EVOLUTION OF THE ECHINOID GENUS ASTRODAPSIS

BY

CLARENCE A. HALL, JR.

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ABSTRACT

Astrodapsis specimens from several areas of California seem on casual observation to be morphologically distinct from others in the same bed or at the same horizon, but upon closer scrutiny and comparison can clearly be shown to represent members of one variable population. Many of the previously described species are morphologically intergrading taxa that come from the same horizon, and thus represent one population, i.e., a group of freely interbreeding individuals at a locality.

Because of these relationships the echinoid genus *Astrodapsis* is revised: the fifty-nine named species, subspecies, and varieties are reduced to twelve species. These species include, from the oldest to the youngest, *A. brewerianus, A. diabloensis, A. pabloensis,* and *A. cierboensis* forming one supraspecific taxon; *A. davisi, A. antiselli, A. spatiosus, A. arnoldi, A. fernandoensis,* and *A. peltoides* forming another; and the closely related *A. whitneyi* and *A. jacalitosensis,* a third. Statistical analyses strongly support the reduction in number of species and subspecies and also lend support to the belief that these twelve species have real stratigraphic value.

Astrodapsis is a late Middle Miocene to Early Pliocene genus that is apparently restricted to California.

INTRODUCTION

The genus *Astrodapsis* has been of interest to paleontologists for over a hundred years. During this time Conrad (1856), Rémond (1864), Gabb (1869), J. C. Merriam (1899), Clark and Twitchell (1915), Kew (1920), Richards (1935), Grant and Hertlein (1938), Eaton *et al.* (1941), and Durham (1955) have named and studied species in this genus. Large collections now make it possible to study more objectively the evolutionary trends and the variation within this Miocene and Early Pliocene genus than was possible earlier.

When collections of *Astrodapsis* were made in western San Luis Obispo County, California, it was immediately apparent that the infraspecific variation was great at a single locality. There is a complete gradational succession between a number of described species that occur together and that were heretofore thought to be distinct. Collections from other areas were studied and similar relationships were evident. The fossil assemblages from San Luis Obispo County play an important part in the proposed taxonomic revision and zonation of species of the genus *Astrodapsis* because in this region there are several continuous and unbroken sequences containing abundant echinoid remains. Moderate-sized samples from Santa Cruz, Monterey, and Fresno counties, and the San Francisco Bay region have also been studied.

Diagnostic characters used here to differentiate species include: position of the periproct, thickness of the test, height of the test and petals, density and size of the tubercles on the test, presence or absence of aboral interambulacral valleys, and the presence of shoulders flanking the petals. A statistical analysis of approximately a hundred specimens of *Astrodapsis,* which included a large number of holotypes, was made to determine if there were significant differences among some previously named species. Both the statistical data and comparative morphology tend to support the view that the fifty-nine named species, subspecies, and varieties can probably be reduced to twelve. Even though the makeup of the genus is considerably revised the taxa continue to have great stratigraphic value.

Because the sequence of echinoids from the Phoenix-Saucelito creeks area, San Luis Obispo County, first called to my attention the morphologically intergrading nature of several previously named *Astrodapsis* species, and because this area is important to the understanding of the age and correlation of *Astrodapsis*, the Phoenix-Saucelito creeks fauna and stratigraphy are discussed.

Acknowledgments

I am indebted to students of the UCLA summer field geology class who aided me in collecting fossils from the Phoenix-Saucelito creeks area. The echinoid collections made earlier by U. S. Grant, IV, J. E. Eaton, E. H. Quayle, and Takeo Susuki were invaluable to this study. L. G. Hertlein, A. M. Keen, and J. H. Peck, Jr., kindly made available to me the collections at the California Academy of Sciences, Stanford University, and University of California, Berkeley, respectively. Thanks are extended to P. M. Kier, U. S. National Museum, and H. G. Richards, Academy of Natural Sciences of Philadelphia, for the loan of *Astrodapsis* specimens. Mrs. Peter Kurtz did the drafting. Special thanks are extended to C. E. Corbató, University of California, Los Angeles, who kindly made a computer program for the statistical analysis and generally aided in the analysis, and to Takeo Susuki, who photographed the fossils.

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Previous Work

Conrad (1856, p. 315; 1857, p. 196, pl. 10, figs. 1, 2) was the first to describe the genus *Astrodapsis*, the type species being *A. antiselli* Conrad, 1856. Since 1856, fifty-nine species, subspecies, or varieties have been described under this genus. The most notable of the early contributions was that made by Kew (1920), who was the first to interpret the evolutionary history of this genus. Many others have made contributions to the understanding of this taxon, as mentioned below.

Richards (1936) made the first major effort to set up *Astrodapsis* faunal zones, and they have proved useful to geologists for the last twenty-six years in correlating Late Miocene and Early Pliocene formations.

Eaton, Grant, and Allen (1941) collected and described a large number of echinoid species from the Caliente Mountains. On the basis of their collections, they delimited zones and assigned these to the Pacific coast megafaunal "stages."

The previous work done in or near the Phoenix-Saucelito creeks area includes the following. Richards (1933, 1935) lists some fossils from the Huasna syncline, Taliaferro (1943, pp. 443–447) describes the geology of this region, and King

(1943, pp. 448–449) discusses the economic development of petroleum in the Huasna area. Merriam (1931) was the first to describe a brittle star from the Nipomo quadrangle.

In the San Luis Obispo–Santa Margarita area immediately to the north, Fairbanks (1904), Nomland (1917), and Richards (1933) list fossils from the Santa Margarita formation. The San Luis Obispo geologic map sheet (Calif. Div. Mines, 1958), scale 1:250,000, includes the area discussed.

THE GENUS ASTRODAPSIS

As Kew (1920, p. 41) observed, the Miocene and Pliocene echinoid genus *Astrodapsis* gives us one of the best examples of an evolutionary series among the Late Cenozoic invertebrates. There is an abundance of specimens of this genus in much of the California Tertiary record, and locally there is a complete or near-complete sequence. Owing to this abundance, and because of the diversity in gross morphology in *Astrodapsis*, there has been a tendency on the part of taxonomists to make each specimen that differs morphologically from known named species—whether slightly or markedly—a new species, subspecies, or variety. This practice has been followed even with specimens from the same horizon, and where there is a complete gradation from one "species" to another. Making species out of slightly different individual variants has greatly confused the systematics of the genus, and has also diminished the usefulness of the species as zonal indicators.

The following premises are used here in species discrimination:

1) The definition, in brief, of a species is that of Mayr *et al.* (1953, p. 25), namely: "Species are groups of actually (or potentially) interbreeding natural populations which are reproductively isolated from other such groups."

2) If individuals are morphologically identical, and from the same population and area, they are members of the same species.

3) If the individuals are morphologically different, but if they come from the same locality (sympatric), and if the individual variants are represented in the same, continuously varying population, the variants probably represent the same species.

4) If the individuals are morphologically different and are from mutually exclusive geographic areas, the variants are probably different species or subspecies.

Morphology

Earlier authors differentiated a large number of taxa on the basis of petal width and elevation and thickness of the margin. Other criteria used have included (1) presence or absence of ambulacral furrows, (2) aboral interambulacral depressions, (3) ambitus notched or unnotched, (4) large apical systems, (5) bell-shaped profile, (6) tubercle size and distribution, (7) position of periproct, and (8) distance between margin and end of petals. These criteria are generally useful in differentiation but were overutilized by earlier authors. Any slight variation in one or a combination of these criteria, to them, warranted a new name. If large or moderately large collections are studied, it is immediately obvious that any one species has a wide range of intergrading variants.

h = height or thickness of test.

T' = thickness of test measured at the posterior interambulacral area three aboral interambulacral plates from the margin.

T" = thickness of the test measured at the central anterior petal (III). This measurement is made parallel with the third aboral interambulacral plate from the margin.

Z = h-T'. The thickness of the test between the top of the interambulacral area three aboral plates from the margin and the most elevated or highest part of the test.

Q = T"-T'. The thickness or height of the petal. The difference in elevation between the bottom of the interambular valley and the top of the petal.

Fig. 1. Measurements of thicknesses used in the statistical analyses.

The postbasicronal ambulacral plates are probably another useful morphologic criterion for specific determinations. An attempt was made to determine statistically the significance of these plates. However, it was not possible to obtain a large enough sample that showed plates. It was hoped that radiographs of specimens might be a means for determining arrangement and number of basicronal plates, but because of the matrix within the test and, even more important, recrystallization, this method was not satisfactory.

In synonymizing the large number of species, subspecies, and varieties, collections were analyzed and specimens compared from the same horizon or locality. Comparisons were also made with collections from other regions. The types of almost all *Astrodapsis* species were studied.

The morphologic criteria used here to differentiate species are: (1) position of the periproct, whether marginal, near-marginal, or inframarginal; (2) relative height of the petal; (3) notched or unnotched margin; (4) aboral interambulacral valleys, or if the interambulacra are convex, concave, or flat; and (5) shoulders flanking the petals. Of slightly less importance is the shape or cross-sectional profile, and the distance of the petal from the margin. Usually of least importance are the thickness, width of petal, and size of tubercules.

To test the validity of synonymizing the large number of previously named taxa, or to suggest in some independent and quantitative way that there are comparatively few species of *Astrodapsis,* a triangular diagram was constructed to show the scatter of ratios of mensurable morphologic features. Following this, distribution fields were delimited and statistical analyses made on the samples in these fields to determine if they were significantly different.

Statistical Analysis

The steps in making a statistical analysis to test significant differences between species or groups of species within the genus were as follows:

1) Measuring with a set of calipers different thicknesses (see fig. 1) of tests of more than a hundred specimens. The measurements were in general restricted to those *Astrodapsis* with distinctly raised petals, which correspond to two of the three taxa that might be considered subgenera. The sample included nearly all the holotypes of *Astrodapsis* with raised petals and collections from different regions of California (see Appendix A).

2) Converting the measurements, h, T', and T'', to ratios of h/S, T'/S, and T''/S, where $S = h + T' + T''$, thus showing proportions rather than absolute size. These ratios are plotted on the triangular graph (see fig. 2, in pocket). All the dimensions are given in Appendix A.

3) Four distribution fields were arbitrarily selected. This was done by grouping the points forming patterns of greatest density.

4) Statistical analyses, using the *t* test (Imbrie, 1956, p. 226), were made on these four fields to determine if they were significantly different. This was done by selecting one of the ratios, h/S, from each group making the four different distribution fields. Other ratios, Z/S_2, where $S_2 = h + T' + (h - T')$, and Q/S_3, where $S_3 = T'' + T' + (T'' - T')$, were also statistically analyzed to see if there were significant differences in the groups or fields using these proportions.

TABLE 1

COMPARISON OF PROBABILITIES OF THE SIGNIFICANT DIFFERENCE BETWEEN SELECTED TAXA

Parameter	$\bar{x}$	S.D.	Group II	Group III	Group IV
			GROUP I (n = 22)		
h	13.636	2.921	t = .952 $P \cong$ .3	t = 3.288 $P \cong$ .001	t = 2.051 $P \cong$ .05
T'	4.363	1.074	t = 3.964 $P <$ .001	t = 5.993 $P <$ .001	t = .603 $P >$ 0.5
T''	6.601	1.910	t = 3.033 $P <$ .01	t = 3.606 $P <$ .001	t = 3.474 $P <$ .01
h/S	55.114	5.144	t = 5.963 $P <$ .001	t = 16.208 $P <$ .001	t = 5.752 $P <$ .001
Z/S_2	33.609	3.401	t = 6.063 $P <$ .001	t = 14.259 $P <$ .001	t = 3.339 $P <$ .01
Q/S_3	16.868	6.436	t = .064 $P >$ 0.5	t = 4.425 $P <$ .001	t = 3.227 $P \cong$ .001
			GROUP II (n = 21)		
h	12.938	1.703		t = 2.446 $P \cong$ .01	t = 2.370 $P \cong$ .02
T'	5.4856	.775		t = 3.007 $P <$ .01	t = 2.722 $P \cong$ .01
T''	8.223	1.341		t = .664 $P \cong$ .5	t = 2.226 $P \cong$ .05
h/S	48.271	1.101		t = 10.551 $P <$ .001	t = 7.952 $P <$ .001
Z/S_2	28.622	1.589		t = 9.384 $P <$ .001	t = .035 $P >$ .5
Q/S_3	16.762	4.221		t = 4.740 $P <$ .001	t = 4.797 $P <$ .001

NOTE: Table shows Student t-values and probability (P) for selected groups of taxa, comparing ratios of h/S, where $S = h + T' + T''$; Z/S_2, where $S_2 = h + T' + (h - T')$; Q/S_3, where $S_3 = T' + T'' + (T'' - T')$; and T''/h. Taking into consideration the degrees of freedom, if the probability (P) is 1 per cent or less it is a reliable indication that the groups actually differ; if the probability is more than 5 per cent, or if it lies between 1 and 5 per cent, the difference is not judged significant. (See text for definitions of h, T', T'', Q, Z, N, $\bar{x}$, and SD.)

TABLE 1—*Continued*

Parameter	$\bar{x}$	S.D.	Group II	Group III	Group IV
		Group III (n = 77)			
h	11.258	3.010			t = .167 $P >$ .5
T'	6.603	1.652			t = 2.901 $P <$ .01
T''	8.560	2.204			t = 1.235 $P \cong$ .2
h/S	42.544	2.413			t = .091 $P >$ .5
Z/S_2	20.348	3.962			t = 5.032 $P <$ .001
Q/S_3	11.368	4.722			t = 7.288 $P <$ .001
		Group IV (n = 6)			
h	11.050	1.774			
T'	4.633	.266			
T''	9.700	1.753			
h/S	42.450	2.767			
Z/S_2	28.633	2.425			
Q/S_3	25.700	3.119			

The distribution of the ratios of these separate fields was plotted on probability paper and the graph was nearly a straight line or approximated a graph of cumulative normal distribution. The same procedure was used and the same results obtained when actual measurements instead of ratios were plotted. The assumption is made here, as it is generally, that the sample is normally distributed.

The t test was selected because of its usefulness in determining samples with a normal distribution and a relatively small size.

5) Finally a statistical analysis was made to determine if there were significant differences among the groups shown on the triangular graph using the actual thickness measurements for specimens in each of these groups.

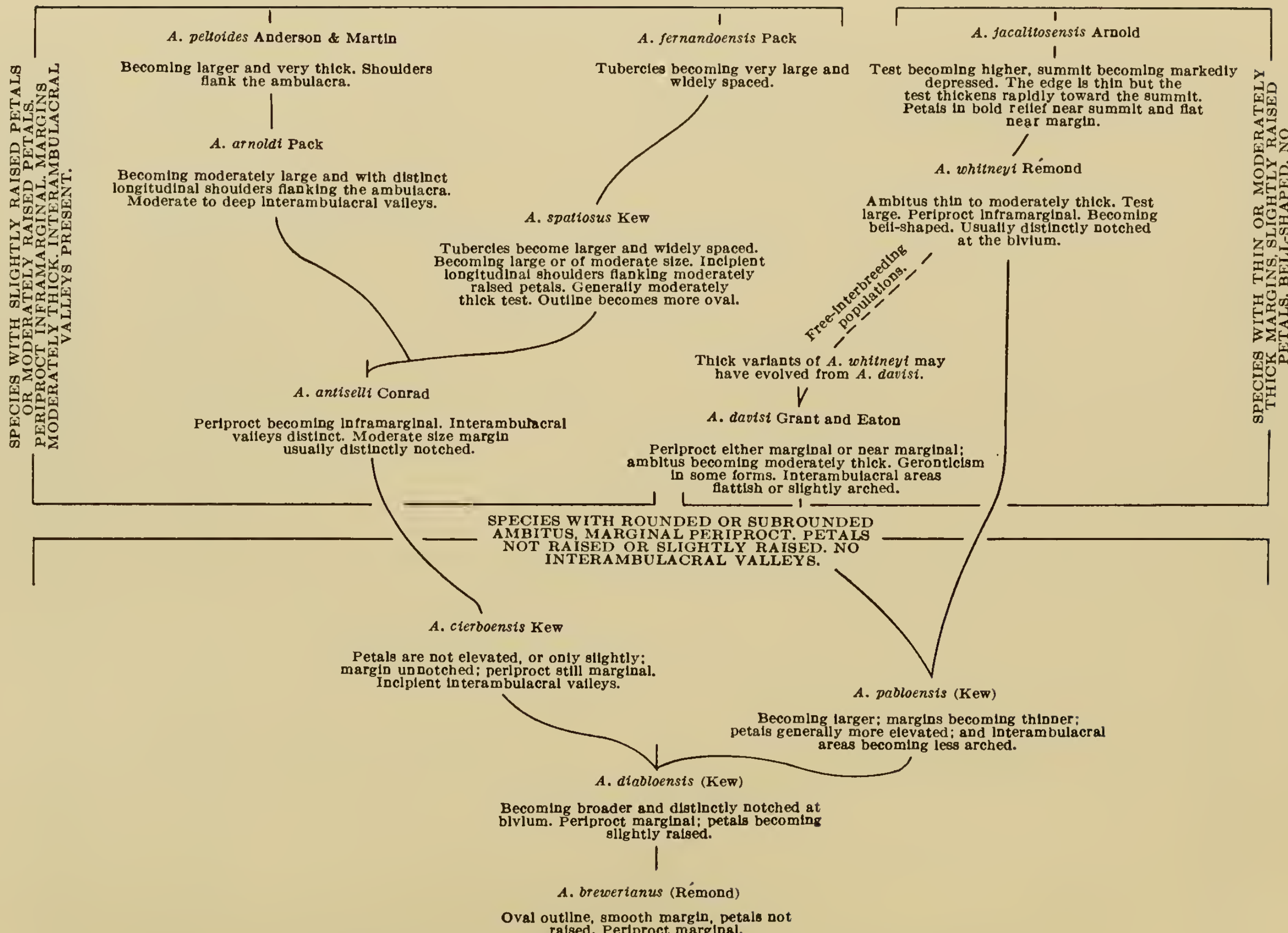

Fig. 4. Relationships and evolution of the species of the echinoid genus *Astrodapsis*.

The statistical formulas used in calculating the level of significance between the different groups or distribution fields were

$$(a) \qquad \bar{x} = \frac{\sum (x)}{N} \qquad\qquad (b) \qquad s = \sqrt{\frac{(d)^2}{N - 1}}$$

and

$$(c) \qquad t = \frac{(\bar{x}_1 - \bar{x}_2)\sqrt{\dfrac{N_1N_2}{N_1 + N_2}}}{\sqrt{\dfrac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2}}}$$

where: x = the thickness measured.
$\bar{x}$ = the mean of x.
N = the number of specimens in the sample.
s or SD = the standard deviation.
$d = x - \bar{x}$, the difference between any observation and the mean.
d.f. = $N_1 + N_2 - 2$ = the number of degrees of freedom.
t = significance of the difference between the means.

When a table of Student *t*-values is consulted, taking into consideration the degrees of freedom, if the probability (P) is 1 per cent or less, i.e., $P < .01$, it is a reliable indication that the taxa actually differ. If the probability is more than 5 per cent, i.e., $P > .05$, or if it lies between 1 and 5 per cent, the difference is not judged significant. (See *Statistical Tables for Biological, Agricultural, and Medical Research,* by R. A. Fisher and F. Yates, for Student *t*-values.)

RESULTS

Group I is significantly different from Group III. Group III is judged to be not significantly different from Group IV. Because of the intermediary nature of Group II it is difficult to ascertain with certainty from the *t* test if it is significantly different from Group I. It is probably different from groups III and IV.

DISCUSSION

Considering only the statistical analysis, there is a very strong suggestion that groups I and II, II and IV, and II and III, are different. The validity of these differences seems to be borne out when the ratios T′/h and T″/h are plotted on a rectangular graph (fig. 3, in pocket), and the same groups delineated, as on the triangular graph. The specimens include holotypes, syntypes, hypotypes, topotypes, and plastotypes of *Astrodapsis* species. By visual comparison and inspection of these specimens the groups are in general judged to be the same or different in the same manner as they were when statistically evaluated above. There are exceptions, one being the apparent statistical difference between groups I and II. In a large collection from the Cuyama region there is a complete morphologically gradational sequence between the thinner margined forms in Group I and the thicker margined forms in Group II. Because of this gradational sequence from a single horizon and at the same loeality, the thieker forms in Group II are eombined with those of Group I.

Group II may be transitional between groups I and III beeause *A. ornatus* (now *A. antiselli*) occurs in both groups I and II and it ean be elearly shown to be part of a gradational morphologie sequenee that ineludes *A. antiselli* Conrad. If it were not for the distinct interambulacral valleys, *A. ornatus* could be a synonym of *A. whitneyi*. The other speeies that suggest that Group II is a transitional group are the holotypes of *A. margaritanus* and *A. major* that oceur in the group, but other speeimens of these speeies are in Group III.

The parameters used in this statistical analysis are useful in delimiting two of three taxa. Those speeimens in groups I and II, and groups III and IV, eonstitute these two taxa. In the first taxon (groups I and II) are *A. whitneyi* and *A. jacalitosensis;* in the other taxon (groups III and IV) are *A. antiselli, A. spatiosus, A. arnoldi, A. davisi, A. fernandoensis,* and *A. peltoides*. All of the other speeies shown on the reetangular graph are probably synonyms of these speeies. Species in these taxa are differentiated on the basis of the length of the petals, presence of shoulders flanking the petals, and eharaeter of the aboral interambulaeral area.

The third taxon, whieh also eould be eonsidered a subgenus, is not evaluated in this statistieal analysis beeause the petals are not distinetly raised. Speeies in this taxon are differentiated on the basis of the position of the periproet, the charaeter of the aboral interambulaeral area, the outline, and the eharaeter of margin. The speeies ineluded are *A. brewerianus, A. diabloensis, A pabloensis,* and *A. cierboensis.*

Relationships and Evolutionary Trends

Basieally there are three natural allianees of related speeies that show eharaeteristie evolutionary trends. These three groups of species are: (1) speeies with a rounded or subrounded ambitus, marginal periproet, petals not raised, and no interambulaeral valleys; (2) speeies with thin or moderately thiek margins, slightly raised petals, bell-shaped profile, and no interambulaeral valleys; and (3) speeies with slightly raised or moderately raised petals, periproet inframarginal, margins moderately thiek, and with interambulaeral valleys present. All the presently known speeies of *Astrodapsis* ean be assigned to one of these three groups of related speeies.

Some species that oeeur together, and differ markedly in morphology, apparently are not variants of the same speeies. *A. cierboensis* may occur with *A. pabloensis,* but it is also in younger rocks than *A. pabloensis,* and it is not always with it in roeks of the same age. During some part of Late Mioeene time *A. cierboensis* was isolated from *A. pabloensis* either in time or spaee. Apparently *A. pabloensis* and *A. cierboensis* evolved from a eommon aneestor (*A. diabloensis*) in different geographie regions at different times, and loeally they later eame together owing to migration. From both these speeies new taxa also evolved in different geographie areas. The evolving taxa were *A. davisi* from *A. pabloensis* and *A. antiselli* from *A. cierboensis;* they do not oeeur together, and are alloehronie. *A. davisi* was relatively short-lived, and may have been aneestral to *A. whitneyi. A. antiselli* and *A. whitneyi* are in part sympatrie but represent different evolving lineages whose ancestors were allopatric. This is also apparently true of the Early Pliocene taxa, *A. jacalitosensis* and *A. peltoides* (see fig. 5, in pocket).

The relationships of species of *Astrodapsis*, together with an outline of the phylogenetic development of the taxon, are presented in figure 4. Figure 5 shows the stratigraphic range of species within this genus is from the late Middle Miocene to the Early Pliocene. As now known, the genus is apparently restricted to California, chiefly between latitudes 34° and 38° N. Although the genus has been reported from eastern Russia (Khomenko, 1931), photographs of the specimens from Kamchatka are of such poor quality that it is not possible to determine whether they are *Astrodapsis*. It is probable that they belong to the genus *Pseudoastrodapsis* Durham (Durham, 1955, p. 168).

Astrodapsis apparently lived in a near-shore environment, because it is associated with genera such as *Ostrea*. The closest living relative of *Astrodapsis* is *Echinarachnius*, which lives along the northwestern coast of North America. Although the habits of *Astrodapsis* may have been in some ways similar to *Echinarachnius*, *Astrodapsis* did not live in temperate or cool temperate marine environments, like the living *Echinarachnius*, but was confined chiefly to warm temperate or tropical seas.

MORPHOLOGIC CHANGES

Certain morphologic changes take place in the evolution of the genus *Astrodapsis*. Some of the more common changes are:

1) The test becomes progressively relatively broader during the evolution of the genus.

2) The margins are at first unnotched, in the earliest forms, and then later they are markedly notched at the bivium, and finally notching at the bivium becomes less pronounced in some of the youngest taxa, or it may develop at the trivium and at the junction of the margin and the aboral interambulacral valleys in others.

3) The periproct moves from the margin to the bottom, that is it becomes inframarginal.

4) The petals are elevated in some early forms and interambulacral valleys may develop.

5) The margins become thinner and the outline becomes more bell-shaped during the evolution of some groups of species, while others become relatively larger, more tumid, and thick margins develop.

6) Ridges develop along the flanks of the petals in some of the youngest thick-margined taxa.

PHOENIX-SAUCELITO CREEKS FAUNA

Introduction

Geologic mapping of the Late Miocene rocks in the Phoenix-Saucelito creeks area in the south-central part of San Luis Obispo County, California, has brought to light an excellent sequence of echinoids, some new species of metazoan invertebrates, and a collection of marine mega-invertebrate fossils containing approximately thirty species. They occur in rocks of the Santa Margarita formation, which here consists of white coarse-grained sandstone, fine-grained sandstone and silt-

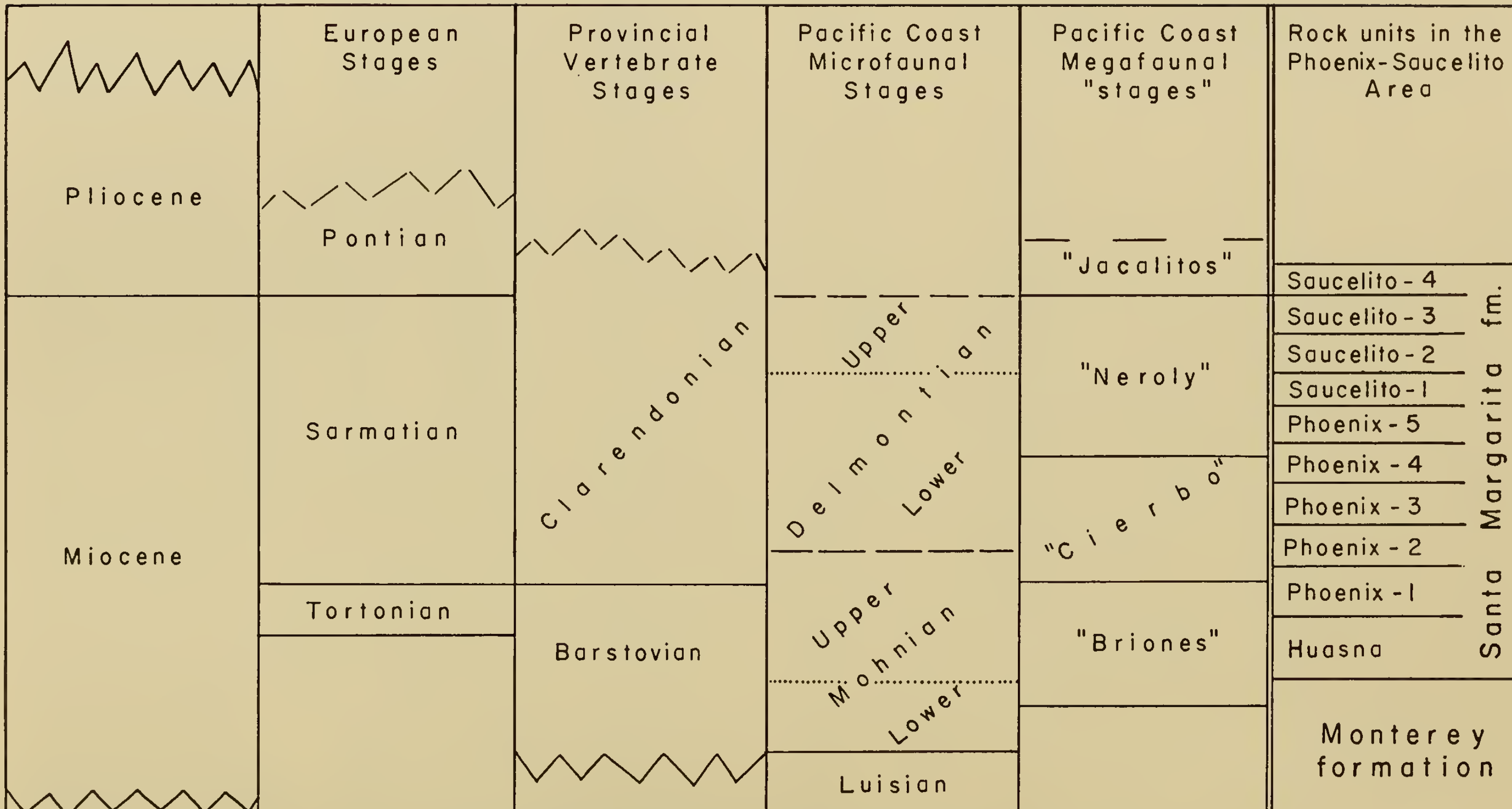

Fig. 7. Age relations of some Late Miocene stratigraphic units.

stone, and siliceous claystone. The faunas, for the most part, lived in a marine littoral environment to depths of 75 feet. Megafossils are not as abundant in the shallow neritic (from depths of 60 to 300 feet), finer-grained sediments. The assemblage is most closely related to communities living today in the Magdalenan molluscan province (see Hall, 1960, map 1).

Geologic Occurence

SANTA MARGARITA FORMATION

Type area.—The rocks now termed the Santa Margarita formation were first mentioned by Antisell (1857, p. 44), but it was not until 1904 that Fairbanks (p. 4) formally named the Santa Margarita and related Pismo formations. Fairbanks noted that the Pismo formation, named after the nearby town, differs only slightly from the Santa Margarita. A major fault—the West Huasna—separates these two type areas. It is likely that the Pismo and Santa Margarita are the same because they are used for a unit of similar stratigraphic position and lithology. Since the name Santa Margarita has gained wider usage, it will be used in preference to Pismo formation.

The type section of the Santa Margarita formation is exposed along Santa Margarita Creek, approximately 10 miles to the north of the Phoenix-Saucelito area. The rocks in the Phoenix-Saucelito creeks area are separated from the type area by at least one fault; its magnitude and direction of slip have not been well established. In its type area the formation consists of white, friable, massive, coarse-grained arkosic sandstone. The sandstone grades laterally into conglomerate or medium-grained sandstone, and only the gross members can be traced for any distance. The rocks in the type area are not as well exposed as those in the Phoenix-Saucelito area. In the type area the section is approximately 1,700 feet thick, whereas in the Phoenix-Saucelito creeks area it is nearly 6,000 feet thick.

General statement.—The Santa Margarita formation is exposed in the central part of the Huasna syncline, which in this area is a broad northwest-southwest trending doubly-plunging fold with slightly shallower dips on the east flank. The strata are not complicated by faults, exposures are good, and the rocks are fossiliferous, thus providing an excellent reference section.

The Santa Margarita concordantly and apparently conformably overlies the Monterey formation in this area. The contact between these formations is drawn at the first appearance of white fine-grained sandstone and siltstone above the siliceous mudstone or, locally, yellowish siltstone of the Monterey formation.

Lithology.—In this area the rocks of the Santa Margarita formation are predominantly white-weathering, coarse-grained arkosic sandstone and siltstone, with some yellowish or tan siliceous mudstone.

The formation can be divided into three members and several submembers in the Phoenix-Saucelito area. Other investigators have divided the rocks in this area into two formations—the Santa Margarita and an unnamed one regarded by some as Pliocene. From the base of the Santa Margarita formation to the top of the section the sediments grade from siltstone or siliceous mudstone to alternating coarse- to medium-grained white or gray calcareous lithic arkosic arenite or quartz

TABLE 2

COMPOSITION OF THE PHOENIX-SAUCELITO CREEKS FAUNA

(Check list of fossils from the Santa Margarita formation)

HUASNA MEMBER

Fossils	UCLA locality numbers 4150	4163
Pelecypoda		
Pecten (Aequipecten) discus Conrad	*	*

SUBMEMBER 2, PHOENIX MEMBER

Fossils	4151
Pelecypoda	
Andadara obispoana (Conrad)....	*
Panope generosa (Gould).........	*
Pecten (Aequipecten) discus Conrad	*
Saxidomus nuttallii (Conrad).....	*
Schizothaerus nuttallii (Conrad)...	*

SUBMEMBER 3, PHOENIX MEMBER

Fossils	4152	4153	4162
Pelecypoda			
Andadara obispoana (Conrad)....		*	
Pecten (Aequipecten) discus Conrad[a]......................	*		*

SUBMEMBER 4, PHOENIX MEMBER

Fossils	4164	4165	4166	4167	4168	4169	4170	4171	4172	4173	4174	4175	4176	4177	4178	4319
Echinodermata																
Astrodapsis antiselli Conrad......		*	*	*	*	*				*	*		*	*		*
Ophuroidea.......................							*	*	*							
Pelecypoda																
Ostrea titan Conrad.............	*	*	*	*									*			
Pecten (Lyropecten) crassicardo Conrad.......................												*	*	*	*	
Pecten (Lyropecten) estrellanus Conrad.......................														*	*	
Gastropoda																
Nucella lamellosa (Gmelin).......														*		
Nucella lima (Gmelin)...........														*		
Trophon cf. *T. perelegans* Nomland.....................														*		

[a] This species is throughout this submember.

TABLE 2—*Continued*

Fossils	UCLA locality numbers		
SUBMEMBER 5, PHOENIX MEMBER			
	4179	4180	4181
Pelecypoda			
Anadara trilineata calcarea (Grant and Gale)		*	
Anadara trilineata trilineata (Conrad)		*	
Anadara sp.	*		
Arca n. sp.		*	
Dosinia aff. *D. arnoldi* Clark	*		
Lucinoma acutilineata (Conrad)	*	*	
Modiolus rectus Conrad		*	
Nuculana furlongi Trask		*	*
Panope generosa (Gould)		*	
Pecten (*Chlamys*) *hodgei* Hertlein		*	
Saxidomus sp.		*	
Trachycardium quadragenarium (Conrad)		*	
Gastropoda			
Calyptraea aff. *C. mamillaris* Broderip		*	
Calyptraea sp.	*		
Turritella cf. *T. margaritana* Nomland	*		

SUBMEMBER 2, SAUCELITO MEMBER

	4154	4155	4156	4157	4158	4159	4160	4161
Echinodermata								
Astrodapsis spatiosus Kew			*		*	*		
Astrodapsis whitneyi Rémond					*	*		
Arthropoda								
Balanus (*Tamiosoma*) *gregaria* Conrad								*
Pelecypoda								
Mytilus coalingensis Arnold						*		
Ostrea atwoodi Gabb						*		
Pecten (*Lyropecten*) *estrellanus* Conrad n. subsp. (?)	*	*		*		*	*	

arenite. Beeause the youngest roeks are lithologieally similar to the rest of the alternating sequence of roeks in the upper part of the Santa Margarita formation, they are all eonsidered as part of the same formation, Late Mioeene in age, exeept for the uppermost submember of the Saueelito member, whieh is Plioeene.

The Santa Margarita formation is here divided into three members (see fig. 6 and map 1, in poeket), these being, from oldest to youngest, the Huasna, Phoenix, and Saueelito. They represent a Late Miocene and Plioeene roek record from lower Mohnian to Lower Plioeene.

The Huasna member eonsists of white to gray-brown quartz arenite or arkosie waeke. In the west there is a silieeous shaley elaystone facies.

The Phoenix member eonsists of sandstone and silty sandstone or siltstone alternating with silieeous mudstone. The sandstone is a fine- to eoarse-grained arkosie or quartz arenite, loeally eontaining a large pereentage of shell debris. The siltstone and silieeous mudstone loeally eontain abundant *Pecten discus* remains. The siltstone is eommonly grayish white or light tan in eolor and the mudstone is either yellowish or brown.

The Saucelito member is an alternating sequenee of sandy siltstone or siltstone and arkosie arenite and waeke, whieh loeally eontains stringers of ehert pebbles.

Age and correlation.—The lower members of the Santa Margarita formation—the Huasna and part of the Phoenix—are Late Miocene, late upper Mohnian; the upper part of the Phoenix and lower Saueelito are Late Mioeene, late Mohnian to lower Delmontian; and the middle parts of the Saueelito member are Late Mioeene, upper Delmontian, and the upper part is Pliocene in age (fig. 7). The Delmontian is eonsidered to be Late Miocene here. For a diseussion of the Mio-Pliocene boundary problem, see Axelrod (1956, pp. 11–14, table 1) and Durham, Jahns, and Savage (1954, fig. 2). Kleinpell's Mioeene mierofaunal stages and ages will be used when diseussing roeks and fossils. Lower Plioeene marine roeks will be referred to as Lower Plioeene and not assigned to Plioeene mierofaunal stages.

The underlying Monterey formation is in part late Middle Mioeene, based on Luisian Foraminifera (Kleinpell, 1938, "0–4," table 2, p. 24); and it is in part Mohnian, based on megafossils.

The typieal Late Mioeene *Pecten discus* Conrad, 1857 (i.e., *P. raymondi* Clark, 1915, of authors; see Grant and Gale, 1931, p. 200), first appears in the upper part of the Monterey formation. It is abundant in the lower part of the Huasna member and is in superabundanee in the yellowish or brown silieeous mudstone of the Phoenix member. Elsewhere, *P. discus* is in the Late Miocene Briones, Cierbo, and Neroly formations in the San Franeiseo Bay region (Weaver, 1949, tables 16–18); in the lower Mohnian of the Santa Maria Basin (Kleinpell, 1938, fig. 14); and in the late Briones and early and middle Cierbo in the Cuyama area (Eaton, *et al.*, 1941). *Pecten discus* is apparently restricted to the Late Mioeene in California.

