



# The Chefar El Ahmar Formation (late Emsian-Frasnian Ib) in the Marhouma section (Saoura, Algerian Sahara): insights from ichnology and sedimentology

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## Abstract

This contribution reports an ichnological study of the well-exposed strata belonging to the Chefar El Ahmar Formation, located in the Saoura Valley (Ougarta Range, Northwestern Algerian Sahara). This unit consists mainly of irregularly alternating shale and limestone with some intercalated sandstone. The data reflect hemipelagic to pelagic carbonate ramp character, episodically interrupted by internal waves in an extra-tempestite context. The ichnological analysis suggests a low bioturbation intensity. Eight ichnotaxa documented represent the *Cruziana* ichnofacies: *Alcyonidiopsis*, *?Balanoglossites*, *Chondrites*, *Nereites missouriensis*, *Neonereites biserialis*, *Palaeophycus*, *Thalassinoides* and *Zoophycos*, distributed in an irregularly manner dominated by a *Zoophycos-Chondrites* assemblage in the lower part (units “a”, “b”, “c” and bottom part of unit “d”), a *Zoophycos-Chondrites-Alcyonidiopsis-?Balanoglossites-Nereites missouriensis-Thalassinoides* assemblage in the middle part (unit “d” and lower part of unit “e”) and a *Chondrites-Alcyonidiopsis-Nereites missouriensis-Neonereites biserialis-Palaeophycus* assemblage in the upper part (major part of unit “e” and unit “g”). The distribution of these trace fossils frame the major bioevents represented in this section. They are more frequent above and below the bioevent levels while rare to absent in the crisis beds themselves. The control was evidently provided by palaeoenvironmental conditions (including bathymetry, oxygenation and nutrient supply), as a result of the general deepening of the northern Gondwana carbonate platform from the late Emsian to the early Frasnian, due to the major transgression during the Middle Devonian.

**Keywords** Saoura · Marhouma section · Chefar El Ahmar Formation · late Emsian-Frasnian Ib · Carbonate ramp · *Cruziana* ichnofacies

## Introduction

Trace fossils constitute an additional contribution to complete the knowledge on sedimentology and paleontology of a

sedimentary succession. In a stratigraphic succession, ecological information provided by trace fossils can be applied to evaluate the controlling factors such as water depth (Seilacher 1967; Frey et al. 1990), substrate type (Pemberton et al. 2004), nutrient supply, oxygenation, salinity and sedimentation rate (Ekdale 1985, 1988; Oschmann 1993; Taylor et al. 2003). Thus, in the Ougarta Range, which constitute the north margin of Gondwana, the global transgression of the Middle Devonian, initiated during the late Emsian (Ouali Mehadjji et al. 2004; Crônier et al. 2016), is accompanied by an enrichment and diversification of trace fossils framing the bioevents that were spotted by Maillet et al. (2013).

The Ougarta Range forms part of the northern Gondwana margin (Fig. 1a), appearing as an alignment of Paleozoic chains oriented NW-SE, and subdivided into two parallel beams separated by the Erg Er-Raoui: the Saoura and Daoura (Fig. 1b). These mountains make up a subsiding structure showing all the characteristics of an aulacogenic basin

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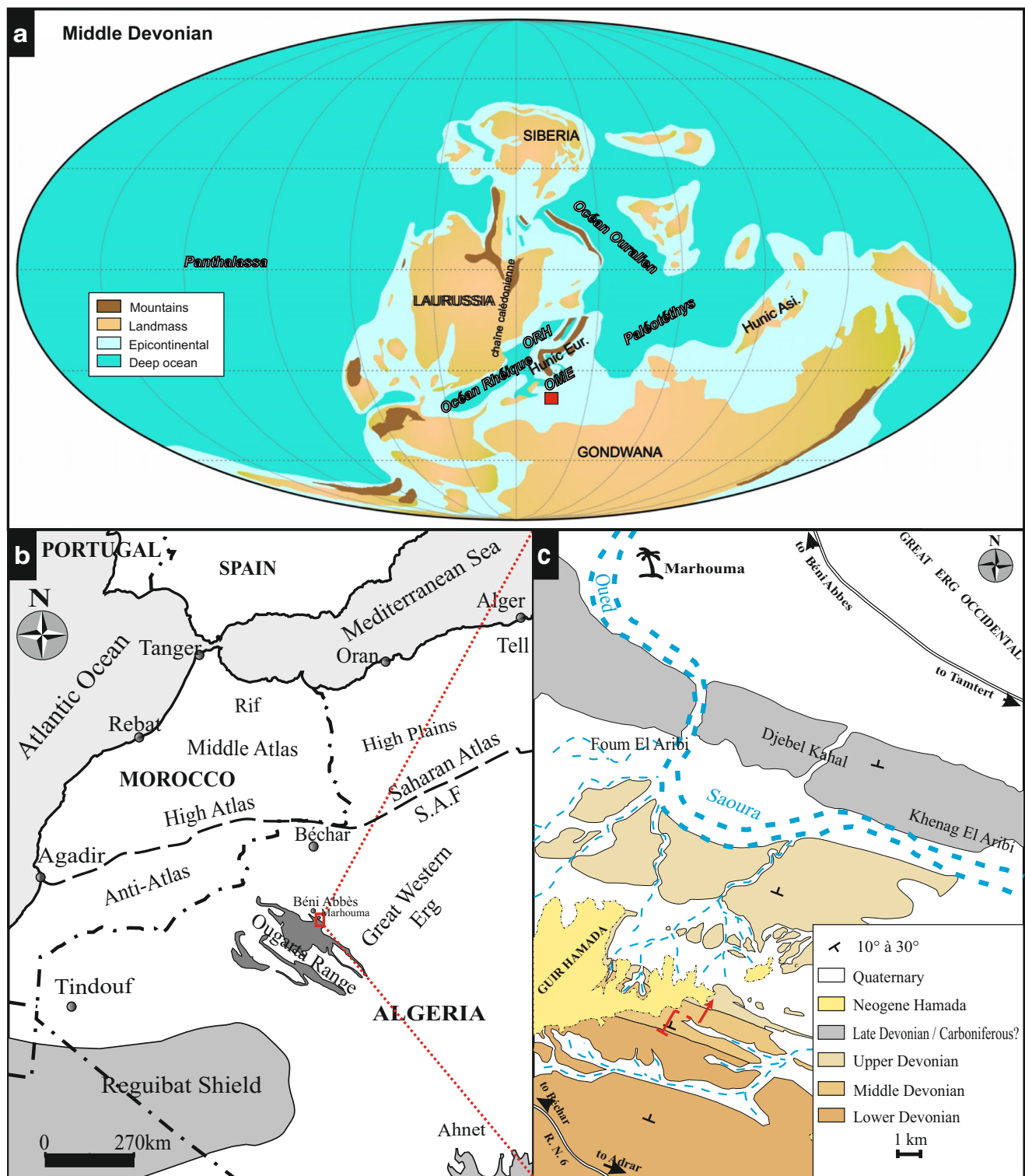
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**Fig. 1** **a** Middle Devonian palaeogeographic reconstruction (adapted from Golonka 2000, 2007a, b; RHO, Rheno-Hercynian Ocean; Hunic Eur., Superterrane Hunic European; Hunic Asi., Superterrane Hunic Asian) and the position of Ougarta Range (red square); **b** Geographic

location of the km 30 area in Algeria. (S.A.F South Atlasic Fault); **c** location of the studied section in the Saoura Valley (extract of the geological map of Ougarta 1/500000; 1982, modified)

(Donzeau 1974; Collomb and Donzeau 1974; Fabre 2005; Hamdidouche 2009), having a thick sedimentary cover (more than 5000 m) overlying a Pan-African basement (Perron et al.

