J. Paleont., 67(2), 1993, pp. 258–263

0022-3360/93/0067-0258$03.00

A NEW SPECIES OF THE CLYPEASTEROID ECHINOID *ASTRODAPSIS* FROM THE MIOCENE ISIDRO FORMATION, BAJA CALIFORNIA SUR, MEXICO

RICHARD L. SQUIRES AND ROBERT A. DEMETRION
Department of Geological Sciences, California State University, Northridge 91330 and
8839 Katherine Avenue, Panorama City, California 91402

ABSTRACT—The clypeasteroid echinoid *Astrodapsis bajasurensis* n. sp. is described from upper middle Miocene beds of the Isidro Formation near the mouth of Arroyo Mezquital on the Pacific coast of north-central Baja California Sur, Mexico. The new species is the first occurrence of *Astrodapsis* outside of California and extends the southern limit of the genus by 1,100 km.

INTRODUCTION

SPECIMENS OF the clypeasteroid echinoid *Astrodapsis bajasurensis* n. sp. were found in the Isidro Formation at California State University, Northridge (CSUN) locality 1495 on the south side of Arroyo Mezquital about 13.5 km south of the village of San Juanico on the Pacific Coast (Figure 1). The locality is near the mouth of Arroyo Mezquital and is approximately at 112°21′15″W and 26°13′11″N on the San Isidro, Baja California Sur, Mexico, 1:250,000 quadrangle map (number NG 12-4), issued in 1973 under the authority of the Instituto Panamericano de Geografia e Historia. At this locality, which is just south of the dirt road leading to the village of San Juanico, the Isidro Formation is about 15 m thick and crops out in north-facing, vertical to near vertical cliffs that are 40 m high. Pictures of the cliffs in the vicinity of the locality are shown in Beal (1948, Pl. 7, fig. 1) and in McLean et al. (1987, fig. 4). The Isidro Formation in this area unconformably overlies middle Eocene exposures of the Bateque Formation (Squires and Demetrion, 1990, 1992). The cliffs are usually too steep to allow direct sampling of the Isidro Formation, but in a few places macrofossils can be collected directly from the outcrops, which consist of several shell-hash layers separated by grayish-green mudstone and sandstone nearly barren of macrofossils.

McLean et al. (1987) reported that shell-hash beds in the Isidro Formation vary widely in fossil content and each tends to contain a different dominant genus. Similarly, at locality 1495 some of the shell-hash beds consist dominantly of large barnacles or large oysters, whereas others consist dominantly of pectinids or the new species of clypeasteroid echinoid. Specimens of *Astrodapsis bajasurensis* n. sp. are present in all the shell-hash beds throughout the 15-m-thick section of Isidro Formation at locality 1495. Some specimens of *A. bajasurensis* n. sp. are encrusted by bryozoans, serpulids, or small barnacles.

Although the macrofossils in the shell-hash beds have obviously been transported, the distance of post-mortem transport was not far, because most specimens do not show any significant signs of abrasion or selective sorting. Other indications that the distance of post-mortem transport was not far include some closed-valved specimens of the pectinid bivalve *Oppenheimopecten vogdesi* (Arnold, 1906) [=*O. heimi* Hertlein, 1925], some closed-valved specimens of the large-sized oysterid bivalve *Crassostrea? eucorrugata* Hertlein, 1934, and a partial growth series of *Astrodapsis bajasurensis* n. sp. with specimens ranging in length from 7.0 to 38.5 mm.

Collecting at locality 1495 is best done by walking along the steep cliffs and examining the numerous fallen blocks that are easily correlated with the outcrop. Specimens of the new species of clypeasteroid can be extracted from these fallen blocks. Easier collecting can be done where the blocks have fallen apart due to weathering, and specimens lie loose on the ground. Most of these specimens do have some rock matrix adhering to the test, but some specimens are free of any rock matrix. Internally, the specimens of the new species are filled with fine sand that is usually well cemented. In exceptional specimens, such as the one shown in Figure 2.6, the internal matrix can be removed by careful cleaning. Magnetite particles were not found in the fine sand within these specimens. Locality 1495 represents collections made from a ground distance of about 350 m along the base of the cliffs. Two hundred specimens were found in about five hours of collecting.

The Isidro Formation was named by Heim (1922). The type section is at the village of San Isidro about 20 km south of locality CSUN 1495 (Figure 1). Among the various names used for the formation are the "yellow beds" of Darton (1921), Ysidro Formation (Hertlein and Jordan, 1927; Beal, 1948), and Monterrey and San Raymundo Formations (Mina, 1957). Beal (1948, Pl. 7, fig. 1) referred to the outcrops that contain the new species as the Ysidro Formation, and McLean et al. (1985) mapped them as the Isidro Formation.