Late Mohnian astrodapses are in the Huasna member just outside of the area mapped. In the upper part of the Phoenix member are *Ostrea titan* Conrad and *A. antiselli* Conrad. This oyster and eehinoid are eommon elsewhere in Upper Mioeene lower Delmontian or "Neroly" roeks.

The lower submember of the Saueelito member is lower Delmontian in age, as shown by Foraminifera from Stanford University microfossil locality 967. The same megafossils (see table 2) from the higher parts of the Saucelito member are associated in other places with upper Delmontian foraminifers. No sharp lithologic breaks occur between the several upper submembers of the Saucelito member. The Early Pliocene Saucelito submember 4 represents the first of the Pliocene or a transition between Miocene and Pliocene. A few miles south of this area this submember contains Pliocene *Dendraster gibbsii* and *Patinopecten löhri,* and fragments of *Astrodapsis.* Elsewhere *D. gibbsii* occurs with *A. jacalitosensis* and *A. peltoides,* all of these fossils being above definite upper Delmontian foraminifers.

The presence of *A. spatiosus* Kew in submember 2 of the Saucelito member has suggested to some a Pliocene age for almost all the Saucelito member. *A. spatiosus* and *A. arnoldi* are common in the Pancho Rico formation, and this formation is generally considered to be Pliocene. However, the Pancho Rico formation contains an upper Delmontian microfauna (Kleinpell, 1938, p. 238), and the upper Delmontian is considered here to be Late Miocene rather than Pliocene.

Also associated with *A. spatiosus* in the Phoenix-Saucelito area is *A. whitneyi. A. whitneyi* occurs elsewhere only in Late Miocene rocks. The age of the lower three submembers of the Saucelito are Late Miocene, submember 1 is lower Delmontian, and submembers 2 and 3 are upper Delmontian. The upper part of the Saucelito member, submember 4, is correlated with the Early Pliocene Jacalitos formation of the North Coalinga region, the Early Pliocene Santa Margarita formation, at Monterey, and the Early Pliocene part of the uppermost "Neroly" in the Cuyama region.

In the Cuyama region, Hill *et al.* (1958, p. 2991) have applied the name Branch Canyon formation to the rocks previously mapped by Eaton *et al.* as "lower Neroly," "Cierbo," "Briones," "Temblor," and "Vaqueros." Even though the names Neroly, Cierbo, and Briones are not appropriate because of the lack of established continuity between the Caliente Mountains and the type localities of these formations in the San Francisco Bay region, and because they are used in a time-rock sense, it still may be argued that the units mapped by Eaton *et al.* (1941) are distinct lithologic units and only need be given established formational names to which they can be traced or be given new names.

Hill *et al.* (1958, fig. 1) show that their Branch Canyon formation is equivalent in age to the Monterey formation and date both formations as Relizian and Luisian. Foraminifera and megafossils from the bottom 1,550 feet of the Branch Canyon are Relizian in age. They also state: "Overlying the Branch Canyon sandstone are the shale of the Santa Margarita formation which contain nondiagnostic shallow-water Foraminifera. Therefore, on the basis of Foraminifera, this formation [Branch Canyon] at its type locality is Relizian and possibly Luisian in age, and the upper 100 feet may be as young as Upper Miocene (Eaton's lower 'Neroly')." The evidence of Relizian fossils from the base of the formation plus nondiagnostic Foraminifera above their Santa Margarita formation does not warrant assigning a Relizian age to all or most of the Branch Canyon formation. Further, the upper 1,450 feet of the Branch Canyon formation contain *Ostrea* *bourgeoisii, O. cierboensis, Astrodapsis brewerianus* [probably *A. diabloensis*], and *A. cierboensis,* all of which occur in Mohnian rocks elsewhere in California. Hence the upper 1,450 feet, not just the upper 100 feet, of the Branch Canyon is definitely Late Miocene, Mohnian in age, and the lower part is Middle Miocene, Relizian and probably Luisian in age.

The upper 1,450 feet of the Branch Canyon formation is correlated with the Huasna and part of the Phoenix members of the Santa Margarita formation in the Phoenix-Saucelito creeks area. The Santa Margarita formation mapped by Hill *et al.* in the Cuyama region is correlated with the upper Phoenix member (late upper Mohnian and lower Delmontian).

Environment.—P. discus, common in the mudstone of the Monterey formation, and in the Huasna and Phoenix members of the Santa Margarita formation, is also in the littoral or shallow neritic, coarse-grained Late Miocene sediments in the San Francisco Bay region. The living genus and subgenus *Pecten* (*Aequipecten*) or *Aequipecten* (*Leptopecten*), of which the extinct species *discus* is a member, lives in water from several feet to nearly 250 feet deep. The abundance in the Phoenix-Saucelito creeks area of this species, in what is apparently a moderately deep-water deposit (possibly shallow neritic or moderately deep neritic), suggests that this is the preferred ecologic niche, although in the San Francisco Bay region *P. discus* is associated with a shallow-water Late Miocene fauna.

The megafauna from the coarse-grained members of the Santa Margarita formation suggests water depths of a few feet to 75 feet, whereas the mega- and microfossils in the finer-grained sediments suggest water depths from 60 to 300 feet or more. The water was probably quiet, with winter minimum sea-surface temperatures of approximately 18° C. Nearby land conditions were probably similar to the modern subtropical regions of northern Mexico and southward (Axelrod, 1956, p. 262).

There may have been alternating deepening and shallowing throughout most of the deposition of the Santa Margarita, as suggested by the thinning and thickening of coarse- and fine-grained sediments. A few miles to the north, similar facies changes were mapped by Page *et al.* (1944). In general, the lower part of the Santa Margarita formation is fine-grained sandstone and siltstone. Near the top there is a more friable coarse-grained sandstone, and the appearance of shallow-water organisms at this level suggests regressing seas at the very end of the Late Miocene. Besides the general coarsening of sediments upward during the deposition of the Santa Margarita, the lower part of this formation, deposited east of what is now the Huasna syncline, is predominantly siltstone, whereas to the west there is a greater percentage of siliceous mudstone. The same situation is reported by Page *et al.* (1944) to the northwest in the Pismo syncline. The early late Mohnian seas were transgressing eastward, with deeper water blanketing the western part of San Luis Obispo County for a longer period than to the east in the Caliente-Cuyama Valley area, where Eaton *et al.* report that almost all of the late Mohnian rocks are coarse-grained *Astrodapsis*-bearing near-shore sediments.

SYSTEMATIC DESCRIPTIONS

Phylum ECHINODERMATA

Class ECHINOIDEA Bronn

Order Clypeasteroida Agassiz

Suborder Scutellina Gray (emended, Durham, 1955)

Family Echinarachniidae Lambert (emended, Durham, 1955)

Genus *Astrodapsis* Conrad, 1856

Astrodapsis Conrad, 1856, Proc. Acad. Nat. Sci. Philad., vol. 8, p. 315; Clark and Twitchell, 1915, U. S. Geol. Surv. Mon. 54, p. 197; Kew, 1920, Univ. Calif. Publ. Geol., vol. 12, pp. 78–80; Lambert and Thiéry, 1925, Ess. nomencl. rais., p. 582; Grant and Hertlein, 1938, Univ. Calif. L. A. Publ. Math. Phys. Sci., vol. 2, pp. 68–69; Mortensen, 1948, Mon. Echin., vol. 4, pt. 2, pp. 393–395; Nisiyama, 1948, Jour. Paleont., vol. 22, pp. 601–602 (in part); Durham, 1952, Jour. Paleont., vol. 26, pp. 844–846; Durham, 1955, Univ. Calif. Publ. Geol. Sci., vol. 31, no. 4, pp. 104–108, 167–168.

Asterodapsis Conrad, A. Agassiz, 1872, Mem. Mus. Comp. Zool. Harvard Coll., vol. 3, p. 172.

Arachnoides Breynius, Duncan, 1889, Jour. Linn. Soc. London, Zool., vol. 23, p. 165 (in part).

Astrodapsis Conrad, Lambert and Thiéry, 1914, Ess. nomencl. rais., p. 314.

Type species.—Astrodapsis antiselli Conrad (U. S. Nat. Mus. Cat. no. 13337), type by monotypy.

Age.—Late Miocene (upper Luisian) to Early Pliocene (lowermost Pliocene).

Astrodapsis brewerianus (Rémond, 1864)

(Pl. 1, figs. 1, 5, 8, 11, 15, 18)

Echinarachnius brewerianus Rémond, 1864[1], Proc. Calif. Acad. Sci., vol. 3, p. 53; Gabb, 1869, Geol. Surv. Calif., Paleont., vol. 2, sec. 1, pp. 36, 109, pl. 12, figs. 65, 65a.

Clypeaster brewerianus (Rémond), Clark and Twitchell, 1915, U. S. Geol. Survey Mon., vol. 54, p. 210, pl. 96, figs. 2a, 2b, 2c, 3.

Astrodapsis brewerianus (Rémond), Grant and Hertlein, 1938, Univ. Calif. Los Angeles Pub. Math. and Phys. Sci., vol. 2, pl. 20, figs. 4, 5.

Astrodapsis hootsi Grant and Eaton, 1941, Amer. Assoc. Petrol. Geol. Bull., vol. 25, no. 2, pl. 5, fig. 11a.

Holotype.—Acad. Nat. Sci. Phila. 1088, Specimen A. The holotype was believed lost and Kew (1920, p. 91) gave as the "neotype" Univ. Calif., Berkeley, Coll. Invert. Pal. no. 11016 (earlier figured by Merriam). Gabb (1869, pl. 2, figs. 65, 65a) figured what is thought to be the type. The specimen figured by Clark and Twitchell (1915, pl. 96, fig. 2a–2c) (Acad. Nat. Sci. Phila. 1088, Specimen A) is probably the type described by Rémond and figured by Gabb because it is from the same locality, has the identical dimensions given by Rémond for the type, and is almost identical with the specimen figured by Gabb considering that Gabb's figure is a drawing.

Hypotypes.—Univ. Calif., Los Angeles, Cat. nos. 820A, 8399, 8399A.

Occurrence.—Rémond gives the type locality as: "Two miles east of Walnut Creek House. . . ." This locality is probably in the Briones formation, upper Mohnian, Upper Miocene. In San Luis Obispo County the species occurs approxi-

[1] Cited by authors as 1863. Paper read August 3, 1863, but not published until 1864.

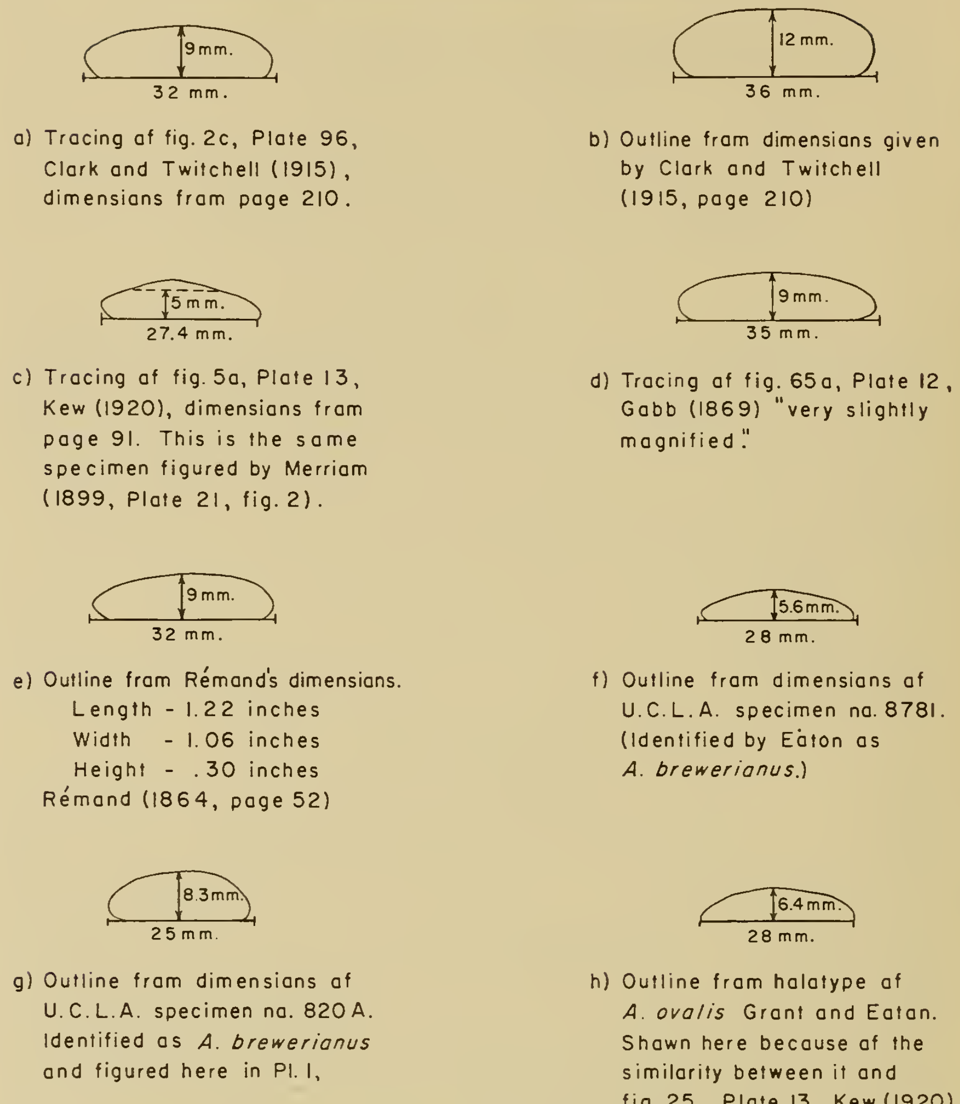

Fig. 8. Comparative cross-sectional outlines of species identified as *Astrodapsis brewerianus*.

mately 1,400 feet below the base of the Santa Margarita formation, and within the Monterey formation, upper Luisian, late Middle Miocene.

Remarks.—Unfortunately Rémond did not figure his species, and his description is rather brief. W. M. Gabb actually presented Rémond's paper (Rémond, first line on page 52) to the California Academy of Sciences, and it was Gabb who first figured the species. If anyone knew what Rémond considered to be the type it was Gabb. From the accompanying diagram (fig. 8) it is clearly seen that Gabb's figure ("very slightly magnified") almost fits exactly the dimensions given by Rémond (i.e., length, 1.22 inches; width, 1.06 inches; height, .30 inches). The specimen described and figured by Merriam (1899) and Kew (1920) and called the "neotype" by Kew (1920) is not as tumid as Rémond's described specimen. Kew (1920, p. 91) states that the *A. brewerianus* described by him is "broadly notched in the posterior ambulacral area." This is certainly not Gabb's figured specimen. Further, UCLA specimens numbered 8780 and 8781 are almost identical with Kew's "neotype" (see pl. 2), and these UCLA specimens grade into typical *A. diabloensis*. When the cross-sectional outlines of *A. brewerianus* (Rémond), figured by Gabb (1869), Merriam (1899), Clark and Twitchell (1915), Kew (1920), Eaton *et al.* (1941), and in plate 1, figs. 15, 18, are studied it is clear that the *Astrodapsis* figured by Merriam, Kew, and Grant and Eaton are not *Astrodapsis brewerianus* (Rémond) because they are not as tumid.

This species is characterized by a small test that is prominently elongate, highly ventricose, and with the dorsal surface uniformly convex. The ambitus is rounded, rather thick, and with a complete absence of indentations or with only a suggestion of indentations at the end of the posterior ambulacra. Small tubercles that are closely spaced cover the surface of the test.

The specimens of what have been called *A. hootsi* Grant and Eaton are somewhat smaller and more pentagonal than the typical *A. brewerianus,* but are most closely allied to this species. They resemble to some degree the juvenile *A. diabloensis* but do not have the posterior ambulacral indentations or the marked flare to the petals near the margin.

Age.—Upper Luisian to Mohnian, late Middle Miocene to Upper Miocene; commonly lower Mohnian to early upper Mohnian. The late Luisian specimens are dated by Luisian Foraminifera that are along strike in the Phoenix-Saucelito creeks area.

Astrodapsis diabloensis Kew, 1920

(Pl. 1, figs. 2–4, 6–7, 9–10, 12–14, 16–17, 19–20; pl. 2, figs. 1–12; pl. 3, figs. 1–12; pl. 4, figs. 1–12; pl. 5, figs. 1–5, 7–8, 10; pl. 6, figs. 1–8)

Astrodapsis brewerianus var. *diabloensis* Kew, 1920, Univ. Calif. Pub. Dept. Geol., vol. 12, p. 92, pl. 13, fig. 6; Grant and Eaton, 1941, Amer. Assoc. Petrol. Geol., Bull., vol. 25, no. 2, pl. 5, fig. 7.

Clypeaster (?) *brewerianus* (Rémond), Merriam, 1899, Proc. Calif. Acad. Sci., ser. 3, Geology, vol. 1, p. 166, pl. 21, fig. 2.

Astrodapsis brewerianus (Rémond), Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, no. 2, pp. 91, 92, pl. 13, figs. 5a, 5b, 5c. Figs. 5a and 5b are photographs of the same specimen figured by Merriam (1899); Grant and Hertlein, 1938, Univ. Calif. Los Angeles Pub. Math. and Phys. Sci., vol. 2, pl. 16, figs. 7, 8, *not* pl. 20, figs. 4, 5; Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 5; Shimer and Shrock, 1944, Index Fossils of North America, p. 223, pl. 85, fig. 6; Durham, 1955, Univ. Calif. Pub. Geol. Sci., vol. 31, no. 4, fig. 22f.

Astrodapsis altus antiquus Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 15.

Astrodapsis armstrongi Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 14.

Astrodapsis auguri Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 4.

Astrodapsis brewerianus var. *bitterensis* Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 9.

Astrodapsis brewerianus var. *emergens* Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 11. Holotype lost.

Astrodapsis brewerianus var. *junior* Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 18.

Astrodapsis brewerianus var. *ovalis* Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 17.

Astrodapsis cierboensis var. *branchensis* Grant and Eaton, 1941, *ibid.*, pl. 5, figs. 12, 12a.

Astrodapsis diabloensis var. *superior* Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 16.

Astrodapsis galei Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 8.

Astrodapsis reedi Grant and Eaton, 1941, *ibid.*, pl. 5, figs. 13, 13a.

Astrodapsis schucherti Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 6.
Astrodapsis schucherti var. *affinis* Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 10.

Holotype.—Univ. Calif., Berkeley, Coll. Invert. Pal. no. 11335.

Hypotypes.—Univ. Calif., Los Angeles, Cat. nos. 8710, 8715, 8720, 8730, 8731, 8732, 8735, 8740, 8748, 8750, 8754, 8765, 8769, 8770, 8775, 8780, 8781, 8783, 8785, 8795, 8798, 9124, 9125, 9200, 9202, 32370, 32371, 32372, 32373, 32374.

Occurrence.—The type is from Univ. Calif., Berkeley, locality 1191. This locality is "about ½ mi. N.E. of summit of Las Trampas Peak, between secs. 15–14, T. 1S., R.2W." It is from the Briones formation, upper Mohnian. "Lower Briones" to "Middle Cierbo" (Eaton *et al.*, 1941).

Remarks.—*A. diabloensis* is characterized by a distinctly notched margin at the trivium. The less notched or imperceptibly notched variations are easily distinguished from *A. brewerianus* by a thin, low test, very slightly raised petals, flat to conical-shaped, and a distinctly indented bivium. Other characteristics include the distinct, although often only slightly, raised petals. The outline is pentagonal to subcircular, but generally not oval, as is *A. brewerianus.*

A. pabloensis is larger, ordinarily has more elevated petals, and does not display such prominent notches at the bivium as *A. diabloensis. A. diabloensis* is ancestral to *A. pabloensis.*

Juvenile forms of *A. diabloensis* somewhat resemble the variant of *A. brewerianus* called *"A. hootsi"* by Grant and Eaton. The petals of these extend very near to the margin, and some display the flare common among the larger variants of *A. diabloensis,* the flare occurring about two-thirds the distance from the center of the test. Some of the juvenile forms are similar in general appearance to *Remondella gabbi* (Rémond) [= *Scutella gabbi* Rémond or *Echinarachnius gabbi* (Rémond) of authors], except that all of the petals are clearly longer and extend to the margins, and the periproct of *R. gabbi* is commonly supramarginal instead of marginal.

Age.—Lower Mohnian (?) to upper Mohnian, Late Miocene.

Astrodapsis pabloensis (Kew, 1915)

(Pl. 5, figs. 6, 9; pl. 7, figs. 1–8)

Scutella pabloensis Kew, 1915, Univ. Calif. Pub. Bull. Dept. Geol., vol. 8, no. 20, p. 369, pl. 39, figs. 6a, 6b.
Astrodapsis (?) *pabloensis* (Kew), Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, no. 2, pp. 106–107, pl. 14, figs. 2a, 2b, 2c.
Astrodapsis pabloensis (Kew), Grant and Eaton, 1941, Amer. Assoc. Petrol. Geol. Bull., vol. 25, no. 2, pl. 5, fig. 19.
Astrodapsis cutleri Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 1.
Astrodapsis elevatum Grant and Eaton, 1941, *ibid.*, pl. 5, fig. 12½.

Holotype.—Univ. Calif., Berkeley, Coll. Invert. Pal. no. 10063.

Hypotypes.—Univ. Calif., Los Angeles, Cat. nos. 8790, 8791, 9205, 9207, 32375.

Occurrence.—"Above the *Scutella gabbi* zone [*Remondella gabbi*], Lower San Pablo group, Upper Miocene. Associated with *Astrodapsis cierboensis* (Kew)" (Kew, 1920, p. 107). The type locality is believed to be near or at the type locality of *A. cierboensis* (Kew), Cierbo formation, upper Mohnian. Grant and Eaton

(1941, fig. 12) identified *A. pabloensis* (Kew) from their "Middle Cierbo" and the variants are in the "Lower and Upper Cierbo."

Remarks.—This species, as with most species of *Astrodapsis,* shows a considerable degree of individual variation, such as width of the petals, height of test, and prominence of the marginal indentations at the bivium. It is characterized by a marginal periproct, moderately thin to thin test, flat to distinctly elevated petals, and flat or distinctly arched interambulacra. The ends of the ambulacra commonly flare, as is characteristic with the older *A. diabloensis.* The species may be differentiated from *A. davisi* by its generally narrower petals and its constant marginal position of the periproct. *A. pabloensis* is differentiated from *A. diabloensis* by its generally larger size and thicker margin, by generally more elevated petals, and less arched interambulacral areas. *A. diabloensis* is commonly more tumid and the bivium is always distinctly notched.

Variants of *A. pabloensis* are easily separated from *A. whitneyi* by the marginal periproct. *A. cierboensis,* with which it may occur, is more tumid, is almost never notched at the bivium, or only indistinctly, and may show incipient interambulacral valleys.

A. pabloensis is apparently the ancestral stock of *A. davisi* and *A. whitneyi.*

Age.—Late Miocene, upper Mohnian.

Astrodapsis cierboensis Kew, 1915

(Pl. 14, figs. 1–4, 6, 8)

Astrodapsis tumidus subsp. *cierboensis* Kew, 1915, Univ. Calif. Pub. Bull. Dept. Geol., vol. 8, no. 20, pp. 370–371, pl. 39, figs. 5a, 5b.

Astrodapsis cierboensis (Kew), Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, no. 2, pp. 94–95, pl. 14, figs. 1a, 1b, 1c.

Lectotype.—Univ. Calif., Berkeley, Coll. Invert. Pal. no. 10061. This was selected as a "cotype" by Kew (1920, p. 94).

Topotypes.—Univ. Calif., Los Angeles, Cat. nos. 9400, 9401, 9402.

Occurrence.—Cierbo formation, San Francisco Bay region. Univ. Calif., Berkeley, locality 522 = "*Astrodapsis* horizon at south end of cliff section at tunnel northwest and close to Union Oil works ¾ mi. from Selby, Napa sheet" (from UCB locality book). This is near Oleum on the Mare Island quadrangle, California, and in the Cierbo formation.

Remarks.—This species is characterized by petals that are not elevated or only slightly, aboral interambulacral areas that are gently arched and that occasionally show incipient valleys, generally unnotched margins, and a marginal periproct. The periproct in some of the more tumid variants appears to be inframarginal, but when viewed laterally the periproct is distinctly on the edge of the test.

Age.—Late Miocene, upper Mohnian.

Astrodapsis davisi Grant and Eaton, 1941

(Pl. 8, figs. 1–8; pl. 9, figs. 1–8; pl. 10, figs. 1–4, 6, 8; pl. 11, figs. 1–8; pl. 12, figs. 1–10; pl. 13, figs. 1–10; pl. 14, figs. 5, 7)

Astrodapsis davisi Grant and Eaton, 1941, Amer. Assoc. Petrol. Geol. Bull., vol. 25, pl. 7, fig. 3.

Astrodapsis blakei Grant and Eaton, 1941, *ibid.*, pl. 7, fig. 7.

Astrodapsis englishi Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 7.

Astrodapsis clarki Grant and Eaton, 1941, *ibid.*, pl. 7, fig. 1.
Astrodapsis desaixi Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 5.
Astrodapsis gregerseni Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 4; Durham, 1955, Univ. Calif. Pub. Geol. Sci., vol. 31, no. 4, pp. 106, 168, fig. 22e.
Astrodapsis gregerseni var. *fragilis* Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 2.
Astrodapsis gregerseni var. *varians* Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 8.
Astrodapsis goudkoffi Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 6.
Astrodapsis isabellae Grant and Eaton, 1941, *ibid.*, pl. 7, fig. 2.
Astrodapsis johnsoni Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 3.
Astrodapsis johnsoni var. *simile* Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 3a.
Astrodapsis major var. *parens* Grant and Eaton, 1941, *ibid.*, pl. 7, fig. 6.
Astrodapsis margaritanus Kew, Grant and Eaton, 1941, *ibid.*, pl. 7, fig. 4.
Astrodapsis quaylei Grant and Eaton, 1941, *ibid.*, pl. 6, fig. 9.
Astrodapsis tumidus Rémond, Grant and Eaton, 1941, *ibid.*, pl. 8, fig. 2.

Holotype.—Univ. Calif., Los Angeles, Cat. no. 8845. UCLA loc. no. 1729.

Paratypes.—Univ. Calif., Los Angeles, Cat. nos. 8805, 8810, 8815, 8820, 8822, 8825, 8835, 8840, 8843, 8844, 8845, 8846, 8848, 8850, 8860, 8865, 9210, 9211, 9212, 9215, 9216, 9217, 32376, 32377.

Type locality.—"White reef beds just below unconformity in Discovery Gulch. Zone 8F (middle and upper)" (from UCLA locality book). Locality 1729 shown on Eaton, Grant and Allen map (1941, fig. 13), 1,650 feet due south of "H" in Branch Canyon. Shown as uppermost "Cierbo."

Occurrence.—"Upper Cierbo–Lower Neroly of Eaton *et al.* (1941). Upper Mohnian to lowermost Delmontian.

Description.—Test moderately large; usually somewhat elongate and faintly subpentagonal or rounded subpentagonal in outline; margins of moderate thickness, usually but slightly indented at the bivium; periproct inframarginal, but very close to the margin; petals moderately elevated; interambulacra flat or gently arched, but depressed below the ambulacra.

Measurements.—Holotype. Length, 50.7 mm.; width, 43.8 mm.; height, 11 mm.

Remarks.—*A. davisi* Grant and Eaton is the most characteristic of a number of generally similar forms named by Eaton *et al.* (1941) and is selected as the type of this group. They also named a number of species with gerontic characteristics such as extremely raised petals and excessively developed basicoronal interambulacral plates (see Durham, 1955, pp. 106 and 168). Gradational variation from the typical *A. davisi* to the gerontic forms can be clearly shown.

The species in general is characterized by a near-marginal periproct, petals becoming more open and wider in some variations, flattish or gently arched aboral interambulacra, moderately thick margins, test flat to conical in shape, and bivium slightly notched; the trivium may be slightly notched or unnotched. The older gerontic forms are similar to the slightly younger gerontic forms of this species, with the exception that the periproct is clearly marginal.

A. davisi is differentiated from thick-margined variants of *A. whitneyi* by a periproct that is closer to the margin and by the flat, flat-depressed, or gently arched interambulacral areas. It is generally smaller. It is differentiated from *A. pabloensis* by the wider petals and generally by a near-marginal rather than a marginal periproct.

This form is intermediate between *A. pabloensis* and the thick-margined variants of *A. whitneyi,* and a few variants within a gradational sequence of several specimens of *A. davisi* are inseparable from one of the two mentioned species.

Age.—Late Miocene, lowermost Delmontian, and possibly uppermost Mohnian.

Astrodapsis antiselli Conrad, 1856

(Pl. 15, figs. 1–7; pl. 16, figs. 1–8; pl. 17, figs. 1–8; pl. 18, figs. 1–8; pl. 19, figs. 1–10; pl. 30, figs. 1, 1a, 2, 2a)

Astrodapsis antiselli Conrad, 1856, Proc. Acad. Nat. Sci. Phila., vol. 8, p. 315; Conrad, 1857, U. S. Pac. R.R. Rept., vol. 7, pt. 2, p. 196, pl. 10, figs. 1, 2; Reed, 1933, Geology of Calif., p. 288, fig. 58.

Astrodapsis tumidus Rémond, 1864, Proc. Calif. Acad. Sci., vol. 3, pp. 52–53; Gabb, 1869, Geol. Survey Calif., vol. 2, p. 37, pl. 13, figs. 68, 68a; Merriam, 1899, Proc. Calif. Acad. Sci., ser. 3, Geology, vol. 1, pp. 166–167, pl. 21, fig. 3; Kew, 1915, Univ. Calif. Pub. Bull. Dept. Geol., vol. 8, pp. 370, pl. 9, figs. 7a, 7b, 7c; pl. 40, figs. 1a, 1b, *not* fig. 2; Clark and Twitchell, 1915, U. S. Geol. Survey, Mon. 54, pp. 202, 203, pl. 95, figs. 3a, 3b, *not* pl. 108, fig. a; Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, no. 2, pp. 108–111, pl. 14, figs. 3a, 3b, 3c, 4a, 4b; Grant and Hertlein, 1938, Univ. Calif. Los Angeles Pub. Math. and Phys. Sci., vol. 2, p. 77, pl. 16, fig. 6; Grant and Eaton, 1941, Amer. Assoc. Petrol. Geol., vol. 25, pl. 8, fig. 2; Shimer and Shrock, Index Fossils of North America, p. 223, pl. 85, figs. 4, 5 (given as holotype, but designated by Kew, 1920, as "holotype" of an unnamed var.); Nisiyama, 1948, Jour. Paleont., vol. 22, pl. 88, figs. 7, 9.

Astrodapsis altus Kew, 1915, Univ. Calif. Pub. Bull. Dept. Geol., vol. 8, pp. 371–372, pl. 40, figs. 3a, 3b.

Astrodapsis ornatus Kew, 1920, *ibid.*, pp. 105–106, pl. 21, figs. 1a, 1b, 1c, 1d.

Astrodapsis margaritanus Kew, 1920, *ibid.*, pp. 103–104, pl. 22, fig. 1a, *not* 1b.

Astrodapsis whitneyi Rémond, Grant and Hertlein, 1938, *ibid.*, pp. 77–78, pl. 16, fig. 9.

Holotype.—U. S. National Mus. Cat. no. 13337.

Topotypes.—Univ. Calif., Los Angeles, Cat. nos. 9511 9512, 9515, 9570, 9572, 9573, 9575.

Hypotypes.—Univ. Calif., Los Angeles, Cat. nos. 9404 (UCB loc. 1697), 9445, 9446, 9447, 9449, 9452, 9454, 32384, 32388, 32389, Univ. Calif., Berkeley, Specimen nos. 34625, 34626 (loc. 482); 34627 (loc. 1697 = type locality of Kew's *A. margaritanus*); 34628 (loc. 3176).

Type locality.—West bank San Juan River, San Luis Obispo County, California. In a sandstone bed with an eastward dip approximately 300 feet above the bed of the San Juan River, T.24S., R.16, 17E.

Occurrence.—Santa Margarita formation, lower Delmontian, Upper Miocene; Neroly formation, San Francisco Bay area, lower Delmontian, Upper Miocene.

Remarks.—*Astrodapsis antiselli* Conrad is the type species of the genus. Antisell (1857, pp. 95, 96) states that he collected *A. antiselli,* [*Lyropecten*] *estrellanus, Ostrea,* etc., from the sides of the valley of the Estrella River at [La] Panza. The U. S. National Museum card accompanying the type, and in Conrad's writing, gives the locality as "Estrella" *not* Monterey County as reported in Kew (1920, p. 83), Richards (1935, p. 62), and Grant and Hertlein (1938, p. 70). The town of Estrella is in San Luis Obispo County, and the oldest rocks that crop out near the town are the Plio-Pleistocene Paso Robles formation. "Estrella" therefore must refer to Estrella Creek, and "the bed of the Estrella River at Panza" (Antisell, 1857, p. 95) would refer to what is now known as San Juan Creek, a tributary of Estrella Creek, in San Luis Obispo County.

With the type *A. antiselli* Conrad is another specimen with the same U. S. National Museum number—13337. This specimen is figured in the 1857 Pacific Railroad Report, plate 9, figure 3. It is labeled "*Echinarachnius* . . . ?" by Conrad but it is actually *Astrodapsis whitneyi* Rémond.

Kew (1920, pp. 105, 106) collected what he named as *A. ornatus* from section 24, T.28S., R.16E., La Panza quadrangle, San Juan Creek Region (Univ. Calif., Berkeley, loc. 2721). This is the same locality in which *A. antiselli* Conrad was collected. Collections were made by J. E. Eaton (UCLA loc. nos. 2171, 2171R, 2174, 2175, 2177) and U. S. Grant IV (UCLA loc. no. 433) from the type locality of *A. ornatus* and *A. antiselli,* and there is a complete gradation from one morphologic extreme to the other.

The type of *A. margaritanus* Kew, 1920, was not found by Kew at the type locality of *A. antiselli* as was *A. ornatus;* however, it should be remembered that when Kew compared *A. margaritanus* with *A. antiselli* (Kew, 1920, p. 104) he was actually comparing it with *A. spatiosus* (or *A. salinasensis* Richards, 1935). Topotypes of *A. margaritanus* Kew when compared with the holotype of *A. antiselli* are nearly identical.

The type of *Astrodapsis tumidus* Rémond is given by Rémond (1864) as: "Kirker's Pass formation; occurs as the preceding *A. whitneyi* Rémond species; also two miles west of Walnut Creek House." Rémond gave the dimensions of *A. tumidus* as: "Greatest diameter, 1.34 inches; shortest diameter, 1.26 inches; height 0.34 inches," but he did not figure the specimen. Gabb (1869, pl. 8, figs. 68, 68a) figured what is believed to be the type of *A. tumidus* since Rémond states that his description is based on collections of the California Academy of Natural Sciences, the State Geological Survey (Gabb), and his own. Merriam (1899, pl. 21, fig. 13) figured what Kew (1920, p. 109) states is the "Neotype" of *A. tumidus.* The figures of Gabb and Merriam agree. The specimens figured by Kew (1920, p. 180, pl. 14) of *A. tumidus* are all hypotypes of *A. tumidus,* even though he refers to specimen number 11006 (Univ. Calif., Berkeley, Coll. Invert. Pal.) as the holotype of a "small thick form." Kew reports that *A. tumidus* occurs with *A. whitneyi* Rémond, *A. ornatus* Kew, *A. altus* Kew, and "*Scutella gabbi* (Rémond)." A complete gradation can be shown between the types of *A. antiselli* and *A. tumidus.* Both have incipient to moderately well-developed aboral interambulacral valleys, their petals are slightly raised, their periprocts are on the under surface close to the margin, and both show differing elevations. Because they are known to occur together, and they are morphologically similar or identical, *A. tumidus* is placed in synonomy.

A. altus Kew differs from *A. tumidus* Kew, according to Kew (1920, p. 81), "in that the apical system is much more elevated, thus giving the test a more distinctly conical appearance; ambulacral furrows are not present on the under surface, and the superior surface shows no interambulacral depression." *A. antiselli* from the type locality also shows such variation, and Kew's *A. tumidus* from its type locality, with which *A. altus* is associated, also shows such variation; *A. altus* is simply a conical-shaped variation of the typical *A. antiselli.*

A. tumidus Rémond is reported by Khomenko (1931, p. 115, pl. 1, fig. 4) in the "Ekhabi series," "Nautu fauna," north of Okha on the right bank of a rivulet draining into the Nautu Gulf, eastern Sakhalin, Russia. However, because of the poor quality of the photographs of the figured specimens it is difficult to determine if they are *Astrodapsis.*

Variation.—The test ranges from small- to medium-sized, rounded to subpentagonal, or slightly longer than broad; margin moderately thin, increasing to moderately thick, clearly indented at bivium, more faintly at trivium, occasionally at the interambulacra; dorsal surface rising evenly to a somewhat flattened central region or a conical-shaped test; moderately developed or deep interambulacral areas; incipient longitudinal shoulders or ridges rising along the outer petals in some; flat-topped to moderately rounded petals, petals unchanneled to distinctly channeled.

Age.—Late Miocene, lower Delmontian.

Astrodapsis whitneyi Rémond, 1864

(Pl. 10, figs. 5, 7; pl. 20, figs. 1–8; pl. 21, figs. 1–4; pl. 22, figs. 1–6; pl. 23, figs. 1–6; pl. 24, figs. 1–4; pl. 25, figs. 1–4; pl. 26, figs. 1–8; pl. 27, figs. 1–6; pl. 28, figs. 1–6; pl. 29, figs. 1, 2)

Echinarachnius ?, Conrad, 1857, U. S. Pac. R.R. Rept., vol. 7, pt. 2, pl. 9, fig. 3.

