A NEW SPECIES OF GONIASTERID STARFISH FROM CHERT IN THE UPPER GREENSAND FORMATION (LOWER CRETACEOUS: ALBIAN) OF LYME REGIS, DORSET, UK

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Andrew, C., Gale, A.S., Howe. P. and Paul, C.R.C. 2015. A new species of goniasterid starfish from chert in the Upper Greensand Formation (Lower Cretaceous: Albian) of Lyme Regis, Dorset, UK. *Geoscience in South-West England*, **13**, 371-376.

A new species of goniasterid starfish, *Nymphaster lymensis*, is recorded in a chert nodule from the Albian Upper Greensand Formation, found loose east of Lyme Regis, Dorset, UK. It preserves much of the largely articulated marginal frame, and clearly shows a stellate outline. The new species is characterized by the presence of at least five broad interradial superomarginal ossicles and extends the known stratigraphic range of *Nymphaster* back to the Albian. The preservation is remarkable as the Upper Greensand is typically a high-energy, cross-bedded sandy formation. Trace fossils imply that sedimentation continued for some time after the initial burial event, thus ensuring the specimen was not subsequently disturbed.

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Keywords: Goniasteridae, *Nymphaster lymensis* sp. nov., Upper Greensand, Palaeoecology, Dorset.

INTRODUCTION

Starfish generally have loosely associated plates that fall apart soon after death. Preservation of articulated starfish requires very rapid burial and no subsequent disturbance. This is so well known that 'starfish beds' are specifically identified at various levels of the geological column, such as the starfish bed in the Downcliff Sand Member of the Dyrham Formation (Upper Pliensbachian) of west Dorset (see Goldring and Stephenson, 1972 for an analysis of this particular starfish bed). Indeed, the term 'starfish bed' is sometimes loosely applied to describe fossil lagerstätten with exceptional preservation due to rapid burial. Starfish beds tend to be formed by an exceptional, sudden influx of sediment into a generally quiet environment. It was, therefore, surprising to discover an articulated goniasterid starfish in a loose chert nodule from the Upper Greensand east of Lyme Regis, because the Upper Greensand is largely a high-energy, cross-bedded sandy unit, especially at the levels where the chert beds are developed (Gallois, 2004) that shows much evidence of sediment reworking. Most other articulated goniasterid starfish from the British Cretaceous are preserved in the Chalk (Gale, 1986, 1987). The specimen is now in the Lyme Regis Museum, registration number LYMPH 2015/6.

Goniasterid starfish are characterized by two sets of large marginal ossicles that are often highly distinctive and can be specifically identified even when preserved as isolated ossicles (see, for example, Gale, 1988; Breton, 1992; Jagt, 2000; Villier, 2001). Thus, the stratigraphic distribution of Cretaceous goniasterid starfish is generally better known than that of most other types of starfish (Gale, 1986, 1987). The marginal ossicles form a strong marginal frame, within which smaller abactinal and actinal plus adambulacral ossicles complete the skeleton on their respective surfaces (see Gale, 1986, 1987 for a more complete review of goniasterid starfish morphology). This marginal frame also makes it easy to recognize fossil goniasterids.

METHODS

The chert nodule was found on the beach loose beneath Black Ven, east of Lyme Regis, Dorset (arrow in Figure 1). It reached the beach via the Black Ven landslip, thus it is impossible to deduce its original stratigraphic position. The nodule was subsequently lightly prepared using an airpen to expose some additional marginal ossicles. A 'silastic' cast was made in a vacuum chamber to study the specimen in positive relief. Photographs of the original chert nodule were taken using tungsten light with a Nikon D300 camera at varying object to camera distances and the proprietary software, Zerene Stacker, was used to produce the final photographs of the nodule.

