

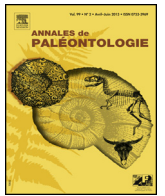


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Original article

Roveacrinids (Crinoidea, Roveacrinida) from the Cenomanian–Turonian of southwest Algeria (Saharan Atlas and Guir Basin)



Ossicules de rovéacrinides (Crinoidea, Roveacrinida) céno-mano-turonien du sud-ouest algérien (Atlas saharien et Bassin du Guir)

Bruno Ferré^{a,*}, Kaddour Mebarki^b, Madani Benyoucef^c, Loïc Villier^d, Luc Georges Bulot^{e,f}, Delphine Desmares^d, Houcine Boumediène Benachour^{f,g}, Lionel Marie^e, Jacques Sauvagnat^h, Mustapha Bensalah^b, Djamila Zaoui^b, Mohammed Adaci^b

^a Dame du Lac 213, 3, rue Henri-Barbusse, F-76300 Sotteville-lès-Rouen, France

^b Laboratoire de recherche n° 25, Université Abou-Bekr-Belkaid, DZ-13000 Tlemcen, Algeria

^c Faculté des sciences de la nature et de la vie, université de Mascara, DZ-29000 Mascara, Algeria

^d MNHN-UPMC-CNRS, UMR 7207 (CR2P), Sorbonne universités, UPMC (University Paris VI), Tour 46–56, 5^e, case 104, 4, place Jussieu, F-75252 Paris cedex 05, France

^e CEREGE UMR34, CNRS (UMR 7330)–IRD (UMR 161)–Collège de France–USC INRA, OSU-Institut Pythéas, Aix-Marseille université, centre Saint-Charles, case 67, 3, place Victor-Hugo, F-13331 Marseille cedex 03, France

^f NARG, School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Williamson Building, Oxford Road, Manchester M13 9PL, United Kingdom

^g Faculté de génie civil et d'architecture, université de Chlef, DZ-02000 Chlef, Algeria

^h 238, route de Bellevue, F-74160 Bossey, France

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ABSTRACT

In the southwestern part of Algeria, the Cenomanian–Turonian marine deposits build up a prominent ledge in a perched syncline (Ksour Mountains, western Saharan Atlas) or at high radius of curvature (Guir Basin). The petrographical analysis of the Cenomanian–Turonian deposits of the Ksour Mountains and of the Guir Basin reveals unexpected assemblages of roveacrinoid ossicles comparable with those formerly reported from the Tinrhert area. For the first time, isolated ossicles of genuine and undisputable Roveacrinidae are illustrated. Three sections, Djebel Rhoundjaia (western Saharan Atlas), Berridel and Kénadsa (Guir Basin), were scrutinized to recognize the microcrinoid sections within the carbonate microfacies and to compile the successive occurrence of respective roveacrinid taxa (besides the classical search for standard index microfossils) in an attempt to pinpoint more precisely the position of the Cenomanian–Turonian boundary (C/T B). These assemblages are particularly morphologically and taxonomically diverse with three species of genus *Roveacrinus* and one of genus *Orthogonocrinus*. The presence of Saccocomidae (*Applinocrinus*) is especially unusual in such stratigraphic levels. The relative abundance and diversity of Roveacrinidae evidence a peak when approaching the C/T B. Such an event is recurring in the latest Cenomanian in various Tethyan and Atlantic areas. These fluctuations are consistent with a high surface-water productivity just before the C/T B.

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* Corresponding author.

E-mail addresses: bruno_ferre@yahoo.fr (B. Ferré), mebarki.kad@gmail.com (K. Mebarki), benyoucefmada@gmail.com (M. Benyoucef), loic.villier@upmc.fr (L. Villier), bulot@cerge.fr (L.G. Bulot), delphine.desmares@upmc.fr (D. Desmares), benachour.hb@live.fr (H.B. Benachour), jsauvagnat@ebogri.com (J. Sauvagnat), mus.bensalah@yahoo.fr (M. Bensalah), djm.zaoui@yahoo.fr (D. Zaoui), m.adaci@yahoo.fr (M. Adaci).

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Dans la partie sud-occidentale de l'Algérie, les dépôts cénomano-turonien dessinent une barre carbonatée massive au sein de synclinaux perchés (Monts des Ksour, Atlas saharién occidental) ou à grand rayon de courbure (Bassin du Guir). L'analyse pétrographique des sédiments cénomano-turonien des Monts des Ksour et du Bassin du Guir révèle des assemblages remarquables d'ossicules de roveacrinoides comparables à ceux déjà rapportés dans la région de Tinrhert. Pour la première fois, sont figurés de manière indiscutable des ossicules de crinoïdes pélagiques. Trois coupes, Djebel Rhoundjaïa (Atlas saharién occidental), Berridel et Kénadsa (Bassin du Guir), furent inspectées en détail afin d'identifier les sections de microcrinoïdes au sein des microfaciès carbonatés et d'évaluer l'extension stratigraphique des différents taxa roveacrinoidiques (parallèlement à la recherche des marqueurs indices classiques) dans une tentative de positionner plus précisément la limite Cénomanién-Turonien. Les assemblages sont particulièrement diversifiés morphologiquement et taxonomiquement avec trois espèces du genre *Roveacrinus* et une d'*Orthogonocrinus*. La présence de Saccocomidae (*Applinocrinus*) est particulièrement inhabituelle dans ces niveaux stratigraphiques. L'abondance relative et la diversité des Roveacrinidae montrent un pic à l'approche de la limite Cénomanién-Turonien. Ce type d'événement se retrouve dans le Cénomanién terminal de nombreuses régions téthysiennes et atlantiques. Elles sont cohérentes avec un événement de haute productivité des eaux de surface précédant la limite Cénomanién-Turonien.

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1. Introduction

Upper Cretaceous sedimentary rocks are outcropping extensively over Northern Africa, as the former southern margin of the Tethys Ocean washing ashore the Precambrian African Craton. Whereas Morocco was extensively explored over the last half century, Northern Algeria did not draw much the attention of field geologists: only a limited number of recent studies (Grosheny et al., 2008 for the eastern part of the Saharan Atlas, Mebarki et al., 2016a, 2016b for the Ksour Mountains, Amédro et al., 1996; Busson et al., 1999; Grosheny et al., 2013; Zaoui et al., 2016; and Ferré et al., 2016 for the Tinrhert Basin, and Benyoucef and Meister, 2015; and Benyoucef et al., 2016 for the Guir Basin¹) did focus on the litho-, biostratigraphy and sedimentological evolution of southern Algeria during the Late Cretaceous times.

In the Ksour Mountains (western part of the Saharan Atlas) and the Guir Basin, the early Late Cretaceous deposits document a marine platform setting of the North African passive margin that was connected to the Tethys Ocean to the North and bordered by the Saharan Craton uplands to the South. They are subdivided into three lithostratigraphic units, from older to younger in the Ksour Mountains:

- the early Cenomanian mixed siliciclastic-carbonated El Rhelida Formation;
- the early to middle Cenomanian marly-evaporitic Mdaouer Formation;
- and the late Cenomanian to Turonian marly-carbonated Rhoundjaïa Formation (Bassoullet, 1973)^{2,3}.

In the Guir Basin:

- the early Cenomanian detrital “Grès rouges” Formation;
- the early to middle Cenomanian marly-evaporitic “Argiles à gypse inférieures” Formation;

- and the late Cenomanian to Turonian “Calcaires de Sidi Mohamed Ben Bouziane” Formation (Benyoucef and Meister, 2015; Benyoucef et al., 2016).

The scope of the present paper is to document and illustrate new microfacies evidence of isolated roveacrinoid ossicles from the Cenomanian-Turonian Rhoundjaïa and the “Calcaires de Sidi Mohamed Ben Bouziane” formations that respectively outcrops in the Ksour Mountains and the Guir Basin (Fig. 1A–C).

2. Geographic and geological framework

Sections at Djebel Rhoundjaïa (Ksour Mountains, western Saharan Atlas; Fig. 1C) and at Kénadsa and Berridel (Guir Basin, Preadfrican Trough; Fig. 1B) provided an unexpected record of roveacrinoid ossicles from the Cenomanian-Turonian carbonates formations.

2.1. Western Saharan Atlas

The Ksour Mountains are situated in the western part of the Saharan Atlas; a SW-NE oriented mountain range, that stretches over more than 1,000 km from the Moroccan High Atlas to the west to the Aurès Mountains to the east. The Ksour Mountains are ranging between two relatively stable areas, the Saharan platform in the south and the High Plateaus in the north. The Saharan Atlas consists of three folded ranges (Ritter, 1902): the Ouled-Naïl Range (eastern Saharan Atlas), the Djebel Amour (central Saharan Atlas) and the Ksour Mountains (western Saharan Atlas). This intracontinental system consists of Meso-Cenozoic rocks folded during the Alpine and Atlasic orogens. The Cenomanian-Turonian deposits are outcropping in perched synclines (e.g., Djebel Sefrat ed Djir, Djebel Mdaouer; Djebel Rhoundjaïa; Djebel Rhelida and Djebel Tismert).

