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386. *BOLIVINA DONIEZI* CUSHMAN AND WICKENDEN
IN CLONE CULTURE

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ABSTRACT

The reproduction, growth, and morphologic variation of the foraminifer *Bolivina doniezi* Cushman and Wickenden in clone culture were studied. Eight consecutive generations were cultured over a period of 25 months. Reproduction, under this laboratory system, consisted of repeated multiple fission. Generation time alternated regularly between an average of 65 days and an average of 95 days. Multiple reproduction and continued postreproductive activity were observed. Reproduction occurred only between temperatures of 18° and 22°C. Temperatures outside this range, but between 10° and 26°C, resulted in slower growth but did not permit reproduction. Population composition consisted of a rhythmic succession of growth stages. Morphologic variation included both reproductive test dimorphism and induced infraspecific variation. Prolocular dimorphism decreased with continued culturing.

INTRODUCTION

Distributional studies of modern foraminifers have disclosed broad correlations between depth, distribution, salinity, and temperature, of which the last varies both with latitude and with depth. In addition, most of the major groups of foraminifers show a correlative relationship between the environment and the shape, size, wall structure, chamber arrangement, and surface ornamentation of the test.

These findings are of significance to foraminiferal research for two reasons: First, they provide qualitative data for paleoenvironmental interpretation of sediments containing foraminifers. Second, and more important, they indicate variables relating directly to foraminiferal taxonomy and the study of population dynamics. These two interrelated aspects of foraminiferal research thus provide a valuable means of taxonomic and biologic correlation.

The environmental and biologic approach to foraminiferal distribution and taxonomy has been applied most successfully to several groups of foraminifers whose ecologic importance is enhanced by their relative abundance, wide bathymetric range, and distinct morphologic variation; in particular, species of *Bolivina*, *Brizalina*, *Bulimina*, and *Uvigerina*. In each of these genera, a series of depth-defined species provides a useful and identifiable bathymetric zonation based on the known distribution and biologic requirements of each taxon (Bandy, 1960; Lutze, 1962, 1964; Smith, 1963). Such morphologic variation in successive biotopes may be related to local isolation and the evolution of distinct taxa, or it may represent a pheno-

typically plastic stock whose morphology varies in response to changing environmental conditions. Indeed, such morphologic variability was demonstrated by Lutze (1964) in a statistical study of the *Brizalina argentea* (Cushman) cline. A like interpretation may also be made of other gradational taxa, in particular, certain uvigerinid and buliminid clines.

Advances in foraminiferal ecology and paleoecology from mere distributional surveys to an application of population dynamics obviously must be founded on sound taxonomic information. Such information can be derived from laboratory observations and experiments with clonal lineages under controlled environmental conditions.

The present study was thus designed to investigate primarily the reproduction, growth, and morphologic variation of a member of the foraminiferal family Bolivinitidae, namely, the inner-neritic species *Bolivina doniezi* Cushman and Wickenden. This species was selected primarily because of its relative abundance, association with a varied bolivinid population (Sliter, 1969), and fecundity in laboratory culture. Infraspecific variation in both natural and laboratory populations and the effect of temperature change on reproduction were studied to improve our understanding of morphologically gradational or clinal taxa, both Holocene and fossil.

Laboratory environments, no matter how carefully constructed, invariably represent a deviation from natural conditions. Among the deviations are the removal or alteration of wave energy, competition, nature and abundance of food species, and the ionic ratio of the medium. As a result, the value of such studies lies not so much in defining specific rates of biologic functions or degree of morphologic variation (although these values are of importance when related to the proper environmental system) as in determining the boundary conditions affecting the system. These conditions may in turn be directly related to field observations.