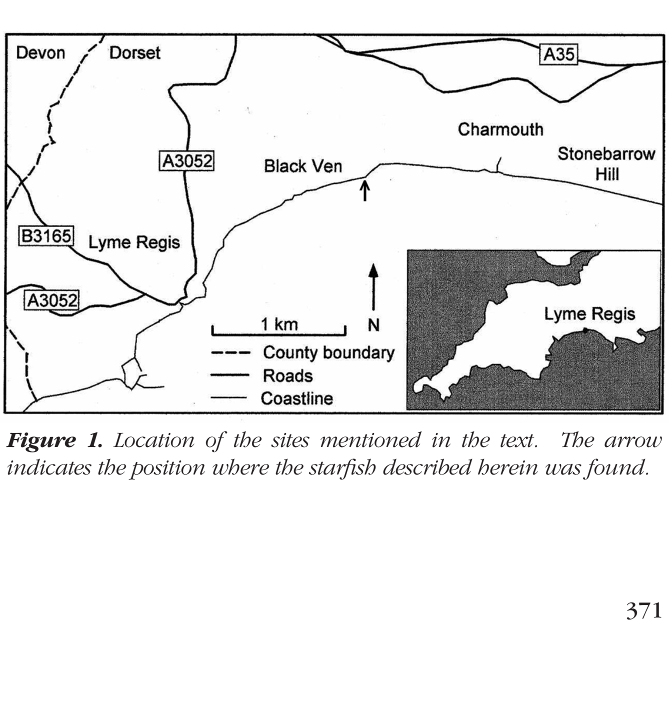

Figure 1. *Location of the sites mentioned in the text. The arrow indicates the position where the starfish described herein was found.*

Locality and horizon

Although the chert nodule was found loose on the foreshore south of Black Ven, it clearly comes from the chert beds within the local Upper Greensand. Mortimore *et al*. (2001) provided a thorough description of the Upper Greensand in South-West England. Gallois (2004) revised the lithostratigraphy of the Upper Greensand in South-West England and introduced three members; the Foxmould Member, the Whitecliff Chert Member and the Bindon Sandstone Member (Figure 2). His generalized section (Gallois, 2004, fig. 2, p. 24) has been modified to show the local succession east of Lyme Regis (Figure 2). This shows that most of the chert is developed in the Whitecliff Chert Member, but some chert beds are developed in bed 2 of the Bindon Sandstone Member as well. The ages of the two chert-bearing members are poorly constrained as age-diagnostic fossils are rare, so at present, we can only be certain that this starfish is late Albian in age.

