

# An unusual echinoderm assemblage from the earliest Bajocian (middle Jurassic) of Luxembourg, with special emphasis on the ophiuroids (Echinodermata: Ophiuroidea)

Lea D. Numberger-Thuy<sup>1, 2</sup> & Ben Thuy<sup>1</sup>

<sup>1</sup>Musée national d'histoire naturelle du Luxembourg, section paléontologie,  
25, rue Münster, L-2160 Luxembourg

<sup>2</sup>lnumberger@gmx.de

## Zusammenfassung

Die Mehrheit der Stachelhäutervergesellschaftungen aus dem Bajocium wurden aus Ablagerungen von Karbonatplattformen beschrieben. Im Nordwesten der Tethys haben diese Ablagerungen aussergewöhnlich häufige Funde von artikulierten Resten geliefert, was eine starke Habitat-bezogene Verzerrung des Fossilberichts der Stachelhäuter im Bajocium bewirkt. Siliziklastische Ablagerungen hingegen haben bisher wesentlich weniger Beachtung bezüglich ihrer möglichen Echinodermenfunde erhalten. In der vorliegenden Arbeit wird eine Vergesellschaftung von Echinodermen aus einer dünnen, lateral begrenzten Schicht aus sandigem Ton mit Phosphoritknollen beschrieben, die in Rumelange, Luxemburg, am nordöstlichen Rand der jungen Burgund Plattform aufgeschlossen sind und auf das früheste Bajocium datiert wird. Die Vergesellschaftung umfasst den rätselhaften *Cyclocrinus*, den Isocriniden

*Balanocrinus*, ein *Balanocidaris*-artiger Psychocidaride, und benthopectinide und korethrasteride/pterasteride Seesterne, welche allesamt in Karbonatplattformsedimenten des nordwestlichen Tethysrandes entweder ganz fehlen oder nur sehr selten vorkommen. Im Gegenzug deuten sie auf einen stärkeren offen-ozeanischen Einfluss hin. Die Schlangensterne, hier ausführlich beschrieben, umfassen fünf Arten, wovon eine als neu (*Lapidaster hellersi* sp. nov.) beschrieben wird. Letztere gehört zu einer ophiacanthiden Gattung, die im Bajocium bisher nur aus Tiefwasserablagerungen der westlichen Tethys bekannt war und somit die offen-ozeanischen Affinitäten der restlichen Echinodermen untermauert. Die vorliegende Arbeit bekräftigt das Beachten von Ablagerungsräumen bei Untersuchungen der Paläobiodiversität, die ungewöhnlich oder Lagerstätten gegenüber weniger attraktiv erscheinen.

## Abstract

The vast majority of Bajocian echinoderm assemblages have been reported from carbonate platform settings. In the northwestern Tethys, these deposits have produced exceptionally abundant articulated remains, thus introducing a strong palaeo-habitat bias in the Bajocian echinoderm fossil record. Siliciclastic deposits, in contrast, have received surprisingly little attention with respect to their potential echinoderm content. Here, we describe an echinoderm fauna from a thin, laterally discontinuous sandy clay bed rich in phosphorite nodules exposed in Rumelange, Luxembourg, on the northeast margin of the incipient Burgundy Platform, and dated to the earliest Bajocian. The assemblage includes the enigmatic *Cyclocrinus*, the isocrinid *Balanocrinus*, a *Balanocidaris*-like psychocidarid, and benthop-

pectinid and korethrasterid/pterasterid asteroids, which lack from or only very rarely occur in Bajocian carbonate platform deposits of the northwestern Tethys margin. Instead, they point to a more open ocean affinity. The ophiuroid assemblage, described in detail, includes five species, one of which is formally described as new (*Lapidaster hellersi* sp. nov.). The latter belongs to the ophiacanthid genus *Lapidaster* which is known only from deep-water deposits of the western Tethys in the Bajocian, thus corroborating the open ocean affinities of the other echinoderms. Our study endorses the inclusion in palaeo-biodiversity surveys of depositional settings which might seem unusual or less promising than Lagerstätten.

## Résumé

La majorité des collections d'échinodermes du Bajocien proviennent de sédiments de plateformes carbonatées. Au nord-ouest de la Téthys, les gisements en question

ont fourni des fossiles d'échinodermes articulés exceptionnellement abondants, ce qui a créé un fort biais dans le registre fossile bajocien des échinodermes pour les

types d'habitats correspondants. Les gisements siliciclastiques par contre n'ont reçu que peu d'attention quant au potentiel de fournir des fossiles d'échinodermes. Dans le présent travail, une collection d'échinodermes provenant d'une couche lenticulaire d'argile sableuse de faible épaisseur riche en concrétions phosphoritiques, exposée à Rumelange, Luxembourg, sur la bordure nord-est de la plateforme de Bourgogne naissante et datée du Bajocien basal. La collection inclut le crinoïde énigmatique *Cyclocrinus*, l'isocrinide *Balanocrinus*, un psychocidaride proche de *Balanocidaris* ainsi que des astérides benthopectinides et korethrasterides/pterasterides, qui ne sont pas ou que

très rarement trouvés dans les gisements bajociens de plateforme carbonatée de la bordure nord-ouest de la Téthys. Les ophiures, décrites en détail, comprennent un total de cinq espèces, dont une nouvelle (*Lapidaster hellersi* sp. nov.) appartiennent au genre ophiacanthide *Lapidaster* qui n'est connu au Bajocien que de sédiments de mer profonde de la Téthys de l'Ouest. Cette observation corrobore le caractère plutôt océanique des autres groupes d'échinodermes de la collection. Le présent travail met l'accent sur l'inclusion dans les analyses de paléo-biodiversité de gisements qui, à première vue, semblent moins prometteurs que les Lagerstätten.

## Introduction

The Bajocian is among the stages that have produced outstandingly well known and diverse echinoderm remains. Most noteworthy are the exceptionally preserved and abundant, intact layers of echinoderms on the Bahama-type Burgundy carbonate platform deposits such as the widespread Hauptrogenstein Formation, including remains of all five extant classes (Hess 1972; Hess & Holenweg 1985; Hess & Meyer 2008; Thuy & Meyer 2012). Echinoderms are only preserved intact under certain sedimentological and taphonomic conditions (Ausich 2001). Therefore, although these articulated assemblages gained a lot of interest in the past, they represent just a small part of the total echinoderm diversity during the Bajocian.

The exceptionally preserved echinoderm assemblages from the Burgundy Platform Lagerstätten originate from a limited number of depositional settings (Hess & Meyer 2008). In fact, almost all published records in this respect originate from oolitic to detrital sand wave obrution deposits (Hess 1972; Hess & Meyer 2008). The abundance and exceptional preservation of the echinoderm fossils in question makes them particularly attractive for both collectors and researchers, and thus introduces a strong bias in the Bajocian echinoderm fossil record towards shallow-water, high energy carbonate platform assemblages. Reefal, peri-reefal and, in particular, siliciclastic settings are heavily underrepresented, at least for the non-echinoid echinoderms.

In the particular case of the ophiuroids, it is noteworthy that, until recently, only species based on articulated skeletons were known from the

Bajocian (Thuy, this volume), which is well in line with the general trend observed in the survey of Bajocian echinoderms. Dissociated ophiuroid lateral arm plates, which are known to allow for much more exhaustive palaeobiodiversity assessments than the patchy record of articulated skeletons, have only recently come into the focus of taxonomic surveys (Thuy 2013; Thuy this volume).