ACKNOWLEDGEMENTS

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CULTURE METHODS

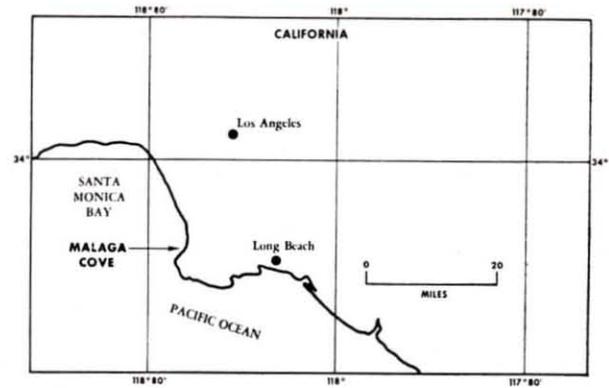
Two basic culture methods were employed during these experiments. Stock cultures of foraminifers obtained from subtidal coralline algae collected at Malaga Cove, California (Sliter, 1965), were placed directly into two interconnected 15-gallon aquaria. Thirty gallons of aerated sea water was circulated through the tanks and refrigerated vessels by means of air pumps and cooled to $20^{\circ} \pm 1^{\circ} \text{C}$, approximating the average summer water temperature at the collection site. All plumbing consisted of flexible $\frac{1}{2}$ -inch-ID Tygon tubing. Filtration was provided by commercial glasswool plus charcoal bottom filters. The tanks were illuminated by 15-watt fluorescent lights on a 24-hour cycle (mean incident light, 200 ft candles). The pH of the medium, varying between 7.5 to 8.5, was routinely checked with a Beckman pH meter (Model N). Salinity of the sea water supplied by Oceanarium Inc., Marineland of the Pacific, was monitored with a modified Solu bridge (Industrial Instruments Inc., Model RB2, using conductivity cells CEL-G20 and CEL-VH20) and was maintained at 34 to 35‰. Foraminifers remained viable in this system for over 2 years and served as a continual stock supply.

Clone and experimental specimens were kept in either unaerated 180-ml covered glass custard dishes containing 100 ml of sea water or 60- by 15-mm petri dishes, both inoculated with the diatom *Nitzschia angularis*. Temperature, pH, salinity, and illumination were identical with those of the stock tanks. Media in these cultures were changed weekly.

REPRODUCTION

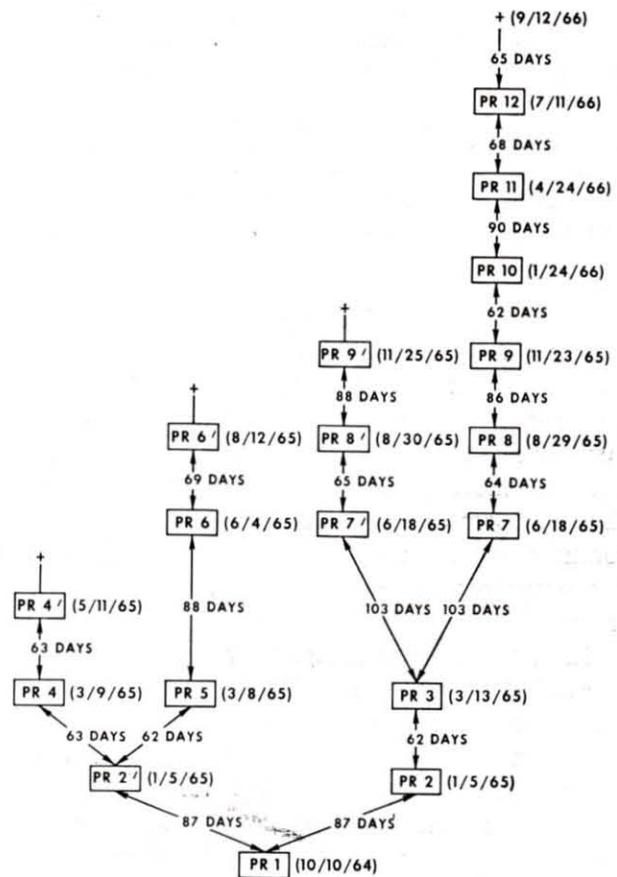
Bolivina doniezi is a common constituent of the benthic subtidal foraminiferal community of southern California and northeastern Baja California, Mexico. Originally described from the Juan Fernandez Islands of Chile, *B. doniezi* is a cosmopolitan species in temperate and tropical waters along the eastern Pacific margin.

Initial laboratory culturing of a mixed foraminiferal fauna from Malaga Cove, California (text fig. 1), in 1963 demonstrated the fecundity and infraspecific variation of this species. Subsequently, clones of eight generations producing thousands of individuals over a period of 25 months were cul-



TEXT FIGURE 1

Locality map showing Santa Monica Bay and Malaga Cove, California.