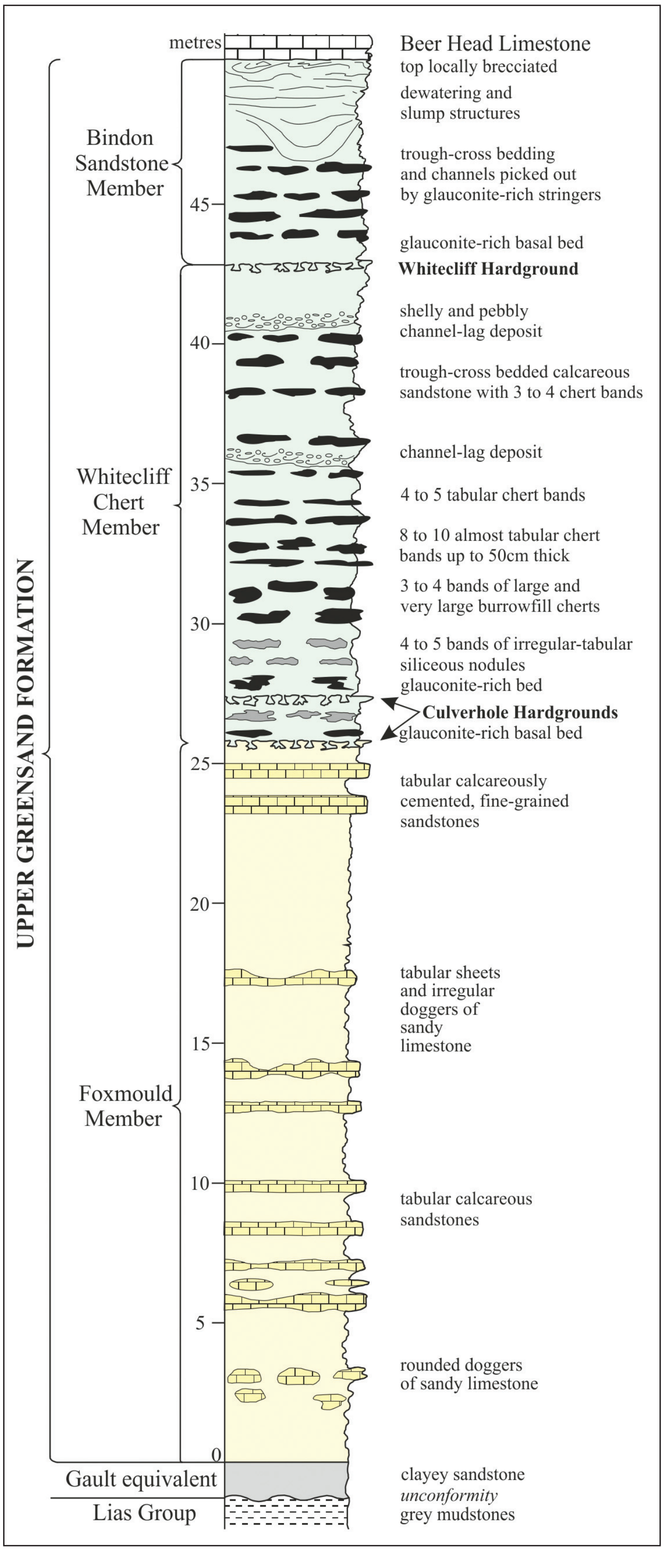

Figure 2. *Stratigraphy of the Upper Greensand Formation near Lyme Regis. Modified from Gallois (2004, fig. 2, p. 6) to reflect the local succession near Lyme Regis.*

Description

The original chert nodule measures approximately 155 by 80 mm and is up to 50 mm thick (Figures 3, 4). It is largely composed of medium sand, bound together to a greater or lesser degree with siliceous cement. No clear evidence of bedding can be detected on the sides of the chert nodule, although on one side differential cementation gives the impression of original bedding that is parallel to part of the upper surface. The upper surface is more porous, due to absence of cement and appears to have been the original surface of the chert bed. In contrast, the lower surface is much better cemented and may represent a break through the original bed, that is, a joint in the chert nodule. The upper surface

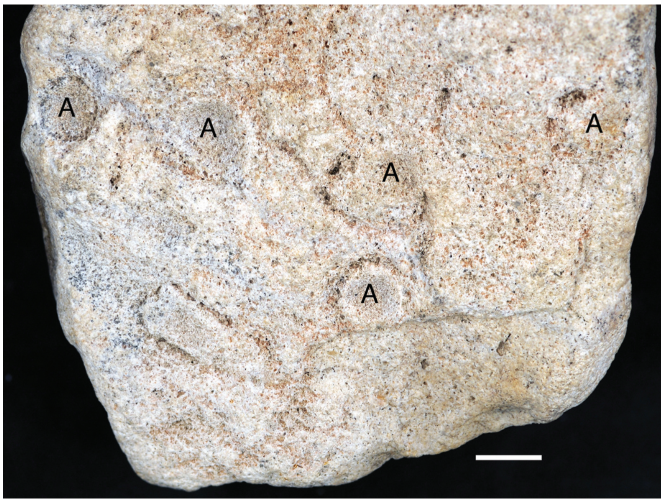

Figure 3. *Part of the upper surface of the chert nodule, LYMPH 2015/6, from the Upper Greensand Formation, east of Lyme Regis, showing the tops of the* Arenicolites *burrows (A). Scale bar = 10 mm.*

