THE ECHINOID GENUS *SALENIA* IN THE EASTERN PACIFIC

by V. A. ZULLO, R. F. KAAR, J. WYATT DURHAM, and E. C. ALLISON

ABSTRACT. The three occurrences of the stirodont echinoid *Salenia* Gray 1835 which Durham and Allison reported from the eastern Pacific in 1960 are described. A single, fragmentary specimen from the Aptian–Albian Alisitos formation of Baja California, Mexico, is tentatively referred to *S. mexicana* Schlüter of the Mexican and Texas middle Cretaceous. Numerous specimens from the lower Oligocene Keasey formation of northwestern Oregon are described as *S. schencki* sp. nov. *S. scrippsae* sp. nov. is based on living specimens dredged from depths between about 200 and 350 metres on an unnamed guyot (Station 73, S10 58–42; lat. 25° 44′ S., long. 85° 25′ W.) near the south-west end of Nasca Ridge, off the coast of Chile.

THE echinoid genus *Salenia* is abundantly represented in the European Cretaceous, but has been less commonly recorded in other areas and in later epochs. Until recently, it had not been reported from the eastern Pacific. Since the publication of volume 2 of Mortensen's (1935) *Monograph of the Echinoidea* with its summary of the Family Saleniidae, there have been at least forty-one reports of the genus *Salenia*, of which only one has been from the Recent fauna. The single Recent record and two of the above-mentioned fossil records were those noted by Durham and Allison (1960*a*, p. 1854; 1960*b*, p. 83) as the first records of *Salenia* in the eastern Pacific. These three eastern Pacific occurrences, based on material contained in the collections of the University of California Museum of Paleontology (abbreviated hereafter as UCMP), form the basis of this study.

In January 1958 during Expedition DOWNWIND, the University of California—Scripps Institution of Oceanography IGY cruise to the south-east Pacific, the R.V. *Horizon* dredged twenty-two specimens of a new species of *Salenia* from an unnamed guyot (text-fig. 1). This flat-topped seamount appears to have a diameter of about 13 kilometres (8 miles) and a minimum depth of 210 metres (115 fathoms). It is located on the south-west end of Nasca Ridge, about 1,280 kilometres (800 miles) off the coast of Chile and 480 kilometres (300 miles) approximately N. 80° W. of San Felix Island (Fisher 1958, fig. 8, station HD–73). A triglid fish with an interesting trans-Pacific distribution (Isla Juan Fernández to Australia) from the same sample has been reported by Hubbs (1959, pp. 313–15). This sample provides the first record of *Salenia* in the Recent fauna of the eastern Pacific, and adds one more species to the five living species previously recognized. Three of the five previously described species of the genus are recorded from the western Pacific and Indian Oceans (Mortensen 1935, pp. 374, 376, 379):

Salenia cincta Agassiz and Clark (1907, p. 116). Goto Islands, Kagoshima Gulf, and Sagami Bay in Japanese Seas; off Tawitawi in the Sulu Archipelago; and off the Kei Islands in the Banda Sea. Distributed bathymetrically between 170 and 520 metres.

Salenia sculpta Koehler (1927, p. 71, pl. 11, figs. 10–13; pl. 12, figs. 1–2, 10; pl. 25, fig. 5). Collected by the *Investigator* from a single locality off the Andaman Islands, Bay of Bengal, at 110–135 metres depth.

Salenia unicolor Mortensen (1934, p. 166). Sagami Sea, Celebes sea, and the Moluccan Straits, from 290 to 470 metres depth.

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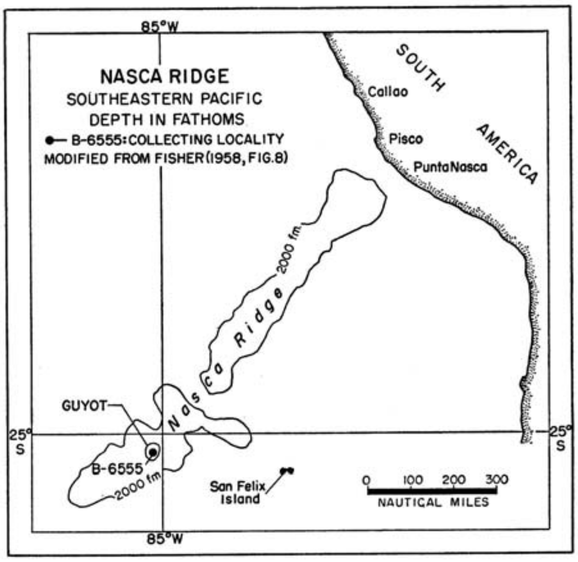
Of the two remaining species, one, *S. phoinissa* Agassiz and Clark (1908, p. 54), is based on a single specimen collected by the *Valdivia* on Agulhas Bank off the southern tip of South Africa at a depth of 102 metres (Mortensen 1935, p. 378), and the other, *S. goeesiana* Lovén (1874, p. 27, pl. 19) [spelling altered from *goësiana* to agree with Article 32(c)(1) of the International Code of Zoological Nomenclature, 1961], is known only from the West Indies at depths between 90 and 540 metres (Mortensen 1935, p. 373).

Geographically the occurrence of *Salenia* off Chile fills a gap in the Recent distribution



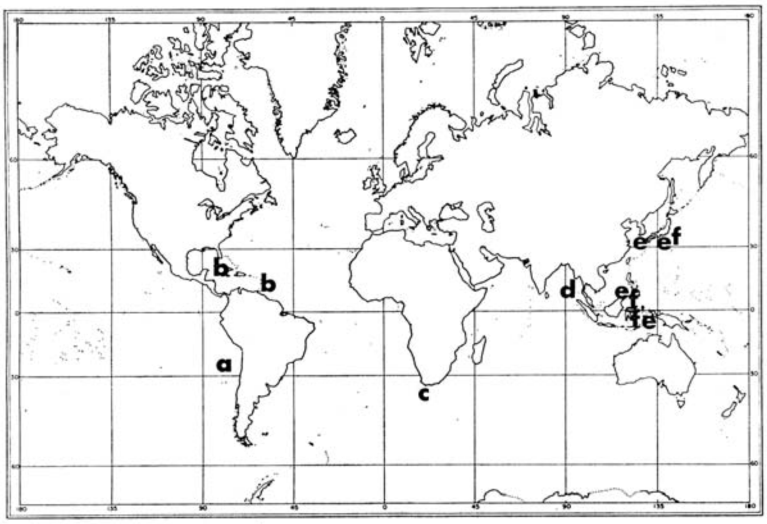
TEXT-FIG. 1. Map showing location of UCMP locality B–6555 on Nasca Ridge, south-eastern Pacific. Nasca Ridge delimited by 2,000-fathom contour. Map modified from Fisher (1958, fig. 8).

of the genus (text-fig. 2) and, perhaps coincidentally, has one or more characters in common with each of the other known living species, yet it is sufficiently distinctive to be easily recognized as a separate species.