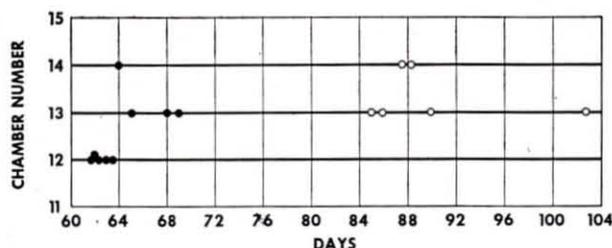
TEXT FIGURE 2

Clonal cultures of *Bolivina doniezi*. Boxes show culture number. Dates represent clone inoculation. Days indicate generation time. Crosses show culture termination.

tured under strict isolation (text fig. 2). Throughout this period, multiple fission of the parental protoplasm was the only type of reproduction observed (plate 8, figs. 1-4).

Initial transfers to new clones were isolated immediately after reproduction. Although this procedure precludes gametic exchange between adults, it does not preclude autogamy. Evidence of autogamy occurring in foraminiferal life cycles has been amply demonstrated by Arnold (1955a) and Grell (1954, 1957).

Successive clones of *B. doniezi* revealed a regular alternation in the time elapsed prior to reproduction (text fig. 3). One group of 9 clones reproduced between 62 and 69 days after birth. A second group of 6 clones reproduced between 85 and 90 days after birth, with one exception which reproduced at 103 days. These two groups are further differentiated by plotting the total number of chambers of each clone inoculant at the time of reproduction. The 62 to 69 day group shows a range of 12 to 14 chambers with the mode at 12 chambers. The 85 to 103 day group has a range of 13 to 14 chambers and the mode has increased to 13 chambers. As discussed more fully later, morphologic measurements of specimens in these clones likewise showed an alternation in test size, and prolocular diameter.



TEXT FIGURE 3

Generation time of *Bolivina doniezi* in clonal culture as a function of chamber number. Two groups are indicated, by open and closed circles.

The presence of an alternating reproductive cycle within cultures reproducing by continued multiple fission raises the possibility of an asexual-autogamic alternating life cycle. Proof of the reproductive nature of the alternating generations of *B. doniezi* would require corroborating chromosomal counts and detailed cytologic investigation. It is unlikely that an alternating physical source within the laboratory environment produced the observable reproductive periodicity, however, because of the strict uniformity in laboratory procedure. Further substantiation is offered by the multiple reproduction of one adult in clone culture (PR4 of text fig. 2), which reproduced twice at the same rate while parallel clones continued successive alternation within the laboratory system.

The characteristic orange-brown color of living specimens of *B. doniezi* varies with age, reproductive maturity, and location of the protoplasm within the test. Protoplasmic pigment within the adult test normally is more deeply red near the apex and becomes more yellow toward the apertural end. The final one or two chambers are normally devoid of pigmented protoplasm (plate 8, figs. 4-5).

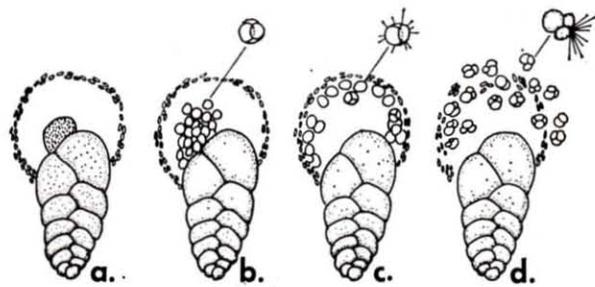
Reproduction is preceded by a reversal in color and a mottling of the protoplasm as cytoplasmic reorganization takes place. The more deeply pigmented protoplasm migrates toward the aperture,

while the apex becomes increasingly yellow. Immediately after reproduction, the juveniles that formed from the extruded, clear, nonpigmented protoplasm become pale yellow as they ingest material of the reproductive cyst. The orange-brown color of adult tests is not commonly attained by juveniles until they develop two to three chambers.