Figure 4. *Part of the lower surface of the chert nodule, LYMPH 2015/6, from the Upper Greensand Formation, east of Lyme Regis, showing the impression of the starfish. Note the large marginal ossicles. Scale bar = 5 mm.*

shows several examples of the U-shaped trace fossil *Arenicolites* (A in Figure 3). At least three of the *Arenicolites* tubes clearly show concave meniscus structures within their tubes, which help establish the original way up even though no complete U-shaped burrow is exposed. On one side a vertical burrow can be traced right through the chert nodule from top to bottom. The *Arenicolites* tubes are about 10 mm in diameter, set apart by about 15-20 mm (centre to centre) and with the axes between the two vertical burrows at various orientations. Three clear pairs can be recognized and each appears to have one tube larger than the other. The individual tubes appear to have been lined with slightly coarser sand grains, which weather out preferentially. Outlines of three more or less horizontal burrows can also be made out (Figure 3). The only other body fossils within the chert nodule are some isolated starfish ossicles, perhaps from the same specimen and a single, thin, curved shell fragment of uncertain affinities (Figure 4, lower left).

The starfish (Figures 4, 5b, d) is incompletely preserved at one end of the chert nodule on the opposite side to the tops of the *Arenicolites* burrows. This surface is better cemented. It reveals the abactinal (dorsal) surface of the starfish, in which case the starfish was preserved in life orientation. As now preserved the maximum major radius (R) of the starfish is about 45 mm and it is incomplete. We estimate R to have been about 50 mm originally. The minor radius (r) is about 20 mm. Thus, the starfish has a distinctly stellate outline, with obvious rows of larger marginal plates, with many abactinal plates scattered in the centre (Figure 4). One arm is almost complete, but unfortunately missing the tip due to truncation at the joint surface on that side of the chert nodule.

Palaeoecology and preservation

Starfish are fully marine predators extending from the intertidal zone down to abyssal depths (Hyman, 1955, p. 245 *et seq*.; Spencer and Wright, 1966, p. U24). Although their suckered tube-feet are most efficient on hard surfaces, starfish can and do live in loose sediments, including sands. Indeed, the development of a double series of large, marginal ossicles in goniasterid starfish may well be an adaptation to living on loose sediment by acting as a weight-belt and rendering overturning less likely. Gale (1988) recorded 18 species of asteroids, several under open nomenclature, from the Wilmington Sands (Lower Cenomanian), of the White Hart Pit, Wilmington, Devon. The Wilmington Sands are a slightly younger, variable series of loosely cemented and partially silicified medium to coarse sands, which were probably originally similar to the chert beds in the Upper Greensand, but subsequently became less thoroughly silicified (Smith *et al*., 1988, pp. 4-11). Similarly, MacLennon (1949) reported the preserved outline of a starfish, possibly *Calliderma*, from the Cenomanian, glass sands of Loch Aline, Scotland. Thus, it is not surprising to find a starfish preserved in the Upper Greensand. However, without exception all Gale's material from the Wilmington Sands was represented by isolated starfish ossicles and this is the usual preservation in high-energy environments. Articulated goniasterid starfish from the British Cretaceous are almost exclusively found in the Chalk, which represents a much quieter environment (Gale, 1986, 1987). The specimen is noteworthy because it was not completely disarticulated before final burial. Indeed it is likely that it was buried within a few days at most of its death and not subsequently disturbed.

The preservation shows that the starfish ossicles had begun to separate, but otherwise the starfish was largely intact when buried. Indeed it is possible that some of the separation of the marginal ossicles happened after burial. Equally, the disruption of the abactinal ossicles may have been due to escape of decomposition gases again after final burial. The fact that a few abactinal ossicles have been overturned or lie on their sides is compatible with this suggestion. If the starfish was still exposed on the sea floor when this disruption occurred one might expect more of the abactinal ossicles to be washed away completely in such a high-energy environment.

