

# Late Ordovician–earliest Silurian palynomorphs from northern Chad and correlation with contemporaneous deposits of southeastern Libya

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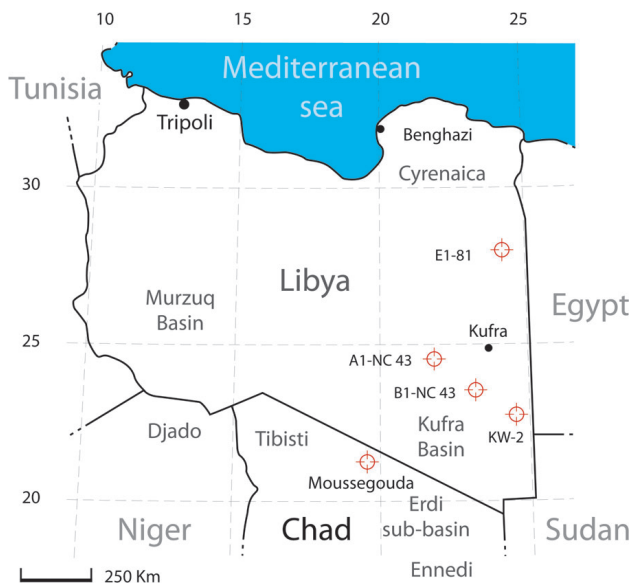
Well preserved assemblages of cryptospores, chitinozoans, acritarchs, leiospheres, tasmanitids, colonies of *Gloecapsomorpha*, scolecodonts and eurypterid fragments from 23 core samples of the Moussegouda core hole in the Erdi Basin, northern Chad, and from two samples from well KW-2 in Kufra Basin, South East Libya are investigated. These palynomorphs were recovered from the southernmost North African marine deposits of Late Ordovician and possibly early Silurian age. The palaeoenvironment evolves from late Hirnantian glacio-marine diamictites to silt-dominated sequences suggesting a marginal marine environment of possibly latest Hirnantian to earliest Rhuddanian age (post-*elongata*–pre-*fragilis* chitinozoan assemblages). The recovered palynomorph assemblages are compared and correlated with contemporaneous assemblages recorded in other northern Gondwana localities (Mauritania, Morocco, Algeria, Libya, Africa, Saudi Arabia, Jordan), and in South Africa, in order to evaluate possible effects of the ice cap melting on palynomorph assemblages and sedimentation. Our goal is also to improve the regional biostratigraphy across the Ordovician–Silurian boundary. The composition of the recovered palynomorph assemblages, with mixed terrestrial and marine microflora, suggests that the topmost Ordovician or earliest Silurian in northern Chad and southeastern Libya, reflects nearshore conditions, with obvious fresh water influences. The lack of black shale or grey shale in the uppermost Ordovician and of “hot shale” in the lower Silurian in these areas, and their replacement by siltstones, are probably related to an isostatic readjustment that rapidly starved the marine sedimentation in the areas previously overlain by a thick ice cover during the climax of the Hirnantian glaciation. *Tasmanites tzadiensis* Le Hérisse sp. nov. and *Euconochitina moussegoudaensis* Paris sp. nov., two new palynomorphs of biostratigraphical interest are described and illustrated. • Key words: northern Gondwana, Chad, Libya, Ordovician–Silurian boundary, acritarchs, chitinozoans, spores, biostratigraphy, palaeoenvironment.

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Transitional Ordovician-early Silurian strata in North Africa and the Middle East, have been extensively investigated, as in many basins the Hirnantian glacially-related deposits constitute significant reservoirs (Hirst *et al.* 2002, Le Heron *et al.* 2009). These deposits are generally sealed by latest Ordovician (Armstrong *et al.* 2005) to Rhuddanian (Lüning *et al.* 2005) organic rich black shale and “hot shale”, which represent the most important Palaeozoic source rocks of northern Gondwana regions. Information about the presence/absence of the “hot shale” and the development of anoxia, but also accurate dating of the series, is

crucial for improved source potential and risk evaluations for hydrocarbon exploration (Lüning & Fello 2006). The final melting of the Hirnantian ice cap, as well as the pattern and timing of the post glacial transgression are controlled mainly by the topography of the glacial floor, and by the effects of deposition within the palaeovalleys. Reactivation of ancient tectonic structures occurred also during the post-glacial isostatic rebound (Le Heron *et al.* 2006). Palaeontological techniques proved to provide the most appropriate data for establishing an accurate timing of the successive events and to document climate changes and



**Figure 1.** Sketch map of north-east Africa and location of the study area, with position of core sections studied and mentioned in reference.

environment modifications during Late Ordovician and early Silurian times. Planktic graptolites are generally common in black shale formations and have been widely used for establishing biostratigraphical subdivisions, for correlations and for dating hydrocarbon source rocks (Massa & Jaeger 1971; Legrand 1981; Štorch & Massa 2006; Fello *et al.* 2006; Loydell 2007, 2012; Loydell *et al.* 2009). Graptolites are mainly collected from outcrops samples. On the contrary, palynomorphs, which are usually absent in Saharan exposures (due to deep weathering) are generally abundantly and continuously represented throughout the subsurface sequences. Palynostratigraphy therefore has been widely used for oil exploration in North Africa since the early 1960s (see main references in Vecoli & Le Hérissé 2004, Butcher 2009, Paris *et al.* 2012). New developments in palynology aim to provide high-resolution biostratigraphical models based on more accurately documented range of the recorded species and on the identification of bioevents of potential chronostratigraphic significance, *e.g.* palynozonations proposed for the Saudi Arabian Kingdom (Al-Hajri & Owens 2000, Paris *et al.* 2013a).

Here we report on a sequence of palynomorph assemblages from Late Ordovician and possibly earliest Silurian sediments in the southern part of the present day Sahara, in southeast Libya and northern Chad. Contemporaneous deposits are poorly known in this area, due to the scarcity of suitable core holes and to their position far to the South, *i.e.* localities close to or periodically overlain by the Hirnantian ice cap. The lack of younger Silurian marine sediments is likely related to the position of the former ice cap (post glacial isostatic readjustment), and to subsequent erosion,

which removed the few possible continental deposits. The aims of this paper are to provide a subsurface biostratigraphic control, and to discuss the palaeoenvironmental conditions of their deposition compared to sequences known elsewhere in Mauritania, Morocco, Algeria, Libya, Saudi Arabia, Jordan or Tunisia.

## Regional geological setting

This paper deals with core material from two separate areas of southeast Libya and northern Chad. The two investigated boreholes and other wells referred to in the text are plotted on Fig. 1. The Moussegouda shallow borehole (21°40' N/18°36' E) was drilled in northern Chad in the Erdi Basin, in the early 1960s. In some publications (*e.g.*, Lüning *et al.* 1999), the Erdi Basin in northern Chad and the Mourdi Basin in northwest Sudan are considered as extensions of the Kufra Basin. Several studies of the Palaeozoic succession in the Chadian and Sudanese parts of the Kufra Basin have been published (Klitzsch 1981, Hissene Mahamoud 1986, Klitzsch & Wicisk 1987, Klitzsch *et al.* 1993, Semtner & Klitzsch 1994). Nevertheless, this area is clearly underexplored compared to other basins, such as the Murzuk or Ghadames basins in Libya. The shallow well KW-2 (22°56' N/24°19' E) was drilled by AGIP in 1975 in the Jebel Asba area, Kufra Basin SE Libya. The KW-2 well is one of the few places in the Kufra Basin where the basal part (54 m) of the Tanezzuft Formation was encountered. This borehole and elements of biostratigraphy by means of graptolites and chitinozoans are mentioned in several publications (Bellini & Massa 1980, Grignani *et al.* 1991, Lüning *et al.* 1999, Thusu *et al.* 2013). The middle part of the grey-green shale unit, between 18 and 31 m, yielded the species "*Climacograptus medius*" (*Normalograptus medius*, see Loydell 2012) and some chitinozoans suggesting a latest Ordovician to early Silurian age. The palynozonation of Grignani *et al.* (1991) is re-evaluated in this paper.

Concerning the Moussegouda core hole, based on preliminary sedimentological evidence cores 9 and 10 (dispersed coarse quartz grains) were referred to the Memouniat Formation of Late Ordovician age, and cores 1 to 8 (greyish siltstone) to the Silurian Tanezzuft and Akakkus formations. The upper sandy interval (0 to 65 m depth) was assigned to the Lower Devonian Tadrart Formation. These early tentative interpretations are collated with the biostratigraphical results obtained in the present study.

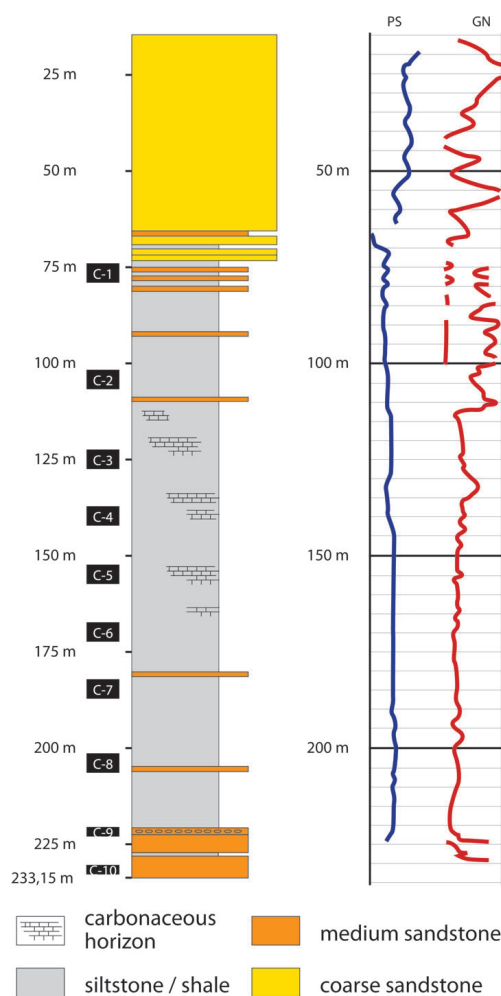
## Material and methods

Material for the present study came from collections of old palynological slides of the Moussegouda core, from

Société Nationale Elf Aquitaine Production (SNEAP, TOTAL, Pau, France), and from new core samples collected in the Moussegouda and KW-2 core holes, provided by Dr. D. Massa. A total of twenty-five samples were analysed for this study. The rock samples were macerated by standard palynological techniques and processed in the Laboratories of Liège, Rennes and Brest. The majority of samples yielded well-preserved palynomorphs indicating a low thermal maturity. The palynologically productive sequence in the Moussegouda core drill is represented from core 2 (100 m) to core 10 (233 m) by 123 m of grey-greenish siltstone and mudstone, with some subordinate more sandy levels and carbonaceous horizons (Fig. 2). In core 9, at 220–221 m depth, large rounded quartz grains occurs within silty material similar to the Late Ordovician glacio-marine diamictites recorded in numerous northern Gondwana regions. Core 1, from 67 to 79 m, is composed of micaceous siltstones, and do not produce any palynomorph. The top of the penetrated sequence, from 0 to 65 m is represented by a sandy interval, and was not sampled. This core material has been previously studied for palynology by Calandra (SNEAP internal report, 1964). Boron content has also been calculated from clays mineral in the samples from the Moussegouda core hole (Stévaux & Kulbicki 1966). These authors obtained values of 25 ppm (C9, C10) to 65 ppm (C2–C8), which correspond to low salinity compared to values of 150 to 250 ppm, for marine waters with normal salinity, as documented in open marine Silurian clays in Algerian Sahara basins. The moderate salinity conditions are consistent with the periglacial conditions for cores 9 and 10 and with littoral to marginal marine environmental conditions, with freshwater influences, for the cores 2 to 8 interval.