Reproductive processes within the protective cyst were observed by placing specimens between the transparent gelatinous substratum produced by the supplied diatoms and the bottom of the culture dish. Hemispherical cysts formed between these

TABLE 1
Reproductive Process in *Bolivina doniezi*

11:15 a.m.	(Day One) Reproductive cyst completed, parental protoplasm mottled.
3:30 p.m.	Clear nongranular protoplasm extruded (text fig. 4a).
4:20 p.m.	First discrete, spherical juveniles formed from extruded protoplasm, averaging 30μ in diameter.
9:00 p.m.	Additional juveniles tightly grouped around parental aperture; most tripartite, yet they retain an unbroken spherical outline (text fig. 4b).
9:45 a.m.	(Day Two) Juveniles at cyst wall; short radial pseudopodia extend from surface membrane; some with one or two discrete chambers with flexible, uncalcified walls (text fig. 4c).
3:15 p.m.	Juveniles penetrated cyst; pseudopodia radiate from position of primary aperture (text fig. 4d).
5:10 p.m.	Chamber walls flexible but with silver sheen suggesting initial calcification.
8:00 p.m.	Walls of two-chambered juveniles rigid and calcified as indicated by optical interference figures.



TEXT FIGURE 4

Reproductive process in *Bolivina doniezi*: a. Extrusion of protoplasm into reproductive cyst. b. Formation of tripartite-appearing juveniles. c. Migration of juveniles to cyst wall; radial pseudopodia extend from surface membrane. d. Two-chambered juveniles penetrate cyst, pseudopodia radiate from position of primary aperture.

surfaces, permitting an unobstructed view of the cyst interior. The sequence presented in table 1 for an adult in the PR7' clone is typical of the reproductive process. As shown, approximately 30 hours was required for the young to become independently active and calcified. Newly expelled young quickly developed a tripartite appearance resulting from the initial organic base of the developing chamber walls (text fig. 4). Distinct chambers were formed after 18 hours. Pseudopodia radiated equally from the entire test periphery until two discrete chambers were formed, and test calcification was initiated at about 26 hours, at which time, the pseudopodia were concentrated at the test aperture.

The number of young produced by initially reproducing adults ranged from 18 to 31 and averaged 24 to 25 per adult. These determinations are based on the number of young produced by the first reproducing adult in each clone.

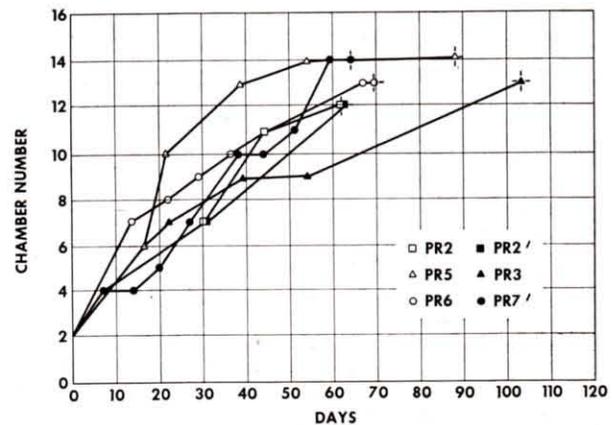
Bolivina doniezi is capable of multiple periods of reproduction. Several isolated specimens and one adult in the clonal succession (PR4 of text fig. 2) reproduced twice. In all cases, the number of young later produced was substantially less (4 to 12) than the number produced in the initial reproduction. Approximately one-third of all reproducing adults retained a portion of the pigmented protoplasm following birth, and a few remained biologically active for as long as 83 days after reproduction. During this period, postreproductive functions included the addition of new chambers, continued pseudopodial activity, and regeneration of pigmented protoplasm. Multiple reproduction and parental postreproductive chamber addition in foraminifers have been reported only once previously (Arnold, 1955b), in the miliolid *Spiroloculina hyalina* Schulze.

Reproductive temperatures for *B. doniezi* studied in the laboratory were determined by culturing isolated specimens at temperatures ranging from 10° to 26°C. Within this range, reproduction was limited to temperatures between 18° and 22°C. Specimens cultured at temperatures ranging from 10° to 18°C and from 22° to 26°C continued growth at a progressively slower rate but failed to reproduce. The largest specimens, nearly twice the size of normally reproducing adults, or up to 370 μ in length (plate 8, figs. 5-6), were those cultured at temperatures above 22°C and extending to the maximum temperature of 26°C used in these experiments. Transfer of juvenile specimens from the 18°-22°C range to the 22°-26°C range interrupted test growth, resulting in increased test flare and chamber height (plate 8, fig. 6). None of these larger specimens reproduced during the 18-month experimental period, even when transferred to stock cultures maintained at 20° \pm 1°C.

GROWTH

Individual Growth

Rates of growth for specimens of *Bolivina doniezi* were determined by noting successive chamber additions starting from birth. Numerous individuals were observed in both experimental and clone cultures. Growth-curve variations of separate cultures used for comparison were minimized by standardizing such environmental variables as temperature, salinity, light intensity, media transfer, and nutrient type and level.