During the summer of 1949, J. Wyatt Durham and H. E. Vokes visited outcrops of the lower Oligocene Keasey formation exposed along the west bank of the Nehalem River near Mist, Oregon. Their primary intention was to collect additional specimens of some stem-bearing crinoids that had recently been discovered in this area. In addition to the discovery of several specimens of the pentacrinoid *Isocrinus* von Meyer, which were later incorporated in Moore and Vokes's (1953) study of the Keasey crinoids, a diverse and abundant fauna and fragmentary plant remains were collected. This collection (UCMP locality A–5018) and additional collections from these exposures made by Durham and a field class in the Fall of 1952 (UCMP locality A–8721) contain numerous remains of echinoderms, among which are four species of asterozoans, one ophiuran, fragments tentatively referred to the spatangoid echinoid *Brisaster maximus*

Clark (1937), and several hundred specimens of a new species of *Salenia*. All the specimens of the *Salenia* are crushed, but remarkably complete. In many instances the primary and secondary spines are attached or in close proximity to their respective tubercles. Complete lanterns, including braces, are apparent in several specimens.

Excellent and unusual preservation is characteristic not only of the *Salenia* specimens, but of the entire fauna and flora from this Keasey locality. These strata have yielded



TEXT-FIG. 2. Distribution of the extant species of *Salenia*. *a*, *Salenia scrippsae* sp. nov.; *b*, *S. goeesiana* Lovén; *c*, *S. phoinissa* Agassiz and Clark; *d*, *S. sculpta* Koehler; *e*, *S. cincta* Agassiz and Clark; *f*, *S. unicolor* Mortensen.

a number of elements not usually found as fossils, and are lacking in many of the common components usually found in Tertiary faunas of similar age. The changed aspect of the fauna is such as to indicate that it must have been deposited under a different environment than most of the known contemporary faunas of the region.

Moore and Vokes (1953, p. 140) concluded from the physical character of the deposits that 'the comparatively great thickness of the Keasey deposits, coupled with the strongly tuffaceous nature of the middle and upper members, indicates that if the site of sedimentation was in moderately deep, or deep water, the area was not far removed from land on which a number of explosive volcanic vents were recurrently active. . . . Lack of bedding and general uniformity through considerable thicknesses of the deposit are not features to be expected in the littoral zone and suggest offshore conditions where the bottom was not agitated by waves or affected by current. Analysis of all known physical characters associated with the crinoid-bearing part of the Keasey formation therefore indicates nearness (at most a few tens of miles) to land and a sea bottom ranging from intermediate depth to greater than 500 fathoms.'

Moore and Vokes (1953, p. 141) further concluded that the molluscan faunas of these deposits were also indicative of 'intermediate' to 'deep' water in which 'intermediate' depth was defined as ranging from 100 to 500 fathoms (183 to 914 metres) and 'deep' water as depths greater than 500 fathoms.

Although the material from this locality in the UCMP collections is not a complete representation of the fauna, the elements available give much information on certain aspects of the environment of deposition. Below is a list of the thirty-six taxa which have been identified from the Keasey locality. Those marked by an '*' were recorded by Moore and Vokes (1953, p. 119), but are not represented in the UCMP collections. Those taxa preceded by a '†' have not previously been reported from this Keasey locality.

Foraminifera	
† *Operculina sp.* (of Durham 1937, p. 367)	rare
† *Plectofrondicularia packardi* Cushman and Schenck	abundant
Coelenterata	
† *Caryophyllia* sp. indet.	one specimen
Flabellum hertleini Durham (1942, p. 92) Thirty-two specimens in a block with less than 80 square inches of surface	eighty-six specimens
† Gorgonid coral	one specimen
Pelecypoda	
Acila (*Truncacila*) *nehalemensis* Hanna	several
Delectopecten sp. nov.	several
* *Ennucula* sp. nov.	
* *Minormalletia* sp. nov.	
* *Nuculana washingtonensis* (Weaver) subsp. nov.	
* *Propeamussium* sp. nov.	
Solemya (*Acharax*) *willapaensis* Weaver	few
* *Tellina* sp. nov.	
Yoldia (*Portlandella*) *chehalisensis* (Arnold)	
Gastropoda	
* '*Cancellaria*' *sp.*	
† *Epitonium keaseyensis*	one specimen
* *Exilia lincolnensis* Weaver	
* *Fulgurofusus* sp. nov.	
* *Polinices* sp. nov.	
* *Scaphander stewarti* Durham	
Arthropoda	
† Fragmentary crustacean remains	few
Crinoidea	
Isocrinus nehalemensis Moore and Vokes	several
I. oregonensis Moore and Vokes	common
Asteroidea	
† Brisingid (?) sp. nov. (new genus?)	one specimen
† *Astropecten* (?) sp. nov.	three specimens
† Two undetermined asteroids	
Ophiuroidea	
Undetermined ophiuran	one specimen

Echinoidea	
† *Brisaster maximus* Clark (?)	one specimen
† *Salenia schencki* sp. nov.	several hundred
Vertebrata	
† Fish scales	common
Plantae	
† Coralline algae	one fragment
† '*Zostera*' *sp.* (with attached diatoms)	few
* *Quercus consimilis* Newberry	
* *Myrica sp.*	
† *Thuja sp.*	few
† *Ocotea eocernua* Chaney and Sanborn	one specimen