The Isidro Formation has been reported as lower to middle Miocene based on macrofossils, stratigraphic position, and radiometric age-date constraints of underlying and overlying formations (Smith, 1984, 1986). Smith (1984), on the basis of preliminary molluscan studies, assigned the outcrops in the vicinity of locality 1495 to the lower Miocene.

During the present study, mudstones at locality 1495 were sampled and analyzed for calcareous nannofossils, benthic and planktic foraminifera, and radiolarians. The samples proved to be siliceous and barren, except for some rare fragments of radiolarians and sponge spicules (M. V. Filewicz and R. Ahrens, personal commun.). The locality 1495 mollusks that were identified during the present study proved to have geologic ranges too long to be useful for more than a Miocene or Neogene determination.

The presence of genus *Astrodapsis* at locality 1495 is significant in determining the geologic age of the outcrops. *Astrodapsis* occurs throughout the California Neogene provincial invertebrate "Margaritan" and "Jacalitos" "Stages" (Addicott, 1972), and it appears to be restricted to these two units. Modern correlations (e.g., Poore et al., 1984; Armentrout et al., 1984) indicate that the "Margaritan Stage" represents the upper middle to lower upper Miocene; the "Jacalitos Stage" represents the upper upper Miocene. Therefore, the stratigraphic range of *Astrodapsis* is upper middle Miocene to uppermost Miocene. Using this range, along with the early to middle Miocene age of the Isidro Formation, indicates that the age of the outcrops at locality 1495 is probably late middle Miocene. This age determination is also supported by the primitive morphology of *As-*

trodapsis bajasurensis n. sp. As will be discussed later in this report, the morphologic features of the new species show that it is an early form of the genus *Astrodapsis*.

Astrodapsis was confined to warm-temperate or tropical seas and apparently lived in nearshore environments (Hall, 1962). A nearshore environment for the deposits at locality 1495 is also supported by the presence of such genera as the barnacle *Balanus* and the oyster *Crassostrea*.

Abbreviations are as follows: IGM = Instituto de Geología, Universidad Nacional Autónoma de México, Mexico City; LACMIP = Natural History Museum of Los Angeles County, Invertebrate Paleontology Section.

SYSTEMATIC PALEONTOLOGY

Order CLYPEASTEROIDA A. Agassiz, 1872
Family ECHINARACHNIIDAE Lambert, 1914
Genus ASTRODAPSIS Conrad, 1856

Type species.—By monotypy, *Astrodapsis antiselli* Conrad, 1856.

ASTRODAPSIS BAJASURENSIS n. sp.
Figure 2

Diagnosis.—An *Astrodapsis* with length slightly greater than width (in most specimens), distinct lobelike posterior region, distinctly indented ambitus (caused by trifurcating food grooves that continue short distance onto aboral side), petaloids narrow and bisected by prominent food groove, ambulacra wider than interambulacra at ambitus, petaloids of equal length and slightly elevated with double row of respiratory pores noticeably converging about 75 percent of distance to ambitus, and periproct usually on curvature of lower margin.

Description.—Small to medium sized, reaching maximum length of 38.5 mm, slightly longer than wide, length/width about 1.06; maximum width just posterior of center, about 93 percent of total length; ambital outline slightly oval with posterior ambulacral marginal indentations prominent and producing lobelike appearance of posterior interambulacral area; interambulacra 80 percent of width of ambulacra at ambitus; apex very slightly depressed and slightly anterior of center; anterior and posterior surfaces of test about equally declined; apical system confluent with apex and not elevated; madreporite large and subpentagonal in outline; four gonopores present in specimens greater than 10.5 mm in length, one at base of each interambulacral area except interambulacrum 5; petaloids slightly elevated, open, approximately equal in length and width, and extending to ambitus; 150° angle between food grooves on anterior lateral petals, 65° angle between food grooves on posterior petals (bivium); respiratory pore areas narrow, one-half width of interporiferous areas and noticeably constricted about 75 percent of distance to ambitus; pores on inner row small and suboval; pores in outer row slitlike, becoming smaller and suboval distally; pore-pairs aligned parallel to petaloid-plate sutures near apex, but inclined about 20° toward ambitus where respiratory pore areas converge; outer pores do not cross petaloid sutures; interporiferous areas twice as wide as poriferous areas and bisected by narrow ambulacral food groove that extends to ambitus, onto oral surface and to peristome; margin indented at each ambulacral food groove with indentations most prominent on posteriormost two ambulacral areas.

Lantern supports single, one on each interambulacral basicoronal plate. Internal buttress system peripheral and fairly well developed, interambulacral areas with two thin, radiating walls, ambulacral areas with thickened calcite elements containing cavities.