The chert nodule is penetrated by *Arenicolites* burrows. There is no clear evidence of such burrows immediately above the starfish on the upper surface of the nodule. However, clearly if such burrowing activity had penetrated the starfish it would account for loss of some ossicles. Indeed, within the abactinal surface there are two patches free of all ossicles that are about the same size as the vertical *Arenicolites* tubes (Figure 4), so this possibility cannot be discounted. Gale (1986, p. 3) recorded examples of chalk goniasterid starfish penetrated by burrows with, in one case, disturbed ossicles distributed in the burrow fill down to 50 cm below the specimen. Similarly, a slab from one of the Downcliff Sand starfish beds in the Lyme Regis Museum (Registration No. LYMPH 1990/1) shows a burrow that has ploughed through numerous brittlestars truncating their arms.

Arenicolites burrows are normally simple U-shaped burrows without internal structures. The presence of meniscus structures in burrows is usually interpreted as due to active backfill by the burrowing organisms (see Bromley, 1990). Furthermore, in horizontal burrows the concave side of the menisci faces the direction in which the animal was moving. Meniscus structures in vertical burrows are usually a response to gradual sedimentation and the organisms adjusting to the rising sediment/water interface, that is, they are equilibrium structures. Thus, we think the starfish was initially buried by a sudden influx of sediment several centimetres thick. This sediment was later colonized by the *Arenicolites*-producing organisms, which responded to more gradual sedimentation by actively backfilling the lower parts of the vertical tubes. Almost certainly, this continued sedimentation eventually buried the starfish deeply enough to prevent any further reworking.

The diagenesis of the specimen is also significant. The first effect must have been the precipitation of inorganic calcite in optical continuity with the original biogenic calcite of the stereom of the starfish ossicles. This produced solid crystals of calcite so characteristic of fossil echinoderms. Later other calcareous sediment particles were both replaced and cemented by diagenetic silica, thus producing a well-cemented chert nodule. However, the solid calcite starfish ossicles resisted the silica replacement. Later still the calcite ossicles were dissolved away leaving hollows in the siliceous chert nodule, which makes the specimen so obvious.

Finally, the chert nodule was cemented by siliceous cement to a greater or lesser degree. Under the microscope the external surface ornament of the marginal and abactinal ossicles appears to have been enhanced by overgrowth of this siliceous cement. However, the originally smoother inner surfaces and the facets between ossicles, although they show evidence of a similar process, are still very much smoother than the external surfaces. Nevertheless, we are doubtful that the surface ornament apparent on the silastic cast truly represents the original external surface of the starfish ossicles.

Systematic palaeontology

Asteroids are uncommon fossils in the Upper Greensand Formation of southern England, although isolated marginals of the astropectinid *Tethyaster* sp. are locally common on the Devon coast. Only a few specimens of articulated asteroids, all goniasterids, have previously been recorded from the Upper Greensand:

1) *Comptonia elegans* Gray; H. *varicosum* subzone, Blackdown (NHMUK E 2567).
2) *Comptoniaster comptoni* (Forbes); *H. varicosum* Subzone, Blackdown (NHMUK OR 34311).
3) *Comptonia wightensis* Breton, 1992; UGS Isle of Wight (NHMUK 48620).

These specimens have been examined in the Natural History

Museum, London (NHMUK). The matrix of the unique specimen of *C. wightensis* contains gastropods typical of the Crackers Member at the top of the Atherfield Clay Formation (Lower Greensand Group, Early Aptian, *D. deshayesi* Zone) and is clearly mislabelled. *Comptonia elegans* is a highly distinctive small goniasterid asteroid (Figure 5c), also known from the Albian of Normandy (Breton 1992). *Comptoniaster* is characterized by the presence of obliquely oriented slit-like bivalved pedicellariae on the marginal ossicles. The new specimen falls in the extant genus *Nymphaster*, and is the oldest known undoubted species of the genus, although Breton (1992) and Villier (2010, p. 702) have recorded two questionable