The above list of taxa is apparently an anomalous association, containing some forms which grow only in shallow water whereas the modern relatives of others live only in 'deep' water. Living members of the genus *Acila* live in depths varying from about 10 to 803 fathoms (Schenck 1936, pp. 33–35). In certain pockets *Acila* (*Truncacila*) *nehalemensis* is rather abundant at this locality. The living mud pecten genus *Delectopecten* is found in depths of 10–1,100 fathoms (Woodring 1938, pp. 37, 38, pl. 3), and is restricted to depths below 100 fathoms in temperate and warmer climates. *Solemya johnsoni* Dall, the closest living relative of *S. willapaensis* on the Pacific Coast, lives in depths of 200–1,100 fathoms (Woodring 1938, pl. 3). Some of the specimens of *S. willapaensis* found at this locality retain impressions of the edge of the mantle extending beyond the margin of the shell. The asteroid listed as Brisingid (?) sp. nov. appears to be a member of the Suborder Brisingina Fisher (1928, p. 4), a group of archaic 'deep sea' starfish. The starfish *Astropecten* (?) sp. nov. appears to belong to a genus which ranges from shallow water to depths of at least 450 fathoms, but with most of its species in shallow water (Durham and Roberts 1948, p. 434). All living members of the genus *Salenia* are found in depths ranging from about 50–250 fathoms (Mortensen 1935, pp 373–80). The specimens of *Salenia* here recorded occur in great numbers in a relatively thin bed, all with their spines attached or in close proximity. The starfish are found in association with them, suggesting that the starfish may have preyed on the echinoids. The coral *Flabellum hertleini* is closely related to the living *F. pavoninum* Lesson which is found in depths of 78–519 fathoms (Faustino 1927, p. 46; Vaughan 1907, p. 55), its optimum being between 178 and 220 fathoms. This coral also occurs abundantly in local pockets. Considering the great abundance of the echinoid and this coral, it would appear that the most likely depth habitat was around 200 fathoms (365 metres).

The coral *Caryophyllia* sp. indet. belongs to a genus with a depth range of 0–1,500 fathoms (Vaughan and Wells 1943, p. 203). The foraminifer *Operculina* belongs to the group of so-called larger foraminifera which characteristically live in waters of less than 100 fathoms depth, but which are carried into deeper water, as is evident by their occurrence in the Marshall Islands (Cushman, Todd, and Post 1954, table 3) where they occur at depths of several hundred fathoms. The foraminifer *Plectofrondicularia packardi* is a member of a genus recorded from 129 to 766 fathoms (Kleinpell 1938, fig. 5); inasmuch as it occurs in much greater numbers than the *Operculina*, it is probably much more significant. The single fragment of coralline alga belongs to a group which is largely confined to continental shelf environments (Lemoine 1940, p. 86; Johnson 1957,

p. 211), but the fragment could have been transported into deeper water. Similarly the fragments of the eelgrass '*Zostera*' could have been transported from depths of less than about 8 fathoms, where it lives (Sverdrup *et al.* 1942, p. 302), to a deeper site. The preceding data are summarized in the following table:

Species	*Depth range of relatives*
Acila nehalemensis	10–803 fathoms
Delectopecten sp. nov.	10–1,100 ,,
Solemya willapaensis	200–1,100 ,,
Brisingid (?) sp. nov.	'deep sea'
Astropecten (?) sp. nov.	0–450 ,,
Salenia schencki sp. nov.	50–250 ,,
Flabellum hertleini	78–519 ,,
Caryophyllia sp. indet.	0–1,500 ,,
Operculina sp.	0–100 ,,
Plectofrondicularia packardi	129–766 ,,
Coralline algae	0–100 ,,
'*Zostera*' *sp.*	0–8 ,,

Inasmuch as other analyses (Durham 1942, p. 87; 1950, p. 1254) have suggested that the surface temperatures prevailing during the Oligocene at this latitude were above 20° C., and from the known fact that many deep water organisms live at somewhat greater depths in the tropics than in cooler areas, it would appear that the minimum depths recorded above for the various 'deep water' organisms would be less than the depths at which this assemblage lived.

The undisturbed condition of the echinoids, the entire star-fish (plates not dissociated), and the complete crinoid skeletons indicate that the site was deep enough to be below the zone of effective wave and current action, a factor which would also indicate a depth of over 100 fathoms. Similarly, the well-preserved state of the organisms listed above would indicate either rapid, live burial, and/or a scarcity of the scavengers and detritus feeders which usually work over dead organisms on the sea floor.

Although the available organic evidence from these strata indicates greater depths of deposition than are common for contemporary deposits, it would appear that the depth at this locality was closer to 200 fathoms (365 metres) than to the 500 fathoms (914 metres) or greater depths as proposed by Moore and Vokes. However, the presence of shallow water, littoral, and land organisms in the deposits, such as the eel grass ('*Zostera*') fragments, the foraminifer *Operculina*, the coralline algae, and the angiosperm and gymnosperm fragments, does support Moore and Vokes's conclusion that the Keasey locality was, at the most, only a few tens of miles from shore.

Although the Keasey specimens agree in most details with Mortensen's (1935, p. 367) definition of the genus *Salenia*, they differ by having crenulations on the primary ambulacral tubercles. The presence of crenulate ambulacral tubercles recalls the genus *Salenocidaris* Agassiz 1869 or *Salenidia* Pomel 1883. In *Salenocidaris*, however, the ambulacra are composed of single plates, except for a few near the peristomial edge which are bigeminate. The ambulacra of *Salenidia* are composed of single plates throughout. The ambulacra of the Keasey specimens are distinctly bigeminate throughout. The crenulations on the primary ambulacral tubercles may be of sufficient taxonomic importance to place the Keasey specimens in a separate genus, but because of the meagre

Tertiary record of *Salenia*, especially in North America, such a change is not considered to be justified at present.

The single Cretaceous record of *Salenia* in the eastern Pacific Basin is based on a fragmentary specimen collected by M. V. Kirk and J. R. McIntyre in February 1950 from exposures of the Alisitos formation at Punta San Isidro on the Pacific coast of Baja California, Mexico. Kirk and McIntyre (1951, p. 1505) correlated the Alisitos formation with the Cenomanian deposits of the State of Jalisco, Mexico. This correlation was based primarily on the comparison of the rudistid fauna of the Alisitos formation with that described by Palmer (1928). Kirk and McIntyre noted also that the coral, echinoid, and rudistid elements of the Alisitos formation were comparable to those found in middle Cretaceous deposits in southern Mexico and Texas. Allison (1955, p. 404), on the basis of the gastropod fauna and the occurrence of *Orbitolina texana* (Roemer), assigned an Aptian–Albian age to the Alisitos formation. This age assignment is repeated by Durham and Allison (1960*b*, table 1).