The shallow stratigraphic well KW-2 penetrated about 54 m of grey-green shales into the Tanezzuft Formation and the sandstones of the Memouniat Formation for 7 m (Grignani *et al.* 1991). Some graptolites (*Normalograptus medius*) and chitinozoans were recovered in cores 2 (18 to 19 m) and 3 (30–31 m), supporting a Late Hirnantian to early Rhuddanian age (Loydell 2012). In core 4 (36–37 m) some chitinozoans of Late Ordovician age have been previously reported (assemblage “A” of Grignani *et al.* 1991). These authors concluded that this lowermost portion of the “Tanezzuft” Formation (at least 18 m) should therefore be assigned to the Late Ordovician. However, these chitinozoans are here included in the synonymy list of *E. moussegoudaensis* Paris sp. nov. and are assigned to the latest Hirnantian–earliest Rhuddanian (see discussion below).

Reference slides are stored in the palynological collections of Liège, Rennes and Brest universities. The locations of illustrated specimens in the slides are indicated by England Finder coordinates.



**Figure 2.** Lithostratigraphy of the Moussegouda section and location of the studied core samples.

## Palynology

### Cryptospores and plant fragments

Abundant and well-preserved cryptospores were observed in samples ranging from 233 to 123 m of the Moussegouda core hole. Significant forms are illustrated in Fig. 10. In all the studied samples the miospore assemblages are very similar and consist of the following taxa: *Dyadospora murusattenuata* and *D. murusdensa* Strother & Traverse, 1979, *Pseudodyadospora petasus* Wellman & Richardson, 1993, *Tetraedraletes medinensis* Strother & Traverse, 1979, *T. grayii* Strother, 1991, *Segestrespora laevigata* Burgess, 1991, *S. rugosa* (Johnson) Burgess, 1991, *S. membranifera* (Johnson) Burgess, 1991, *Rugosphaera cerebra* Miller & Eames, 1982, *Velatitetras laevigata* Burgess, 1991, *V. rugosa* Steemans *et al.*, 1996, *V. retimembrana* (Miller & Eames) Wellman & Richardson, 1996, *Rimosotetras problematica* Burgess, 1991, *Imperfectotriletes patinatus* Steemans *et al.*, 2000, *Imperfectotriletes vavrdovae* (Richardson)

Stemans *et al.*, 2000. Only three specimens of a true trilete spore have been observed (one in sample 150–156 m and two in sample 120–126 m). It belongs to the morphon *Ambitisporites avitus-dilutus sensu* Stemans *et al.*, 1996.

## Chitinozoans

Most of the chitinozoans recovered from the Moussegouda core samples are well preserved. Significant elements of the assemblage are illustrated on Figs 6 and 7. The thermal alteration is low as demonstrated by the brownish to yellowish colour of their vesicle neck. The chitinozoan abundance ranges from less than one to nine specimens per gram of rock. Such values are low when compared to the abundances usually recorded in pre-glacial Late Ordovician marine deposits from northern Gondwana localities (*e.g.*, Bourahrouh *et al.* 2004, Paris *et al.* 2013a). However, in latest Ordovician marine strata related to the Hirnantian glaciation, low chitinozoan abundances ranging around a few specimens per gram of rock have been recorded previously (*e.g.*, Oulebsir & Paris 1995, Paris *et al.* 2000a). In the case of glacio-marine diamictites, which are regarded as resulting from the melting of icebergs originating from the Gondwanan ice cap, a dilution effect can be invoked to explain such low chitinozoan abundances. Indeed, rapid sedimentation occurred due to a large amount of detrital material available (*i.e.* composed of clay, “glacial flour”, and dropstones of various size and origin), and to an important accommodation space available and resulting from a rapid rise of the sea-level subsequently to the melting of the ice cap.

## Organic-walled microphytoplanktonic elements and miscellaneous organic debris

The organic residues contain also well-preserved acritarchs, various microalgal remains such as prasinophycean phycmata (*e.g.* *Tasmanites* and leiospheres), few scolecodonts, fragments of eurypterids and miscellaneous organic debris. The most important elements in the assemblages are illustrated in Figs 8 and 9. The majority of acritarchs are considered to be cysts of marine phytoplanktonic algae (Martin 1993, Le Hérisse *et al.* 2009). They are never abundant in this material, with an average value of 5% of all palynomorphs. The prasinophycean algae are a class of green algae, represented in the deposits by their phycmata (Tappan 1980, Colbath & Grenfell 1995, Guy-Ohlson 1996). They dominate the marine fraction, reaching an average proportion of 80% of all palynomorphs, throughout the section, with exception of the base of core 8. They are well represented herein by abundant leiospheres of various sizes and by tasmanitids. Other palynomorphs suggesting a transitional marine–freshwater environment, are represented

by colonies of *Gloeocapsomorpha* (Fig. 9N, O), specimens of *Moyeria* and *Clypeolus* and cuticular fragments of eurypterids (Fig. 9P, Q).

In a few samples, some enigmatic sac-like microfossils, sub-spherical or ovoid, with a pigmented wall and a striate mesh-like ornamentation, generally only developed at one pole (Fig. 9I, J, K), have also been recovered. They could be some metazoan remains. They recall sac-like fossils assigned to cocoons (egg-cases) of clitellate annelid as illustrated by Manum *et al.* (1991). The fossil record of these mesofossils is presently restricted to the Mesozoic and Neogene (see Manum *et al.* 1991, Manum 1996, Jansson *et al.* 2008). They have never been mentioned in the Palaeozoic, and their occurrence in the Moussegouda material is related to very specific palaeoenvironmental conditions, with freshwater and terrestrial inputs.

Significant fluctuations in abundance and diversity of broad groups within the palynomorph assemblages are likely to have reflected environmental changes.

The acritarch diversity remains low through the section. The acritarchs comprise a total of 24 species, and many are simple spiny acritarchs (acanthomorphs) referred to *Dorsennidium*, *Micrhystridium*, *Multiplicisphaeridium*, *Veryhachium* or *Villosacapsula*, and netromorphs referred to *Dactylofusa* and *Eupoikilofusa*. More diagnostic Late Ordovician species of *Neoverhachium*, *Saharidia* or *Tunisphaeridium* are also encountered in the base of the studied interval. The low abundance and diversity of the acritarchs is attributed to the nearshore environmental conditions. By comparison the *Leiosphaeridia* that we assigned to prasinophycean phycmata are abundant. *Tasmanites* are represented both by simple or ornamented forms. The new described species, *Tasmanites tzadiaensis* nov. sp., has a characteristic ornamentation made of low solid verrucae (*cf.* systematic part).

The palynomorph *Moyeria cabottii* (Cramer) Miller & Eames 1982, never abundant, is known from the base of the core hole, and is sporadically present throughout the section. It is diversely interpreted in the literature, either as a terrestrial or freshwater acritarch (Dorning & Harding 1998), or as a possible euglenoid inhabiting freshwater terrestrial environment (Gray & Boucot 1988). A plant origin is even envisaged (Wellman & Richardson 1993, Richardson 1996). In agreement with Dorning & Harding (1988), we consider that they are probably freshwater aquatic forms. As for the cryptospores, their occurrence in the material resulted from periodic terrestrial inputs into a marginal marine environment. Some *Clypeolus*, with possible affinity to the zygnetaceae (Miller *et al.* 1997) are also present.

*Gloeocapsomorpha prisca* Zalesky, 1917, emend. Foster, Reed & Wicander, 1989, is common in several samples. *Gloeocapsomorpha prisca* is an enigmatic palynomorph whose biological affinity is still debated. Foster *et al.* (1989, 1990) suggested they must have been



**Figure 3.** Distribution and absolute abundances of chitinozoan species in the Moussegouda core hole. Abbreviations: ■ > 50 %, ● – 20–50 %, ○ – 10–20 %, △ – 0–10 %.

Moussegouda core hole (Depth in m)	Core number	Conochitinae indet.	Ordochitina nevadensis	Belonechitina sp. 1 (in Paris et al. 2000)	?Tanuchitina sp.	Armoroichitina nigerica	Euconochitina moussegoudaensis sp. nov.	Euconochitina sp.	Conochitina sp.	Cyathochitina "caputol/kuckersiana" complex	Spinachitina vermiersi	Spinachitina oulebsiri	Specimens per gram / rock	Age assignment
74–79	C-1													
104–105	C-2						■		○				<1	
120–126	C-3						■					△	4	
123–124	C-3						■		●	△?	△		2	
135–141	C-4						■		●		△		3	
150–156	C-5						■		△				9	
153–154	C-5						■		△	○	△?	△	6	
165–171	C-6						■	○	△				5	
180–186	C-7						■	△			△		8	
200	C-8						■			●	△?		3	
205–206	C-8						■			○	△		5	
220–221	C-9	■	●	○	△	△		△					2	
220–222	C-9													
229–233	C-10													

mat-forming cyanobacteria similar to *Enthophysalis major* from an intertidal environment. Derenne *et al.* (1990, 1992) suggested they were preserved algaenan cell walls of green algae like *Botryococcus braunii*. The colonies of *G. prisca* can be abundant in oil-prone source rocks, such as Ordovician kukersites (Blokker *et al.* 2001), but also in the late Devonian (Fowler *et al.* 2004).