2.2. Guir Basin

The Guir Basin is situated at the southern foot of the Atlas System, bordered to the north by the Carboniferous Ranges of Djebel Antar, Djebel Horreit and the Cambrian rocks of the Boukais massif; to the south and south-east by the Carboniferous deposits of Chebket Mennouna, Chebket Djihani and Djebel Béchar; to the west by the Hamada of Guir, and is terminating V-shaped eastwards in the Ben Zireg area. The Guir Basin, as the eastern continuation of the Preadfrican Trough (Benyoucef et al., 2012; Benyoucef and Meister, 2015), is built of Cenomanian-Turonian deposits generally

¹ Mebarki K., 2017. Stratigraphie et sédimentologie des formations cénomano-turonien des l'Atlas saharién occidental et du bassin du Guir (Thèse de Doctorat). Université de Tlemcen 186 pp. (submitted).

² Same as footnote 1.

³ Benyoucef, M., Mebarki, K., Ferré, B., Adaci, M., Bulot L.G., Desmares, D., Villier, L., Bensalah, M., Zaoui, D. 2017. Litho- and biostratigraphy, facial patterns and depositional sequences of the Cenomanian-Turonian deposits in the Ksour Mountains (Saharan Atlas, Algeria). Cretaceous Research (submitted).

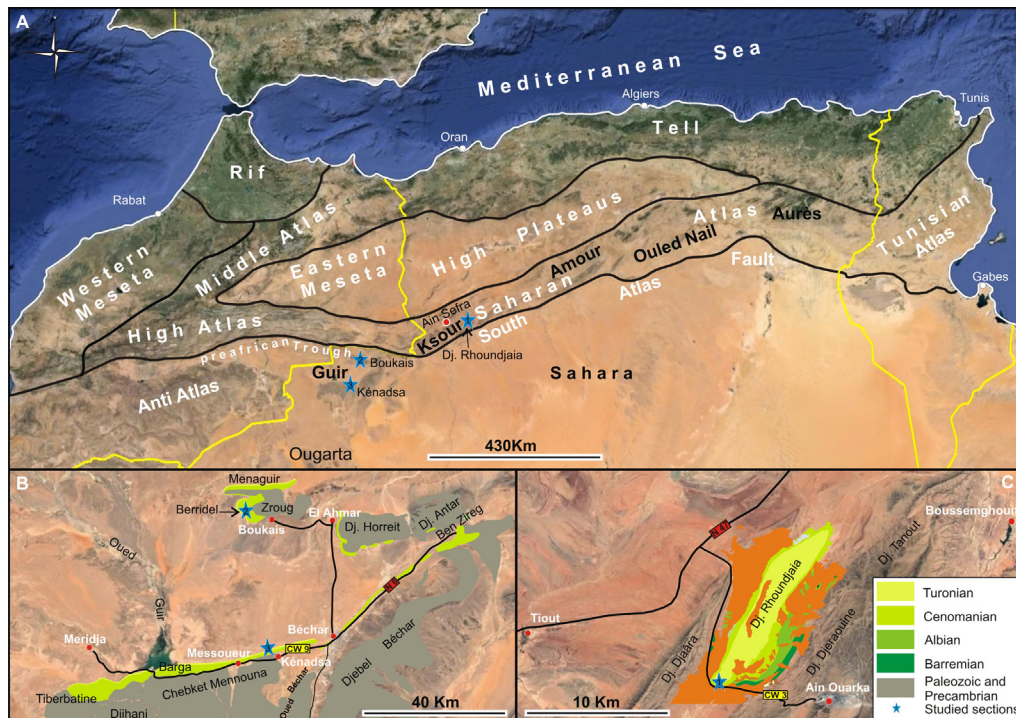


Fig. 1. Satellite images (from Google Earth) showing the location of the studied sections. **A.** General view over northern Africa. **B.** Close-up view of Djebel Rhoundjaia. *Images satellite (d'après Google Earth) montrant la localisation des coupes étudiées. A. Vue générale de l'Afrique du Nord. B. Vue détaillée du bassin du Guir. C. Vue détaillée du Djebel Rhoundjaia.*

erected as vertical ledges (e.g., crests of Bezazil El Kelba, first Barga, Djebel Asfar, Chebket Berridel, El Megsem and El Menaguir) on a dark and folded ante-Cretaceous substratum.

3. Lithostratigraphical description of studied sections

3.1. Saharan Atlas

3.1.1. Rhoundjaia section

This section lies within the perched syncline of Djebel Rhoundjaia, that is bounded to the north by the Djebel Tanout, to the south by the Djebel Chemarikh, to the east by the Djebel Djeraouine, and to the west by the Djebel Djara (Fig. 2). From bottom to top, the late Cenomanian to early Turonian Rhoundjaia Formation (Bassoulet, 1973) consists of three units⁴ that are described below:

Lower Limestones Unit: This unit consists of a massive, beige carbonate ledge, about 35 m thick. The lower and middle parts of the ledge contains ammonites [*Neolobites vibrayeanus* (d'Orbigny)], echinoids [*Tetragramma variolare* (Brongniart), *Heterodiadema libycum* Agassiz & Desor, and *Mecaster batnensis* (Coquand)], planktonic foraminifers [*Whiteinella archaeocretacea* Pessagno, *W. prae-helvetica* (Trujillo), and *Dicarinella* aff. *imbricata* (Monod)], benthic foraminifers [*Gavelinella berthelini* (Keller), *Valvulammina picardi* (Henson), *Fronicularia* sp., cf. *Dictyoconus*, *Ammobaculites benuensis* (Peters), and *Ammobaculites* sp.], exogyrine oyster and gastropod fragments.

The microfacies document a wackestone-packstone texture with pelagic crinoids (Roveacrinidae indet.), pithonellids, sponge spicules, holothuroid sclerites and bivalve fragments.

The uppermost part of the ledge consists of a succession of bioclastic carbonate beds of decimetric thickness, that yields gas-

tropods and oysters. A single ammonite [*Calycoceras* (*Calycoceras*) *naviculare* (Mantell)] was collected at this level.

Middle Marls Unit: This unit forms a yellowish-whitish marly hill, about 15 m thick, intercalated between decimetric to metric calcareous beds.

These marly levels contain a rich ostracode fauna (for a detailed list, see Mebarki et al., 2016), echinoderm ossicles (brachial and thecal plates of roveacrinoids, lateral plates and vertebrae of ophiuroids, echinoid spines, holothuroid sclerites, and marginal and dental plates of asteroids), benthonic foraminifers [*Gavelinella berthelini* (Keller), *Thomasinella* sp., *Valvulammina picardi* (Henson), *Fronicularia* sp., *Ammobaculites benuensis* (Peters), *Ammobaculites* sp.] and planktonic foraminifers [*Heterohelix reussi* (Cushman), *H. moremani* (Cushman), *H. globulosa* (Ehrenberg)]. The carbonate beds are showing a thinning-upward trend, from 1.5 to 0.3 m thickness. They contain echinoids, such as *Anorthopygus michelini* (Cotteau) and *Orthopsis ovata* (Coquand), tylostomid gastropods and scarce bivalves. The ammonite assemblage consists of *Nigericeras gadeni* (Chudeau), *Fikaitea subtuberculatus* (Collignon), *Vascoceras durandi* (Thomas & Peron) and *Vascoceras gamai* (Chofat). This latter species is restricted to the middle part of the unit.

The microfacies of these beds are wackestone to packstone carbonates with planktonic foraminifers [*Whiteinella archaeocretacea* Pessagno, *W. prae-helvetica* (Trujillo), *Dicarinella* aff. *imbricata* (Mornod), *Muricohedbergella delrioensis* (Carsey), *Asterohedbergella asterospinosa* (Hamaoui), and *Praeglobotruncana stephani* (Gandolfi)], benthonic foraminifers [*Valvulammina picardi* (Henson) and *Fronicularia* sp.], ostracode valves, ophiuroid ossicles, pelagic crinoids (*Roveacrinus alatus* Douglas, *R. cf. alatus*, *R. sp. cf. alatus*, *R. communis* Douglas, *Roveacrinus* sp., *Roveacrinidae* indet., *Applincrinus* sp.), calcispheres (*Pithonella ovalis*) and bivalve fragments.

Upper Limestones Unit: This unit consists of a carbonate ledge, about 30 m thick, with both greyish patina and break, marked at the base by a very bioturbated horizon with *Thalassinoides* burrows.

⁴ Same as footnote 3.