The *Salenia* from the Alisitos formation, tentatively referred to *S. mexicana* Schlüter of the Mexican and Texas middle Cretaceous, is much larger than previously reported specimens of the species and differs somewhat in the shape of the primary interambulacral tubercles. This specimen may represent another species distinct from *S. mexicana*, but the available material is not adequate for a detailed comparison.

Tertiary records of *Salenia* are meagre, especially in the Western Hemisphere. According to Cooke (1959) only one valid species, *S. tumidula* Clark (1891, p. 75), from the Paleocene Vincentown formation of New Jersey, has hitherto been described from Cenozoic deposits in North America. *Salenia bellula*, which was also described by Clark (1891, p. 75) from the same formation, is considered a synonym of *S. tumidula* by Cooke (1959, p. 13). Unidentifiable, isolated plates of *Salenia*, possibly representing *S. tumidula*, have also been reported by Cooke (1941, p. 7) from the Paleocene Salt Mountain limestone of Alabama.

On a world-wide basis, eleven Tertiary species have been referred to the genus *Salenia*. These include the following species in addition to those recorded by Lambert and Thiéry (1911, p. 212; 1925, p. 567):

Paleocene
Salenia sp. of Cooke (1941, p. 7), Alabama.

Eocene
S. persica Clegg (1933, p. 8, pl. 1, fig. 3*a–d*), Iran.

Oligocene
'*Salenia novemprovincialis* Nisiyama MS' reported by Morishita (1960, p. 54) from the Oligocene of Japan (a *nomen nudum*).

Pliocene
Salenia (?) *hakkaidoensis* Loriol (1902, p. 29, pl. 3, fig. 1), Tokunaga (1903, p. 4, pl. 2, fig. 1), Morishita (1960, p. 54). This species has been referred to *Pleurosalenia* Pomel (a synonym of *Salenidia* Pomel) by all the above-mentioned authors. However, the specimen (the type?) illustrated by Tokunaga (1903, pl. 2, fig. 1) exhibits bigeminate ambulacral plates with non-crenulate ambulacral tubercles which are features suggestive of *Salenia*.

The earliest recorded occurrence of *Salenia* is that of *S. taurica* Veber (1934) from the Kimmeridgian of the Crimea. The genus is otherwise unknown from the Jurassic. The greatest specific diversification was achieved in the Cretaceous. Mortensen (1935, p. 368) noted that about seventy-five nominal species had been described from Cretaceous deposits, and since that time at least fourteen nominal species have been added. The following nominal species of Mesozoic age in addition to those recorded by Lambert and Thiéry (1911, p. 212; 1925, p. 567) have been referred to *Salenia*. Some, as indicated, have been referred subsequently to other genera. With few exceptions no attempt has been made to evaluate the specific validity or stratigraphic allocation of these species.

Salenia acupicta Desor 1856, *in* Desor (1855–8), referred to *Hyposalenia* Desor.
S. alcaldei Sanchez-Roig (1949, p. 44, pl. 2, figs. 14–17), Maestrichtian, Cuba.
S. areolata Agassiz (1838), referred to *Hyposalenia*.
S. bella Szörényi (1955, p. 163, pl. 1, figs. 7–9), Cenomanian, Hungary.
S. bella parva Szörényi (1955, p. 164, pl. 1, figs. 21–23), Cenomanian, Hungary.
S. blanfordi Duncan and Sladen (1882), referred to *Salenidia* Pomel.
S. bonissenti Cotteau (1858–80), referred to *Salenidia*.
S. bunburyi Forbes, *in* Morris (1854), referred to *Hyposalenia*.
S. clathrata Agassiz, *in* Morris (1843), referred to *Hyposalenia*.
S. cottreaui Lambert 1931, *in* Lambert (1931–2, p. 63, pl. 3, figs. 2–4, text-fig. 3), Neocomian, Algeria.
S. dombeensis triangularis Gregory (1916, p. 586, figure p. 587), Cenomanian, Angola; Darteville (1953, p. 16, fig. 2), Albian, Angola.
S. gibba Agassiz (1838), type species of *Salenidia*.
S. hawkinsi Checchia-Rispoli (1948, p. 169, text-figs. 1–2; plate figs. 1–4), Cenomanian, Somaliland.
S. heberti Cotteau (1861–7), referred to *Salenidia*.
S. heliophora Agassiz and Desor (1846), referred to *Hyposalenia*.
S. heliophora Sorignet (1850), referred to *S. granulosa* Forbes.
S. hemisphaerica Agassiz (1836), referred to *Hemicidaris* Agassiz.
S. hoffmani Agassiz (1836), referred to *Hemicidaris*.
S. hondoensis Cooke (1953, p. 6, pl. 1, figs. 3–4). Possibly a synonym of *S. whitneyi* Cannon, *in* Ikins (1940).
S. kansasense Twenhofel (1924, p. 52, pl. 7, fig. 7), Comanchean, Kansas. Cooke (1946, p. 204) questionably refers this species to *S. mexicana* Schlüter.
S. keatingi Fourtau (1919, p. 38, pl. 1, fig. 3), ?Cenomanian (Bagh beds), India.
S. lamberti Checchia-Rispoli (1932, p. 6, pl. 2), Maestrichtian, Tripoli.
S. leanderensis Ikins (1940, p. 16, pl. 1, fig. 4*a–c*), Albian, Texas. Cooke (1946, p. 204) questionably refers this species to *S. volana* Whitney. From Ikins's description of the ambulacra (composed throughout of single plates, each bearing a crenulate tubercle), this species is probably referable to *Salenidia*.
S. leucorhodion Bronn (1848, p. 1107). New name for *Echinus areolatus* var. König (1825).
S. lunulata Morris (1854), referred to *Goniophorus* L. Agassiz.
S. mathuri Chiplonker (1937, p. 61, pl. 6, fig. 3*a–d*), Cenomanian, India.
S. ornata Agassiz, *in* Morris (1843), referred to *Hyposalenia*.
S. peltata Agassiz (1836), type species of *Goniopygus* L. Agassiz.
S. pentagonifera Gras (1848), referred to *Hyposalenia heliophora* (Agassiz and Desor).
S. personata Agassiz and Desor (1846), referred to *S. petalifera* (Desmarest).
S. portlockii Forbes, *in* Morris (1854), referred to *S. geometrica* Agassiz.
S. pseudowhitneyi Ikins (1940, p. 17, pl. 1, fig. 5*a–c*), Campanian, Texas.
S. punctata Forbes, *in* Morris (1854), referred to *Hyposalenia wrightii* Desor.
S. saxigera Lamarck (1840), misspelling of *S. scutigera*?
S. scotti Ikins (1940, p. 18, pl. 2, fig. 1*a–c*), Albian, Texas. Cooke (1946) questionably refers this species to *S. mexicana*.
S. scripta Agassiz (1838, p. 8, pl. 1, figs. 9–16), locality unknown.
S. scutigera Cotteau (1861–7), referred to *S. geometrica* Agassiz.