Astrodapsis whitneyi Rémond, 1864, Proc. Calif. Acad. Sci., vol. 3, p. 52; Gabb, 1869, Geol. Surv. Calif., vol. 2, p. 37, pl. 13, figs. 67, 67a; Merriam, 1899, Proc. Calif. Acad. Sci., ser. 3, Geology, vol. 1, pl. 167, pl. 21, figs. 4, 4a; Arnold, 1909, U. S. Geol. Survey Bull., vol. 396, p. 63, pl. 11, fig. 1; *idem.*, 1910, U. S. Geol. Survey Bull., vol. 398, p. 94, pl. 33, fig. 1; Kew, 1915, Univ. Calif. Pub. Bull. Dept. Geol., vol. 8, no. 20, p. 372, pl. 40, fig. 4; B. L. Clark, 1915, *ibid.*, no. 22, pl. 42, fig. 1 (no text); Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, no. 2, pp. 111–112, pl. 16, figs. 1a, 1b, pl. 17, fig. 2; Grant and Eaton, 1941, Amer. Assoc. Petrol. Geol. Bull., vol. 25, pl. 8, fig. 3; Durham, 1955, Univ. Calif. Pub. Geol. Sci., vol. 31, no. 4, fig. 22d.

Astrodapsis arnoldi Twitchell, Clark and Twitchell, 1915, U. S. Geol. Survey Mon., vol. 54, pp. 199–200, pl. 95, fig. 1.

Astrodapsis coalingaensis Kew, 1920, *ibid.*, pp. 96–97, pl. 16, figs. 2a, 2b; Clark, 1929, Strat. Faunal Horizons Coast Ranges Calif., p. 24, pl. 35, fig. 4; Grant and Eaton, 1941, *ibid.*, pl. 9, figs. 3, 3a.

Astrodapsis cuyamanus Kew, 1920, *ibid.*, pp. 97–98, pl. 19, figs. 1a, 1b; Grant and Eaton, 1941, *ibid.*, pl. 7, fig. 5.

Astrodapsis californicus Kew, 1920, *ibid.*, pp. 93–94, pl. 18, fig. 2; Grant and Eaton, 1941, *ibid.*, pl. 9, fig. 1.

Astrodapsis grandis Kew, 1920, *ibid.*, pp. 100–101, pl. 17, figs. 1a, 1b, pl. 18, fig. 5; Durham, 1955, *ibid.*, fig. 22c.

Astrodapsis hertleini Grant and Eaton, 1941, *ibid.*, pl. 9, fig. 2.

Astrodapsis laimingi Grant and Eaton, 1941, *ibid.*, pl. 8, fig. 4.

Astrodapsis perrini Grant and Eaton, 1941, *ibid.*, pl. 8, fig. 6.

Astrodapsis whitneyi Rémond, Grant and Eaton, 1941, *ibid.*, pl. 8, fig. 3.

Astrodapsis woodringi Grant and Eaton, 1941, *ibid.*, pl. 8, fig. 1.

Astrodapsis whitneyi Rémond, Durham, 1955, Univ. Calif. Pub. Geol. Sci., vol. 31, no. 4, fig. 22d.

Astrodapsis grandis Kew, Durham, 1955, *ibid.*, fig. 22c.

Holotype.—Univ. Calif., Berkeley, Coll. Invert. Pal. no. 12574. *A. whitneyi*, another classic species, was not figured by Rémond. Gabb, and later Merriam, figured a small, high bell-shaped form which is identical with Rémond's description. The type material has with it an old, faded label, apparently in Merriam's handwriting, which reads: "*A. whitneyi*, frag. of holo., State Coll. 1209." The largest fragment is well preserved and is similar to Rémond's description.

Hypotypes.—Univ. Calif., Los Angeles, Cat. nos. 8854, 8855, 8867, 8868, 8870, 8870D, 8880, 8881, 8882, 8885, 8886, 8890, 8892, 8895, 8900, 8901, 8907, 8910, 9235, 32378, 32379, 32380, 32381, 32382, 32383, 32385, 32387.

Type locality.—No specific locality is given for this species by Rémond. He says of the locality: "Kirker's Pass formation. Found in lower Pliocene beds."

Occurrence.—Neroly sandstone, San Francisco Bay region; Delmontian, Upper Miocene. Santa Margarita formation, Coalinga District; lower Delmontian, upper Miocene. Santa Margarita formation, San Luis Obispo District; lower and upper Delmontian.

Remarks.—*A. whitneyi* Rémond is characterized by moderately thick to thin to exceedingly thin margins, a prevailingly bell-shaped dorsal surface, and flat to slightly raised petals. The test is always distinctly notched at the bivium, unnotched or less distinctly notched at the trivium. The periproct is on the bottom, and the aboral interambulacral areas are flat or gently down-curving, rarely with incipient aboral interambulacral valleys. The petals may be elevated only slightly and not along the entire length, or they may be distinctly elevated throughout the length of the petal. The species evolved from the older *A. pabloensis*. Occasional high bell-shaped variants of *A. pabloensis* approach *A. whitneyi*, but they are easily distinguishable by the marginal periproct of *A. pabloensis* versus the inframarginal periproct of *A. whitneyi*.

Although the figures of *A. whitneyi* of Gabb (1869) and Merriam (1899) suggest gentle depressions between the petals, *A. whitneyi* is characterized by nearly flat aboral interambulacral areas as clearly shown in Kew's figures (Kew, 1920, pl. 16, figs. 1a, 1b).

High bell-shaped variants of *A. antiselli* approach *A. whitneyi;* however, these variants always have a slightly thicker ambitus and the interambulacral areas are clearly depressed.

Kew (1920, p. 112) stated that *A. whitneyi* "seems to be very closely allied to the southern form *A. coalingaensis* Kew, but it is readily distinguished from the latter by having a smaller though relatively higher test," etc. The differences given by Kew are highly variable and do not warrant differentiation into separate species.

A. grandis and *A. coalingaensis* occur together at the type locality of the former. Kew has differentiated these species on the basis of greater size and slightly elevated petals; however, these characters are not constant.

Variants of *A. whitneyi* Rémond occasionally display somewhat wider petals than is characteristic, and these may be elevated to the margin. The most noticeable variation is that the margins of some are distinctly thicker than the typical *A. whitneyi. A. californicus* Kew is such a variant. Kew states that this species has depressed interambulacral areas. This is true of his type, but the depressions are along the sutures and are due to slight crushing; other specimens do not show this character. When the thickness parameters of specimens belonging to this group are plotted on a triangular graph, the moderately thick-margined *A. californicus, A. cuyamanus, A. perrini, A. hertleini, A. woodringi*, etc., are, in general, isolated from the typical thin-margined *A. whitneyi*. However, the type of *A. californicus* and some typical *A. cuyamanus* lie near *A. whitneyi* on this graph. Further, *A. cuyamanus* is associated with *A. whitneyi* at the type locality of the former. Because there was free interbreeding of *A. cuyamanus* and *A. whitneyi*, because *A. cuyamanus* and *A. californicus* are morphologically inseparable, and because there is a complete morphologic gradation between the species listed in the synonymy, they are all treated here as one species.

Age.—Most common in the Late Miocene, lower Delmontian, but also occurs in the upper Delmontian.

Genus *Astrodapsis spatiosus* Kew, 1920

(Pl. 29, figs. 3, 4; pl. 30, figs. 3, 3a, 4, 4a; pl. 31, figs. 1–6; pl. 32, figs. 1–7; pl. 33, figs. 1–7, 9; pl. 34, figs. 1–8; pl. 35, figs. 1–8; pl. 36, figs. 1–10)

Astrodapsis arnoldi subsp. *spatiosus* Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, no. 2, pp. 89–90, pl. 22, figs. 2a, 2b; Clark, 1929, Strat. Faunal Horizons Coast Ranges Calif., pl. 39, fig. 3; Shimer and Shrock, 1944, Index fossils of N. Amer., p. 223, pl. 85, figs. 8, 9.

Astrodapsis antiselli Conrad, Arnold, 1908, Proc. U. S. Nat. Mus., vol. 34, pl. 35, fig. 10; Arnold, 1909, U. S. Geol. Survey Geol. Atlas, Santa Cruz folio, no. 163, pl. 2, fig. 58; Clark and Twitchell, 1915, U. S. Geol. Survey Mon., vol. 54, pp. 198–199, pl. 94, figs. 3, 4a, 4b; Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, no. 2, pp. 81–83, pl. 19, figs. 2a, 2b, 2c; Grant and Hertlein, 1938, Univ. Calif. Los Angeles Pub. Math. and Phys. Sci., vol. 2, p. 70, pl. 16, figs. 3, 4.

Astrodapsis scutelliformis Kew, 1920, *ibid.*, pp. 107–108, pl. 21, fig. 2.

Astrodapsis salinasensis Richards, 1935, Trans. San Diego Soc. Nat. Hist., vol. 8, pp. 59–66, pl. 7, figs. 2a, 2b, 2c; Grant and Hertlein, *ibid.*, pl. 16, fig. 2; Durham, 1955, Univ. Calif. Pub. Geol. Sci., vol. 31, no. 4, fig. 22b.

Astrodapsis cierboensis Kew, Grant and Herlein, 1938, *ibid.*, p. 71, pl. 16, fig. 1.

Holotype.—Univ. Calif., Berkeley, Coll. Invert. Pal. no. 11041.

Hypotypes.—U. S. National Mus. Cat. no. 165466a, Specimen B (holotype of Richards *A. salinasensis*); Univ. Calif., Berkeley, Specimen no. 34631 (locality A 911, and same locality as U. S. Nat. Mus. no. 165466a); Univ. Calif., Los Angeles, Cat. nos. 9470, 9471, 9473, 9480, 9482, 32386, 32390, 32391, 32392, 32393, 32394, 32397, 32398, 32399, 32406, 32407, 32408, 32409, 32411, 32412, 32413, 32414, 32415.

Occurrence.—Pancho Rico formation, Upper Miocene, upper Delmontian. Uppermost Santa Margarita formation, here called the Saucelito member, San Luis Obispo County, Late Miocene, upper Delmontian; Santa Margarita formation, Santa Cruz County, upper Delmontian.

Remarks.—*A. spatiosus* was described by Kew from a single specimen. Additional material from the type area of this species indicates that the holotype has some features developed more than is average. The average upper surface is not greatly depressed; the average aboral interambulacral depression is less deep, and the average summit is in the center of the test, not anterior as in the slightly crushed holotype. The species is variable, and the types of *A. spatiosus* Kew and *A. salinasensis* Richards represent extremes of one species. A collection from the type locality of *A. salinasensis* Richards contains *A. spatiosus* Kew (Richards, 1935, p. 63). Richards (1935) states that his *A. salinasensis* is distinct from *A. antiselli* Conrad but he does not contrast *A. salinasensis* and *A. spatiosus*. Topotypes of *A. salinasensis* reveal a closer relation between the two forms than would appear from the extreme specimens.

Astrodapsis scutelliformis Kew is a juvenile of *A. spatiosus* Kew. Small *A.*

spatiosus are figured here for comparison with *A. scutelliformis* Kew (Kew, 1920, pl. 21, fig. 2; note that his figure is *times* 2).

Tubercles are of moderate size and spacing on the test. Care must be taken when identifying weathered specimens because tubercles will be faint or absent, and the plates will be more pronounced. Generally, the tubercles are larger and more widely spaced than those of *A. antiselli.*

The ambulacra are always raised, although often only slightly, and almost not at all when the specimen is crushed or juvenile. Juvenile specimens are consistently thinner than adults and in general they resemble *A. antiselli* Conrad. Specimens from Santa Cruz County are generally smaller and thinner and have nearly flat petals as compared with those from Monterey and San Luis Obispo counties; although, as figured here, specimens from near Edna, San Luis Obispo County, are identical with those near Felton, Santa Cruz County. Because the Santa Cruz variants are consistently thinner and flatter than the typical *A. spatiosus,* they may constitute a separate species or subspecies. However, the juvenile specimens of the typical *A. spatiosus* are inseparable from the thin Santa Cruz specimens, and the adult and largest of the Santa Cruz specimens so closely resembles the typical *A. spatiosus* that they are all grouped together. Variants of *A. antiselli* often closely resemble this species; however, generally *A. spatiosus* will not be indented at the bivium, has larger and more widely spaced tubercles, and is larger.

In some of the large, well-developed *A. spatiosus* there is a faint hint of incipient longitudinal shoulders flanking the ambulacra. Since *A. spatiosus* Kew is stratigraphically slightly lower in the Pancho Rico formation than *A. arnoldi,* it is probable that *A. spatiosus* is the ancestor of *A. arnoldi.*

As figured here, there is an obvious gradation from *A. antiselli* [the *A. tumidus* of Kew and others (small, thick form)] to a somewhat larger thick form of *A. antiselli* and to the large, thick *A. spatiosus. A. spatiosus* is differentiated from this small, thick variant of *A. antiselli* on the basis of a larger test, usually more oval than pentagonal, larger and moderately spaced tubercles, generally shallower aboral interambulacral valleys, less pronounced indentations at the ends of the posterior ambulacra, and lack of indentations at the margin of the anterior aboral interambulacra; however, the largest and youngest of this variant of *A. antiselli* is nearly inseparable from the juvenile and usually more pentagonal variant of *A. spatiosus.*

Variation.—The small to medium or moderately large-sized; slightly elongate-pentagonal or oval to nearly circular; margins thin to thick.

Tubercles are usually large and prominent, the margin is generally not indented or only imperceptibly so at the bivium, and the petals flare gently.

Age.—Late Miocene, upper Delmontian.

Astrodapsis fernandoensis Pack, 1909

(Pl. 33, figs. 8, 10)

Astrodapsis fernandoensis Pack, 1909, Univ. Calif. Pub. Bull. Dept. Geol., vol. 5, p. 279, pl. 24, figs. 3, 4; Clark and Twitchell, 1915, U. S. Geol. Survey Mon., vol. 54, pp. 217–217, pl. 101, figs. 1, 2; Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, pp. 98–100, pl. 24, figs. 2a, 2b, 2c; Grant and Hertlein, 1938, Univ. Calif. Los Angeles Pub. Math. and Phys. Sci., vol. 2, p. 72, pl. 25, figs. 4, 5.

Lectotype.—Univ. Calif., Berkeley, Coll. Invert. Pal. specimen no. 11377. Pack (1909) figured two specimens but did not designate a holotype. Kew (1920, pl. 24) figured what he believed were Pack's syntypes (called cotypes by Kew). These syntypes were UCB specimens, nos. 11042, 11377. Specimen 11042 (Kew, 1920, pl. 24, figs. 2a, 2b) is not either of Pack's figures; it is a topotype.

Hypotype.—Univ. Calif., Los Angeles, Cat. no. 32410.

Occurrence.—Elsmere member of Towsley or Repetto formation.

Remarks.—The tubercles of *A. fernandoensis* are more prominent than any other form of *Astrodapsis*. Except for these large deeply sunken and widely spaced tubercles covering *A. fernandoensis,* other morphologic features are almost identical with *A. spatiosus*. *A. fernandoensis* is usually smaller and more elongate or oval than *A. spatiosus.* Immature individuals of these two species are inseparable.

Age.—Lowermost Pliocene.

Astrodapsis arnoldi Pack, 1909

(Pl. 37, figs. 1, 1a, 2, 3, 3a, 4; pl. 38, figs. 1–8; pl. 39, figs. 1–6)

Astrodapsis antiselli var. *arnoldi* Pack, 1909, Univ. Calif. Pub. Bull. Dept. Geol., vol. 5, pp. 279–281, pl. 24, figs. 1, 2.

Astrodapsis anticelli Conrad, McLaughlin and Waring, 1914, Calif. State Min. Bur. Bull., no. 69, map folio, fig. 37, text on cover.

Astrodapsis tumidus Rémond, large form. Kew, 1915, Univ. Calif. Pub. Bull. Dept. Geol., vol. 8, p. 370, pl. 40, fig. 2.

Astrodapsis whitneyi Rémond, Twitchell, Clark and Twitchell, 1915, U. S. Geol. Surv. Mon., vol. 54, pp. 201, 202, pl. 95, figs. 2a, 2b, 2c.

Astrodapsis arnoldi subsp. *arnoldi* (Pack), Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, pp. 83–85, pl. 21, figs. 3a, 3b, 3c.

Astrodapsis arnoldi subsp. *crassus* Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, no. 2, pp. 85, 86, pl. 23, fig. 1, pl. 24, figs. 1a, 1b, 1c.

Astrodapsis arnoldi var. *depressus* Kew, 1920, *ibid.*, p. 85, pl. 23, figs. 2a, 2b, 2c.

Astrodapsis arnoldi var. *fresnoensis* Kew, 1920, *ibid.*, pp. 87, 88, pl. 23, figs. 3a, 3b, 3c.

Astrodapsis major Kew, 1920, *ibid.*, pp. 102, 103, pl. 15, figs. 1a, 1b, 1c; Clark, 1929, Strat., Faunal Horiz., Coast Ranges, Calif., pl. 44, fig. 2, pl. 45, fig. 1.

Astrodapsis antiselli Conrad, Durham, 1955, Univ. Calif. Pub. Geol. Sci., vol. 31, no. 4, figs. 3d and 22a.

Some of the specimens figured here are thought to be topotypes of *Astrodapsis arnoldi* Pack. However, the type locality of *A. arnoldi* was given by Pack only as "Monterey, Salinas Valley." Kew's *Astrodapsis crassus* from "NW¼ of sec. 8. (22–11), S. side Pancho Rico Creek, E. side Salinas Valley, Monterey Co." is thought to be near the type area of *Astrodapsis arnoldi* Pack. The types of Kew's *A. depressus* and *A. fresnoensis* are from "1000 feet above Santa Margarita shale, near S.E. corner of sec. 8, T.23S., R.17E., Cholame Quad." Typical *A. arnoldi* Pack were also collected from this same locality.

Holotype.—Univ. Calif., Berkeley, Coll. Invert. Pal. no. 11030.

Hypotypes.—Univ. Calif., Berkeley, Specimen nos. 34632, 34633; Stanford Univ. Paleo. Types Coll. no. 8552; Univ. Calif., Los Angeles, Cat. nos. 32400, 32401, 32402, 32403, 32404, 32405.

Occurrence.—Pancho Rico formation, Late Miocene, upper Delmontian. Lower Jacalitos formation. Kew's *A. depressus* and *A. fresnoensis* are from the same locality, i.e., 1,000 feet above the base of the Jacalitos formation; the type locality of *A. jacalitosensis* Arnold is approximately 3.5 miles northwest and along strike from the type locality of *A. depressus,* and it is also approximately 1,000 feet above the base of the Jacalitos formation. With *A. jacalitosensis* Arnold at the type locality are "*Dendraster gibbsii* Rémond and *Astrodapsis peltoides* Anderson and Martin, lowermost Pliocene." Woodring (1950, p. 102) reports *A. arnoldi* from the Tinaquaic member of the Sisquoc formation.

Remarks.—Richards (1935, p. 63) states that Clark and Twitchell (1915, p. 199) named the true *A. antiselli* Conrad as *A. arnoldi,* i.e., he says that *A. antiselli* Conrad = *A. arnoldi* Twitchell. This is in error, because *A. whitneyi* Rémond in Arnold (1909, p. 63, pl. 11, fig. 1) was renamed by Twitchell (in Clark and Twitchell, 1915, p. 199, pl. 95, fig. 1) as *A. arnoldi* Twitchell. Kew (1920, pp. 83, 84) then raised Pack's (1909, p. 279–281, pl. 24, figs. 1, 2) *A. antiselli* var. *arnoldi* to *A. arnoldi* subsp. *arnoldi* (Pack) and changed the name of *Astrodapsis arnoldi* Twitchell to *A. californicus* Kew (1920, p. 93, pl. 18, fig. 2) because *A. arnoldi* Twitchell was preoccupied. Therefore, *A. arnoldi* Twitchell = *A. californicus* Kew, not *A. antiselli* Conrad, as stated by Richards. *A. californicus* Kew is a synonym of *A. whitneyi* Rémond.

Richards (1935, p. 63) further states that the true *A. antiselli* Conrad was named *A. arnoldi* by Kew (1920, p. 83–85). This is also in error because the holotype and topotypes of *A. antiselli* Conrad *do not* have the outer aboral ambulacra rising to form longitudinal shoulders that flank the petals. Further, *A. antiselli* Conrad does not have the prominent tubercles almost always present on *A. arnoldi* Pack.

A. arnoldi Pack is a highly variable taxon. It is known to range through the lower 125 feet of the Pancho Rico formation and is 800 to 1,000 feet above the base of the Jacalitos formation. Features such as the thickness of the ambitus, depth of aboral interambulacral areas or valleys, and relatively depressed apices are variable and cannot be relied upon for differentiation into subspecies or species. The distinguishing characteristic that is always present in this species is that the outer edges of the ambulacra and outer edges of the aboral interambulacra are raised forming pronounced longitudinal ridges or shoulders that flank the petals. Depressions between the petals may be of varying depths and shapes.

Variation.—Moderately high to low test, narrow to relatively wide petals, petals curved to straight, V-shaped aboral interambulacral areas to gently sloping aboral interambulacral valleys.

Age.—Late Miocene, upper Delmontian to lowermost Pliocene.

Astrodapsis peltoides Anderson and Martin, 1914

(Pl. 40, figs. 1, 1a, 2; pl. 41, figs. 1–4)

Astrodapsis peltoides Anderson and Martin, 1914, Proc. Calif. Acad. Sci., ser. 4, vol. 4, pp. 52, 53, pl. 2, fig. 2.

Astrodapsis arnoldi subsp. *peltoides* (Anderson and Martin), Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, pp. 88, 89, pl. 15, fig. 3, *not* fig. 2a, 2b.

Neotype.—Univ. Calif., Los Angeles, Cat. no. 6815-A. Univ. Calif., Los Angeles, locality 2181, i.e., "Center of NE¼ of sec. 14, T21S, R13E, M.D.M.," Priest Valley quadrangle, Fresno County. Presented to UCLA by P. W. Reinhart, 1934. This locality is approximately 11 miles from the type locality of the holotype; it is in the same formation, the Jacalitos, and is probably at about the same horizon. Both the lost holotype and the neotype are associated with *Dendraster gibbsii* Rémond and *A. jacalitosensis.*

The holotype, originally housed at the California Academy of Sciences, was loaned several years ago and was apparently lost. A search was made at the California Academy of Sciences and at the University of California, Berkeley, but the specimen could not be located (L. G. Hertlein, Calif. Acad. Sci., personal communication, 1959). Kew (1920, pl. 15, figs. 2a, 2b) figured a topotype; however, this specimen is *A. jacalitosensis* and not *A. peltoides.*

Description of the neotype.—Size moderately large: length, 80 mm.; width, 67 mm., height, 16 mm. Outline, oval. Ambitus, unnotched. Thick-margined, upper surface rising to a relatively low, rather uniform summit. Apical system only slightly depressed. Petals broad and extending to the margin, moderately wide and slightly elevated. Tubercles of moderate size and closely spaced. Distinct ridges flank petals and aboral interambulacral areas clearly depressed. Sterofigure of the aboral surface of the neotype is on plate 40.

Hypotypes.—Univ. Calif., Los Angeles, Cat. nos. 6815B, 9495.

Occurrence.—Jacalitos formation (lower part).

Remarks.—Kew (1920, p. 88, 89) presumably on the basis of mutually possessed flanking ridges grouped this species under *A. arnoldi.* However, only in the ridged ambulacral shoulders do these two forms approach each other. *A. peltoides* averages twice as large, is typically elongate instead of subcircular, has a low instead of a relatively high test, and a very thick ambitus.

Occurs with *A. jacalitosensis* Arnold, *Dendraster gibbsii* Rémond, and found near *A. arnoldi.*

Age.—Lowermost Pliocene.

Astrodapsis jacalitosensis Arnold, 1909

(Pl. 42, figs. 1–5; pl. 43, figs. 1–4; pl. 44, figs. 1–6)

Astrodapsis jacalitosensis Arnold, 1909, U. S. Geol. Survey Bull., vol. 396, pp. 63–64, pl. 15, fig. 1; Arnold and Anderson, 1910, U. S. Geol. Survey Bull., vol. 398, p. 111, pl. 37, fig. 5; Clark and Twitchell, 1915, U. S. Geol. Survey Mon., vol. 54, pp. 203–204, pl. 95, fig. 4; Kew, 1920, Univ. Calif. Pub. Bull. Dept. Geol., vol. 12, no. 2, pp. 101–102, pl. 20, figs. 1a, 1b.

Astrodapsis arnoldi subsp. *peltoides* (Anderson and Martin), Kew, 1920, *ibid.*, pp. 88–89, pl. 15, figs. 2a, 2b, *not* 3.

Astrodapsis schencki Grant and Hertlein, 1938, Univ. Calif. Los Angeles Pub. Math. and Phys. Sci., vol. 2, p. 76, fig. 8.

Astrodapsis schencki var. *mirandaensis* Grant and Eaton, 1941, Amer. Assoc. Petrol. Geol. Bull., vol. 25, no. 2, pl. 9, figs. 4, 4a.

Holotype.—U. S. Nat. Mus. no. 165610.

Hypotypes.—Univ. Calif., Los Angeles, Cat. nos. 8401, 8925, 8928, 8929, 8932; Univ. Calif., Berkeley, Specimen nos. 34629, 34630.

Type locality.—Ridge southeast of Garza Creek, in section 2, T.23S., R.16E., Kings County.

Occurrence.—*A. jacalitosensis* Arnold and the synonym *A. schencki* occur in the lower part of the Jacalitos formation. *A. jacalitosensis* Arnold is associated with *Dendraster gibbsii* Rémond and *A. peltoides* Anderson and Martin according to Kew (1920); and at its type locality it is stratigraphically slightly below and to the northwest from the type locality of *A. fresnoensis* and *depressus* (here called *A. arnoldi*). At the type locality of *A. schencki* (here called *A. jacalitosensis*), *A. arnoldi* is also present.

Remarks.—This species apparently evolved from *A. whitneyi. A. jacalitosensis* is extremely specialized and variable. It has a wide range of such attributes as height of test, height of petals, and distinctness of poriferous areas and plates. A common characteristic is that the petals are markedly raised near the summit of the test, but become flush with the surface approximately one-half the distance to the margin; another characteristic is that the summit is markedly depressed and the extreme margin is always thin. Interambulacral depressions are present or lacking, and incipient shoulders are sometimes present along the flanks of the petals. *A. schencki* and *A. schencki mirandaensis* are extreme variants of *A. jacalitosensis,* and, as figured here, there is an obvious gradational sequence.

Age.—Lowermost Pliocene.

LITERATURE CITED

ANTISELL, THOMAS

1857. Geological Report. Pacific Railroad Rept., vol. 7, pt. 2, pp. 1–188.

ARNOLD, RALPH

1909. Paleontology of the Coalinga district, Fresno and Kings counties, Calif. U. S. Geol. Surv., Bull. 396, p. 63, pl. 15, fig. 5.

AXELROD, D. I.

1956. Mio-Pliocene floras from west-central Nevada. Univ. Calif. Pub. Geol. Sci., vol. 33, pp. 1–322.

CLARK, W. B., and M. W. TWITCHELL

1915. Mesozoic and Cenozoic Echinodermata of the United States. U. S. Geol. Surv., Mon., vol. 54, pp. 210–218.

CALIFORNIA DIVISION OF MINES

1958. Geologic map of California, San Luis Obispo sheet, Olaf P. Jenkins edition. Calif. State Div. Mines.

CONRAD, T. A.

1856. Description of three new genera, twenty-three new species middle Tertiary fossils from California, and one from Texas. Proc. Acad. Nat. Sci. Phila., vol. 8, pp. 312–316.

1857. Report on the paleontology of the survey. Pacific Railroad Rept., vol. 7, pt. 2, chap. 29, pp. 189–196.

DURHAM, J. W.

1955. Classification of Clypeasteroid echinoids. Univ. Calif. Pub. Geol. Sci., vol. 31, no. 4, pp. 104–108, 167–168.

DURHAM, J. W., R. H. JAHNS, and D. E. SAVAGE

1954. Marine-nonmarine relationships in the Cenozoic section of California. Calif. Div. Mines Bull. 170, Geol. of So. Calif., Chap. III, pp. 60–61, fig. 2.

EATON, J. E., U. S. GRANT, IV, and H. B. ALLEN

1941. Miocene of Caliente Range and environs, California. Amer. Assoc. Petrol. Geol. Bull., vol. 25, no. 2, pp. 193–262.

FAIRBANKS, H. W.

1904. San Luis folio. U. S. Geol. Surv., Geol. Atlas, folio 101.

GABB, W. M.

1869. Geological survey of California. Paleontology, vol. 2, pp. 109–110.

GRANT, U. S., IV, and H. R. GALE

1931. Catalogue of the marine Pliocene and Pleistocene Mollusca of California. Mem. San Diego Soc. Nat. Hist., vol. 1, p. 200.

GRANT, U. S., IV, and L. G. HERTLEIN

1938. The west American Cenozoic echinoides. Pub. Univ. Calif. Los Angeles in Math. and Phys. Sci., vol. 2, pp. 68–78.

HALL, JR., C. A.

1960. Displaced molluscan provinces along the San Andreas fault, California. Univ. Calif. Pub. Geol. Sci., vol. 34, no. 6, pp. 281–308.

HILL, M. L., S. A. CARLSON, and T. W. DIBBLEE, JR.

1958. Stratigraphy of Cuyama Valley–Caliente Range area, California. Amer. Assoc. Petrol. Geol. Bull., vol. 42, no. 12, pp. 2973–3000.

IMBRIE, JOHN

1956. Biometrical methods in the study of invertebrate fossils. Amer. Mus. Nat. Hist. Bull., vol. 108, art. 2, pp. 226–227.

KEW, W. S. W.

1915. Tertiary echinoids from the San Pablo group of middle California. Univ. Calif. Pub. Bull. Dept. Geol., vol. 8, pp. 365–376.

1920. Cretaceous and Cenozoic echinoides of the Pacific coast of North America. Univ. Calif. Pub. Bull. Sept. Geol., vol. 12, no. 2, pp. 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, p. 120, pl. 1.
KING, V. L.
1943. Huasna area development. Geologic formations and economic development of the oil and gas fields of California. Calif. Div. Mines Bull. 118, pp. 448–449.
KLEINPELL, R. M.
1938. Miocene stratigraphy of California. Amer. Assoc. Petrol. Geol., Tulsa, Oklahoma.
MAYR, E., E. G. LINSLEY, and R. L. USINGER
1953. Methods and principles of systematic zoology. New York: McGraw-Hill Book Co., Inc.
MERRIAM, C. W.
1931. Notes on a brittle-star limestone from the Miocene of California. Amer. Jour. Sci., 5th Ser., no. 124, vol. 21, pp. 304–310.
MERRIAM, J. C.
1899. The Tertiary sea-urchins of middle California. Proc. Calif. Acad. Sci., 3rd Ser., vol. 1, no. 5, pp. 161–174.
NOMLAND, J. O.
1917. Fauna of the Santa Margarita beds in the North Coalinga region of California. Univ. Calif. Pub. Bull. Dept. Geol., vol. 10, no. 18, p. 303.
PACK, R. W.
1909. Notes on echinoids from the Tertiary of California. Univ. Calif. Pub. Bull. Dept. Geol., vol. 5, no. 18, p. 279.
PAGE, B. M., *et al.*
1944. Geology of the bituminous sandstone deposits near Edna, San Luis Obispo County, California. U. S. Geol. Surv., Oil and Gas Prelim. Map 16.
RÉMOND, AUGUSTE
1864. Description of four new species of Echinodermata, from the tertiaries of Contra Costa County. Proc. Calif. Acad. Sci., vol. 3 (proceedings of meetings for years 1863–1867, paper read Aug. 3, 1863), pp. 52–53.
RICHARDS, G. L.
1933. Geology of the Santa Margarita formation, San Luis Obispo County, California. Unpublished M.A. thesis, Stanford University.
1935. Revision of some California species of *Astrodapsis*. Trans. San Diego Soc. Nat. Hist., vol. 8, no. 9, pp. 59–66.
1936. *Astrodapsis* faunal zones of California Upper Miocene and Lower Pliocene formations. Proc. Geol. Soc. Amer. for 1935, abstract, pp. 412–413.
TALIAFERRO, N. L.
1943. Geology of Huasna area. Geologic formations and economic development of the oil and gas fields of California. Calif. Div. Mines Bull. 118, pp. 443–447.
WEAVER, C. E.
1949. Geology of the Coast Ranges immediately north of the San Francisco Bay region, California. Geol. Soc. Amer. Mem. 35.
WOODRING, W. P., and M. N. BRAMLETTE
1950. Geology and paleontology of the Santa Maria district, California. U. S. Geol. Surv. Prof. Paper 222, p. 102.

APPENDIX A

Measurements Used in the Statistical Analysis of *Astrodapsis*

(In millimeters)

Specimen number[a]	h[b]	T'[c]	T''[d]	Z[e]	Q[f]	Species (of authors)[g]	Specific name or revised specific name[h]	Type number[i]
1	16.0	6.5	10.5	9.5	4.0		*A. whitneyi*	32387
2	13.0	6.0	8.0	7.0	2.0		*A. whitneyi*	32382
3	11.3	4.8	6.5	6.5	1.7		*A. whitneyi*	32385
4	13.0	5.5	8.0	7.5	2.5		*A. whitneyi*	32381
5	13.0	5.5	8.0	7.5	2.5		*A. whitneyi*	32383
6	14.5	7.0	11.0	7.5	4.0		*A. spatiosus*	32386
7	not used						*A. spatiosus*	32413
8	15.7	6.8	10.0	8.9	3.2	*A. perrini*	*A. whitneyi*	8895*
9	11.0	5.1	7.8	5.9	2.7	*A. davisi*	*A. davisi*	8845*
10	14.9	4.8	8.2	10.1	3.4	*A. cuyamanus*	*A. whitneyi*	8855
11	13.5	5.0	8.7	8.5	3.7	*A. californicus*	*A. whitneyi*	8903
12	11.0	4.1	6.0	6.9	1.9	*A. grandis*	*A. whitneyi*	8890
13	14.0	6.0	9.0	8.0	3.0	*A. hertleini*	*A. whitneyi*	8910*
14	12.5	5.0	9.0	7.5	4.0	*A. woodringi*	*A. whitneyi*	8870*
15	12.7	5.0	9.0	7.7	4.0	*A. laimingi*	*A. whitneyi*	8885*
16	11.0	4.0	5.5	7.0	1.5	*A. coalingaensis*	*A. whitneyi*	8905
17	12.0	4.2	6.8	7.8	2.6		*A. whitneyi*	32380
18	10.0	4.6	9.0	5.4	4.4	*A. gregerseni fragilis*	*A. davisi*	8800*
19	10.3	4.9	9.0	5.4	4.1	*A. johnsoni*	*A. davisi*	8805*
20	11.7	4.5	10.3	7.2	5.8	*A. gregerseni*	*A. davisi*	8810*
21	10.0	4.3	8.4	5.7	4.1	*A. gregerseni* var. *varians*	*A. davisi*	8830*
22	18.5	2.7	6.0	15.8	3.3	*A. schencki mirandaensis*	*A. jacalitosensis*	8925*
23	13.0	6.0	7.0	7.0	1.0	*A. isabellae*	*A. davisi*	8840*
24	11.0	6.8	7.5	4.2	.7	*A. clarki*	*A. davisi*	8835*
25	9.0	5.7	6.2	3.3	.5	*A. blakei*	*A. davisi*	8865*
26	14.4	5.0	13.0	8.4	8.0	*A. gregerseni*	*A. davisi*	32376
27	9.9	4.5	8.5	5.4	4.0	*A. gregerseni*	*A. davisi*	32377
28	8.1	5.5	5.5	5.5	0.0	*A. ovalis*	*A. diabloensis*	8780*
29	8.2	5.4	6.0	2.8	.6	*A. cierboensis branchensis*	*A. diabloensis*	8750*
30	14.5	8.0	9.5	6.5	1.5		*A. spatiosus*	32414
31	13.0	7.0	9.0	6.0	2.0		*A. spatiosus*	32393
32	14.0	6.0	8.0	8.0	2.0		*A. spatiosus*	32427
33	11.0	6.5	8.0	4.5	1.5		*A. spatiosus*	32395
34	13.1	7.5	10.7	5.6	3.2		*A. spatiosus*	32408
35	15.4	7.5	10.0	7.9	2.5		*A. spatiosus*	32412

[a] Number assigned to the specimen. Used on the triangular and rectangular graphs and for cross reference with register of fossil localities.

[b] Maximum height of thickness of the test, in millimeters.

[c] Thickness (in millimeters) of test measured at the posterior interambulacral area, three aboral interambulacral plates from the margin.

[d] Thickness (in millimeters) of the test measured at the central anterior ambulacral area. Measurement made parallel with the third aboral interambulacral plate from the margin.

[e] Thickness (in millimeters) of the test between the top of the interambulacral area, three aboral plates from the margin, and the most elevated or highest part of the test.

[f] Thickness (in millimeters) or height of the ambulacral area or petal. The difference in elevation between the bottom of the interambulacral valley and the top of the petal.

[g] Specific name of specimen figured or identified by others, and commonly placed in synonymy.

[h] Revised name or name of the species to which the specimen belongs.

[i] These numbers refer to figured, listed, or described specimens. An asterisk indicates that the species of authors (note [g]) was or is a holotype, neotype of lectotype. L.S.J.U. precedes Stanford Univ. Paleo. Type Coll. numbers, Stan. Coll. precedes Stanford Paleo. Coll. numbers; U.S.N.M. precedes U. S. Nat. Mus. collection numbers; C.A.S. precedes Calif. Acad. Sci. numbers; Univ. of Calif., Berkeley, collection numbers are italicized (e.g. *11337*); and all other numbers refer to Univ. of Calif., Los Angeles, invertebrate paleontology catalogue numbers.