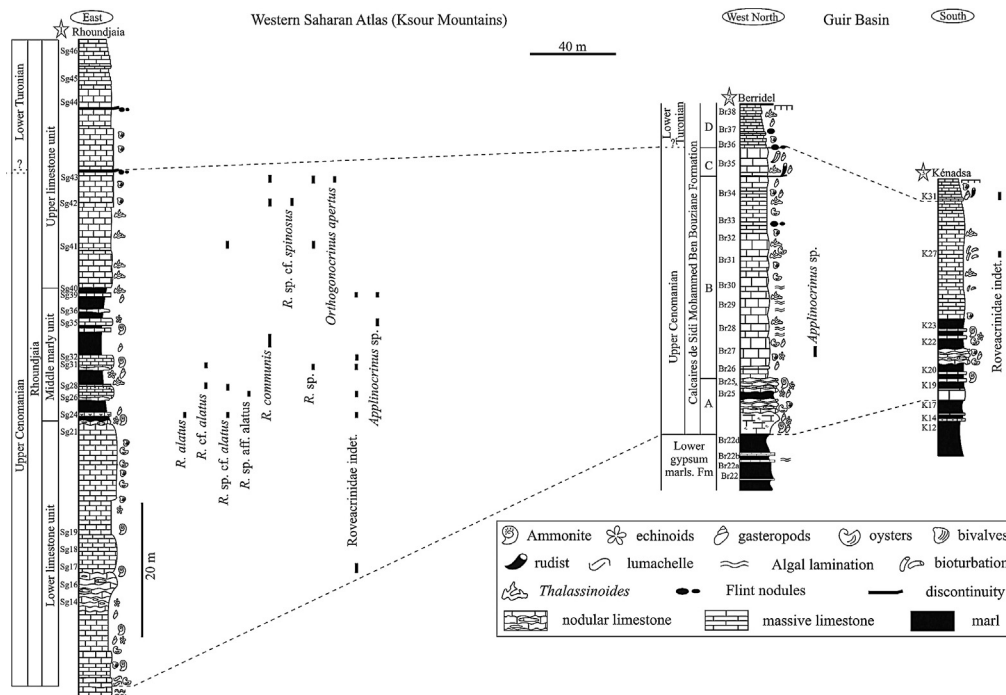


Fig. 2. Correlation of the studied lithological sections and occurrence ranges of roveacrinoïd material.

Corrélation entre les différentes coupes lithologiques et distribution stratigraphique des restes de roveacrinoïdes.

The microfossils document a wackestone texture with benthonic foraminifers [*Cuneolina* sp., *Gavelinella berthelini* (Keller), *Valvulamina* cf. *picardi* Henson], roveacrinoïd ossicles [*Roveacrinus* sp. cf. *alatus*, *R. communis*, *R. sp. cf. spinosus* Peck, *Roveacrinus* sp., *Orthogonocrinus apertus* Peck], ophiuroid and echinoid plates, and bivalve fragments. The uppermost part of the unit displays decimetric silicified carbonate beds.

Up to date, the C/T B was placed at the base of the flint-nodule level, above sample SGH43 that delivered some acetolysis-damaged planktonic foraminifers. In the meantime, the roveacrinoïd assemblages suggested that sample SGH34 might correspond to the roveacrinoïd-packstone level (Plenus Marls bed 1) of the top of the *R. cushmani* Zone detected in the Anglo-Paris basin (Ferré, 1995) and samples SGH42/43 could be coeval with the first Turonian *Roveacrinus*-level recorded by Gale et al. (1993).

3.2. Sections from the Guir Basin

Within this basin, we focused on the “Calcaires de Sidi Mohamed Ben Bouziane” Formation, of latest Cenomanian–earliest Turonian age (Benyoucef et al., 2012; Benyoucef et al., 2016). This formation has been fully documented through two outcropping sections: the Berridel and the Kénadsa sections respectively on the northern and southern sides of the Guir Basin.

3.2.1. Berridel section

The “Calcaires de Sidi Mohamed Ben Bouziane” Formation forms a massive carbonate ledge in the Berridel area. Its lower boundary is situated at the first nodular calcareous or fossiliferous marly bed that overlies a ferruginous surface, of regional significance. It can be subdivided into four lithological units (Benyoucef and Meister, 2015).

Unit A: consists of an alternation of whitish marls and pseudonodular or massive marly limestones. From its base, this lithological succession contains an abundant and diversified biophase, mostly consisting of ammonites [*Neolobites vibrayeanus* (d’Orbigny)], nautiloids (*Angulithes* sp.), gryphaeid oysters, bivalves (plicatulids,

pectinids, cardiids, arcticids, glossids, and pholadomyids), gastropods (cerithiids, campanilids, strombids, aporrhoids, and tylostomids) and echinoids (cidaroids, holectypoids, and spatangoids). Microscopic analysis of the thin sections shows a wackestone texture with planktonic and benthonic foraminifers, ostracode valves, and ophiuroid ossicles. The marly interbeds contain rich ostracode assemblages (for details see Mebarki et al., 2016b), planktonic and benthonic foraminifers, and roveacrinoïd sections.

Unit B: represented by decimetric to metric, wackestone-textured, bioclastic carbonate beds with bivalves, bourgueticrinid columnals and brachials, ophiuroid ossicles, echinoid plates, inoceramid prisms, oysters, and gastropod (nerineids) fragments.

Unit C: mostly composed of a metric caprinid-rich carbonate ledge. Its uppermost part is composed of thin carbonate beds that can be traced laterally, with abundant *Nerinea* sp.

Unit D: characterized by thin laminated mudstone carbonate beds, yielding flint nodules, recrystallized gastropod debris, asteroid and ophiuroid ossicles, fish teeth, benthonic foraminifers (e.g., *Valvulamina picardi* Henson), and exogyrine oysters.

The C/T B is placed at the base of Unit D by microfacial analogy with neighboring sections (Erfoud, Ziz and Goulmima) from Morocco (Rhalmi et al., 2000; Ettachfni and Andreu, 2004; Lézin et al., 2012; Andreu et al., 2013). This position might be consistent with the correlated coeval roveacrinoïd level of the Kénadsa section.

3.2.2. Kénadsa section

At Kénadsa, the “Calcaires de Sidi Mohamed Ben Bouziane” Formation forms a distinctive carbonate ledge, usually called “Première Barga”. The formation can be subdivided into three lithological units.

Unit A: composed of beige marls intercalated with bioclastic carbonates, about 0.5 m thick. The unit is rich in ammonites [*Neolobites vibrayeanus*], exogyrine oysters, ostracods, bivalves, asteroid ossicles, calcispheres, gastropods, and echinoids. The marly layers contain an abundant ostracode assemblage (for details see Mebarki et al., 2016b), benthonic foraminifers [*Gavelinella* gr. *cenomanica*

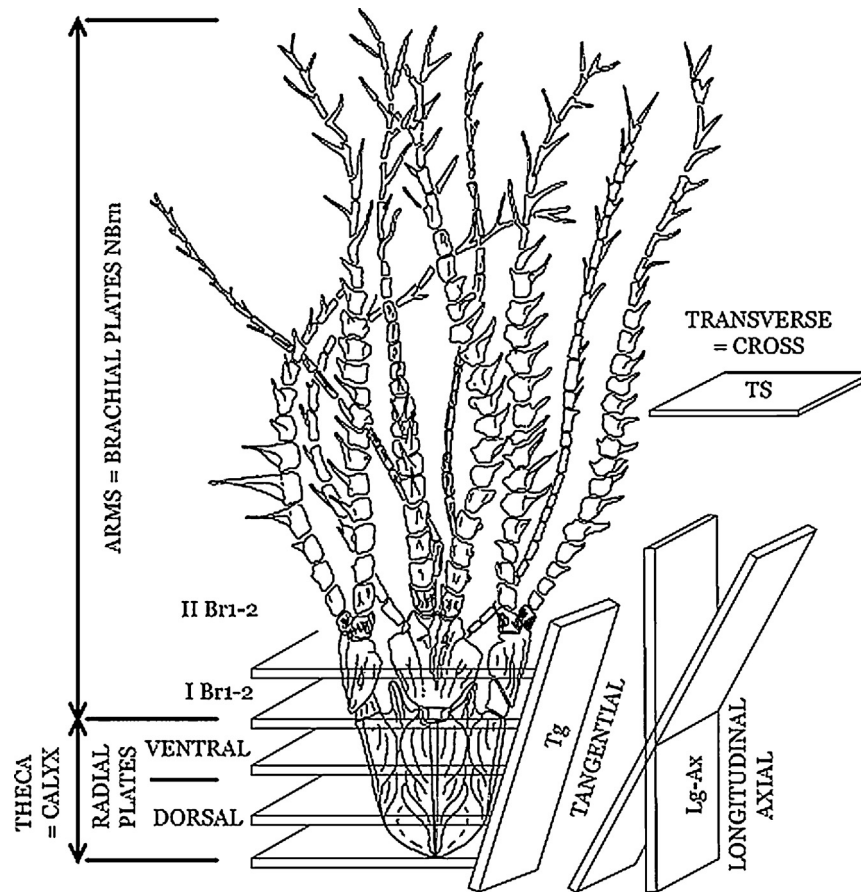


Fig. 3. Morphological reconstruction of a complete roveacrinid individual and terminology of the various possible section planes (from Ferré and Granier, 1997).
Reconstitution morphologique d'un spécimen complet de roveacrinide et terminologie des différents plans de section possibles (d'après Ferré et Granier, 1997).