TEXT FIGURE 5

Growth of *Bolivina doniezi* in clones from two parallel lineages. Members of each lineage are indicated by open or closed figures. Curves represent individual specimen in each culture. Crosses indicate reproduction.

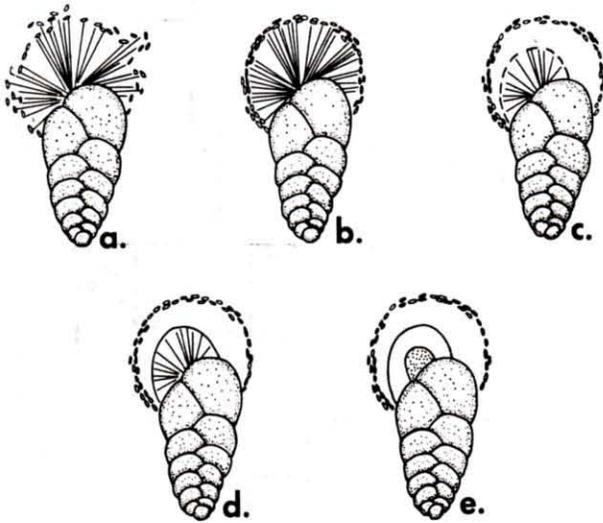
Growth curves for several individuals from successive clones in parallel lineages are shown in text fig. 5. The curves are initiated within the first day after birth at the two-chambered stage, and they terminate at the time of reproduction, generally when laboratory specimens attained 12 to 14 chambers. Growth proceeded relatively rapidly until approximately 30 to 40 days after birth, when the stationary phase was reached.

Growth-rate variability likewise was observed between the progeny of a single parent. In one such case, 39 days after reproduction, the number of chambers of 8 specimens closely associated on a single mass of diatoms ranged from 8 to 13.

Chamber formation and development within the protective growth cyst were observed as described earlier for the reproductive process. By this means, an unobstructed view of chamber wall formation and internal developments was obtained. The procedure described in table 2 is characteristic of the process and time involved in numerous specimens observed. In all, 11 hours was required for a new chamber to form and the specimen to leave the growth cyst, whereas the first indications of chamber-wall calcification were observed 6 hours after cyst construction was initiated (text fig. 6). Individual pseudopodia involved in these stages could

TABLE 2
Chamber Formation in *Bolivina doniezi*

11:15 a.m.	First evidence of cyst formation (text fig. 6a).
1:30 p.m.	Cyst construction completed (text fig. 6b).
2:45 p.m.	Pseudopodia withdrawn to form outline of new chamber or chamber template (text fig. 6c).
4:00 p.m.	Organic base of new chamber wall formed; no optical interference figure indicating calcification was observed (text fig. 6d).
5:15 p.m.	First weak axial figure observed, indicating measurable degree of chamber-wall calcification.
9:00 p.m.	Cytoplasm extruded into newly-formed chamber (text fig. 6e).
10:45 p.m.	Growth cyst abandoned.



TEXT FIGURE 6

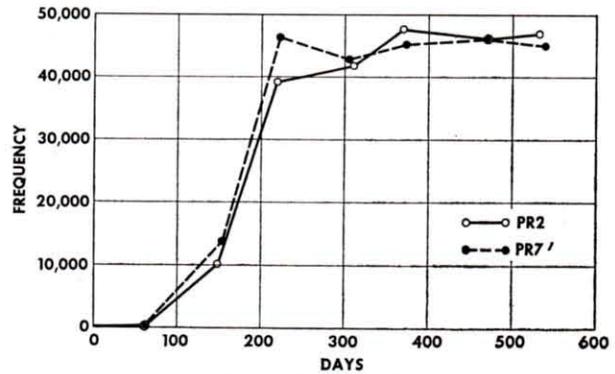
Chamber formation in *Bolivina doniezi*: a. Pseudopodia constructing growth cyst. b. Completion of cyst. c. Formation of chamber outline. d. Secretion of basal organic lining of new chamber. e. Extrusion of cytoplasm into completed chamber.

not be differentiated, as they were reported to be in *Discorbinella* (Le Calvez, 1950). Instead, the pseudopodia were extremely fine, and no granules were observed at 250 \times magnification. Chamber wall perforations were not observed with transmitted light in the early stages of calcification. Later, as the axial optical figure became stronger and the wall exhibited an increasingly silver sheen, pores progressively appeared.

