Crinoids from the Ouarsenis Massif (Algeria) fills the Lower Cretaceous (Berriasian and Valanginian) gap of northern Africa

Les crinoïdes du massif de l'Ouarsenis (Algérie) comblent la lacune du Crétacé inférieur (Berriasien et Valanginien) de l'Afrique du Nord

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Abstract

The Ouarsenis Massif belongs to the Algerian Tell domain which is considered as the eastern part of the Maghrebian Tethys former margin. The Berriasian-Valanginian Oued Fodda Formation outcropping in the Kef Aïn El Hadjela section, at the foot of the great peak of the Ouarsenis Massif, is composed of marls and laminated and bioturbated limestone alternations. The marl facies reveals diverse microfauna, including crinoids. These latter are represented by: Isocrinida [isocrinids (*Balanocrinus* cf. *gillieroni* (de Loriol), *Percevalicrinus aldingeri* Klikushin, *Isocrinus*? *lissajouxi* (de Loriol)], Cyrtocrinida [cyrtocrinids (*Phyllocrinus* sp., *Hemibrachiocrinus* sp.)], and Roveacrinida [roveacrinids (Gen. indet. sp. indet.)]. All these, with exception of roveacrinids and phyllocrinids, are noted for the first time from Algeria and African continent (southern margin of Tethys in the Maghreb). Knowledge on Cretaceous crinoids formerly described from Algeria is presented. It is also shown that crinoid assemblage and associated invertebrates are typical for relatively shallow, distal depositional setting situated below storm wave base.

RÉSUMÉ

Le massif de l'Ouarsenis appartient au domaine du Tell algérien qui est considéré comme l'extrémité orientale de l'ancienne marge de la Téthys maghrébine. La Formation d'Oued Fodda (Berriasien-Valanginien) affleurant sur la coupe du Kef Aïn El Hadjela, au pied du grand pic du massif de l'Ouarsenis, est constituée d'alternances de marnes et de calcaires laminés et bioturbés. Les faciès marneux contiennent une microfaune diversifiée, comportant des crinoïdes. Ces derniers sont représentés par : *Balanocrinus* cf. *gillieroni* (de Loriol), *Percevalicrinus aldingeri* Klikushin, *Isocrinus*? *lissajouxi* (de Loriol), *Phyllocrinus* sp., *Hemibrachiocrinus* sp., et Roveacrinida. Tous ici, à l'exception des rovéacrinides et phyllocrinides, sont rapportés pour la première fois en Algérie et sur le continent africain (marge méridionale de la Téthys dans le Maghreb). Nous faisons l'état des connaissances actuelles sur les crinoïdes crétacés décrits jusqu'alors en Algérie. Nous montrons également que l'assemblage de crinoïdes et les invertébrés associés sont caractéristiques d'un environnement de dépôt distal, relativement peu profond, localisé sous la limite d'action des vagues de tempête ('SWB').

Keywords: echinoderms, crinoids, Africa, Maghrebian Tethys, Lower Cretaceous.

Mots clés : échinodermes, crinoïdes, Afrique, Téthys Maghrébine, Crétacé inférieur

1. Introduction

The Cretaceous, and even the Mesozoic, crinoids of Algeria, have never been comprehensively characterised. Any information about them is contributory in nature; the only exception being roveacrinids (Roveacrinida), recently documented in the Cenomanian and Turonian strata of SE Algeria (Ferré et al., 2016, 2017).

The literature only provides information on the presence of three isocrinid (Isocrinida) taxa in the Cretaceous sediments of Algeria. Coquand (1854) and later Klikushin (1992) mentioned Hauterivian-Barremian *Isocrinus*? *neocomiensis* (Desor, 1847); however, Rasmussen (1961) mentioned this taxon only from the Hauterivian of France in his monumental monograph. Therefore, the occurrence of this taxon in Algeria should be treated with extreme caution. Oppenheim (1903), Pervinquière (1903) and finally Valette (1926) indicated the occurrence of *Isselicrinus africanus* (de Loriol, in Peron, 1883) in the

Maastrichtian or Danian sediments. Klikushin (1992) indicated the occurrence of *Buchicrinus buchii* (Hagenow, in Roemer, 1840) in the Maastrichtian of Algeria, referring to Rasmussen (1961), although the latter did not write anything about it. Rasmussen (1961, 1978; see also Hess and Messing, 2011; Lach, 2016) listed comatulid (Comatulida) taxa (*sensu* Hess and Messing, 2011), *Marsupites testudinarius* (von Schlotheim, 1820) in the Santonian of Algeria. Hess and Messing (2011) indicated the presence of the roveacrinid crinoid *Roveacrinus* in the sediments of the Hauterivian and Albian of Algeria and Angola. In recent works, Ferré et al. (2016, 2017) described and illustrated several taxa of roveacrinids. In the Cenomanian and Turonian sediments the following taxa were collected: Roveacrinidae indet.; *Applinocrinus* sp.; *Orthogonocrinus* sp.; *Roveacrinus* sp.; *Roveacrinus alatus* Douglas, 1908; *Roveacrinus* cf. *alatus* Douglas, 1908; *Roveacrinus* sp. cf. *alatus* Douglas, 1908; and *Roveacrinus communis* Douglas, 1908.

The present article characterises in detail for the first time three isocrinid taxa that have never been mentioned before from any Cretaceous sediments of Algeria. Likewise with cyrtocrinids (Cyrtocrinida), they have never been described from Algeria. They are associated with free-living saccocomids (Roveacrinida).