APPENDIX A—*Continued*

Specimen number[a]	h[b]	T'[c]	T''[d]	Z[e]	Q[f]	Species (of authors)[g]	Specific name or revised specific name[h]	Type number[i]
36	12.5	6.0	8.0	6.5	2.0		*A. spatiosus*	32429
37	14.0	6.5	10.0	7.5	3.5		*A. spatiosus*	32428
38	10.0	6.0	8.5	4.0	2.5		*A. spatiosus*	32392
39	12.0	6.0	10.0	6.0	4.0		*A. spatiosus*	32390
40	10.5	5.0	8.0	5.0	3.0		*A. spatiosus*	32394
41	13.0	7.0	10.0	6.0	3.0		*A. spatiosus*	32432
42	7.5	4.5	5.5	3.0	1.0		*A. spatiosus*	32430
43	15.0	8.5	11.0	6.5	2.5	Same as no. 67	*A. peltoides*	9495
44	13.3	7.8	10.0	5.2	2.2	*A. salinasensis*	*A. spatiosus*	*34631*
45	16.0	10.8	11.0	5.2	.2		*A. peltoides*	6815A*
46	17.5	11.0	13.0	6.5	2.0		*A. peltoides*	6815B
47	7.5	4.5	5.2	3.0	.7		*A. antiselli*	32389
48	7.5	4.5	5.5	3.0	1.0		*A. antiselli*	32419
49	7.5	4.5	6.0	3.0	1.5		*A. antiselli*	32420
50	10.0	6.0	7.5	4.0	1.5		*A. antiselli*	32421
51	7.0	5.0	6.0	2.0	1.0		*A. antiselli*	32388
52	10.0	7.0	7.5	3.0	.5		*A. antiselli*	32422
53	14.0	8.0	11.5	6.0	3.5		*A. antiselli*	32417
54	12.5	8.5	11.0	4.0	3.0		*A. antiselli*	32383
55	12.5	9.0	10.5	3.5	1.5		*A. antiselli*	32418
56	9.0	6.0	8.0	3.0	2.0		*A. antiselli*	32423
57	9.0	5.0	7.0	4.0	2.0		*A. antiselli*	32424
58	9.0	6.0	7.5	3.0	1.5		*A. antiselli*	32416
59	9.5	5.8	7.0	3.7	1.2		*A. antiselli*	32426
60	15.0	9.0	11.5	6.0	2.5		*A. antiselli*	32425
61	9.0	6.0	6.5	3.0	.5	*A. jacalitosensis*	*A. arnoldi*	7733B
62	11.5	6.5	6.5	5.0	0.0	*A. jacalitosensis*	*A. arnoldi*	7733A
63	12.0	7.5	8.0	4.5	.5	*A. arnoldi crassus*	*A. arnoldi*	*34633*
64	14.5	8.0	9.0	6.5	1.0	*A. arnoldi crassus*	*A. arnoldi*	*34632*
65	11.5	5.5	9.0	6.0	3.5	*A. arnoldi*	*A. arnoldi*	9494
66	15.5	3.5	5.5	12.0	2.0	*A. schencki mirandaensis*	*A. jacalitosensis*	8929
67	15.0	8.5	11.0	6.5	2.5	*A. peltoides*	*A. peltoides*	9495
68	6.0	3.0	4.0	3.0	1.0		*A. spatiosus*	9479
69	7.5	4.5	5.5	3.0	1.0		*A. spatiosus*	9482
70	8.5	5.5	7.0	3.0	1.5		*A. spatiosus*	9480
71	7.5	4.5	6.0	3.0	1.5		*A. spatiosus*	9471
72	14.5	6.5	9.5	8.0	3.0	*A. altus*	*A. antiselli*	*34628*
73	6.5	4.5	5.5	2.0	1.0		*A. antiselli*	9455
74	6.5	4.5	6.0	2.0	1.5		*A. antiselli*	9451
75	7.0	4.5	6.5	2.5	2.0		*A. antiselli*	9452
76	7.8	5.0	6.5	2.8	1.5		*A. antiselli*	9454
77	8.0	6.0	7.0	2.0	1.0		*A. antiselli*	9450
78	6.0	4.0	5.0	2.0	1.0		*A. antiselli*	9453
79	12.5	5.0	7.0	7.5	2.0	*A. coalingaensis*	*A. whitneyi*	8918
80	11.0	4.0	5.0	7.0	1.0	*A. whitneyi*	*A. whitneyi*	9440
81	9.0	3.5	5.5	5.5	2.0	*A. whitneyi*	*A. whitneyi*	9442
82	12.0	5.5	7.5	6.5	2.0		*A. whitneyi*	8908
83	10.0	5.0	6.0	5.0	1.0		*A. whitneyi*	8906

APPENDIX A—*Continued*

Specimen number[a]	*h*[b]	*T′*[c]	*T″*[d]	*Z*[e]	*Q*[f]	Species (of authors)[g]	Specific name or revised specific name[h]	Type number[i]
84	13.5	6.0	8.0	7.5	2.0		*A. whitneyi*	8907
85	12.0	6.0	9.0	6.0	3.0		*A. antiselli*	9446
86	10.0	5.0	7.0	5.0	2.0		*A. antiselli*	9449
87	12.0	6.0	9.0	6.0	3.0		*A. antiselli*	9445
88	14.0	8.5	11.0	5.5	2.5		*A. spatiosus*	32407
89	15.0	9.5	12.5	5.5	3.0		*A. spatiosus*	32434
90	12.5	8.0	10.5	4.5	2.5		*A. spatiosus*	32409
91	14.0	9.0	11.0	5.0	2.0		*A. spatiosus*	32435
92	10.0	7.0	9.0	3.0	2.0		*A. spatiosus*	32436
93	11.0	7.5	9.5	3.5	2.0		*A. spatiosus*	32406
94	10.0	6.0	8.5	4.0	2.5		*A. spatiosus*	32437
95	10.0	7.0	8.5	3.0	1.5		*A. spatiosus*	32483
96	9.0	4.5	6.0	4.5	1.5	*A. antiselli*	*A. antiselli*	9515
97	9.4	4.0	5.5	5.4	1.5	*A. ornatus*	*A. antiselli*	9573
98	14.5	4.5	9.5	10.0	5.0	*A. ornatus*	*A. antiselli*	9570
99	9.0	3.0	5.2	6.0	2.0	*A. ornatus*	*A. antiselli*	*11375**
100	11.0	4.5	7.0	6.5	2.5	*A. ornatus*	*A. antiselli*	*11374**
101	11.0	6.2	9.2	4.8	3.0	*A. antiselli* or *A. salinasensis*	*A. spatiosus*	*11373*
102	6.5	4.5	5.5	2.0	1.5	*A. antiselli* or *A. salinasensis*	*A. spatiosus*	*11372*
103	14.2	8.5	11.2	5.7	2.7	*A. spatiosus*	*A. spatiosus*	*11041**
104	16.0	9.0	10.0	7.0	1.0	*A. arnoldi* var. *crassus*	*A. arnoldi*	*11350**
105	9.5	6.0	7.0	3.5	1.0	*A. arnoldi crassus*	*A. arnoldi*	*11376*
106	19.0	9.0	14.0	10.0	5.0	*A. arnoldi peltoides*	*A. peltoides*	*11336*
107	10.1	5.0	6.5	5.1	1.5	*A. altus*	*A. antiselli*	*10065**
108	12.0	7.0	9.0	5.0	2.0	*A. arnoldi fresnoensis*	*A. arnoldi*	*11032**
109	14.0	3.5	7.0	10.5	3.5	*A. californicus*	*A. whitneyi*	*11354**
110	15.0	4.0	4.5	11.0	.5	*A. coalingaensis*	*A. whitneyi*	*11355**
111	12.5	7.8	8.5	4.7	.7	*A. arnoldi depressus*	*A. arnoldi*	*11038**
112	13.5	5.1	9.5	8.4	4.4	*A. cuyamanus*	*A. whitneyi*	*11045**
113	13.0	3.0	4.5	10.0	1.5	*A. whitneyi*	*A. whitneyi*	*11004*
114	11.5	4.5	5.0	7.0	.5	*A. whitneyi*	*A. whitneyi*	*11036*
115	11.0	4.5	7.0	6.5	2.5	*A. whitneyi*	*A. whitneyi*	*11391*
116	18.5	5.0	9.0	13.5	4.0	*A. jacalitosensis*	*A. jacalitosensis*	*11037*
117	14.0	4.5	5.0	9.5	.5	*A. grandis*	*A. whitneyi*	*11046**
118	9.0	5.5	8.0	3.5	2.5	*A. fernandoensis*	*A. fernandoensis*	*11042*
119	14.5	6.0	10.0	8.5	4.0	*A. major*	*A. arnoldi*	*11003**
120	14.5	7.0	11.5	7.5	4.5	*A. major*	*A. arnoldi*	*11337**
121	13.6	6.0	8.0?	7.6	2.0	*A. margaritanus*	*A. antiselli*	*11023**
122	16.0	7.2	13.0	8.8	5.8	*A. antiselli*	*A. spatiosus*	C.A.S. Plasto. 184
123	15.6	5.0	9.0	10.0	4.0	*A. arnoldi peltoides*	*A. jacalitosensis*	C.A.S. 451
124	11.0	4.0	5.5	7.0	1.5	*A. whitneyi*	*A. whitneyi*	C.A.S. 5923

APPENDIX A—*Concluded*

Specimen number[a]	h[b]	T'[c]	T''[d]	Z[e]	Q[f]	Species (of authors)[g]	Specific name or revised specific name[h]	Type number[i]
125	19.5	7.2	11.5	12.3	4.3	*A. schencki*	*A. jacalitosensis*	C.A.S. 6896
126	10.0	7.0	9.5	3.0	2.5	*A. salinasensis*	*A. spatiosus*	L.S.J.U. 7923
127	15.0	8.0	9.5	7.0	1.5	*A. arnoldi*	*A. arnoldi*	Stan. Coll. 3245
128	16.0	6.0	9.0	10.0	3.0	*A. jacalitosensis*	*A. whitneyi*	Stan. Coll. 3209
129	10.0	4.8	7.5	5.2	2.7	*A. antiselli*	*A. antiselli*	USNM 13337*
130	13.7	9.0	10.5	4.7	1.5	*A. salinasensis*	*A. spatiosus*	USNM 165466a*

APPENDIX B

GROUPS OF *Astrodapsis* SHOWN ON THE TRIANGULAR AND RECTANGULAR GRAPHS
(See figs. 2 and 3, in pocket)

Specimen number (see Appendix A)	Specific name of specimen figured or identified by others[a]	Specific name or revised specific name
GROUP I		
10	*A. cuyamanus*	*A. whitneyi*
12	*A. grandis*	*A. whitneyi*
16	*A. coalingaensis*	*A. whitneyi*
17		*A. whitneyi*
22	*A. schencki mirandaensis*	*A. jacalitosensis*
23	*A. isabellae*	*A. davisi*
66	*A. schencki mirandaensis*	*A. jacalitosensis*
79	*A. coalingaensis*	*A. whitneyi*
80	*A. whitneyi*	*A. whitneyi*
81	*A. whitneyi*	*A. whitneyi*
98	*A. ornatus*	*A. antiselli*
99	*A. ornatus*	*A. antiselli*
109	*A. californicus*	*A. whitneyi*
110	*A. coalingaensis*	*A. whitneyi*
113	*A. whitneyi*	*A. whitneyi*
114	*A. whitneyi*	*A. whitneyi*
116	*A. jacalitosensis*	*A. jacalitosensis*
117	*A. grandis*	*A. whitneyi*
123	*A. arnoldi peltoides*	*A. jacalitosensis*
124	*A. whitneyi*	*A. whitneyi*
125	*A. schencki*	*A. jacalitosensis*
128	*A. jacalitosensis*	*A. whitneyi*
GROUP II		
1		*A. whitneyi*
2		*A. whitneyi*
3		*A. whitneyi*
4		*A. whitneyi*
5		*A. whitneyi*
8	*A. perrini*	*A. whitneyi*
11	*A. californicus*	*A. whitneyi*
13	*A. hertleini*	*A. whitneyi*
14	*A. woodringi*	*A. whitneyi*
15	*A. laimingi*	*A. whitneyi*
32		*A. spatiosus*
72	*A. altus*	*A. antiselli*
82		*A. whitneyi*
83		*A. whitneyi*
84		*A. whitneyi*
97	*A. ornatus*	*A. antiselli*
100	*A. ornatus*	*A. antiselli*

[a] These names were given the specimens either by researchers or curators and appear with the specimens on the labels and with the explanation of the plate of figured specimens.

APPENDIX B—*Continued*

Specimen number (see Appendix A)	Specific name of specimen figured or identified by others[a]	Specific name or revised specific name
Group II—*Continued*		
112	*A. cuyamanus*	*A. whitneyi*
115	*A. whitneyi*	*A. whitneyi*
119	*A. major*	*A. arnoldi*
121	*A. margaritanus*	*A. antiselli*
Group III		
6		*A. spatiosus*
9	*A. davisi*	*A. davisi*
28	*A. ovalis*	*A. diabloensis*
29	*A. cierboensis branchensis*	*A. diabloensis*
30		*A. spatiosus*
31		*A. spatiosus*
33		*A. spatiosus*
34		*A. spatiosus*
35		*A. spatiosus*
36		*A. spatiosus*
37		*A. spatiosus*
38		*A. spatiosus*
39		*A. spatiosus*
40		*A. spatiosus*
41		*A. spatiosus*
42		*A. spatiosus*
43		*A. peltoides*
44	*A. salinasensis*	*A. spatiosus*
45		*A. peltoides*
46		*A. peltoides*
47		*A. antiselli*
48		*A. antiselli*
49		*A. antiselli*
50		*A. antisclli*
51		*A. antiselli*
52		*A. antiselli*
53		*A. antiselli*
54		*A. antiselli*
55		*A. antiselli*
56		*A. antiselli*
57		*A. antiselli*
58		*A. antiselli*
59		*A. antiselli*
60		*A. antiselli*
61	*A. jacalitosensis*	*A. arnoldi*
62	*A. jacalitosensis*	*A. arnoldi*
63	*A. arnoldi crassus*	*A. arnoldi*
64	*A. arnoldi crassus*	*A. arnoldi*
65	*A. arnoldi*	*A. arnoldi*

APPENDIX B—*Concluded*

Specimen number (see Appendix A)	Specific name of specimen figured or identified by others[a]	Specific name or revised specific name
Group III—*Continued*		
67	*A. peltoides*	*A. peltoides*
68		*A. spatiosus*
69		*A. spatiosus*
70		*A. spatiosus*
71		*A. spatiosus*
73		*A. antiselli*
75		*A. antiselli*
76		*A. antiselli*
77		*A. antiselli*
78		*A. antiselli*
85		*A. antiselli*
86		*A. antiselli*
87		*A. antiselli*
88		*A. spatiosus*
89		*A. spatiosus*
90		*A. spatiosus*
91		*A. spatiosus*
92		*A. spatiosus*
93		*A. spatiosus*
94		*A. spatiosus*
95		*A. spatiosus*
96	*A. antiselli*	*A. antiselli*
101	*A. antiselli* or *salinasensis*	*A. spatiosus*
102	*A. antiselli* or *salinasensis*	*A. spatiosus*
103	*A. spatiosus*	*A. spatiosus*
104	*A. arnoldi crassus*	*A. arnoldi*
105	*A. arnoldi crassus*	*A. arnoldi*
106	*A. arnoldi peltoides*	*A. peltoides*
107	*A. altus*	*A. antiselli*
108	*A. arnoldi fresnosensis*	*A. arnoldi*
111	*A. arnoldi depressus*	*A. arnoldi*
118	*A. fernandoensis*	*A. fernandoensis*
120	*A. major*	*A. arnoldi*
122	*A. antiselli*	*A. spatiosus*
126	*A. salinasensis*	*A. spatiosus*
127	*A. arnoldi*	*A. arnoldi*
129	*A. antiselli*	*A. antiselli*
130	*A. salinasensis*	*A. spatiosus*
Group IV		
18	*A. gregerseni fragilis*	*A. davisi*
19	*A. johnsoni*	*A. davisi*
20	*A. gregerseni*	*A. davisi*
21	*A. gregerseni varians*	*A. davisi*
26	*A. gregerseni*	*A. davisi*
27	*A. gregerseni*	*A. davisi*

PLATES

All figures are natural size. All side views are oriented with the posterior to the right, except plate 16, figure 4, which is oriented with the anterior to the right.

Plates 30, 37, and 40 are stereoscopic views.

Unless otherwise stated all types are at the University of California, Los Angeles, the type numbers referring to the paleontology collection catalogue numbers.

PLATE 1

Figs. 1, 5. *Astrodapsis brewerianus* (Rémond). Hypotype no. 8399. UCLA loc. 1920. Modelo formation. Lower Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis diabloensis* Kew. Hypotype no. 9200. UCLA loc. 1798B. Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 3, 7. *Astrodapsis diabloensis* Kew. Hypotype no. 8783. UCLA loc. 1794. Middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 9. *Astrodapsis diabloensis* Kew. Hypotype no. 9202. UCLA loc. 1798B. Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 8, 11. *Astrodapsis brewerianus* (Rémond). Hypotype no. 8399A. UCLA loc. 1920 (holotype of Grant and Eaton *A. hootsi*). Modelo formation. Lower Mohnian, Late Miocene.

Figs. 10, 13. *Astrodapsis diabloensis* Kew. Hypotype no. 32372. UCLA loc. 1838. Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 12, 14. *Astrodapsis diabloensis* Kew. Hypotype no. 8769. UCLA loc. 1745. Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 15, 18. *Astrodapsis brewerianus* (Rémond). Hypotype no. 820A. UCLA loc. 1222. Upper Monterey formation, San Luis Obispo Co. Upper Luisian, Middle Miocene.

Figs. 16, 19. *Astrodapsis diabloensis* Kew. Hypotype no. 8765. UCLA loc. 1335 (holotype of Grant and Eaton *A. reedi*). Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 17, 20. *Astrodapsis diabloensis* Kew. Hypotype no. 32371. UCLA loc. 1838. Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

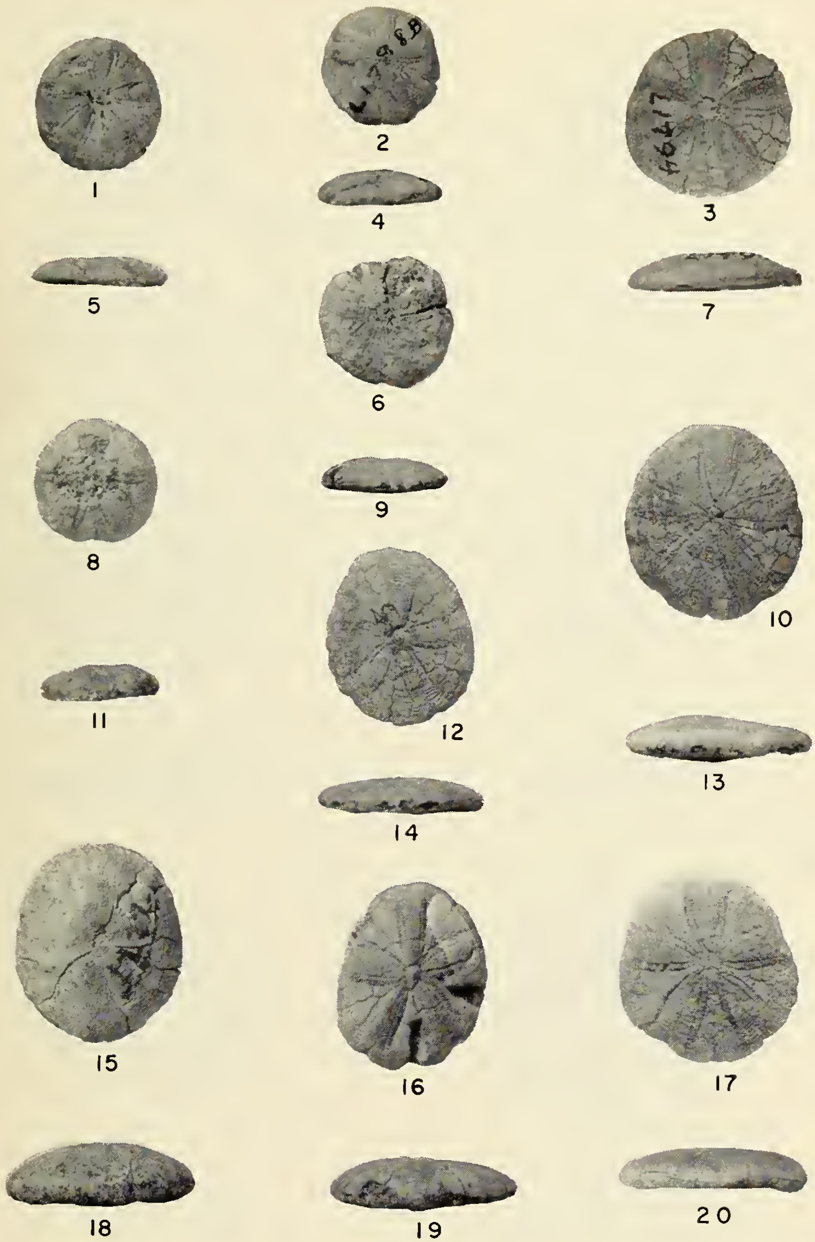
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PLATE 2

Figs. 1, 3. *Astrodapsis diabloensis* Kew. Hypotype no. 11016, Univ. Calif., Berkeley, Coll. Invert. Paleo. Reproductions of figs. 5a, 5b, pl. 13, Kew (1920, p. 178). Referred to as the "Neotype" of *A. brewerianus* by Kew. Briones formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis diabloensis* Kew. Hypotype no. 8785. UCLA loc. 1794 (holotype of Grant and Eaton *A. brewerianus junior*). Middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis diabloensis* Kew. Hypotype no. 8781. UCLA loc. 1798A. Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis diabloensis* Kew. Hypotype no. 8780. UCLA loc. 1847 (Eaton *et al.*, 1941, pl. 5, fig. 17; locality given as 1841, which is in error) (holotype of Grant and Eaton *A. ovalis*). Middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 9, 11. *Astrodapsis diabloensis* Kew. Hypotype no. 8715. UCLA loc. 1333. Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 10, 12. *Astrodapsis diabloensis* Kew. Hypotype no. 32374. UCLA loc. 1745. Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

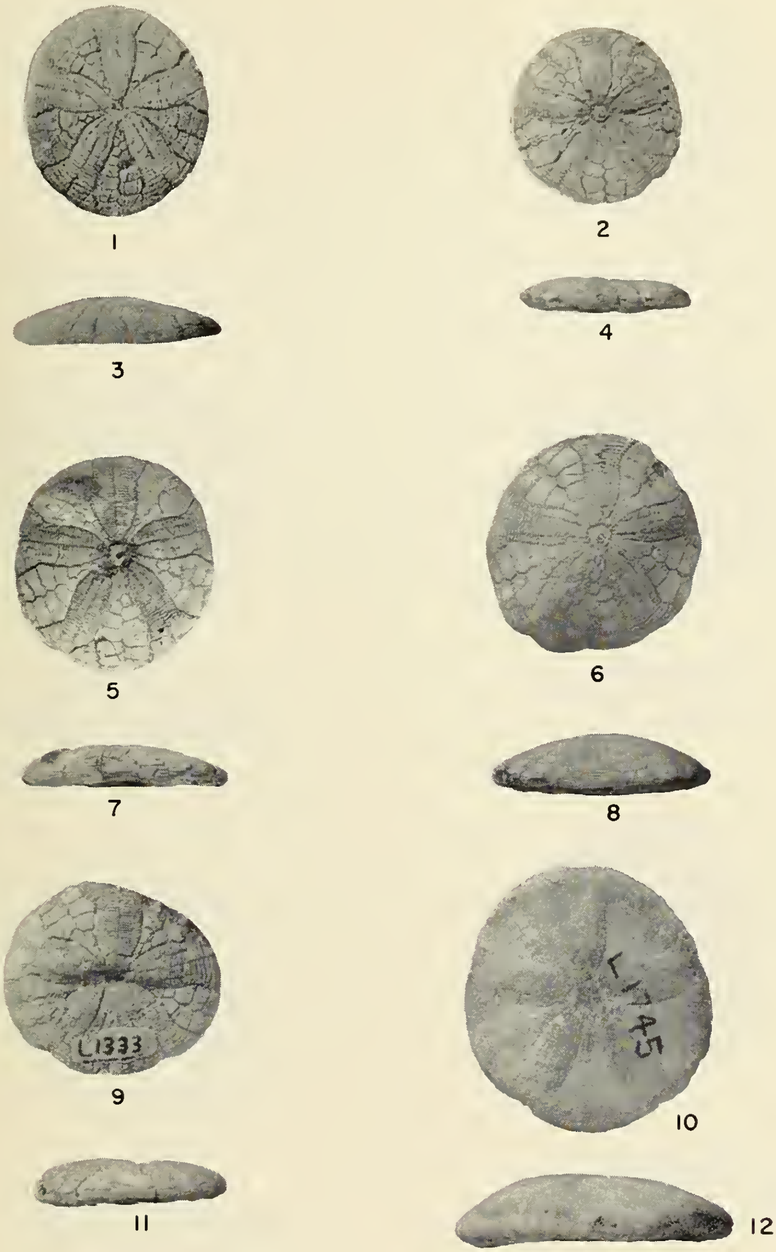
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PLATE 3

Figs. 1, 3. *Astrodapsis diabloensis* Kew. Hypotype no. 8775. UCLA loc. 1770B (holotype of Grant and Eaton *A. armstrongi*). Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis diabloensis* Kew. Hypotype no. 9124. UCLA loc. 1855. Middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis diabloensis* Kew. Hypotype no. 8750. UCLA loc. 1854 (holotype of Grant and Eaton *A. cierboensis brancheensis*). Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis diabloensis* Kew. Hypotype no. 8770. UCLA loc. 1745A (holotype of Grant and Eaton *A. diabloensis superior*). Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 9, 11. *Astrodapsis diabloensis* Kew. Hypotype no. 32370. UCLA loc. 1333. Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 10, 12. *Astrodapsis diabloensis* Kew. Hypotype no. 8754. UCLA loc. 1854. Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

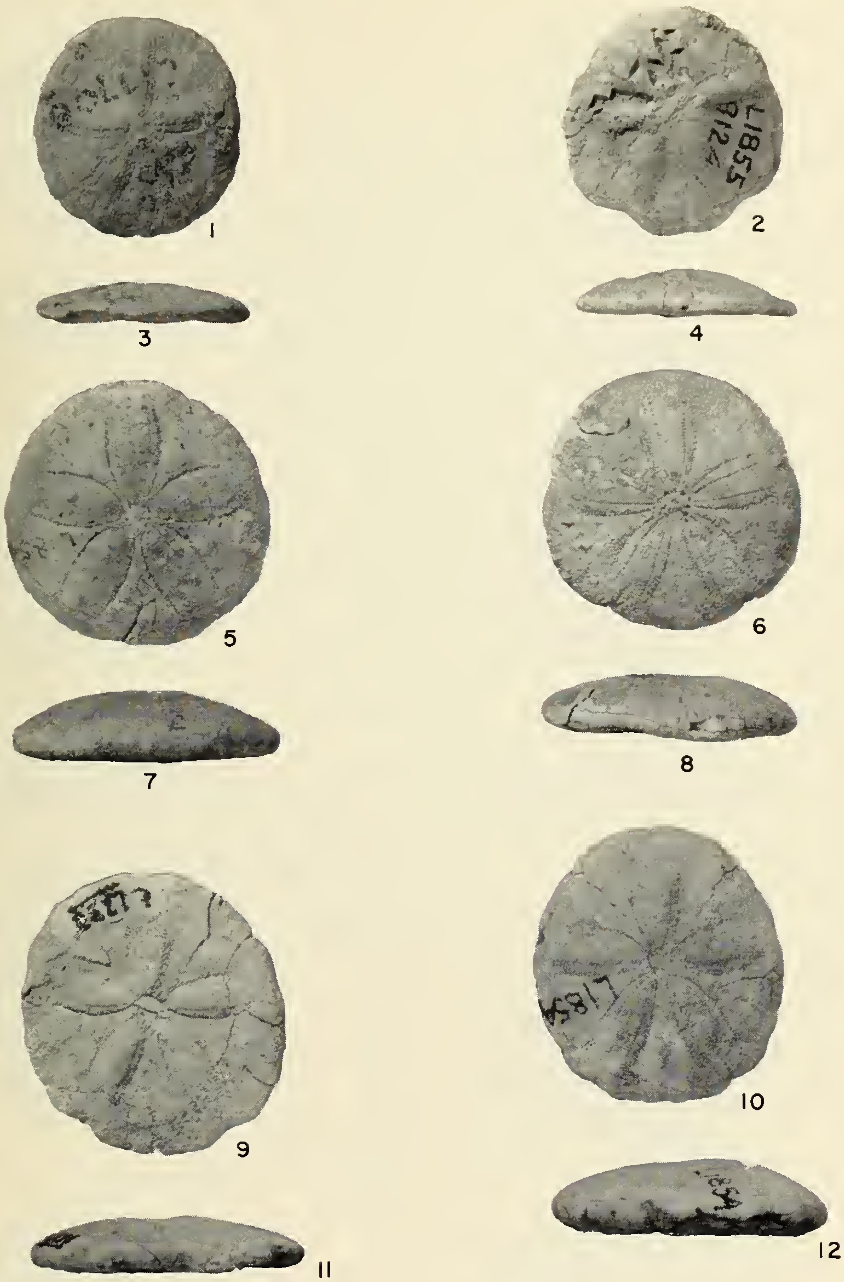
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PLATE 4

Figs. 1, 3. *Astrodapsis diabloensis* Kew. Hypotype no. 8748. UCLA loc. 1838R. Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis diabloensis* Kew. Hypotype no. 8761. UCLA loc. 1745A. Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis diabloensis* Kew. Hypotype no. 8710. UCLA loc. 1333 (holotype of Grant and Eaton *A. auguri*). Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis diabloensis* Kew. Hypotype no. 8760. UCLA loc. 1745 (holotype of Grant and Eaton *A. altus antiquus*). Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 9, 11. *Astrodapsis diabloensis* Kew. Hypotype no. 32373. UCLA loc. 1854. Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 10, 12. *Astrodapsis diabloensis* Kew. Hypotype no. 9125. UCLA loc. 1745. Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

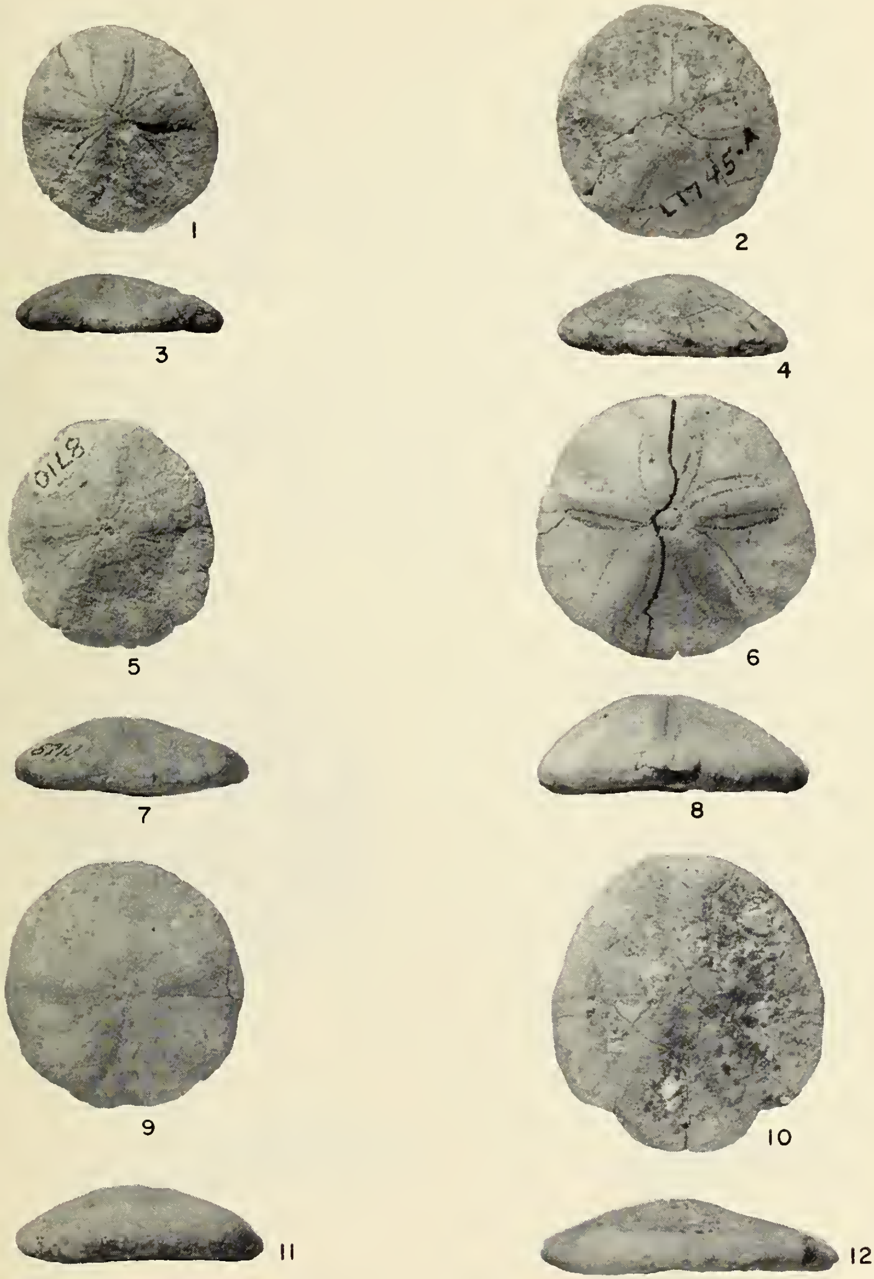
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PLATE 5

Figs. 1, 4. *Astrodapsis diabloensis* Kew. Hypotype no. 8740. UCLA loc. 1838 (holotype of Grant and Eaton *A. schucherti affinis*). Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 3. *Astrodapsis diabloensis* Kew. Hypotype no. 8720. UCLA loc. 1333 (holotype of Grant and Eaton *A. schucherti*). Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis diabloensis* Kew. Hypotype no. 8735. UCLA loc. 1838 (holotype of Grant and Eaton *A. brewerianus bitterensis*). Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 9. *Astrodapsis pabloensis* (Kew). Hypotype no. 9205. UCLA loc. 1876 (holotype of Grant and Eaton *A. elevatum*). Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 8, 10. *Astrodapsis diabloensis* Kew. Hypotype no. 8730. UCLA loc. 1838 (holotype of Grant and Eaton *A. galei*). Lower Santa Margarita formation. Upper Mohnian, Late Miocene.

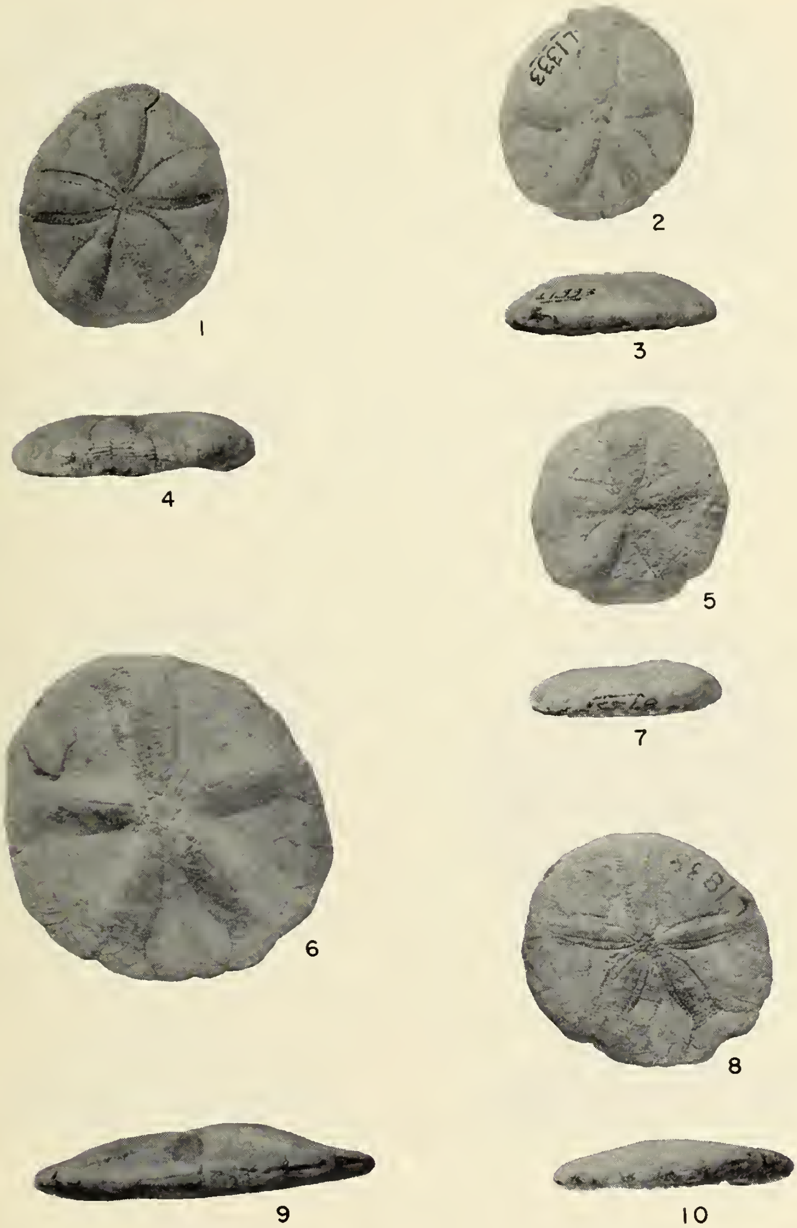
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PLATE 6

Figs. 1, 3. *Astrodapsis diabloensis* Kew. Hypotype no. 8731. UCLA loc. 1745. Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis diabloensis* Kew. Hypotype no. 8732. UCLA loc. 1745. Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis diabloensis* Kew. Hypotype no. 8795. UCLA loc. 1848 (holotype of Grant and Eaton *A. cutleri*). Middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis diabloensis* Kew. Hypotype no. 8798. UCLA loc. 1848. Middle Santa Margarita formation. Upper Mohnian, Late Miocene.

