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CRETACEOUS ASTEROIDS FROM CALIFORNIA[1]

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WHILE examining the strata exposed in a roadcut along the North Fork of Matilija Creek, Ventura County, California, the junior author made an unusual paleontologic discovery. In an otherwise barren sequence of shales he uncovered a colony of fossil starfish, a group of animals that are very poorly represented in the North American Mesozoic and Cenozoic fossil record. At the time of the original discovery only a few fragmentary specimens were collected. Later after the importance of his find had been recognized, the junior author made a second trip to the locality and collected additional material. Subsequently the senior author visited the locality but no additional specimens were collected. In all, material representing over 35 individuals of *Astropecten* and one specimen of *Henricia* was collected.

The regional geology of the area has previously been mapped in a reconnaissance manner and the general stratigraphic succession established by Kerr and Schenck (1928). According to their work, the fossil locality here described falls in the "Chico formation" of upper Cretaceous age (*loc. cit.*, fig. 4a). Inasmuch as no fossils other than the ones here described have been found in the area by the authors the age of the present fossils is determined by Kerr and Schenck's work.

For comparison with the present species, a search of the literature has been made for references to North American Jurassic, Cretaceous and Cenozoic asteroids and their relatives, the ophiuroids. Thirty-three citations were found in which there are 6 references to Jurassic species, 18 references to Cretaceous occurrences and 16 references to Tertiary records.

The Jurassic records are very few, only two species of asteroids have been described. These are *Asterias* (?) *dubium* Whitfield (1877) and *Astropecten pêwêi* Miller and Unklesbay (1943).

The following asteroids have been recorded from the Cretaceous of North America:

Astropecten (?) *montanus* Douglas (1903)
Colorado shale, Upper Cretaceous, Montana.
Austinaster mc-carteri Adkins (1928)
Austin chalk, Upper Cretaceous, Texas.
Comptonia wintoni Adkins (1920)
Pawpaw sandstone, Lower Cretaceous, Texas.
Metopaster hortensae Adkins and Winton (1920)
Pawpaw sandstone, Lower Cretaceous, Texas.
Metopaster tennesseensis Wade (1926)
Ripley formation, Upper Cretaceous, Tennessee.
Pentaceros americanus Adkins (1920)
Pawpaw sandstone, Lower Cretaceous, Texas.
Pentagonaster browni Weller (1905)
Fox Hills sandstone, Upper Cretaceous, Wyoming.
Pentagonaster texensis Adkins and Winton (1920)
Weno Clay, Lower Cretaceous, Texas.
Genus and species undescribed, Whiteaves (1903)
Nanaimo Group, Upper Cretaceous, British Columbia.

In addition to the asteroids, the following ophiuroids have been recorded from the Cretaceous:

Amphiura lymani Waring (1917)
Chico formation, Upper Cretaceous, California.
Ophioderma (?) *bridgerensis* Meek (1873)
Colorado shale (?), Upper Cretaceous, Montana.
Ophioglypha[2] *graysonensis* Alexander (1931)
Grayson marl, Lower Cretaceous, Texas.
Ophioglypha texana Clark (1893)
Denison formation, Lower Cretaceous, Texas.
Ophioglypha n. sp. *a* Packard (1916)
Chico formation, Upper Cretaceous, California.
Ophiura travisana Berry (1941a)
Kemp clay, Upper Cretaceous, Texas.

[1] Contribution No. 413, Balch Graduate School of the Geological Sciences, California Institute of Technology, Pasadena, California.

[2] The generic name *Ophioglypha* should be replaced by *Ophiura* (Berry, 1941a, p. 62).

"Ophiuroids" Adkins (1928)
Various levels of Washita Group, Upper Cretaceous, Texas.
"Vertebral ossicles" Vanderpool (1933)
Upper Trinity Group, Lower Cretaceous, Texas.