2. Geological setting

Northern Africa (= Maghreb), located at the boundary between the Eurasian and African plates (Bouillin, 1986), is part of the Maghrebides Alpine chains (Fig. 1A). From the Atlantic Ocean to the Pelagian Sea, the Atlas system (= Maghrebides Belts) extends over more than 2,500 km, parallel to the northern edge of Africa, between the Mediterranean Sea and the Saharan platform. Depending on the tectonic style, two belts can be distinguished in this system (Fig. 1A, B): (1) to the north, the Tell-Rif chain (Tell in Algeria and Tunisia; Rif in Morocco) is the orogenic system fringing the West Mediterranean basins to the south (Durand-Delga, 1969; Wildi, 1983). It includes three main parallel tectonic domains, from north to south: (a) the internal zones belonging to the AlKaPeCa (AlKaPeCa for Alboran, Kabylies, Peloritan, and Calabria) microcontinent and originated from the former northern European margin of the Maghrebian Tethys; (b) the Maghrebian flysch nappes regarded as the former sedimentary cover of the Maghrebian Tethys and (c) the external zones, interpreted as the North-African palaeo-margin inverted during the Cenozoic collision. These flysch nappes correspond to the mid-Tellian units of Wildi (1983). (2) the Atlas belt (High and Middle Atlas in Morocco, Saharan Atlas in Algeria and Tunisian Atlas) is located between the Rif-Tell chain to the north and the Saharan platform to the south. It differentiates from the Rif-Tell by a weaker general shortening, the overall steep dip of the outcropping structures and the general lack of a conspicuous metamorphism (Leprêtre et al., 2018). It is separated from the Saharan platform by a clear physiographic boundary often referred to as the South-Atlasic fault (Accident Sud Atlasique). In western Maghreb, the Rif-Tell and the Atlas are mostly separated from each other by the Moroccan or Western Meseta and by the High-Plateaus or Eastern Meseta, or Oran Meseta, whereas they merge eastwards in Tunisia (Fig. 1B).

The study area occupies the eastern part of the Ouarsenis Massif (northwestern Algeria) located in the external zones of the central part of the Tell Belt (Fig. 1B, C). The Ouarsenis massif corresponds to a very complex structural edifice (Mattauer, 1958; Polvèche, 1960) and comprises overlapping allochtonous nappes imbricated inside each other, mainly of Triassic to Neogene sedimentary sequences (Benaouali-Mebarek et al., 2006), coming from the African palaeo-margin and sometimes thrusted ca. 100 km southwards. Autochthonous massifs also present (Durand-Delga, 1969) such as the Bou Maad, Blida Range and Chelif massifs. The stratigraphic series of the Ouarsenis area is transected by numerous anomalous contacts, vertical accidents and faults oriented NNW-SSE and ENE-WSW (Benyoucef, 2006). They show a remarkable tectonic complexity represented in the eastern part by the autochthonous part, the complex A, the nappe B and the nappe C (Mattauer, 1958). According to Polvèche (1960), the western part of the Ouarsenis area is composed by the superimposition of the five structural units: the Oligo-Miocene unit, the Chouala unit (Lower Cretaceous), the Senonian unit, the Albo-Cenomanian, and finally the Numidian unit (Oligocene).

The Ouarsenis area is bounded by the Chlef Plain (vast Neogene basin) and Djebel Zaccar to the north; by the Miocene sandstones of Sersou Plateau to the south; by the Bibans Range (Media region) and by the post-Miocene formations of Miliana to the east; there is no natural limit to the Ouarsenis to the west. However Polvèche (1960) set the Miocene deposits of Zemmoura as the western limit of the Ouarsenis massif. Beyond these latter appear the Cretaceous formations of Mina (Relizane area) (Fig. 1C).

The studied section (UTM coordinates: 35°52’52.01” N; 01°35’44.11” E) consists of the Oued Fodda Formation (Tchoumatchenco et al., 1995). It is located in the Kef Aïn El Hadjela locality (Kef = mound in Arabic language), 1.5 km southwest of the mining village of Bou Caïd, 5 km north of the Bordj Bou Naâma town and 2 km from the National Road no. 19 which connects the town of Chlef (formerly Orléansville) with that of Tissemsilt (formerly Vialar).

Figure 1 around here

3. Description of the studied section

The general lithostratigraphy of the Cretaceous succession in the Ouarsenis matches the subdivisions designated by Tchoumatchenco and Khrischev (1992) and Tchoumatchenco et al. (1995) that have subsequently been accepted by most investigators. The Lower Cretaceous strata exposed in the Kef Ain El Hadjela have been assigned to the Oued Fodda Formation (Tchoumatchenco et al., 1995). This formation is mainly composed of limestones and marly interbeds and can reach ca 108 m in thickness. It overlies the Ain El Hamra Formation (= 'ammonitico-rosso' facies, Oxfordian-Berriasian) through a gradual facies transition, and underlies, in abnormal contact, the El Malaab Formation (= 'flysch facies', Barremian-Albian) (Tchoumatchenco et al., 1995; Benyoucef, 2006; Cherif et al., 2021). Based on lithologic, palaeontologic, ichnologic, and stratonomical features, the Oued Fodda Formation is subdivided into four informal lithostratigraphic units, from base to top (Fig. 2):

Unit 1: marl-nodular limestone alternation (38 m)

This unit characterises the lower part of the Oued Fodda Formation. It is mostly composed of red, gray to bluish, nodular to wavy bedded (0.05-0.70 m-thick), micritic limestone, containing ammonites and belemnites, and interbedded with soft, reddish to greenish, marls. The top surface of the limestone bed is marked by asymmetrical ripple marks. The interbedded marls (0.20-1.10 m-thick) yielded planktonic foraminifers, pelagic crinoids, ophiuroids, calpionellids, and aptychi. Microfacies analysis documents a predominance of skeletal components, a lower occurrence of non-skeletal grains, and displays low diversity of wackestone and packstone-textured carbonates. The fossil allochems include thin-shelled bivalves (*Posidonomya*), calpionellids, planktonic foraminifers, and sections of saccocomids and ammonites.

Unit 2: marl-bioturbated limestone alternation (45 m)

This unit starts with a well-exposed, ammonite-rich, limestone bed (0.40 m) which can be followed by an alternation of soft, grey marls (0.20-1 m) with gray to blueish, centimetric, moderately to strongly bioturbated, limestone beds (0.10-0.30 m), containing abundant ammonites and belemnites (Fig. 3A). Bioturbation is mostly observed in cross-section and indicated by a general, non-homogenous fabric of burrows. It is composed of a dense network of *Zoophycos* (*Zoophycos brianteus*, *Zoophycos* aff. *cauda-galli*, and *Zoophycos* isp.), *Chondrites* (*Chondrites intricatus* and *Chondrites* isp.), *Thalassinoides*, *Ophiomorpha*, and *Planolites* (Fig. 3B-C). Microscopic analysis reveals a mudstone-wackestone texture including calpionellids, crinoids and thin-shelled bivalves. The marls contain planktonic foraminifers, crinoids, ophiuroids, and smooth ostracods.