(Brotzen), *Dorothia trochus* (Marsson), *D. cf. oxycona* Reuss, *Dorothia* sp. and *Valvulammina picardi* (Henson)], and roveacrinoid ossicles.

Unit B: consists of *Thalassinoides*-bioturbated, beige to greyish carbonate beds that yields bivalve and exogyrine oyster fragments, echinoid spines, asteroid ossicles, calcispheres, benthonic foraminifers [*Gavelinella* gr. *cenomanica*], and roveacrinid sections.

Unit C: lacking.

Unit D: characterized by centimetric to decimetric mudstone carbonate layers, alternating with wackestone-packstone carbonate beds rich in gastropods, gryphaeid oysters, benthonic foraminifers [*Chrysalidina gradata* d'Orbigny in de la Sagra, *Merlingina cretacea* Hamaoui & Saint Marc, *Valvulammina picardi*, *Nezzazata simplex* Omara, *Pseudolituonella reicheli* (Marie)], ostracodes, bivalve and gastropod debris. The last beds display a dark hue and are rich in flint nodules.

By means of microfacial analogy and correlation with the Berridel section, the C/T B is placed at the base of Unit D, which is consistent with the roveacrinid occurrence of sample K31.

4. Roveacrinid significance and microfacies identification

Though usually turned down by microfossil specialists, the glut of roveacrinoid ossicles originating from a single individual provides a noticeable sedimentary contribution to the Mesozoic limestones variously documented over the second half of the XIXth century (e.g., Lombard, 1937, 1945; Brönnimann, 1955; Verniory, 1954, 1955, 1956, 1960, 1961, 1962; Bengtson and Berthou, 1983; Berthou and Bengtson, 1988; Dias-Brito, 1994, 1995; Dias-Brito and Ferré, 1997, 2001; Benzaggagh et al., 2015). Though widely spotted out by field geologists and explorationists, these sections

were rarely mentioned in the literature. Over the last decade, the oil industry engineers paid more attention to these opportunistic roveacrinoid remains that thrive in oxygen-depleted mud-environments and are partially responsible for poro-necrosis within mid-Cretaceous oil-prone carbonate series worldwide.

Some 30 years after, following Verniory's seminal works (1954, 1955, 1956, 1960, 1961, 1962) based on both microfacies sections and isolated ossicles of Jurassic saccocomids, some Cretaceous sections of stratigraphical significance (Bengtson and Berthou, 1983; Berthou and Bengtson, 1988) were formally re-interpreted as genuine roveacrinids by Ferré and Berthou (1993, 1994). While providing a morphological 3D-reconstruction from diverse sections of diverse section planes, these authors provided preliminary baseline clues towards a formal terminology for section orientation. These schemes were then fully extended to saccocomid sections (Ferré and Dias-Brito, 1999). As a whole, Cretaceous roveacrinoid sections can be quite confidently assigned to the roveacrinids or the saccocomids (Ferré, 1997; Ferré and Granier, 1997, 2001; Ferré et al., 1999).

Fig. 3 shows the tentative reconstruction of a complete roveacrinid individual and the orientation of the main plane sections, as used in the following analytical study.

Roveacrinoids can be frequent in washing residues of pelagic and hemipelagic facies (outer-shelf and upper-slope environments), as a secondary component besides other standard microfossil groups (foraminifers, ostracods, etc.).

Roveacrinida are small, mostly pelagic crinoids ranging from the Permian-Triassic B event of the Tethyan realm (Salamon et al., 2015) to the Neogene of the Boreal Realm (Gorzela et al., 2011). According to the last edition of the Treatise of Invertebrate

Paleontology (Hess and Messing, 2011), this pelagic crinoid order consists of four families: the exclusively Triassic Axocrinidae and Somphocrinidae (e.g., Kristan-Tollmann, 1970, 1977, 1991), the mostly Late Jurassic (and Cretaceous) Saccocomidae (e.g., Hess, 2002; Gale, 2016), and the Cretaceous (and Neogene) Roveacrinidae (e.g., Jagt, 1999; Ferré and Granier, 2000; Gorzelak et al., 2011). These last two families were found in the Cenomanian-Turonian deposits of the Rhoundjaia Formation: the material at hand is reported and described hereafter.

5. Systematic paleontology

The suprageneric systematics follow the classification of Hess and Messing (2011). Both studied and illustrated thin sections are catalogued (under registration numbers UTL.25-SGH14/46 for samples from the Djebel Rhoundjaia section; UTL.25-CK12/31 and UTL.25-CB22/38 for samples from the Kénadsa and Berridel sections respectively) and housed in the collections of the Research Laboratory No. 25 of Tlemcen University (Algeria).

In the following, we use the term “cf.” to describe morphological features that are comparable but not sufficient to clearly state a specific assignment, while the term “aff.” indicates analogous features in possible spin-offs that might coin a new species, along with future additional material.

Class: Crinoidea Miller, 1821

Subclass: Articulata Zittel, 1879

Order: Roveacrinida Sieverts-Doreck, 1953

Family: Roveacrinidae Peck, 1943

Genus: *Roveacrinus* Douglas, 1908

Roveacrinus alatus Douglas, 1908

Fig. 4A

Material: Thin section of sample Rep. No. UTL.25-SGH24 (Photo SGH24-2).

Description: Fig. 4A shows a transverse sub-oblique section of the dorsal part of a complete theca. The basal dorsal cavity is rather small but recovered by the glassy vertical expansions of the radial plates that are responsible for the star-like pattern. The basal cavity outline is circular and displays a thin basal wall. The radial expansions are sharp, lamellar, wing-like and glassy.

Occurrence: In Algeria (Oued Takouazet, Tinrhert area), *R. alatus* is reported from the late Cenomanian (*Vascoceras* limestones, coeval to the *Neocardioceras juddii* Zone) to the early Turonian carbonates (*Pseudotissotia nigeriensis* limestone bed, coeval to the upper part of the *Watinoceras coloradoense* Zone).

Roveacrinus cf. alatus Douglas, 1908

Fig. 4B-C

Material: Thin sections of samples Rep. No. UTL.25-SGH28-1 and UTL.25-SGH31-2 (Photos SGH28-1 and SGH31-2).

Description: Fig. 4B documents an oblique section of a nearly complete theca displaying a small “triangular” dorsal cup under a wide rounded ventral bowl. The radial extremities are minute and glassy. The respective proportion of thecal cavities recalls *R. alatus* but the section at hand does not display the characteristic wing-like radial expansions.

Fig. 4C illustrates a tangential section of a first primibrachial plate. The overall morphology looks like a key-hole; the articular pit is large; the facet is narrow at its adradial basis and diamond-shaped abradially. The picture shows thin lamellar expansions recalling the wing-like ornamentations of *R. alatus*.

Occurrence: same as *R. alatus*.

Roveacrinus sp. cf. alatus Douglas, 1908

Fig. 4D-F.

Material: Thin sections of respective samples Rep. No. UTL.25-SGH24, UTL.25-SGH28, and UTL.25-SGH41 (Photos SGH24-14, SGH28-2, and SGH41-38).

Description: Fig. 4D shows two plates in pseudo-connection: a transverse section at the top of a thecal radial plate showing a minute articular facet and a sharp triangular radial expansion, along with an oblique section of the associated first primibrach (diamond-oval outline, fairly large articular pit).

Fig. 4E shows a transverse section of a radial plate. The morphology is frail and its ornamentation reduced.

Fig. 4F documents an oblique section of a second primibrach with a blunt articular area and radially-oriented alar expansions on its outer side. This kind of outer ornamentation is consistent (but not sufficient to a precise specific assignment) with *R. alatus*.

Occurrence: same as *R. alatus*.

Roveacrinus sp. aff. alatus Douglas, 1908

Fig. 4G

Material: Thin section of sample Rep. No. UTL.25-SGH26 (Photo SGH26-7).

Description: Fig. 4G documents an oblique section of a second primibrach with a blunt articular area and radially-oriented alar expansions on its outer side. This kind of outer ornamentation is consistent (but not sufficient to a precise specific assignment) with *R. alatus*.

Occurrence: comparable to *R. alatus* and *R. sp. cf. alatus*.

Roveacrinus communis Douglas, 1908

Fig. 4H; Fig. 6G-H.

Material: Thin section from sample Rep. No. UTL.25-SGH42 (Photo SGH42-9) and isolated ossicles from respective samples Rep. No. UTL.25-SGH34 and UTL.25-SGH43 (SEM Photos SGH34-30 and SGH43-11).