Fragments of invertebrates, mainly referred herein to eurypterids are known in the interval C4 to C9. Fragments consist of chitinous pieces of exoskeletons such as cuticles and spines. Organic-walled invertebrate remains are reported from Cambrian to Carboniferous strata (Miller 1996). In northern Gondwana, they are fairly common in latest Ordovician and in Silurian nearshore deposits.

## Biostratigraphy

### Cryptospores

Most of the cryptospore species identified in the Moussegouda samples are typical of the interval ranging from the Katian to Llandovery (Edwards & Wellman 2001). Such assemblages are known from South America in Brazil and Paraguay (Gray 1991; Gray *et al.* 1985, 1992; Laranjeira *et al.* 1997; Melo 1997; Melo & Steemans 1997; Mizusaki *et al.* 1992; Steemans 2000; Steemans & Pereira 2000), from North America (Strother & Traverse 1979, Miller & Eames 1982, Duffield 1985, Johnson 1985), from Europe in Belgium (Steenmans 2001), Bulgaria (Lakova *et al.* 1992), the Czech Republic (Vavrdová 1984, 1988, 1989), United Kingdom (Burgess 1991, Wellman 1996), from Asia in

China (Wang *et al.* 1997), Turkey (Steenmans *et al.* 1996), Saudi Arabia (Steenmans *et al.* 2000, Wellman *et al.* 2000), and from north Africa in Libya (Richardson 1988).

There is only very limited palynostratigraphic evidence based on miospores to distinguish Late Ordovician from earliest Silurian miospore assemblages. The miospore biostratigraphy across the Ordovician–Silurian boundary has been revised by Steemans *et al.* (2000). The main criteria include the first occurrence and proliferation of true trilete spores (*Ambitisporites avitus* morphon *sensu* Steemans *et al.* 1996), the first occurrence of *L. divellomedia*, and the progressive decline of cryptospores enclosed in a membranous envelope. The assemblage herein observed is characterised by very rare true trilete spores, by a high abundance of cryptospores enclosed in an outer envelope, by numerous specimens of *Imperfectotriletes* and by the absence of *L. divellomedia*. Accordingly, this assemblage can be attributed to Sub-zone β of the *Imperfectotriletes* Interval Biozone (Steenmans 2000). The possible age for this biozone has a maximum range from Hirnantian to early Aeronian, but most probably not younger than Rhuddanian because of the absence of *L. divellomedia*.

### Chitinozoans

Two chitinozoan assemblages are identified in the Moussegouda core material. The first one is restricted to core 9 (sample from depth 200–221 m). The second extends from core 8 to core 2, *i.e.* ranging at least over 102 m. These two chitinozoan assemblages are very different (Fig. 3).

Assemblage 1 is dominated by undetermined Conochitinae (50%). Several species are grouped under this name. However, the preservation is too poor in this sample to allow even a generic assignment (broken vesicles, eroded spines, possibly related to reworking processes). *Ordochitina nevadensis* Soufiane & Achab (see Fig. 7A1, 2, G, H) (30%) and to a lesser extent, *Belonechitina* sp. 1 (*sensu* Paris *et al.* 2000b) (11%) are also well represented (Fig. 3). The subordinate taxa are *Armoricochitina nigerica* (5%), *Euconochitina* sp. (3%) and a form possibly belonging to *Tanuchitina* (< 2%). SEM observations were necessary to identify the fragments of *A. nigerica*, which may be reworked. This chitinozoan material, especially *O. nevadensis*, and *A. nigerica*, clearly documents the occurrence of Late Ordovician marine deposits in the lowermost part of Moussegouda core hole.

Assemblage 2 is largely dominated by *Euconochitina moussegoudaensis* Paris sp. nov. (Figs 6A, B, I, J, 7D). The relative frequency of this new species (see description below) ranges from 60% to more than 90% of the recorded taxa. Among the associated taxa is *Spinachitina verniersi* Vandenbroucke (Figs EI-2, G, H, 6C), which seems identical to the specimens previously identified as *Spinachitina* sp. aff. *oulebsiri* by Paris *et al.* (2000a, pl. 1, figs 1 and 4) in well NI-2 (north-eastern Algerian Sahara), from the M'Kratta Formation. *Spinachitina oulebsiri* Paris *et al.* (Fig. 6K) is represented by a single specimen, recorded in core 5 at 153–154 m depth. Various *Cyathochitina* forms occur in Assemblage 2. Some specimens (Fig. 7F) are very close to *Cyathochitina caputoi* Da Costa; others have a wide carina and a more elongate neck (Fig. 7E), and thus recall *C. kuckersiana* (Eisenack). However, because the large morphological variations observed in the Moussegouda material, all the recorded forms are provisionally grouped within a “*caputoi-kuckersiana* complex” (Fig. 3). The relative frequency of *Cyathochitina* species is highly variable. It reaches 36% in core 8, and 11% in core 5 where only forms very similar to *C. caputoi* have been observed. *Euconochitina* sp. (restricted to cores 6 and 7) and *Conochitina* sp., which is better represented in cores 3 and 4, are the other components of Assemblage 2.

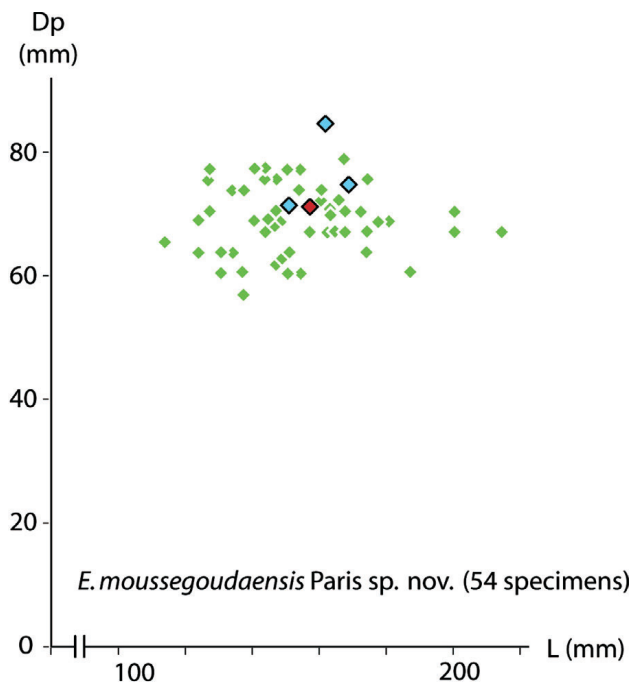
The Late Ordovician chitinozoan data available from Baltica (Nölvak 1999, Nölvak & Grahn 1993) and from eastern Laurentia (Achab 1978, 1981; Soufiane & Achab 2000a) do not allow precise correlation with the chitinozoan assemblages from northern Gondwana. Surprisingly, some ties exist with chitinozoan assemblages from western and northern Laurentia. The best correlation is provided by *Ordochitina nevadensis*. Soufiane & Achab (2000b, figs 2 and 3) reported this species from the uppermost Vinini Formation and from the Hanson Creek Formation, in Nevada. These authors (2000b, fig. 4) also report *O. nevadensis* from the *O. fastigatus* and *P. pacificus* graptolite zones in the lower part of the Cape Phillips For-

mation (Arctic Canada), *i.e.* Katian (formerly Ashgill *pro parte*). In Nevada, however, this species clearly extends within the *N. persculptus* graptolite Zone. This means that the last appearance datum (LAD) of *O. nevadensis* is in the late Hirnantian, *i.e.* after the  $\delta^{13}\text{C}$  excursion and after the eustatic sea level fall in Nevada (see Finney *et al.* 1999, fig. 2). Thus, based on the well-documented range of *O. nevadensis* in the uppermost part of the Vinini Formation (Soufiane & Achab 2000b, fig. 3), Assemblage 1 from Moussegouda may be as young as the late Hirnantian. This is in agreement with the presence of *Armoricochitina nigerica* in our Assemblage 1, because this Late Ordovician species (Paris 1990) has also its LAD in the latest Hirnantian (Paris *et al.* 2000a, Bourahrouh 2002). The absence of the other usual components of the Gondwanan Hirnantian chitinozoan species (*e.g.*, *Tanuchitina elongata*, *Calpichitina lenticularis*) or of Laurentian (*e.g.*, *N. vininica*) in core 9 of Moussegouda core hole, however, must be stressed.

*Belonechitina* sp. 1 (Fig. 7B, C) is another taxon from our Assemblage 1. In northern Gondwana, an exclusive occurrence of *Belonechitina* sp. 1 has been documented in Saudi Arabia, in the upper part of the Quwarah Member of the Qasim Formation (well Ain Dar-196, core 24), some 50 m below strata referred to the Sarah Formation, and possibly within the Sarah Formation (well Shedgum-239, core 8; see Paris *et al.* 2000b). The Sarah Formation was regarded as “latest Asgill-earliest Silurian” in age (Al Hajri & Owens 2000), but recent palynological data (Paris *et al.* 2013a in press) indicate that this formation does not range beyond the top of the Hirnantian.

Other data from well NI-2, located in north-eastern Algerian Sahara, strongly suggest that Assemblage 2 recorded in cores 2 to 8 in Moussegouda is of latest Hirnantian and possibly basalmost Rhuddanian age. Indeed, in well NI-2, cores 29 and 30 from the upper part of the M'Kratta Formation yield a chitinozoan assemblage representative of the *Spinachitina oulebsiri* biozone, including the index species itself, but also *Spinachitina verniersi*, a species recently described by Vandenbroucke *et al.* (2009) in the Soom shale, in South Africa. This species is identical to the specimens recorded in Moussegouda (Fig. 6C, G, H). In Algerian Sahara, before an exclusive occurrence in the upper part of the M'Kratta Formation (marine post-glacial deposits), these two taxa are briefly associated with classical components of the chitinozoan assemblages from the Hirnantian glacio-marine diamictites of the Hassi el Hadjar Formation (*i.e.*, *T. elongata*, *C. lenticularis*, *E. lepta*, *A. nigerica*; see Oulebsir & Paris 1995, Paris *et al.* 2000a, Videt *et al.* 2010). However, in the M'Kratta Formation, reworking processes cannot be excluded as the preservation of these species is poor with regard to those of *S. oulebsiri* and *S. verniersi* (provisionally identified as *S. sp. aff. oulebsiri* in Paris *et al.* 2000a). The





**Figure 5.** Biometric evaluation of *Euconochitina moussegoudaensis* Paris sp. nov. with the chamber diameter (Dp) plotted against the vesicle length (L). This type material (red diamond: holotype from 123 m depth; blue diamonds: paratypes from 153 and 205 m depth) from the Moussegouda core is compared to a population of 50 specimens (green diamonds) from the JA-2 shallow core at 48.18 m depth (Kufra Basin, Libya; see Thusu *et al.* 2013 in press).