Unit 3: marl-laminated limestone alternation (18 m)

This unit is composed of an alternation of grey marls (0.10-0.80 m-thick) and well-laminated, tabular, limestone beds (0.10-0.30 m-thick) frequently containing pyritic ammonites and belemnites (Fig. 3D-F). Subordinate taxa include gastropod and bivalve shells. Some limestone beds show trace fossils of *Chondrites* and *Zoophycos*.

Microscopic analysis documents a predominance of skeletal components, an absence of non-skeletal grains, and displays low diversity of mudstone and rare wackestone-textured limestone. The fossil allochems include molluscan debris (ammonites and bivalves), crinoids, radiolarian sections, and siliceous sponge spicules. The marl facies contains benthonic and planktonic foraminifers, and crinoids.

Unit 4: marl-massive limestone alternation (6 m)

With truncated top, this unit consists of alternating greenish marl (0.30-0.45 m-thick) and grey to blueish massive, slumped limestone beds (0.30-0.80 m-thick). The marl facies show microfaunistic content composed of pelagic crinoids, and benthonic and planktonic foraminifers. The dominant microfacies in this unit is micrite (mudstones) with radiolarian sections.

Figure 2 and 3 around here

4. Biostratigraphic assignments

The biostratigraphic assignment of the Oued Fodda Formation is based on our own collecting of ammonite shells and the biozonation established by Tchoumatchenco et al. (1995) and Cherif et al. (2021).

The Berriasian age was identified at the base of the section (Unit 1 and lower part of Unit 2), on the basis of an ammonite association composed of *Fauriella boissieri* (Pictet), *Berriasella* cf. *calisto* (d'Orbigny), *Lamellaptychus* sp., and *Berriasella* sp. The species *Fauriella boissieri* (Pictet) identified in the lower part of Unit 2 indicates a late Berriasian age.

The early Valanginian is defined by the first occurrence of the ammonite species *Thurmanniceras* cf. *pertransiens* (Sayn) and *Thurmanniceras* cf. *gratianopolitense* (Sayn) at the upper part of Unit 2. The early Valanginian age persists toward the topmost part of Unit 2 and is represented by an ammonite assemblage dominated by *Neolissoceras grasianum* (d'Orbigny), *Neocomites neocomiensiformis* (Uhlig), *Olcostephanus* aff. *tenuituberculatus* (Bulot), *Vergoliceras salinarium* (Uhlig), and *Kilianella roubaudiana* (d'Orbigny) (Cherif et al., 2021).

The first laminated limestone bed of Unit 3 is marked by the appearance of several ammonite species indicating the lowermost part of the upper Valanginian: *Saynoceras verrucosum* (d'Orbigny), *Saynoceras contestanum* (Company), *Karakaschiceras inostranzewi* (Karakasch), *Saynoceras verrucosum* (d'orbigny), *Neocomites neocomiensis* (d'Orbigny), and *Phylloceras (Hypophylloceras) tethys* (d'Orbigny). The lower part of Unit 4 is assigned to the upper Valanginian thanks to the presence of the ammonite species *Oosterella gaudryi* (Nickl).

5. Remark on the palaeoenvironment of the Ouarsenis Massif during the Berriasian and Valanginian times

The presence of an appreciable number of ammonites and pelagic microfauna (planktonic foraminifers, thin-shelled bivalves, calpionellids, and sponge spicules), the fine-grained muddy matrix, and the absence of high-energy hydrodynamic structures, all point to limited water movement in a distal depositional setting below storm wave base (SWB). *Zoophycos* and *Chondrites*, accompanied by other rare trace fossils (*Thalassinoides*, *Ophiomorpha*, and *Planolites*) are interpreted as the distal *Cruziana* ichnofacies, possibly transitional to the *Zoophycos* ichnofacies typical of the lower offshore zone (Cherif et al., 2021). This interpretation is also supported by the presence of pelagic crinoids: roveacrinids (Roveacrinida). As for the other crinoid groups, including the currently documented isocrinids (Isocrinida), in terms of palaeo-depth, they dominate in shallow environments. The sole exception being cyrtocrinids (Cyrtocrinida), that are ubiquitous and occur in both shallow (near shore and shallow marine) and slightly deeper (deeper sublittoral to open shelf) settings

(Salamon et al., 2021 and literature cited therein; see also Głuchowski, 1987; Zatoń et al., 2008; Zamora et al., 2018; Zamora and López-Horgue, 2022).

6. Material and methods

The crinoid collection from the Oued Fodda Formation of northern Algeria is housed at the University of Silesia in Katowice, Faculty of Natural Sciences, Institute of Earth Sciences, Poland, and acronymed under catalogue number: GIUS 8-3689/Hg.

In Kef Ain El Hadjela, the Oued Fodda Formation consists of marls and limestones. Sampling at a more or less close interval was carried out; loose samples (marls) had been soaked in water for several days, then washed on a series of sieves with decreasing mesh (300, 250, 180, 125 μm) under a strong jet of water. The retrieved residues from each sieve were dried, steamed and then sorted under a Euromex Dzet Optika ST-40-2L binocular loupe in order to identify their micropalaeontological content. As for hard samples, thin sections were processed for microfacial and microfaunal purposes.

Sorted crinoid specimens were fixed on studs using double-sided carbon adhesive tape and then metallised with a thin layer of gold (Cressington sputter coater 108 auto). They were then photographed with a scanning electron microscope (SEM) of the Zeiss DSM940a type, at the Jagiellonian University in Kraków (Poland).

7. Results

170 columnals and a dozen of radials and primibrachials belonging to isocrinids (Isocrinida), 3 cyrtocrinid (Cyrtocrinida) cups and 1 interradial projection, and more than 1,000 roveacrinid (Roveacrinida) ossicles, were collected. They were found in the following samples: AH15, AH21, AH24 (Berriasian), AH30, AH33, AH34, AH36, AH54, AH59 (Valanginian); for details see numbering on Fig. 2.