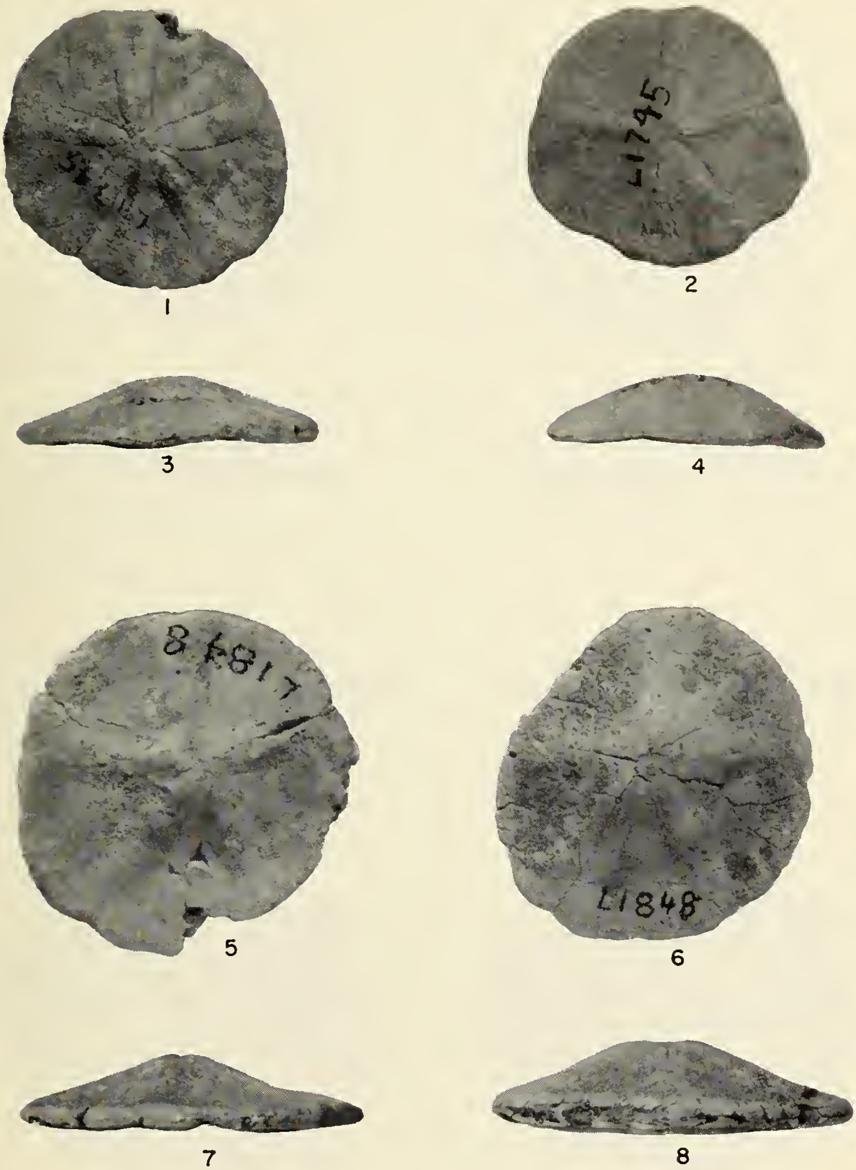
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PLATE 7

Figs. 1, 3. *Astrodapsis pabloensis* (Kew). Hypotype no. 8791. UCLA loc. 1727A. Middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis pabloensis* (Kew). Hypotype no. 8790. UCLA loc. 1727. Middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis pabloensis* (Kew). Hypotype no. 9207. UCLA loc. 1876. Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis pabloensis* (Kew). Hypotype no. 32375. UCLA loc. 1876R. Lower middle Santa Margarita formation. Upper Mohnian, Late Miocene.

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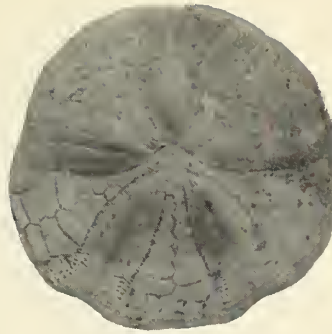

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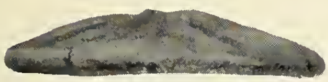

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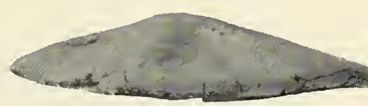

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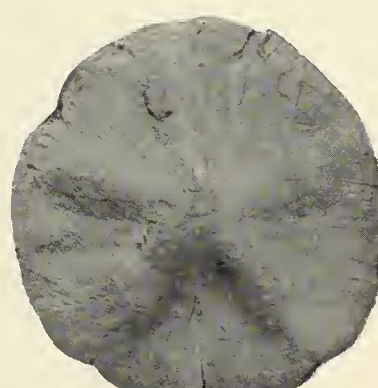

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PLATE 8

Figs. 1, 3. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8840. UCLA loc. 1791 (holotype of Grant and Eaton *A. isabellae*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis davisi* Grant and Eaton. Holotype no. 8845. UCLA loc. 1729. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis davisi* Grant and Eaton. Holotype no. 8845. UCLA loc. 1729. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8845. UCLA loc. 1729. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

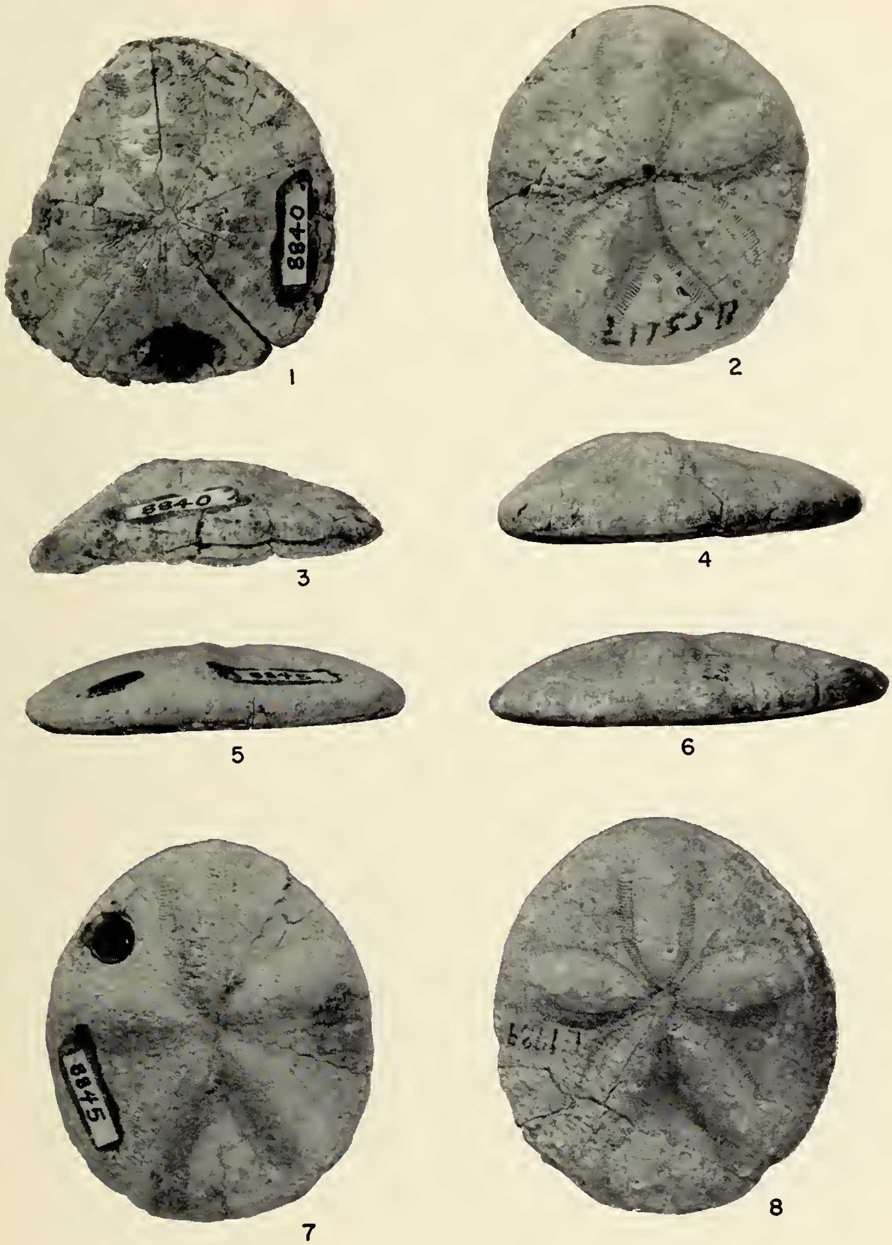
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PLATE 9

Figs. 1, 3. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8827. UCLA loc. 1711. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 9216. UCLA loc. 1866R. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8865. UCLA loc. 1718A (holotype of Grant and Eaton *A. blakei*). Lower upper Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8835. UCLA loc. 1755 (holotype of Grant and Eaton *A. clarki*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

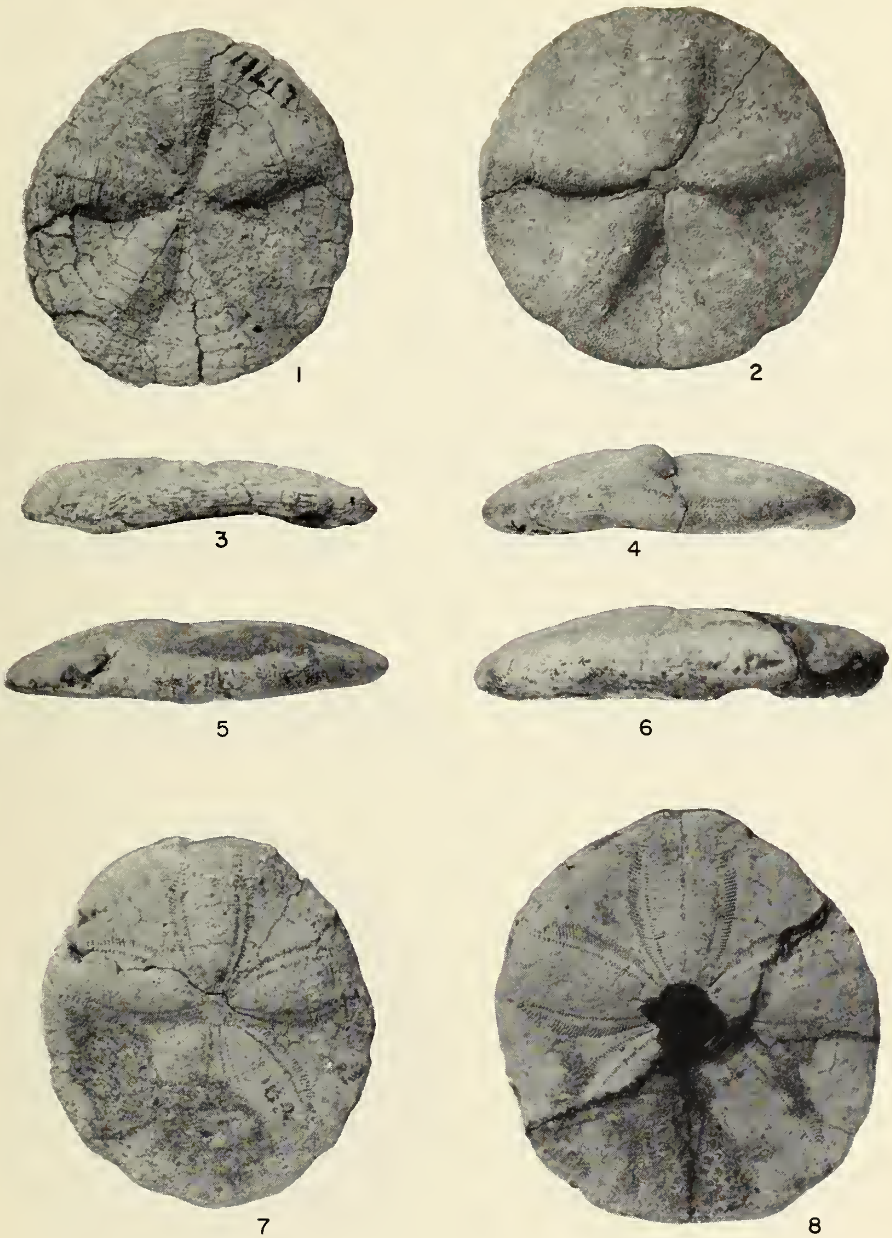
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PLATE 10

Figs. 1, 3. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8860. UCLA loc. 1843. Lower upper Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8830. UCLA loc. 1711 (holotype of Grant and Eaton *A. gregerseni varians*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis whitneyi* Rémond. Hypotype no. 8870D. UCLA loc. 1786. Lower upper Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 6, 8. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8800. UCLA loc. 1342 (holotype of Grant and Eaton *A. gregerseni fragillis*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

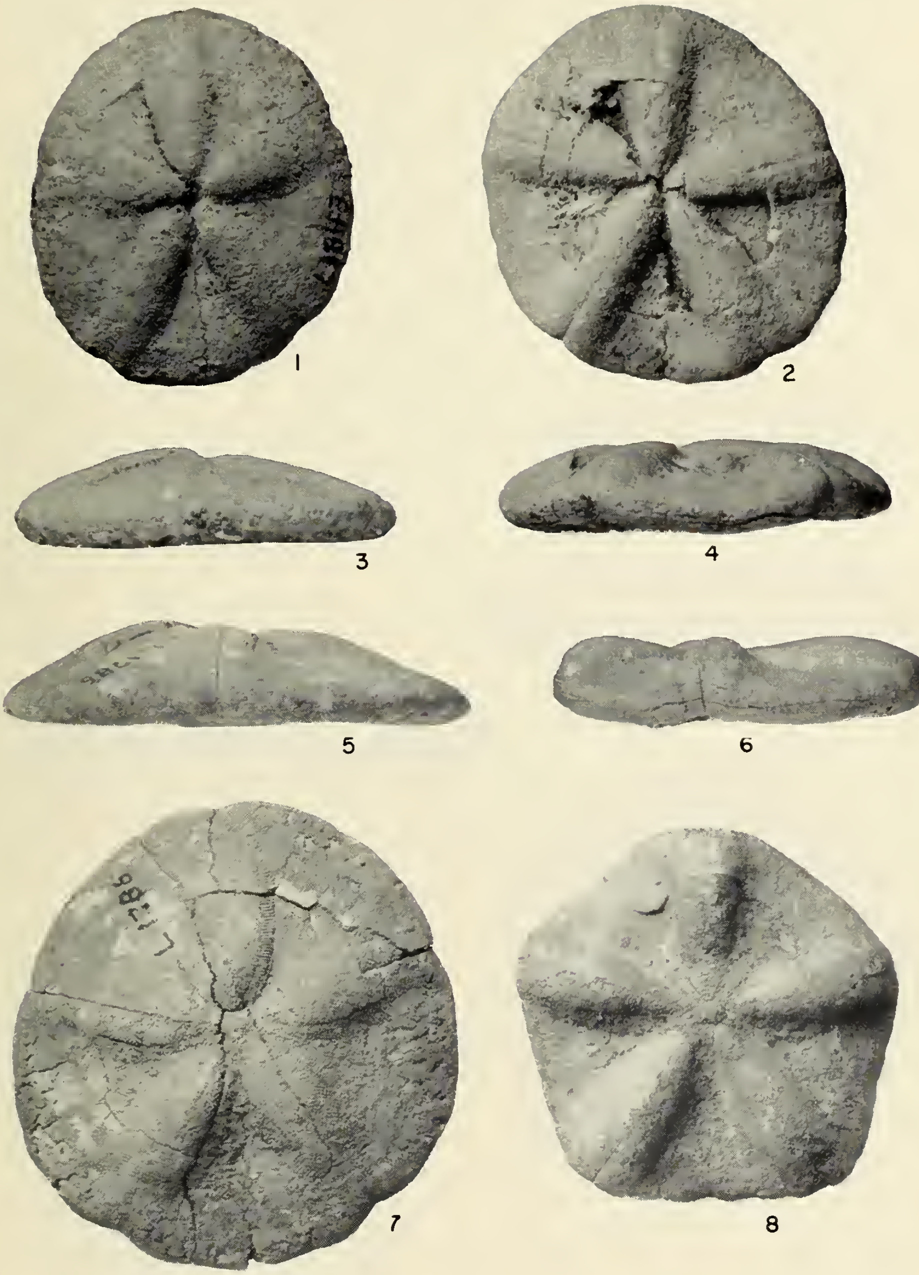
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PLATE 11

Figs. 1, 3. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 32377. UCLA loc. 1717. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8805. UCLA loc. 1748 (holotype of Grant and Eaton *A. johnsoni*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8810. UCLA loc. 1717 (holotype of Grant and Eaton *A. gregerseni*). Upper middle Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 32376. UCLA loc. 1717. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

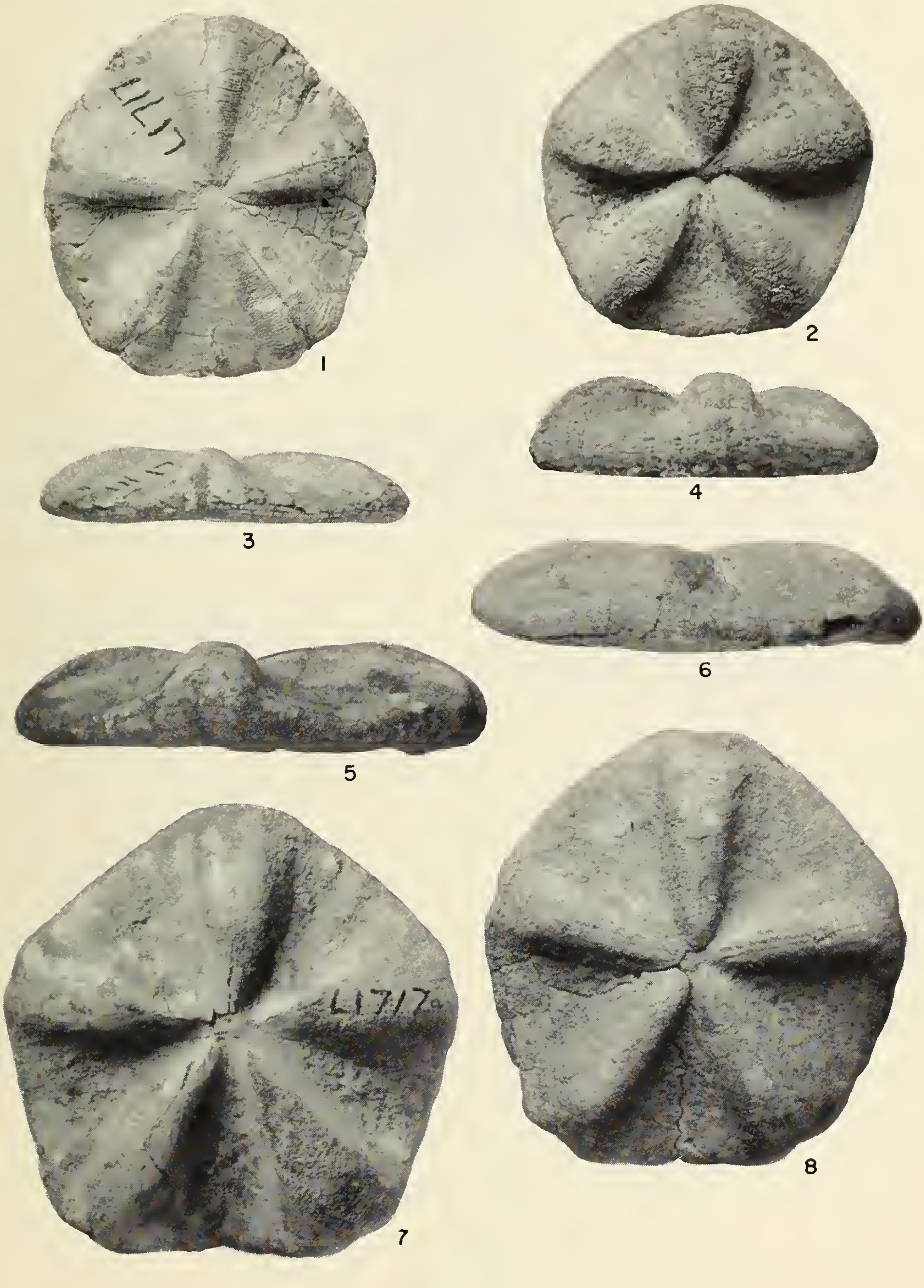
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PLATE 12

Figs. 1, 4. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 9212. UCLA loc. 1711. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 5. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 9211. UCLA loc. 1711. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 3, 6. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8822. UCLA loc. 1751. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 7, 9. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8825. UCLA loc. 1791 (holotype of Grant and Eaton *A. englishi*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 8, 10. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8843. UCLA loc. 1729. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

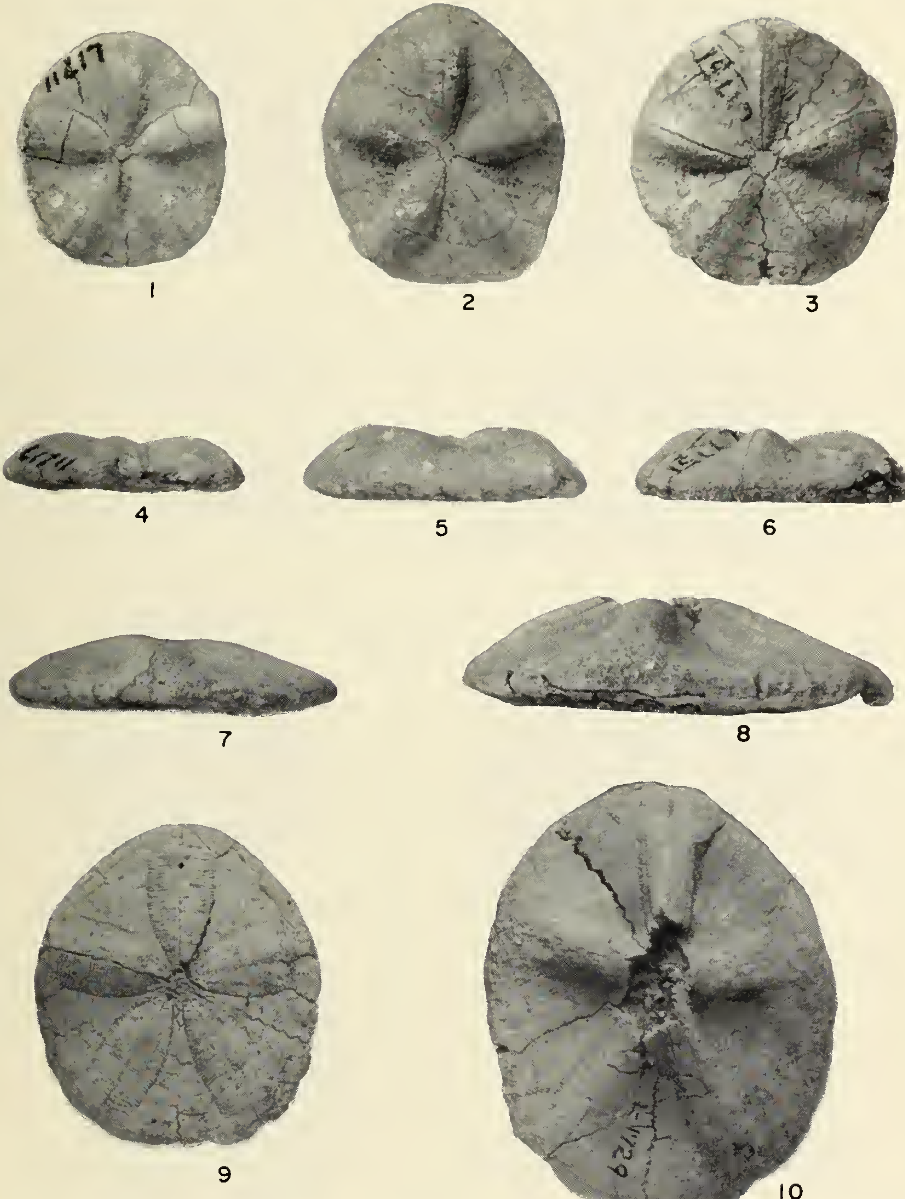
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PLATE 13

Figs. 1, 3. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 9210. UCLA loc. 1711 (holotype of Grant and Eaton *A. johnsoni simile*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 9215. UCLA loc. 1752 (holotype of Grant and Eaton *A. quaylei*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8820. UCLA loc. 1644A (holotype of Grant and Eaton *A. goudkoffi*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 9217. UCLA loc. 1866R. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 9, 10. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8844. UCLA loc. 1711. Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

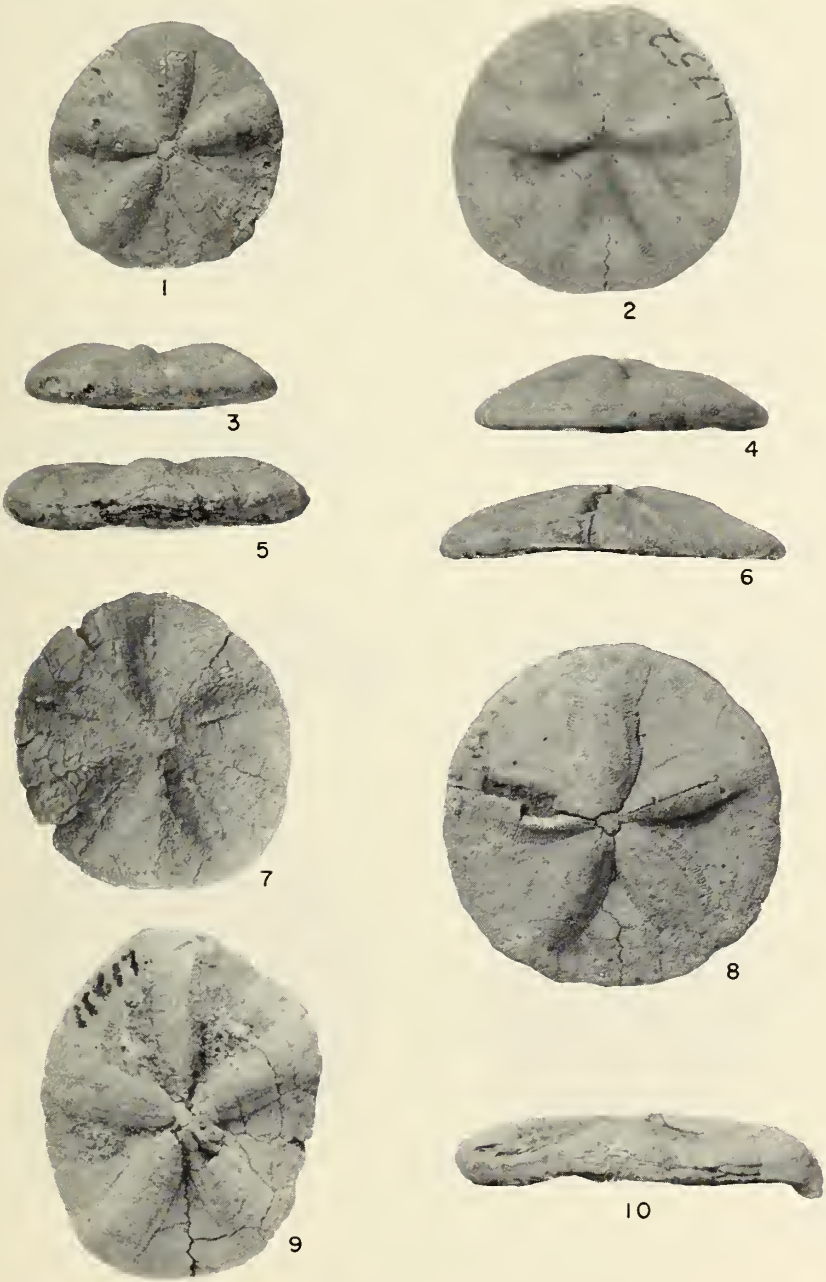
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PLATE 14

Figs. 1, 3. *Astrodapsis cierboensis* Kew. Topotype no. 9402. Univ. Calif., Berkeley, loc. 522. Cierbo formation. Upper Mohnian, Late Miocene.

Figs. 2, 4. *Astrodapsis cierboensis* Kew. Topotype no. 9401. Univ. Calif., Berkeley, loc. 522. Cierbo formation. Upper Mohnian, Late Miocene.

Figs. 5, 7. *Astrodapsis davisi* Grant and Eaton. Hypotype no. 8815. UCLA loc. 1748 (holotype of Grant and Eaton *A. desaixi*). Upper middle Santa Margarita formation. Upper Mohnian, Late Miocene.

Figs. 6, 8. *Astrodapsis cierboensis* Kew. Topotype no. 9400. Univ. Calif., Berkeley, loc. 522. Cierbo formation. Upper Mohnian, Late Miocene.

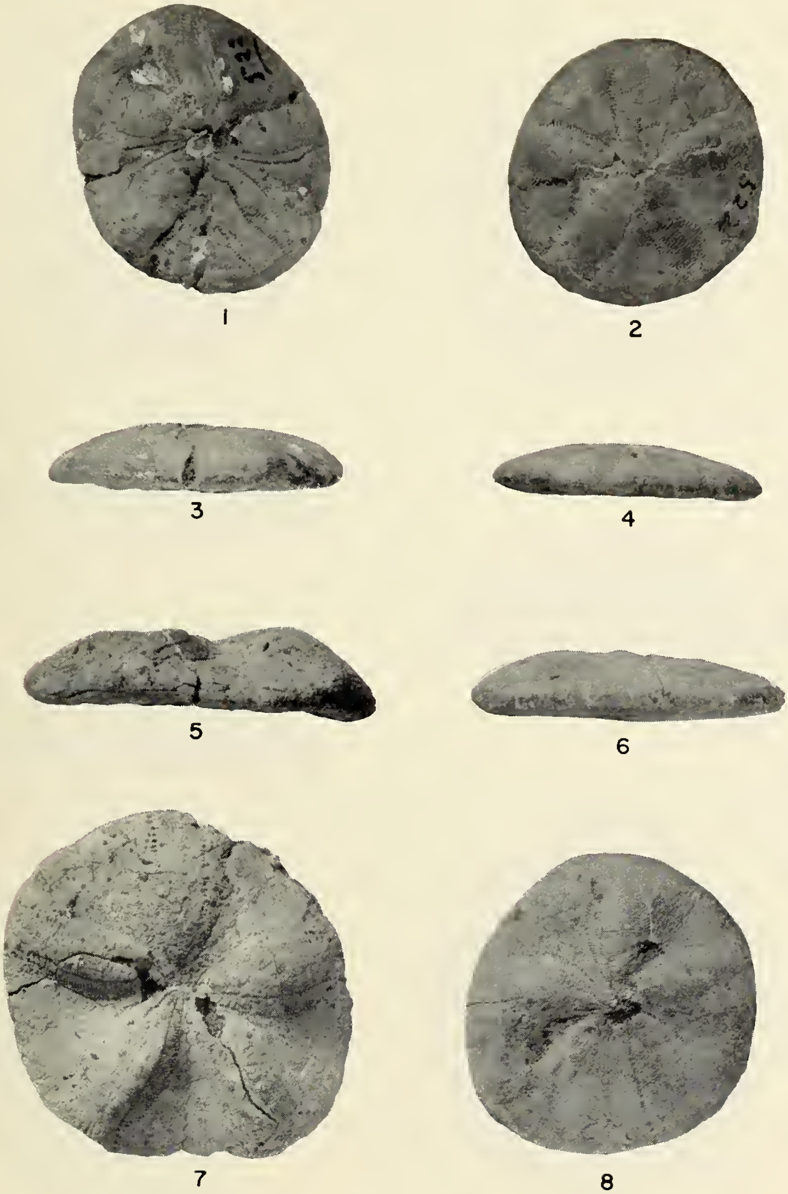

PLATE 15

Figs. 1, 3. *Astrodapsis antiselli* Conrad. Topotype no. 9511. UCLA loc. 2171. Santa Margarita formation. Lower Delmontian, Late Miocene.

Fig. 2. *Astrodapsis antiselli* Conrad. Holotype no. 13337, U. S. Nat. Mus. Cat. West bank San Juan River, San Luis Obispo Co., Calif. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 4, 7. *Astrodapsis antiselli* Conrad. Topotype no. 9570. UCLA loc. 2171R. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 5, 6. *Astrodapsis antiselli* Conrad. Topotype no. 9572. UCLA loc. 2171R. Santa Margarita formation. Lower Delmontian, Late Miocene.

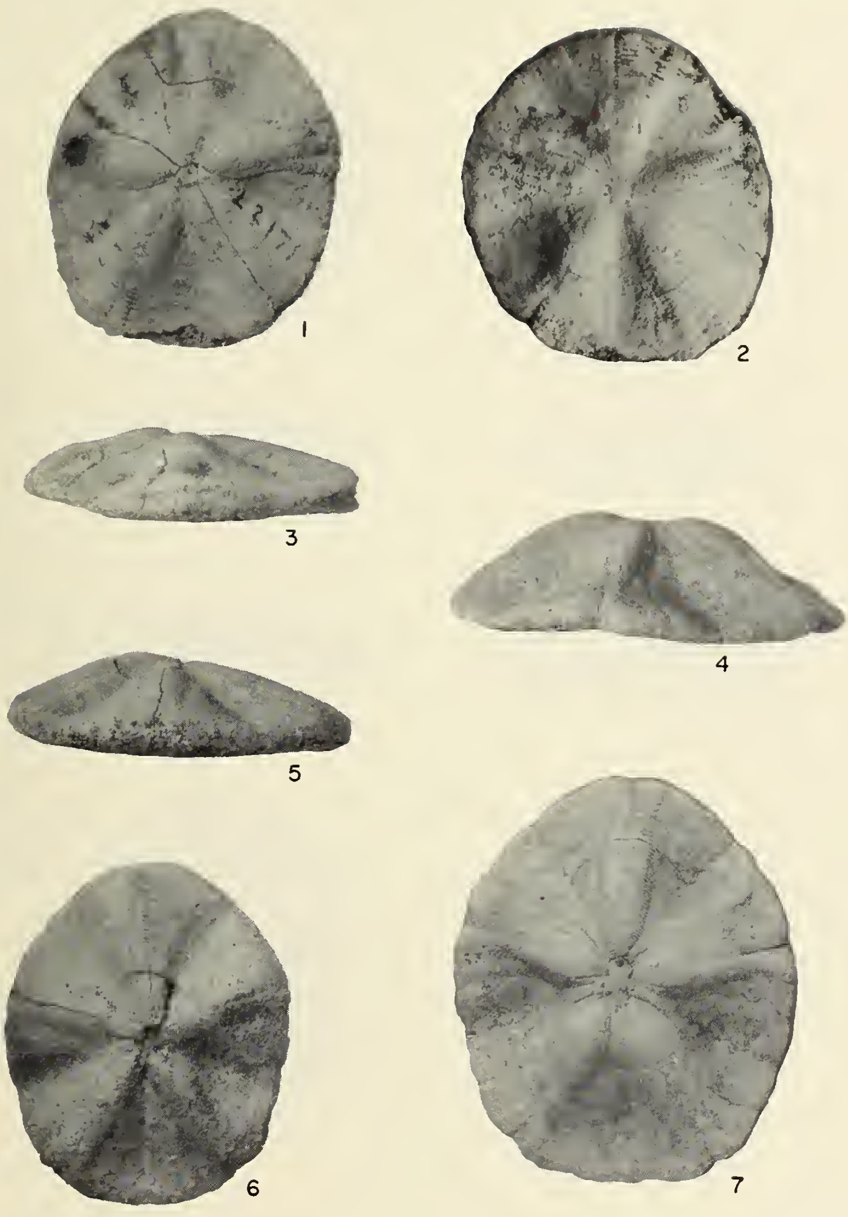
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PLATE 16

Figs. 1, 3. *Astrodapsis antiselli* Conrad. Topotype no. 9515. UCLA loc. 2171R. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 2, 4. *Astrodapsis antiselli* Conrad. Topotype no. 9573. UCLA loc. 2171R. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 5, 7. *Astrodapsis antiselli* Conrad. Hypotype no. 34627, Univ. Calif., Berkeley. Univ. Calif., Berkeley, loc. 1697. Santa Margarita formation (type locality). Lower Delmontian, Late Miocene.

Figs. 6, 8. *Astrodapsis antiselli* Conrad. Hypotype no. 9447. UCLA loc. 2153A. Santa Margarita formation. Lower Delmontian, Late Miocene.