With the two species here described, there are 10 described and one undescribed species of Asteroidea and five described and at least three undescribed species of Ophiuroidea known from the Cretaceous of North America. In contrast, there are 44 species of Asteroidea and seven species of Ophiuroidea recorded from the Cretaceous of the British Isles (Sladen, 1891, 1893; Spencer, 1905, 1907). Most of the British species have been found in the Cretaceous chalks. Most of the American species have been found in the Cretaceous of Texas, but there does not seem to be any restriction to a particular lithology.

In contrast to the asteroids and ophiuroids recorded from the American Cretaceous the following is a list of the species recorded from the Tertiary:

ASTEROIDEA

Asterias remondii Gabb (1869)
Lower San Pablo formation (Clark, 1915, p. 417), Miocene, California.
Asterias (?) sp. Morton, (Clark and Twitchell, 1915) Eocene, South Carolina.
Goniaster mammilata Gabb (1876)
Vincentown sand, Lower Eocene,[3] New Jersey.
Pentaceros asperulus Clark (in Weller, 1907)
Vincentown sand, Lower Eocene,[3] New Jersey.
Starfish plates, Howe (1942, fig. 18)
Chickasawhay formation, upper Oligocene, Mississippi.
Starfish plates, Howe (1942)
Vicksburg group, Oligocene, Gulf Coast.
Starfish plates, Howe (1942)
Jackson formation, Eocene, Gulf Coast.
Starfish plates, Howe (1942)
Jackson formation, Eocene, Georgia.
Starfish plates, Howe (1942)
Choctawhatchee formation, Miocene, Florida.

OPHIUROIDEA

Amphiophiura oligocenica Berry (1937)
Byram Marl, Oligocene, Mississippi.
Amphiura sanctaecrucis Arnold (1908)
Santa Margarita formation, Upper Miocene, California.
Amphiura (?) sp. Clark (1918)
Markley formation, Upper Eocene (referred to Oligocene at time of description), California.
Ophioderma sp. Clark (1904)
St. Marys formation, Miocene, Maryland. (Same ? as *Ophiura marylandica*, Berry, 1934, p. 26).
Ophiomusium stephensoni Berry (1942)
Vincentown sand, Lower Eocene, New Jersey.
Ophiura marylandica Berry (1934)
St. Marys formation, Miocene, Maryland.
"Basket fish" Howe (1942, figs. 23, 24)
Jackson formation, Eocene, Alabama.
Ophiuran, Howe (1942, fig. 9)
Jackson formation, Eocene, Alabama.
Ophiuroid sp. Durham (1944)
Blakeley formation, Upper Oligocene, Washington.
Ophiuroid spp. Merriam (1931)
Records an ophiuran limestone from Santa Margarita formation, Upper Miocene, California. In addition makes reference to occurrences in the "Eocene"; "lower zone of the San Pablo Upper Miocene of Contra Costa County"; and "upper Miocene of Carneros Creek, 3 miles west of Napa, California."

Besides the preceding, the following ophiuroids have not previously been recorded in the literature:

Ophioglyphus (?) sp. (Univ. Calif. Mus. Pal., no. 11060, loc. 1318), Briones fm., Calif., Miocene.
Ophiuroid sp. (Calif. Acad. Sci., loc. 27789)
Santa Margarita fm., Calif., upper Miocene (not the same as *Amphiura sanctaecrucis* Arnold).
Ophiuroid sp. (Univ. Calif. Mus. Paleo. no. 11067, loc. A-715) Umpqua fm., Ore., Eocene.

A summary of the above North American Tertiary records shows that there are three described and at least six undescribed species of Asteroidea known, and four described and at least 11 undescribed species of Ophiuroidea known.

As Howe has indicated (1942) the remains of both ophiurans and asteroids may be rather abundant in certain sediments. From the data assembled by Howe, and from the other references in the literature, it appears probable that both groups are much better represented in the fossil record than the few described species might lead one to believe. Probably most workers have passed by the disarticulated plates, not recognizing the organisms represented, and therefore having no further interest in them.

In addition to the material recorded above, it is worth noting that Berry (1935, 1941b) has recorded a number of species of ophiuroids from the Tertiary of Venezuela and Trinidad.