1) Sample AH15: *Balanocrinus* cf. *gillieroni*, *Percevalicrinus aldingeri*, *Isocrinus*? *lissajouxi*, roveacrinids;
2) Sample AH21: *Percevalicrinus aldingeri*;
3) Sample AH24: *Phyllocrinus* sp.;
4) Sample AH30: *Percevalicrinus aldingeri*, roveacrinids;
5) Sample AH33: *Balanocrinus* cf. *gillieroni*, *Percevalicrinus aldingeri*, *Isocrinus*? *lissajouxi*, roveacrinids;

6) Sample AH34: *Balanocrinus* cf. *gillieroni*, *Percevalicrinus aldingeri*, *Isocrinus*? *lissajouxi*, *Hemibrachiocrinus* sp., roveacrinids;
7) Sample AH36: *Percevalicrinus aldingeri*, *Phyllocrinus* sp.;
8) Sample AH 54: *Percevalicrinus aldingeri*;
9) Sample AH59: *Percevalicrinus aldingeri*, *Isocrinus*? *lissajouxi*, roveacrinids.

8. Systematic palaeontology

Systematics of crinoids follows the schemes proposed by Hess and Messing (2011).

Order Isocrinida Sieverts-Doreck, 1952

Suborder Isocrinina Sieverts-Doreck, 1952

Family Isocrinidae Gislén, 1924

Subfamily Balanocrininae Roux, 1981

Genus *Balanocrinus* Agassiz, in Desor, 1845

Type species. *Pentacrinites subteres* Münster, in Goldfuss, 1831 [in 1826-1844].

Balanocrinus cf. *gillieroni* (de Loriol, 1879)

Fig. 4D-F

1879. *Pentacrinus Gillieroni* de Loriol, p. 183, pl. 18, fig. 3.

Material: 34 nodal columnals and pluricolumnals.
Repository: Laboratory of Palaeontology and Stratigraphy of the University of Silesia in Katowice, Poland, and acronymed with catalogue number: GIUS 8-3689/Hg.
Description: Columnals are circular to (sub-) pentagonal in outline. Articular facets are flat. Petal floors are moderately large, triangular or ellipsoidal. Petal floors are separated with

adradial crenulae belts consisting of two parallel systems of minute tubercles. Marginal crenulae are of equal size; max. 8 crenulae per petal. Lateral surface is smooth and slightly concave. Lumen is small and circular.

Discussion: The Cretaceous occurrences of *Balanocrinus* make this genus the longest-ranged of all isocrinids, with the earliest proven record in the Early Jurassic (Simms, 1989). Two taxa of balanocrinids (*B. gillieroni* and *B. infrasilvensis*) are known from Valanginian sediments. The first one was mentioned by Rasmussen (1961) in the lower Valanginian of Switzerland; the other from the Neocomian of Switzerland. Klikushin (1992) also mentioned *B. gillieroni* from the Berriasian of Crimea. Rasmussen (1961) mentioned two more Cretaceous taxa (Santonian *B.*? *senonensis* and Cenomanian *B.*? *valettei*). They all were documented from isolated skeletal remains, and new taxa established based on the differences evidenced in the morphological structure of the columnals. The youngest finds of balanocrinids are reported from the Albian of England (Hess and Gale, 2010) and the Coniacian of Poland (Niedźwiedzki and Salamon, 2005), *B. smithi* and *Balanocrinus* sp. respectively.

The specimens collected in the present study resemble Jurassic-Cretaceous *B. gillieroni* with its circular and/or (sub-)pentagonal and smooth columnals, articular facets of which are covered by rather uniform crenullae surrounding distinct, triangular or ellipsoidal, petal floors (see de Loriol, 1879, pl. 18, fig. 3; Klikushin, 1982, pl. 2, figs. 3, 4; Rasmussen, 1961, pl. 9, fig. 3). In the case of the second taxon reported from the Valanginian of Switzerland, *B. infrasilvensis*, columnals are pentagonal to pentalobate, and their petal floors are covered by distinctly thicker crenullae than those of of *B. gillieroni* (see Ooster, 1865, pl. 2, figs. 18, 19; Rasmussen, 1961, pl. 9, fig. 2).

Distribution: Lower Cretaceous (Berriasian-Valanginian) of Africa (Algeria) and Europe (Switzerland, Ukraine - Crimea).

Genus *Percevalicrinus* Klikushin, 1977

Type species. *Picteticrinus beaugrani* de Loriol, in de Loriol and Pellat, 1875, p. 298.

Percevalicrinus aldingeri Klikushin, 1979

Fig. 5A-N

1992. *Percevalicrinus aldingeri* Klikushin, p. 94, drawing no. 103a, Pl. 7, Fig. 4-6.

Material: 112 columnals and pluricolumnals; a dozen of isolated cup remains including radials and primibrachials.

Repository: Laboratory of Palaeontology and Stratigraphy of the University of Silesia in Katowice, Poland, and acronymed with catalogue number: GIUS 8-3689/Hg.

Description: Distalmost juvenile columnals are extremely high, three to five times higher than wide. They are circular or pentagonal in outline. Medial and most proximal juvenile columnals are pentagonal and (sub-)stellate in outline. Their articular surface is covered with max. 16, rather short and thick, crenulae. Distalmost adult columnals are circular in outline and as tall as wide. Their articular surface is covered with max. 16, short and thick crenulae. Medial and proximal, adult columnals are pentagonal to (sub-)stellate and covered with varied crenulae. They may be short and thick, but, in the case of most proximal specimens, they are longer and thicker. Sometimes they form large petal floors. Petal floors are triangular and separated one from another with thin, adradial crenulae belts consisting of two parallel systems of minute tubercles. Marginal crenulae are nearly equal in size. Nodal columnals are very high. Cirrus scars are placed in the lower part of nodals. Cirrus scars are small- to medium-sized, they are directed obliquely upwards. Some cirrus scars are strongly depressed. Lumen of all columnals is small and circular. A series of internodals demonstrates a continuous passage of facets with strong marginal crenulae which are separate and have granulose radial bands to bifurcate fused radial crenulae to radial zones with one or two additional fused, bifurcate crenulae. Lateral surfaces of almost all columnals are smooth. However, there are some with very distinct keels composed of tubercles, bumps and fine spikes. The longest pluricolumnal found has four internodals and one nodal. It evidences that the noditaxis must have had at least six columnals. Radials are smooth with two relatively large oblique facets. Radial proximal side is covered with two distinctly small facets to the basals. Distal facet is wide and possesses two distinct near the lateral-oral margin. The interarticular ligament fossae and the adoral muscle fossae are distinct and wide. The ridges between the interarticular ligament fossae and the adoral muscle fossae are nearly parallel to the transverse ridge. Primibrachials are smooth and relatively low. They are triangular in aboral projection. The proximal facet is an embayed synarthry with weak fulcral ridge, and bifurcated near the aboral margin. Interarticular ligament fossae and the adoral muscle fossae are weakly developed. The adoral grooves are rather deep.