Aboral interambulacara slightly sunken; double column of alternating plates in interambulacra adjacent to apical system; each interambulacral area with food grooves that pass onto aboral surface and ambitus correspondingly indented by trifurcating food grooves, with indentations most prominent on bivium.

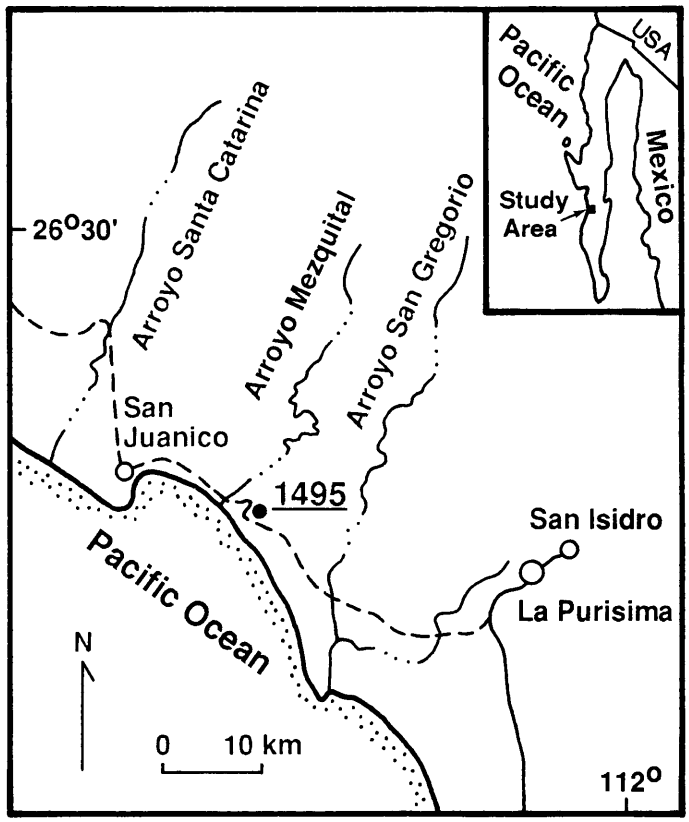

FIGURE 1—Index map to California State University, Northridge collecting locality 1495, Isidro Formation, Baja California Sur, Mexico.
= LACMIP loc. 16122 [on 16656]

Oral surface concave; peristome slightly anterior of center, relatively large and circular in outline; keel in food groove along perradial suture does not extend beyond ambulacral basicoronal plates, keel terminates in peristomial point projecting into peristome; food grooves well developed with straight-line trunk that trifurcates at about 60 percent of distance from center of peristome to ambitus.

Periproct just submarginal on curvature of lower margin, uncommonly on margin, small and oval to pentagonal in outline, in small notch; 15 indentations on ambitus (i.e., 5 ambulacral food grooves and 10 laterally branching interambulacral food grooves), periproct indentation present on some specimens.

Basicoronal plates well developed, in larger specimens (length greater than about 19 mm) ambulacral basicoronal plates become obscured by keel in food groove along perradial suture, interambulacral basicoronal plates project farther than ambulacral basicoronal plates, four to five oral interambulacaral coronal plates, seven to eight oral ambulacral coronal plates, oral interambulacra 2 and 3 continuous or discontinuous; oral interambulacra 1, 4, and 5 discontinuous.

Tubercles small to medium sized (0.1–0.2 mm); on aboral surface present everywhere with largest tubercles on interporiferous areas; on oral surface present everywhere except on food grooves, interambulacral tubercles larger than ambulacral ones and in scrobicules wider than those on aboral surface, with smallest tubercles near food grooves.

Dimensions of type specimens in Table 1.