Here, we present a new echinoderm assemblage, comprising disarticulated remains of crinoids, echinoids, asteroids and ophiuroids, retrieved from sieving residues of a sandy clay bed rich in phosphorite nodules exposed on the northeast margin of the incipient Burgundy Platform. The aim is to contribute to a more complete picture of shallow-water echinoderm biodiversity during the Bajocian by focusing on siliciclastic depositional settings which, compared to carbonate platform deposits, are strongly undersampled. The faunal spectrum is highly unusual, comprising echinoderm taxa which are only very rarely, if at all, found in the coeval and later carbonate platform settings. We provide a very brief general overview on the echinoid, crinoid and asteroid taxa with the aim to spark more detailed investigations, and provide a detailed assessment of the ophiuroid assemblage.

## Geological context

The here described assemblage was predominantly retrieved from sieving residues of a 0,10 m thin, laterally discontinuous bed of grey sandy clay with pea- to walnut-sized phosphorite nodules and numerous abraded and encrusted belemnite

rostra, approximately 1 m above the base of the Micaceous Marls. The sand size fraction of the sandy clay predominantly consists of quartz grains and iron ooids. The bed was dated to the earliest Bajocian *Discites* Zone (*Walker*i Subzone) based on ammonite evidence (Guérin-Franiatte & Weis 2010). It is exposed on the shores of a pond on an artificial plateau in the former "Hutbiert" opencast mine in Rumelange, Luxembourg.

The nodule bed is highly fossiliferous, in contrast to the over- and underlying marls, and yields, apart from the here described echinoderms, abundant cephalopod remains (mainly belemnite rostra, occasional ammonites), bivalves, gastropods, millimeter-sized brachiopods, solitary corals, sponges and bryozoans. The micaceous marl succession including, at its base, the sandy clay bed yielding the here-described echinoderms, was deposited under falling sea-level conditions at, or shortly before, the onset of the Burgundy Platform formation (Boulvain et al. 2001; Brigaud et al. 2009, 2013). The general geological context of the area suggests deposition in a shallow to mid-shelf setting, at or slightly below storm wave base (Pierkowski et al. 2008).

## Material and methods

More than 200 echinoderm plates and spines, assignable to echinoids, asteroids, crinoids and ophiuroids, were examined in the present study. Some of the larger remains were picked in the field from the weathered surface of the sandy claybed. The vast majority of the specimens, however, was retrieved from sieving residues. The coarse (>5 mm) fraction was screen-washed and picked directly in the field, taking advantage of the nearby pond. The smaller fraction was screen-washed in a laboratory sink. No chemical treatment was necessary. Specimens from the smaller residue fractions were picked under a dissecting microscope. Selected specimens were cleaned in an ultrasonic bath, then either photographed using a VEHO USB camera, or mounted on aluminium stubs and gold-coated for scanning electron microscopy (SEM) using a JEOL Neoscope JMC-5000.

In the particular case of the ophiuroids, identifications, if possible to species level, were exclusively based on the lateral arm plates (abbreviated in the descriptions as LAPs), following the terminology and recommendations of Thuy and Stöhr (2011). Higher-level classification follows Smith et al.

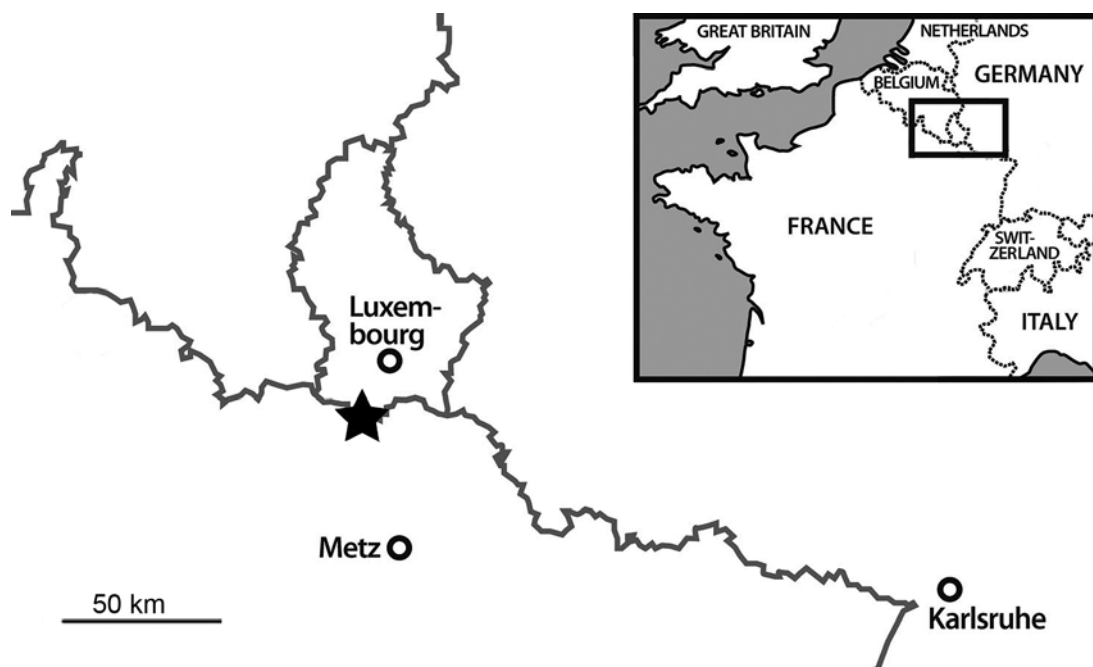
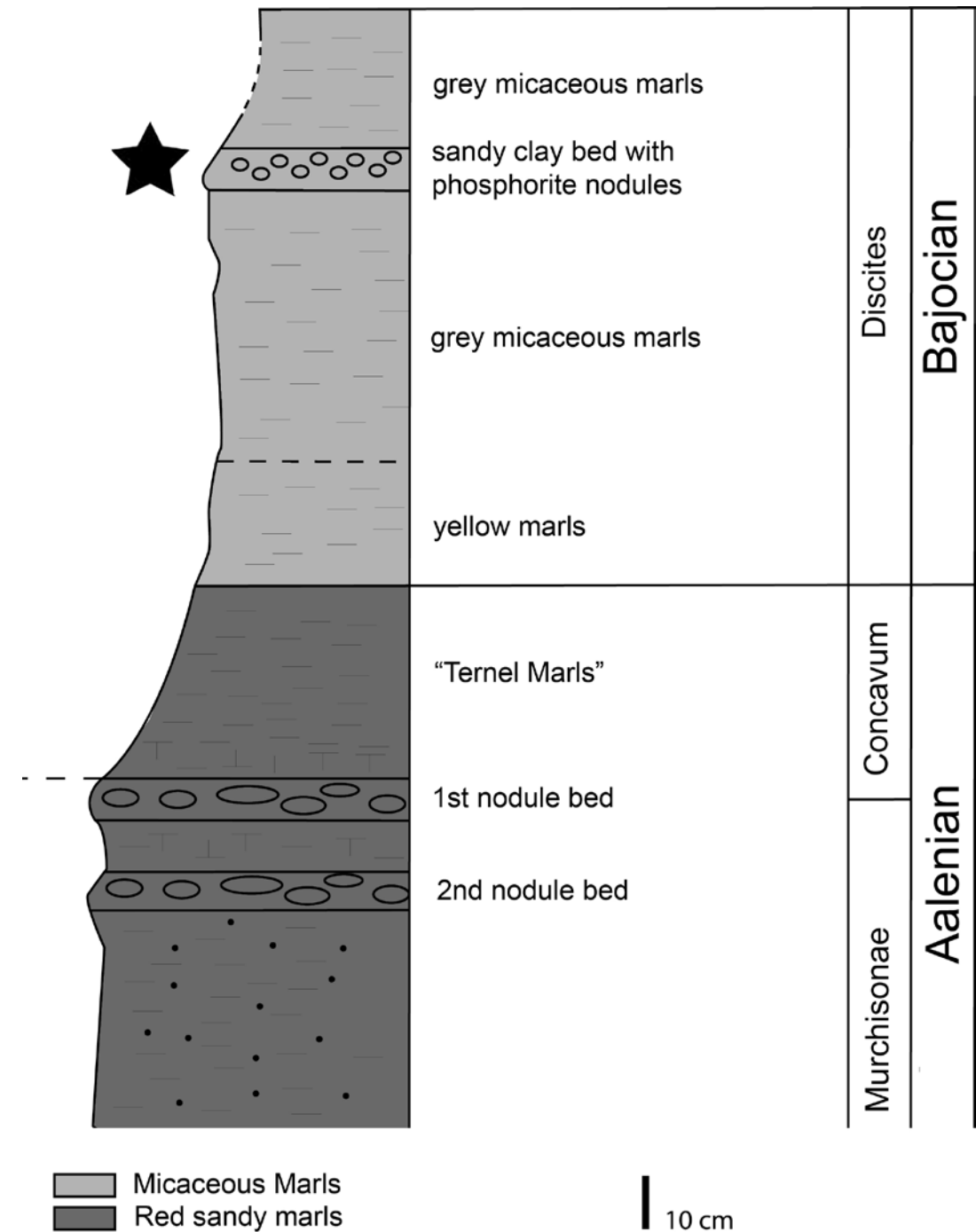