Population Growth

Population growth of *Bolivina doniezi* in mass culture was studied utilizing the isolated cultures of successive clones. Each culture contained thousands of individuals at the end of the experimental

program and provided excellent data concerning morphologic variations produced by laboratory culturing. For the duration of experimentation, observations were made weekly on the total number of living adults and juveniles, time of reproduction, and chamber addition. For some cultures, the observation period exceeded 2 years. *Nitzschia angularis* was added to each dish as required to maintain a continued nutritional substrate.



TEXT FIGURE 7

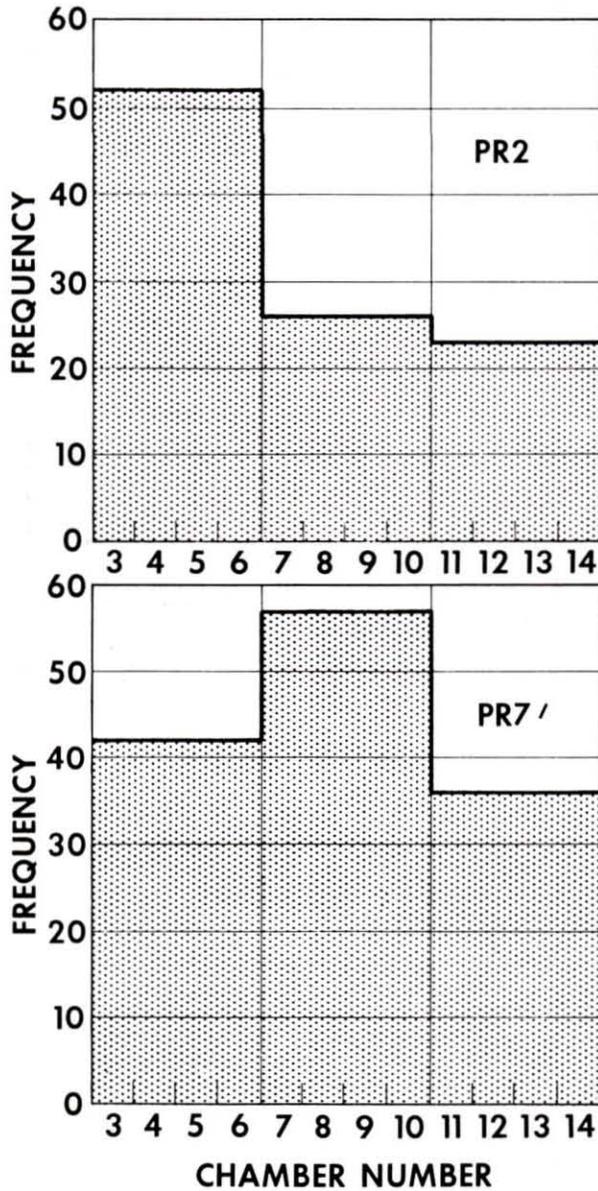
Population growth curves for two cultures of *Bolivina doniezi*.

Growth curves for two mass cultures having like reproductive cycles are shown in text fig. 7. Specimen counts for both were made at the onset of reproduction. Both curves exhibit a sigmoid growth pattern. Following an initial lag phase, growth proceeds rapidly until the third reproduction at approximately 220 days. Thereafter the number of specimens fluctuates between 40,000 to 48,000 per dish.

Population size in these cultures is a function of the food species and specimen density rather than the amount of nutrient utilized, since a continuous nutritional substrate was supplied.

The population composition within mass cultures showed a broad alternation between predominantly adult specimens and predominantly juvenile specimens over a given period of time in response to reproductive periodicity. The periodic alternation became less pronounced in older cultures, no doubt reflecting the variability of individual growth. Nevertheless, after 25 months of continued culturing, populations were still broadly divisible into adult versus juvenile cycles.