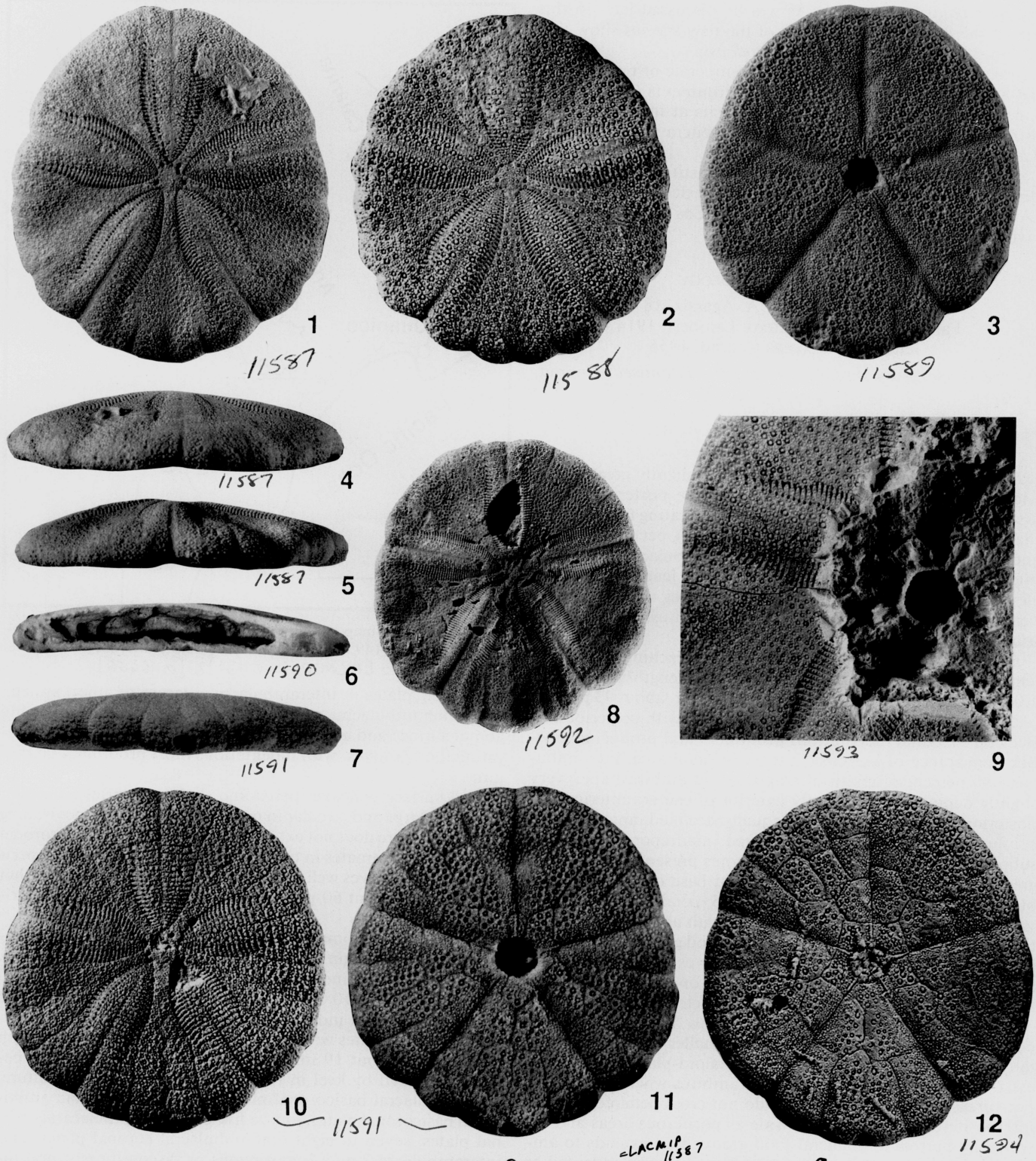

FIGURE 2—*1–12, Astrodapsis bajasurensis* n. sp., locality CSUN 1495. (1) holotype, IGM 5926, aboral view, ×2.1. (2) paratype, IGM 5927, aboral view, ×2.7. (3) paratype, IGM 5928, oral view, ×2.7. (4,5) holotype, IGM 5926, ×2.2. *4,* anterior view; *5,* left-lateral view. (6) paratype, IGM 5929, cut-away figure showing the internal buttressing of right-lateral half of test, ×2.2. (7) paratype, IGM 5930, posterior view, ×3.9. (8) paratype, IGM 5931, aboral view of largest specimen found at locality CSUN 1495, ×1.3. *9,* paratype, IGM 5932, interior view showing lantern supports, ×3.3. *10, 11,* paratype, IGM 5930, ×3.9. (10) aboral view showing plate patterns; (11) oral view showing plate patterns with interambulacra 2 and 3 continuous. *12,* paratype, IGM 5931, oral view showing plate patterns with all interambulacra discontinuous, ×3.3.

Remarks.—Gonopores are not present until specimens reach a length of about 10.5 mm. This development marks the onset of sexual maturity. Branching of the food grooves on the oral side of the test does not become apparent until specimens reach a length of about 12 mm. The posterior interambulacral lobelike protrusion is present in the smallest specimens found (i.e., 7 mm in length).

In those specimens that do show the plate patterns, about half have oral interambulacra 2 and 3 continuous and oral interambulacra 1, 4, and 5 discontinuous (Figure 2.11). These specimens are 19 mm in length or less. The other specimens that show plate patterns have all the oral interambulacra discontinuous (Figure 2.12), and these specimens are usually greater than 19 mm in length. There is some overlap, however, in the size groups between these two types of plate patterns on the oral surface. Some specimens between 15 and 19 mm in length have oral interambulacra 2 and 3 continuous, and other specimens in this size range have all the interambulacra discontinuous. In rare specimens of the new species, the width of the test is slightly greater than the length.