[3] When these two species were described, the Vincentown sand was referred to the Upper Cretaceous, it is now considered to be of lower Eocene Age (Cooke, Gardner, and Woodring, 1943).

DESCRIPTION OF CIT LOCALITY 1679

The outcrop in which the fossils were found, is 6.3 miles northeast along the road from Wheeler Springs, on the highway from Ojai to the Cuyama Valley. Referring to the 1942 reprint of the 1903 edition of the Mt. Pinos, Calif. Quadrangle (scale 1:125,000) topographic map, the locality appears to be in the SE$\frac{1}{4}$ of the SE$\frac{1}{4}$ of Sec. 2, T 5 N, R 23 W, Ventura County, California. The fossils were found in the middle part of a large cut along the northwest side of the road at a point just past the northeast end of a smaller cut on the southeast side of the road. The large cut occurs about $\frac{1}{4}$ mile southwest along the road from a point where it crosses a small canyon with a spring in it. The beds are dipping at a high angle in the cut and transect the face of the cut at a rather large angle. The fossil layer is associated with more massive beds than those characteristic of the shale a short distance on either side. The sediments in general are well bedded, dark greenish black, silty shales, indicated as belonging to the Chico formation by Kerr and Schenck (1928). The shales contain many fragments of leaves and a few small pockets of carbonized plant material, both above and below the fossiliferous layer. The echinoderms were found only on the adjacent surfaces of two beds where they were in contact with one another along the bedding plane, further the starfish appeared to be restricted to a very limited area on the surfaces, as they disappeared up dip. Possibly some may remain if the bedding plane is followed back into the outcrop. Other parts of the same surface were covered with irregular trails and markings, probably of invertebrate origin, but no other identifiable fossils were noted. Collector: Wayne A. Roberts, April 19th and May 4th, 1947.

PRESERVATION

The material collected appears to represent more than 35 individuals of *Astropecten* and one of *Henricia* (?). Many individuals are represented only by fragments, due to the breaking up of the fossiliferous bed during collecting, and the fact that the bed could not be followed into the cliff face with the equipment at hand. All specimens occur as molds in a silty, olive gray, micaceous shale, containing a layer of plant fragments from 2 to 10 mm. from the asteroid layer. The asteroids occur on the surface of a bedding plane and penetrate into the surface of each of the adjacent beds to variable depth up to 3 mm. No trace of the fossils was found within the rocks of the individual beds, nor in any adjacent beds. The conditions requisite for the preservation of the asteroids were apparently confined to the particular interval represented by the bedding plane separating the two beds and to a limited area on that surface. The surface of the bedding plane is marked by irregular undulations, suggesting ripple marks and various other small irregularities. The suggested ripple marks, the irregular surface of the bedding plane, and the plant fragments (rushlike as far as determinable) suggest "shallow" water deposition, probably in depths of less than 100 meters, and perhaps near the low tide mark. Clark (1946, p. 72) says that the 14 Australian species of *Astropecten* are "shallow water" forms, but two other genera of the family are represented by "deep water" species. Sladen (1889, p. 198) recorded species of *Astropecten* from depths of 2–450 fathoms, with most of the species from depths of less than 50 fathoms.

The individual molds vary from very well preserved to some in which only generalized structure is apparent. These poorer molds can in most cases be shown to represent the impression of individuals that were largely preserved in the surface of the opposing bed. The well preserved molds appear in three forms: one representing the oral surface; one representing the aboral surface; and one representing the aboral surface with the paxillae and integument completely removed so that the aboral surface of the ambulacral plates is exposed. The form of the mold appearing for a particular specimen appears to depend first on whether or not the individual was right side up or overturned; and second, the accidents of uncovering the impression determined whether or not the remains of the dorsal plates and integument were removed and the upper surface of the ambulacral plates visible. Where the remains of the paxillae have not been removed, the paxillae and integument have been superimposed on the upper surface of the ambulacral plates, so that the ambulacral plates can be seen, but less clearly (and cleanly) than in the other two types of molds.