During the Late Ordovician, in northern Chad and in southeast Libya, the palaeogeographical, and palaeoenvironmental situations were fairly close to those of south-eastern Mauritania (*e.g.*, Nseirat section, Hodh region, Paris *et al.* 1998). Both areas were located in a proximal position with regard to the Hirnantian inlandsis, and were temporary covered by the ice cap (see Ghienne 2003 and Monod *et al.* 2003 for references). They registered a ma-

rine sedimentation overlaying glacial and /or glacio-marine diamictites. As far as chitinozoans are concerned, both localities yield post-*elongata*, but pre-*fragilis* chitinozoan assemblages (Paris *et al.* 1998) suggesting the existence of temporary marine excursions in depressed areas related to isostatic processes. The lack of Silurian black shale in northern Chad and south-eastern Libya, and the truncated early Llandovery sequence in south-eastern Mauritania are likely related to the isostatic readjustment that rapidly starved the marine sedimentation in the areas previously overlain by a thick ice cover.

### Microphytoplankton

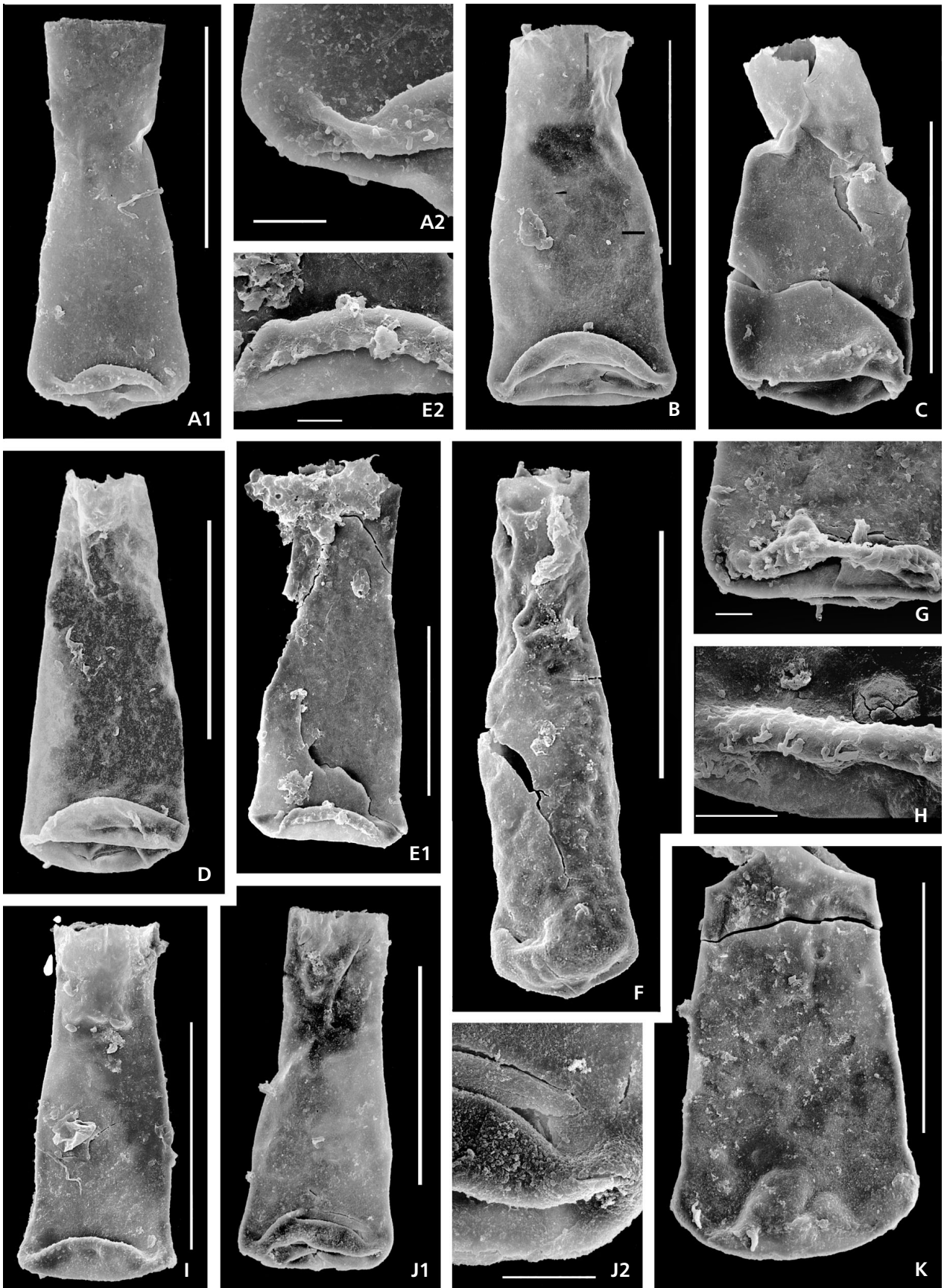
Based on the composition of assemblages of organic-walled microphytoplanktonic elements, the stratigraphic section can be subdivided into two distinct assemblages which are described in ascending stratigraphic order: a lower unit with the deepest samples of cores 10 and 9, and an upper unit from cores 8 to 1.

The basal assemblage is only defined from two samples (229–233 and 220–221A m) of cores 10 and 9. Particularly noteworthy are the following species present in core 9: *Eupoikilofusa platynetrella*, *Neoveryhachium* sp. A, *Ordovicidium elegantulum* probably reworked, *Saharidia munfarida*, *Veryhachium mareki*, *Veryhachium subglobosum*, and *Villosacapsula setosapellicula*.

The association of *Eupoikilofusa platynetrella*, *Saharidia munfarida*, *Veryhachium mareki* and *Veryhachium subglobosum*, is diagnostic of the late Ordovician (Hirnantian) acritarch microflora, in glacial to periglacial successions of many localities around the margin of Gondwana (Vecoli & Le Hérisse 2004), even though *Veryhachium mareki* is also known in the preglacial sediments of the Králův Dvůr Formation in Bohemia (Vavrdová 1989). The original material of *Eupoikilofusa platynetrella*

**Figure 6.** Chitinozoans from the Upper Ordovician of northern Chad and south-eastern Libya. The specimens are housed in the University of Rennes I (France) under the repository numbers IGR 58089 to 58099. The England-Finder coordinates are in brackets. The scale bar represents 100 micrometers on Figs A1, B–E1, F, I, J1, and K, and 10 micrometers on Figs A2, E2, G, H and J2. • A1, 2 – *Euconochitina moussegoudaensis* Paris sp. nov., Moussegouda core hole (northern Chad), core 8, 205–206 m; A1 – paratype, flattened vesicle, IGR 58092 (Q39), A2 – detail of the granular wall surface. • B – *Euconochitina moussegoudaensis* Paris sp. nov., Moussegouda core hole (northern Chad), core 8, 205–206 m, IGR 58092 (R39). Short paratype. • C – *Spinachitina verniersi* Vandenbroucke in Vandenbroucke *et al.*, 2009, Moussegouda core hole (northern Chad), core 3, 123–124 m, IGR 58094 (R39/1). Note the eroded spines on the margin. • D – *Spinachitina verniersi* Vandenbroucke in Vandenbroucke *et al.*, 2009, KW-2 core drill (Jebel Asba, Kufra Basin, south-eastern Libya), 34–36 m. • E1-2 – *Spinachitina verniersi* Vandenbroucke in Vandenbroucke *et al.*, 2009, KW-2 core drill (Jebel Asba, Kufra Basin, south-eastern Libya), 34–36 m. Note the tiny spinose ornamentation on the margin of the specimens on D and E2. • F – *Euconochitina* sp. aff. *moussegoudaensis* Paris sp. nov., Moussegouda core hole (northern Chad), core 3, 123–124 m, IGR 58094 (P38). Slender vesicle with granular surface. • G – *Spinachitina verniersi* Vandenbroucke in Vandenbroucke *et al.*, 2009, Moussegouda core hole (northern Chad), core 8, 205–206 m, IGR 58092 (O40/3); detail of the margin showing eroded lambda spines. • H – *Spinachitina verniersi* Vandenbroucke in Vandenbroucke *et al.*, 2009, Moussegouda core hole (northern Chad), core 8, 200 m, IGR 58091 (?P38/1); detail of the margin showing closely spaced lambda minute spines. • I – *Euconochitina moussegoudaensis* Paris sp. nov., Moussegouda core hole (northern Chad), core 5, 153–154 m, IGR 58093 (U40/4). Paratype. • J1-2 – *Euconochitina moussegoudaensis* Paris sp. nov., Moussegouda core hole (northern Chad), core 3, 123–124 m; J1 – holotype, IGR 58094 (O40), with a close up of the margin (J2). • K – *Spinachitina oulebsiri* Paris *et al.*, 2000a, Moussegouda core hole (northern Chad), core 5, 153–154 m, IGR 58093 (R38/2); note the conical spines on the margin.





comes from the Upper Ordovician of U.S.A (Loeblich & Tappan 1978). *Saharidia munfarida* is an interesting component of the interval with diamictites of the Late Ordovician Kosov Formation in Bohemia (Vavrdová 1982). Occurrences of *Eupoikilofusa platynetrella* and *Saharidia munfarida* established in the microconglomeratic clays of the Hassi el Hadjar Formation of wells NI-2 and Gd-1bis in Algeria (Vecoli 1999, Le Hérissé *et al.* 2003), and coeval Tifarouine Formation of the Tazzeqa succession in Morocco, close to the Ordovician-Silurian boundary (Le Hérissé, unpublished data). In well NI-2, *Saharidia munfarida* persist in the M'Kratra Formation post dating the ice cap melting, assigned to the late Hirnantian (Le Hérissé, unpublished data). In the Moussegouda core rare specimens have also been encountered in the basal part of the succeeding assemblage. *Saharidia munfarida* is also mentioned, but not illustrated, in the uppermost Djefara Formation, of latest Ordovician age, in the Ghadames Basin, Tunisia (Vecoli *et al.* 2009). These elements allow cores 10 and 9 from Moussegouda to be correlated with late Hirnantian strata. This is consistent with the occurrence of few reworked specimens, *e.g.* *Ordoviciidium elegantulum* in core 9 (220–221 m). The occurrence of reworked elements of older strata is a characteristic of the late Ordovician, during the deglacial period or related to final isostatic movements (Vecoli & Le Hérissé 2004).