2018). The Autuno-Stephanian tectonic inversion (Fabre 1976, 2005) is reflected by compressional movements and weak shortening (Hervouet and Duée 1996).

In the Saoura Valley (Fig. 1b), the Chefar El Ahmar Formation (Poueyto 1965) has been investigated in numerous biostratigraphic works (Le Maître, 1952; Petter 1959; Göddertz 1987; Boumendjel et al. 1997; Ouali Mehadji 2004; Ouali Mehadji et al. 2004; Ait-Ouali 2007; Maillet et al. 2013; Tandjaoui-Arif 2014; Besseghier 2014; Khaldi 2014; Khaldi et al. 2015; Mahboubi 2015; Mahboubi and Gatovsky 2015; Crônier et al. 2016). In contrast, the depositional environments have been much less studied (Abbache 2001; Benhamou et al. 2004; Benachour 2011; Ouali Mehadji and Bouterfa 2015; Abbache et al. 2019). An ichnological analysis of this formation has not previously been attempted; hence, the aims of this study are essentially to identify the ichnotaxa and explore their significance.

The studied section is located in the Marhouma area, also known as the “km30” area (Fig. 1b). It is located about 23 km from SE of Beni Abbes city, 7 km south of the Marhouma locality and a few thousand metres close to Bechar-Adrar road N°6 (Fig. 1c).

## Materials and methods

The high quality and the preservation of the outcrops and its facies allow us to establish an ichnological study of the Chefar El Ahmar Formation. Thus, a detailed geological log was constructed, taking into consideration the thicknesses, the faunal content and the lithological characters including depositional texture as well as the associated sedimentary structures. The lithostratigraphic nomenclature adopted in this paper is that of Bastien (1967) and Boumendjel et al. (1997). In addition to the lithological description, identification and analysis of the trace fossils are presented herein following the widely accepted ichnological practices. The bioturbation intensity is evaluated over three classes (high, medium and low) based on the frequency itself, described as rare, less frequent and/or frequent as represented in Fig. 7 (following the methodology of Bromley and Ekdale 1986; Droser and Bottjer 1986, 1989; Taylor and Goldring 1993; Miller and Smail 1997). The analysed facies are associated with the inventoried ichnotaxa and integrated with the results of ichnological analysis to evaluate the depositional environment.

## Results

### Lithostratigraphy and sedimentology

The studied formation is approximately 160-m thick, beginning with the first limestone bed of the “niveau à Faune Benthique Variée” (FBV) of Ouali Mehadji (2004) (= “niveau coralligène” *sensu* Le Maître 1952), dated as late Emsian, and

extending to the “griotte limestones” referred to as Frasnian Ib (Petter 1959; Boumendjel et al. 1997; Abbache 2001; Mahboubi and Gatovski 2015; Abbache et al. 2019). It consists mainly of irregular alternations of carbonate and shale units, ranging from limestones and muddy-nodular limestones to occasional sandy limestones interrupted by marl and some silty-sandstone intercalations. We distinguish seven lithological units (Fig. 2).

Unit “a” (15 m) consists of an irregularly alternating marl and limestone including the FBV level. The marls are grey to green, sometimes containing nodules of muddy limestone. The limestones are pseudonodular, bioturbated, biomicritic and bioclastic packstone in the lower part, grading upward to wackestone. The fauna is represented by bivalves (*Panenka* sp.), brachiopods, tabulate and rugosan corals, trilobites, orthoceratid, bryozoans and some rare gastropods with ammonoids towards the top of unit. The trace fossils are mainly represented by *Zoophycos* and *Chondrites*.

Unit “b” (17 m) is a more or less regular alternation of grey to green marls with reddish, pseudonodular to nodular limestones, wackestone to mudstone biomicrites bearing ammonoids, brachiopods, trilobites, tentaculites, crinoid stems and trace fossils mainly represented by *Zoophycos* and *Chondrites*.

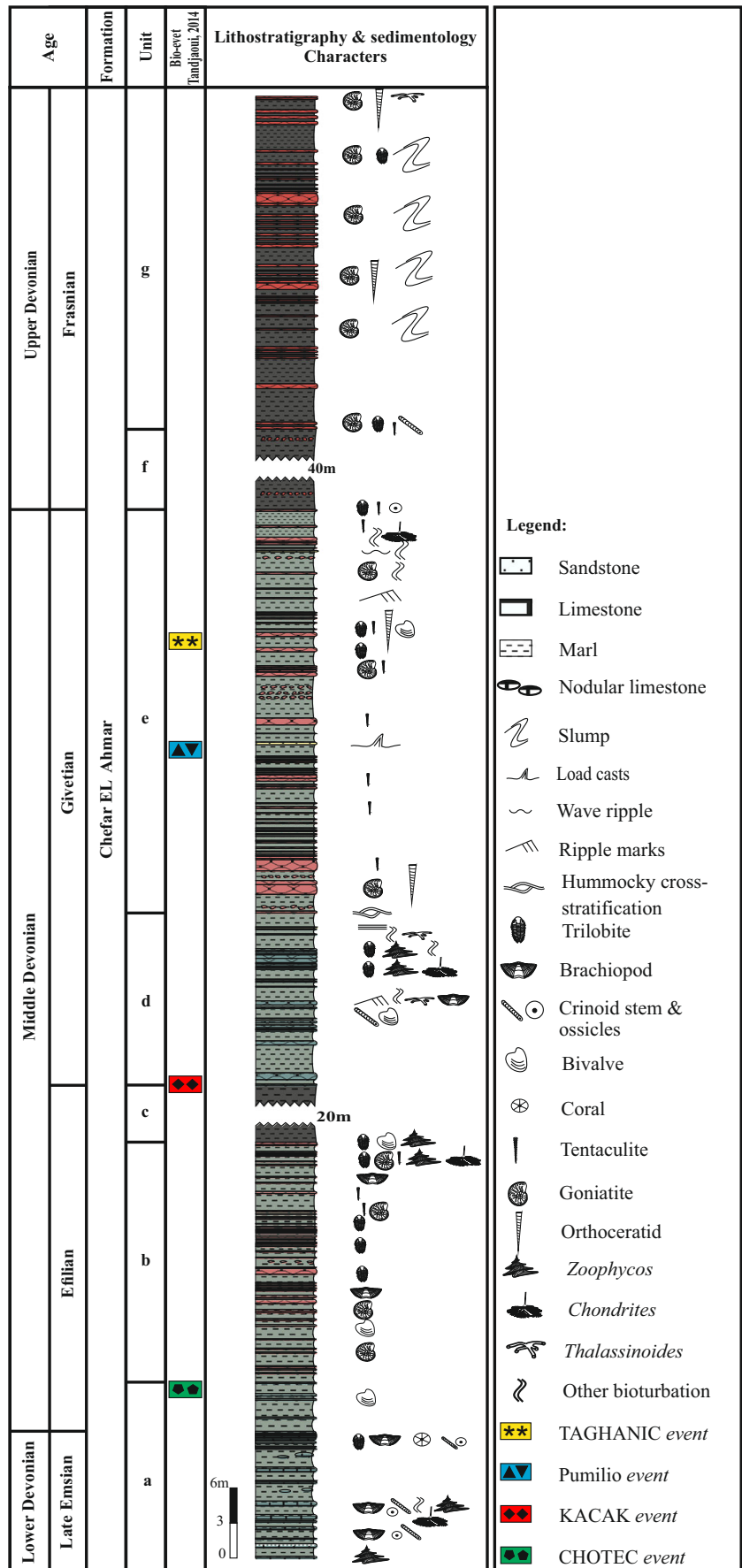
Unit “c” (20 m) consists of a relatively thick shale, with black shale levels of 0.10- to 0.20-m thickness (Fig. 3b') and brownish, thin-bedded siltstone showing horizontal laminations or climbing ripples.