Discussion: According to Klikushin (1992), the genus *Percevalicrinus* includes five species [*P. aldingeri* Klikushin, 1979; *P. asteriscus* (Meek and Hayden, 1859); *P. beaugrandti* (de Loriol and Pellat, 1875); *P. inderensis* Kliksuhin, 1981; and *P. tenellus* (Eichwald, 1868)]. Among these, only *P. aldingeri* is known from the Valanginian. The others are reported from Upper Jurassic (Portlandian) of North America and Europe. The only exception known from the Berriasian is *P. tenellus* as the only one listed from the Boreal Province (Greenland, Norway - Spitzbergen). This form was incorporated by Rasmussen (1961) and Jäger (1981a) into *Neocrinus* and by Jäger (1981b, c) and Rasmussen (1978) into *Chladocrinus*; however, according to Klikushin (1992, p. 95; see also Klikushin, 1982, pl. 2, figs.7, 8), the genus *Percevalicrinus* strongly differs from representatives of the genera *Neocrinus* and *Chladocrinus*.

Jäger (2010) included columnals having strongly ornamented lateral surfaces (see pl. 3, fig. 3a in Jäger, 2010) into *Percevalicrinus* sp. We have done likewise. Pentagonal and subpentagonal columnals with very distinct keel composed of tubercles, bumps and fine spikes (Fig. 4L) were included to this taxon. It is possible, however, that this type of columnals belongs to another isocrinid, which was also pointed out by Jäger (2010), this latter also mentioned smaller individuals that some specimens: "... listed under *Isocrinus*? *bleytonensis* might belong to *Percevalicrinus* sp. in fact". Klikushin (1992, pl. 7, figs. 4, 5) illustrated the medial and proximal parts of the stem of *P. aldingeri*, columnals of which have straight and smooth lateral surfaces. In the case of the proximalmost part of the stem, the columnals become much lower, but still no obvious keel is visible.

Distribution: Lower Cretaceous (Valanginian) of Africa (Algeria), Europe (England, Germany, Russia) and North America (Greenland).

Subfamily Isocrininae Gislén, 1924

Genus *Isocrinus* von Meyer, in Agassiz, 1836.

Type species. *Isocrinites pendulus* von Meyer, 1836, p. 57.

Isocrinus? *lissajouxi* (de Loriol, 1904)

Fig. 4A-C

1904. *Pentacrinus lissajouxi* de Loriol, p. 63, pl. 4, fig. 22.

Material: 24 columnals and pluricolumnals.
Repository: Laboratory of Palaeontology and Stratigraphy of the University of Silesia in Katowice, Poland, and acronymed with catalogue number: GIUS 8-3689/Hg.
Description: Internodal columnals are pentalobate to (sub-)stellate in outline. Nodal columnals are stellate; they are distinctly taller and wider than internodals. Articulation between nodals and infranodals is smooth and synostosial. Articular facets are flat. Petal floors are relatively small, drop-like or ellipsoidal. Petal floors are separated with adradial crenulae belts consisting of two parallel systems of minute tubercles in number of 4 to 6. Marginal crenulae in number of 10-16 are thick and of equal size. Latera is covered with thickening that may be continuous in form of horizontal ridge, sometimes consisting of rounded tubercles or fine spikes. Cirrus sockets in nodals are elliptical, sometimes circular with a slightly protruding edge. Cirrus sockets are directed outwards and cover the full nodal height. Articular ridge possesses tubercles at the ends. Lumen is small and circular.
Discussion: Jäger (2010), based on a very rich material from the Barremian (Lower Cretaceous) of Serre de Bleyton (France), distinguished *Isocrinus*? *bleytonensis*. He added that this taxon is closest to *Isocrinus*? *lissajouxi*. In his opinion, however, in *Isocrinus*? *bleytonensis* the columnals are larger in diameter and comparatively lower, the difference in diameter between nodals and internodals is larger, the horizontal ridge on the latera is stronger, and the noditaxes (4–8 in fully-grown columns) are slightly shorter than in *I.*? *lissajouxi* (5-9). It is possible that currently some of the remains should be associated with the species distinguished by Jäger (2010), but the small amount of research material does not allow to find significant differences in their diameters and the probable occurrence of shorter noditaxes in some of them.

Distribution: Lower Cretaceous (Valanginian-Hauterivian) of Africa (Algeria) and Europe (France, Switzerland).

Order Cyrtocrinida Sieverts-Doreck, in Moore, Lalicker and Fischer, 1952

Suborder Cyrtocrinina Sieverts-Doreck, 1952

Superfamily Eugeniacrinitoidea Roemer, in Bronn and Roemer, 1856

Family Phyllocrinidae Jaekel, 1907

Genus *Phyllocrinus* d'Orbigny, 1850, in [1850-1852]

Type species. *Phyllocrinus malbosianus* d'Orbigny, 1850, in [1850-1852], p. 110.

Phyllocrinus sp.

Fig. 4H, I

Material: 2 incomplete cups and 1 interradial projection.

Repository: Laboratory of Palaeontology and Stratigraphy of the University of Silesia in Katowice, Poland, and acronymed with catalogue number: GIUS 8-3689/Hg.

Description: Cups are small and pentagonal in outline. They display short interradial processes that are triangular in outline. Radial articular facets are small, low, with a flat triangular surface. Radials display a protruding central part and two lateral portions running inwards. Radial cavity is slightly pentagonal, wide and moderately deep. Cups are narrow at their lower part and gradually expanding up to radial facets. Suture lines are not visible. Facet to stem is small and distinctly pentagonal.