Fig. 1: Locality map showing the position of the studied site (marked by a star).



**Fig. 2:** Stratigraphic log with the position of the sandy clay bed (marked by a star) that yielded the here described echinoderm assemblage, modified from Weis and Guérin-Franiatte (2010).

(1995). All type, figured and additional specimens were deposited in the collection of the Natural History Museum Luxembourg (MnhnL), under series number BU.

## Results

### The crinoids

The echinoderm assemblage studied herein is markedly dominated by the conspicuous columnals of *Cyclocrinus rugosus* (d'Orbigny, 1841) (Fig. 3 a-d). Hess (2008) recently revised the genus *Cyclocrinus* and summarised its currently known occurrences. In spite of more than two decades of research, not a single cup plate has been identified so far, precluding any robust conclusions on the higher taxonomic classification of the genus. The here presented specimens fail to add to the debate as they exclusively consist of columnals. The material is nevertheless noteworthy as it ranks among the very few Bajocian occurrences of the genus. It might even be the oldest known record of *Cyclocrinus*.

Almost all other crinoid remains from the here described assemblage are assignable to the isocrinid genus *Balanocrinus* (Fig. 3 e-f). In a recent revision of the taxonomic concept and fossil record of *Balanocrinus*, Hess (2013) highlighted the abundance of the genus in Lower and Upper Jurassic mudstones. Middle Jurassic occurrences of the genus, and even more Bajocian ones, are less common and predominantly found in areas of the northwestern Tethys margin which are closer to the open ocean (e.g. Hess & Pugin 1983; Hess 2012). Almost all Middle Jurassic peri-Tethyan assemblages, in particular those of the carbonate platforms, are dominated by other isocrinids (*Chariocrinus*, *Hispidocrinus* and *Pentacrinites*) (e.g. Hess 1972; Thuy & Meyer 2012).

### The asteroid

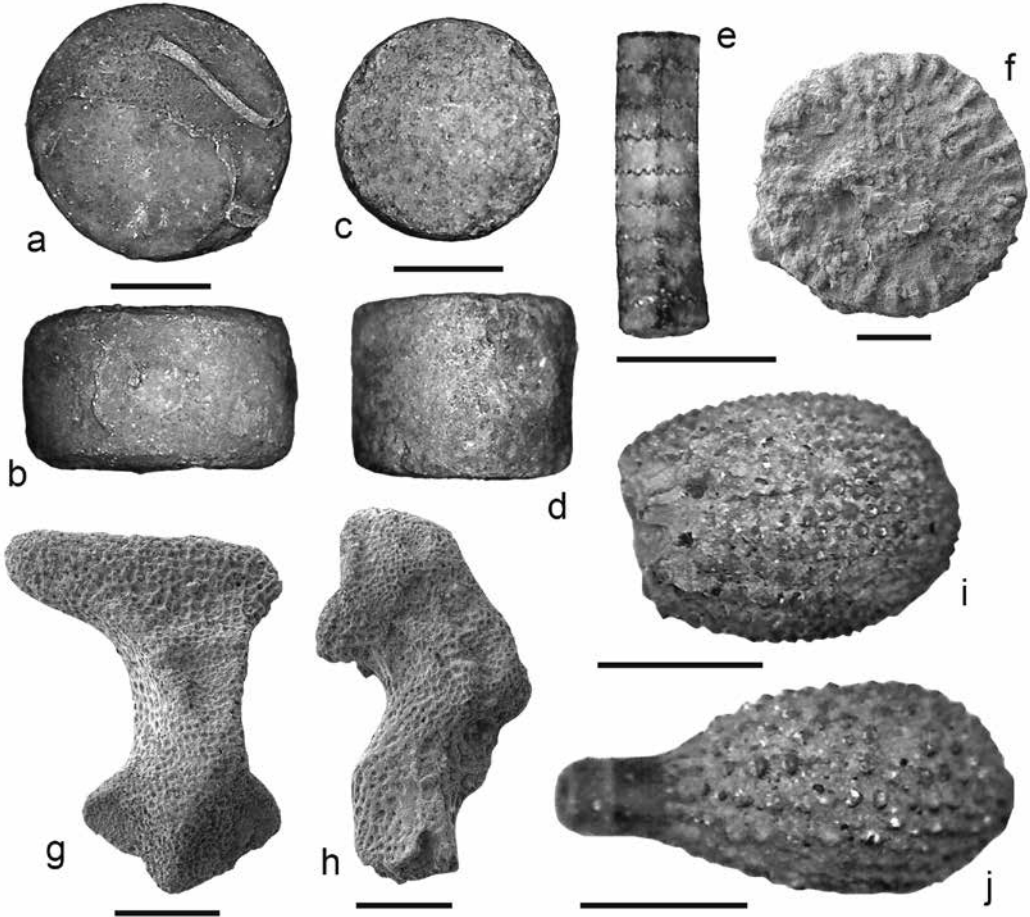
Asteroid fossils are surprisingly abundant in the here presented assemblage. The most conspicuous remains are large, dissociated goniasterid marginals, which are complemented by the excep-

tional find of an articulated arm fragment. Goniasterids are commonly found in Middle Jurassic echinoderm assemblages of the peri-Tethys, including those from carbonate platform settings (e.g. Hess 1972). The most remarkable asteroid remains, however, are much smaller marginals and ambulacrals which are assignable to the Benthoptectinidae (Fig. 3 g), as well as adambulacrals which show clear korethrasterid-grade pterasterid affinities (Fig. 3 h). The presence of these two asteroid groups is noteworthy because their remains have only recently been shown to occur in Jurassic sediments on the basis of robust, unambiguous morphological evidence based on dissociated plates (Gale 2011). The here presented benthoptectinid and pterasterid records are among the oldest of the groups and significantly add to their yet very sparse fossil record.

### The echinoids

Various test and spine fragments have been recorded but one type of primary spines is particularly noteworthy (Fig. 3 i-j), first because it is the most common echinoid remain in the assemblage, and second because it is not or only rarely found in Bajocian carbonate platform deposits. The spines in question are small, stout, short, glandiform with a rounded, blunt distal tip and a shaft ornamented with beaded ribs developing into an irregular granulation towards the distal tip of the spine. The distinctive spine morphology suggests assignment to the Psychocidaridae. Although *Caenocidaris* is the typical Middle Jurassic representative of the family (e.g. Vadet 1991), similarities of the here described material are greater with the spines of the late Jurassic *Balanocidaris*, in particular with respect to the blunt distal tip and the fine ornamentation of the shaft (Smith & Kroh 2010).

