

Low-diversity conodont and cephalopod assemblages from the Silurian of the Tinduf Basin, Western Sahara

Annalisa Ferretti¹, Paolo Serventi¹, Giulia Ferrari¹, Maria Giovanna Corriga^{2,*}, Carlo Corradini²

¹ Dipartimento di Scienze Chimiche e Geologiche, Università degli Studi di Modena e Reggio Emilia, Via Campi 103, I-41125 Modena, Italy; e-mails: annalisa.ferretti@unimore.it; paolo.serventi@unimore.it; 294522@studenti.unimore.it

² Dipartimento di Matematica, Informatica e Geoscienze, Università degli Studi di Trieste, Via Weiss 2, I-34128 Trieste, Italy; e-mails: corrigamariagiovanna@gmail.com; ccorradini@units.it

*corresponding author

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Abstract. A peculiar cephalopod slab collected in Western Sahara hosts almost monospecific cephalopod and conodont associations, preliminarily attributed to the Ludfordian based on the occurrence of *Wurmiella* sp. A Corriga *et al.*, 2021. *Arionoceras submoniliforme* (Meneghini, 1857) dominates the nautiloid fauna that reveals a clear bimodal orientation. The microfacies analysis documents a cephalopod packstone associated with abundant skeletal elements coated by micrite. The origin and significance of this association are discussed and possibly interpreted as a post-Lau Event fauna, still deeply affected by the extinction event.

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INTRODUCTION

Cephalopod limestones represent one of the most iconic facies that developed in Silurian to Devonian times along the northern margin of Gondwana. They are generally characterized by a rich faunal content, both in cephalopods and other faunas, and high diversity of the associations. Their color may vary from black to light-gray to reddish according to the organic matter and iron contents (Histon, 2012a). However, diverse depositional settings and environmental conditions have been associated with cephalopod event beds that mostly document relatively shallow-water facies related to wave or cur-

rent action on the seafloor (*e.g.*, Gnoli *et al.*, 1980; Ferretti and Kříž, 1995; Brett *et al.*, 2009, 2012; Histon, 2012b). On the contrary, micritic nodular limestones, often argillaceous, were deposited in lower-energy/deeper areas of the basin (*e.g.*, Ferretti and Serpagli, 1996; Corradini *et al.*, 1998a). While other fossils appear to be more abundant in the cephalopod-dominated facies, conodont contents do not vary significantly between the two facies, and rich and diverse assemblages have been recorded also in the latter environment (*e.g.*, Corradini *et al.*, 1998b).

A peculiar situation is documented by a slab, 6–8 cm thick and 62 cm to 39 cm wide, collected in

the north-eastern part of Western Sahara (Fig. 1a), at coordinates 26°32'30" N 9°16'26" W, and naturally polished by wind action. The slab, according to Gnoli (2003) who preliminarily studied the material, hosts a mostly monospecific mass association (MMA *sensu* Bruthansová *et al.*, 2022) of nautiloids dominated by *Arionoceras submoniliforme* (Meneghini, 1857) with rare *A. affine* (Meneghini, 1857) and *Michelinoceras michelini* (Barrande, 1868). The same author suggested that *A. affine* could represent the possible female dimorph of *A. submoniliforme*. The material was assigned to the *Ancoradella ploeckensis* conodont Zone with no further details on the conodont association, and a high-energy depositional environment exposed to wave-action was inferred (Gnoli, 2003).

A key objective of the present paper is to complete/revise the study on the Sahara cephalopod slab in order to provide a more detailed description of the material, assess a precise chronostratigraphic assignment and clarify the connection of this occurrence with penecontemporaneous beds inside and outside North Africa.

GEOLOGICAL SETTING

The Silurian rocks of north-eastern Western Sahara belong to the Tindouf Basin, an 800 km elongated

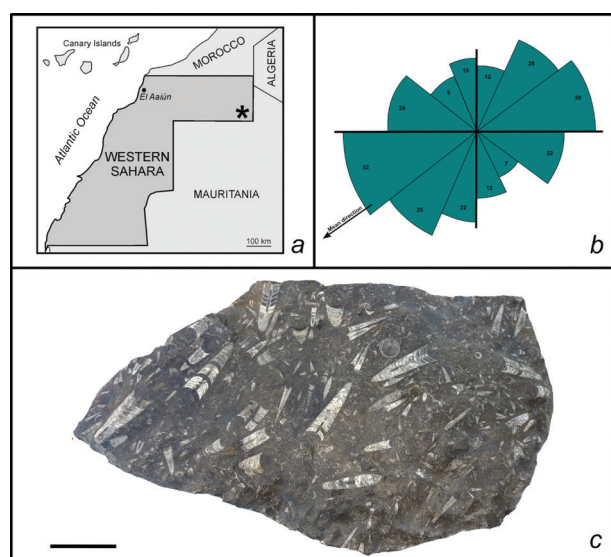


Fig. 1. a) Location map of the sampled area. The asterisk marks the precise position of the cephalopod slab herein investigated. b) Rose-diagram plot of the orientations of the cephalopod shells (modified after Malagoli, 2006). c) General view of the cephalopod slab; scale bar: 10 cm. Note that differences in size and shape also depend on the surface of erosion.