The test of the new species is slightly ovoid and widest posteriorly. In addition, the apical system is slightly eccentric, and on the oral surface the posterior interambulacra are discontinuous. These features have all been observed in other sand dollars, both modern and fossil (including *Astrodapsis brewerianus*), and have been shown to be the result of unequal growth patterns (Beadle, 1989).

The new species was compared to all previously known astrodapsids. Since 1856, workers had named a total of 59 species, subspecies, and varieties from California (Hall, 1962, p. 48), and a large number of these names were erected by Grant and Eaton (*in* Eaton et al., 1941). Hall (1962) reduced these 59 species, subspecies, and varieties to 12 species. The type specimens of Grant and Eaton (*in* Eaton et al., 1941) and the hypotypes and other type specimens illustrated by Hall (1962) are now stored at LACMIP. These specimens were examined during the course of the present investigation, as were specimens of various species of *Astrodapsis* collected by the senior author from the Branch Canyon Formation in the vicinity of Branch Canyon, south of New Cuyama, Santa Barbara County, California.

The new species is most similar to a few (but not all) specimens of *Astrodapsis diabloensis* Kew (1920) and to some (but not all) specimens of *A. brewerianus* var. *bitterensis* Grant and Eaton (*in* Eaton et al., 1941). *Astrodapsis diabloensis* is a morphologically variable species that, according to Hall (1962, p. 67–68), is synonymous with many of the taxa that Grant and Eaton (*in* Eaton et al., 1941) named, including *A. brewerianus* var. *bitterensis.*

The specimens of *Astrodapsis diabloensis* that are most similar to the new species are from the upper Miocene Santa Margarita Formation, San Luis Obispo County, southern central California. Examples of these types of specimens of *A. diabloensis* are illustrated by Hall (1962, Pl. 1, figs. 10, 12–14, 17, 20). The specimens of *A. brewerianus* var. *bitterensis* that are most similar to the new species are from the Branch Canyon Formation, Branch Canyon area, south of New Cuyama, Santa Barbara County, California. Perri and Fritsche (1988) assigned the Branch Canyon Formation in the Branch Canyon area to the middle Miocene. An example of this type of specimen of *A. brewerianus* var. *bitterensis* is illustrated by Grant and Eaton (*in* Eaton et al., 1941, Pl. 5, fig. 9).

The new species differs from the above-mentioned specimens of *Astrodapsis diabloensis* and its junior synonym *A. brewerianus* var. *bitterensis* in the following features: ambitus much more indented, petaloids bisected by a prominent food groove, petaloids narrower and more elevated, petaloids not as open near margin and do not flare, interporiferous areas on petaloids twice as wide rather than three times as wide as poriferous areas, trifurcating food grooves on oral surface, and posterior aboral interambulacral area with two food groves and corresponding indentations at ambitus. The new species shows the following additional differences when compared to the rest of the many illustrated specimens of *A. diabloensis* in Hall (1962): posterior lobe region present, petaloids do not flare near the margin, and poriferous areas converge toward ambitus.

TABLE 1—Dimensions (in mm) of the type specimens of *Astrodapsis bajasurensis* n. sp.

IGM specimen	Length	Width	Height
5926	29.5	27.0	5.7
5927	22.5	20.6	4.5
5928	22.5	20.7	3.9
5929	27.8	*	4.4
5930	15.8	14.9	2.7
5931	38.5	36.6	6.8
5932	31.4	*	*
5933	18.9	17.0	3.1

* Incomplete specimen, measurement not possible.

The new species superficially resembles a few (but not all) specimens of *Astrodapsis pabloensis* (Kew, 1915) from the Branch Canyon Formation, Branch Canyon area, south of New Cuyama, Santa Barbara County, California, and from the Santa Margarita Formation, San Luis Obispo County, California. An example of this type of specimen of *A. pabloensis,* which has moderately elevated petaloids and a distinct posterior lobe, is illustrated in Hall (1962, Pl. 7, fig. 1). The new species differs in the following features: test more elongate and usually smaller, ambitus much more indented, periproct submarginal (in most specimens), petaloids less elevated, petaloids bisected by a prominent food groove, and poriferous areas much more convergent.