Typical *Caenocidaris* commonly occurs in Bajocian carbonate platform settings (e.g. Vadet & Slowik 2001; Thuy 2003). The more *Balanocidaris*-like spine type presented herein, in contrast, has not been reported previously, except for the spine figured by Thuy (2010) from the earliest Bajocian of Differdange, Luxembourg (Plate 2, fig. h) which was found in stratigraphically and sedimentologically comparable settings.



**Fig. 3:** Echinoderm remains from a sandy clay bed with phosphorite nodules approximately 1 m above the base of the micaceous marls, Discites Zone, Walkeri Subzone, earliest Bajocian, Middle Jurassic, of Rumelange, Luxembourg. *Cyclocrinus rugosus* (d'Orbigny, 1841), a-d: HU 306, columnals in facet (a, c) and lateral (b, d) views; *Balanocrinus* sp., e: HU 322 pluricolumnal in lateral view; f: BU 337, columnal facet; Benthoptectinid asteroid, g: BU 338, ambulacral; Korethrasterid/Pterasterid asteroid, h: adambulacral; Psychocidaroid echinoid, i-j: HU 321, primary spines. Scale bars equal 5 mm in a-e and i-j; 500  $\mu$ m in f, and 250  $\mu$ m in g-h.

## The ophiuroids

Our study includes the first exhaustively described ophiuroid assemblage from non-carbonate platform deposits for the Bajocian. Although the diversity is low, with only five species identified, the composition of the ophiuroid assemblage is rather unusual for the Bajocian. It shares the ophiacanthid *Alternacantha* and the ophiolepidid *Enakomusium* with coeval ophiuroid assemblages from carbonate platform settings, where these

taxa are among the most abundant (e.g. Thuy & Meyer 2012; Thuy this volume). The ophiidermatid *Ophiotitanos* is reported for the first time from Bajocian deposits by Thuy (this volume) and seems to be a rather common component of coeval carbonate platform deposits, judging from unpublished preliminary survey based on dissociated LAPs. The occurrence of the ophiacanthid *Lapidaster*, in contrast, is unusual since the genus is only known from deep-water sediments of the western Tethys in the Bajocian (Thuy 2013).

## Systematic palaeontology

Class Ophiuroidea Gray, 1840

Order Ophiurida Müller & Troschel, 1840

Family Ophiacanthidae Ljungman, 1867

**Genus *Lapidaster* Thuy, 2013**

Type species: *Lapidaster hystericarboris* Thuy, 2013

***Lapidaster hellersi* sp. nov.**

Fig. 4a-f

**Derivation of name:** Species named in honour of our step father (in law) Marcel Hellers, for his friendship and his companionship during fieldwork, and in recognition of his contributions to invertebrate zoology.

**Types:** BU 321 (holotype); BU 322, BU 323 (paratypes)

**Other material:** BU 324 (12 dissociated LAPs)

**Type locality:** Pond shore on artificial plateau, former "Hutbiert" opencast mine in Rumelange, Luxembourg.

**Type horizon:** Sandy clay bed with phosphorite nodules approximately 1 m above the base of the micaceous marls, Discites Zone, Walkeri Subzone, earliest Bajocian, Middle Jurassic.

**Diagnosis:** Species of *Lapidaster* with very small, horizontally elongate LAPs; outer surface with very coarsely meshed stereom transformed into a weakly to moderately well developed, irregular vertical striation near the spine articulations; very weakly developed, oblique spur on the outer proximal and inner distal edges of the LAP; three spine articulations; inner side of LAPs with narrow, well defined ridge with dorsalwards tapering dorsal portion.

**Description of holotype:** BU 321 is a very small proximal LAP; slightly wider than high; dorsal edge fragmented but originally weakly convex or straight; proximal edge strongly concave, with very weakly defined, poorly prominent and non-protruding, oblique spur between ventral and median third of proximal edge; ventral third of LAP strongly ventro-proximalwards protruding, with concave ventro-proximal edge; ventro-distal tip of LAP weakly protruding ventralwards; very large, deeply concave tentacle notch. Outer surface with very coarsely meshed stereom, with trabecular intersections merged into irregular, vertical ridges

near the row of spine articulations; narrow band of much more finely meshed stereom lining proximal edge of LAP. Three medium-sized, free-standing spine articulations on distal edge of LAP; clear dorsalward increase in size of spine articulations and of gaps separating them; spine articulations ear-shaped, composed of thin dorsal and ventral lobes, proximally separated by a shallow notch and distally connected by a sigmoidal fold; spine articulations separated from distal edge of LAP by a gap narrower than half a spine articulation.

Inner side of LAP with well defined, thin, arcuate ridge, with oblique, dorso-proximalwards pointing and dorsalwards tapering dorsal part, and shorter, wider ventro-proximalwards pointing ventral part merged with ventral portion of LAP; dorsal and ventral parts of ridge connected by rounded kink. Poorly defined, weakly prominent, oblique spur on inner distal edge, composed of more densely meshed stereom. Very large, deeply concave tentacle notch, bordered by thickened ventral edge of the LAP and with horizontally stretched stereom. No perforations discernible.

**Paratype supplements and variation:** BU 322 is a very small proximal to median LAP, almost 1.5 times wider than high; dorsal edge gently convex; ventro-proximalwards pointing ventral portion of LAP smaller than in holotype and with weakly convex ventro-proximal edge; proximal edge strongly concave, with kink in ventral half; no spurs on outer proximal edge. Outer surface with very coarsely meshed stereom, with no vertical stripes. Three spine articulations as in holotype separated from distal edge of LAP by a gap as wide as half a spine articulation.

Inner side of LAP as in holotype.

BU 323 is a very small distal LAP, almost two times wider than high; dorsal edge straight; ventral quarter strongly ventro-proximalwards pointing, with very weakly concave ventral and ventro-proximal edges. Outer surface as in holotype but with shorter vertical stripes. Three spine articulations as in holotype but separated from distal edge by gap as wide as half a spine articulation.

Inner side with moderately well defined, short ridge, with wide ventral basis and narrow, dorso-proximalwards pointing, dorsal extension.

**Remarks:** The genus *Lapidaster* was introduced by Thuy (2013) to accommodate dissociated

ophiuroid LAPs which are essentially similar to those of extant *Ophiologinus* but differ in displaying spurs on the outer proximal and inner distal edges. The here described LAPs comply with the diagnosis of *Lapidaster* in particular with respect to the strongly ventro-proximalwards pointing ventral portion of the LAP, the spur on the outer proximal and inner distal edges, the large tentacle notches, the ear-shaped spine articulations which are neither on an elevated ridge nor sunken into depressions of the distal edge, and the shape of the ridge on the inner side.

Within this genus, similarities are greatest with the LAPs of *Lapidaster fasciatus* (Kutscher & Villier, 2003) from the Toarcian-Aalenian of Germany and France, and *L. varuna* Thuy, 2013 from the Callovian of India. The here described material differs in the smaller size of the LAPs, lower number of spine articulations (three rather than four), the lower height/width ratio, the weakly developed vertical striation on the outer surface, and the dorsalwards tapering dorsal part of the ridge on the inner side of the LAPs. In particular the latter character is not related to size or ontogenetic stage (Thuy & Stöhr 2011), which prompts us to consider the here described LAPs as belonging to a new species.