asymmetrical syncline, oriented ENE to WSW from southern Morocco to Western Sahara (Villeneuve, 2005). Rocks from Cambrian to Pennsylvanian age are exposed here. Silurian rocks are represented by graptolitic shales with interbedded cephalopod calcarenites, which Ratschiller (1967, 1970–1971) named as the Afreyiat Formation. The unit, 30–100 m thick, unconformably lies above Upper Ordovician sandstones; at places, some conglomerates are exposed at the boundary as a result of the sea-level drop connected with the Hirnantian glaciation. Above, the Afreyiat Formation is covered, after a sedimentary gap, by sandstones and shales of Early Devonian age belonging to the Dammia Formation. Based on graptolites collected from the shales, Ratschiller (1967, 1970–1971) suggested an age spanning the late Wenlock to Ludlow for the Afreyiat Formation. According to Berry and Boucot (1973), the unit is lithologically similar to coeval rocks exposed in Mauritania, Algeria and Morocco. The cephalopod slab studied herein was collected at the top of the Afreyiat Formation (Fig. 1a), at the boundary with the Dammia Formation (Gnoli, 2003).

MATERIAL AND METHODS

Sample preparation and study was undertaken with the equipment of the Department of Chemical and Geological Sciences of the University of Modena and Reggio Emilia, Italy. A total of 1.7 kg was processed with conventional formic acid technique. Two sets of uncovered polished oriented thin-sections (both perpendicular to stratification) were prepared, resulting in five polished 45×60 mm thin-sections. Conodont elements were extracted by hand picking from unseparated residue under a Zeiss Stemi SV 11 binocular microscope (magnification 25–100×). Thin-sections were characterized under optical microscopy with a transmitted and reflected Optech SL 8 T optical light-microscope (magnification 6–50×) equipped with a Canon EOS HS 1200D camera. Selected conodont specimens were mounted on aluminum stubs previously covered with carbon-conductive adhesive tape. Electron microscopy data were collected using a JEOL JSM–6010PLUS/LA InTouchScope scanning electron microscope (SEM). SEM measurements were performed in high vacuum with an accelerating voltage between 5 keV and 20 keV.

The cephalopod slab is stored in the “Inventario Paleontologia Università di Modena e Reggio Emilia (IPUM)” at the Department of Chemical and

Geological Sciences, University of Modena and Reggio Emilia, Italy. The illustrated conodont specimens are kept in the Type Collection of the same Institution under the Repository Numbers IPUM 35087–35095.

FAUNAL ASSOCIATION

Cephalopod record

The slab under investigation (Fig. 1c) documents a rich nautiloid fauna, with adjacent cephalopod conchs ranging in length from a few millimeters to 15 cm, all situated on the same bedding plane. Although the erosive action of the wind has unevenly eroded the calcareous slab, the preservation of the specimens is generally good (Fig. 2), since the inner features such as siphuncles and septal necks (Fig. 2c–d) and cameral deposits (Fig. 2b) are clearly visible even to the naked eye. Though difficult to identify, a few protoconchs are present. As already indicated by Gnoli (2003), the fauna is dominated by representatives of the genus *Arionoceras* Barskov (1966), in particular by *Arionoceras submoniliforme* (Fig. 2a) and a few specimens of *A. affine* (Fig. 2b, d) and scattered *Michelinoceras michelini* (Fig. 2c). Representatives of the genus *Nucleoceras* (Kolebaba, 1999) are possibly present (Fig. 2e), but