Unit “d” (10 m) is characterized by greenish limestones that alternate with grey to green marls and some thin beds of sandstone. The limestones are bioclastic, displaying wackestone to packstone texture, some beds showing climbing ripples (Fig. 3d). This unit yields trilobites, brachiopods, bivalves, tentaculites, crinoid stems, ammonoids and trace fossils such as *Balanoglossites*, *Nereites missouriensis*, *Alcyonidiopsis*, *Zoophycos* and *Chondrites*.

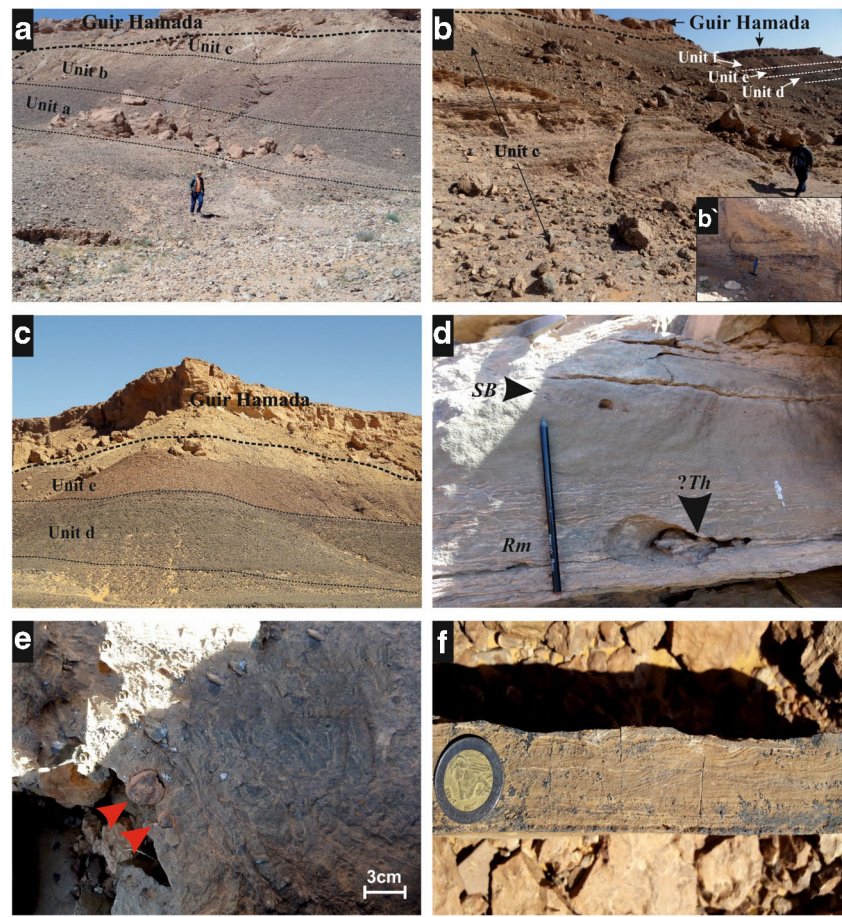
Unit “e” (36 m) is a regular alternation that is made up of reddish, pseudonodular to nodular biomicritic limestones (pseudo-griotte) bearing ammonoids, orthoceratid, trilobites, tentaculites and crinoid stems. Some sandy-limestone beds show storm structures (hummocky cross-lamination, wave ripples, ripple marks, horizontal lamination) (Figs. 3f, 4a and 4) and sandstone with loadcast structures (Fig. 4d) associated with *Alcyonidiopsis*, *Chondrites*, *Neonereites biserialis*, *Nereites missouriensis*, *Thalassinoides* and *Palaeophycus* (Fig. 6e). These beds previously aforementioned intercalate with grey greenish shale and some millimetric intercalations of blackish shale bearing millimetric particles of pyrite. Towards the top of this unit, we distinguish a black laminated limestone beds.

Unit “f” (40 m) is a thicker, dark grey shale with decimetre- to metre-thick limestone nodules (Fig. 4f) and some centimetric beds of nodular limestone. This unit is capped

**Fig. 2** Lithostratigraphic succession of the Chefar El Ahmar Formation



**Fig. 3** a panoramic view of the basal part of the Chefar El Ahmar Formation; b thick shale layer with black shale levels of unit “c”; b’ detail of B; C- panoramic view of units “d” and “e”; d limestone bed with ripple marks (*Rm*) and *Thalassinoides?* (*Th*) surmounted by a massive limestone with shell-beds (*SB*) from unit “d” in the middle part of formation; e entrochites (crinoidal limestone) bearing bivalves (red arrow) in the middle part of formation (unit “d”); f sandy limestone with *HCS* from unit “e” in the middle part of formation



by the first “griotte limestone” bed of the Frasnian Ib (Petter, 1959 ; Boumendjel et al. 1997; Abbache 2001; Mahboubi 2015; Abbache et al. 2019).

Unit “g” (22 m) consists of griotte limestones affected by slumps (Fig. 4g). These biomicritic limestones are centimetre-to decimetre-thick, reddish, pseudonodular to nodular, bioturbated, in places yielding a diverse fauna (goniatites, crinoid stems, trilobites and tentaculites) on the surface of some beds. These limestones are interbedded with reddish and greyish to blackish shale bearing black nodules and films (mineralized hydrocarbons; Ouali Mehadji et al. 2018; Abbache et al. 2019) and some fine-grained sandstone with climbing ripples (Fig. 4h).