Description: Fig. 4H depicts a partial oblique section of a second primibrachial plate. Though the left upper part of the articular facet is partly missing, the articular side is still visible. The radial ornamentation of the outer side of this second primibrachial is simple, elongate and does not display any secondary ornamentation, such as corrugation, reticulation or fine ribbing.

Fig. 6G documents a loose thecal radial plate with a smooth surface and gross vertical ribbing; its elongated outline is lacking any reticulation or pitted pattern. On the one hand, the ventral cavity is of medium size while the dorsal one is minute and not visible from the outer side. On the other hand, this thecal plate with a rectangular radial “keel” is flanked by two vertical blunt bulges at both interradsial junctions. The articular facet is fairly small and slightly outwards sloping, as shared characteristic features for genus *Roveacrinus*. Fig. 6H displays a larger “fragment” of broken theca, that is a central complete radial plate still flanked with adjacent radials. These radials bear the same enhanced morphological features as described in Fig. 6G. However, the interradsial bulge is not showing but replaced by a regular finely-keeled vertical process running at the interradsial junction and slightly overhanging the oblique articular facet. This large fragment gives a wider than high outline for this theca. There is a slight porous, vertically linear pattern faintly visible at the surface of the ventral cavity.

Occurrence: This taxon has the longest stratigraphical distribution of the family, from the Albian deposits of US and Mexico (Peck, 1943), through the Late Cretaceous chalks of Boreal Europe (Douglas, 1908; Peck, 1955; Rasmussen, 1961), with awkward records from the Campanian of England (Gale, 2016), and the Paleogene and Neogene of Poland (Salamon et al., 2010; Gorzelak et al., 2011).

Roveacrinus sp. cf. spinosus Peck, 1943

Fig. 5A

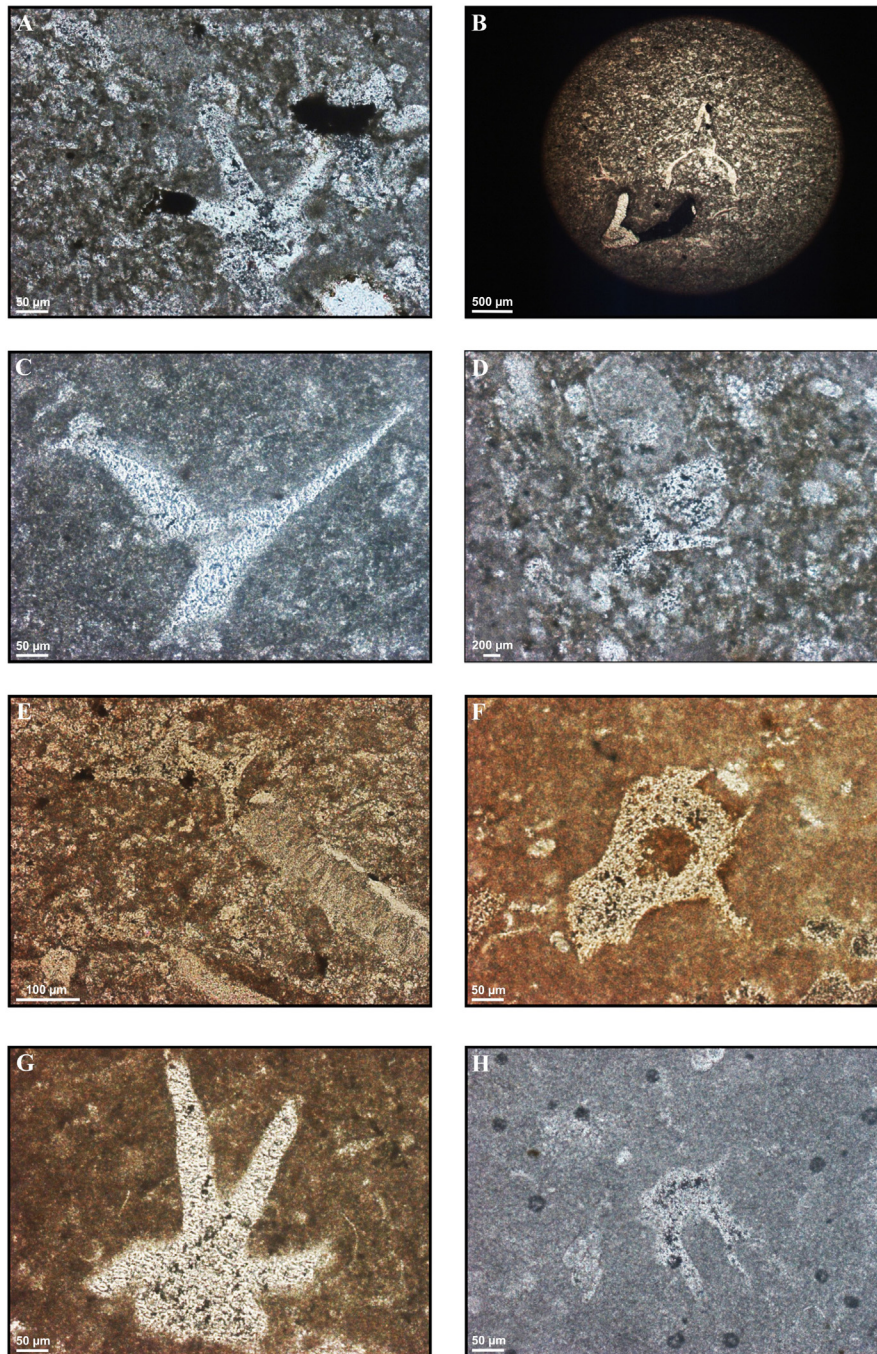


Fig. 4. Thin section microphotographs of roveacrinid ossicles, Late Cenomanian deposits, Djebel Rhoundjaïa, Ksour Mountains, Algeria. **A.** Transverse sub-oblique section of the dorsal thecal part (sub-Obl/TS-Theca) of *Roveacrinus alatus* Douglas, 1908, Photo SGH24-2, Rep. No. UTL.25-SGH24. **B.** Oblique section of a nearly complete theca (OblS-Theca) of *Roveacrinus* cf. *alatus* Douglas, 1908, Photo SGH28-1, Rep. No. UTL.25-SGH28. **C.** Transverse section of a radial plate of *Roveacrinus* cf. *alatus* Douglas, 1908, Photo SGH31-2, Rep. No. UTL.25-SGH31. **D.** Transverse section of the summit of a radial plate (articular facet – TS-Rad) with a tangential section of the first primibrach (TgS-IBr1) of *Roveacrinus* sp. cf. *alatus* Douglas, 1908, Photo SGH-24-14, Rep. No. UTL.25-SGH-24. **E.** Transverse section of a radial plate (TS-Rad) of *Roveacrinus* sp. cf. *alatus* Douglas, 1908, Photo SGH28-2, Rep. No. UTL.25-SGH28. **F.** Tangential section of a first primibrach of *Roveacrinus* sp. cf. *alatus* Douglas, 1908, Photo SGH41-38, Rep. No. UTL.25-SGH41. **G.** Oblique section of a first primibrach of *Roveacrinus* sp. aff. *alatus* Douglas, 1908, Photo SGH26-7, Rep. No. UTL.25-SGH26. **H.** Partial oblique section of a second primibrachial plate (OblS-IBr2) of *Roveacrinus communis* Douglas, 1908, Photo SGH42-9, Rep. No. UTL.25-SGH42.

Microphotographies d'ossicules de rovéacrinides en lame mince, dépôts du Cénomaniens supérieur, Djebel Rhoundjaïa, Monts du Ksour, Algérie. **A.** Section transversale sub-oblique de la partie dorsale d'une thèque (sub-Obl/TS-Theca) de *Roveacrinus alatus* Douglas, 1908, Photo SGH24-2, no. d'inventaire UTL.25-SGH24. **B.** Section oblique d'une thèque quasi complète (OblS-Theca) de *Roveacrinus* cf. *alatus* Douglas, 1908, Photo SGH28-1, no. d'inventaire UTL.25-SGH28. **C.** Section transversale d'une radiale de *Roveacrinus* cf. *alatus* Douglas, 1908, Photo SGH31-2, no. d'inventaire UTL.25-SGH31. **D.** Section transversale du sommet d'une radiale (facette articulaire – TS-Rad) avec section tangentielle d'une première primibrachiale (TgS-IBr1) de *Roveacrinus* sp. cf. *alatus* Douglas, 1908, Photo SGH-24-14, no. d'inventaire UTL.25-SGH-24. **E.** Section transversale d'une radiale (TS-Rad) de *Roveacrinus* sp. cf. *alatus* Douglas, 1908, Photo SGH28-2, no. d'inventaire UTL.25-SGH28. **F.** Section tangentielle d'une première primibrachiale de *Roveacrinus* sp. cf. *alatus* Douglas, 1908, Photo SGH41-38, no. d'inventaire UTL.25-SGH41. **G.** Section oblique d'une première primibrachiale de *Roveacrinus* sp. aff. *alatus* Douglas, 1908, Photo SGH26-7, no. d'inventaire UTL.25-SGH26. **H.** Section partielle oblique d'une seconde primibrachiale (OblS-IBr2) de *Roveacrinus communis* Douglas, 1908, Photo SGH42-9, no. d'inventaire UTL.25-SGH42.