The basal assemblage includes also *Villosacapsula setosapellicula*. The last specimens are observed in basal part of the succeeding assemblage, in situ or possibly reworked. The species *Villosacapsula setosapellicula* has a long stratigraphical range, from Dariwillian to Hirnantian (see discussion of occurrences in Wicander & Playford 2007), but is more common in the Katian (Asghill *pro parte*), *e.g.* in the Sylvan Shale of Oklahoma (Loeblich 1970), in north-east Libya (Molyneux & Paris 1985), and particularly in the Hirnantian (Vecoli & Le Hérissé 2004). This species, associated to *Veyhachium subglobosum* is present in assemblage “B” of Grignani *et al.* (1991), described in the Kufra Basin, southern Libya, and here reattributed to the Hirnantian (see the discussion for chitinozoans).

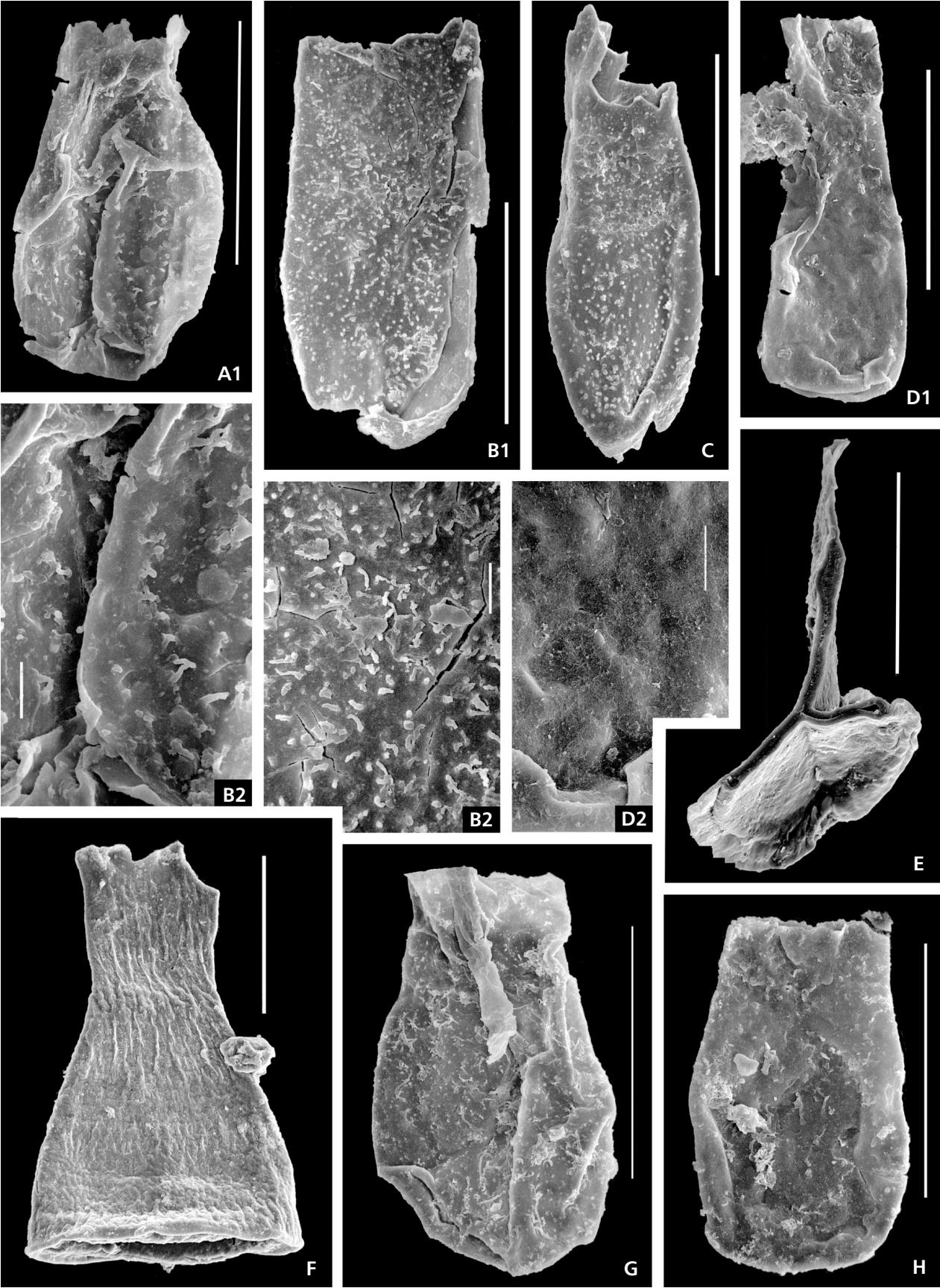
Comparing this Upper Ordovician acritarch and prasinophyte assemblage in the basal unit of Moussegouda, with published correlative assemblages, particularly from North Africa (*e.g.* Algeria, Morocco, Libya), or Bohemia, highlights the absence of several diagnostic species such as *Beromia clipeata*, *Dactylofusa cucurbita*, *Oppilatala cf. frondis etc.*, and a low percentage of reworked elements. This suggests (1) a possible palaeoecological control on the distribution of these species, or (2) that the interval represents the end of synglacial units, equivalent to part of the M'Kratra Formation in well NI-2 (north-eastern Algerian Sahara). In southern Libya (Kufra Basin), Grignani *et al.* (1991) reported *Dactylofusa cucurbita*, *Veyhachium subglobosum etc.*, in their assemblage “B”, which is comparable to our first assemblage in the basal unit from Moussegouda. This is also consistent with the results on chitinozoans.

The second assemblage is recorded from 11 samples of core 8 to 2 (between 205–206 m and 104–105 m). It is significantly different from the preceding assemblage, within which many characteristic taxa are replaced by forms such as *Multiplicisphaeridium aff. cladum*, *Multiplicisphaeridium raspa*, *Eupoikilofusa striata*, *Dorsennidium polorum*, *Dactylofusa striatogranulata*, *Eupoikilofusa striatifera* or *Tasmanites tzadiaensis* Le Hérissé *nov. sp.* However, the species turnover is not total because two classical Upper Ordovician species, *Saharidia munfarida* and *Villosacapsula setosapellicula*, which occur earlier, range into the base of the second assemblage.

The assemblage is of moderate diversity, with a dominance of *Tasmanites* and leiospheres, of netromorphs and quite simple acanthomorphic acritarchs. Latitudinal and inshore-offshore trends have been mentioned in the studies of Lower Palaeozoic microphytoplankton (see synthesis in Mullins *et al.* 2004). Changes in microphytoplankton associations for determining nearshore to offshore trends, globally suggest a low diversity microflora comprising abundant simple sphaeromorphs and tasmanitids in nearshore environments, while open marine environments yield a highly diversified microflora (*e.g.*, Jacobson 1979, Dorning 1981, Al-Ameri 1983, Vecoli 2000). Littoral to

**Figure 7.** Chitinozoans from the Upper Ordovician of northern Chad (A–C, E–H) and south-eastern Libya (D). The specimens are housed in the University of Rennes I (France) under the repository numbers IGR 58089 to 58099. The England-Finder coordinates are in brackets. The scale bar represents 100 micrometers on A1, B1–D1, E–H, and 10 micrometers on A2, B2 and D2. • A1, 2 – *Ordochitina nevadensis* Soufiane & Achab, 2000b, Moussegouda core hole (northern Chad), core 9, 220–221 m; A1 – flattened and folded vesicle, IGR 58099 (N45/4), A2 – detail of the closely spaced lambda spines arranged in vertical rows. • B1, 2 – *Belonechitina* sp. 1 (in Paris *et al.*, 2000b), Moussegouda core hole (northern Chad), core 9, 220–221 m; B1 – damaged flattened vesicle, IGR 58099 (P43/4), B2 – detail of the ornamentation showing preserved spines. • C – *Belonechitina* sp. 1 (in Paris *et al.*, 2000b), Moussegouda core hole (northern Chad), core 9, 220–221 m, IGR 58099 (P42/4). Note the large broken spines. • D1, 2 – *Euconochitina moussegoudaensis* Paris *sp. nov.*, KW-2 core hole (Jebel Asba, Kufra Basin, south-eastern Libya), 34–36 m; D1 – flattened vesicle, D2 – detail of the finely granular surface. • E – *Cyathochitina e.g. kuckersiana* (Eisenack, 1931), Moussegouda core hole (northern Chad), core 8, 200 m; IGR 58091 (R41/2), broken specimen showing the collapsing of the vesicle during flattening process. • F – *Cyathochitina e.g. caputoi* Da Costa, 1971, Moussegouda core hole (northern Chad), core 5, 153–154 m, IGR 58093 (R39/2). • G – *Ordochitina nevadensis* Soufiane & Achab, 2000b, Moussegouda core hole (northern Chad), core 9, 220–221 m, IGR 58099 (P46/4). • H – *Ordochitina nevadensis* Soufiane & Achab, 2000b, Moussegouda core hole (northern Chad), core 9, 220–221 m, IGR 58099 (P47).





nearshore conditions for the association are proposed in the second assemblage of Moussegouda, but also in the samples from KW-2 in the Kufra Basin, is consistent with significant freshwater input. This is supported by the presence of forms such as *Moyeria cabottii* regarded to be of freshwater origin (Gray & Boucot 1989, Dorning & Harding 1998). The good representation of miospores, and tubular structures (*Tortotubus protuberans*) believed to derive from nematophytes (Wellman 1995), is further evidence of deposition in a nearshore shallow water marine environment.

The recovered assemblage contains species with a restricted stratigraphic range, making them useful for biostratigraphic correlation such as *Dactylofusa striatogranulata*. Previous records of *Dactylofusa striatogranulata*, with exclusion of specimens misidentified in the literature, occur in the Upper Ordovician and early Silurian of Algeria, zones F and G1 (Jardiné *et al.* 1974), in the Upper Ordovician of Algeria and Tunisia (Vecoli 1999), the Czech Republic (Vavrdová 1988, 1989), in well NI-2 (north-eastern Algerian Sahara) from the middle part of Hassi El Hadjar Formation and in the M'Kratta Formation, in pre-glacial and post-glacial Hirnantian sediments (Le Hérisse *et al.* 2003, Le Hérisse unpublished data), and in the Hirnantian in Turkey (Le Hérisse *in Paris et al.* 2007). The assemblage is also well characterized by *Tasmanites tzadiaensis* Le Hérisse nov. sp. This species has also been encountered in core material from the Jebel Asba area of the Kufra Basin, in post-glacial deposits of latest Hirnantian or earliest Rhuddanian age (Thusu *et al.* 2013 in press). It could represent a fossil guide for the nearshore environments represented in southeastern Libya (Kufra Basin) and northern Chad, in the latest Ordovician–earliest Silurian intervals referred to the base of Tanezzuft Formation.