S. scutigera Forbes, *in* Morris (1854), referred to *S. granulosa* Forbes.
S. scutigera hungarica Szörényi (1955, p. 165, pl. 1, figs. 15–17), Senonian, Hungary.
S. similis lastroensis Maury (1936, p. 269), middle Albian, Brazil. Possibly a synonym of *S. mexicana* Schlüter (Cooke 1946, p. 204).
S. somaliensis Hawkins, *in* Cox (1935, p. 48, pl. 6, fig. 9*a–b*, text-figs. 1–2), upper Senonian (?), British Somaliland.
S. stellulata Agassiz (1838), referred to *Hyposalenia*.
S. stenzeli Ikins (1940, p. 19, pl. 2, fig. 2*a–c*), Albian, Texas. Cooke (1946, p. 204) questionably refers this species to *S. volana* Whitney.
S. studeri Agassiz (1840), referred to *Hyposalenia*.
S. taurica Veber (1934, pp. 59, 86, pl. 9, fig. 6*a–d*; text-fig. 5), Kimmeridgian, Crimea.
S. tertiaria Tate (1877), referred to *Salenidia*.
S. triboleti Desor 1856, *in* Desor (1855–8, p. 151), referred to *S. prestensis* Desor.
S. trigeri Desor 1858, *in* Desor (1855–8, p. 448), Cenomanian, France.
S. trigonopyga Lambert (1933, p. 13, pl. 1, figs. 25–27), upper Turonian, Madagascar.
S. umbrella Agassiz, *in* Morris (1843), referred to *Hyposalenia*.
S. whitneyi Cannon, *in* Ikins (1940, p. 20, pl. 2, fig. 3*a–c*), Campanian, Texas.

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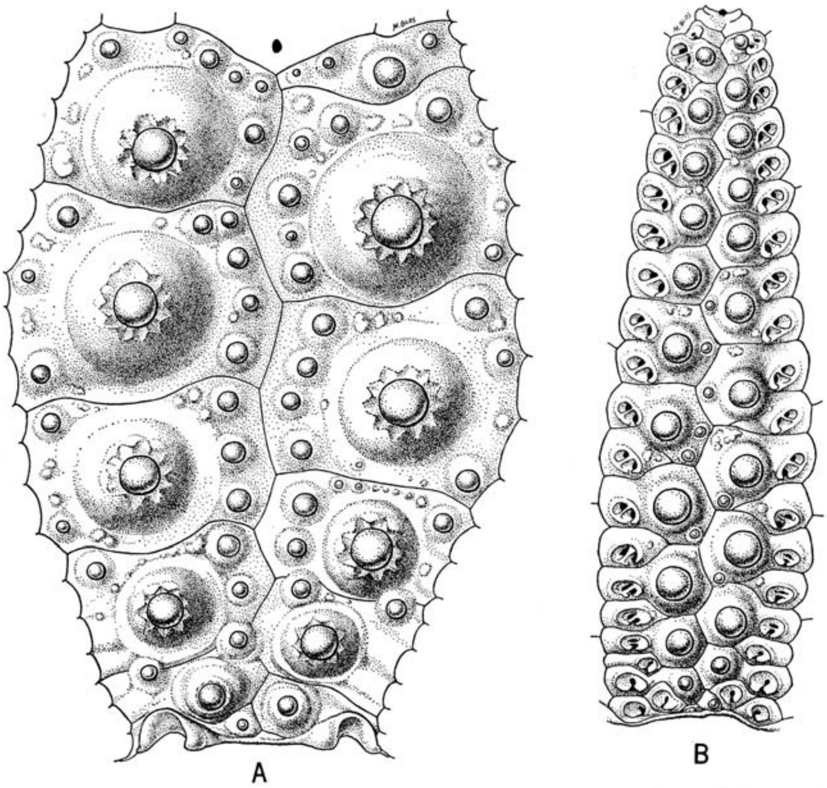
SYSTEMATIC DESCRIPTIONS

Class ECHINOIDEA Leske
Subclass EUECHINOIDEA Bronn
Superorder ECHINACEA Claus
Order HEMICIDAROIDA Beurlen
Family SALENIIDAE Agassiz
Subfamily SALENINAE Mortensen
Genus SALENIA Gray 1835

Salenia scrippsae sp. nov. [by Zullo and Allison]