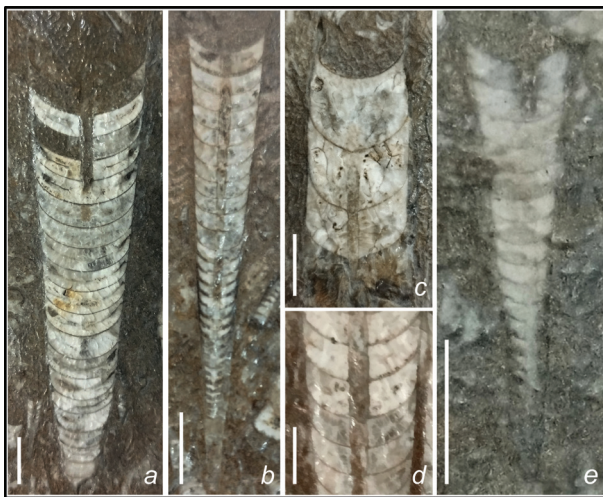


Fig. 2. Cephalopods from the cephalopod slab from Western Sahara under investigation: a) *Arionoceras submoniliforme* (Meneghini, 1857); b) *Arionoceras affine* (Meneghini, 1857) with clearly recognizable cameral deposits; c) *Michelinoceras michelini* (Barrande, 1868) with orthochoanitic septal necks; d) *Arionoceras affine* (Meneghini, 1857), detail of suborthochoanitic, acuminate septal necks; e) *Nucleoceras?* sp. Scale bars: 1 cm (a–c), 5 mm (d–e).

the small size of the sole specimen found prevents a precise taxonomic assignment.

Specimens are oriented parallel to the bedding, with a clear, pronounced bidirectional orientation (Fig. 1b), as revealed by measurements run on 278 shells on the same bedding plane (only two conchs were sub-vertical; Malagoli, 2006). Telescoping of the shells is visible mainly in the lateral faces of the slab.

Conodont record

A total of 355 conodont elements was recovered. Their preservation is generally poor, with only a few elements complete, the majority of the faunal elements having broken processes but still identifiable, nevertheless. Conodont color is pale brown, corresponding to a Colour Alteration Index (CAI) of 1.5.

The conodont fauna consists of an almost monospecific association of *Wurmiella* sp. A Corriga *et al.*, 2021 (Fig. 3), representing more than 99% of the fauna. Beside *Wurmiella* sp. A, only two specimens of the long-ranging coniform species *Pseudooneotodus beckmanni* (Bischoff and Sannemann, 1958) were collected (Fig. 3i). *Wurmiella* sp. A is characterized by a strongly asymmetrical blade in the P1 element (Fig. 3a, b), as the anterior process is longer and somewhat higher than the posterior process, which is very short. The species has been documented from the Ludfordian of the Carnic Alps, from the uppermost part of the *A. ploeckensis* Zone into the *Oz. crista* Zone (Corradini *et al.*, 2015; Schönlaub *et al.*, 2017; Corriga *et al.*, 2021), and is especially abundant in the *Oz. snajdri* Interval Zone.

Microfacies

Thin-section analysis reveals that the Sahara slab is represented by a cephalopod packstone (Fig. 4). Skeletal debris is dominated by cephalopods, associated with equidimensional bioclasts, frequently coated by micrite. Coated grains, which represent the main constituents of the matrix, have an average size of 0.5–1 mm. Coating is mostly developed around cephalopod fragments, resulting in oblong grains. Articulated ostracods, bivalves and trilobite debris are present as well. Bioclasts, cephalopod ones *in primis*, often exhibit microborings or a common corroded outer surface (Fig. 4g). Cephalopod fragments dispersed in the matrix share a preferred orientation (Fig. 4c–d).

The peculiar matrix admixture is present also inside the cephalopod shells, reaching even the innermost part of the siphuncle (Fig. 4e, h), suggesting a common depositional event for the larger conchs