The impressions of the oral surface can be separated from the others by the clean and smooth appearance of the ambulacral plates, by the appearance of the adambulacral plates (which are rarely visible in the aboral impressions), and by the downward projecting oral plates. The aboral impression (where the dorsal plate and integument have not been removed) shows the madreporite (in complete specimens), and the upper impression of the oral plates projects upwards. In some of the impressions the ambulacral plates are still arched as in life, in others they have been flattened out. A cross-section of the arm of the genotype of *Astropecten*, showing the relationship of the various plates is given by Clark (1913, fig. 349).

All illustrations have been made by making a latex cast of the original mold and photographing it, rather than photographing the original mold which would have resulted in a reversed illustration.

ORIENTATION OF SPECIMENS IN MATRIX

Examination of the orientation of the specimens in the matrix shows no alignment of any sort. Approximately the same number of individuals are right side up as are overturned. There are no indications of any type of distribution, the individuals are apparently heterogenously scattered over the surface. Most specimens have the arms fully extended, but a few have them bent back on themselves, so that part of the oral and part of the aboral surface of a single arm can be seen at the same time.

DESCRIPTION OF SPECIES

Phylum ECHINODERMATA
Class ASTEROIDEA
Order PHANEROZONIA
Family ASTROPECTENIDAE
Genus ASTROPECTEN Gray

GRAY (1840), Ann. Mag. Nat. History, vol. 6, p. 180; CLARK (1946), Carnegie Inst. Washington, Pub. 566, pp. 72–73.

Genotype: *Asterias aranciaca* Linnaeus (subs. desig. Fisher, 1908).

The present species is referred to the genus *Astropecten* because the superomarginal and inferomarginal plates, although not equal, are of approximately equal size in lateral view, and apparently form vertical lateral faces to the ray, while the adambulacral plates are in contact with the inferomarginals throughout the ray and the aboral surface is covered with paxillae. The excentric madreporite precludes referring the species to the genus *Archaster*.

ASTROPECTEN MATILIJAENSIS
Durham and Roberts, n. sp.
Plate 65, figures 1–5; plate 66, figures 2, 4, 5

Rays 5, average radius of rays 26.5 mm., average radius of disk 8.2 mm., average width of ray at base 8.2 mm. Rays moderately slender, tapering gracefully, most rapidly so at base, to an acute tip. Interbrachial arcs acute. Margins of rays vertical, formed by superomarginal and inferomarginal plates, one above the other and corresponding in number and position. On different specimens the number of marginal plates appears to vary from about 23 to 31, but the apparently low counts are probably due to poor preservation. The most complete rays (on paratypes nos. 4861, 4864, and 4868) appear to have 30 to 31 marginal plates, but even on these the preservation of the tip is not perfect and there may be one or two additional plates. The aboral surface was apparently covered by an integument studded with numerous fine paxillae (paratypes nos. 4859, 4862, 4867), and apparently a few spines in the interbrachial areas. The precise character of the upper surface of the paxillae is not evident, but they do not appear to have been studded with numerous modified spinelets as in most modern Astropectens (Sladen, 1889, pls. 37, 38). The madreporite is about one third the radius of the disk in from the margin, moderately large, and well preserved on some specimens (paratypes nos. 4859 and 4869 especially). In position and character it is similar to that of *Astropecten pectinatus* Sladen, but is comparatively larger.

On the oral surface the ambulacral grooves are moderately wide. The ambulacral plates are bounded by adambulacral plates and both correspond in number and position to the inferomarginal plates except in the interbrachial areas and near the mouth. Apparently there are five more ambulacral plates than inferomarginals. The interbrachial area is occupied by about eight small subpolyhedral (in equatorial section) plates, of variable size, with the largest about twice the size of the smallest.

The superomarginal plates are approximately equal in height to the inferomarginals, but in other respects they do not correspond. The ratio of the longitudinal (length of ray) to lateral dimensions in equatorial section is about 3:4. The height of these plates is approximately the same as the longitudinal dimension. The surface of the superomarginal plates appears to be ornamented by very numerous minute pits without any apparent order, and there is no evidence of any spines.