Discussion: The genus *Phyllocrinus* includes almost 30 species (see Dumortier, 1871; Spenden, 1959; Rasmussen, 1961; Arendt, 1974; Manni et al., 1992; Salamon, 2008; Salamon and Gorzelak, 2010; Hess and Messing, 2011). All later authors pointed out that phyllocrinids are, in principle, only found in Europe [Albania, Austria, Czech Republic, France, Hungary, Italy, Poland, Portugal, Romania, Slovakia, Spain, Switzerland, and Ukraine (Crimea)]. There are two non-European occurrences of phyllocrinids. The first is *Phyllocrinus furcillatus* Spenden from the middle Kimmeridgian of Kawhia, New Zealand (Spenden, 1959) and the second, *Apsidocrinus* sp. (apsidocrinids are classified as plyllocrinids), from the lower Albian of Madagascar; however, the latter one will be published elsewhere. Manni et al. (1992) classified a small phyllocrinid from the Upper Jurassic sediments of the Bakony Mountains, Hungary, as *Phyllocrinus furcillatus*. They added that this taxon includes closely related taxa that are morphologically inseparable forms probably representing a lineage. The synonymy of *P. furcillatus* includes forms reported from the Czech Republic, Poland, Slovakia, and Ukraine, and previously belonging to *P. belbekensis* or *P. pieninensis* (Arendt, 1974; Pisera and Dzik, 1979; Głuchowski, 1987). Manni et al. (1992) concluded that *P. furcillatus* is a cosmopolitan and long-range taxon (widespread from the Bajocian to the Valanginian and from the easternmost Pacific to Europe) and therefore does not represent a biological species. We disagree with the determination of Manni et al. (1992), because the specimens they considered are very distinct from *P. furcillatus*. The Hungarian specimens are very small and their interradial projections are massive and short (comp. pl. 3, fig. 3 in Manni et al., 1992). The cup of *P. furcillatus* is tall and, most importantly, its interradial projections are long, slender and very clearly bending towards the radial cavity (comp. e.g., pl. 20, fig. 2, 4 in Spenden, 1959). Due to their strong morphological similarities, Hungarian specimens should be associated with *P. belbekensis*, originally described from the Lower Cretaceous valley of the Belbek River in Crimea (Arendt, 1974, fig. 1-21). It is very likely that specimens originating in Algeria, though partly preserved, should be associated with this taxon.

Distribution: Middle Jurassic (Bajocian) - Lower Cretaceous (Barremian) of Africa (Algeria), Australia and Oceania (New Zealand) and Europe (Albania, Austria, Czech Republic, France, Hungary, Italy, Poland, Portugal, Romania, Slovakia, Spain, Switzerland, and Ukraine - Crimea).

Suborder Holopodina Arendt, 1974

Family Hemibrachiocrinidae Arendt, 1968

Genus *Hemibrachiocrinus* Arendt, 1968

Type species. *Hemibrachiocrinus manesterensis* (=*Dibrachiocrinus* Arendt) Arendt, 1968, p. 156.

Hemibrachiocrinus sp.

Fig. 4G

Material: 1 cup.

Repository: Laboratory of Palaeontology and Stratigraphy of the University of Silesia in Katowice, Poland, and acronymed with catalogue number: GIUS 8-3689/Hg.

Description: Cup is smooth, fused with the basal part and pentagonal in outline. Radial cavity is relatively wide and deep. Radial facets in number of 5. 3 of them are of similar size. They are positioned one next to another. Two radial facets lying one by one are distinctly smaller. The attachment is flat and circularly elongated.

For detailed discussion see Krajewski et al., 2020.

Distribution: Lower Cretaceous (Berriasian-Barremian) of Africa (Algeria) and Europe (Czech Republic, Ukraine - Crimea).

Order Roveacrinida Sieverts-Doreck, in Ubaghs, 1953

Family Roveacrinidae Peck, 1943

Gen. indet. sp. indet.

Fig. 6A-K

Material. More than 1,000 ossicles.

Repository: Laboratory of Palaeontology and Stratigraphy of the University of Silesia in Katowice, Poland, and acronymed with catalogue number: GIUS 8-3689/Hg.

Description: The broken theca (three connected radial plates, Fig. 6K) displays a rather short outline, its surface being rather smooth with minute radial articular facets and small rounded apical horn. The second primibrachial plate IBr2 (Fig. 6J), though broken on its borders, is wider than high, with medium-size radial flanges and small articular facets. The second secundibrachial plates IIBr2 (Fig. 6F-H) bear a finely reticulated ornamentation on its outer side (Fig. 6F); some specimens display a faint radial keel (Fig. 6G); the proximal articular facet is elongated with an oval articular pit; the distal articular facet is semi-crescentic with a small, shallow and slightly oval articular pit. The brachial plates NBrn (Fig. 6A-E) are rather short (proximal brachial plates being longer than distal ones), covered by a finely reticulated, even pitted, ornamentation and bearing a faint, slightly spinose, radial keel on its outer radial edge; their articular facets are shallow and minute. Some distal brachial plates bear a dichotomous distal end (Fig. 6E) with a finely elongated reticulation pattern.

Discussion: The material at hand collected in the Oued Fodda Formation clearly displays the morphological features of the family Roveacrinidae. Compared to the glut of brachial ossicles of a single individual, thecal remains are rather scarce and bear minimal ornamentation as pitted, finely corrugated surfaces. They appear as simple, less exuberant roveacrinid specimens with small articular facets and ‘reduced’ radial ornamentation. These remains constitute a most valuable bio-stratigraphic and taxonomic milestone bridging the gap between the Late Jurassic saccocomid representatives from Germany (Hess, 2002), the saccocomid microfacies from the Upper Jurassic-Lower Cretaceous of southern France (Turner, 1965), the non-illustrated roveacrinoidal references from Algeria (unpublished oil-exploration in-house reports), the holotype of *Roveacrinus berthoui* Ferré & Granier, 2000 from the Hauterivian microfacies of Spain (Ferré & Granier, 1997, 2000), and the first isolated ossicles from the Albian Shenley Limestone (Gale & Hess, 2010). Bed-by-bed study of retrieved isolated material is required to perform a complete reconstruction of specimens from dissociated ossicles and sound taxonomic assessment.