### Ichtnology

In the “km 30” area, the Chefar El Ahmar Formation shows a low bioturbation intensity. The trace fossil assemblage is characterized by the following ichnotaxa (presented in alphabetical order).

#### *Alcyonidiopsis* Massalongo, 1856 (Fig. 6B, D)

This is a horizontal, winding, unbranched cylindrical burrow preserved in semirelief, up to 15-mm wide, while the length

can reach up to 10 cm. The outer surface is covered with elliptical nodules that are regarded as pellets ovoid. It may have been actively filled by muddy-pelletal sediment or faecal pellets produced by the trace maker (Pickerill and Narbonne 1995; Uchman 1995; Uchman et al. 2005). However, Uchman (1995) suggested that pellets in *Alcyonidiopsis* have poor potential for preservation.

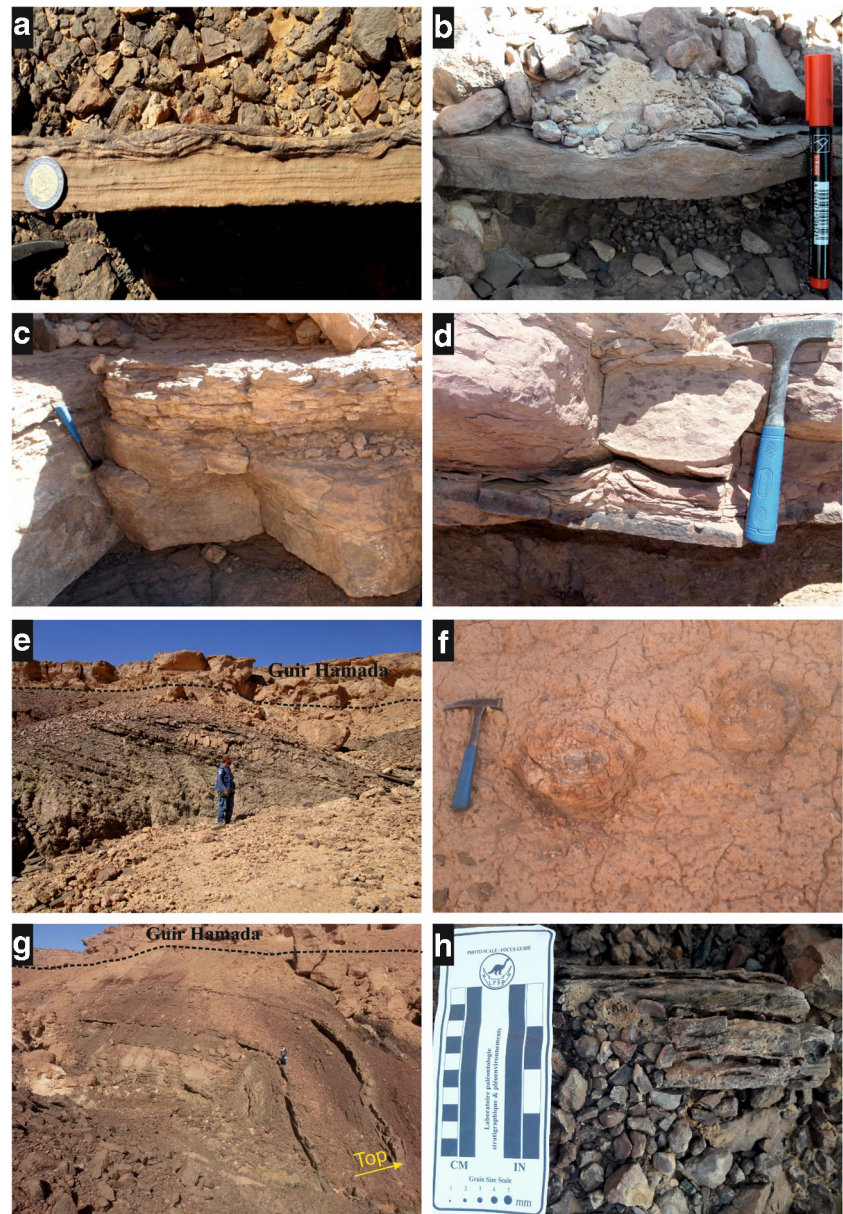
*Alcyonidiopsis* is interpreted as a feeding burrow (fodinichnion) attributed to polychaetes, recorded mainly in marine environments (Chamberlain and Clark 1973; Chamberlain 1977; Uchman 1995; Pickerill and Narbonne 1995; Uchman et al. 2005), but a few non-marine occurrences have been reported (Metz 2015). It is reported from the Ordovician to Miocene (Chamberlain 1977; Uchman 1995).

This ichnogenus is recorded in units “d” and “e” of the studied formation.

#### ?*Balanoglossites* Mägdefrau, 1932 (Fig. 6B)

It consists of horizontal branches forming complex networks with Y-shaped junctions appearing as fingerprints (epichnial grooves), with several openings and acorn, preserved on the top surface of the bed. The margin is unlined and the tunnel

**Fig. 4** **a** Sandstone bed with horizontal laminations surmounted by eroded ripples from unit “e”; **b** sandstone bed with wave ripples; **c** pseudonodular to nodular limestone from the lower part of unit “e” (pseudo-griotte limestones); **d** sandstone with loadcasts; **e** panoramic view of the upper part of unit “e” (pseudo-griotte limestones); **f** nodular limestone (*Septaria*) in the shale of the upper part of the Chefar El Ahmar Formation (unit “f”); **g** panoramic view of slumped “griottes limestones” (unit “g”); **h** fine-grained sandstone with climbing ripples from unit “g”



size is 20–30 mm in diameter, with medium-grained sand grains, passively filled into the burrow.