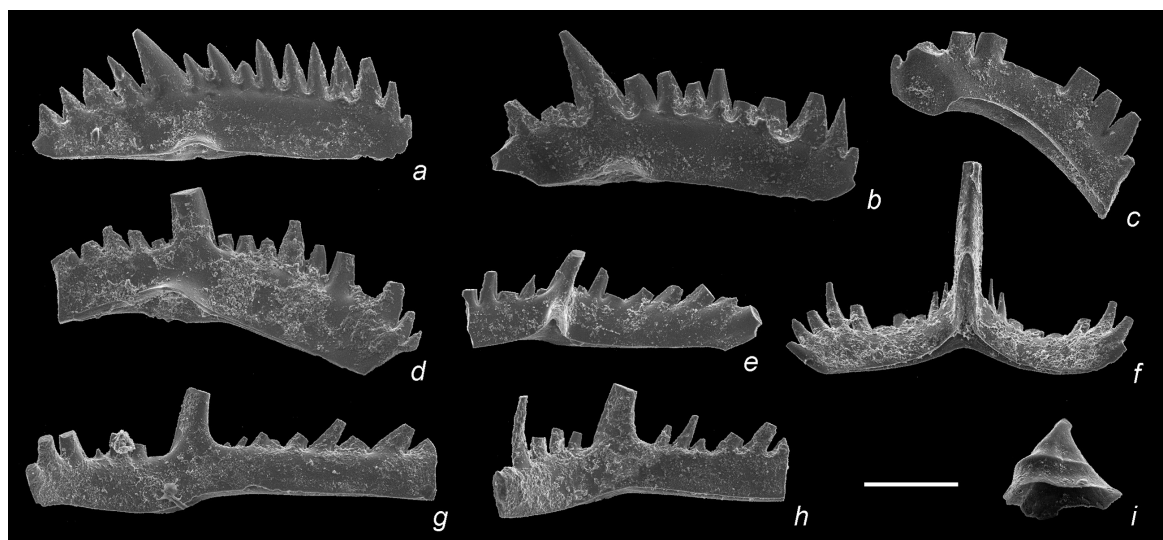


Fig. 3. Conodonts from the cephalopod slab from Western Sahara under investigation. All elements are figured in lateral view. *a–h*) *Wurmiella* sp. A Corrìga *et al.*, 2021; P1 elements, IPUM 35087 (*a*) and IPUM 35088 (*b*); M element, IPUM 35089 (*c*); P2 element, IPUM 35090 (*d*); S1 element, IPUM 35091 (*e*); S0 element, IPUM 35092 (*f*); S2 elements, IPUM 35093 (*g*) and IPUM 35094 (*h*); *i*) *Pseudooneotodus beckmanni* (Bischoff and Sannemann, 1958), IPUM 35095. Scale bar: 200 μ m.

and the matrix. Telescoping (of both cephalopods and other shells; Fig. 4*a–b*) and geopetal structures are present.

RESULTS AND DISCUSSION

Monospecific mass associations may be explained as a response to special taphonomic features, to unique paleoecological conditions or as a peculiar strategy in reproductive biology (Bruthansová *et al.*, 2022). Remarkably, the fact that both cephalopods and conodonts are affected by such a low diversity in the Sahara slab could favor a sort of environmental control. A high-energy deposition in shallow-waters, possibly associated with wave-action, is suggested for the Sahara slab by a series of indexes such as the cephalopod bimodal orientation, the sorting of bioclastic grains, the preferred orientation of both oblong coated grains and skeletal debris, and the deep filling of the matrix in the nautiloid siphuncles. However, shallow waters are commonly populated by faunas of moderate to high-diversity. The cephalopod-rich Fluminimaggiore Formation from SW Sardinia, for instance, associated with a wave-dominated setting (Gnoli *et al.*, 1980), has provided a rich conodont fauna (Corrìga *et al.*, 2009). A possible fourth explanation to justify such a mass association of conodonts and cephalopods is that the Sahara material records the true fauna that lived at

that time. Both genera *Arionoceras* and *Wurmiella* are extremely widespread and common in the Silurian, possibly representing the most resilient taxa to any biotic perturbation. Due to the distribution of *Wurmiella* sp. A in the Ludfordian of the Carnic Alps, from the uppermost part of the *A. ploeckensis* Zone to the *Oz. crispa* Zone, we cannot exclude that the cephalopod slab investigated herein documents the post-Lau Event fauna, still deeply affected by the extinction event. In fact, the conodont association is always rich and diverse before the Lau Event (*A. ploeckensis* and *Pol. siluricus* zones), when several species of *Kockelella* are present, among others (*e.g.*, Walliser, 1964; Serpagli and Corradini, 1999; Corrìga *et al.*, 2014), whereas diversity dramatically drops in the lower part of the *Oz. snajdri* Zone, just after the Lau Event (*e.g.*, Slavík *et al.*, 2010; Jeppsson *et al.*, 2012; Slavík and Carls, 2012).

CONCLUSIONS

Monospecific mass associations of cephalopods and conodonts are documented from Western Sahara with an integrated approach. Cephalopod and conodont specimens are described and figured for the first time, and a microfacies analysis has been completed. The almost monospecific conodont record does not allow to confirm the original attribution to the *Anco-radella ploeckensis* conodont Zone by Gnoli (2003).