The new species also resembles *Vaquerosella tejonensis* (Kew, 1920, p. 76–77, Pl. 12, fig. 2a, 2b) from the lower Miocene upper Vaqueros Formation, Tejon Hills, Kern County, California. The new species differs in the following features: test more elongate, petaloids not flared, all petaloids somewhat elevated, odd anterior petaloid same size as other petaloids, poriferous area width narrower, distal ends of rows of pores converge, posterior and anterior parts of upper surface with even slopes, ambulacral food grooves on oral surface strongly developed and branching near margin, each interambulacral area with a pair of food grooves, a more notched ambitus, and periproct indentation much less prominent. *Vaquerosella* Durham, 1955, is closely related to genus *Astrodapsis,* and work is needed to establish how they interrelate.

Although the species-level taxonomy of the genus *Astrodapsis* is quite confusing, there are broad patterns in the evolution of the genus, and these patterns have long been recognized for their biostratigraphic value. Richards (1936), Grant and Hertlein (1938, p. 69), and Weaver et al. (1944) all recognized a succession of *Astrodapsis* zones in the provincial "upper Miocene" and "lower Pliocene" (now known to be middle and upper Miocene). In the comparisons discussed above, *Astrodapsis bajasurensis* n. sp. was reported to be most similar to *A. brewerianus* var. *bitterensis* and to *A. diabloensis.* Both of these are early forms and can be referred to the old "Briones" and "Cierbo" "Stages," as used by Eaton et al. (1941, fig. 12) and by Weaver et al. (1944). These units form the lower part of the "Margaritan Stage" (Addicott, 1972). As noted above in the geologic age discussion of the Isidro Formation, the "Margaritan

Stage" is now regarded as upper middle to lower upper Miocene. Because *A. bajasurensis* is most comparable to lower "Margaritan Stage" forms, its age is probably late middle Miocene. This would be fully consistent with the authors' conclusions regarding the age of the Isidro Formation. Overall, *A. bajasurensis* appears to be a primitive representative of the genus. It resembles early species in its relatively small size, rounded ambitus, and posterior lobe. It commonly has continuous interambulacra, which is a primitive character. It does not have markedly raised petals, well-developed interambulacral valleys, or large tubercules. All of these are advanced characters.

Hall (1962) and Durham (1966) restricted *Astrodapsis* to California, chiefly between latitudes 34° and 38°N. *Astrodapsis bajasurensis* n. sp. is the first species of genus *Astrodapsis* known outside of California, and the new species extends the southern geographic limit of the genus by 1,100 km to 26°14'N. Previously, the southern geographic limit of *Astrodapsis* was 34°07'N in the basal Modelo Formation, eastern Santa Monica Mountains, just south of Tarzana, Los Angeles County, southern California (Hoots, 1931, p. 110; Eaton et al., 1941, Pl. 5, fig. 11a). In addition, all previously known *Astrodapsis* localities are located within about 500 km of each other.

Early workers reported two species of *Astrodapsis* from Baja California, but later taxonomic work showed that the species belong in another genus. *Astrodapsis israelskyi* Jordan and Hertlein (1926) was reported from upper Pliocene strata on Cedros Island, Baja California (Jordan and Hertlein, 1926; Grant and Hertlein, 1938), from Pliocene strata in the Bahia Tortugas area, Vizcaino Peninsula, Baja California Sur (Hertlein, 1933; Grant and Hertlein, 1938; Minch et al., 1976), and from Pliocene strata in the San Diego area (Grant and Hertlein, 1938). Hertlein and Grant (1960), however, reassigned *A. israelskyi* to genus *Merriamaster.*

Astrodapsis kewi Jordan and Hertlein (1926) was reported from upper Pliocene strata on Cedros Island, Baja California (Jordan and Hertlein, 1926; Grant and Hertlein, 1938), but Hertlein and Grant (1960) reassigned the species to genus *Merriamaster.*

The genus *Astrodapsis* has been reported from Kamchatka and Sakhalin in eastern Russia (Khomenko, 1931; Argamakova, 1934), but Durham (1955) stated that it appears highly improbable that any of the species reported from there are correctly identified. Hall (1962) tentatively assigned the eastern Russian specimens to genus *Pseudoastrodapsis* Durham, 1953. Also, the genus *Astrodapsis* has been reported from Japan (Nisiyama, 1948), but Durham (1952, 1966) assigned the specimens from there to the genus *Nipponaster* Durham, 1952 [=*Pseudoastrodapsis* Durham, 1953].

Etymology.—The new species is named for Baja California Sur.

Material.—Two hundred specimens. Holotype, IGM 5926 = plastoholotype, LACMIP 11587; paratypes, IGM 5927–5933 = plastoparatypes, LACMIP 11588–11594; paratypes, LACMIP 11595–11599.

Occurrence.—Upper middle Miocene, Isidro Formation; type locality = CSUN locality 1495, near mouth of Arroyo Mezquital, north central Baja California Sur, Mexico.