The new species adds to the sparse middle Jurassic fossil record of the genus, closing a gap in the shallow-water record between the earliest Aalenian *Lapidaster fasciatus* and the Callovian *L. varuna* (Thuy 2013). The only other middle Jurassic species of the genus is *Lapidaster wolfii* Thuy, 2013 from Bajocian-Bathonian bathyal sediments of France.

### Genus *Alternacantha* Thuy & Meyer, 2012

Type species: *Alternacantha occulta* Thuy & Meyer, 2012, by original designation.

#### *Alternacantha cf. occulta* Thuy & Meyer, 2012

Fig. 4h-i

**Material examined:** BU 325, and BU 326 (4 dissociated LAPs in total).

**Description:** Large dissociated median to distal LAPs, as high as wide or slightly wider; with strongly concave dorsal edge as a result of a strong constriction; proximal edge weakly concave, with up to four poorly to moderately well defined, slightly prominent and protruding spurs; ventral third very large and strongly protruding ventro-proximalwards; ventro-distal tip of LAP tongue-shaped,

protruding ventralwards.. Outer surface with well developed, vertical striation, with stripes largest in dorso-distal part of outer surface, disintegrating into coarsely meshed stereom towards ventral and distal edges of LAP; narrow band of finely meshed stereom lining proximal edge. Three large, ear-shaped, nearly equidistant spine articulations in shallow notches of distal edge, moderately deeply incising outer surface stereom; median spine articulation largest.

Inner side of LAPs with well defined, prominent, simple, arcuate ridge, with very weakly widened, blunt, well defined dorsal and ventral tips. Two to three well defined, horizontally elongate, prominent spurs on inner distal edge. Small but very deep tentacle notch. One to two small, irregular perforations dorsally bordering inner side of tentacle notch.

**Remarks:** *Alternacantha occulta* was amply described on the basis of articulated skeletons (Thuy & Meyer 2012) and dissociated LAPs (Thuy 2013). The examined specimens are all from median to distal arm positions. A reliable assessment of the full set of diagnostic characters is ideally based on proximal LAPs (Thuy & Stöhr 2011). This is particularly the case in the *Alternacantha-Dermocoma* group, species of which commonly have indistinguishable median to distal LAPs (Thuy 2013). Therefore, in spite of the strong similarities with the median LAPs of *Alternacantha occulta* figured by Thuy and Meyer (2012) and Thuy (2012), we consider the species-level assignment as tentative.

Family Ophiodermatidae Ljungman, 1867

### Genus *Ophiotitanos* Spencer, 1907

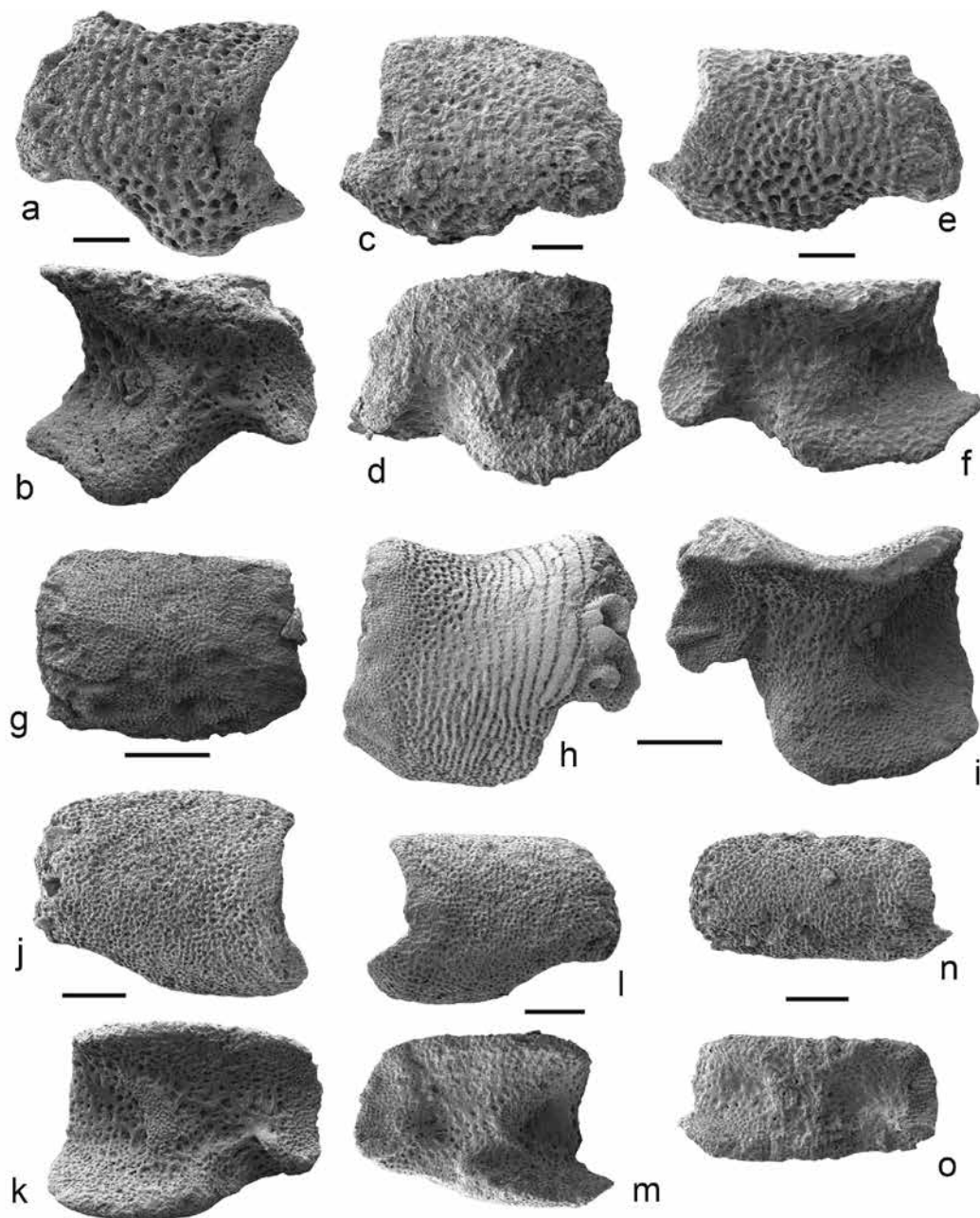
Type species: *Ophiotitanos tenuis* Spencer, 1907, by original designation.

#### *Ophiotitanos* sp.

Fig. 4g

**Material examined:** BU 335, and BU 336 (2 dissociated LAPs).

**Description:** Median to distal LAPs, as high as wide to almost 1.5 times wider than high; with ventro-proximalwards protruding ventral fifth in median LAPs to rounded rectangular in outline in distal ones; ventral and distal edges weakly convex; dorsal edge gently convex in median LAPs, straight in distal ones; proximal edge irregularly concave, tapered, with two large, poorly developed and weakly prominent spurs on the ventro-distal and dorso-distal tips; outer



**Fig. 4:** Dissociated ophiuroid lateral arm plates (LAPs) from a sandy clay bed with phosphorite nodules approximately 1 m above the base of the micaceous marls, Discites Zone, Walkeri Subzone, earliest Bajocian, Middle Jurassic, of Rumelange, Luxembourg. *Lapidaster hellersi* sp. nov., a-b: BU 321 (holotype), proximal LAP in external (a) and internal (b) views; c-d: BU 322 (paratype), median LAP in external (c) and internal (d) views; e-f: BU 323 (paratype), distal LAP in external (e) and internal (f) views; *Ophiotitanos* sp., g: BU 335, median to distal LAP in external view and with detail of spine articulation (h). *Alternacantha* cf. *occulta* Thuy & Meyer, 2012, h-i: BU 325, distal LAP in external (h) and internal (i) views. *Eozonella* sp. nov., j-k: BU 327, proximal LAP in external (j) and internal (k) views; l-m: BU 328, median LAP in external (l) and internal (m) views; n-o: BU 329, distal LAP in external (n) and internal (o) views. Scale bars equal 250 µm.

surface with finely meshed stereom, with trabecular intersections transformed into small, inconspicuous tubercles. Four to five nearly equal-sized spine articulations sunken in shallow notches of the distal LAP edge, with weak dorsalward increase in size of gaps separating the spine articulations; notches of the spine articulations tightly encompassed by outer surface stereom and separated by distalward projections of the latter; spine articulations composed of a large, crescent-shaped dorsal lobe and a smaller ventral lobe; lobes proximally merged by a thin ridge.