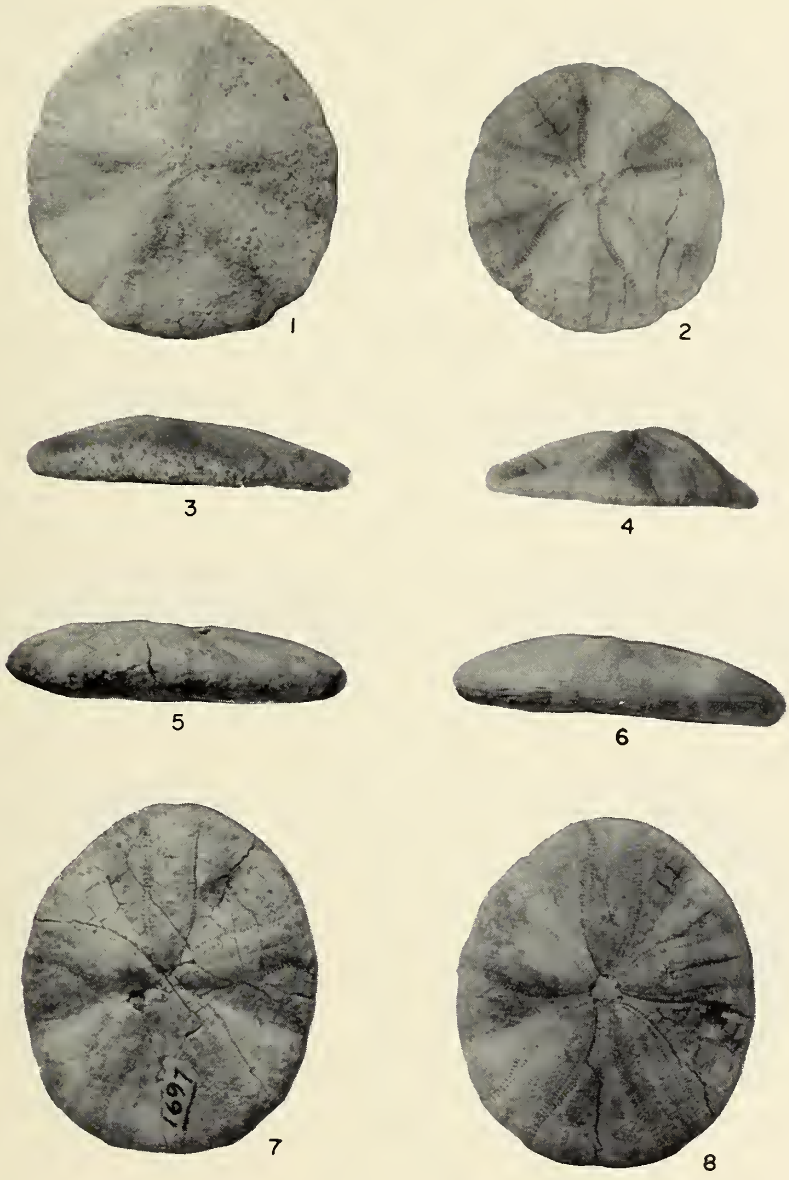
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PLATE 17

Figs. 1, 3. *Astrodapsis antiselli* Conrad. Topotype no. 9575. UCLA loc. 2171R. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 2, 4. *Astrodapsis antiselli* Conrad. Hypotype no. 34625, Univ. Calif., Berkeley. Univ. Calif., Berkeley, loc. 482. Neroly formation. Lower Delmontian, Late Miocene.

Figs. 5, 7. *Astrodapsis antiselli* Conrad. Hypotype no. 9404. Univ. Calif., Berkeley, loc. 1697. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 6, 8. *Astrodapsis antiselli* Conrad. Hypotype no. 9446. UCLA loc. 2153A. Santa Margarita formation. Lower Delmontian, Late Miocene.

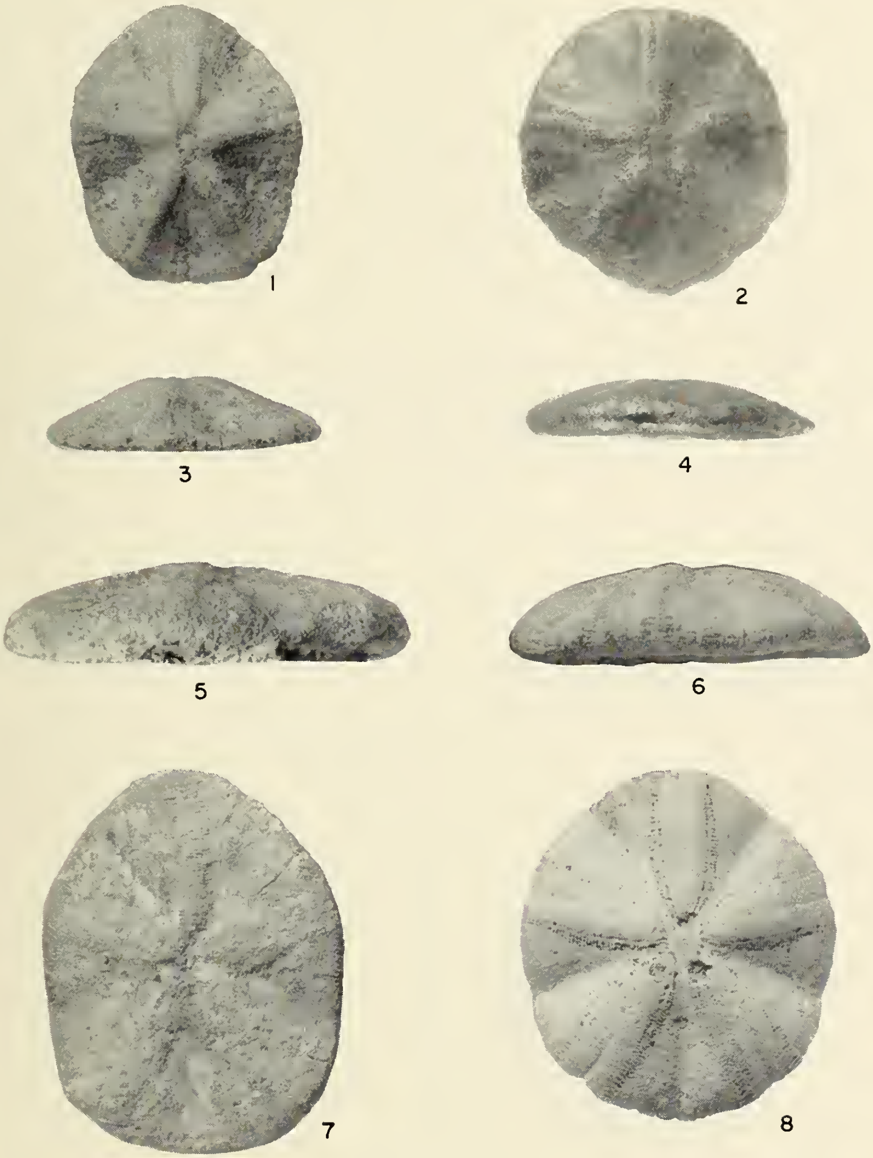
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PLATE 18

Figs. 1, 3. *Astrodapsis antiselli* Conrad. Hypotype no. 32389. UCLA loc. 4177. Submember 4, Phoenix member, Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 2, 4. *Astrodapsis antiselli* Conrad. Hypotype no. 34626, Univ. Calif., Berkeley. Univ. Calif., Berkeley, loc. 482. Neroly formation. Lower Delmontian, Late Miocene.

Figs. 5, 7. *Astrodapsis antiselli* Conrad. Topotype no. 9512. UCLA loc. 2171R. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 6, 8. *Astrodapsis antiselli* Conrad. Hypotype no. 34628, Univ. Calif., Berkeley. Univ. Calif., Berkeley, loc. A3176. San Pablo formation (i.e., undifferentiated Cierbo and Neroly). Upper Mohnian to lower Delmontian, Late Miocene.

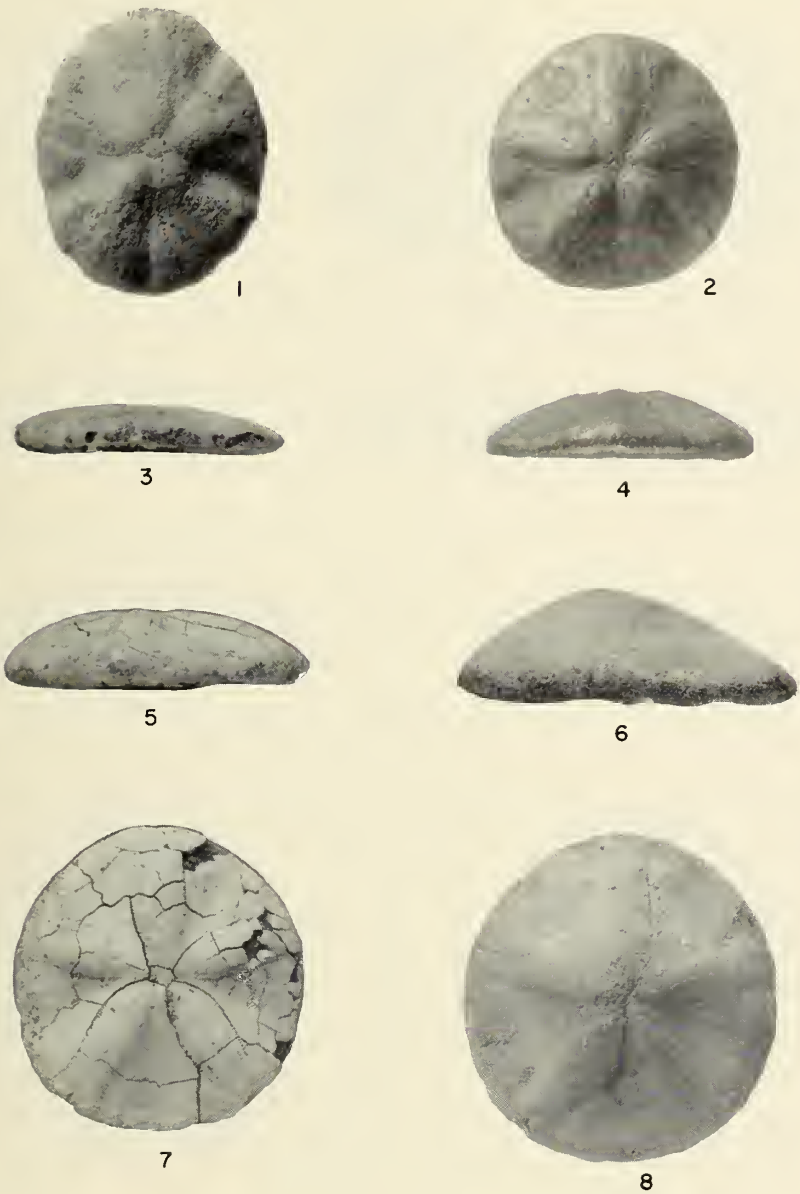
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PLATE 19

Figs. 1, 4. *Astrodapsis antiselli* Conrad. Hypotype no. 32388. UCLA loc. 4177. Submember 4, Phoenix member, Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 2, 5. *Astrodapsis antiselli* Conrad. Hypotype no. 9452. UCLA loc. 2151. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 3, 6. *Astrodapsis antiselli* Conrad. Hypotype no. 9454. UCLA loc. 2151. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 7, 9. *Astrodapsis antiselli* Conrad. Hypotype no. 9445. UCLA loc. 2153A. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 8, 10. *Astrodapsis antiselli* Conrad. Hypotype no. 9449. UCLA loc. 1895. Santa Margarita formation. Lower Delmontian, Late Miocene.

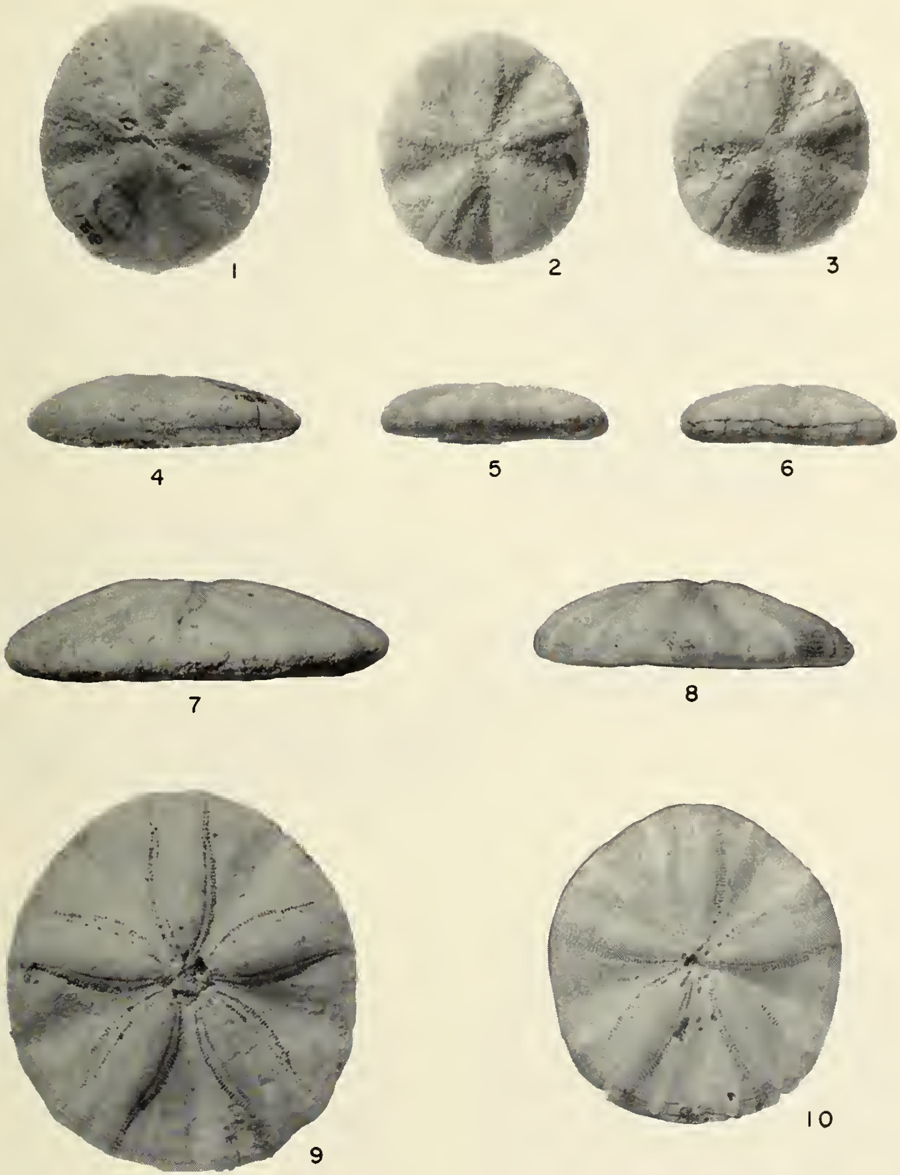
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PLATE 20

Figs. 1, 4. *Astrodapsis whitneyi* Rémond. Hypotype no. 8854. UCLA loc. 1844. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 2, 3. *Astrodapsis whitneyi* Rémond. Hypotype no. 32378. UCLA loc. 1785. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 5, 8. *Astrodapsis whitneyi* Rémond. Hypotype no. 8895. UCLA loc. 1854 (holotype of Grant and Eaton *A. perrini*). Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 6, 7. *Astrodapsis antiselli* Conrad. Hypotype no. 32384. UCLA loc. 4166. Submember 4, Phoenix member, Santa Margarita formation. Lower Delmontian, Late Miocene.

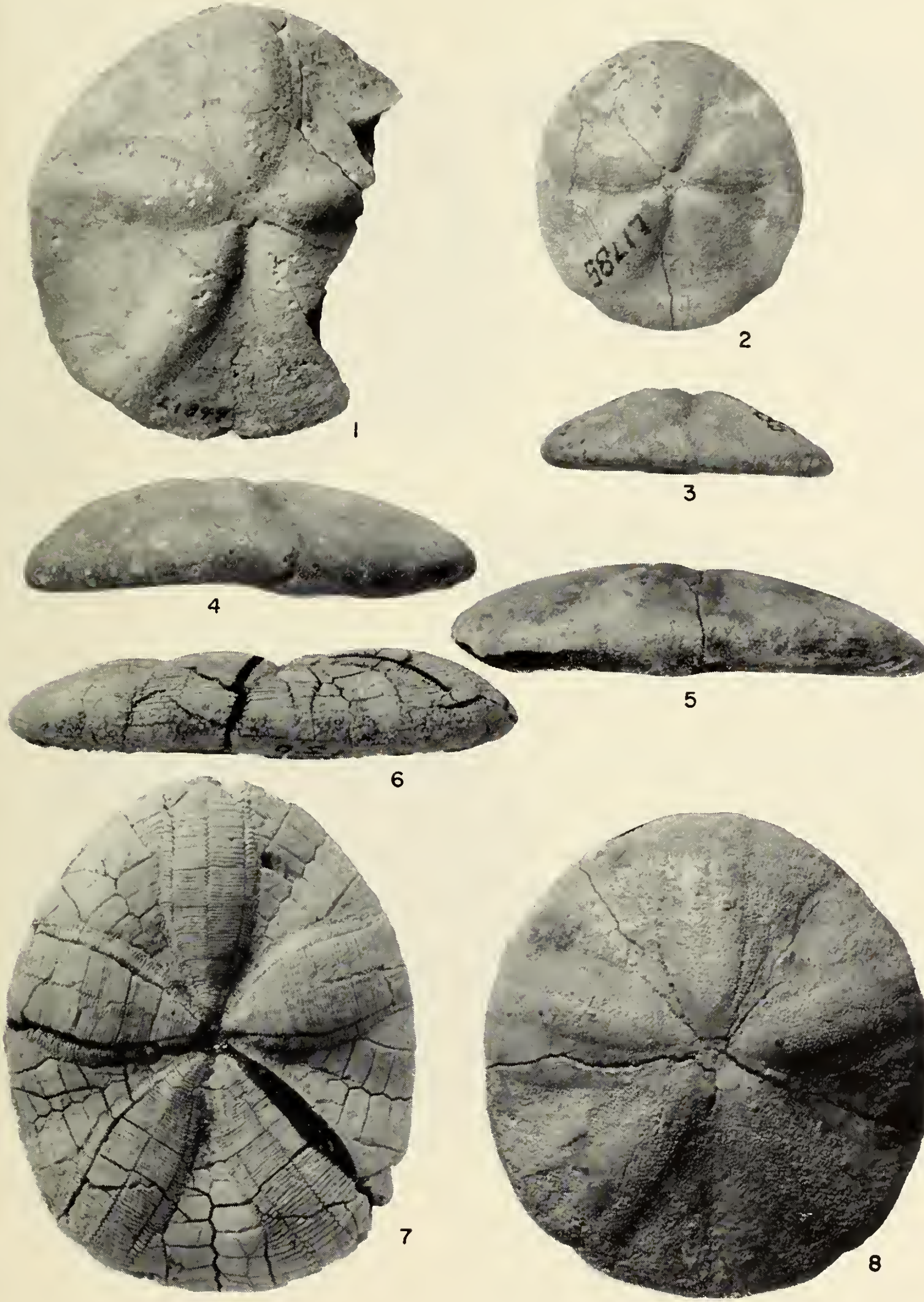
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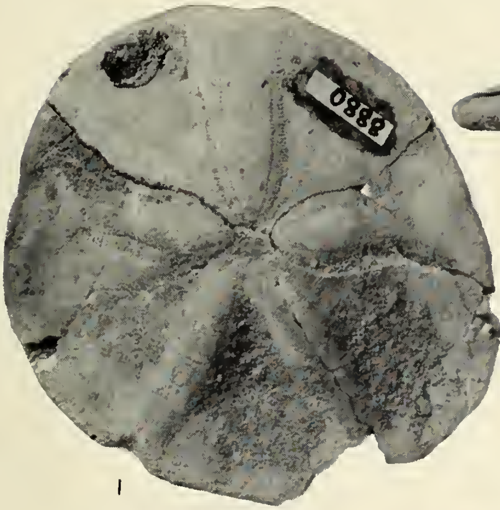
PLATE 21

Figs. 1, 2. *Astrodapsis whitneyi Rémond.* Hypotype no. 8880. UCLA loc. 1844. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 3, 4. *Astrodapsis whitneyi* Rémond. Hypotype no. 32380. UCLA loc. 4159. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.



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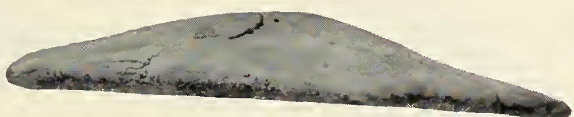

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PLATE 22

Figs. 1, 2. *Astrodapsis whitneyi* Rémond. Hypotype no. 8867. UCLA loc. 1843R. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 3, 5. *Astrodapsis whitneyi* Rémond. Hypotype no. 8881. UCLA loc. 1844. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 4, 6. *Astrodapsis whitneyi* Rémond. Hypotype no. 8882. UCLA loc. 1844. Santa Margarita formation. Lower Delmontian, Late Miocene.


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PLATE 23

Figs. 1, 2. *Astrodapsis whitneyi* Rémond. Hypotype no. 8868. UCLA loc. 1843R. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 3, 5. *Astrodapsis whitneyi* Rémond. Hypotype no. 8907. UCLA loc. 1719. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 4, 6. *Astrodapsis whitneyi* Rémond. Hypotype no. 9235. UCLA loc. 1843R. Santa Margarita formation. Lower Delmontian, Late Miocene.

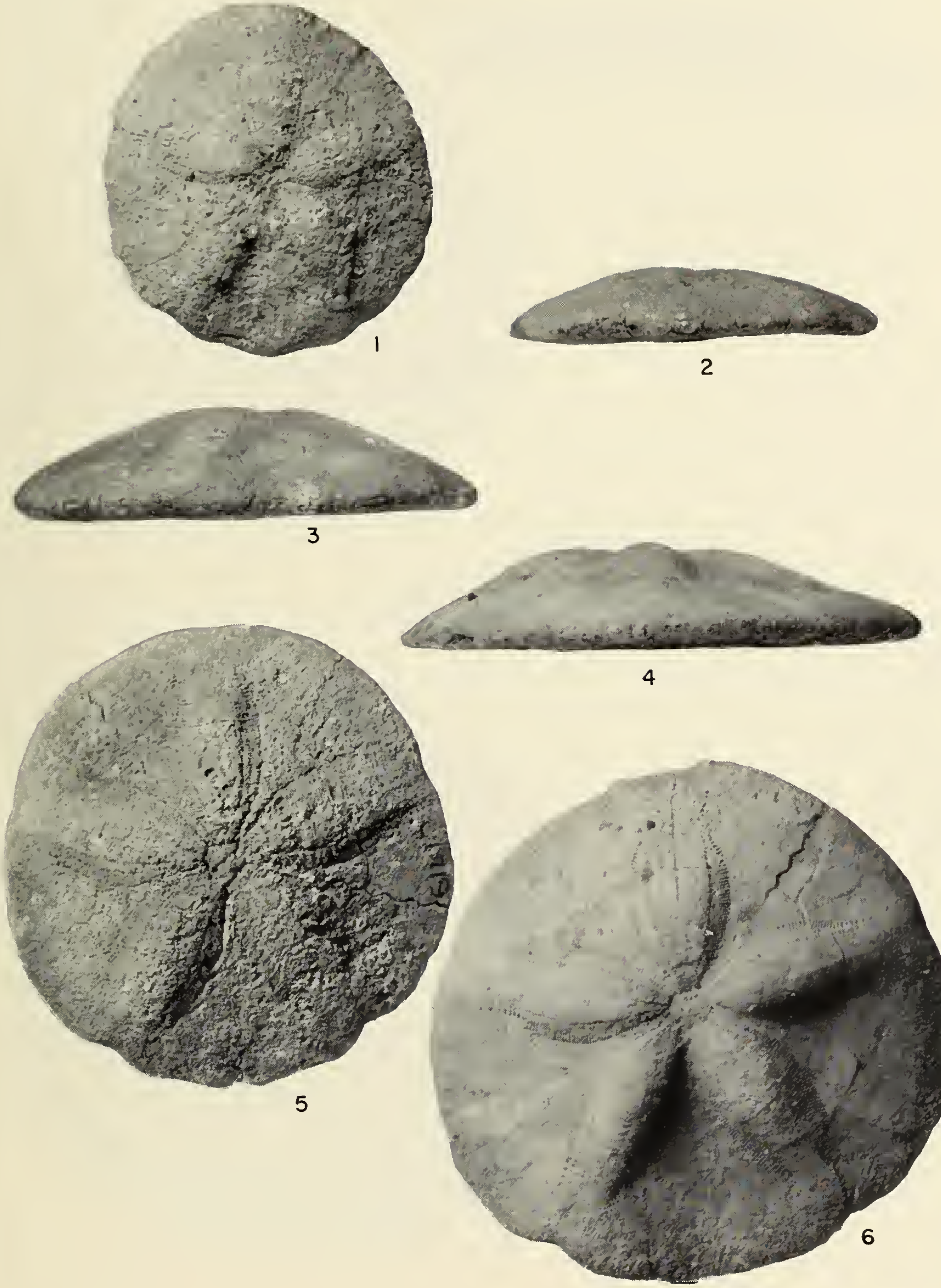
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PLATE 24

Figs. 1, 2. *Astrodapsis whitneyi* Rémond. Hypotype no. 8890. UCLA loc. 1718. (Figured by Eaton *et al.*, 1941, as *A. grandis.*) Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 3, 4. *Astrodapsis whitneyi* Rémond. Hypotype no. 8892. UCLA loc. 1718A. Santa Margarita formation. Lower Delmontian, Late Miocene.

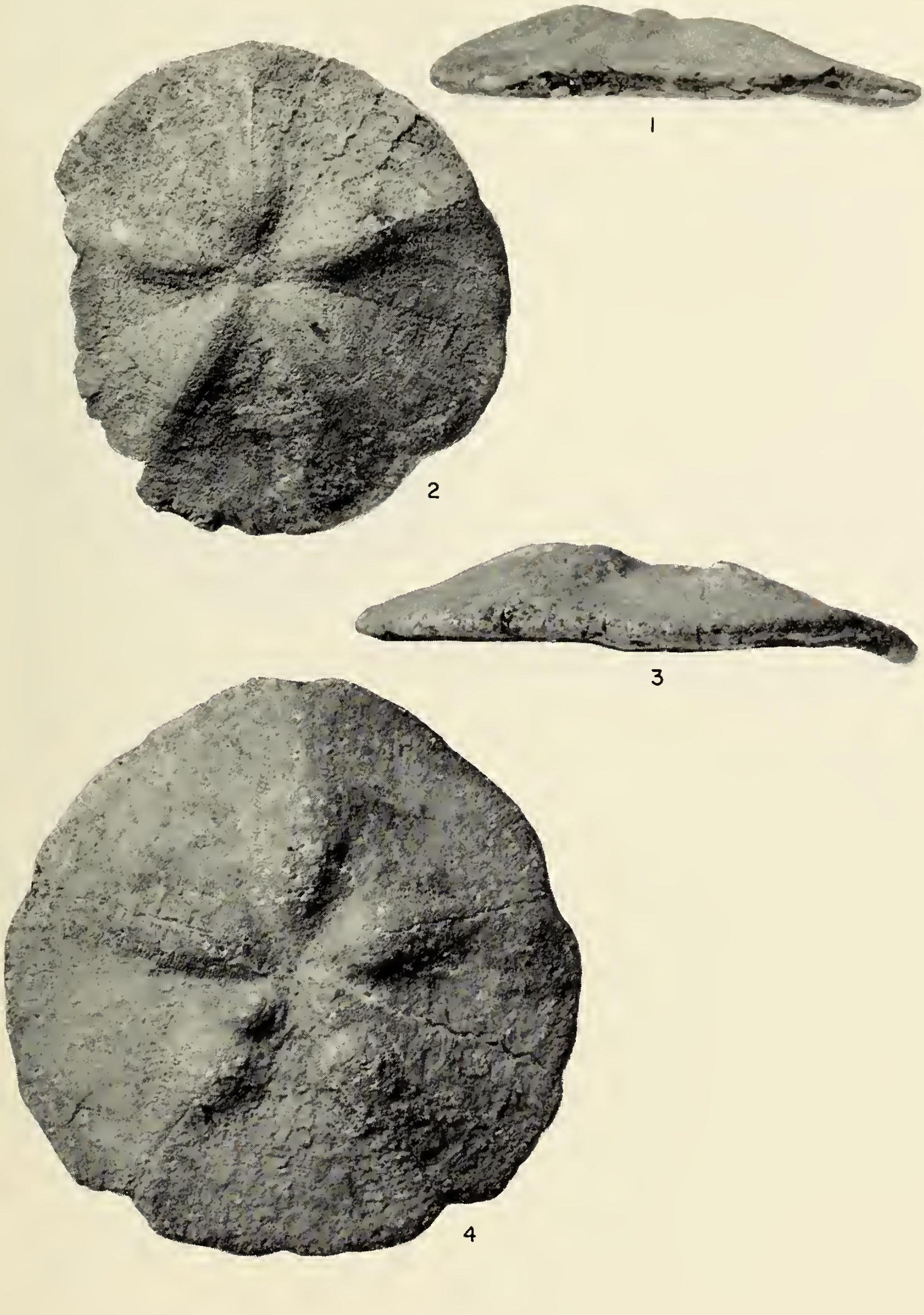
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PLATE 25

Figs. 1, 2. *Astrodapsis whitneyi* Rémond. Hypotype no. 8855. UCLA loc. 1859. (Figured by Eaton *et al.*, 1941, as a topotype of *A. cuyamanus.*) Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 3, 4. *Astrodapsis whitneyi* Rémond. Hypotype no. 8901. UCLA loc. 1888. Santa Margarita formation. Lower Delmontian, Late Miocene.

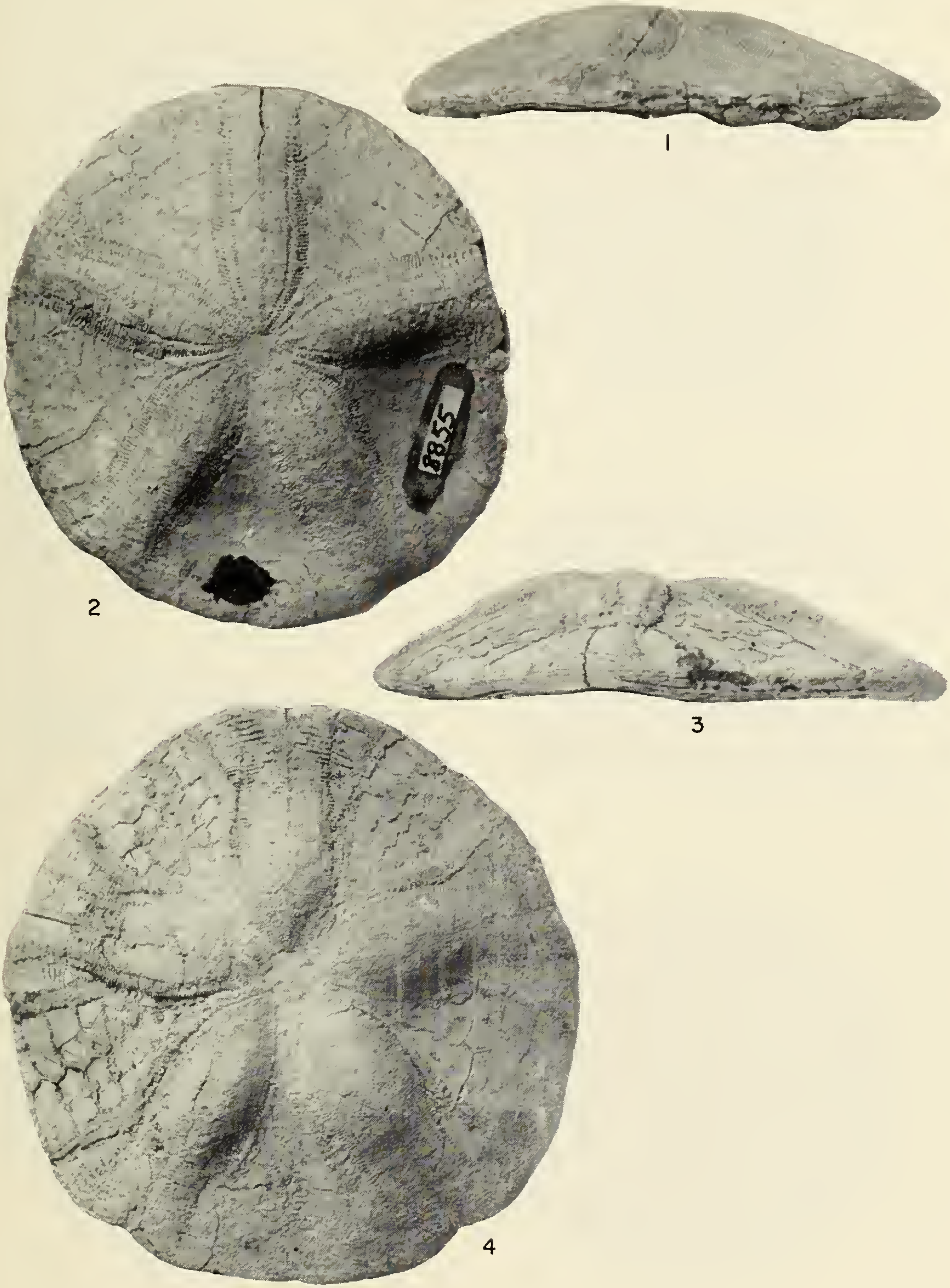
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PLATE 26

Figs. 1, 3. *Astrodapsis whitneyi* Rémond. Hypotype no. 8885. UCLA loc. 1797 (holotype of Grant and Eaton *A. laimingi*). Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 2, 4. *Astrodapsis whitneyi* Rémond. Hypotype no. 32379. UCLA loc. 1852. Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 5, 7. *Astrodapsis whitneyi* Rémond. Hypotype no. 8870. UCLA loc. 1852 (holotype of Grant and Eaton *A. woodringi*). Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 6, 8. *Astrodapsis whitneyi* Rémond. Hypotype no. 8886. UCLA loc. 1341. Santa Margarita formation. Lower Delmontian, Late Miocene.

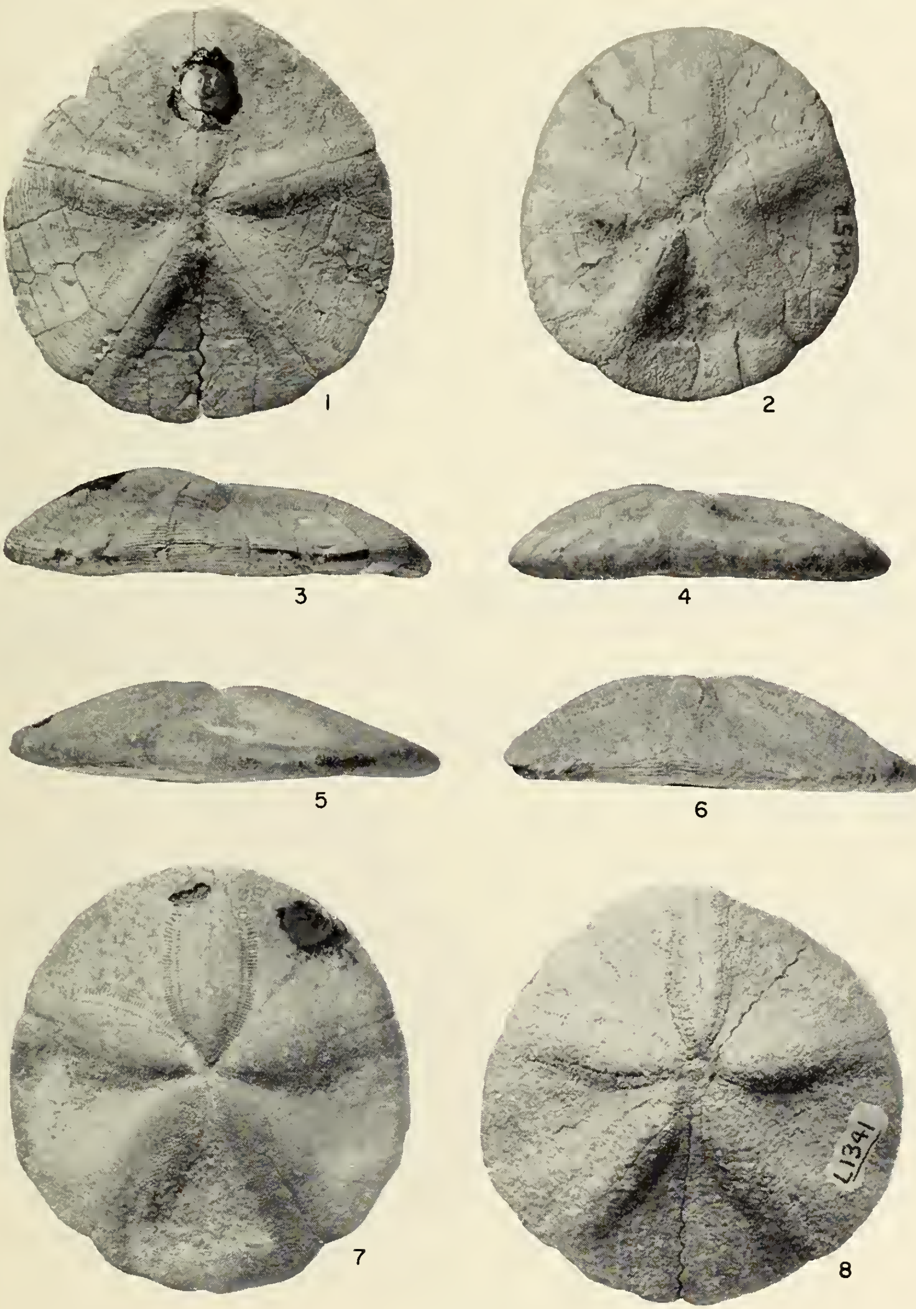
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PLATE 27

Figs. 1, 4. *Astrodapsis whitneyi* Rémond. Hypotype no. 32382. UCLA loc. 4158. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 2, 3. *Astrodapsis whitneyi* Rémond. Hypotype no. 8910. UCLA loc. 1719 (holotype of Grant and Eaton *A. hertleini*). Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 5, 6. *Astrodapsis whitneyi* Rémond. Hypotype no. 8900. UCLA loc. 1721. Santa Margarita formation. Lower Delmontian, Late Miocene.