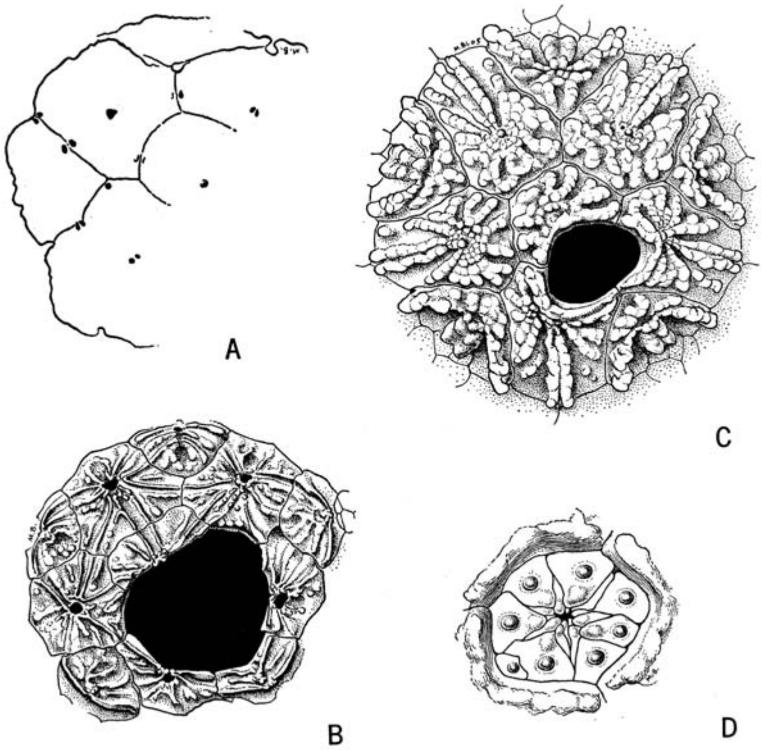
Text-figs. 3A, B; 4C, D; 6D–G; Plate 56, figs. 1–3

Description. Small (6 to 9 mm. in diameter, 3 to 5 mm. in height), white; test hemispherical with flattened oral surface; apical system slightly raised, covering most of aboral surface; ambulacra narrow, straight; ambulacral plates bigeminate except for few single plates interposed between bigeminate plates near apical system; pore-zones widening slightly at peristomial edge; primary tubercles of ambulacra non-crenulate, imperforate, coloured orange-red with tinges of green above ambitus, coloured white below ambitus, increasing gradually in size from apical system to ambitus, decreasing in size from ambitus to peristomial edge; few (5–7) secondary tubercles present between primary ambulacral tubercles near ambitus; interambulacra consisting of five to six plates per column; primary interambulacral tubercles crenulate, imperforate, coloured white, large and equal in size except near apical system and peristomial edge; areoles large, shallow, confluent throughout interambulacral column; secondary tubercles variable in number, not forming complete scrobicular circle; median area of interambulacra without tubercles, slightly sunken.



TEXT-FIG. 3. *Salenia scrippsae*, paratype UCMP no. 30758, ×24. A, interambulacrum 1. B, ambulacrum V.

Apical system with single, large angular suranal plate of regular pentagonal shape, except where notched on right posterior side by periproct; periproct to the right posterior between ocular I and the suranal plate; oculars exsert; genitals, including madreporite, of equal size; madreporite indistinguishable from exterior; madreporic pores visible on interior in small pit located in adapical part of plate; exterior surface of apical system highly ornamented by well-developed ridges and knobs; median ridges of genital plates and central knobs of oculars usually coloured yellow-green; other knobs and protuberances of apical system variously coloured white, yellow-green, or red; periproct bordered by elevated rim interrupted at the intersections of bordering apical plates sutures of apical plates defined by shallow grooves in ornamented surface; proximal edges of oculars delimited by white or light green-tinted elevated ridge; genital pores located on distal margin of plates; both genital and ocular pores not observable from above, being covered by prolongations of the median ridge of the genital plates and the



TEXT-FIG. 4. A, Apical system of *Salenia sp.* aff. *S. mexicana*, hypotype, UCMP 30741, ×6. B, Apical system of *S. schencki*, paratype, UCMP 30752, ×6. C, Apical system of *S. scrippsae*, paratype, UCMP 30758 (periproctal plates not shown), ×12. D, Detail of periproctal plates of *S. scrippsae*, paratype, UCMP 30757, ×20.

central knob of the ocular plates respectively; periproct covered by imbricating whorls of small plates; each plate (numbering up to eight) of the outer whorl bearing a small sp ne and tubercle.

Peristome violet-tinged, with numerous, small, imbricating plates surrounding larger buccal plates; gill notches shallow.

Primary interambulacral spines above ambitus long (up to 24 mm. on holotype), slender, straight or slightly curved at distal end, longitudinally ribbed with a slight indication of verticillation, but not thorny, banded green and white, usually with bands or zones of pink or orange-red on either side of white bands; collar of spine short, finely longitudinally striate; shaft of spine covered with cortex layer; milled ring finely striate; acetabular edge crenulate; transverse section of spine with small, central core with irregular holes throughout, thick median layer of radiating septa, and thin outer cortex; largest primaries at ambitus; interambulacral primary spines of oral surface coloured white, short, spear-shaped, flattened, longitudinally striate, occasionally with serrate edges; primary ambulacral spines short, broad, flat, longitudinally striate, coloured orange-red to dark brown-red, with yellow-green bases; secondary spines of interambulacra similar to ambulacral primaries in shape, but white in colour; secondary spines of ambulacra located between primary ambulacrals, short, stout, tinted yellow-green; spines of periproct light yellow-green and white in colour, short, stout, somewhat triangular.

Ophiocephalous pedicellariae (paratype UCMP 30763) present on and about apical system and also on peristomial plates; triphyllous pedicellariae (paratype UCMP 30763) present in ambulacral areas near ambitus; tridentate and claviform pedicellariae not observed.

Sphaeridia hyaline, ovoid, situated between tube feet and primary ambulacral spines at ambitus; a single sphaeridium situated in midline between ambulacral plates at peristomial edge.

Tube feet with well-developed sucking disk; lantern of stirodont type, with keeled teeth and open foramen magnum.

Name. This species is named in honour of the Scripps Institution of Oceanography, University of California.

Holotype. UCMP 30756. *Paratypes.* UCMP 30757–63.

Occurrence. Recent, 200–350 metres depth on an unnamed guyot, situated near the south-west end of Nasca Ridge, longitude 85° 25′ W., latitude 25° 44′ S., about 800 miles (1,280 kilometres) off the coast of Chile and 300 miles (480 kilometres) N. 85° W. of San Felix Island in the south-eastern Pacific. Dredged by the R.V. *Horizon* on 26 January 1958, during Expedition DOWNWIND, University of California–Scripps Institution of Oceanography IGY cruise to the south-east Pacific. UCMP locality B–6555 (listed as station HD–73 in Fisher 1958, table 8).

