K., Ferré, B., Adaci, M., Bulot, L. G., Desmares, D., Villier, L., Bensalah, M., Frau, C., Ifrim, C. & Malti, F.-Z. 2017. Litho- and biostratigraphy, facies patterns and depositional sequences of the Cenomanian–Turonian deposits in the Ksour Mountains (Saharan Atlas, Algeria). *Cretaceous Research*, **78**, 34–55.

Bottjer, D. J., Droser, M. L. & Jablonski, D. 1988. Palaeoenvironmental trends in the history of trace fossils. *Nature*, **333**, 252–255.

Bromley, R. G. 1990. *Trace Fossils. Biology and Taphonomy*. Unwin Hyman, London, Boston, Sydney, Wellington, 280 pp.

Bromley, R. G. 1991. *Zoophycos*: strip mine, refuse dump, cache or sewage farm? *Lethaia*, **24**, 460–462.

Bromley, R. G. & Ekdale, A. 1984. *Chondrites*: a trace fossil indicator of anoxia in sediments. *Science*, **224**(4651), 872–874.

Bromley, R. G. & Hanken, N. M. 2003. Structure and function of large, lobed *Zoophycos*, Pliocene of Rhodes, Greece. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **192**(1–4), 79–100.

Brongniart, A. T. 1828. *Historie des végétaux fossiles, ou, Recherches botaniques et géologiques sur les végétaux renfermés dans les diverses couches du globe*. G. Dufour and E. d'Ocagne, Paris, Vol. 1, 136 pp.

Cornet, A. 1952. L'Atlas saharien Sud-Oranais. *Publications du XIXème Congrès Géologique International-Alger, Monographies régionales, 1 ère série*, 12, 1–51.

Dewey, J. F., Pitman, W. C., Ryan, W. B. F. & Bonnin, J. 1973. Plate tectonics and the evolution of the alpine system. *Geological Society America Bulletin*, **84**, 3137–3180.

Doucek, J. & Mikuláš, R. 2014. Cambrian trace fossil *Zoophycos* from the Czech Republic. *Geologica Carpathica*, **65**, 403–409.

Douihasni, M. 1976. *Etude géologique de la région d'Aïn Ouarka–Boussemghoun (partie centrale des Monts des Ksour). Stratigraphie et analyse structurale*. Thèse 3ème cycle, Université d'Oran, 272 pp.

Ekdale, A. A. 1992. Muckraking and mudslinging: the joys of deposit-feeding. In *Trace Fossils* (Maples, C. G. & West, R. R., eds), *Paleontological Society, Short Course in Paleontology*, 5, 145–171.

Flamand, G. B. M. 1911. *Recherches géologiques et géographiques sur le haut-pays de l'Oranie (Algérie et territoires du Sud)*. Thèse ès-Sciences, Lyon, n°47 (Rey, A., ed.), 1001 pp.

Fu, S. 1991. Funktion, Verhalten und Einteilung fucoider und lophocteniider Lebensspuren. *Courier Forschungsinstitut Senckenberg*, **135**, 1–79.

Gong, Y. & Droser, M. L. 2001. Periodic anoxic shelf in the Early-Middle Ordovician transition: ichnosedimentologic evidence from West-Central Utah, USA. *Science in China Series D, Earth Science*, **44**, 979–989.

Hall, J. 1863. Observations upon some spiral growing fucoidal remains of the Paleozoic rocks of New York. In *New York Cabinet, 16th Annual Report*, pp. 76–83.

Häntzschel, W. 1975. Trace fossils and problematica. In *Treatise on Invertebrate Paleontology, W, Supplement 1, 2nd ed.* (Teichert, R. C., ed.). University of Kansas Press, Lawrence, 269 pp.

Jach, R. & Reháková, D. 2019. Middle to Late Jurassic carbonate-biosiliceous sedimentation and palaeoenvironment in the Tethyan Fatricum Domain, Krížna Nappe, Tatra Mts, Western Carpathians. *Annales Societatis Geologorum Poloniae*, **89**, 1–46.

Knaust, D. 2004. The oldest Mesozoic nearshore *Zoophycos*: evidence from the German Triassic. *Lethaia*, **37**, 297–306.

Knaust, D. 2009. Complex behavioural pattern as an aid to identify the producer of *Zoophycos* from the Middle Permian of Oman. *Lethaia*, **42**, 146–154.

Massalongo, A. 1855. *Zoophycos, novum genus plantarum fossilium*. Typis Antonellianis, Veronae, 52 pp.

Mekahli, L. 1995. *Hettangien-Bajocien supérieur dans les Monts des Ksour. Biostratigraphie, évolution paléogéographique et stratigraphie séquentielle (Atlas Saharien Occidental)*. Thèse de Doctorat d'état, Université d'Oran, 358 pp.

Mekahli, L. 1998. Evolution des Monts des Ksour (Algérie), de l'Hettangien au Bajocien: biostratigraphie, sédimentologie, paléogéographie et stratigraphie séquentielle. *Documents des Laboratoires de Géologie de Lyon*, **147**, 1–319.