Material: Thin section of sample Rep. No. UTL.25-SGH42 (Photos SGH42-7/8).

Description: Fig. 5A depicts a ‘tangential’ oblique section of an isolated first primibrachial plate. This latter shows the usual heart-shape with two small pits at its distal outer articular side and, most particularly, a spinose expansion. Such an ornamentation recalls the spinose expansions occurring on any brachial plate of *R. spinosus*, but does not bring proper specific substantiation, therefore we prefer leaving this taxon in open nomenclature. A slight grey ‘horn’ is showing on the right side and might be interpreted as a symmetric counterpart of this spinose ornamentation.

Occurrence: *R. spinosus* is rarely found and, so far, only reported from middle Turonian carbonates (Rasmussen, 1961; Ferré and Bengtson, 1997). Such an ornamentation is consistent with low sea-bottom hydrodynamics and fine-grained deposits.

Roveacrinus sp.

Figs. 5B–C

Material: Thin sections of respective samples Rep. No. UTL.25-SGH41-17 and UTL.25-SGH43-6 (Photos SGH41-17 and SGH43-6).

Description: Fig. 5B shows a transverse section of a partial theca at the level of the articular facet ‘crown’. The radial wall is thin with a slightly oblique radial articular facet, characteristic of genus *Roveacrinus*. There is no secondary ornamentation visible.

Fig. 5C illustrates a tangential oblique section of a second primibrachial plate (Tg/OblS-IBr2) with a blunt median radial expansion and a wide transverse articular ridge.

Genus *Orthogonocrinus* Peck, 1943

Orthogonocrinus apertus Peck, 1943

Fig. 5D

Material: Thin section of sample Rep. No. UTL.25-SGH43 (Photo SGH43-2).

Description: Fig. 5D displays a sub-tangential section of the upper part of an isolate radial plate. The HMC calcite piece is slightly pitted. The articular facet occupies most of the area lying between the two interrachial projections. The radial ridge is sturdy and blunt but its outline is grossly triangular and slender.

Occurrence: While the genus is known from the Albian deposits of United States (Peck, 1943, 1955; Hess, in Hess and Messing, 2011) to the early Coniacian chalks of the Anglo-Paris Basin (Valette, 1917; Rasmussen, 1961; Ferré, 1995), *O. apertus* ranges from Albian to late Cenomanian; some blunt spin-off forms are reported from the earliest Turonian. In Algeria, this genus was reported from a late Cenomanian limestone at Oued Takouazet (*Neocardioceras juddii* Zone; Ferré et al., 2016).

Roveacrinidae indet.

Figs. 5E–H

Material: Various Obl-TS of indeterminable brachials (NBrn) from respective samples Rep. No. UTL.25-CK27, UTL.25-SGH17, UTL.25-SGH24, UTL.25-SGH32, UTL.25-SGH24, UTL.25-SGH24, UTL.25-SGH26, UTL.25-SGH27, UTL.25-SGH34, UTL.25-SGH32, UTL.25-SGH39, and UTL.25-SGH41 (Photos CK27-1/2, SGH17-5, SGH24-3, SGH32-2, SGH24-14, SGH24-30, SGH26-6, SGH27-2, SGH34-3/4/6, SGH32-11, SGH39-7, and SGH41-2).

Description: Under this family assignment are placed various plane sections of mostly indeterminable brachial plates: Fig. 5E shows an oblique section of an articular facet of an indeterminable brachial plate; Fig. 5F illustrates a transverse section of a brachial plate (OblS-NBrn); Fig. 5G displays a longitudinal tangential section of an indeterminate brachial plate, very similar to the classical Jurassic saccocomid microfacies; Fig. 5H depicts an axial longitudinal section of a low arm plate with an hourglass outline.

Occurrence: Frequently found in great numbers across the C/T boundary and during other periods of oxygen-depleted environments (e.g., OAE1, Destombes, 1985; Santonian-Campanian boundary; Gale, 2016), taxonomic assignment of sections or of loose ossicles from washing residues remains a difficult task since complete Cretaceous specimens are extremely rare and brachial plates still connected to their respective identifiable theca are scarce. Nevertheless, it is worth reporting their occurrence (even so their glut was noticed by field geologists, they have most often been looked down by over-specialized micropaleontologists or neglected by field explorationists). They provide a most interesting complement to the faunal spectrum for paleoenvironmental reconstructions, and are quite useful to locate flooding events in monotonous sedimentary sequences (barren of standard microfossils; Ferré and Granier, 1997, 2001; Ferré et al., 1997, 2005). Around the C/T B, they display several recurring abundance levels (Gale et al., 1993; Ferré, 1995; Ferré et al., 1997, 2005) that can be correlated with heterohelicid events. The recognition of the respective roveacrinid accumulation beds around the C/T B can be used as another proxy tool to constrain the discrepancy of the *Whiteinella archaeocretacea* Partial Range Zone (Ferré et al., 2005; Ferré et al., 2016).

Family: Saccocomidae d’Orbigny, 1852

Genus: *Applinocrinus* Peck, 1973

(= *Microcalamoides* Bonet, 1956)

Applinocrinus sp.

Figs. 6A–E

Material: Thin sections from respective samples Rep. No. UTL.25-CB27, UTL.25-CK31, UTL.25-SGH35, and UTL.25-SGH39 (Photos CB27-9, CK31-10, SGH35-8, and SGH39-5/8).

Description: Under this generic assignment are gathered mostly transverse sections of a radial plate originating from the post-mortem thecal breakage and short transportation. The lack of prominent ornamental features born by the radial plates hinders any specific assignment of such radial section. These sections are typical of the so-called *Microcalamoides*-microfacies (since Bonet erected genus *Microcalamoides* for HMC sections of unknown affinity. Such sections were later assigned to saccocomids, see Ferré, 1997; Ferré et al., 1999); these transverse sections are rather short and smooth. While they do not show the usual corrugation illustrated by Bonet (1956), they are showing strong affinity to *Applinocrinus cretaceus* Peck.

Occurrence: This taxon is fairly common in the Guir Basin (Mebarki et al., 2016a), more abundant than in southern Tinrhert (Ferré et al., 2016). However, it always occurs as isolated radials in transverse sections. Likewise, their world-famous Jurassic relatives found complete in fine Solnhofen limestone slabs (Hess, 1999), this soft-bottom dwelling taxon is usually found in mudstone carbonates with low sea-bottom currents. Supposed to feed on “planktonic snow” (e.g. calcareous dinocysts, algal blooms, pellets), its presence provides reasonable evidence of a more restricted and shallowing/shallower environment (Ferré et al., 1999; Hess, in Hess and Messing, 2011).

6. Palaeo-environments

In the western Saharan Atlas, the roveacrinoid material shows a regular, diversified and rock-contributive presence but is always found as disarticulated and discarded pieces. This is a mere sign of parautochthonous assemblages: post-mortem, the roveacrinoid skeletons were not transported far away, even stirred by bottom currents and locally dismantled before final burial (or even slightly bioturbated).

Roveacrinids, as well as saccocomids, were hemipelagic to pelagic benthonic organisms. Therefore, they can be regarded as