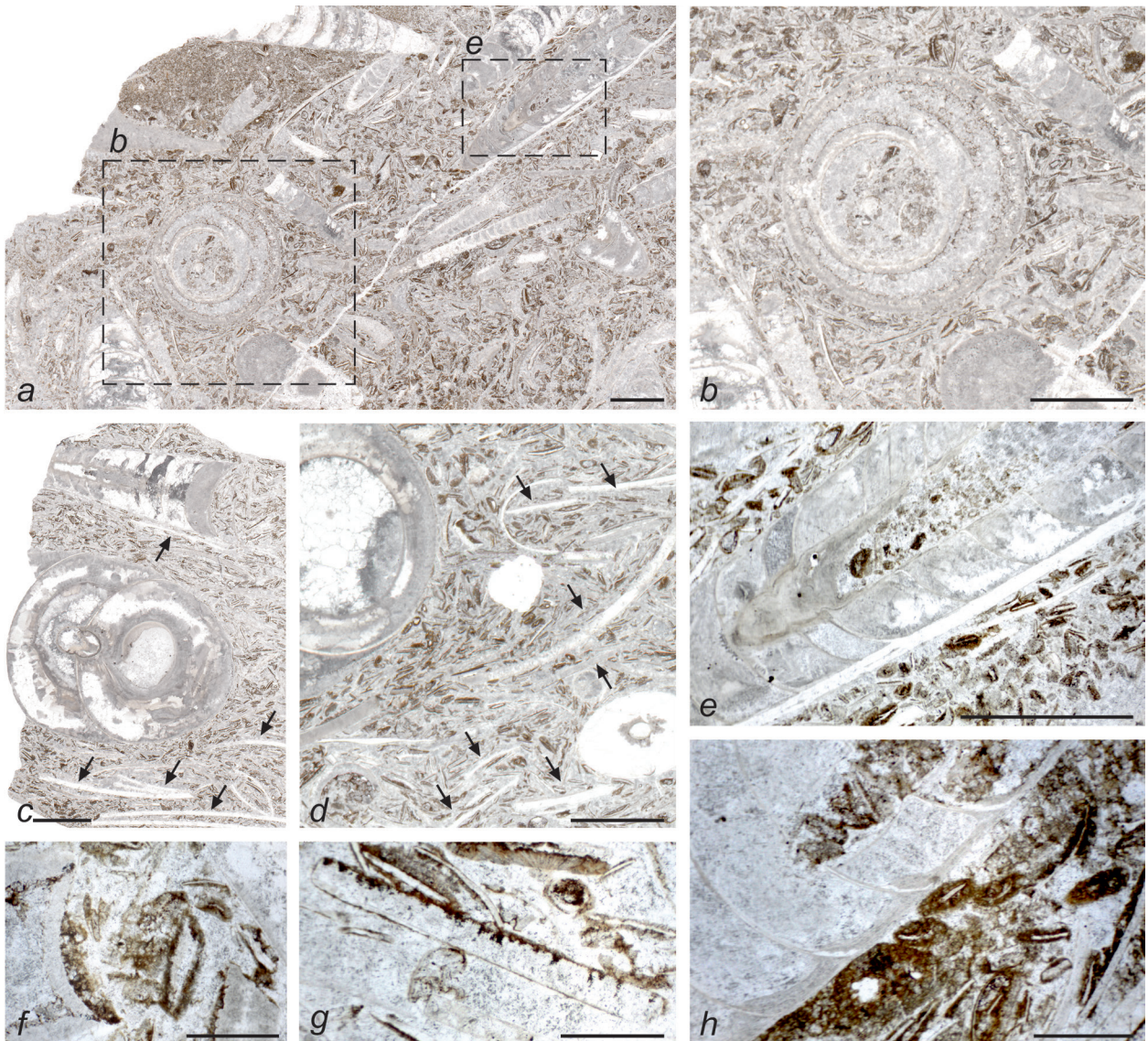


Fig. 4. Scanned (*a–d*) and transmitted-light (*e–h*) micrographs of petrographic thin-sections illustrating main microfacies of the cephalopod slab from Western Sahara under investigation. *a, b* Cephalopod packstone with accumulation of equidimensional biodebris in the matrix, mostly represented by micritic coated grains. Note telescoped orthocone shells on the left of frame *a* (detailed in *b*) and matrix infilling of a shell on the top right of frame *a* (detailed in *e*); *c, d* cephalopod packstone with abundant isoriated cephalopod skeletal elements (black arrows) in the matrix between larger cephalopod conchs; disarticulated bivalve shells, ostracodes and rare trilobites constitute a minor part of the matrix; *e, h* close views of the matrix filling the cephalopod siphuncle and the living chamber; *f* close view of coated grains with undetermined biodebris as nuclei; *g*) corroded cephalopod fragment, a possible prior step of micritization. Scale bars: 5 mm (*a–e*), 1 mm (*f–h*).

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