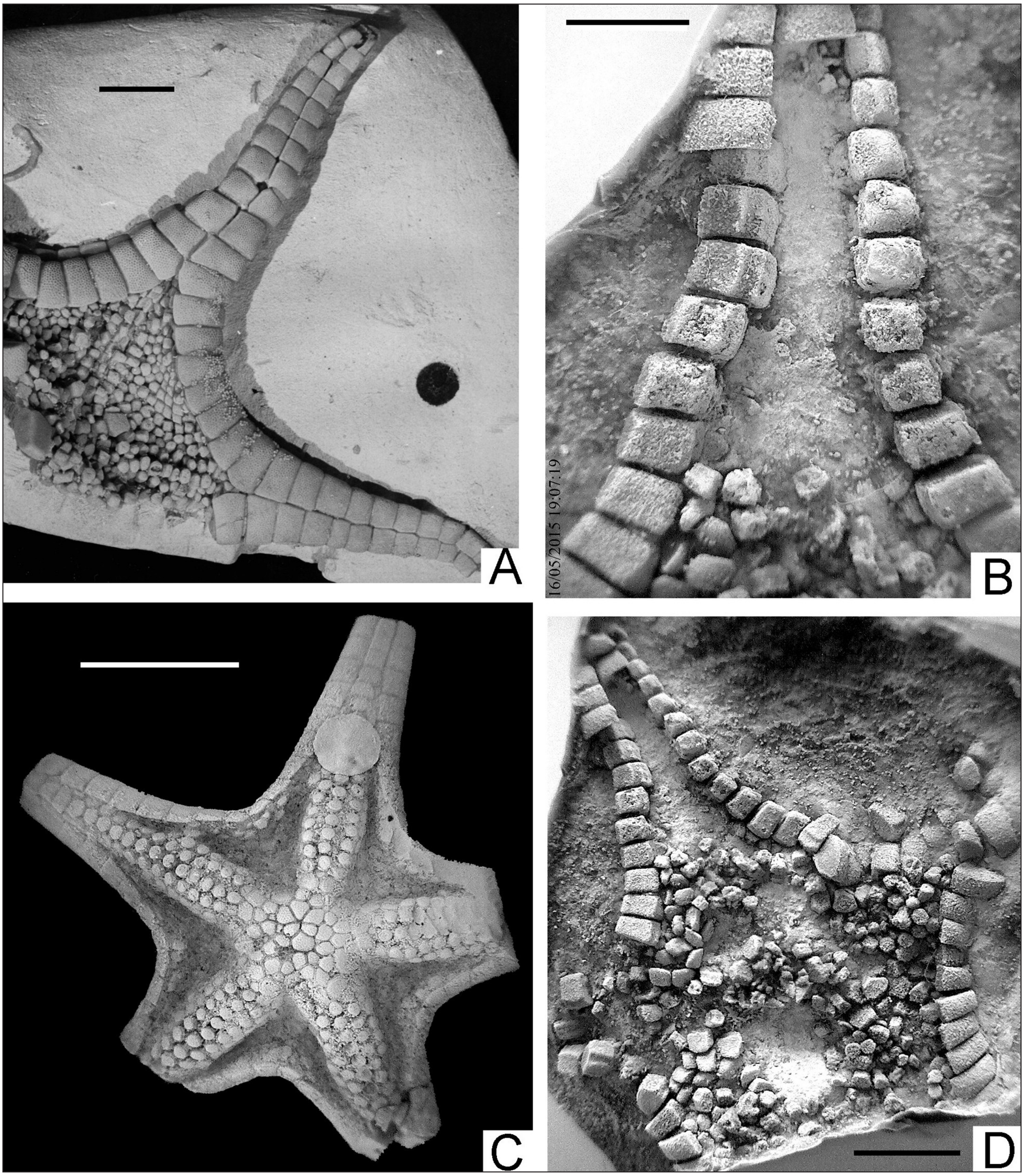

Figure 5. ***(a)*** Nymphaster humilis *Schulz and Weitschat 1975; abactinal aspect of holotype NHMUK E 28407, Santonian, Broadstairs, Kent. Original of Schulz and Weitschat 1975, pl. 29, figs 1,2, and Gale 1987, pl. 2, fig. 3. B, D,* Nymphaster lymensis *sp. nov. silastic cast from holotype LYMPH 2015/6 external mould, Chert Beds, Upper Albian, east of Lyme Regis, Dorset, UK.* ***(b)*** *View of radius, showing articular faces of inferomarginals where superomarginals have disarticulated prior to burial, and (upper part of image) four distal superomarginals in place.* ***(d)*** *Abactinal aspect of holotype.* ***(c)*** *Lectotype of* Comptonia elegans *Gray, original of Forbes in Dixon 1850, pl. 22, fig. 9, and Spencer 1907, pl. 27, fig. 4. Blackdown Greensand, Upper Albian,* H. varicosum *Subzone, Blackdown, Devon. NHMUK E2567. Scale bars in* ***(a)***, ***(c)*** *and* ***(d)*** *= 10 mm; in* ***(b)*** *= 5 mm.*

Albian species of *Nymphaster* from France, based on isolated ossicles.

Genus *Nymphaster* Sladen, 1889, p. 294 (=*Nymphaster* Sladen 1885, p. 612, which is not an available name as no species were cited. ICZN Article 12.2.5. Ride *et al.* 1999).

Nymphaster lymensis Gale sp. nov.
Figures 4; 5b, d; 6c, d.

Type specimen

Preserved in a chert nodule in Lyme Regis Philpot Museum, registration number LYMPH 2015/6.

Derivation of name

In reference to Lyme Regis, Dorset, UK, the source of the unique specimen.

Diagnosis

Nymphaster which possesses short, broad interradial superomarginals; at least five interradial superomarginals present.

Description

The cast of the natural external mould in chert (Figures 5b, d) shows the overall form of the asteroid, but many ossicles, notably superomarginals, have fallen away, presumably before burial. The abactinal ossicles are disarticulated but remain within the disc, and the external surfaces of the marginals, although sharply defined, have lost all surface features - the pits for granular spines and any pedicellariae which may have been present. The specimen includes one partial articulated radius, missing most superomarginals, and an interradius in which the superomarginals are articulated but slightly displaced. A camera lucida drawing of the interradial superomarginals was made, and this permits reconstruction of the form