A plot of the number of chambers for randomly selected living specimens (text fig. 8) illustrates the population composition for two mass cultures at the termination of the experiments. Individuals from both cultures are divided into three size groups, 3 to 6 chambers, 7 to 10 chambers, and 11 to 14 chambers, and assigned the arbitrary terminology, juvenile, intermediate, and adult, respectively. The population from mass culture PR2 at the time of inspection, after 21 months of continued cultur-



TEXT FIGURE 8

Population composition related to chamber number in two cultures of *Bolivina doniezi*.

ing, is clearly juvenile in composition, whereas the PR7' culture shows a slight increase of intermediate specimens over both juveniles and adults after 15 months. Both graphs illustrate the continuation of the rhythmic reproductive cycle after months of culturing. The population composition within this system thus consists of a stepwise succession of growth stages from juvenile to adult.

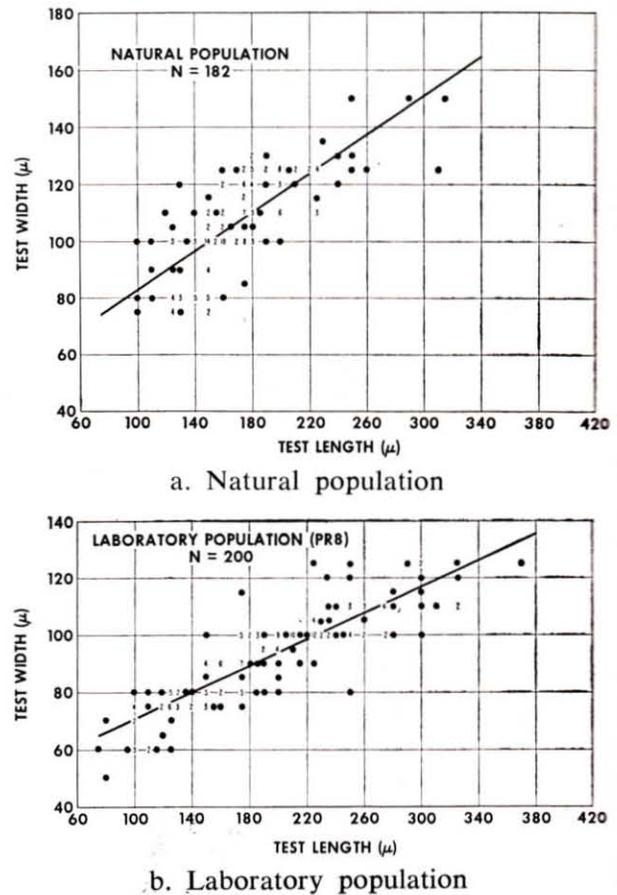
MORPHOLOGIC VARIATION

Two broad patterns of morphologic variation are observed in *Bolivina doniezi*, infraspecific variation in both natural and laboratory assemblages, and morphologic variation related to reproduction.

Test characteristics of *B. doniezi* measured in natural populations can be compared with test modifications produced in laboratory cultures to determine a range of infraspecific variation for

both environments. A natural sample taken at Malaga Cove, California, August 1964, was compared with a laboratory sample taken from clone culture PR8 inoculated in August 1965 from the clonal lineage originally initiated in October 1964. Following reproduction, the culture was maintained as a mass culture until September 1966.

Text fig. 9 illustrates the relationship between test length and width for 182 living and dead individuals selected at random from the natural population and for 200 randomly selected living and dead individuals from the laboratory population.



TEXT FIGURE 9

Test length and width relationship in *Bolivina doniezi*. Dots represent single observations; numbers indicate multiple observations.

The regression line and correlation coefficient values for the two populations are shown in table 3. Laboratory specimens characteristically were longer and narrower than specimens from the natural population (plate 8, figs. 1-5; plate 10, figs. 1-3), nevertheless, a statistical test of the slope of the two regression lines failed to show a significant difference. The increased linear relationship exhibited by the measurements of the laboratory specimens no doubt is related in part to both (1) the controlled laboratory culture system as opposed to the fluctuating natural environment, and (2) the direct transfer of hereditary material inherent in clone culturing.

TABLE 3

Values for slope (b), intercept (a), and correlation coefficient (r) for the linear regression $y = a + b x$ of test dimensions for *Bolivina doniezi* in natural and laboratory populations (text fig. 9).