Inner side of median LAPs unknown due to poor preservation; distal LAPs with large, conspicuous contact surfaces with opposite LAP; small, inconspicuous, well defined ridge with proximalwards bent, pointed dorsal tip; two moderately large, poorly defined and hardly prominent spurs composed of slightly more densely meshed stereom on inner distal edge. Large, round tentacle perforation between the distal and middle third of the inner side, proximally bordering the ventral spur. No other perforation or furrow discernible.

**Remarks:** The available material is very limited both in terms of abundance and preservation. To make matters worse, only median to distal LAPs are available. This is unfortunate considering that the analysis of Thuy and Stöhr (2011) clearly showed that identifications of dissociated LAPs should be based on adult, proximal plates. The here proposed identification is thus to be considered as preliminary.

The above described LAPs share striking similarities with the median and distal LAPs described by Thuy (this volume) as the new species *Ophiotitanos aschmannicor*. The spine articulation morphology of the LAPs at hand, however poorly preserved, corroborates assignment to the Ophiidermatidae. Awaiting the discovery of more complete material, and in particular of well preserved proximal LAPs, and in the light of the similarities with the LAPs of near-coeval *Ophiotitanos aschmannicor*, we thus consider the above described material as undetermined record of *Ophiotitanos*.

Family Ophiolepididae Ljungman, 1867

**Genus *Eozonella* Thuy, Marty & Comment, 2013**

Type species: *Eozonella bergeri* Thuy, Marty & Comment, 2013, by original designation

*Eozonella* sp. nov.

Figs. 4j-p

**Material examined:** BU 327, BU 328, BU 329; and BU 330 (20 dissociated LAPs)

**Description:** Very small, fragile dissociated LAPs, elongate, 1.5 (proximal LAPs) to 2.5 (distal LAPs) wider than high, rounded outline, with convex dorsal, distal and ventral edges; ventral quarter of proximal and median LAPs protruding ventro-proximalwards; proximal edge concave, with two poorly defined, slightly prominent and protruding spurs composed of slightly more densely meshed stereom, one in the middle of the proximal edge, the second in the middle of the ventral half of the proximal edge. Outer surface of LAPs with moderately coarsely meshed stereom devoid of any conspicuous ornamentation; narrow band of slightly more finely meshed stereom lining proximal edge of LAPs. Three (proximal and median LAPs) to two (distal ones) small, equal-sized and equidistant spine articulations sunken into and tightly surrounded by outer surface stereom at distal edge of LAPs; spine articulations composed of horizontal, nearly parallel dorsal and ventral lobes composed densely meshed stereom, proximally separated by two to three very small, irregular knobs.

Inner side of LAPs with sharply defined, prominent ridge composed of more finely meshed stereom, with round, ventralwards pointing ventral portion not merged with ventral part of LAP, and slightly tapering dorso-proximalwards pointing dorsal portion. Well defined, elongate, strongly oblique, prominent spur on the ventro-distal tip of the inner side of the LAP. Large, deep tentacle notch on all LAPs, bordered by slightly thickened edges of ventral portion of LAP. No perforations or furrow discernible.

**Remarks:** The LAPs described above are unambiguously assignable to the group of ophiolepidids comprising extant *Ophiozonella* Matsumoto, 1915 and its morphologically very similar extinct relative *Eozonella* Thuy, Marty & Comment, 2013, on account of the outline of the LAPs, the ventro-proximalwards protruding ventral portion, the spurs on the outer proximal and inner distal edges, the shape of the ridge on the inner side, and the shape and position of the spine articulations. When introducing the new genus *Eozonella* to accommodate extinct *Ophionella*-like ophiuroids, Thuy et al. (2013) worked out clear-cut differences between the two in terms of general skeletal morphology. They stressed, however, that both share very

similar LAP morphologies. A LAP-based diagnosis of *Eozonella* is yet to be put forward. The shape and position of the spurs on the outer proximal and inner distal edges as well as the absence of a fine horizontal striation lining the outer proximal edge of the LAPs suggest assignment of the here described specimens to *Eozonella* rather than *Ophiozonella*, at least when referring to the type species *Ophiozonella longispina* (Clark, 1908).

Three species have been assigned to *Eozonella* so far, namely the type species *E. bergeri*, the Oxfordian *E. oertlii* (Hess, 1965) and the Bajocian/Bathonian *E. bathonica* (Hess, 1964). All three display much larger and stouter LAPs with a higher number of spine articulations than the here described specimens. We nevertheless refrain from formally introducing a new species as there are some more named records of Middle Jurassic *Ophiozonella*-like ophiuroids based on articulated skeletons, which are at present insufficiently known, especially with respect to their LAP morphology, and which thus cannot be satisfyingly compared with the material at hand. The records in question are *Ophiura tinurtiensis* Valette, 1929 from the Aalenian of France, *Ophiopeza ferrugineum* (Boehm, 1889) from the Bajocian/Bathonian of Germany and France, and *Ophiopeza portei* Guillaume, 1926 from the Bathonian of France, which Hess and Meyer (2008) assigned to the ophioleucin genus *Sinosura* on the basis of very limited morphological evidence. Pending a detailed re-assessment of the type specimens of these species, we treat the material at hand as an unknown, most probably new species of *Eozonella*.

Family unnamed (see O'Hara et al. 2014)

### Genus *Enakomusium* Thuy, this volume

Type species: *Ophioderma weymouthiense* Damon, 1880, by original designation.

#### *Enakomusium* cf. *ferrugineum* (Boehm, 1889)

Fig. 5

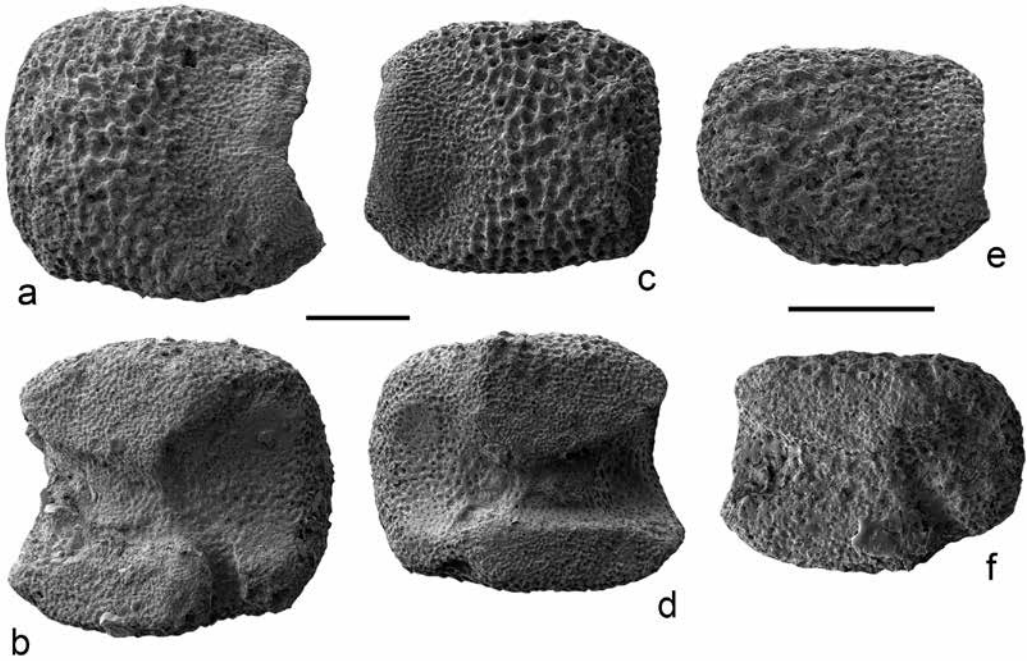
**Material examined:** BU 331, BU 332, BU 333; and BU 334 (42 dissociated LAPs)