Among the spiny acanthomorphic acritarchs distinctive subrectangular to subpolygonal forms with unequal distribution of the processes on the vesicle needs to be mentioned. They are attributed to *Dorsennidium* (*Microhystridium?*) *polorum* nov. comb., described in the shallow water Power Glen Formation of the Medina Group, dated as early Rhuddanian in the New York State, USA (Miller & Eames 1982).

Classically the post-glacial uppermost Ordovician assemblages elsewhere, in more open marine sediments in northern Gondwana or Bohemia are marked by the first appearance of new distinct morphotypes of Silurian affinity such as species of the genera *Cymbosphaeridium*, *Oppilatala*, *Tylotopalla* or *Visbysphaera* (Dufka & Fatka 1993, Vecoli & Le Hérisse 2004, Vecoli 2008, Delabroye & Vecoli 2010). The occurrence of the species attributed to *Dorsennidium polorum* in our assemblage of latest Ordovician–earliest Silurian age, is another example of sporadic appearance of species that continue in the early Silurian.

## Systematic palaeontology

### Chitinozoa (F. Paris)

Order Prosomatifera Eisenack, 1972

Family Conochitinidae Eisenack, 1931, emend. Paris, 1981

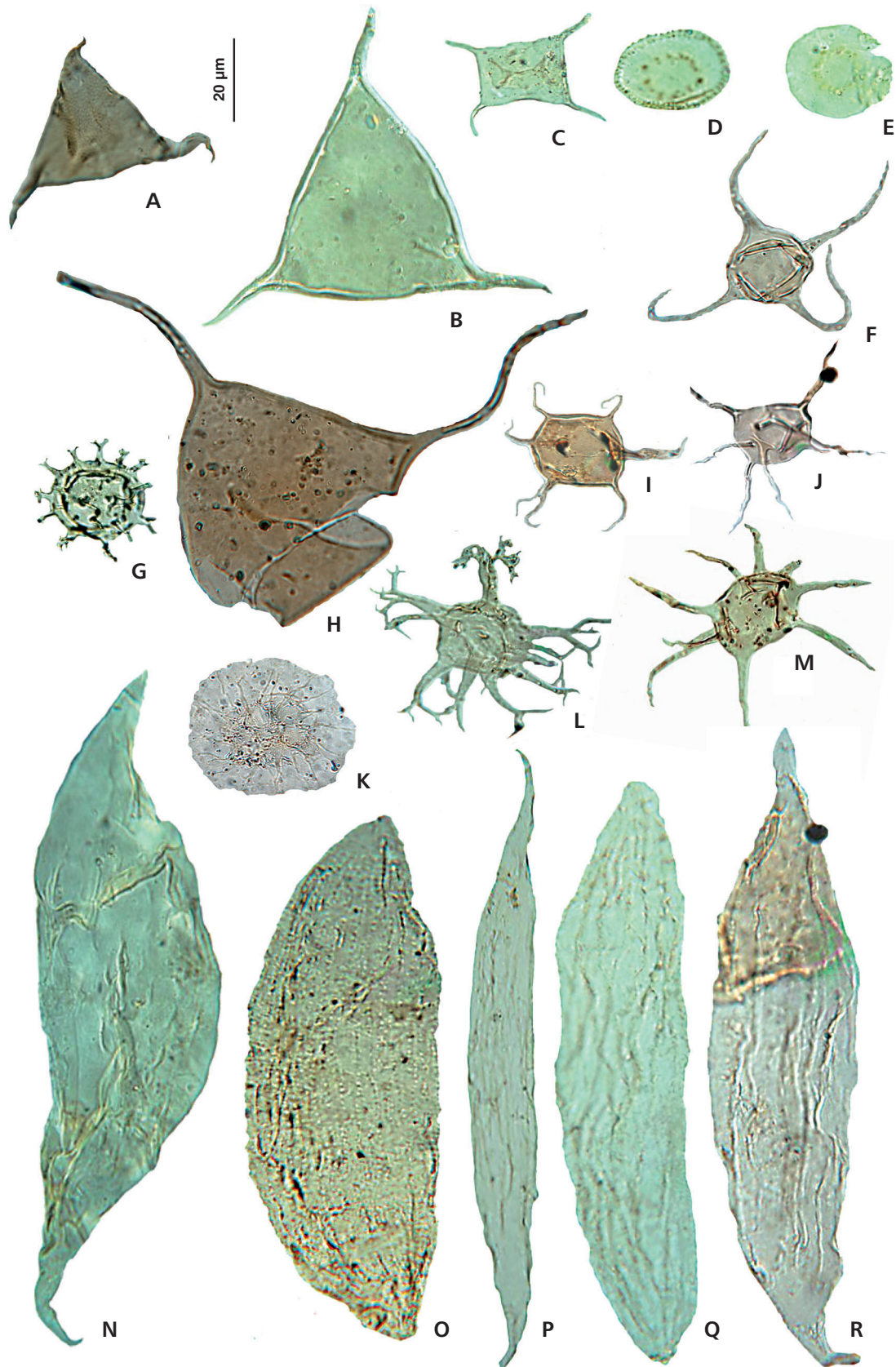
Subfamily Conochitininae Paris, 1981

### Genus *Euconochitina* Taugourdeau, 1966, emend. Paris *et al.*, 1999

*Type species.* – *Conochitina conulus* Eisenack, 1955.

**Figure 8.** Acritarchs from the Upper Ordovician–Early Silurian of northern Chad and southeastern Libya. The specimens are housed in the University of Liège (Belgique) under the repository numbers, 60900, 60947, 60949.2, 60949.3, 60950, 60950.1, 60950.3, 60979.3, and in the University of Brest (France) under the repository numbers LPB 13067 to 13070 and 13195 to 13199. The England-Finder coordinates are in brackets. • A – *Villosacapsula setosapellucula* (Loeblich, 1970) Loeblich & Tappan, 1976, Moussegouda core drill, core 9, 220–221 m (A), slide 60950.1 (026.4). • B – *Veryhachium mareki* Vavrdová, 1989, Moussegouda core drill, core 9, 220–221 m (A), slide 60950.1 (P49.1). • C – *Neoveveryhachium carminae* (Cramer, 1964) Cramer, 1970, Moussegouda core drill, core 9, 220–221 m (A), slide 60950.1 (N34.2). • D, E – *Saharidia munfarida* Vavrdová, 1982; D – Moussegouda core drill, core 9, 220–221 m (A), slide 60950.1 (W39); E – Moussegouda core drill, core 9, 220–221 m (A), slide 60950.1 (E26). • F – *Dorsennidium europaeum wenlockianum* (Downie, 1959 *ex* Wall & Downie, 1963) Sarjeant & Stancliffe, 1994, emend. Mullins, 2001, Moussegouda core drill, core 8, 205–206 m (A), slide 60979.3 (N49). • G – *Multiplicisphaeridium raspa* (Cramer) Eisenack *et al.*, 1973, Moussegouda core drill, core 8, 205–206 m, slide 60949.2 (E35.4). • H – *Veryhachium subglobosum* Jardiné, Combaz, Magloire, Peniguel & Vachey, 1974, Moussegouda core drill, core 9, 220–221 m (A), slide 60950.3 (C25). • I, J, M – *Dorsennidium polorum* Miller & Eames, 1982 nov. comb.; I – KW2 core drill, 36 m, 13194 (F22.2), J – Moussegouda core drill, core 7, 180–186 m, slide 13195 (T24), M – Moussegouda core drill, core 8, 200 m, slide LPB 13196 (C30.2). • K – *Tunisphaeridium cf. eisenackii* Loeblich & Tappan, 1978, Moussegouda core drill, core 8, 205–206 m, slide 60949.3 (D39). • L – *Multiplicisphaeridium irregulare* Staplin, Jansonius & Pocock, 1965, Moussegouda core drill, core 9, 220–221 m (A), slide 60950 (025). • N – *Eupoikilofusa platynetrella* Loeblich & Tappan, 1978, Moussegouda core drill, core 9, 220–221 m (A), slide 60950 (K46.3). • O – *Dactylofusa striatogranulata* Combaz, Magloire, Peniguel & Vachey, 1974, Moussegouda core drill, core 5, 150–156 m, slide 13198 (M19). • P – *Eupoikilofusa striatifera* (Cramer, 1964) Cramer, 1970, Moussegouda core drill, core 8, 200 m, slide 13197 (W33). • Q – *Eupoikilofusa cf. Eupoikilofusa striata* (Staplin, Jansonius & Pocock, 1965) Eisenack, Cramer & Diez, 1976, a specimen with striae at the poles and blunt poles, Moussegouda core drill, core 5, 150–156 m, slide 13198 (E27). • R – *Eupoikilofusa striata* (Staplin, Jansonius & Pocock, 1965) Eisenack, Cramer & Diez, 1976, Moussegouda core drill, core 7, 180–186 m, slide 13195 (K31).





***Euconochitina moussegoudaensis* sp. nov.**

Figures 6A, B, I, J, 7D

- 1991 *Conochitina chydaea* Jenkins. – Grignani *et al.*, pl. 1, figs 2–10.  
 2013 *Euconochitina moussegoudaensis* Paris in Thusu *et al.*, pl. VI, figs 4a, b, 8a, b; pl. 7, fig. 5; pl. VIII, figs 3a, b, 4, 5a, b; pl. X, figs 1, 5–10, 12, 14–16, 18; pl. XI, figs 16, 18–20.

*Holotype.* – Fig. 6J, IGR 58094 (O40).

*Paratypes.* – Fig. 6A, IGR 58092 (Q39); 6B IGR 58092 (R39); 6I, IGR 58093 (U40/4).

*Etymology.* – Species name referring to the locality Moussegouda, northern Chad.

*Material.* – Several tens of specimens in the Moussegouda core hole (northern Chad) and several hundreds of additional specimens from JA-2 core hole, Jebel Asba, Kufra Basin, SE Libya (see Thusu *et al.* 2013 in press).

*Type locality.* – Moussegouda shallow core hole, northern Chad.

*Type horizon.* – Core 3, at depth 123–124 m, basal Tanezzuft Formation referred to the latest Hirnantian–basal Rhuddanian?.

*Diagnosis.* – Conochitiniidae with an elongate conical vesicle, a glabrous wall surface, a straight aperture, and a rounded margin; a slight constriction of the flanks occurs in the lower third of the chamber; neck short.