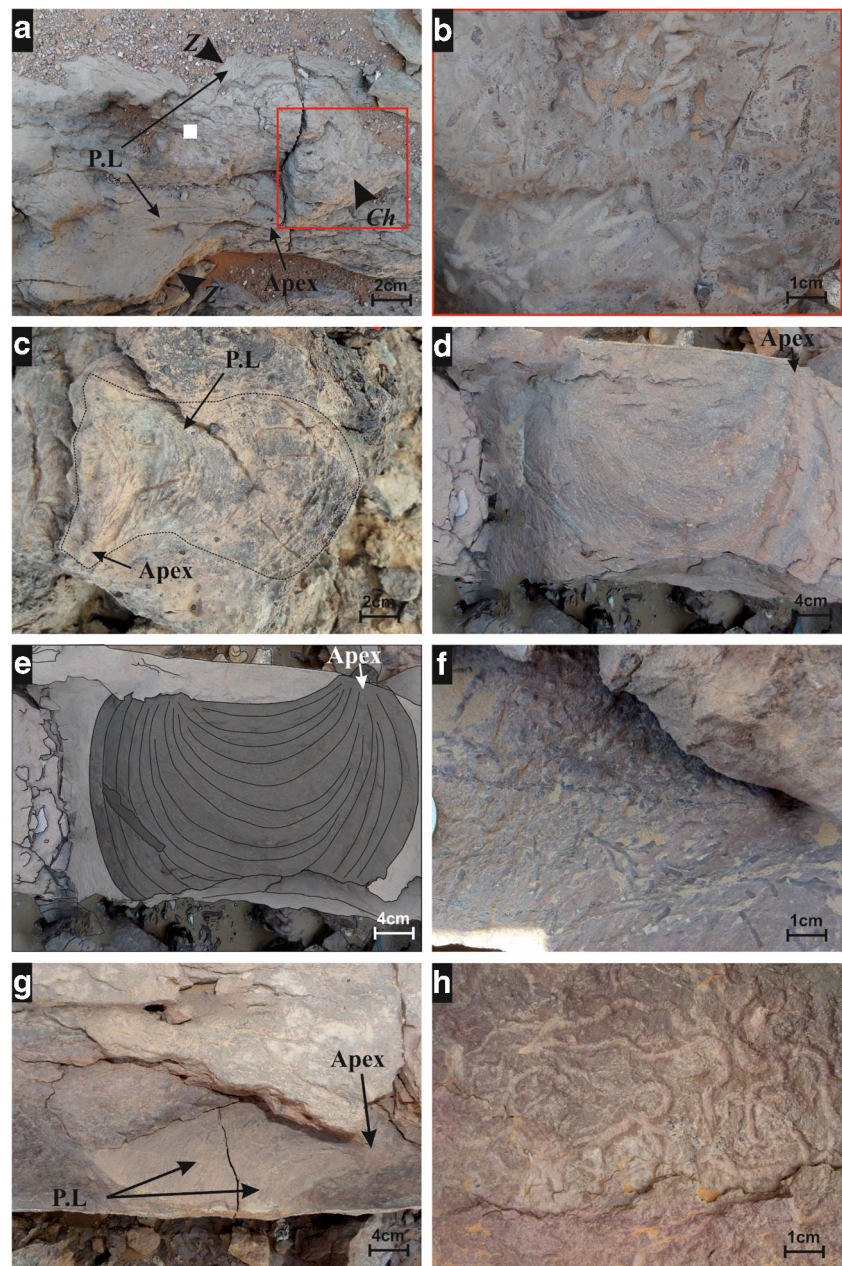
*Balanoglossites* is reported as domichnion traces (Desai and Saklani 2012), probably made by eunicid polychaetes and enteropneusts (acorn worms) (Knaust 2008; Knaust and Dronov 2013); it is especially typical of shallow marine environments (Chamberlain 1977; Knaust 2008; Knaust and Dronov 2013; Desai and Saklani 2012), ranging from Ordovician (Knaust 2008; Knaust and Dronov 2013) and Devonian sediments of Nevada (Chamberlain 1977) to Holocene and recent deposits (Patel and Desai 2009). Moreover, in many cases, it may partly be related to the complexity of the trace fossil as well as its similarity to the well-established ichnogenus *Thalassinoides* (Knaust and Dronov 2013).

This trace fossil is found in unit “d” of the formation.

#### ***Chondrites* von Sternberg, 1833 (Fig. 5A, B, F, G, H)**

This ichnofossil appears as small branched, root-like tunnels looking like bird feet, 1 to 1.5 mm in diameter and several centimetres long, preserved as endichnia and epichnia. The diameter decreases upward within the section. This development may be linked to a decrease in oxygenation, as pointed out elsewhere by Bromley and Ekdale (1984). *Chondrites* has been interpreted as a chemichnion (Bromley 1996; Baucon et al. 2019) and a feeding burrow (Richter 1927; Seilacher 1955), probably made by a sipunculid, polychaete or similar marine worm (Simpson 1957), or also by an unknown chemosymbiotic organism (Fu 1991; Seilacher 1990;

**Fig. 5** The traces fossils from the Chefar El Ahmar Formation: **a** *Zoophycos* (*Z*) and *Chondrites* (*Ch*) in limestone from unit “a”; **b** inset from (a) shows *Chondrites*, in detail; **c,d,g** *Zoophycos* from unit “b”; **e** detailed schema of photo (d); **f** *Chondrites* from unit “d”; **h** *Nereites missouriensis* from basal part of unit “e” (*P.L* primary lamellae)



Baucon et al. 2019) in dysoxic to anoxic sediments (Cluff 1980; Bromley and Ekdale 1984; Pratt 1984; Ekdale 1985; Savrda and Bottjer 1989). It is often reported from shallow marine to deep-sea deposits (see Baucon et al. 2019).

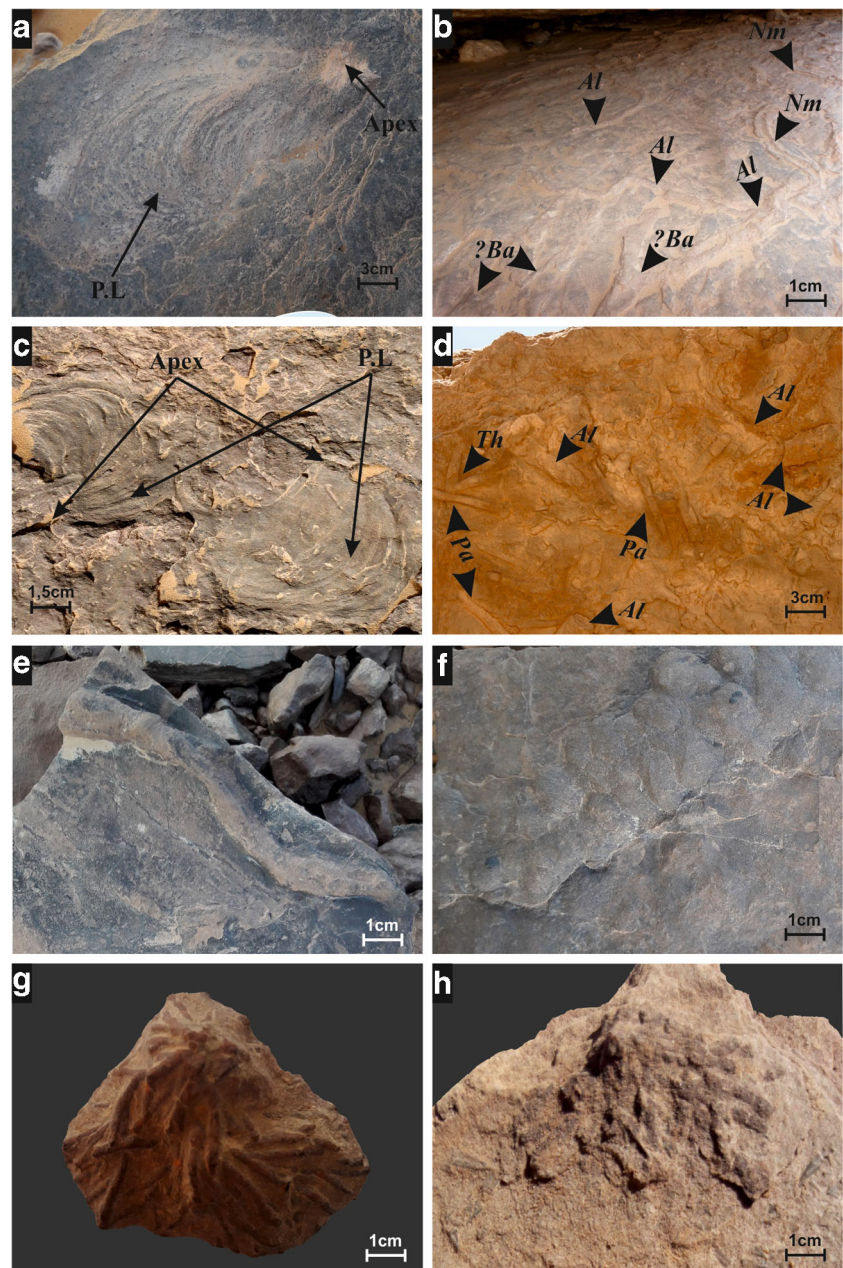
This ichnogenus is observed in units “a”, “b”, “d” and “e” of the formation.