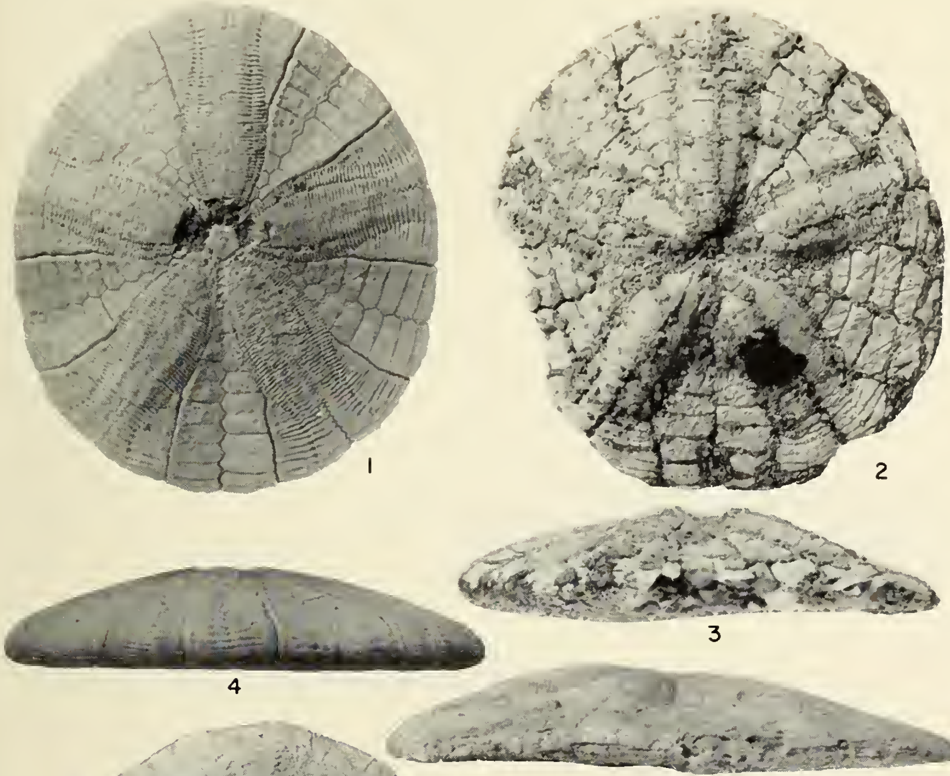
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PLATE 28

Figs. 1, 2. *Astrodapsis whitneyi* Rémond. Hypotype no. 32385. UCLA loc. 4158. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 3, 6. *Astrodapsis whitneyi* Rémond. Hypotype no. 32381. UCLA loc. 4158. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 4, 5. *Astrodapsis whitneyi* Rémond. Hypotype no. 32383. UCLA loc. 4158. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

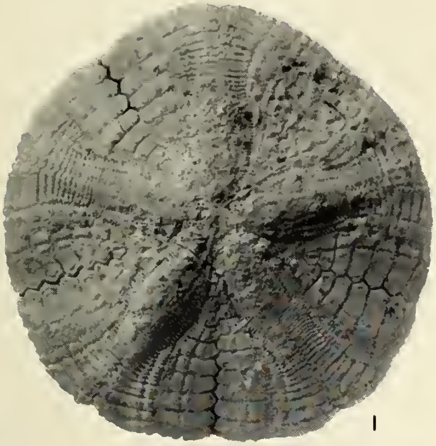

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PLATE 29

Figs. 1, 2. *Astrodapsis whitneyi* Rémond. Hypotype no. 32387. UCLA loc. 4158. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 3, 4. *Astrodapsis spatiosus* Kew. Hypotype no. 32386. UCLA loc. 4158. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

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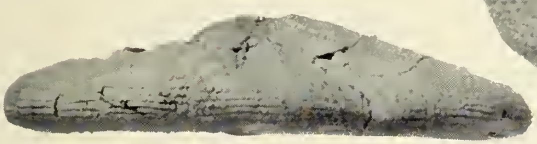

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PLATE 30

Figs. 1, 1a, 2, 2a. *Astrodapsis antiselli* Conrad. Holotype no. 13337, U. S. Nat. Mus. Cat. West bank San Juan River, San Luis Obispo Co., Calif. Santa Margarita formation. Lower Delmontian, Late Miocene. Stereo-pair.

Figs. 3, 3a, 4, 4a. *Astrodapsis spatiosus* Kew. Hypotype no. 165466a, specimen B, U. S. Nat. Mus. Cat. Two miles south of San Lucas. Pancho Rico formation. Upper Delmontian, Late Miocene. (Figured by Richards [1935] as *Astrodapsis salinasensis.*)

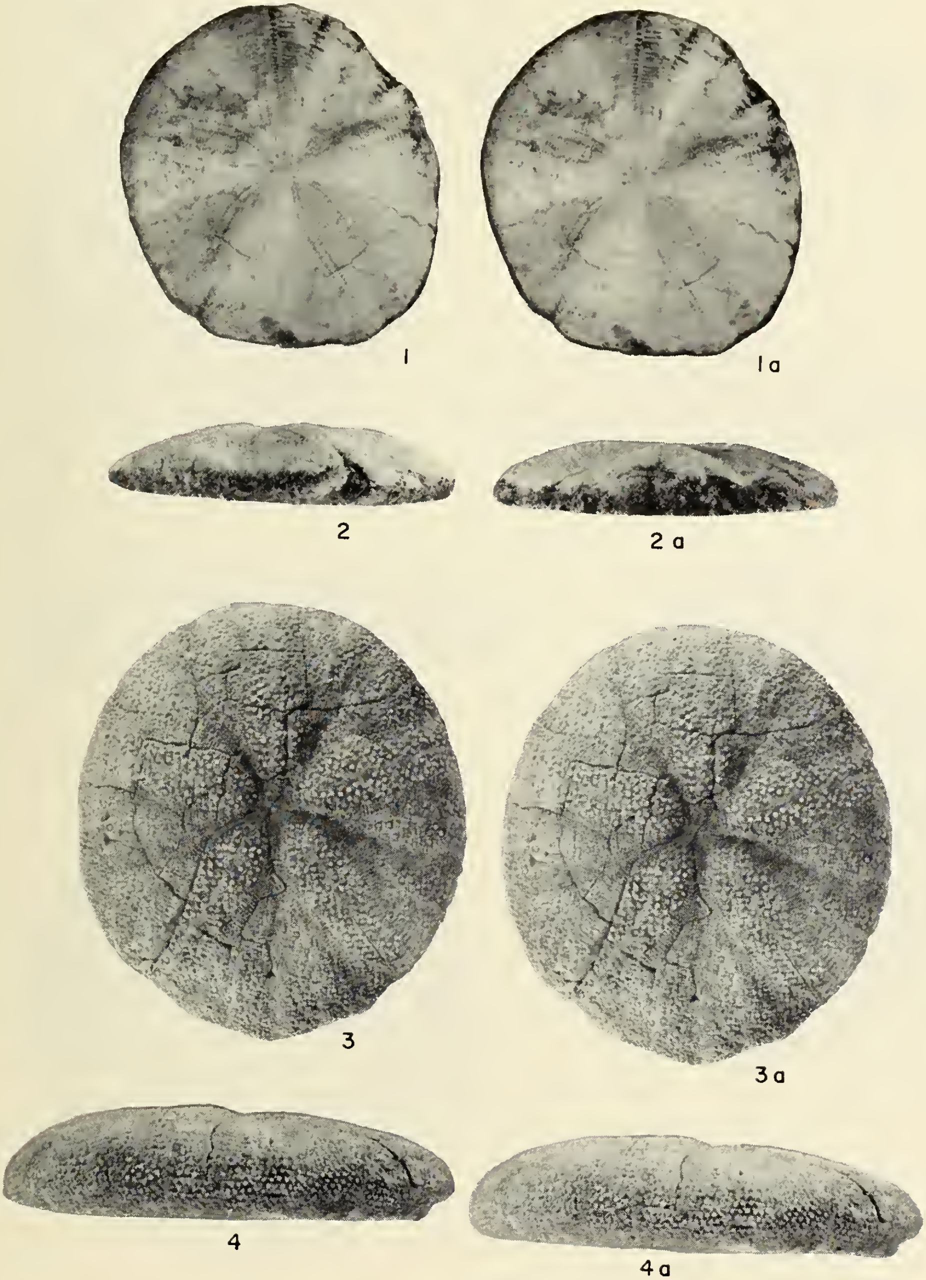
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PLATE 31

Figs. 1, 2. *Astrodapsis spatiosus* Kew. Hypotype no. 34631, Univ. Calif., Berkeley. Univ. Calif., Berkeley, loc. A 911 (this is the same locality as the holotype of *A. salinasensis* Richards). Pancho Rico formation. Upper Delmontian, Lae Miocene.

Figs. 3, 5. *Astrodapsis spatiosus* Kew. Hypotype no. 32409. UCLA loc. 4159. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 4, 6. *Astrodapsis statiosus* Kew. Hypotype no. 32407. UCLA loc. 4159. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

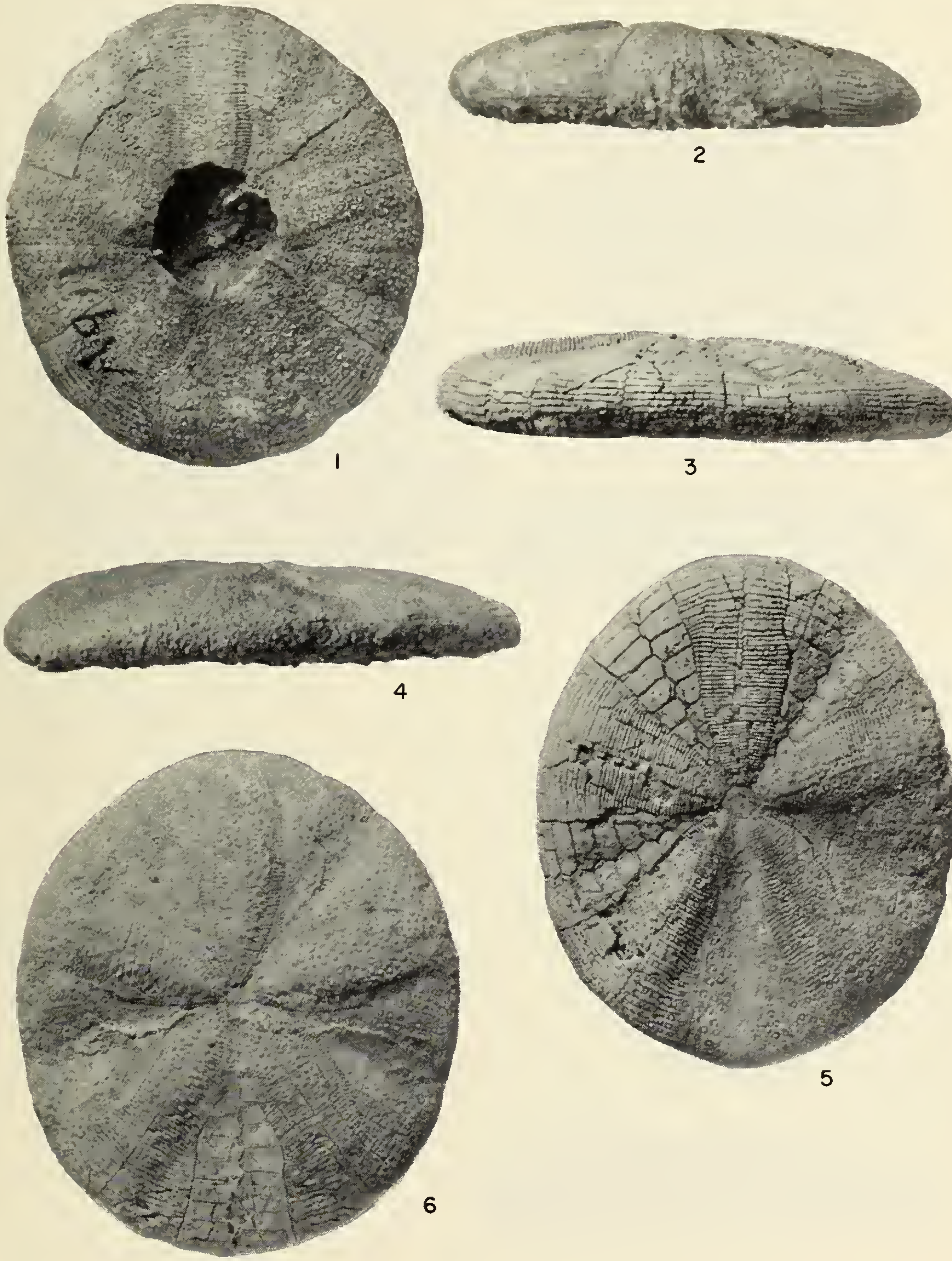

PLATE 32

Figs. 1, 3. *Astrodapsis spatiosus* Kew. Hypotype no. 32412. UCLA loc. 4158. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Fig. 2. *Astrodapsis spatiosus* Kew. Hypotype no. 32413. UCLA loc. 4158. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 4, 5. *Astrodapsis spatiosus* Kew. Hypotype no. 32411. Eight miles east of junction of U. S. 101 and 198, on Highway 198, near San Lucas, Monterey Co., Calif. Pancho Rico formation. Upper Delmontian, Late Miocene.

Figs. 6, 7. *Astrodapsis spatiosus* Kew. Hypotype no. 32414. UCLA loc. 4159. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

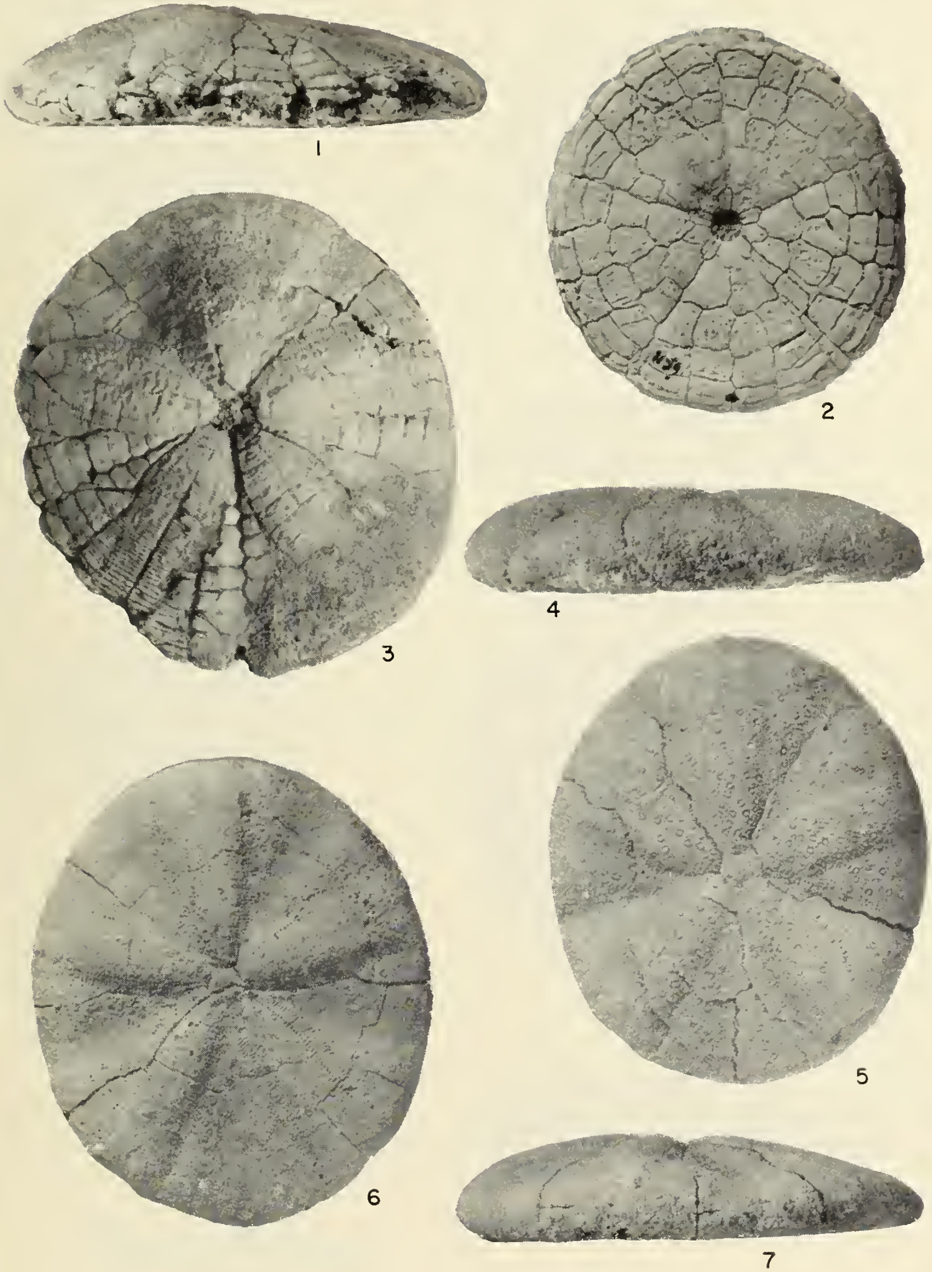
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PLATE 33

Figs. 1, 3. *Astrodapsis spatiosus* Kew. Hypotype no. 32398. Locality same as hypotype no. 32411, pl. 32, figs. 4, 5. Pancho Rico formation. Upper Delmontian, Late Miocene.

Figs. 2, 5. *Astrodapsis spatiosus* Kew. Hypotype no. 32406. UCLA loc. 4159. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 4, 6. *Astrodapsis spatiosus* Kew. Hypotype no. 32397. Locality same as hypotype no. 32411, pl. 32, figs. 4, 5. Pancho Rico formation. Upper Delmontian, Late Miocene.

Figs. 7, 9. *Astrodapsis spatiosus* Kew. Hypotype no. 32408. UCLA loc. 4159. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 8, 10. *Astrodapsis fernandoensis* Pack. Hypotype no. 32410. UCLA loc. 4320. Lower "Pico" or Elsmere member of Repetto formation. Lowermost Pliocene.

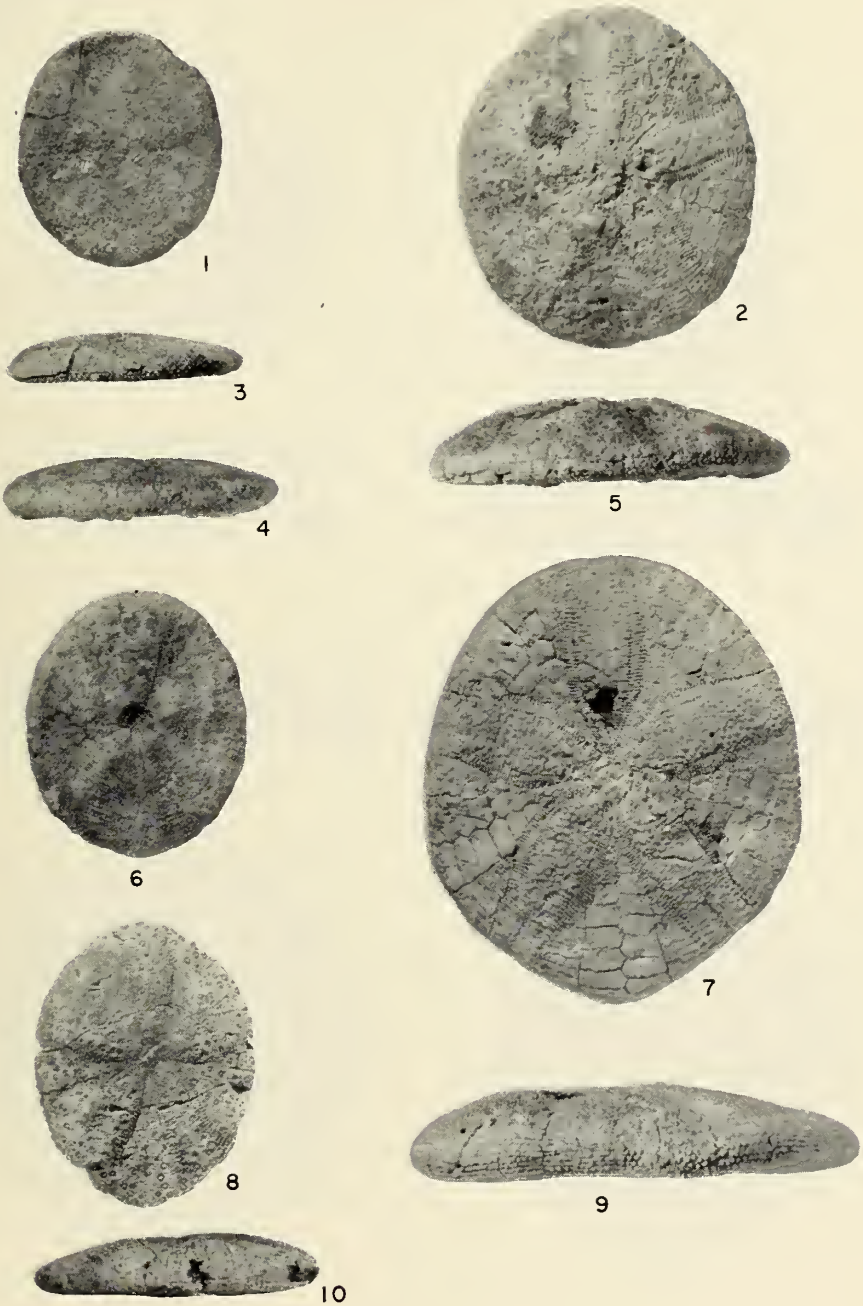
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PLATE 34

Figs. 1, 3. *Astrodapsis spatiosus* Kew. Hypotype no. 32390. UCLA loc. 4156. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 2, 4. *Astrodapsis spatiosus* Kew. Hypotype no. 32393. UCLA loc. 4159. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 5, 7. *Astrodapsis spatiosus* Kew. Hypotype no. 32399. Pancho Rico Canyon, near San Ardo, Monterey Co., Calif., Pancho Rico formation. Upper Delmontion, Late Miocene.

Figs. 6, 8. *Astrodapsis spatiosus* Kew. Hypotype no. 32395. UCLA loc. 4159. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

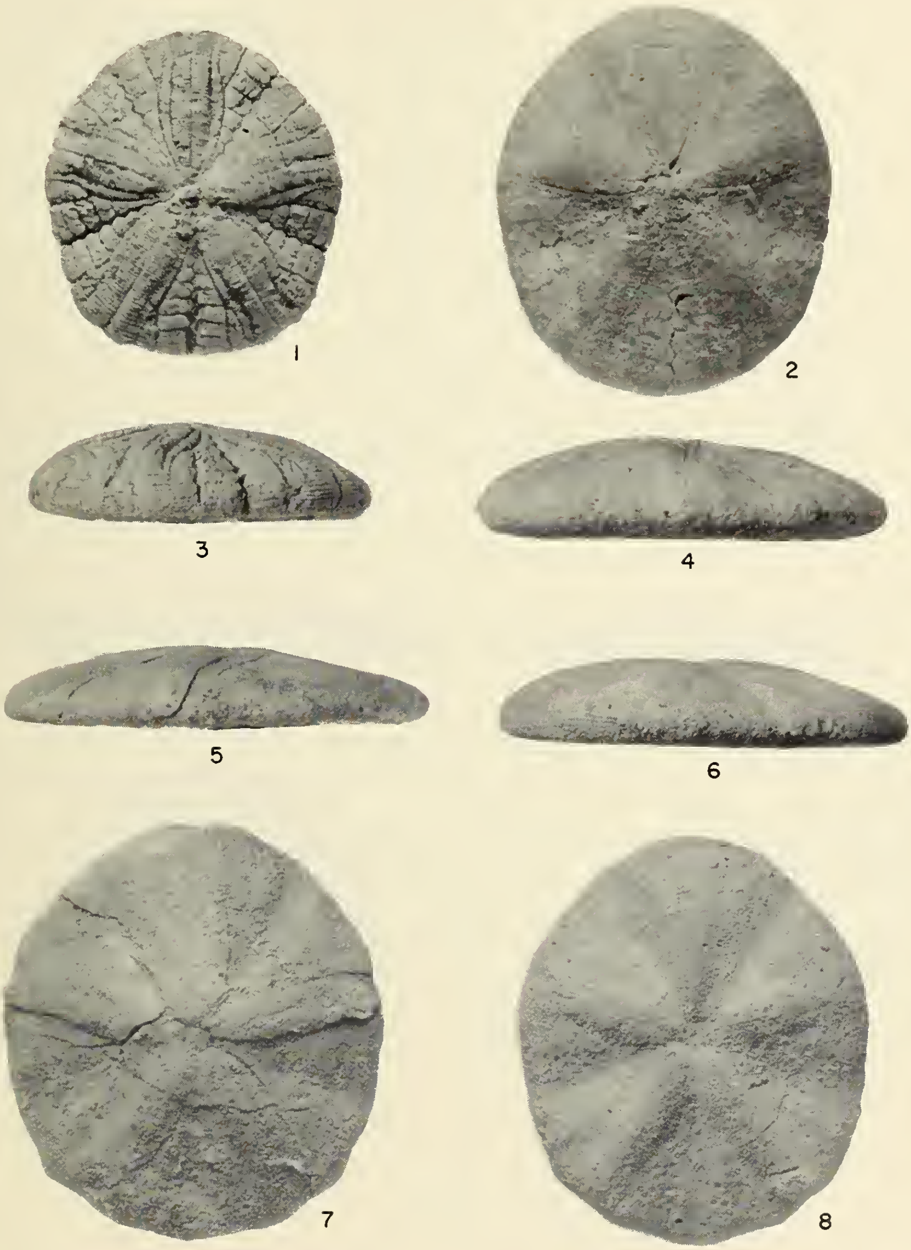
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PLATE 35

Figs. 1, 3. *Astrodapsis spatiosus* Kew. Hypotype no. 9471. UCLA loc. 1647. Santa Margarita formation (Pismo formation). Upper Delmontian, Late Miocene.

Figs. 2, 4. *Astrodapsis spatiosus* Kew. Hypotype no. 9473. UCLA loc. 1647. Santa Margarita formation (San Luis Obispo Co.). Upper Delmontian, Late Miocene.

Figs. 5, 7. *Astrodapsis spatiosus* Kew. Hypotype no. 32415. UCLA loc. 2182. Santa Margarita formation (Santa Cruz Co.). Upper Delmontian, Late Miocene.

Figs. 6, 8. *Astrodapsis spatiosus* Kew. Hypotype no. 9470. UCLA loc. 1647. Santa Margarita formation. Upper Delmontian, Late Miocene.


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PLATE 36

Figs. 1, 4. *Astrodapsis spatiosus* Kew. Hypotype no. 9480. UCLA loc. 1647. Santa Margarita formation (Pismo formation), San Luis Obispo Co. Upper Delmontian, Late Miocene.

Figs. 2, 5. *Astrodapsis spatiosus* Kew. Hypotype no. 32394. UCLA loc. 4156. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

Figs. 3, 6. *Astrodapsis spatiosus* Kew. Hypotype no. 9482. UCLA loc. 1218. Submember 5, Phoenix member, Santa Margarita formation. Lower Delmontian, Late Miocene.

Figs. 7, 9. *Astrodapsis spatiosus* Kew. Hypotype no. 32391. UCLA loc. 2182. Santa Margarita formation (Santa Cruz Co.). Upper Delmontian, Late Miocene.

Figs. 8, 10. *Astrodapsis spatiosus* Kew. Hypotype no. 32392. UCLA loc. 4156. Submember 2, Saucelito member, Santa Margarita formation. Upper Delmontian, Late Miocene.

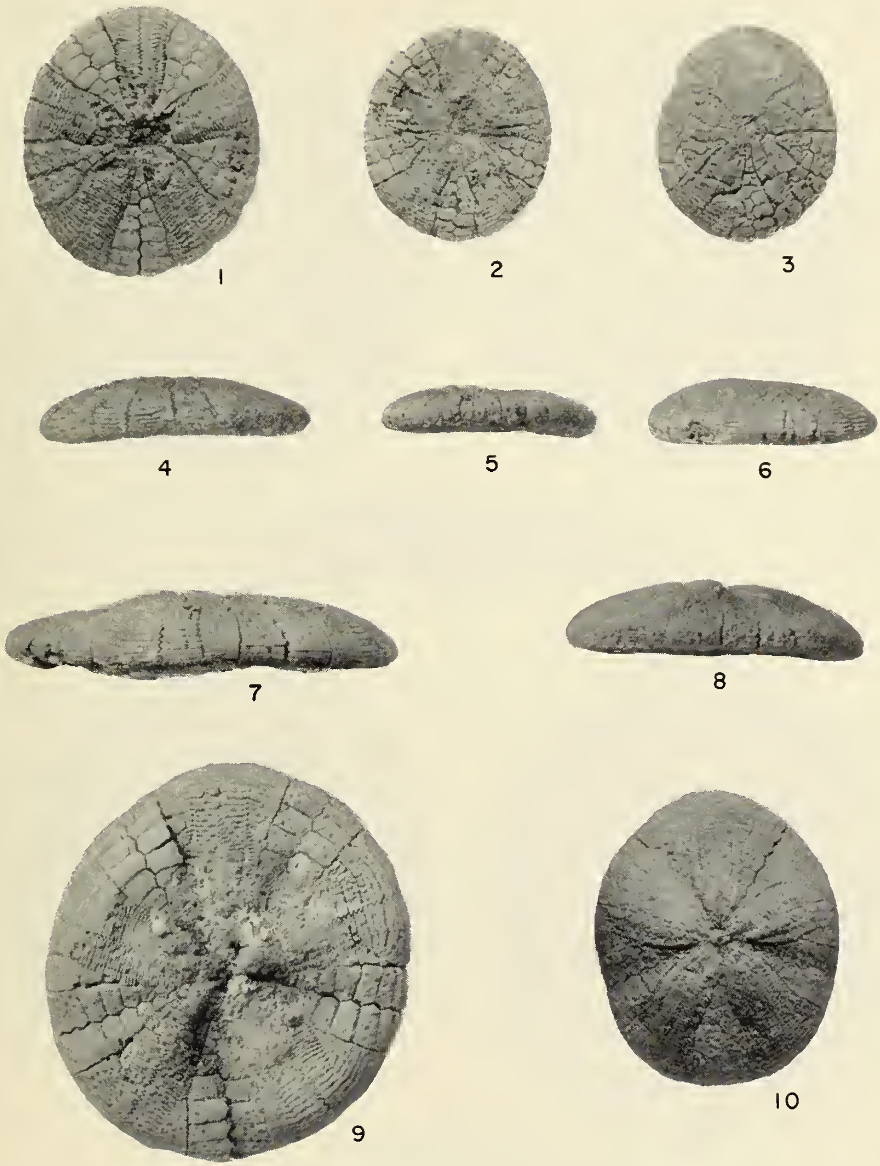
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PLATE 37

Figs. 1, 1a, 2. *Astrodapsis arnoldi* Pack. Hypotype no. 32404. UCLA loc. 2586. Pancho Rico formation. Upper Delmontian, Late Miocene. Stereo-pair.

Figs. 3, 3a, 4. *Astrodapsis arnoldi* Pack. Hypotype no. 32400. UCLA loc. 2586. Pancho Rico formation. Upper Delmontian, Late Miocene. Stereo-pair.

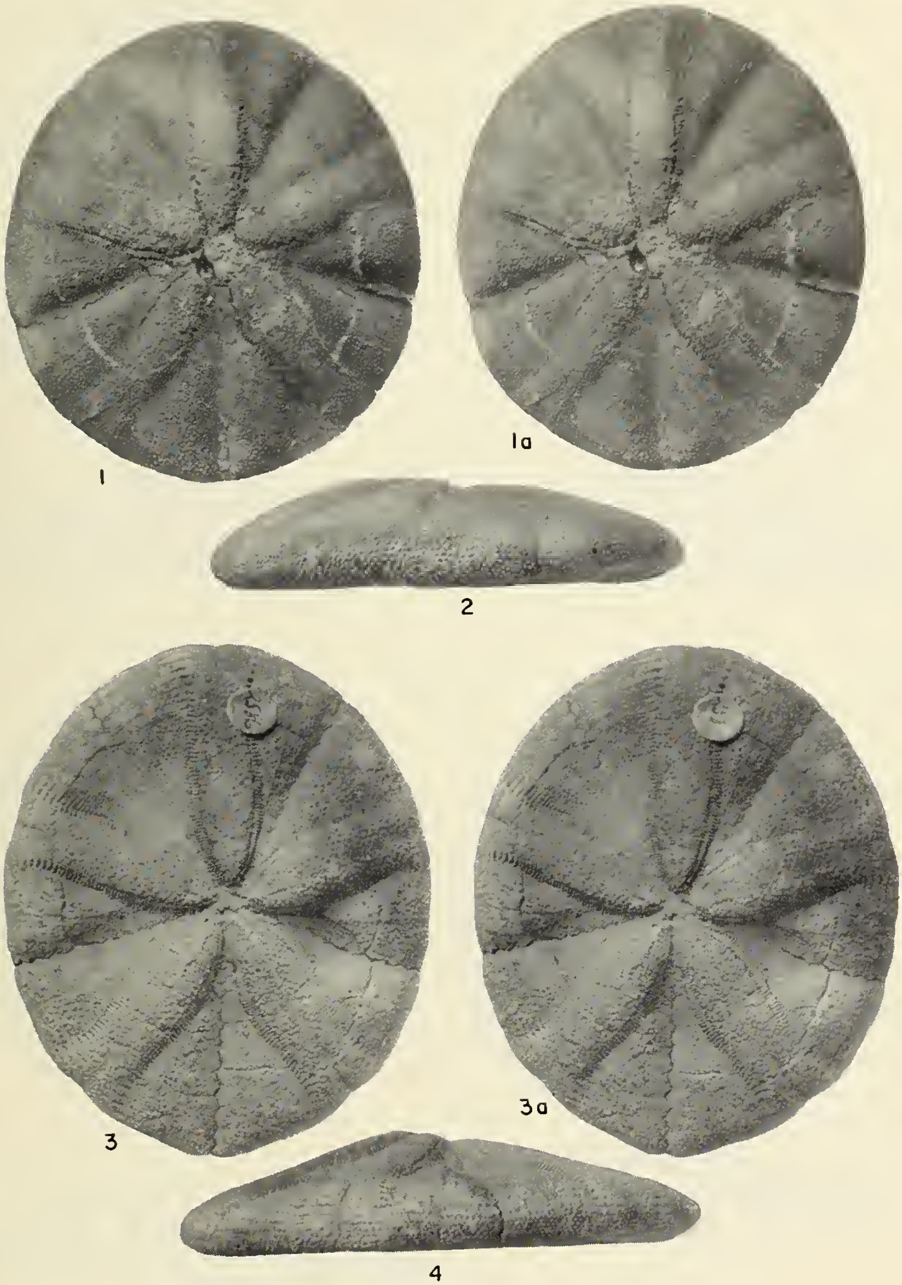
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PLATE 38

Figs. 1, 3. *Astrodapsis arnoldi* Pack. Hypotype no. 8552, Stanford Univ. Paleo. Type Coll. Stanford Univ. loc. C 1014, Indian Valley, Monterey Co. Pancho Rico formation. Upper Delmontian, Late Miocene.

Figs. 2, 4. *Astrodapsis arnoldi* Pack. Hypotype no. 34632, Univ. Calif., Berkeley. Univ. Calif., Berkeley, loc. 3242, northwest corner of NW¼ sec. 6, T.21S., R.12E., 1937 ed. Priest Valley Quad. Jacalitos formation. Uppermost Miocene.

Figs. 5, 7. *Astrodapsis arnoldi* Pack. Hypotype no. 32401. UCLA loc. 2586. Pancho Rico formation. Upper Delmontian, Late Miocene.

Figs. 6, 8. *Astrodapsis arnoldi* Pack. Hypotype no. 34633, Univ. Calif., Berkeley. Locality same as Figs. 2, 4, above. Jacalitos formation. Uppermost Miocene.

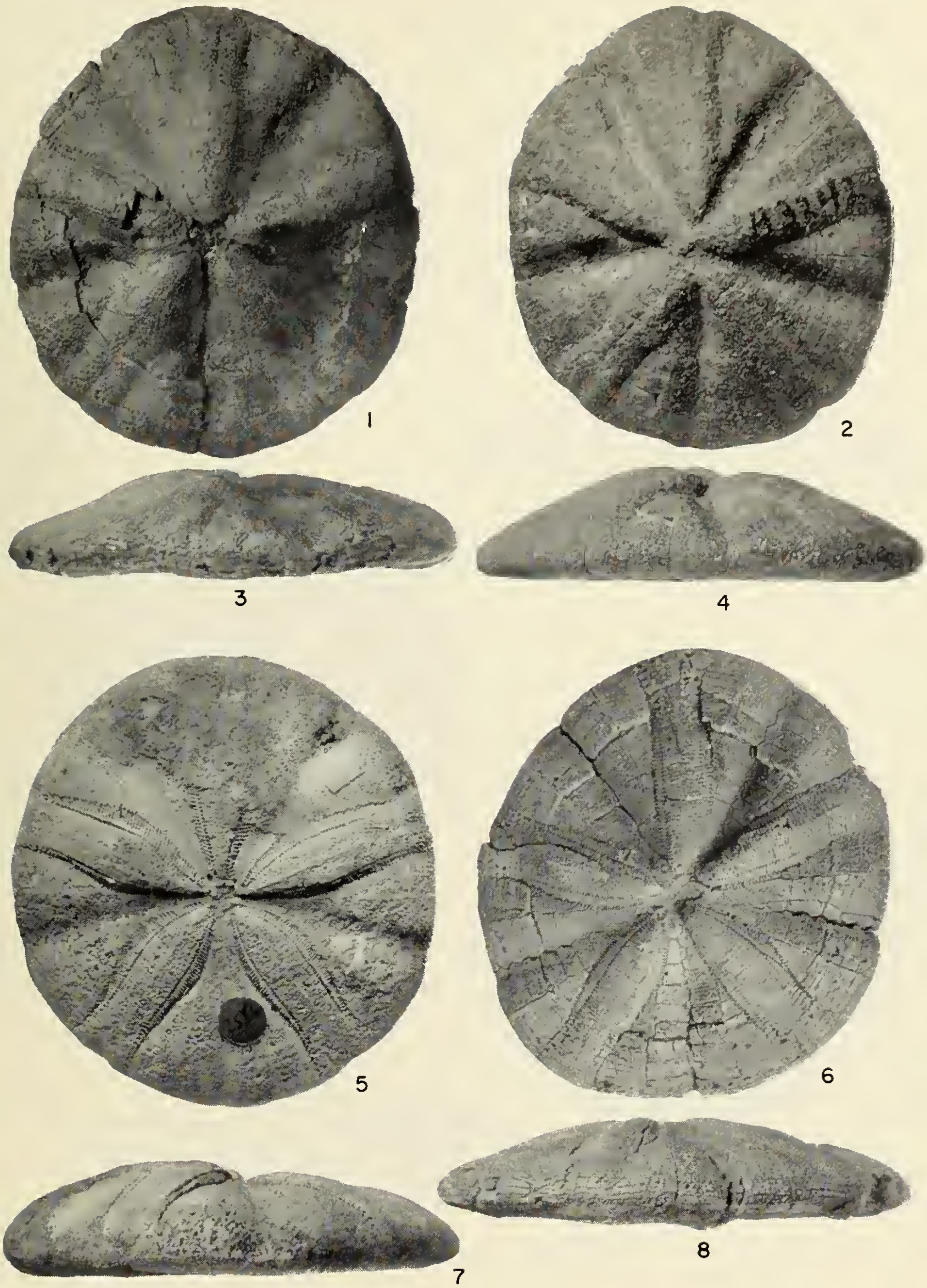
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PLATE 39

Figs. 1, 2. *Astrodapsis arnoldi* Pack. Hypotype no. 32403. UCLA loc. 2586. Pancho Rico formation. Upper Delmontian, Late Miocene.