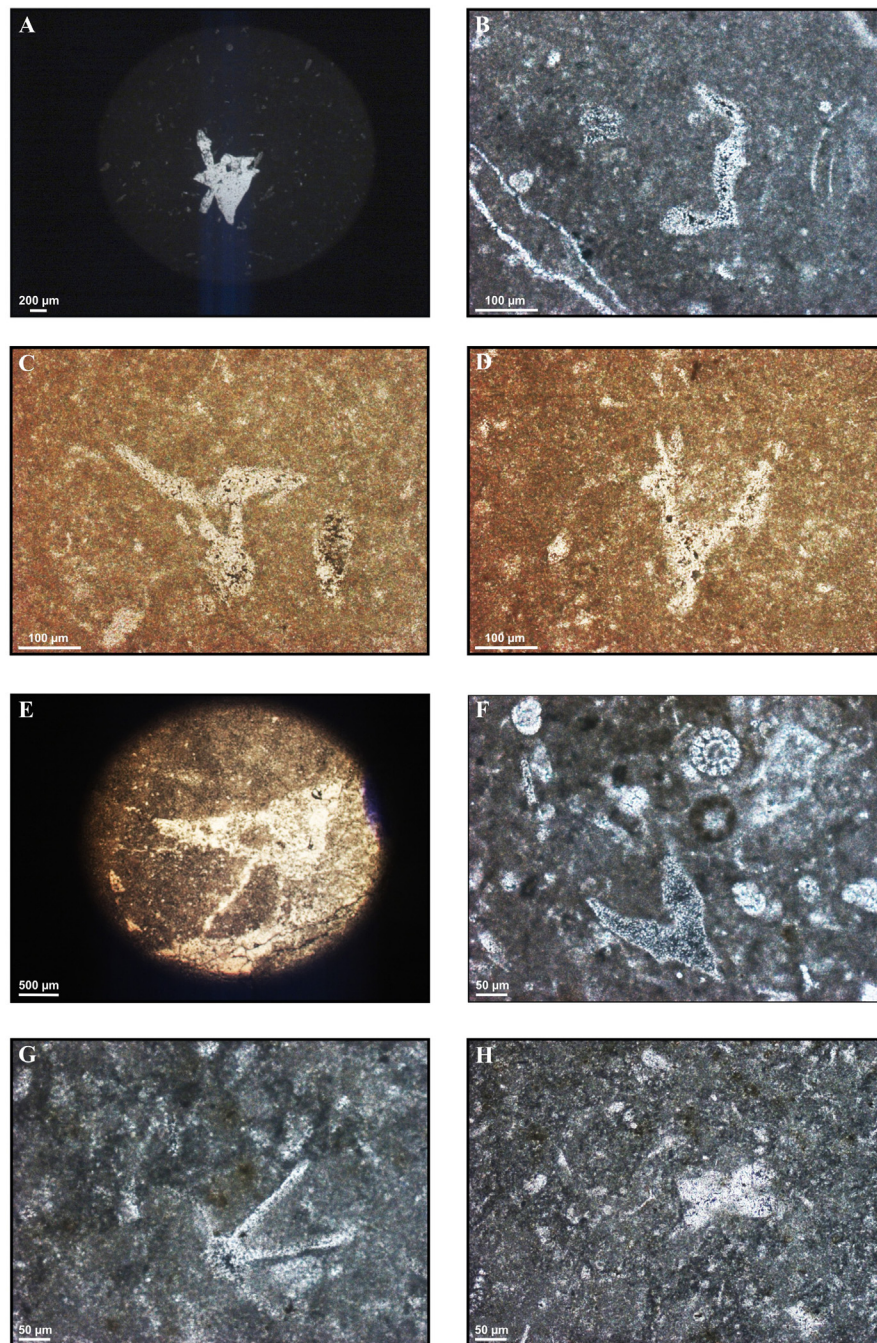


Fig. 5. Thin section microphotographs of roveacrinid ossicles, Late Cenomanian deposits, Djebel Rhoundjaia, Ksour Mountains (except E from Guir Basin), Algeria. **A.** Oblique section of a first primibrachial plate (ObIS-Ibr1) of *Roveacrinus* sp. cf. *spinus* Peck, 1943, Photo SGH42-7, Rep. No. UTL.25-SGH42. **B.** Transverse section, at the level of the radial articular facet, of a partial theca (TS-Theca) of *Roveacrinus* sp., Photo SGH41-17, Rep. No. UTL.25-SGH41. **C.** Tangential oblique section of a second primibrachial plate (Tg/ObIS-Ibr2) of *Roveacrinus* sp., Photo SGH43-6, Rep. No. UTL.25-SGH43. **D.** Tangential section of a radial plate (TgS-Rad) of *Orthogonocrinus apertus* Peck, 1976, Photo SGH43-2, Rep. No. UTL.25-SGH43. **E.** Oblique section of an articular facet of an indeterminate brachial plate (ObIS-NBrn) of *Roveacrinidae* indet., Photo CK27-1, Rep. No. UTL.25-CK27. **F.** Transverse section of a brachial plate (ObIS-NBrn) of *Roveacrinidae* indet., Photo SGH24-30, Rep. No. UTL.25-SGH24. **G.** Section tangentielle oblique d'une seconde primibrachiale (Tg/ObIS-Ibr2) de *Roveacrinus* sp., Photo SGH43-6, no. d'inventaire UTL.25-SGH43. **D.** Section tangentielle d'une pièce radiale (TgS-Rad) de *Orthogonocrinus apertus* Peck, 1976, Photo SGH43-2, no. d'inventaire UTL.25-SGH43. **E.** Section oblique d'une face articulaire d'une brachiale indéterminée de *Roveacrinidae* indet., Photo CK27-1, no. d'inventaire UTL.25-CK27. **F.** Section transverse d'une pièce brachiale (ObIS-NBrn) de *Roveacrinidae* indet., Photo SGH24-30, no. d'inventaire UTL.25-SGH24. **G.** Section tangentielle longitudinale d'une brachiale indéterminée (Tg/LgS-NBrn) de *Roveacrinidae* indet., Photo SGH31-3, no. d'inventaire UTL.25-SGH31. **H.** Section longitudinale axiale d'une brachiale indéterminée (Ax/LgS-NBrn) de *Roveacrinidae* indet., Photo SGH31-4, no. d'inventaire UTL.25-SGH31.

Microphotographies d'ossicules de roveacrinides en lame mince, dépôts du Cénomaniens supérieur, Djebel Rhoundjaia, Monts du Ksour (sauf E : bassin du Guir), Algérie. **A.** Section oblique d'une première primibrachiale (ObIS-Ibr1) de *Roveacrinus* sp. cf. *spinus* Peck, 1943, Photo SGH42-7, no. d'inventaire UTL.25-SGH42. **B.** Section transversale, au niveau de la couronne de facettes articulaires, d'une thèque partielle (TS-Theca) de *Roveacrinus* sp., Photo SGH41-17, no. d'inventaire UTL.25-SGH41. **C.** Section tangentielle oblique d'une seconde primibrachiale (Tg/ObIS-Ibr2) de *Roveacrinus* sp., Photo SGH43-6, no. d'inventaire UTL.25-SGH43. **D.** Section tangentielle d'une pièce radiale (TgS-Rad) de *Orthogonocrinus apertus* Peck, 1976, Photo SGH43-2, no. d'inventaire UTL.25-SGH43. **E.** Section oblique d'une face articulaire d'une brachiale indéterminée de *Roveacrinidae* indet., Photo CK27-1, no. d'inventaire UTL.25-CK27. **F.** Section transverse d'une pièce brachiale (ObIS-NBrn) de *Roveacrinidae* indet., Photo SGH24-30, no. d'inventaire UTL.25-SGH24. **G.** Section tangentielle longitudinale d'une brachiale indéterminée (Tg/LgS-NBrn) de *Roveacrinidae* indet., Photo SGH31-3, no. d'inventaire UTL.25-SGH31. **H.** Section longitudinale axiale d'une brachiale indéterminée (Ax/LgS-NBrn) de *Roveacrinidae* indet., Photo SGH31-4, no. d'inventaire UTL.25-SGH31.