Distribution: Lower Cretaceous (Uppermost Berriasian) of Algeria.

9. Discussion and concluding remarks

In shallow marine Lower Cretaceous (Berriasian – Barremian) deposits of European Tethys, crinoids are abundant and, at least locally, highly diversified. The most common are Berriasian – Barremian sections of central and eastern Europe (Czech Republic, Poland, Ukraine - Crimea) dominated by cyrtocrinids, but also include isocrinids and much more rarely comatulids (excluding stalked thiolliericrinids; Thiolliericrinidae); Žítt, 1973, 1974, 1975, 1978, 1979a, b, 1982, 1983; Arendt, 1974; Głuchowski, 1987; Hess et al., 2011. True stalked comatulids (thiolliericrinids) are known from few Jurassic (Oxfordian) – Cretaceous (Hauterivian) localities, but the most famous was described by Klikushin (1987) from Berriasian and Valanginian of Crimea. The diversified thiolliericrinid assemblage was accompanied by rare fragments of isocrinids [“*Isocrinus*” *arzierensis* (de Loriol)] and millericrinids (Millericrinida; *Apiocrinites*). Barremian assemblage from the Serre de Bleyton, France, presented by Jäger (2010), was quite different. It was dominated by comatulids and isocrinids, with small involvement of millericrinids. The latter author added that the high percentage of new species in this locality is mainly due to the fact that the Barremian fauna fills a stratigraphic gap from which only very few crinoids have so far been described. Apart from some Hauterivian crinoids the stratigraphically closest crinoid-rich localities to the Serre de Bleyton are known from the Valanginian of France, Spain, Switzerland and epicratonic Poland (e.g., Rasmussen, 1961 and literature cited therein; Salamon, 2009; Jäger, 2010; Hess and Messing, 2011). Jäger (2010), also citing data by e.g., Rasmussen, 1961, 1978; Simms, 1988; Klikushin, 1992; Hess and Messing, 2011, concluded that the Barremian crinoid fauna fits well into the overall faunal composition known from Late Jurassic to other Early Cretaceous sites. In his opinion there is a qualitative change among isocrinids and a shift from Isocrindiae to Cainocrinidae; the growing importance of comatulids; a gradual change from Solanocrinitoidea to Notocrinoidea within comatulids; presence of millericrinids (Apiocrinitidae), but with a clear decrease in their number and size. This scenario does not work for crinoids from the Early Cretaceous of southern margin of Tethys (Algeria). The samples are dominated by free-swimming roveacrinids and isocrinids accompanied by cyrtocrinids. The presence of comatulids or millericrinids has not been reported here. Additionally, among the isocrinids, the most numerous are the representatives of Isocrinina and Balanocrininae, and the most numerous among them is *Percevalicrinus*. The flaw of this pattern is even more clearly visible in the case of crinoids known from the sediments of the upper part of the Lower Cretaceous. Hess and Gale (2010) listed in Albian Shenley Limestone of UK, isocrinids from Isocrininae and Balanocrininae and without Cainocrinidae, millericrinids, relatively numerous cyrtocrinids and single roveacrinids. On the other hand, Zamora and López-Horgue (2022), illustrated undoubted representatives of Cainocrinidae from northeastern Spanish upper Albian succession. Specimen shown in fig. 5g-h by Zamora and López-Horgue (2022) and described by them as *Isocrinus*? sp. certainly must be associated with *Nielsenicrinus*. These crinoids were accompanied by the cyrtocrinid *Proholopus holopiformis* (Remeš, 1902). Moreover, in older work, Zamora et al. (2018) from another Spanish Forcall Formation, Aptian, indicated the presence of numerous comatulids which likely lived in dense aggregations on muddy substrates within the outer ramp and classified as *Decameros*. Interestingly, *Decameros* belongs to the Solanocrinitoidea, and other comatulids coexisting here include *Atopocrinus* (unknown superfamily), *Eudiocrinus* (Mariametroidea), Pentametrocrinidae, and other Decameridae.

Concerning the roveacrinoid ossicles, their mention in Algeria is from now on illustrated and no more restricted to grey literature and in-house reports. The material herein briefly described consists in a major milestone bridging the stratigraphic gap between the classical Late Jurassic saccocomids (see Hess, 2002) and their Cretaceous relatives, namely the isolated occurrence of *R. berthoui* from the Lower Hauterivian of Spain (Ferré and Granier, 1997) and the first “mass” occurrence of Roveacrinidae from the lower Albian of northern Europe and northern Africa (Ferré et al., 2016, 2017; Gale, 2020). However these roveacrinoids are indeed genuine Roveacrinidae but do not allow us to draw any conclusion as to their date of origination from the saccocomid stock. Further material is now required to precise their morphological reconstruction (especially thecae) and to refine taxonomic assignment and phylogeny.

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Figure captions:

Fig. 1. Geographic and geologic framework of the studied area. **A**. Western Mediterranean Alpine belts, including the Tell domain. **B**. Betic-Maghrebian chain (modified from Chalouan et al., 2008) with location of the Ouarsenis massif. **C**. Simplified geographical map of the Ouarsenis area showing the location of the studied section.

Fig. 1. Schéma géographique et géologique de la région d'étude. **A**. Chaînes alpines méditerranéennes occidentales comprenant le domaine du Tell. **B**. Chaîne bétique-maghrébine (modifié d'après Chalouan et al., 2008) et localisation du massif de l'Ouarsenis. **C**. Carte géographique simplifiée de la région de l'Ouarsenis montrant la position de la coupe étudiée.

Fig. 2. The Berriasian-Valanginian succession of the Kef Ain El Hadjela area. **A.** Measured stratigraphic section of the Kef Ain El Hadjela showing the distribution of some index ammonite species and the studied crinoids. **B**. Panoramic view of the Kef Ain El Hadjela showing the position of some marl samples.

Fig. 2. La succession du Berriasien-Valanginien de Kef Ain El Hadjela. **A**. Coupe lithostratigraphique de Kef Ain El Hadjela montrant la répartition verticale de quelques espèces-indices d'ammonites et des crinoïdes étudiés. **B**. Vue panoramique de Kef Ain El Hadjela montrant la position de certains échantillons marneux.