#### *Neonereites biserialis* Seilacher 1960 (Fig. 6F)

This ichnospecies corresponds to a sinuous trajectory with a double chain (two rows = *biserialis*), made up of organic remains (probably representing a faecal pellet ribbon) (Uchman 1995), produced either by gastropods (Richter

1927) or by polychaete worms (Książkiewicz 1977), preserved in positive hyporelief. The width ranges from 10 to 20 mm, while the length can reach 10 cm. *Neonereites biserialis* has been interpreted as an endogenic burrow (Seilacher 1960) or a grazing trail of a deposit-feeder animal (Häntzschel and Reineck 1968). It is characteristic of deep flysch, often referred to the *Nereites* ichnofacies (Chamberlain and Clark 1973; Crimes and Anderson 1985; Uchman 1995; Bendella and Ouali Mehadji 2014) but also reported in the shallow marine environments of the *Cruziana* ichnofacies (e.g. Narbonne 1984; Rindsberg 1994; Bendella et al. 2011). Furthermore, *Neonereites* has been considered a toponymic expression (a junior synonym) of

**Fig. 6** The trace fossils from the Chefar El Ahmar Formation (continued): **a,c** *Zoophycos* from unit “d”; **b** *Nereites missouriensis* (*Nm*), *?Balanoglossites* (*?Ba*) and *Alcyonidiopsis* (*Al*) from unit “d”; **d** *Alcyonidiopsis* (*Al*), *Thalassinoides* (*Th*) and *Palaeophycus* (*Pa*) from unit “e”; **e** *Palaeophycus* from unit “e”; **f** *Neonereites biserialis*; **g,h** *Chondrites* (*P.L* primary lamellae)



*Nereites*. An interpretation that was widely accepted with some exceptions (e.g. Uchman et al. 2005; Shi et al. 2009; Pazos et al. 2015).

This ichnospecies is found in unit “e” of the Chefar El Ahmar Formation.

#### *Nereites missouriensis* Weller 1899 (Fig. 5D, B)

It consists of an epichnial, horizontal, unbranched, sinuous to winding trail, 5- to 10-mm wide, with the length reaching several centimetres. The median furrow is bounded by an even to lobate zone of reworked sediment at 1- to 2-mm wide. This trace fossil is mostly preserved as negative epirelief on the top

sandstone beds. *N. missouriensis* is usually described as *Neonereites biserialis* (Uchman et al. 2005) and regarded as a typical pascichnion and fodinichnion burrow produced by gastropods, annelids or arthropods (Devera 1989; Rindsberg 1994; Uchman 1995; Mángano et al. 2000; Wetzel 2002).

*N. missouriensis* is often preserved in deep marine facies and turbidite sediments (Tchoumatchenco and Uchman 2001; Uchman 1995; Callow and McLroy 2011; Bendella and Ouali Mehadjji 2014). However, examples are known within sedimentary rocks deposited very close to storm wave base (e.g. Uchman 2007; Zheng et al. 2018).

In the Chefar El Ahmar Formation, this trace fossil is reported herein in units “d” and “e”.



### *Palaeophycus* Hall 1847 (Fig. 6D, E)

*Palaeophycus* is a lined, cylindrical, unbranched, more or less straight burrow, predominantly horizontal, 5 to 10 mm in diameter, a few centimetres to 0.20-m long, preserved as hypichnia, while the burrow fill is similar to the host rock. It is a eurybathic trace interpreted as a feeding burrow (fodinichnion) and a dwelling (domichnion), produced probably by a predatory worm-like animal. This burrow occurs in all sedimentary environments, including marine and continental depositional environments (Pemberton and Frey 1982; Uchman 1995; Keighley and Pickerill 1995; Ekdale et al. 2007).

This trace fossil is found in unit “e” of the formation.

### *Thalassinoides* Ehrenberg 1944 (Fig. 6D)

This is a branched, horizontal burrow system with Y-shaped junctions, consisting of segments forming an angle of 30° to 40°, while the diameter is 1 to 2 cm. The walls are flattened, and the fill in lithology is identical to the host rock. In some cases, the burrows are partially eroded. Usually, *Thalassinoides* is referred to as domichnia and fodinichnia (Frey et al. 1984; Buatois et al. 2017) produced by crustaceans (Frey et al. 1984; Knaust 2017), or by vermiform animals (Knaust and Dronov 2013); it is especially typical of shallow marine deposits (Mángano and Buatois 1991) and occurred in oxygenated, low to medium energy environment; soft to firm sediments likely belong to the *Cruziana* ichnofacies (MacEachern et al. 2007), but it has also been noted in deep-sea deposits (Uchman 1995).

*Thalassinoides* is observed in units “d”, “e” and “g” of the formation.

### *Zoophycos* Massalongo 1855 (Fig. 5A, C, D, G, 6A, C)

This ichnogenus is the most abundant in our section. It is represented by a roughly helical and/or trumpet-like trace, preserved in epirelief, with a penetration depth of less than 0.05 m. In the lower part of the Formation, *Zoophycos* includes U-shaped, centrifugal forms, with a spreite consisting of spaced, simple primary lamellae (Fig. 5a, c and d) and retrusive, J-shaped forms, with spaced primary lamellae preserved at the top of beds in the upper part of the formation (Fig. 5g, 6 a and c). The width ranges between 0.10 and 0.30 m. The reduced width shapes were observed in the beds of tempestite-type sequences (unit “d”).