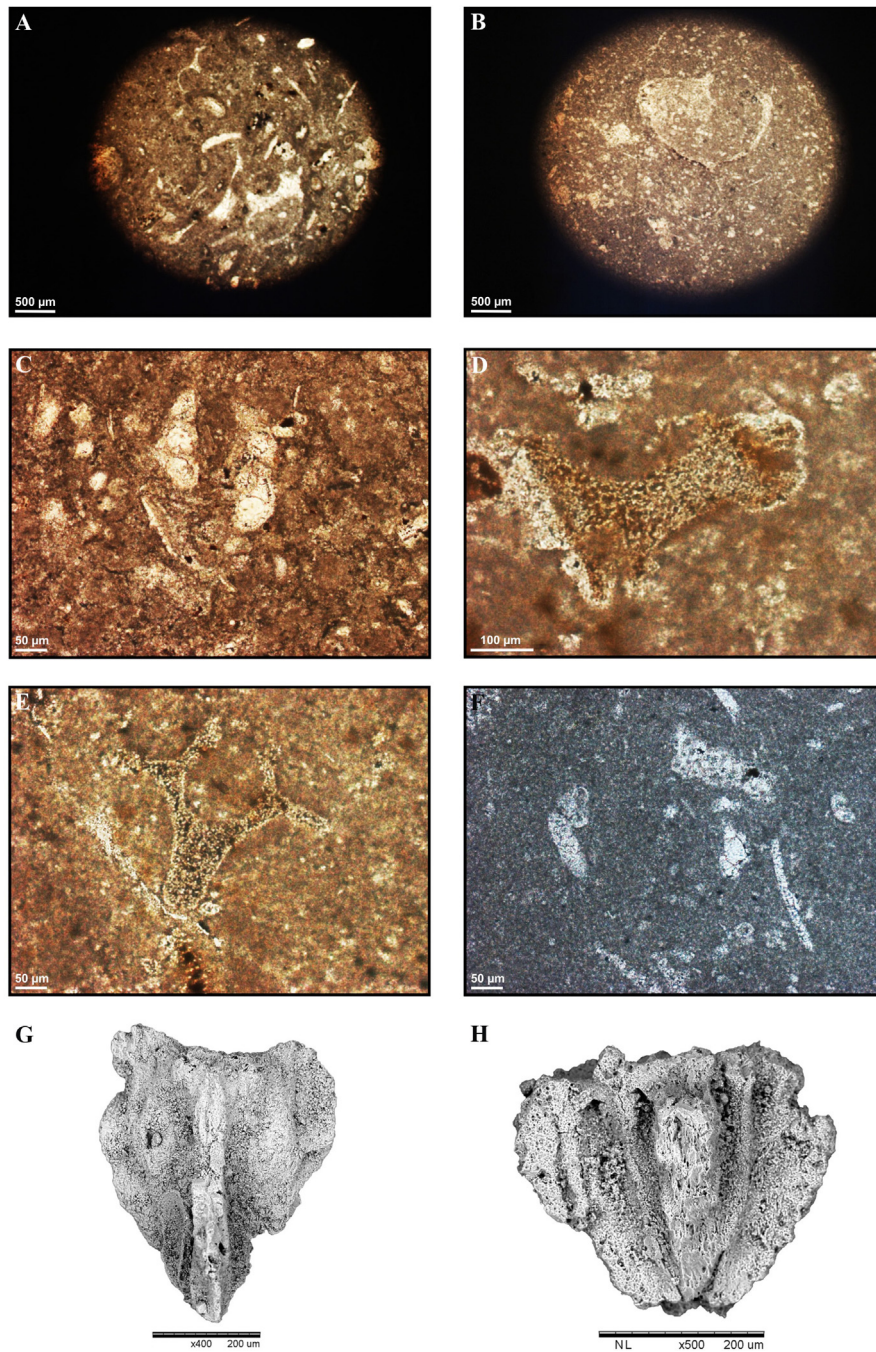


Fig. 6. Thin section microphotographs and SEM pictures of roveacrinid ossicles, Late Cenomanian deposits, Ksour Mountains (B–C, E–H) and Guir Basin (A, D), Algeria. **A.** Transverse/oblique section of a radial plate fragment (Obl/TS-Rad) of *Applinocrinus* sp., Photo CB27-9, Rep. No. UTL.25-CB27. **B.** Transverse section of a radial plate (TS-Rad) and tangential section of a primibrach (TgS-IBrn) of *Applinocrinus* sp., Photo SGH35-8, Rep. No. UTL.25-SGH35. **C.** Transverse section of a radial plate (TS-Rad) and tangential section of a primibrach (TgS-IBrn) of *Applinocrinus* sp., Photo SGH46-3, Rep. No. UTL.25-SGH46. **D.** Transverse sub-axial section of a whole theca of *Applinocrinus* sp., Photo CK31-10, Rep. No. UTL.25-CK31. **E.** Axial transverse section of a radial plate (AxTS-Rad) of *Applinocrinus* sp. below an ophiuroid vertebral section, Photo SGH39-8, Rep. No. UTL.25-SGH39. **F.** Axial transverse section of a fragmented radial plate (Ax/TS-Rad) of *Applinocrinus* sp., Photo SGH41-2, Rep. No. UTL.25-SGH41. **G.** Loose radial plate (Rad) of *Roveacrinus communis* Douglas, 1908, SEM Photo SGH34-30, Rep. No. UTL.25-34. **H.** Loose radial plate (Rad), still connected to relics of adjacent ones, of *Roveacrinus communis* Douglas, 1908, SEM Photo MEB SGH43-11, Rep. No. UTL.25-43.

Microphotographies de lames minces et clichés MEB d'ossicules de rovéacrinides, dépôts du Cénomaniens supérieur, Monts du Ksour (B–C, E–H) et bassin du Guir (A, D), Algérie. **A.** Section oblique transversale d'un fragment de pièce radiale (Obl/TS-Rad) de *Applinocrinus* sp., Photo CB27-9, no. d'inventaire UTL.25-CB27. **B.** Sections transversale d'une radiale (TS-Rad) et tangentielle d'une primibrachiale (TgS-IBrn) de *Applinocrinus* sp., Photo SGH35-8, no. d'inventaire UTL.25-SGH35. **C.** Section longitudinale transverse d'une radiale (Lg/TS-Rad) de *Applinocrinus* sp., Photo SGH46-3, no. d'inventaire UTL.25-SGH46. **D.** Section transversale sub-axiale de thèque complète de *Applinocrinus* sp., Photo CK31-10, no. d'inventaire UTL.25-CK31. **E.** Section axiale transverse d'une radiale (AxTS-Rad) de *Applinocrinus* sp. située sous une vertèbre d'ophiuroides, Photo SGH39-8, no. d'inventaire UTL.25-SGH39. **F.** Section axiale transverse d'une radiale fragmentée (Ax/TS-Rad) de *Applinocrinus* sp., Photo SGH41-2, no. d'inventaire UTL.25-SGH41. **G.** Radiale dégagée (Rad) de *Roveacrinus communis* Douglas, 1908, Photo MEB SGH34-30, no. d'inventaire UTL.25-34. **H.** Radiale dégagée (Rad), encore en connexion avec des restes de radiales adjacentes, de *Roveacrinus communis* Douglas, 1908, Photo MEB SGH43-11, no. d'inventaire UTL.25-43.

good potential stratigraphical index species thanks to a wide paleogeographic dispersal (through open-sea or littoral migrations around the Tethyan shores and island archipelagoes) as a genuine consequence of their early planktonic stage. During their adult and gerontic stages, they are thought to be benthic bottom-dweller adults with active escape swimming, feeding from the pelagic sinking nutrients (as epibenthic hemipelagic ‘dredgers’ whose raised arms build a feeding-basket as a net device, either passively when ‘hidden’ in the bottom current flow, or actively when moving to settle in a more prosperous habitat). They are regarded as opportunistic organisms since their own abundance levels are positively correlated with those of first-level carbonate producers (calcareous dinocysts, calcispheres and heterohelicids blooming; Ferré, 1997).

The western Saharan Atlas shows unexpectedly the presence of both families (saccocomids and roveacrinids): while mostly saccocomids had been dwelling in mud-supported lagoonal environments, roveacrinids have been occurring more frequently in carbonate-grain, open-shelf marine environments. Their co-occurrence advocates for a mixed environment or, at least, that saccocomids are secondarily coming from shallower areas. This is also supported by the morphological diversity of roveacrinoid plates. In the Guir Basin that displays a broad environmental range, the recorded roveacrinid contribution is indeed faint but their point occurrence at Kénadsa is consistent with the microfacial and lithological correlations.

7. Biostratigraphic inferences

In the present state of the art, in the western Saharan Atlas, the roveacrinoid assemblages of the lower part of the Middle marly unit might correspond to the roveacrinid-bioclastic level of the top of the *R. cushmani* Zone (Ferré, 1994, 1995), while the C/T B could be placed some 10 metres above the base of the Upper limestones at a level coeval with the first Turonian *Roveacrinus*-level (Gale, 1996). In the Guir Basin (Berridel and Kénadsa sections), the roveacrinoid occurrence at Kénadsa might be correlated to the first *Roveacrinus*-bed reported in southeastern England by Gale et al. (1993) and Gale (1996), and supports the lithological correlation with the base of Unit D at Berridel.

Their high morphology and diversity of the microfacial, as well as loose-ossicle, assemblages of this crinoid order provide a wide array of stratigraphical indices that can be used to frame a potential secondary macrozonal scheme, and provide baseline data to link the Moroccan occurrences (Terrab, 1996) and the Tunisian counterparts (Abdallah et al., 2006).

8. Conclusions

The finding of roveacrinid plates in the Cenomanian-Turonian deposits of the Saharan Atlas and the Guir Basin documents the second occurrence of this crinoid order in Algeria and evidences more vividly its extensive presence and stratigraphic value. The roveacrinoid assemblages of southwestern Algeria are very similar to those previously described from the Tinrhert area (Ferré et al., 2016) but show noticeable discrete differences, among which the relative abundance and regular presence of saccocomids, and the high morphological diversity of roveacrinids. They provide supplementary data for correlation between the Moroccan counterparts (Terrab, 1996; Grosheny et al., 2013) and the western Tunisian data (Abdallah et al., 2000, 2006). This second finding provides an additional station to bridge the gap between the ill-dated Mexican microfacies and the unexpected Arabian assemblages. Besides, this site is at a latitudinal intermediate position between the northern margin of the Tethyan Realm (Portugal, Spain, southeastern France, Crimea. . .) and the Central Atlantic (Congo basin, Brazilian

marginal coastal basins. . .). Furthermore, they constitute an additional proxy criterion (of equal meaning along with the *Heterohelix* and platycopid ostracode events) precisising the position of the C/T B. Consequently, in the western Saharan Atlas, the roveacrinoid assemblages support the C/T B to be placed lower than previously thought, i.e. some 10 metres below the flint-nodule level (some 10 m above the base of the Upper limestones), while the C/T B should be placed at the base of Unit D in the Guir Basin.

Disclosure of interest

The authors declare that they have no competing interest.

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