The inferomarginal plates on the holotype have a longitudinal to lateral dimension ratio of about 3:10 but on paratype no. 4861 it does not appear to be much more than about 3:6. However it is not believed that this variation is sufficient to be of specific value. In the interradial area the inferomarginal plates have a more nearly triangular shape with a base to altitude ratio of 3:10 where the base corresponds to the longitudinal dimension. The surface of these plates is similar to that of the superomarginals, and in addition there are laterally at least one small and two larger spines (obscurely shown on parts of the holotype, and moderately well shown on paratypes no. 4859, 4860, and 4867). These spines are finely fluted and have a length apparently about three-quarters that of the lateral dimension of the corresponding plate. The two larger spines are about equal in size while the smaller one has a diameter about half that of the larger ones but is nearly as long. The diameter of the larger spines is slightly less than half the width of the corresponding plate.

The adambulacral plates are smaller than either the infero- or superomarginal plates. They are roughly rectangular in shape and have a longitudinal to lateral dimension ratio of 2:3. Those adambulacral plates in an interradial position become triangular shaped as with the marginals. The surface of the adambulacral plates appears to have several tubercles or seats for spines, but no spines were found in place. A few detached spines on the impression of the aboral surface appeared as if they might have originally been attached to the adambulacrals and subsequently forced into their present position, but there is no surety of this.

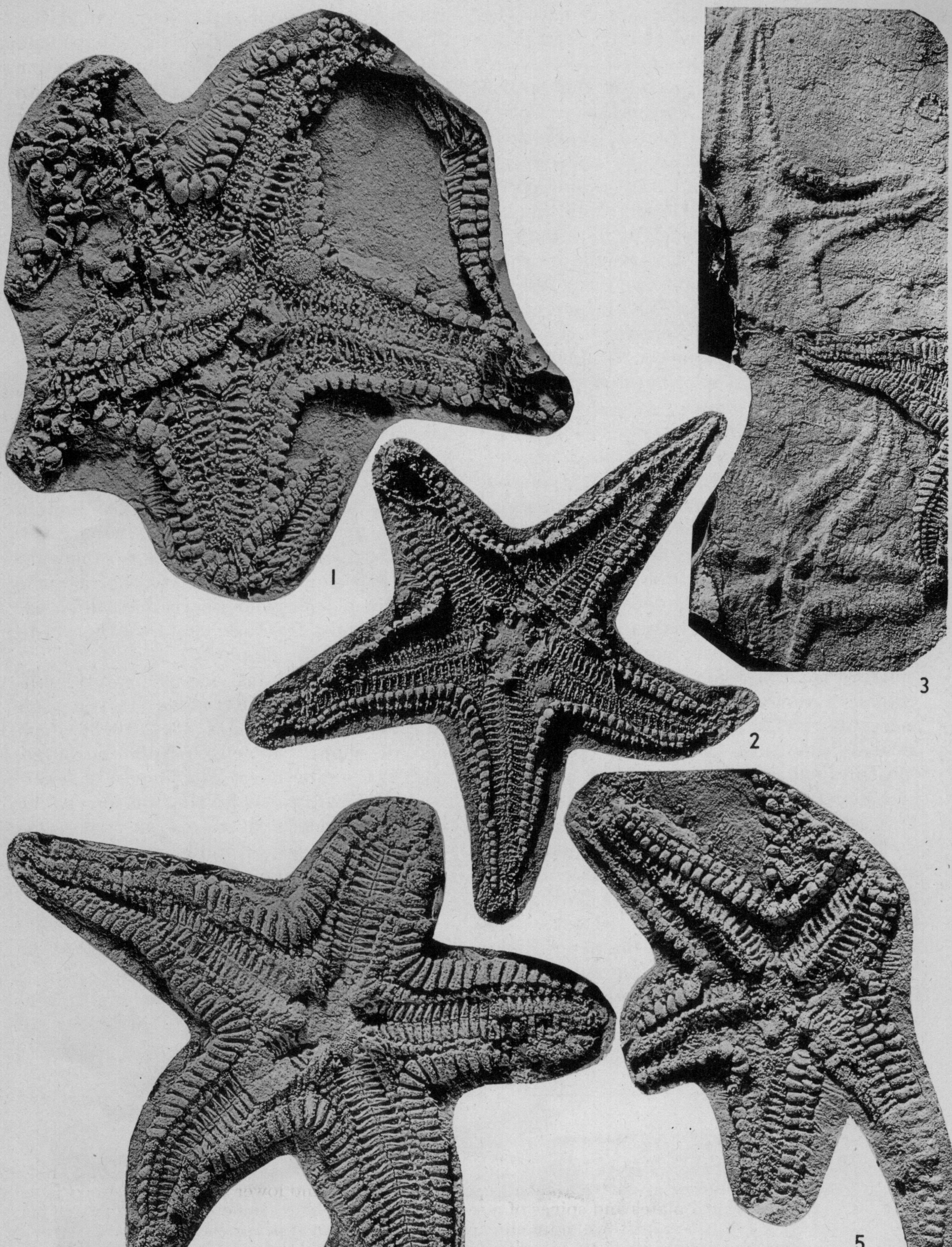
The ambulacral plates are elongately triangular in shape when seen in an oral view, with the apex pointing away from the axis of the ray. The base to altitude ratio is approximately 2:7. The longitudinal vertical section of the ambulacral plate is triangular, while the lateral vertical section appears to be trapezohedral. When seen from the aboral view the plate is somewhat dumb-bell shaped. On the oral surface the plate has a triangular depression which extends laterally from the center of the ray to the vertex of the plate.