Figs. 3, 4. *Astrodapsis arnoldi* Pack. Hypotype no. 32402. UCLA loc. 2586. Pancho Rico formation. Upper Delmontian, Late Miocene.

Figs. 5, 6. *Astrodapsis arnoldi* Pack. Hypotype no. 32405. UCLA loc. 2586. Pancho Rico formation. Upper Delmontian, Late Miocene.

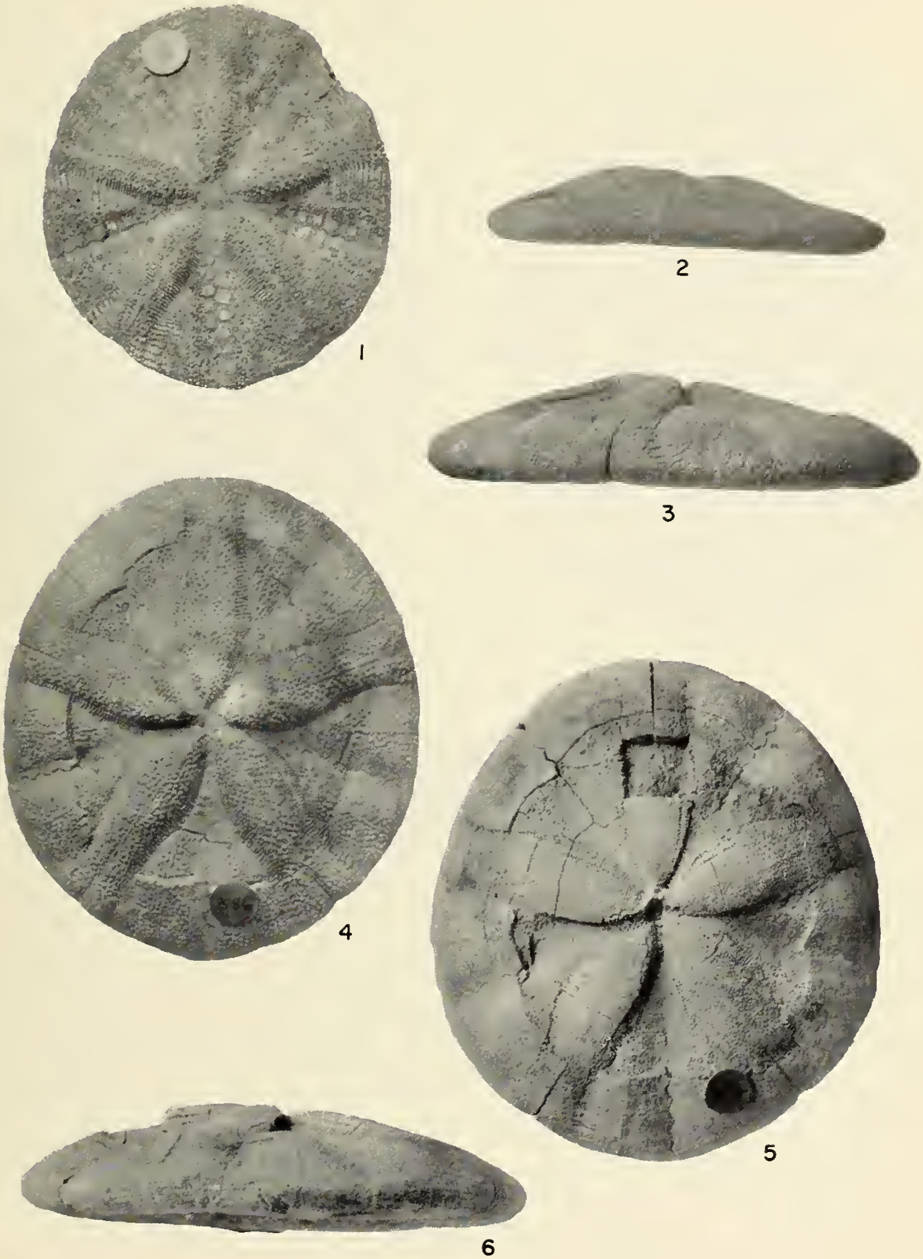
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PLATE 40

Figs. 1, 1a, 2. *Astrodapsis peltoides* Anderson and Martin. Neotype no. 6815A. UCLA loc. 2181. Jacalitos formation. Lowermost Pliocene. Stereo-pair.

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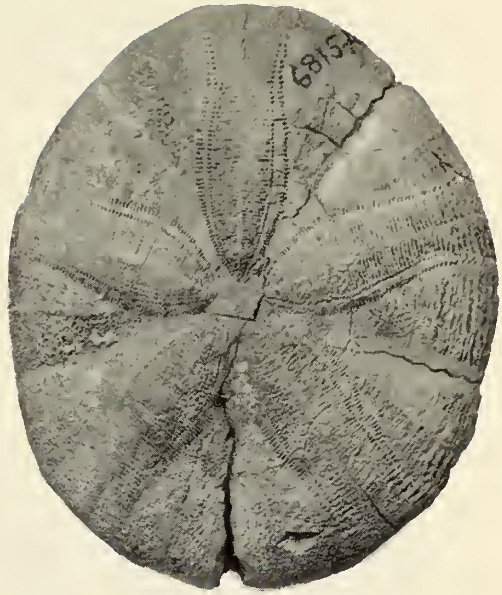

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PLATE 41

Figs. 1, 2. *Astrodapsis peltoides* Anderson and Martin. Hypotype no. 9495. UCLA loc. 1821 (near 2181). Jacalitos formation. Lowermost Pliocene.

Figs. 3, 4. *Astrodapsis peltoides* Anderson and Martin. Hypotype no. 6815B. UCLA loc. 2181. Jacalitos formation. Lowermost Pliocene.

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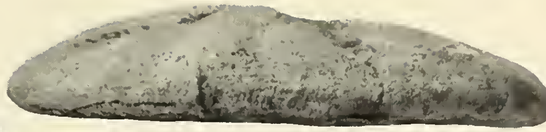

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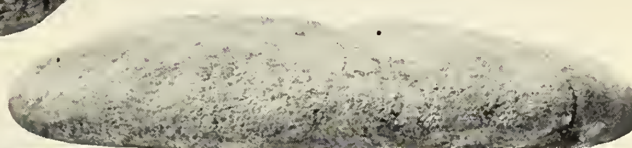

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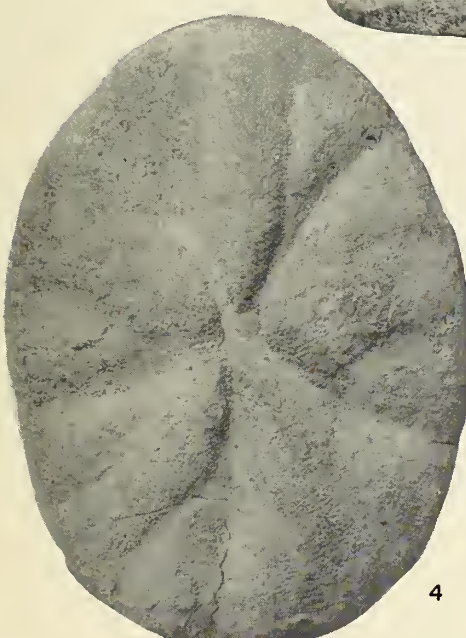

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PLATE 42

Figs. 1, 2. *Astrodapsis jacalitosensis* Arnold. Hypotype no. 8401. UCLA loc. 1776. Upper Santa Margarita formation. Lowermost Pliocene.

Figs. 3, 5. *Astrodapsis jacalitosensis* Arnold. Hypotype no. 34629, Univ. Calif., Berkeley. Univ. Calif., Berkeley, loc. A-3048. Jacalitos formation. Lowermost Pliocene.

Fig. 4. *Astrodapsis jacalitosensis* Arnold. Holotype no. 165610, U. S. Nat. Mus. Cat. U.S.G.S. loc. 4745. Jacalitos formation. Lowermost Pliocene. Photographic reproduction of fig. 5, pl. 15, Arnold (1909).

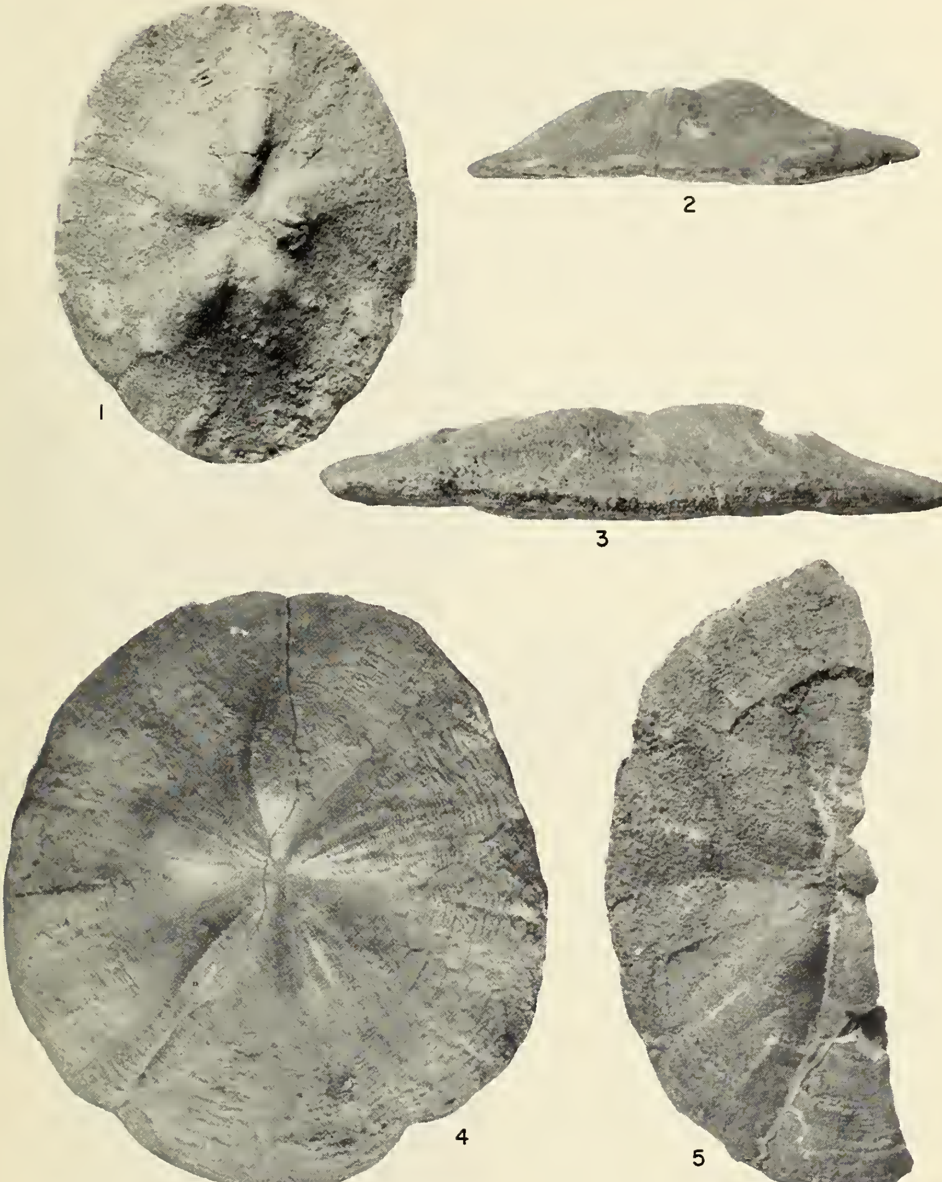
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PLATE 43

Figs. 1, 2. *Astrodapsis jacalitosensis* Arnold. Hypotype no. 8929. UCLA loc. 1776 (paratype of Grant and Eaton *A. schencki mirandaensis*). Upper Santa Margarita formation. Lowermost Pliocene.

Figs. 3, 4. *Astrodapsis jacalitosensis* Arnold. Hypotype no. 8932. UCLA loc. 1781. Upper Santa Margarita formation. Lowermost Pliocene.

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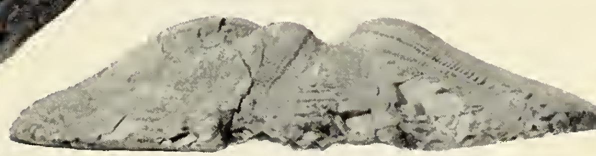

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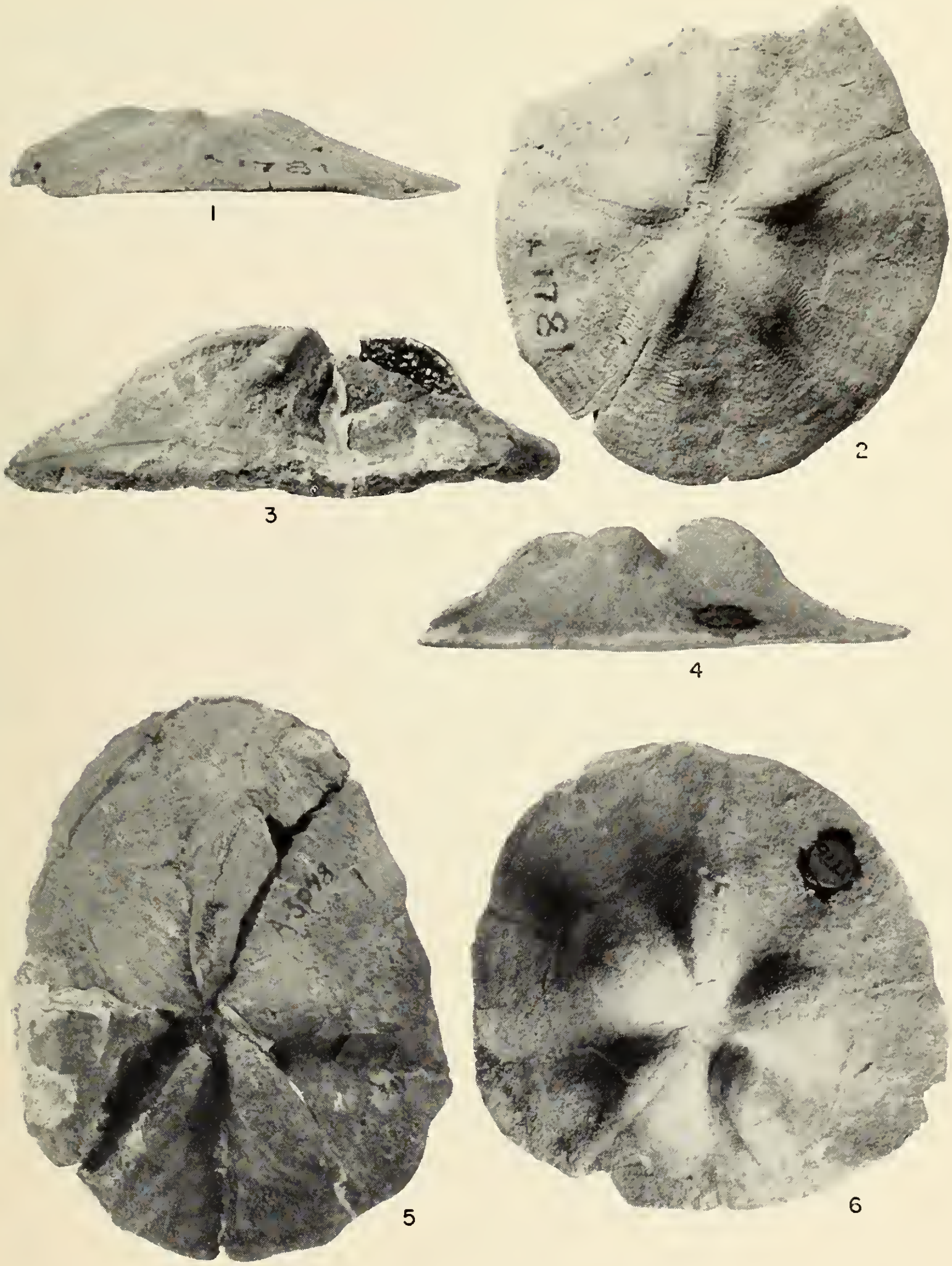
PLATE 44

Figs. 1, 2. *Astrodapsis jacalitosensis* Arnold. Hypotype no. 8928. UCLA loc. 1781. Upper Santa Margarita formation. Lowermost Pliocene.

Figs. 3, 5. *Astrodapsis jacalitosensis* Arnold. Hypotype no. 34630, Univ. Calif., Berkeley. Univ. Calif., Berkeley, loc A-3048. Jacalitos formation. Lowermost Pliocene.

Figs. 4, 6. *Astrodapsis jacalitosensis* Arnold. Hypotype no. 8925. UCLA loc. 1776 (holotype of Grant and Eaton *A. schencki mirandaensis*). Upper Santa Margarita formation. Lowermost Pliocene.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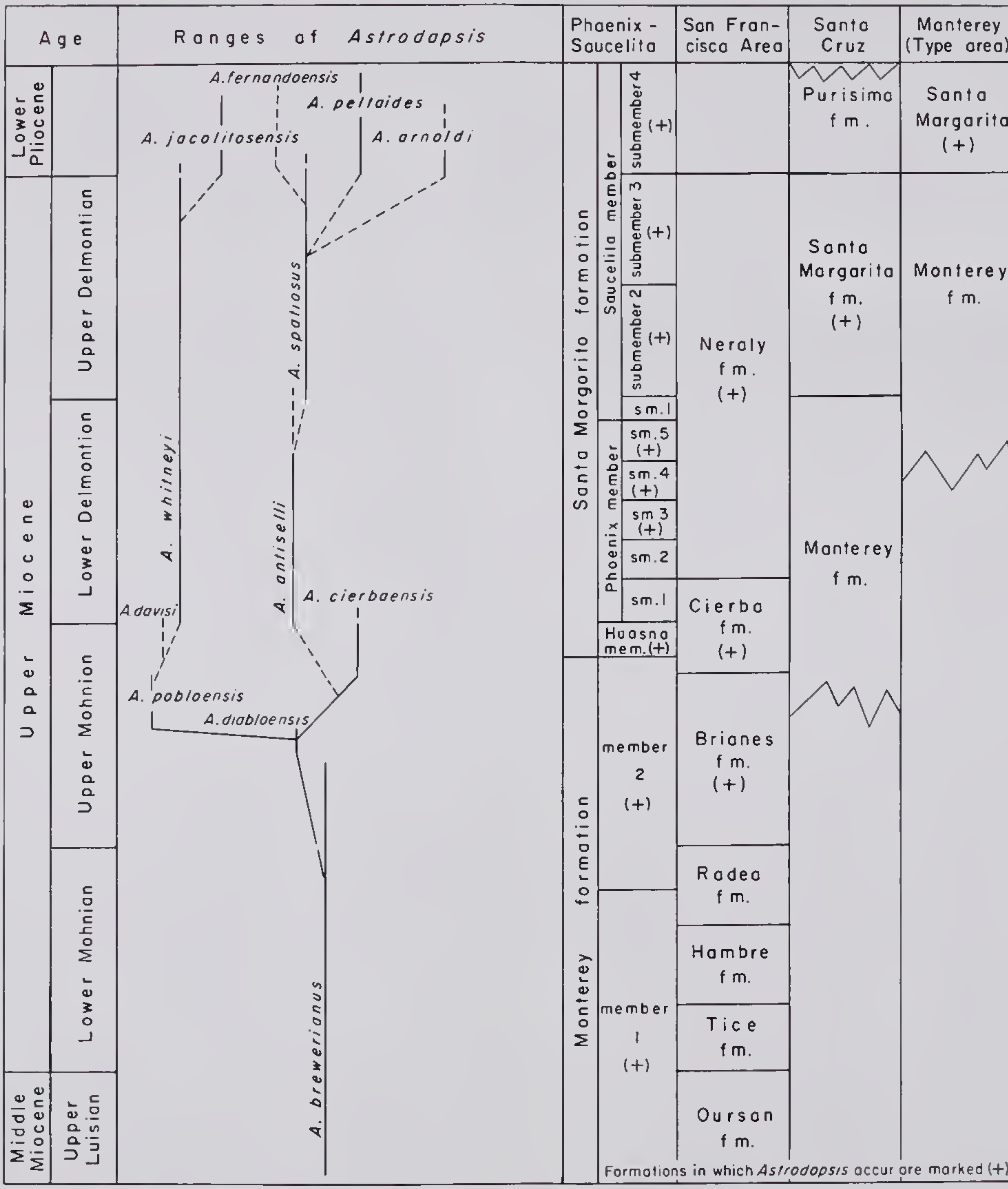
GEOLOGIC MAP AND STRUCTURE SECTION OF THE PHOENIX-SAUCELITO CREEKS AREA, SAN LUIS OBISPO CO., CALIF.

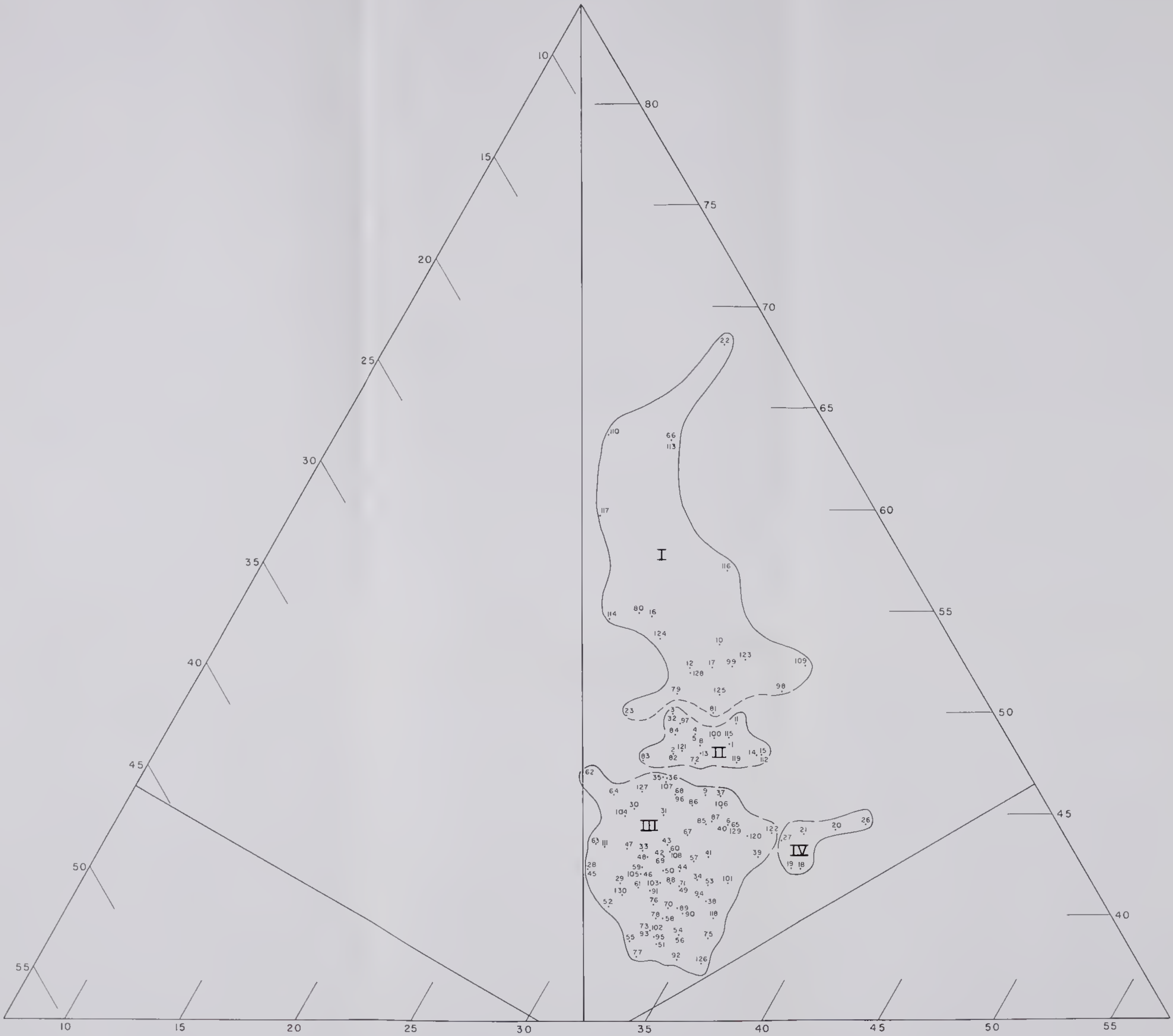
To accompany Clarence A. Hall, Jr., "Evolution of the Echinoid Genus Astrodapsis," Univ. Calif. Publ. Geol. Sci., Vol. 40, No. 2

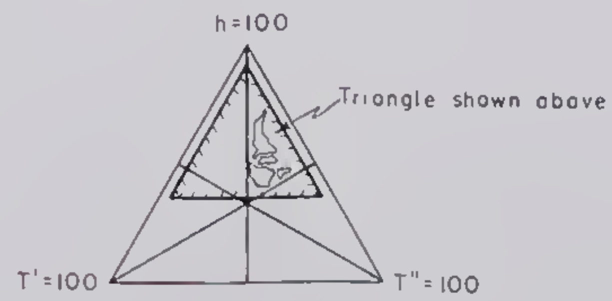
Map 1. Geologic map and structure section of the Phoenix-Saucelito creeks area, San Luis Obispo County, Calif.



To accompany Clarence A. Hall, Jr., "Evolution of the Echinoid Genus *Astrodapsis*," Univ. Calif. Publ. Geol. Sci., Vol. 40, No 2.

Fig. 5. Geologic occurrence of *Astrodapsis*.





Index to triangular graph from which the above part is extracted.

h = maximum height or thickness of the test

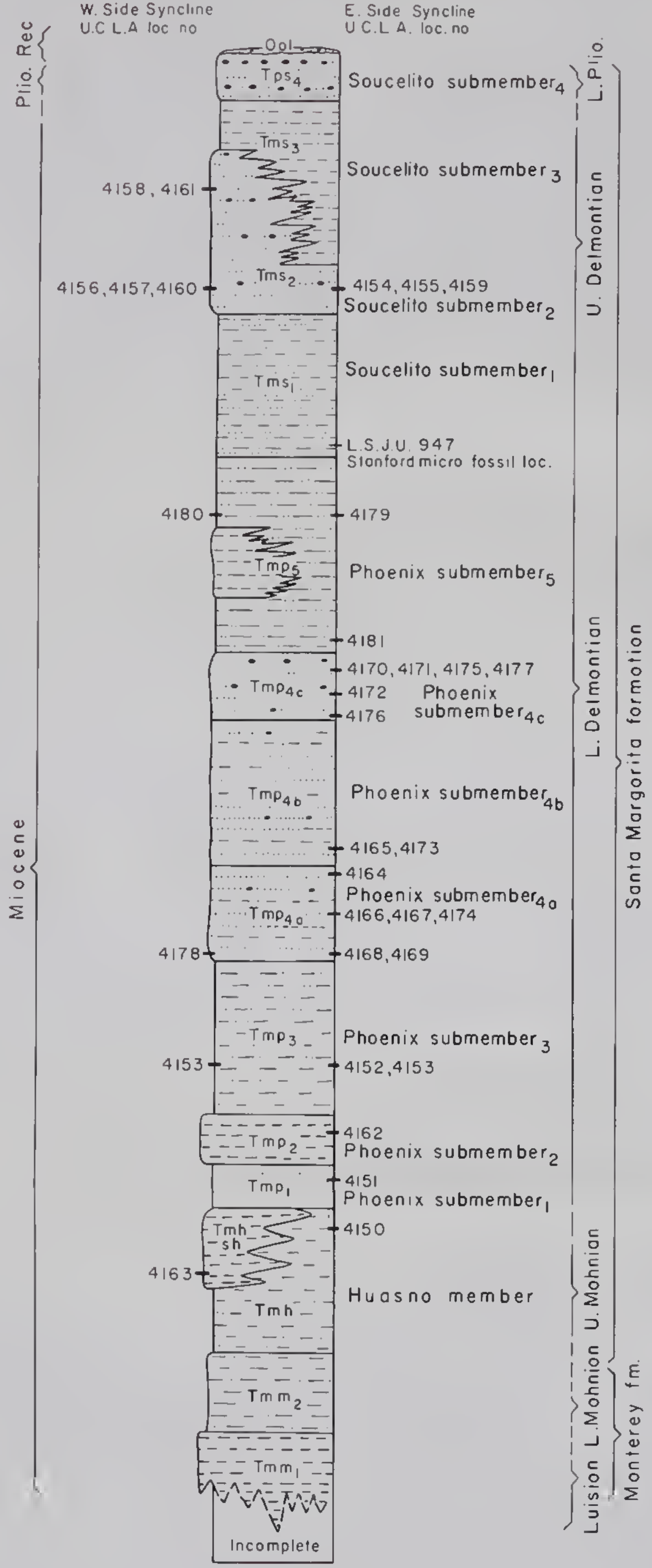
T'= thickness of test measured at the posterior interambulacral area, three aboral interambulacral plates from the margin.

T"= thickness of the test measured at the central anterior ambulacral area. This measurement is made parallel with third aboral interambulacral plate from the margin.

The numbers refer to specimens, the specific names being given in Appendices A and B

To accompany Clarence A. Hall, Jr., "Evolution of the Echinoid Genus *Astrodapsis*," Univ. Calif. Publ. Geol. Sci., Vol. 40, No. 7

Fig. 2. Triangular graph of the ratios of h/S, T'/S, and T"/S, where S = h + T' + T", using approximately a hundred specimens of *Astrodapsis*.



Tps4 – Coarse-grained sandstone. Commonly pebbly light gray or brown slightly resistant arkosic wacke and arenite. Poorly bedded becomes silty near base. Subangular grains. Dark chert pebbles. Unfossiliferous here, fossiliferous to south where *Patinopecten lohri* Hertlein, *Dendraster gibbsii* Rémond etc. occur.

Tms3 – Fine-grained sandstone and siltstone. Weathering whitish gray, tan when fresh, silty arkosic wacke. Poorly bedded. Few pebbles. Some calcareous layers.

Tms2 – Medium- to coarse-grained sandstone. White cliff-forming massive poorly bedded calcareous arkosic arenite. Some dark chert pebbles. Poorly sorted, alternating beds of medium- or fine- and coarse-grained sandstone. White or gray when fresh.

Tms1 – Siltstone or silty sandstone. Whitish-gray massive, poorly consolidated and easily eroded arkosic wacke and siltstone.

Tmp5 – Sandy siltstone or fine-grained sandstone. Light gray or buff on weathered surfaces, generally gray when fresh. Fossils locally abundant. Locally, hard yellowish siliceous angular fracturing poorly bedded mudstone commonly containing abundant casts of *Lucinoma acutilineata* (Conrad).

Tmp4 – Medium- to coarse-grained sandstone and some siltstone. White or gray weathering massively bedded arkosic sandstone, gray when fresh, interbedded with buff to gray siltstone. Sandstone is calcareous, siltstone is not. Brittle stars abundant near top on east limb of syncline. Tmp4c is not richly fossiliferous, whereas Tmp4b contains abundant *Ostrea* and *Astrodapsis*, and Tmp4a contains abundant oysters. These submembers are separable on the relative abundance of fossils, using fossils as rock constituents. Other beds can be mapped, *i.e.* each bed of coarse-grained sandstone and each intervening bed of siltstone. Locally chert pebbles are abundant to rare in the coarse-grained sandstone. Massive cross-bedding near base.

Tmp3 – Silty sandstone and siltstone. White to buff massively-bedded siltstone locally containing a few *Pecten discus* Conrad.

Tmp2 – Siliceous mudstone. Resistant opaline, porcelaneous, or siliceous mudstone and some shale almost everywhere containing abundant casts of *Pecten discus*. On the west limb of the Huasno syncline there is a fine- to medium-grained quartz or feldspathic arenite also containing abundant *Pecten discus*.

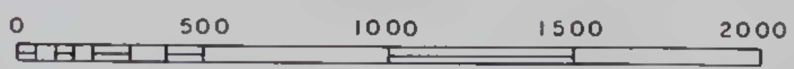
Tmp1 – Massive sandstone. Locally cross-bedded medium- to coarse-grained arkosic to quartz arenite. Locally bituminous.

Tmh – Fine-grained sandstone and siltstone. White to gray brown quartz arenite or arkosic wacke. Locally concretionary. Gray calcareous concretions a foot or more in diameter. Locally siliceous shaley claystone.

Tmm2 – Well-bedded siliceous siltstone and soft silt.
Tmm1 – Lithologically similar to the Phoenix submember2 of the Santa Margarita formation, but generally whiter, more porcelaneous or opaline. Locally buff siltstone.

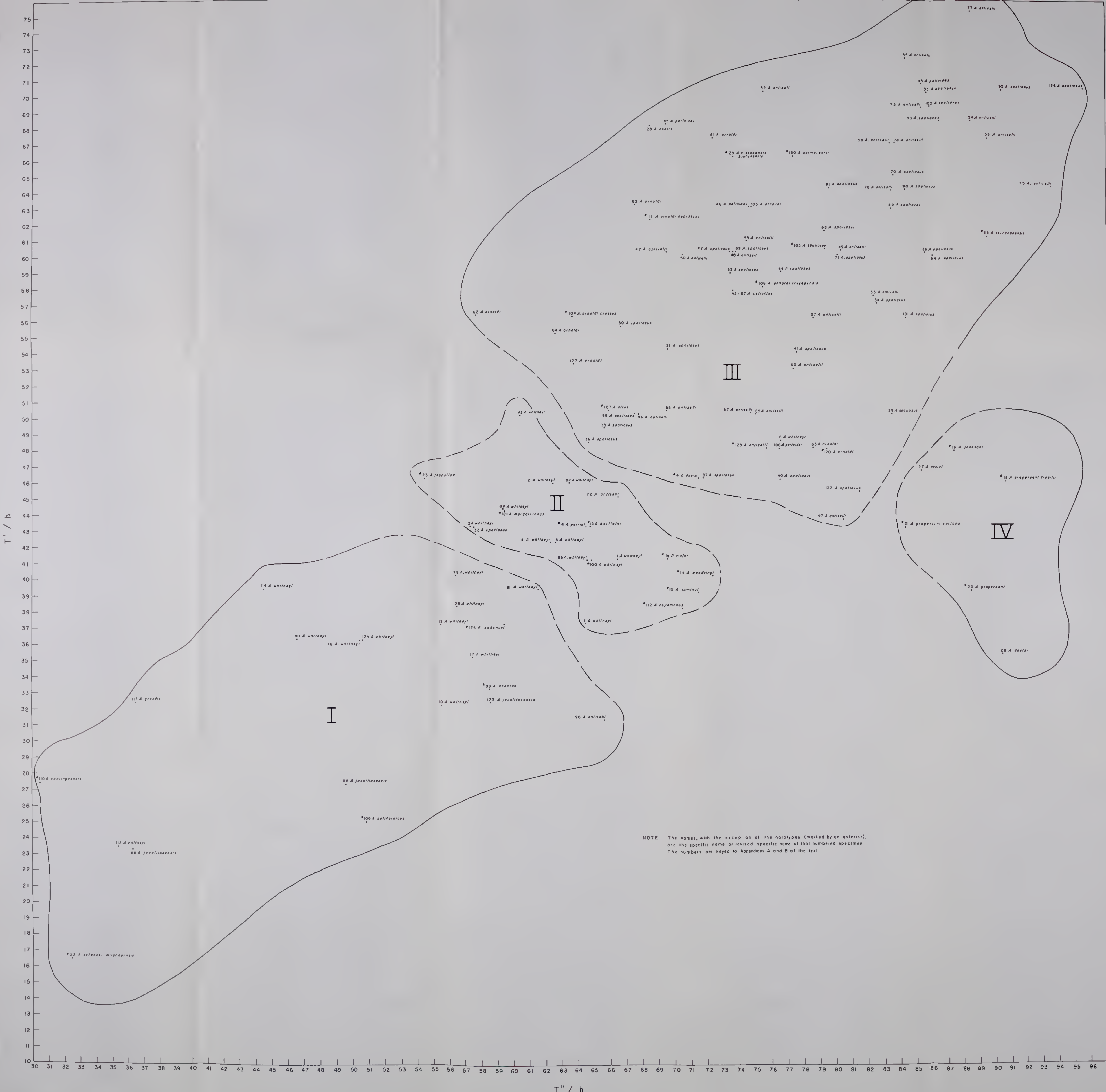
SCALE

1 in. = 500 ft.



To accompany Clarence A. Hall, Jr., "Evolution of the Echinoid Genus Astrodapsis." Univ. Calif. Publ. Geol. Sci., Vol. 40, No. 2.

Fig. 6. Composite columnar section, Phoenix-Saucelito creeks area.



To accompany Clarence A. Hall, Jr., "Evolution of the Echinoid Genus *Astrodapsis*," Univ. Calif. Publ. Geol. Sci., Vol. 40, No. 2.

Fig. 3. Rectangular graph showing the ratios of maximum height (h) to thickness of the test (T'), at the posterior interambulacral area, three aboral interambulacral plates from the margin, plotted against the ratios of (h) thickness of the test (T"), measured at the central anterior petal.