Monaco, P., Bracchini, L., Rodríguez-Tovar, F. J., Uchman, A. & Coccioni, R. 2016. Evolutionary trend of *Zoophycos* morphotypes from the Upper Cretaceous–Lower Miocene in the type pelagic sections of Gubbio, central Italy. *Lethaia*, **50**, 41–57.

Olivero, D. 1996. *Zoophycos* distribution and sequence stratigraphy. Examples from the Jurassic and Cretaceous deposits of southeastern France. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **123**, 273–287.

Olivero, D. 2003. Early Jurassic to Late Cretaceous evolution of *Zoophycos* in the French Subalpine Basin (southeastern France). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **192**, 59–78.

Olivero, D. 2007. *Zoophycos* and the role of type specimens in ichnotaxonomy. In *Trace Fossils: Concepts, Problems, Prospects* (Miller, W., ed.), pp. 466–477. Elsevier, Amsterdam.

Osgood, R. G. 1970. Trace fossils of the Cincinnati area. *Palaeontographica Americana*, **41**, 282–444.

Osgood, R. G. & Szmuc, E. J. 1972. The trace fossil *Zoophycos* as an indicator of water depth. *Bulletin of American Paleontology*, **62**, 5–22.

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

Roemer, F. A. 1836. *Die Versteinerungen der norddeutschen Oolithen-Gebirges*. Im Verlage Hahn'schen Hofbuchhandlung, Hannover, 218 pp.

Sappenfield, A., Droser, M., Kennedy, M. & Mckenzie, R. 2012. The oldest *Zoophycos* and implications for Early Cambrian deposit feeding. *Geological Magazine*, **149**, 1118–1123.

Seilacher, A. 1967. Bathymetry of trace fossils. *Marine Geology*, **5**, 413–429.

Seilacher, A. 2007. *Trace Fossil Analysis*. Springer, Berlin, 226 pp.

Sternberg, G. K. von. 1833. *Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt*. IV Heft V. C. E. Brenck, Regensburg, 48 pp.

Uchman, A. 1999. Ichnology of the Rhenodanubian Flysch (Lower Cretaceous-Eocene) in Austria and Germany. *Beringeria*, **25**, 67–173.

Uchman, A. & Jach, R. 2017. Ichnological record in Jurassic sediments of the Fatricum Domain in the Tatra Mountains, southern Poland and northern Slovakia. In *Jurassica XIII, Jurassic Geology of Tatra Mts, Abstracts and Field Trip Guidebook, Poland, Kościelisko near Zakopane, June 19th–23rd, 2017* (Grabowski, J., ed.), p. 60. Polish Geological Institute – National Research Institute, Warsaw.

Uchman, A. & Wetzel, A. 2012. Deep-sea fans. In *Trace Fossils as Indicators of Sedimentary Environments* (Knaust, D. & Bromley, R. G., eds), *Developments in Sedimentology*, **64**, 643–671.

Uchman, A., Caruso, C. & Sonnino, M. 2012. Taxonomic review of *Chondrites affinis* (Sternberg, 1833), from Cretaceous-Neogene offshore-deep-sea Tethyan sediments and recommendation for its further use. *Rivista Italiana di Paleontologia e Stratigrafia*, **118**, 313–324.

Vanuxem, L. 1842. *Geology of New York, Part III. Survery of the third Geological district, New York*. W. & A. White & J. Visscher, Albany, 306 pp.

Vinn, O. & Toom, U. 2015. The trace fossil *Zoophycos* from the Silurian of Estonia. *Estonian Journal of Earth Sciences*, **64**, 284–288.

Zhang, L.-J. 2014. Lower Devonian tempestites in western Yangtze, South China: insight from *Zoophycos* ichnofabrics. *Geological Journal*, **49**, 177–187.

Zhang, L, Fan, R. & Gong, Y. 2015. *Zoophycos* macroevolution since 541 Ma. *Scientific Reports*, **5**, 14954.

## Alžeeria Sahara Atlase Mélahi kihistu Kesk-Juura vanused *Zoophycos* ja *Chondrites*

Fayçal Mekki, Li-Jun Zhang, Olev Vinn, Ursula Toom, Madani Benyoucef, Mohamed Bendella, Emad Bouchemla, Mustapha Bensalah ja Mohammed Adaci

Jäljefossiilid *Zoophycos* ja *Chondrites* on esmakordselt kirjeldatud Alžeeria Kesk-Juurast. Uuritud jäljefossiilide kooslus sisaldab seitset liiki jälgi (*Chondrites targionii*, *C.* ?*intricatus*, *Zoophycos brianteus*, *Z. cauda-galli*, *Zoophycos* isp. A, *Zoophycos* isp. B ja *Zoophycos* isp. C), mis kõik esindavad *Zoophycos*'e ihnofaatsiest. Mélahi kihistu *Zoophycos*'e ja *Chondrites*'e jäljed tekitati tundmatute ussilaadsete selgrootute poolt. Mélahi kihistu setendid on süvaveelist päritolu (settinud tormilainete mõjupiirkonnast sügavamal) ja *Zoophycos*'e ning *Chondrites*'e jälgede esinemine võib viidata hapniku puudusele kunagise merepõhja setetes.