of the abactinal interradius and base of the arms (Figure 6c), which proved important in identifying the generic affinity of the specimen. The interradial superomarginals broaden progressively distally from SM1 to SM4, and the line of contact between successive marginals becomes slanted towards the interradius. SM1 and 2 are broader than long and symmetrically trapezoidal in outline; SM3 and 4 are asymmetrical and the distal margin is longer than the proximal one. SM5 is symmetrically trapezoidal. The distally broadening, progressively more asymmetrical interradial marginals are characteristic of *Nymphaster* (compare with *N. humilis* (Schulz and Weitschat, 1975, fig. 1A; see also Gale 1987)). The superomarginals of the radius in *N. lymensis* sp. nov. appear to have been in contact over the mid-radial line (Figure 5b) and there is no evidence of intercalated abactinal ossicles having been present. The contact of the superomarginals over the radius is also characteristic of *Nymphaster*. The interradial profile of the proximal marginals (Figure 6d) shows a wedge-shaped superomarginal, with a slanted abactinolateral surface. The inferomarginal profile has a more curved external surface.

Remarks

The specimen is placed in *Nymphaster* for the following reasons:

1) The interradii are straight (Figure 6a), and therefore the arms were quite sharply demarcated from the disc.
2) The superomarginals on each side of the arms appear to have articulated across the radius (Figure 6b), as in *N. humilis* (Figure 6b).
3) The interradial marginals broaden distally from SM1 to SM4-5.

N. lymense differs from *N. coombi* (Forbes, 1850) in the larger number of interradial marginals and the gently sloping interradial profile of the proximal marginals (in *N. coombi* these have discrete lateral and abactinal surfaces). It differs from more derived Cretaceous *Nymphaster* species in the apparent absence of an enlarged 'angle' superomarginal, typically SM3 or SM4) which marks the base of the radii (e.g. *N. alseni* Schulz and Weitschat, 1971; pl. 25, figs 20, 21). *N. lymensis* sp. nov. is closest to *N. humilis*, but differs in the broader, shorter form of the interradial superomarginals, and the fact that the contact between superomarginals over the radius must have commenced at SM6 rather than SM4 as in *N. humilis* (Figure 6).