*Description.* – This rather small conical chitinozoan (vesicle length ranging from *ca* 105 to 190 micrometers; see Fig. 5) has sigmoid flanks due to the occurrence of a discrete constriction above the margin, roughly in the lower third of the chamber, *i.e.* about 1/5 of the total length of the vesicle. The

flexure and the shoulder are inconspicuous. The neck is cylindrical or flares gently towards a straight aperture. It is fairly short and represents usually 1/4 to 1/3 of the vesicle length. A well-developed prosome usually provided with a rica (up to 40 micrometers) is frequently present at the base of the neck (Fig. 6B; see also pl. X, figs 5, 6, 8–10 in Thusu *et al.* 2013 in press). The chamber wall is glabrous, *i.e.* it bears no spines or cones, but shows a microgranular surface at high magnification (granule diameter less than 1 micrometer; see Fig. 6A2, J2). These granules are better developed on the rounded margin. The chamber bottom is flat to slightly convex (the convexity may be accentuated during the compression of the vesicle). The apex of the chamber is devoid of any conspicuous mucron.

*Measurements.* – (See Fig. 5.) Because the species is much more abundant in JA-2 core hole, Kufra Basin, the biometric evaluation is made on a population (50 specimens) randomly measured in a preparation from 48.18 m depth in JA-2 core hole. Correction coefficients of 0.8 and 0.7 are respectively used for the chamber width (Dp) and the collar diameter (Dcoll.) as the compression of the vesicle is moderate, both in the Moussegouda and JA-2 material.

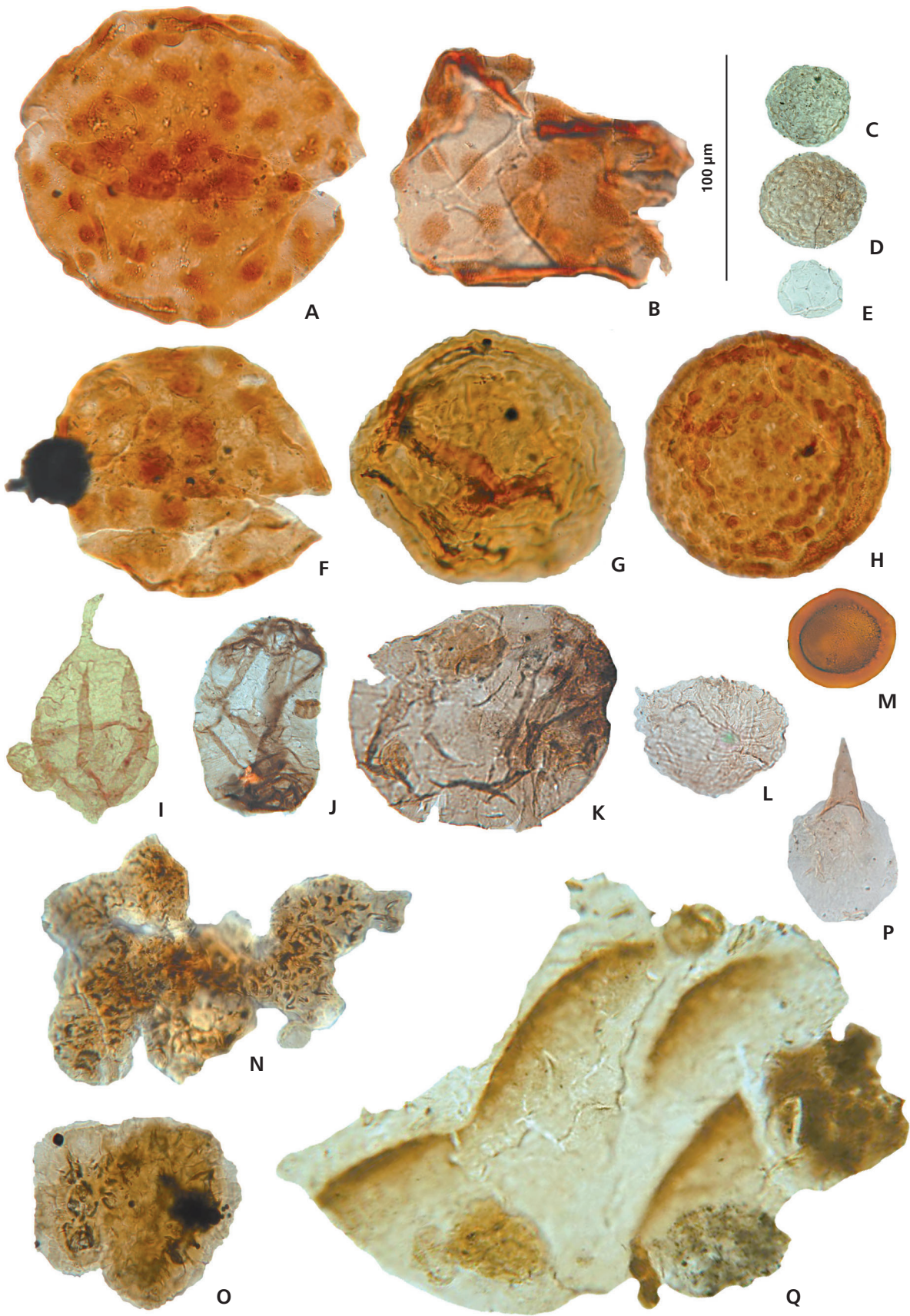
	L (µm)	Dp (µm)	Dcoll. (µm)
Holotype	157	71	45
Paratypes	151–169	71–85	47–55
Mean (JA-2, 50 specimens)	153	69 *55	44 **31
Smallest value (JA-2, 50 specimens)	114	57 *46	34 **24
Largest value (JA-2, 50 specimens)	195	79 **63	54 **38

coefficient of correction = 0.8; \*\* coefficient of correction = 0.7

*Discussion.* – Because of its glabrous vesicle, *Euconochitina moussegoudaensis* Paris sp. nov., like most of the *Euconochitina* species, lacks clear and fully discriminating features. The vesicle size (L ranging from 115 to 195 micrometers),

**Figure 9.** Prasinophycean phycmata, chlorophycean microalgal remains and problematica from the Upper Ordovician of northern Chad and southeastern Libya. • A, B, F – *Tasmanites tzadiaensis* nov. sp.; A – holotype, Moussegouda core hole, core 8, 201–202 m, slide 60948 (K46.4), B – paratype, Moussegouda core hole, core 8, 104–105 m, slide 60900 (M35.3), F – Moussegouda core drill, core 8, 201–202 m, slide 1 LPB 13199 (F33.2). • C – *Retisphaeridium? fragile* Miller & Eames, 1982, Moussegouda core hole, core 8, 200 m, LPB 13067 (G47). The form is flattened and bears no equatorial reticulum, as for the type material. • D – *Dictyotidium* sp., Moussegouda core hole, core 8, 201–202 m, LPB 13199 (Q27). • E – *Clypeolus tortugaides* Miller, Playford & Le Hérisse, 1997, Moussegouda core hole, core 8, 200 m, slide 60947 (C35.1). • G – *Tasmanites* sp., Moussegouda core drill, core 8, 205–206 m, slide snpa LPB 13068(Q31). Large form with rugulate to corrugate ornamentation. • H – *Tasmanites* sp., Moussegouda core hole, core 5, 150–156 m, LPB 13198 (P27). Large form with punctate ornamentation. • I, J, K – possible metazoan remains; I – Moussegouda core hole, core 5, 150–156 m, LPB13198 (J41.2), J – Moussegouda core hole, core 5, 150–156 m, LPB 13198 (S38), K – Moussegouda core hole, core 7, 180–186 m, LPB 13195 (H18.3). • L – *Moyeria cabottii* (Cramer) Miller & Eames, 1982, Moussegouda core hole, core 5, 150–156 m, LPB 13198 (E23.2). • M – *Tasmanites* sp. Moussegouda core hole, core 3, 120–126 m, LPB 13069 (C26.3). A small specimen of *Tasmanites*, with a diameter of 40 µm, but very thick vesicle wall of 5.5 µm width. • N, O – *Gleocapsomorpha prisca* Zalessky, 1917; N – large colony of connecting cells, enclosed in a lamellated sheath, dimensions 90 × 135 µm, Moussegouda core drill, core 8, 220–221 m, LPB 13199 (K45.4), O – colony, 83 µm in diameter, Moussegouda core drill, core 4, 135–141 m, LPB 13070 (L24.2) • P, Q – eurypterids fragments; P – eurypterid cuticle spine, Moussegouda core drill, core 8, 200 m, LPB 13199 (R38.3), Q – nail-shaped thickenings from eurypterid cuticle fragment, Moussegouda core drill, core 3, 120–126 m, LPB 13070 (S28).





and the overall silhouette with the gently tapering flanks (Dp/Dcoll. close to 1.5) and the weak constriction of the chamber above the margin are the main diagnostic morphological elements. This silhouette separates the new species from other early Silurian Conochitiniinae, such as *C. edjelensis* Taugourdeau, 1963, *C. elongata* Taugourdeau, 1963 or *E. vitrea* (Taugourdeau 1962).

**Stratigraphical and geographical distribution.** – *Euconochitina moussegoudaensis* dominates the rather poor chitinozoan assemblage recovered from a siltstone dominated sequence tentatively referred to the lower part of the Tanezzuft Formation in core 1 to core 8 from the Moussegouda core hole (northern Chad). These strata are regarded as latest Hirnantian or earliest Rhuddanian in age. No independent stratigraphical control, by mean of graptolite data, is available in this core hole.

The species is extremely abundant in the JA-2 core hole and in the neighbouring Remsa well (Kufra Basin SE Libya) from strata tentatively assigned to the latest Hirnantian or earliest Rhuddanian (Thusu *et al.* 2013 in press). If one accepts the synonymy proposed herein, *E. moussegoudaensis* was also recorded by Grignani *et al.* (1991) in core 4 (36–37 m depth) from well KW-2. The corresponding strata yielded us specimens of *E. moussegoudaensis* associated with *S. verniersi* (see above). The graptolite *Normalograptus medius* reported by Grignani *et al.* (1991) in cores 2 (18–19 m) and 3 (30–31 m) from this well does not provide a definite age assignment for this material as the species ranges through the Ordovician-Silurian boundary (see Loydell 2012).