**Description:** Medium-sized dissociated LAPs, proximal ones nearly as high as wide, distal ones 1.5 wider than high, all of rounded rectangular outline, with convex dorsal, distal and ventral edges; proximal edge weakly concave, with two to three, weakly prominent and protruding, poorly defined (proximal LAPs) to almost indiscernible

(median to distal LAPs) spurs composed of slightly more densely meshed stereom; proximal edge paralleled by a deep, conspicuous furrow. Outer surface with coarsely meshed stereom, with irregularly angular, pointed trabecular intersections; outer surface stereom mesh size strongly decreasing towards furrow paralleling proximal edge. Four (proximal LAPs) to two (distal LAPs) small, prominent but poorly discernible spine articulations integrated into and tightly surrounded by outer surface stereom; spine articulations separated from distal edge by a gap as wide as the spine articulations or slightly narrower; dorsalward increase in size of spine articulations and of gaps separating them; large gap between dorsalmost spine articulation and dorsal edge in proximal LAP; spine articulations composed of a small muscle opening ventro-proximally tightly encompassed by a coarsely rugose semi-circular ridge, and distally separated from a slightly smaller nerve opening by a short, vertical, rugose ridge; distal LAPs with conspicuously enlarged, lip-shaped ridge separating muscle and nerve openings.

Inner side of LAP with large contact surfaces with opposite LAP; small, sharply defined, prominent ridge with tongue shaped, proximalwards bent and tapering dorsal tip in proximal LAPs, and small, poorly defined triangular ridge in median to distal ones. Deep, narrow but sharply defined, ventralwards pointing tentacle notch in proximal to median and sometimes even distal LAPs; large, round tentacle perforations in median to distal LAPs. Two poorly defined, non-prominent spurs on inner distal edge, composed of more densely meshed stereom. No perforation discernible.

**Remarks:** The above described LAPs display the combination of characters typically found in the genus *Enakomusium*, introduced by Thuy (this volume) to accommodate ophiuroids which are superficially similar to extant *Ophiomusium* but which differ in a higher number of between-plate tentacle openings (in contrast to within-plate tentacle perforations) per arm, a generally rounder outline of the LAPs, and a deep furrow paralleling the proximal LAP edge. The LAPs at hand share striking similarities with those assigned by Thuy (this volume) to *Enakomusium ferrugineum* from the early Bajocian of nearby Longwy, France. Minor differences pertain to a smaller size, a lower height/width ratio, a coarser outer surface



**Fig. 5:** Dissociated lateral arm plates (LAPs) of *Enakomusium ferrugineum* (Boehm) from a sandy clay bed with phosphorite nodules approximately 1 m above the base of the micaceous marls, Discites Zone, Walkeri Subzone, earliest Bajocian, Middle Jurassic, of Rumelange, Luxembourg. a-b: BU 331, proximal to median LAP in external (a) and internal (b) views; c-d: BU 332, median LAP in external (c) and internal (d) views; e-f: BU 333, distal LAP in external (e) and internal (f) views. Scale bars equal 250  $\mu$ m.

stereom and a higher number of arm segments with between-plate perforations.

Chances thus are that the here described LAPs belong to a new species. It must be reminded, however, that the assignment of the material described by Thuy (this volume) to *E. ferrugineum* is based on comparison with non-type articulated skeletons. Considering that currently known species of *Enakomusium* show highly similar LAP morphologies, and pending a detailed re-examination of the holotype of *E. ferrugineum*, in particular with respect to its LAP morphology, we refrain from introducing a new species here.

## Discussion

The echinoderm assemblage described herein is among the first from the Bajocian of the north-western Tethys to be recovered from purely siliciclastic sediments. The most striking difference to

coeval echinoderm assemblages from carbonate platform deposits is the composition of the crinoid fauna. The enigmatic *Cyclocrinus* is reasonably common in siliciclastic settings of Bathonian to Oxfordian age but Bajocian occurrences are exceedingly rare (Hess 2008). The second common crinoid of the here described assemblage is a species of *Balanocrinus*, an isocrinid which, in contrast to its relatives such as *Chariocrinus*, *Hispidocrinus* and *Pentacrinites*, generally lacks from the north-western Tethyan carbonate platform settings and instead more commonly occurs in siliciclastic deposits, especially those closer to the open ocean of the Tethys (Hess & Pugin 1983; Hess 2012). The asteroids and ophiuroids of the assemblage at hand corroborate a more open ocean or more Tethyan affinity of the assemblage, as they include extant deep-water taxa (Benthoptectinidae and Korethrasteridae/Pterasteridae) and the extinct *Lapidaster* which have not yet been reported from coeval carbonate platform settings.

Altogether, the echinoderm fauna described in this study seems to document a stronger Tethyan affinity than coeval and slightly younger carbonate platform equivalents. Our study endorses the inclusion in palaeo-biodiversity surveys of depositional settings which might seem unusual or less attractive than those producing more abundant and/or articulated remains. As shown here, such settings are likely to yield taxa which would otherwise pass unnoticed.

## Acknowledgments

We are grateful to Jean-Michel Guinet (Luxembourg, L) for granting access to the Scanning Electron Microscope facilities of the Natural History Museum in Luxembourg, to Roby Weis (Luxembourg, L) for inciting submission of the present contribution to *Ferrantia*, to Marcelline Haas (Steinsel, L) who collected some of the specimens and donated them to the Natural History Museum Luxembourg, and an anonymous reviewer whose comments greatly improved an earlier version of the manuscript.