Essentially, *Zoophycos* is interpreted as a deposit-feeding burrow (fodinichnion) (Seilacher 1953; Ekdale et al. 1984; Bromley 1996), in which the animal probed into the sediment in order to exploit the nutritive material. It is reported in different Phanerozoic marine environments, shifting from shallow-water environments in the Paleozoic to deep-sea sediments in the Meso-Cenozoic (Lewis 1970; Martinsch and

Finks 1982; Kotake 1989; Gaillard and Olivero 1993; Olivero and Atrops 1996; Olivero 1994, 2003; Bottjer et al. 1988; Seilacher 2007; Zhang et al. 2015; Richiano 2015), and it has even reported in glaciomarine environments (Gong et al. 2008; Dorador et al. 2016).

This ichnogenus is found in units “a”, “b” and “d” of the formation.

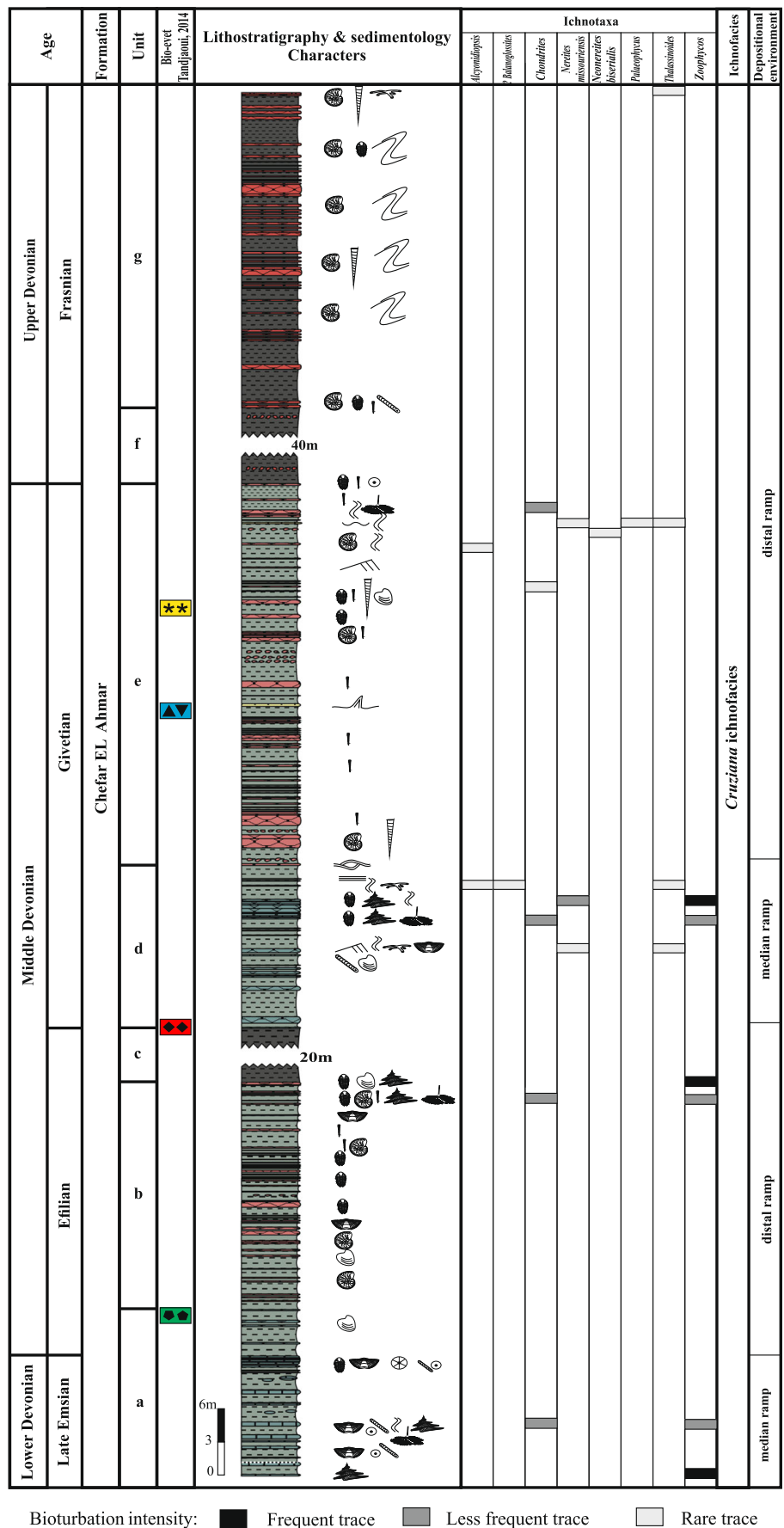
## Discussion

The lithological characters (marl-limestone alternations) and fauna (goniatites, tentaculites, trilobites, etc.) of the Chefar El Ahmar Formation aforementioned allow us to distinguish a carbonate ramp environment (*sensu* Ahr 1973; Burchette and Wright 1996), in a mid-distal to distal position according to Mailliet et al. (2013) on the basis of ostracodes assemblages and Tandjaoui-Arif (2014) on the basis of conodonts assemblages towards an apron slope in the Frasnian Ib (Abbache et al. 2019). The facies are typical of pelagic-hemipelagic environment (alternating between mudstone-wackestone biomicritic limestones and marlstones with dominance of pelagic fauna (goniatites and orthoceratid) and microfauna (*Dacryoconarides* tentaculitids, ostracodes) with moderate presence of benthic fauna (trilobites, bivalves, gasteropodes, etc.). One Givetian level (at the top of unit “d” and at the bottom of unit “e”) shows a structure similar to hummocky cross-lamination associated with wave ripples, indicating a distal ramp in an extra-tempestite context. We interpret this as an internalite sequence (Pomar et al. 2012; Ouali Mehadji and Bouterfa 2015) caused by internal waves compatible with water stratification and the development of dysoxic to anoxic levels, even the trophic levels.