## Prasinophyte phycomata (A. le Hérisse)

Division Chlorophyta Pascher, 1914  
Class Prasinophyceae Christensen, 1962  
Order Pterospermatales Schiller, 1925  
Family Tasmanitaceae Sommer, 1956

## Genus *Tasmanites* Newton, 1875

**Type species.** – *Tasmanites punctatus* Newton, 1875, by original designation.

### *Tasmanites tzadiaensis* sp. nov.

Figure 9A, B, F

**Holotype.** – Fig. 9A, core 8, 201–202 m, slide 60948 Liège (K46/4).

**Paratypes.** – Fig. 9B, core 8, 104–105 m, slide 60900 Liège (M35/3); Fig. 9F, core 8, 201–202 m, LPB 131999 (F33/2).

**Etymology.** – From the Latin name of Chad.

**Material.** – 20 specimens from core 8 (201–202 m) to core 2 (104–105 m).

**Type locality.** – Moussegouda shallow core drill, northern Chad.

**Type horizon.** – Core 8, at depth 201–202 m, basal Tanezzuft Formation referred to the late Hirnantian to early Rhuddanian.

**Diagnosis.** – A species of *Tasmanites*, with spherical vesicle, thick-walled, and characteristic discoid ornaments or low verrucae, regularly distributed on the surface, finely pitted by small pores continuing by narrow canals. The opening has not been observed.

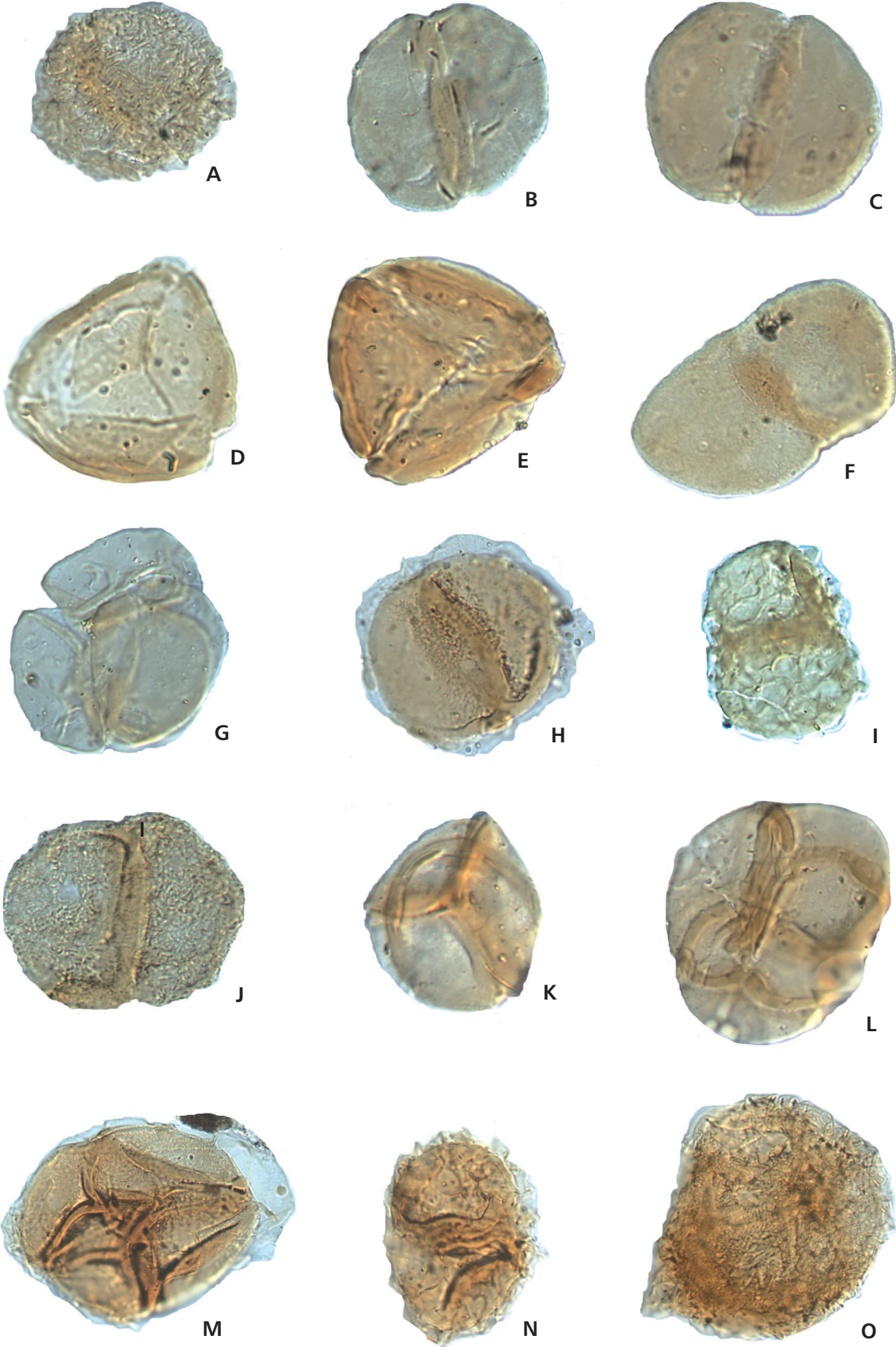
**Dimensions.** – 100 to more than 145 µm in diameter; wall 2–3 µm in thickness; discoid ornaments 6.5 to 11 µm in diameter.

**Discussion.** – Diagnostic morphological features such as radial pores confirm the attribution of the species to the genus

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**Figure 10.** Cryptospores from the Upper Ordovician of northern Chad and southeastern Libya. The specimens are housed in the University of Liège (Belgique) under the repository numbers, 60901, 60947, 60948, 60950, 60979. The England-Finder coordinates are in brackets. All specimens × 1000. • A – *Rugosphaera cerebra* Miller & Eames, 1982, Moussegouda core hole, core 9, 220–221A, slide 60950 (H30/4). • B, C – *Dyadospora murusattenuata* Strother & Traverse, 1979; B – Moussegouda core hole, core 9, 220–221A m, slide 60950 (Q34.3), C – Moussegouda core drill, core 8, 201–202 m, slide 60948 (L31/2). • D, E – *Imperfectotrilites vavrdovae* Steemans *et al.*, 2000; D – Moussegouda core hole, core 8, 200 m, slide 60947 (H33), E – Moussegouda core drill, core 8, 201–202 m, slide 60948 (Q28/2). • F – *Pseudodyadospora* sp., Moussegouda core hole, core 8, 201–202 m, slide 60948 (G25). • G – *Rimosotetras problematica* Burgess, 1991, Moussegouda core hole, core 9, 220–221 m, slide 60950 (C34/1). • H – *Segestrespora laevigata* Burgess, 1991, Moussegouda core hole, core 8, 201–202 m, slide 60948 (M38). • I – *Segestrespora membranifera* (Johnson, 1985) Burgess, 1991, Moussegouda core hole, core 8, 205–206 m, slide 60979 (L37). • J – *Segestrespora rugosa* (Johnson, 1985) Burgess, 1991, Moussegouda core drill, core 9, 220–221A m, slide 60950 (C33/1). • K – *Tetraedraletes grayii* Strother, 1991, Moussegouda core hole, core 9, 220–221A m, slide 60950 (Q34/3). • L – *Tetraedraletes medinensis* Strother & Traverse, 1979, Moussegouda core hole, core 9, 220–221A m, slide 60950 (J30/4). • M – *Velatitetras laevigata* Burgess, 1991, Moussegouda core hole, core 8, 201–202 m, slide 60948 (H37). • N – *Velatitetras retimembrana* (Miller & Eames, 1982) Wellman & Richardson, 1996, Moussegouda core hole, core 3, 123–124 m, slide 60901 (H36). • O – *Velatitetras rugosa* (Strother & Traverse, 1979) Steemans *et al.*, 2000, Moussegouda core hole, core 9, 220–221A m, slide 60950 (Q30).





*Tasmanites*. *Tasmanites tzadiaensis* sp. nov. differs from the other species of the genus in having a very particular surface ornamentation. It recalls *Tapajonites roxoi* Sommer & Van Boekel, 1963, showing some little dark spots on the surface, but the latter are irregularly distributed and without any pores. A few additional specimens are characterized by corrugate ornamentation, and are identified as *Tasmanites* sp. A, and some with verrucate ornamentation, illustrated as *Tasmanites* sp. B. They are rare and therefore are kept in open nomenclature. Specimens of various size attributed to *Leiosphaeridia* (very abundant) are comparatively thin walled and have no pores or canals.

*Stratigraphical and geographical distribution.* – *Tasmanites tzadiaensis* is recorded in an interval referred to the basal Tanezzuft Formation in northern Chad, in Moussegouda core hole between 201–202 m and 104–105 m (present study). The species is also mentioned in subsurface deposits of the Jebel Asba area, Kufra Basin, southeast Libya in an interval also referred to the latest Ordovician-earliest Silurian Tanezzuft Formation (Thusu *et al.* 2013 in press).

## Conclusions

This paper has provided biostratigraphical information and interpretation for the sedimentary sequence within the Late Ordovician to earliest Silurian (?) succession in the subsurface of the northern Chad and in southeastern Libya that can be summarised as follows. The microfossils from the glacio-marine deposits in the deeper part (C10 and C9) of the core section of the Moussegouda core hole, clearly indicate a Hirnantian age for these deposits. Evidence of acritarch and possibly chitinozoan reworking are consistent with this age assignment, as reworking is a common feature of Late Ordovician glacial to end-glacial deposits in northern Gondwana regions. In the Moussegouda core hole, the Hirnantian diamictites are overlain by a sequence of siltstones and sandstones with carbonaceous horizons, referred to the Tanezzuft Formation. Cores 1 to 4 from the KW-2 shallow well in southeastern Libya are also referred to this formation. In both areas these strata correspond to post-glacial deposits generated by the dramatic sea-level rise resulting from the final melting of the main part of the Gondwanan inlandsis. These deposits seem concentrated in short-lived shallow marine depressions that developed prior to the post-glacial rebound in areas previously overlain by a thick ice cover. This sedimentation starved rapidly due to these isostatic readjustments and did not shift to hemipelagic graptolite-bearing shales as commonly observed during the Rhuddanian and even later, in many localities along the north Gondwanan margin. The admixture of land-derived, freshwater and marine palynomorphs in

the Moussegouda material, and evidence of low salinity indicate a strong continental influx. These features suggest the existence of nearshore restricted environments consistent with the filling up of large but shallow depressions (several tens of meters to one or two hundred meters depth) with moderate oceanic communication. The duration of such sedimentological processes was in the range of a few thousand years if one refers to the timing of the Holocene transgression and to the contemporaneous post-glacial rebound in north European areas, where a thick ice cover occurred during Quaternary times.

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