Discussion. Salenia scrippsae is readily distinguished from the other known living species of *Salenia* by its unique pattern of colouration, which consists of rows of orange- or brownish-red primary ambulacral spines and tubercles radiating from a greenish-white apical system flecked with spots of brownish-red. The tricolour banding of the primary interambulacral spines is also distinctive, differing from the solid greenish-white spines of *S. unicolor* and the white, or greenish-white, and red-banded spines of the other species (text-fig. 6E; Plate 56, fig. 1).

The ambulacral plates of *Salenia scrippsae* are not all bigeminate, as a few single plates alternate with the bigeminate plates near the apical system (text-fig. 3B). In this character *S. scrippsae* somewhat resembles species of the genus *Salenocidaris*. The ambulacra of

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EXPLANATION OF PLATE 56

Fossil and extant representatives of the echinoid *Salenia* from the eastern Pacific.

Figs. 1, 3, 4. *Salenia scrippsae* sp. nov. 1, 3, Paratype UCMP 30956, oral and aboral views, ×4·7. 4, Holotype, UCMP 30756, lateral view, ×2·3.

Fig. 2. *Salenia sp.* aff. *S. mexicanus* Schlüter. Hypotype, UCMP 30741, lateral view, ×2.

Fig. 5. *Salenia schencki* sp. nov. Block, UCMP 30755, showing distribution and abundance, ×0·6.

Salenocidaris consists of single plates except for one to three near the distal end which are bigeminate (Mortensen 1935, p. 348). This condition, however, is evidently not confined to *S. scrippsae* in the genus *Salenia*, but also has been noted in some fossil species (Mortensen 1935, p. 348).

The ornamentation of the apical system of *S. scrippsae* is more complex than that of any of the previously described extant species (text figure 4C). The well-developed, angular, elevated ledge bounding the proximal side of the ocular plates is not dark in colour as it is in other species.

The primary interambulacral spines of *S. scrippsae* (text fig. 6E, F) are similar to those of *S. goeesiana* in lacking distinct verticillation, but differ in bearing distinct longitudinal ribs, whereas the spines of *S. goeesiana* are smooth.

Salenia scrippsae also differs from other extant species of *Salenia* in the possession of a single sphaeridium at the peristomial edge in the ambulacral midline. Mortensen (1935, p. 332) states that 'sphaeridia are found, usually two in number, at the peristomial edge of each ambulacrum, in the genus *Salenocidaris*', but notes that sphaeridia occur only in the region of the ambitus in species of the genus *Salenia*.

Salenia schencki sp. nov. [by Kaar]

Text-figs. 4B, 5, 6A–C; Plate 56, fig. 5

Description. Test large for genus (up to 15 mm. in diameter), circular in outline at ambitus, flattened orally and aborally; apical system somewhat elevated.

Ambulacra straight, narrow; ambulacral plates bigeminate; primary ambulacral tubercles crenulate; eight minute crenulations on each tubercle; each pore of pore-pair surrounded by ridge externally; pore openings flush with plate surface internally; marginal pore perpendicular to plate surface, inside pore oblique to plate surface, approaching marginal pore externally.

Interambulacra more than twice as wide as ambulacra; interambulacral plates with one large, crenulate primary tubercle on each plate; boss convex; eight to ten crenulations on each primary interambulacral tubercle; about five secondary interambulacral tubercles along marginal and intermarginal sutures of each plate.

Apical system without spines; periproct elliptical in outline, elevated, displaced to the right posterior, encroaching on suranal plate, ocular I, and genitals 1, 2, 4, 5; periproctal plates unknown; genital pore displaced distally from centre of genital plate; genital plates ornamented by serrated ridges with chevron pattern radiating from genital pores; periproct encroaching on all genitals except genital 3; ocular I insert, remaining oculars exsert.

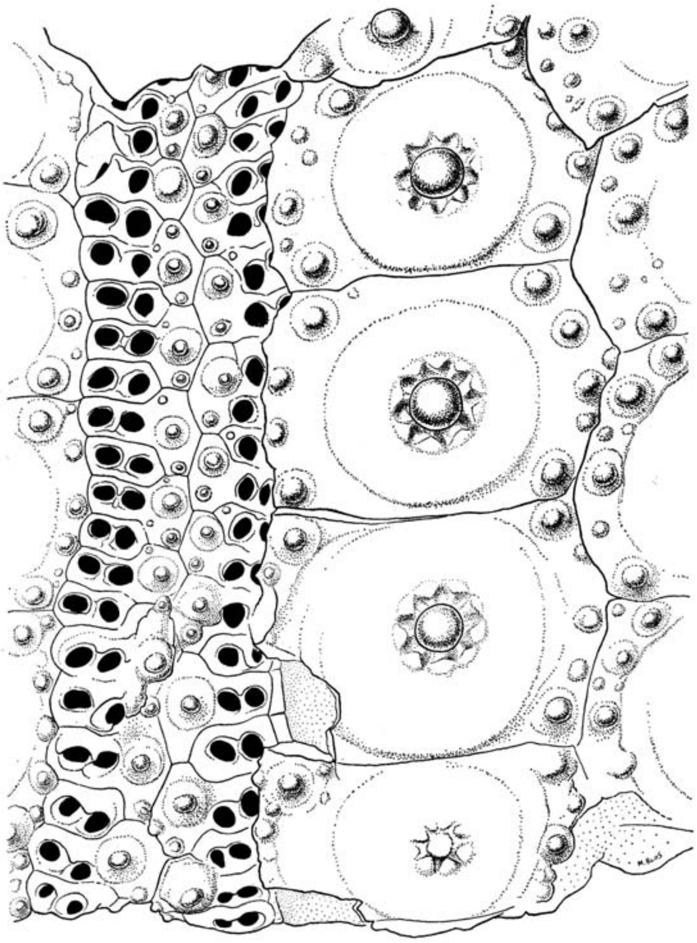
Primary interambulacral spines long, slender, nearly smooth, slightly curved toward distal end, occasionally with longitudinal ridges near distal end; tip of primary ambulacral spine occasionally flattened; marginal and secondary spines short, paddle-shaped; pedicellariae unknown.

Peristome concave; gill notches shallow; character of buccal and peristomial plates unknown; lantern stirodont.

Name. *Salenia schencki* is named after the late Dr. Hubert G. Schenck.