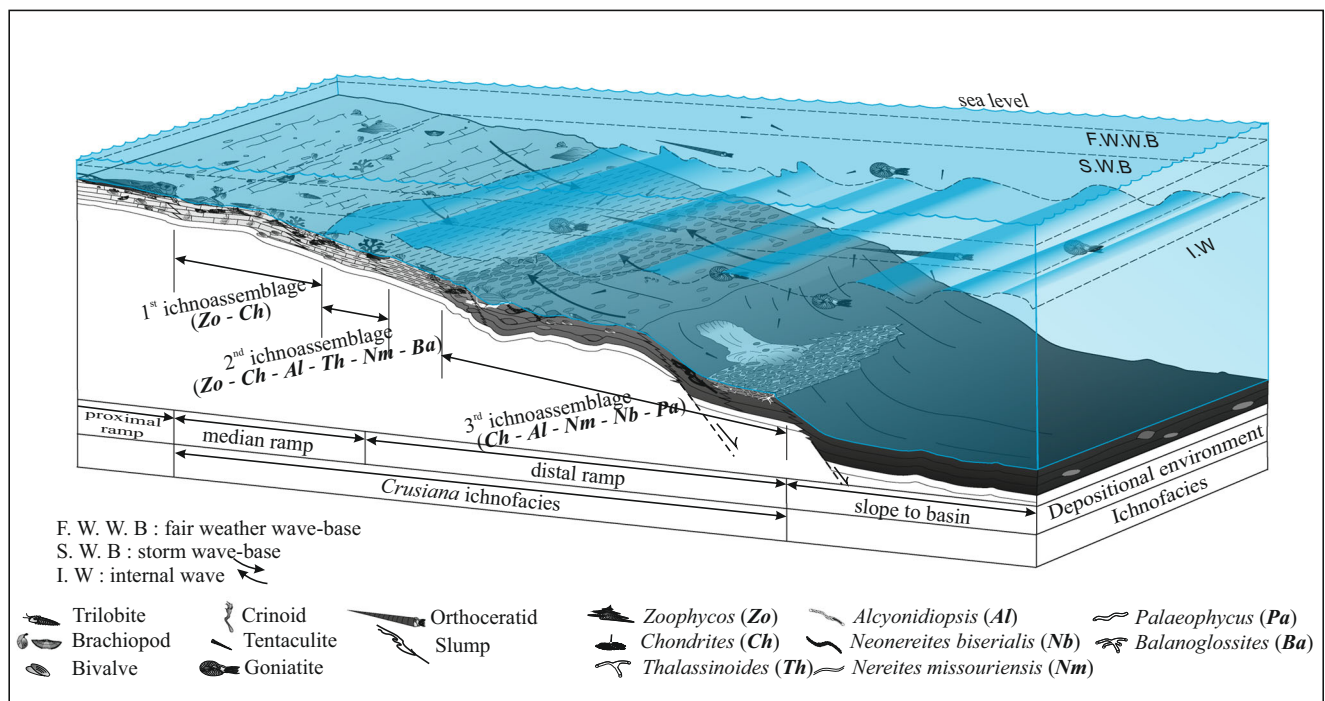
The trace fossil assemblage of the Chefar El Ahmar Formation indicates the *Cruziana* ichnofacies (*sensu* Seilacher 1967; Knaust et al. 2012), distributed irregularly but dominated by a *Zoophycos-Chondrites* assemblage in the lower part (units “a”, “b”, “c” and bottom part of “d”), a *Zoophycos-Chondrites-Alcyonidiopsis-?Balanoglossites-Nereites missouriensis-Thalassinoides* assemblage in the middle part (units “d”, lower part of “e”) and a *Chondrites-Alcyonidiopsis-Nereites missouriensis-Neonereites biserialis-Palaeophycus* assemblage in the upper part (most of “e” and all of “g”) (Fig. 7; Fig. 8). This distribution of trace fossils and the bioturbation intensity are highly variable, which involve changes of palaeoenvironmental conditions including bathymetry, sedimentation rate, erosion, oxygenation, nutrient supply and substrate quality, and suggest a general deepening of the North Gondwana carbonate platform from the latest Emsian to the early Frasnian.

The first ichnoassemblage is characterized by extremely low-energy conditions, in which a low deposition rate and decreased erosion prevailed (Patel and Patel 2015). The

**Fig. 7** Distribution of trace fossils (ichnofacies) and depositional environments of the Chefar El Ahmar Formation



Bioturbation intensity: ■ Frequent trace ■ Less frequent trace □ Rare trace



**Fig. 8** Schematic model for the distribution of ichnoassemblages, ichnofacies and depositional environments of the Chefar El Ahmar Formation (the scale is not taken into consideration)

overall dominance of *Zoophycos* and *Chondrites* indicates exploitation of a soft to firm, highly organic-rich sea floor and oxygen-depleted conditions under the water-sediment interface. This is correlated with the ostracode assemblage indicating slight hypoxia in a quiet and distal neritic environment below the storm wave base (Maillet et al. 2013). Furthermore, we suspect a hydrothermal event at the Emsian-Eifelian transition (*cementstone* facies and chemosynthetic fauna) synchronized with the proposed age of a magmatic event (doleritic dyke, Mekkaoui 2015) in the Saoura region.

The second ichnoassemblage is manifested by the presence of typical trace fossils of aerobic substrates, occurring in moderate to low-energy marine settings characterized by the accumulation of organic matter in a firm substrate, associated with poorly preserved ostracodes indicating well-oxygenated environments (*Thuringian* Mega-Assemblage of Casier 2008; Maillet et al. 2013), along or together with other well-preserved forms (*Metacopina* and *Podocopina*) typical of the distal platform (Casier 2008), remobilized and brought back from deep marine environments (Maillet et al. 2013) by internal waves or upwelling flows. Therefore, this trace fossil assemblage characterized by the occurrence of epichnia and shallow-tier endichnia burrow reflects an increase in the burial of organic matter supply and oxygen caused by internal waves.

The third ichnoassemblage is dominated by *Chondrites* with the presence of other trace fossils attesting desoxygenation (Bromley and Ekdale 1984) and a benthic food availability within substrates. This is correlated with an ostracodes-

assemblage (*Entomozoacea*) that indicate a hypoxia in a distal ramp environment, very quiet below the storm wave base.

In addition, the presence of small gravel-sized pyrite at some levels in the upper part of the Chefar El Ahmar Formation (Givetian) associated with small *Chondrites* may witness anoxia within the sediment (Bromley and Ekdale 1984), as suggested by the bioevents during the Middle Devonian, in particular the Taghanic event (Maillet et al. 2013; Tandjaoui-Arif 2014), in which conditions favoured sulphate reduction.

### Conclusion

In the Saoura Valley (Northwestern Algerian Sahara), the Chefar El Ahmar Formation is characterized by pelagic to hemipelagic sedimentation with an episode of pseudonodular to nodular limestone formation. The sedimentary environment changed from a mid-distal ramp (Emsian to Eifelian) to a distal ramp (Givetian) interrupted by internal waves, and then finally shifted to an apron slope (Frasnian Ib; Abbache et al. 2019). The ichnological study indicates a low bioturbation intensity represented by eight ichnotaxa ascribed to the *Cruziana* ichnofacies: *Alcyonidiopsis*, *Balanoglossites*, *Chondrites*, *Nereites missouriensis*, *Neonereites biserialis*, *Palaeophycus*, *Thalassinoides* and *Zoophycos*. The distribution of these trace fossils as well their ichnoassemblage indicates fluctuation in palaeoenvironmental conditions. Indeed, these trace fossils always correspond to the bioevents, and

they are rare to absent in biological crisis beds. The conjunction of causes (including bathymetry, oxygenation, nutrient supply and substrate quality) explains their spatiotemporal divisions (ichnoassemblages) in a globally deepening regime of the carbonate platform on the North Gondwana margin from the late Emsian to the early Frasnian, concomitant with the major transgression of the Middle Devonian.

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