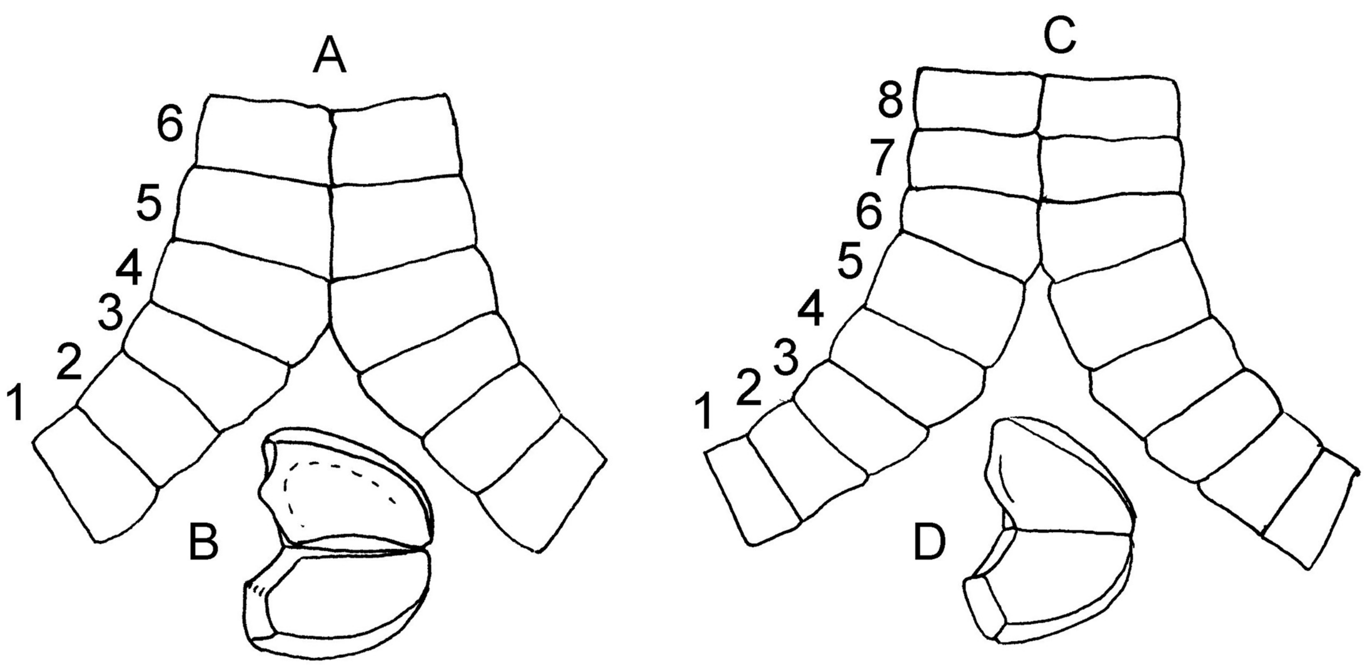

Figure 6. *Comparison of Cretaceous species of* Nymphaster. ***(a)*** *Reconstruction of a radius of* Nymphaster humilis *and* ***(b)*** *profile of interradial marginals.* ***(c)*** *Reconstruction of a radius of* Nymphaster lymensis *sp. nov. and* ***(d)*** *profile of interradial marginals.*

ACKNOWLEDGEMENTS

The starfish was found on a fossil walk organized through Lyme Regis Museum. We are grateful to the anonymous finder who immediately donated it to the Museum. Patrick D. McDermott, of St Clears, Carmarthenshire, prepared silastic casts in a vacuum chamber and John Marriage of Uplyme, Devon, helped with the photography. Ramues Gallois provided Figure 2. Comments from J.W.M. Jagt and Ramues Gallois greatly improved the original version of the manuscript.

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