## References

- Ausich, W.I., 2001. - Echinoderm taphonomy, in: Jangoux, M., Lawrence, J.M. (Eds.), *Echinoderm studies* 6. Balkema, Rotterdam: 171-227.
- Boehm, G. 1889. - Ein Beitrag zur Kenntnis fossiler Ophiuren. Bericht der naturforschenden Gesellschaft Freiburg. Breslau 4: 232-287.
- Boulvain, F., Belanger, I., Delsate, D., Ghysel, P., Godefroit, P., Laloux, M., Monteyne, R., Roche, M. 2001. - Triassic and jurassic lithostratigraphic unites (Belgian Lorraine). *Geologica Belgica* 4(1-2): 113-119.
- Brigaud, B., Durllet, C., Deconinck, J.-F., Vincent, B., Puc  at, E., Thierry, J. & Trouiller, A. 2009. - Facies and climate/environmental changes recorded on a carbonate ramp: A sedimentological and geochemical approach on Middle Jurassic carbonates (Paris Basin, France). *Sedimentary Geology* 222: 181-206.
- Brigaud, B., Vincent, B., Carpentier, C., Robin, C., Guillocheau, F., Yven, B. & Huret, E. 2013. - Growth and demise of the Jurassic carbonate platform in the intracratonic Paris Basin (France): Interplay of climate change, eustasy and tectonics. *Marine and Petroleum Geology*, doi: <http://dx.doi.org/10.1016/j.marpetgeo.2013.09.008>.
- Clark, H.L. 1908. - Some Japanese and East Indian Echinoderms. *Bulletin of the Museum of Comparative Zoology* 51(11): 279-311.
- Damon, R. 1880. - Supplement to the Geology of Weymouth and the Isle of Portland. 2nd edition. London.
- Gale, A. S. 2010. - The phylogeny of post-Palaeozoic Asteroidea (Neoasteroidea, Echinodermata). *Special Papers in Palaeontology* 85: 1-112.
- Gu  rin-Franiatte, S. & Weis, R. 2010. - Le passage Aal  nien-Bajocien pr  s de Rumelange: la s  rie biostratigraphique dans le Bassin d'Esch-sur-Alzette (Grand-Duch   de Luxembourg). *Ferrantia* 62 : 73-96.
- Guillaume, L. 1926. - *Ophiopeza portei*, Ophiure nouvelle du Bathonien sup  rieur de Ranville (Calvados). *Compte Rendu Sommaire et Bulletin de la Soci  t   G  ologique de France* 4(26): 117-127.
- Hess H. 1964. - Die Ophiuren des englischen Jura. *Eclogae geologicae Helvetiae* 57: 756-801.
- Hess H. 1965. - Mikropal  ontologische Untersuchungen an Ophiuren IV: Die Ophiuren aus dem Renggeri-Ton (Unter-Oxford) von Chapois (Jura) und Longcombe (Ain). *Eclogae geologicae Helvetiae* 58: 1059-1082.
- Hess, H. 1972. - Eine Echinodermenfauna aus dem mittleren Dogger des Aargauer Juras. *Schweizerische Pal  ontologische Abhandlungen* 92: 1-87.
- Hess, H. 2008. - *Cyclocrinus*, an enigmatic Jurassic-Cretaceous crinoid. *Swiss Journal of Geosciences* 101: 465-481.
- Hess, H. 2012. - Crinoids from the Middle Jurassic (Bajocian-Lower Callovian) of Ard  che, France. *Swiss Journal of Palaeontology* 131: 211 - 253.
- Hess, H. 2013. - *Balanocrinus* (Crinoidea) from the Jurassic: species concept, reconstruction, ontogeny, taphonomy and ecology. *Swiss Journal of Palaeontology*. <http://dx.doi.org/10.1007/s13358-013-0062-2>.

- Hess, H. & Holenweg, H. 1985. - Die Begleitfauna auf den Seelilienbänken im mittleren Dogger des Schweizer Juras. Tätigkeitsberichte der Naturforschenden Gesellschaft Baselland 33: 141-177.
- Hess, H. & Meyer, C.A. 2008. - A new ophiuroid (*Geocoma schoentalensis* sp. nov.) from the Middle Jurassic of north-western Switzerland and remarks on the family Aplocomidæ Hess, 1965. Swiss Journal of Geosciences 101: 29-40.
- Hess, H. & Pugin, L. 1983. - *Balanocrinus berchteni* n.sp., un nouveau crinoïde bajocien des Préalpes médianes fribourgeoises. Eclogae geologicae Helvetiae 76: 691-700.
- Kutscher, M. & Villier, L. 2003. - Ophiuroid remains from the Toarcian of Sainte-Verge (Deux-Sèvres, France): paleobiological perspectives. Geobios 36: 179-194.
- Matsumoto, H. 1915. - A new classification of the Ophiuroidea: with description of new genera and species. Proceedings of the Academy of Natural Sciences of Philadelphia 68: 43-92.
- O'Hara, T.D., Hugall, A.F., Thuy, B. & Moussalli, A. 2014. - Phylogenomic Resolution of the Class Ophiuroidea Unlocks a Global Microfossil Record. Current Biology 24: 1-6.
- Orbigny, A. d' (1840-41). - Histoire naturelle, générale et particulière, des Crinoïdes, vivants et fossiles, comprenant la description géologique et zoologique de ces animaux. Livr. 1, 1-32 (1840); livres 2-3, 33-98 (1841) (republished 1858), published by the author. Paris.
- Pieńkowski G., Schudack M.E., Bosák P., Enay R., Feldman-Olszewska A., Golonka J., Gutowski J., Herngreen G.F.W., Jordan P., Krobicki M., Lathuilière B., Leinfelder R.R., Michalik J., Mönnig E., Noe-Nygaard N., Pálffy J., Pint A., Rasser M.W., Reisdorf A.G., Schmid D.U., Schweigert G., Surlyk F., Wetzel A. & Wong T.E. 2008. Jurassic. In: McCann T. (ed.) The geology of central Europe 2: Mesozoic and Cenozoic: 823-922. The Geological Society, London.
- Smith, A. B. & Kroh, A. 2011. - The Echinoid Directory. World Wide Web electronic publication. <http://www.nhm.ac.uk/research-curation/projects/echinoid-directory> [accessed 23.01.2014].
- Smith, A. B., Paterson, G. L. J. & Lafay, B. 1995. - Ophiuroid phylogeny and higher taxonomy: morphological, molecular and palaeontological perspectives. Zoological Journal of the Linnean Society 114: 213-243.
- Spencer, W.K. 1907: A Monograph of the British Fossil Echinodermata from the Cretaceous formations. Volume second: The Asteroidea and Ophiuroidea. Paleontographical Society Monographs 2(4): 91-132.
- Thuy, B. 2003. - Les échinides du Bajocien de Rumelange (Grand-Duché de Luxembourg). Ferrantia 36: 79-123.
- Thuy, B. 2010. - An early Bajocian echinoid fauna from Differdange and Pétange (Luxembourg), including a new Rhabdocidaroid species. Ferrantia 62: 97-114.
- Thuy, B. 2013. - Temporary expansion to shelf depths rather than an onshore-offshore trend: the shallow-water rise and demise of the modern deep-sea brittle star family Ophiacanthidae (Echinodermata: Ophiuroidea). European Journal of Taxonomy 48: 1-242.
- Thuy, B. this volume. - A peri-reefal brittle-star (Echinodermata : Ophiuroidea) assemblage from the Middle Jurassic of the northeast Paris Basin. Ferrantia.
- Thuy, B., Marty, D. & Comment, G. 2013. - A remarkable example of a Late Jurassic shallow-water ophiuroid assemblage from the Swiss Jura Mountains. Swiss Journal of Geosciences 106: 409-426.
- Thuy, B. & Meyer, C.A. 2012. - The pitfalls of extrapolating present-day depth ranges to fossil communities: new insights from brittle stars (Echinodermata: Ophiuroidea) from the Middle Jurassic of Switzerland. Swiss Journal of Palaeontology 132: 5-21.
- Thuy, B., Stöhr, S. 2011. - Lateral arm plate morphology in brittle stars (Echinodermata: Ophiuroidea): new perspectives for ophiuroid micropalaeontology and classification. Zootaxa 3013: 1-47.
- Vadet, A. 1991. - Revision des "Cidaris" du Lias et du Dogger Européens. Mémoires de la Société du Bolognais 10 : 1-167, pls 1-9.
- Vadet, A. & Slowik, D. 2001. - Les oursins du Bajocien de Liocourt. Mémoires de la Société Académique du Boulonnais. Série Histoire Naturelle 22 : 1-48.
- Valette, A. 1929. - Note sur quelques stellerides jurassiques du Laboratoire de Géologie de la Faculté des Sciences de Lyon. Travaux du Laboratoire de Géologie de la Faculté des Sciences de Lyon, 16, 1-62.