ACKNOWLEDGMENTS

M. del Carmen Perrilliat (Instituto de Geología, Universidad Nacional Autónoma de México) arranged for paleontologic collecting in Baja California Sur and graciously provided type-specimen numbers.

G. L. Kennedy and L. R. Saul (Natural History Museum of Los Angeles County) made the type collections of Grant and Eaton *in* Eaton et al. (1941) available for study. M. V. Filewicz and R. Ahrens (Unocal Corporation, Ventura, California) processed and analyzed microfossil samples.

J. W. Durham (University of California, Berkeley) shared his knowledge on clypeasteroids. J. T. Smith (Palo Alto, California) shared her knowledge on the stratigraphy of the study area. R. Mooi (California Academy of Sciences, San Francisco) provided important references and critically reviewed an early draft of the manuscript. S. C. Beadle (Whittier, California) and B. D. Carter (Georgia Southwestern College) gave very beneficial reviews.

REFERENCES

ADDICOTT, W. O. 1972. Provincial middle and late Tertiary molluscan stages, Temblor Range, California, p. 1–22. *In* E. H. Stinemeyer and C. C. Church (eds.), The Pacific Coast Miocene Biostratigraphic Symposium, Proceedings. Pacific Section, Society of Economic Paleontologists and Mineralogists.

AGASSIZ, A. 1872–1874. Revision of the Echini. Illustrated Catalogue of the Museum of Comparative Zoology at Harvard College, No. VII. University Press, Cambridge, 761 p.

ARGAMAKOVA, V. F. 1934. On some Neogene Echinoidea of Sakhalin. Transactions of the Oil Geology Institute (Leningrad), Series A, Fascicle 41:1–44.

ARMENTROUT, J. M., R. J. ECHOLS, AND J. C. INGLE. 1984. Neogene biostratigraphic-chronostratigraphic scale for the northeastern Pacific margin, p. 171–177. *In* N. Ikebe and R. Tsuchi (eds.), Pacific Neogene Datum Planes, Contributions to Biostratigraphy and Chronology. University of Tokyo, Tokyo.

ARNOLD, R. 1906. The Tertiary and Quaternary pectens of California. U.S. Geological Survey, Professional Paper 47, 264 p.

BEADLE, S. C. 1989. Ontogenetic regulatory mechanisms, heterochrony, and eccentricity in dendrasterid sand dollars. Paleobiology, 15: 205–222.

BEAL, C. H. 1948. Reconnaissance of the geology and oil possibilities of Baja California, Mexico. Geological Society of America Memoir 31, 138 p.

CONRAD, T. A. 1856. Description of three new genera, twenty-three new species middle Tertiary fossils from California and one from Texas. Proceedings of the Academy of Natural Sciences of Philadelphia, 8:312–316.

DARTON, N. H. 1921. Geologic reconnaissance in Baja California. Journal of Geology, 29:720–748.

DURHAM, J. W. 1952. Not *Astrodapsis* in Japan. Journal of Paleontology, 26:844–846.

——. 1953. New name for *Nipponaster* Durham, 1952. Journal of Paleontology, 27:756.

——. 1955. Classification of clypeasteroid echinoids. University of California Publications in Geological Sciences, 31:73–198.

——. 1966. Clypeasteroids, p. U450–U491. *In* R. C. Moore (ed.), Treatise on Invertebrate Paleontology, Pt. U, Vol. 2, Echinodermata 3. Geological Society of America and University of Kansas Press, Lawrence.

EATON, J. E., U. S. GRANT, AND H. B. ALLEN. 1941. Miocene of Caliente Range and environs, California. American Association of Petroleum Geologists Bulletin, 25:193–262.

GRANT, U. S., IV, AND L. G. HERTLEIN. 1938. The west American Cenozoic Echinoidea. Publications of the University of California at Los Angeles in Mathematical and Physical Sciences, 2:1–225.

HALL, C. A., JR. 1962. Evolution of the echinoid genus *Astrodapsis.* University of California Publications in Geological Sciences, 40:47–180.

HEIM, A. 1922. Notes on the Tertiary of southern Lower California (Mexico). Geological Magazine, 59:529–547.

HERTLEIN, L. G. 1925. Pectens from the Tertiary of Lower California. California Academy of Sciences, 4th series, 14:1–35.

——. 1933. Additions to the Pliocene fauna of Turtle Bay, Lower California, with a note on the Miocene diatomite. Journal of Paleontology, 7:440.

——. 1934. New oysters and a new *Pecten* from the Tertiary of California. Southern California Academy of Sciences Bulletin, 33(Pt. 1): 1–5.

——, AND U. S. GRANT, IV. 1960. The geology and paleontology of the marine Pliocene of San Diego, California (Paleontology: Coelenterata, Bryozoa, Brachiopoda, Echinodermata). Memoirs of the San Diego Society of Natural History, 2(Pt. 2a):73–133.