The mouth plates are elongately subtriangular shaped, with at least seven conical spines (paratypes nos. 4863, 4868) which increase slightly in length from the outermost to the innermost. The longest or innermost spines are about 1.5 times as long as the shortest spines and are about the same length as the largest inferomarginal plate spines. These spines are fine fluted and apparently circular in cross-section.

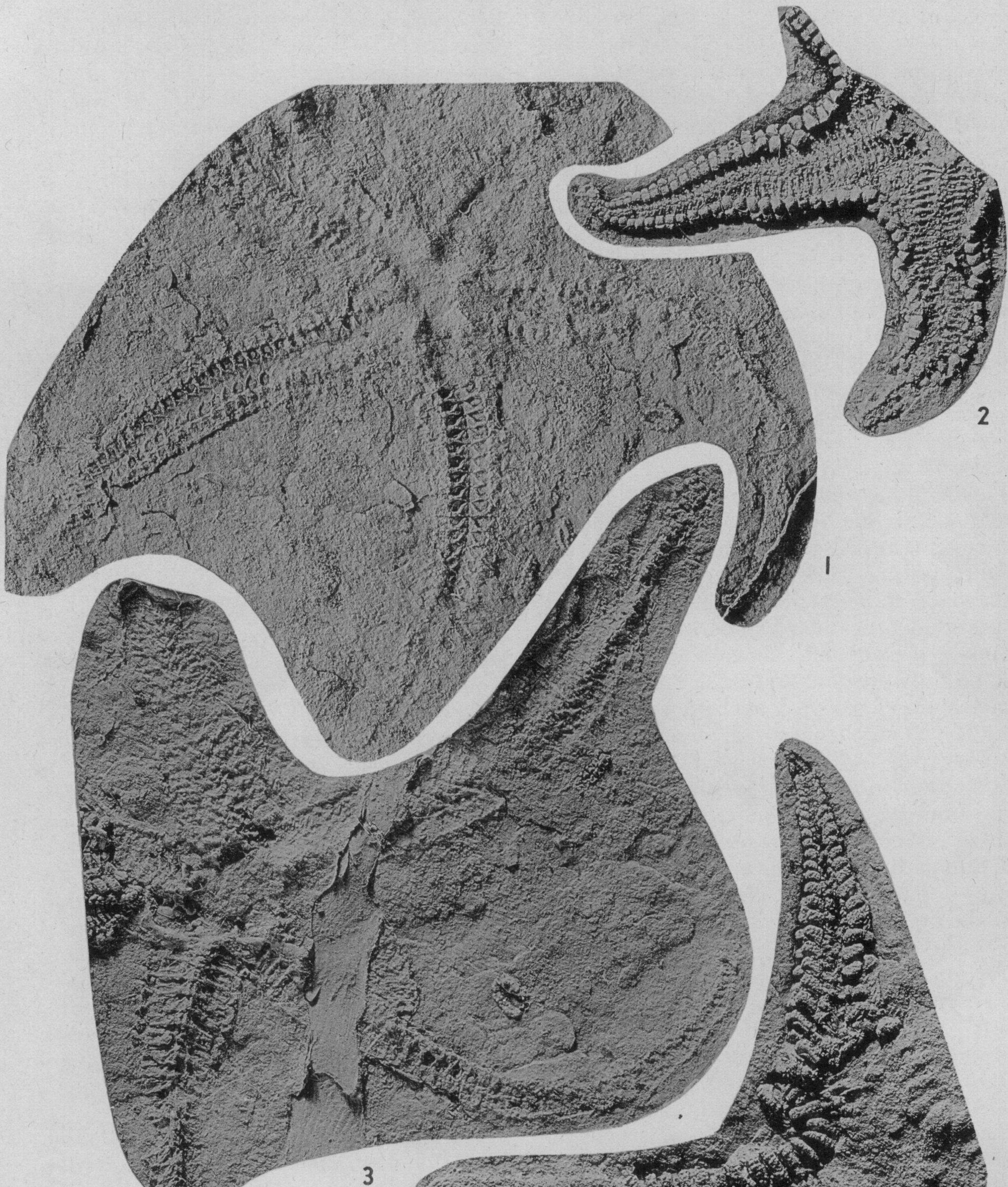
A plate that may be the ocular is discernible on one ray of paratype no. 4868. It appears almost spherical in shape with a diameter three to four times the longitudinal dimension of the adjacent superomarginal plates.

EXPLANATION OF PLATE 65

FIGS. *1–5*—*Astropecten matilijaensis* Durham and Roberts, n. sp. *1*, Paratype no. 4867, ×2.5, note spines on inferomarginal plates, madreporite, and upper and lower surfaces on two twisted arms. Marginal plates and spines of a second individual at extreme right. *2*, Paratype no. 4859, ×1.80, aboral surface, note numerous small paxillae appearing as granules. *3*, Two of poorer impressions adjacent to ray of holotype, ×1.3. *4*, Holotype no. 4858, ×1.8, oral surface. *5*, Paratype no. 4860, ×2.2, aboral surface, integument and paxillae largely removed, ambulacral plates arched. (p. 435)



Durham and Roberts, Cretaceous Asteroids



Durham and Roberts, Cretaceous Asteroids

In paratype no. 4860 most of the aboral integumental covering has been removed and the rays apparently were not flattened during fossilization. In this specimen (preserved so that the aboral surface is seen) the ambulacral plates are arched, presumably as in life, making an angle of about 150° with one another, except adjacent to the mouth where it is about 120°. Most specimens have been flattened during preservation and in those that show least evidence of further distortion (as in the holotype, and paratype no. 4859) it appears that the ambulacral, adambulacral, and marginal plates were all slightly inclined towards the tip of the ray, usually at an angle of about 70° with the axis of the ray.

Some specimens, for example paratype no. 4864, have the rays much more rounded. This may have been the outline of the animal during life, or it may be that the flattened impressions like the holotype and paratype no. 4859 represent more nearly the true shape in life. If this latter is the case, then specimens like paratype no. 4865 must represent individuals which had died some time previous to burial and had their rays somewhat rolled up before interment. At first it was thought that these individuals represented another species, but upon careful examination it was seen that they had the same number of marginal plates, and these plates are the same shape as in individuals like the holotype, so it was concluded that they are distorted individuals of the present species.