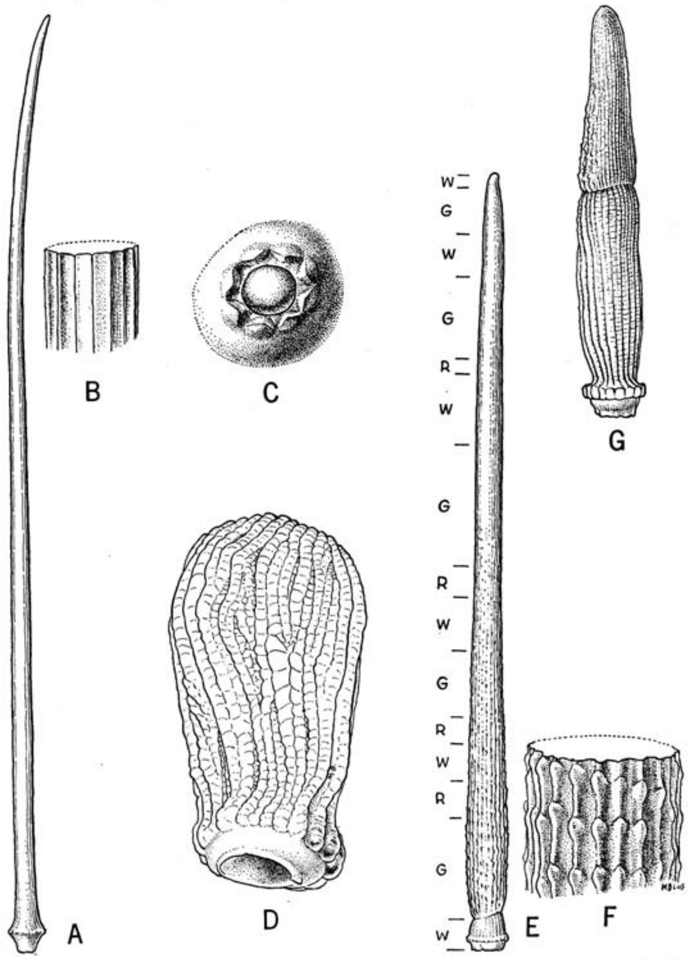
Holotype. UCMP 30751. *Paratypes* UCMP 30752–5.

Occurrence. Early Oligocene, upper half of the middle member of the Keasey formation, Oregon. UCMP localities A–5018 and A–8721. Fossils occur in grey, tuffaceous mudstone and fine-grained sandstone in the upper part of the Keasey formation exposed for about 200 yards along the west bank of the Nehalem River, approximately ¼-mile upstream from secondary highway bridge and ½-mile upstream from town of Mist, Oregon.



TEXT-FIG. 5. Ambulacral and interambulacral detail of *Salenia schencki*, holotype, UCMP 30751, × 19·2.

Discussion. Salenia schencki is characterized by crenulate primary ambulacral tubercles, nearly smooth primary interambulacral spines, and genital plates ornamented with about twelve serrated ridges radiating outward from the genital pore, and intercalated with smaller, discontinuous ridges which do not touch the genital pore.



TEXT-FIG. 6. A–C, *Salenia schencki.* D–G, *S. scrippsae.* A, Primary interambulacral spine, paratype, UCMP 30754, ×3·5. B, Detail of ornamentation of paratype, UCMP 30754, ×21. C, Primary ambulacral tubercle, paratype, UCMP 30753, ×36. D, Primary ambulacral spine, paratype, UCMP 30759, ×48. E, Primary interambulacral spine of ambitus, paratype, UCMP 30761, ×6. Letters to the left of the figure indicate colour bands: W = white, R = red, G = green. F, Detail of ornamentation of paratype, UCMP 30761, ×24. G, Primary interambulacral spine of oral surface, paratype, UCMP 30760, ×24.

Salenia schencki compares with *S. tumidula* Clark as figured by Cooke (1959, p. 13, pl. 2, figs. 1–7) from the Paleocene Vincentown formation of New Jersey. These two species are somewhat similar in the overall size and shape of the corona, and in the radial pattern of the ridges on the apical plates, but *S. schencki* differs from *S. tumidula* by having fewer radiating ridges on the apical plates and by the chevron pattern of these ridges. *S. schencki* differs further by having crenulated primary ambulacral tubercles with slightly convex bosses instead of slightly concave bosses, and by the somewhat larger periproct and peristome.

Salenia sp. aff. *S. mexicana* Schlüter

Text-fig. 4A; Plate 56, fig. 4

Hypotype. UCMP 30741.

Occurrence. Aptian-Albian, Alisitos formation, UCMP locality A–6278. From well-indurated, buff, weathering grey, silty sandstone in sea cliffs north of Punta San Isidro, Baja California, Mexico. Associated with numerous echinoids and pelecypods, small gastropods, sponges, an unidentifiable ammonoid, and several belemnoids.

Discussion. The single, partially crushed, incomplete specimen of *Salenia* collected from this locality is characterized by a strongly lobed apical system, narrow, somewhat sinuous ambulacra, and a large (diameter approximately 22 mm.) test. Except for its large size and the narrow, conic shape of the primary interambulacral tubercles, this specimen closely resembles the specimens of *S. mexicana* Schlüter described and figured by Böse (1910, p. 153, pl. 32, figs. 4–19) from the Vraconian (Albian) of La Encantada, Placer de Guadalupe, Chihuahua, Mexico. Maldonado-Koerdell (1953, p. 39) designated *S. mexicana* as a subspecies of *S. prestensis* Desor upon comparison of Böse's (1910) specimens with published figures of *S. prestensis*. In size the specimen resembles *S. texana* Credner, but can be distinguished by the strongly lobed apical system and the more widely spaced rows of primary ambulacral tubercles (see Cooke 1946, pp. 202–4, pl. 31, figs. 1–4 for a description of *S. texana*).

The fragmentary nature of the specimen from the Alisitos formation does not afford sufficient data to form an adequate conclusion regarding its affinities. From its size and the rather tenuous differences cited in the form of the primary interambulacral tubercles, it would appear that this specimen may represent a hitherto undescribed species closely resembling *S. mexicana*. However, until more complete and better preserved material is available, a more positive identification cannot be made.

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