Fig. 3. Field photographs of the Oued Fodda Formation in the Ain El Hadjela section. **A**. Panoramic views showing an alternation of gray marls and massive limestones (Unit 2). **B**. Limestone bed (Unit 2) including a well-preserved *Zoophycos brianteus* Massalongo and ammonite mineralised with limonite (white arrow). **C**. Limestone bed (Unit 2) showing a dense network of *Chondrites intricatus* (Brongniart). **D**. Outcrop pictures showing an alternation of gray marls and laminated limestone beds (Unit 3). **E-F**. Laminated limestone beds (Unité 3) including pyritized ammonites (white arrows) and belemnite rostra (black arrows).

Fig. 3. Photos de terrain de la Formation d'Oued Fodda à Kef Ain El Hadjela. **A**. Vue panoramique montrant une alternance de marnes grises avec des bancs calcaires massifs (Unité 2). **B**. Banc calcaire renfermant une trace de *Zoophycos brianteus* Massalongo bien conservée et d'une ammonite minéralisée par de la limonite (flèche blanche). **C**. Banc calcaire (Unité 2) montrant un réseau dense de *Chondrites intricatus* (Brongniart). **D**. Photos de terrain montrant une alternance de marnes grises avec des bancs calcaires laminées (Unité 3). **E-F**. Bancs calcaires laminées (Unité 3) renfermant des ammonites pyriteuses (flèches blanches) et des rostres de bélemnites (flèches noires).

Fig. 4. Berriasian and Valanginian crinoids from the Ouarsenis Massif (Algeria). Repository number: GIUS 8-3689/Hg. Scale bar equals 1 mm. **A-C.** *Isocrinus*? *lissajouxi* (de Loriol, 1904), columnals, articular faces. **D-F.** *Balanocrinus* cf. *gillieroni* (de Loriol, 1879), latera of pluri-columnal (D) and columnals, medial (E), distal (F). **G.** *Hemibrachiocrinus* sp., cup, distal view. **H, I.** *Phyllocrinus* sp., cups, lateral (H) and proximal (I) view.

Fig. 4. Crinoïdes du Berriasien et du Valanginien du massif de l'Ouarsenis (Algérie). Numéro de dépôt : GIUS 8-3689/Hg. Barre d'échelle : 1 mm. **A-C.** *Isocrinus*? *lissajouxi* (de Loriol, 1904), columnales, facettes articulaires. **D-F.** *Balanocrinus* cf. *gillieroni* (de Loriol, 1879), vues latérales de pluri-columnales (D) et de columnales, médiane (E), distale (F). **G.** *Hemibrachiocrinus* sp., thèque, vue distale. **H, I.** *Phyllocrinus* sp., thèques, vues latérale (H) et proximale (I).

Fig. 5. Berriasian and Valanginian *Percevalicrinus aldingeri* Klikushin, 1979, from the Ouarsenis Massif (Algeria). Repository number: GIUS 8-3689/Hg. Scale bar equals 1 mm. **A.** juvenile pluri-columnal, lateral view. **B.** juvenile distal columnal, lateral view. **C-E.** distal columnals, lateral views. **F.** juvenile columnal, articular face. **G, K.** nodal columnal, lateral view. **H.** juvenile nodal columnal, lateral view. **I.** medial/proximal columnal, articular face. **J.** juvenile columnal, oblique view. **L.** proximal columnal, articular face. **M.** radial, distal facet. **N.** primibrachial, proximal view.

Fig. 5. *Percevalicrinus aldingeri* Klikushin, 1979, du Berriasien et du Valanginien du massif de l'Ouarsenis Massif (Algérie). Numéro de dépôt : GIUS 8-3689/Hg. Barre d'échelle : 1 mm. **A.** Pluri-columnale juvénile, vue latérale. **B.** Columnale distale juvénile, vue latérale. **C-E.** Columnales distales, vues latérales. **F.** Columnale juvénile, facette articulaire. **G, K.** Columnale nodale, vue latérale. **H.** Columnale nodale juvénile, vue latérale. **I.** Columnale médiane/proximale, facette articulaire. **J.** Columnale juvénile, vue oblique. **L.** Columnale proximale, facette articulaire. **M.** Radiale, facette distale. **N.** Primibrachiale, vue proximale.

Fig. 6. Berriasian and Valanginian Roveacrinidae, gen. indet sp. indet., from the Ouarsenis Massif (Algeria). Repository number: GIUS 8-3689/Hg. Scale bar equals 1 mm. **A-C.** proximal brachial plates (NBrn); **A.** relic of spinose radial keel on outer side, outer view. **B.** lateral view; **C.** lateral-slightly tilted inner view. **D.** distal brachial plate (NBrn), lateral view. **E.** tertibrachial plate (NBrn) with dichotomous distal articulation, outer lateral view. **F-G.** second secundibrachial plate (IIBr2); **F.** distal articular facet, slightly tilted outer view; **G.** distal articular facet, oblique view; **H.** proximal articular facet, lower view. **I.** ?broken theca, outer view, **J.** second primibrachial plate, outer view; **K.** broken theca (three radial plates), ventral cavity, upper view.

Fig. 6. Roveacrinidae, gen. indet sp. indet., berriasiens et valanginiens du massif de l'Ouarsenis (Algérie). Numéro de dépôt : GIUS 8-3689/Hg. Barre d'échelle : 1 mm. A-C. pièces brachiales proximales (NBrn); A. trace de carène radiale épineuse à la face externe, vue externe. B. vue latérale; C. vue latérale interne légèrement basculée. D. pièce brachiale distale (NBrn), vue latérale. E. pièce tertibrachiale (NBrn) avec une articulation distale dichotome, vue latérale externe. F-G. seconde secondibrachiale (IIBr2); F. facette articualaire distale, vue externe légèrement basculée; G. facette articulaire distale, vue oblique; H. facette articulaire proximale, vue inférieure. I. ? thèque brisée, vue externe, J. seconde

primibrachiale, vue externe; K. ? thèque brisée (trois pièces radiales connectées), cavité ventrale, vue supérieure.