Types.—In the California Institute of Technology Paleontological Collections, holotype no. 4858; paratypes nos. 4859–4865, 4867, 4868. In addition there are the fragments and poorly preserved impressions representing the remaining 25 specimens which have not been assigned type numbers. Plaster casts of all the numbered specimens have been deposited with the U. S. National Museum and in the Museum of Paleontology of the University of California at Berkeley, Calif. Unfortunately part of the mold of the ambulacral area of the holotype was destroyed during the making of the casts. Fortunately the photographs used in illustrating it, and an excellent latex impression of it were taken before it was damaged.

Astropecten pêwêi Miller and Unklesbay (1943) from the Jurassic Sundance formation of Wyoming does not appear to be closely related to the present species; it has fewer and differently shaped marginal plates.

Order SPINULOSA
Family ECHINASTERIDAE
Genus HENRICIA Gray

Henricia GRAY (1840), Ann. Mag. Nat. Hist., vol. 6, p. 184; CLARK (1946), Carnegie Inst. Washington, Pub. 566, p. 148.

Genotype: *Henricia oculata* Gray = *Asterias sanguinolenta* Müller

HENRICIA (?) VENTURANA Durham and Roberts n. sp.
Plate 66, figures 1, 3

This species is represented by both oral and aboral impressions of a single individual. Unfortunately the details are not consistently well preserved, but it is believed that sufficient characters are preserved to warrant giving it a specific name. The disc is very small in comparison to the length of the arms. The arms are more or less gracefully curved, both the oral and aboral surfaces are represented. The margins of the arms are not distinct but it is believed that this is due to a lack of conspicuous marginal plates. However on one ray of the aboral mold, the integument has been removed and the aboral surface of the ambulacral plates is exposed and in this particular area the ambulacral plates appear to terminate laterally against vertical plates which might represent marginal plates.

Rays 5, radius of rays about 40 mm., radius of disk about 5 mm. Rays slender, width at base about 6.8 mm., tapering grace-

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EXPLANATION OF PLATE 66

FIGS. *1, 3*—*Henricia venturana* Durham and Roberts, n. sp. Holotype no. 4866. *1*, oral surface no. 4866a, ×1.7. *3*, aboral surface no. 4866b, ×1.8. (p. 437)

2, 4, 5—*Astropecten matilijaensis* Durham and Roberts, n. sp. *2*, Paratype no. 4868, ×1.8, aboral surface. *4*, Paratype no. 4867, ×11, madreporite (retouched), *5*, Paratype no. 4864, ×2.45, oral surface, note contracted state of arms. (p. 435) fully to tip. Interbrachial arcs acute. Margin of rays uncertain, probably rounded, marginal plates not conspicuous. The ambulacral plates occupy over one-half the width of oral surface of rays. It is suspected that this is due to flattening during fossilization. Aboral surface covered by a coarse granular network, possibly a few traces of short spines near the margins of the rays. Apparently about 35 ambulacral plates to a ray. Tube feet pores large, about 0.8 mm. in longitudinal diameter, adambulacral plates apparently corresponding to ambulacrals, not spinose, apparently about as long as wide. Madreporite dorsal, on margin of disk, about 1.5 mm. in diameter, surface marked by numerous vermiform radiating ridges.

Holotype, California Institute of Technology Paleontological Collections, nos. 4866A (oral surface), 4866B (aboral surface). Plaster casts have been deposited with the U. S. National Museum, and in the Museum of Paleontology of the University of California at Berkeley, Calif.

The reference of this species to the genus *Henricia* is very uncertain because of the apparent wide ambulacral grooves and lack of adambulacral spines, but it is possible that this is an apparent condition produced by flattening during fossilization. If, as suggested on the arm showing the aboral surface of the ambulacral plates, there are conspicuous marginals bounding the ray, the species might better be assigned to *Linckia* which may also have granular adambulacral plates.

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