——, AND E. K. JORDAN. 1927. Paleontology of the Miocene of Lower California. Proceedings of the California Academy of Sciences, 4th series, 16:605–647.

HOOTS, H. W. 1931. Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, California. U.S. Geological Survey Professional Paper 165-C:83–134.

JORDAN, E. K., AND L. G. HERTLEIN. 1926. Contributions to the geology and paleontology of the Tertiary of Cedros Island and adjacent parts of Lower California. Proceedings of the California Academy of Sciences, 4th series, 15:409–464.

KEW, W. S. W. 1915. Tertiary echinoids from the San Pablo Group of middle California. University of California Publications, Bulletin of the Department of Geology, 8:365–376.

——. 1920. Cretaceous and Cenozoic Echinoidea of the Pacific coast of North America. University of California Publication, Bulletin of the Department of Geology, 12:23–236.

KHOMENKO, J. 1931. Materials on the stratigraphy of the Tertiary beds of the eastern Sakhalin oilfield. Transactions of the Geological and Prospecting Service of U.S.S.R., Fascicle 79:1–126.

LAMBERT, J. 1914. P. 241–320. *In* J. Lambert and P. Thiéry, Essai de Nomenclature Raisonneé des Échinides, Fascicule IV. Libraire L. Ferrière, Chaumont.

MCLEAN, H., B. P. HAUSBACK, AND J. H. KNAPP. 1985. Reconnaissance geologic map of part of the San Isidro quadrangle, Baja California Sur, Mexico. U.S. Geological Survey Miscellaneous Field Studies, Map MF-1799.

——, ——, AND ——. 1987. The geology of west-central Baja California Sur, Mexico. U.S. Geological Survey Bulletin, 1579, 15 p.

MINA, F. 1957. Bosquejo geológico del Territorio Sur de la Baja California. Asociacíon Mexicana de Geólogos Petroleros Boletín, 9:139–269.

MINCH, J. C., G. GASTIL, W. FINK, J. ROBINSON, AND A. H. JAMES. 1976. Geology of the Vizcaino Peninsula, p. 136–195. *In* D. G. Howell (ed.), Aspects of the Geologic History of the California Continental Borderland. American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publications 24.

NISIYAMA, S. 1948. *Astrodapsis* in Japan. Journal of Paleontology, 22: 601–605.

PERRI, M. L., AND A. E. FRITSCHE. 1988. Stratigraphy and depositional environments of the Miocene Branch Canyon Formation in the Sierra Madre, Caliente Range, and Sespe Creek areas, California, p. 87–98. *In* W. J. M. Bazeley (ed.), Tertiary Tectonics and Sedimentation in the Cuyama Basin, San Luis Obispo, Santa Barbara, and Ventura Counties, California. Pacific Section, Society of Economic Paleontologists and Mineralogists, Book 59, Los Angeles.

POORE, R. Z., J. A. BARRON, AND W. O. ADDICOTT. 1984. Biochronology of the northern Pacific Miocene, p. 165–169. *In* N. Ikebe and R. Tsuchi (eds.), Pacific Neogene Datum Planes, Contributions to Biostratigraphy and Chronology. University of Tokyo, Tokyo.

RICHARDS, G. L., JR. 1936. *Astrodapsis* faunal zones of California upper Miocene and lower Pliocene formations. Geological Society of America Proceedings for 1935, p. 412–413.

SMITH, J. T. 1984. Miocene and Pliocene marine mollusks and preliminary correlations. Vizcaino Peninsula to Arroyo La Purisima, northwestern Baja California Sur, Mexico, p. 197–217. *In* V. A. Frizzell, Jr. (ed.), Geology of the Baja California Peninsula. Pacific Section, Society of Economic Paleontologists and Mineralogists, Los Angeles.

——. 1986. Middle Tertiary rocky substrate mollusks from Baja California Sur, Mexico. American Malacological Bulletin, 4:1–12.

SQUIRES, R. L., AND R. DEMETRION. 1990. New Eocene marine bivalves from Baja California Sur, Mexico. Journal of Paleontology, 64:382–391.

——, AND ——. 1992. Paleontology of the Eocene Bateque Formation, Baja California Sur, Mexico. Natural History Museum of Los Angeles County, Contributions in Science, 430, 55 p.

WEAVER, C. E., AND THE WESTERN CENOZOIC SUBCOMMITTEE. 1944. Correlation of the marine Cenozoic formations of western North America. Geological Society of America Bulletin, 55:569–598.

ACCEPTED 2 MARCH 1992

Richard L. Squires provided $50.00 in support of this article.