	Natural Population	Laboratory Population
b	0.3356	0.2346
a	49.1694	47.8364
r	0.7102	0.8744

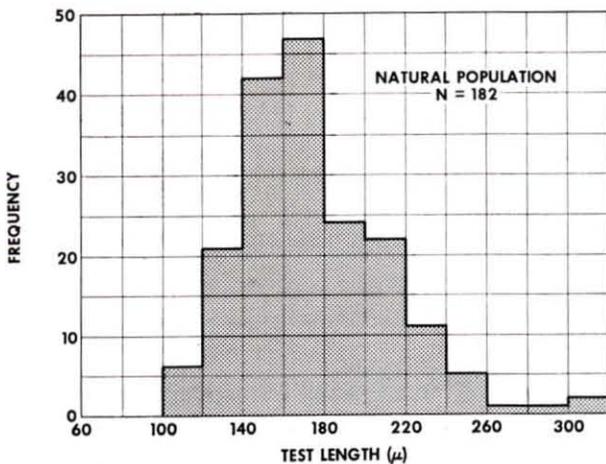
The size-frequency distribution of test length in the natural population (text fig. 10) is relatively symmetrical, with a strong mode at 160-170 μ . The corresponding size-frequency distribution in the laboratory population is less symmetrical, with the strongest mode at 200-210 μ and lesser modes at 120-130 μ and 160-170 μ . This irregular size-frequency distribution with several modes may reflect induced laboratory variations, the sampling procedure, or growth variations caused by the presence of more than one age group. The greater range of the laboratory test lengths is believed to be due to (1) an increase in larger specimens produced by laboratory culturing and (2) an increase in juveniles, representing a more complete recovery of the smaller size fraction. Natural populations were sampled routinely from the fronds and holdfasts of

coralline algae. The majority of bolivinids were obtained from within the holdfasts; thus unprotected specimens or those from surrounding sediments probably had been removed or size-sorted by wave or tidal currents.

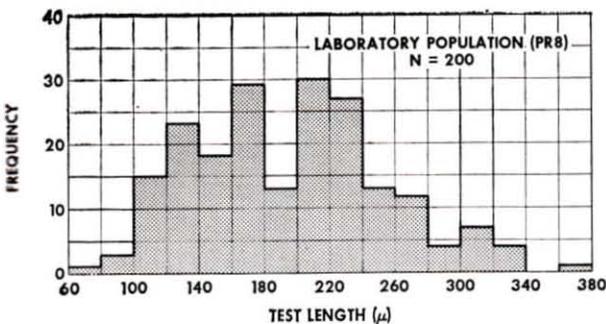
In addition to morphometric variation, laboratory culturing also produced changes in surface ornamentation and pore pattern (plate 10, figs. 1-3). The test surface became smoother and less ornamented in laboratory specimens; subsequently, pores were less depressed. The number of pores in the initial chambers were somewhat reduced due to a progressive closing of earlier pores as test growth continued. And finally, the pore pattern became more linear as pores were increasingly restricted to the basal margin of the chambers.

Reproductive test dimorphism is shown in text fig. 11 and on plate 9. Within the natural population (text fig. 11A) specimens are divisible into two groups on the basis of prolocular size and chamber number, and secondarily on their test dimensions. Prolocular size variation is relatively subtle, with the diameter ranging from 9 to 21 μ ; nevertheless, specimens fall into two classes—one with a smaller proloculus, more numerous chambers, and a longer test, here referred to as microspheric; and the other with a larger proloculus, fewer chambers, and a shorter test, here termed megalospheric. These terms refer solely to a morphologic dimorphism and although associated with the reproductive cycle do not necessarily indicate an evolutive dimorphism of alternating gamont and schizont generations. In the laboratory lineage (text fig. 11B), specimens in early clone cultures showed two prolocular size classes, each with its corresponding chamber and test variations as in the natural population; however, prolocular diameters were greater, ranging from 18 to 33 μ . In addition, the prolocular size classes alternated with one another in response to the rhythmic reproductive cycle, producing the classic succession of microspheric and megalospheric tests. Prolocular dimorphism became progressively less apparent, however, following clone cultures PR7 and PR7' on the right-hand lineage and PR5 on the left-hand lineage. Nevertheless, the periodic reproductive cycle continued until the termination of experiments one year later. The increase in prolocular diameters following the initial clone culture is characterized by a progressive rather than an abrupt change (text fig. 12). The curves shown represent the distribution of prolocular diameters for juveniles produced in each clone from the right-hand lineage of text figs. 2 and 11B.

The size-frequency distribution of prolocular diameters is shown in text fig. 13. Class sizes are dictated by the limitations of the ocular micrometer at a magnification of 100 \times ; hence the continuous



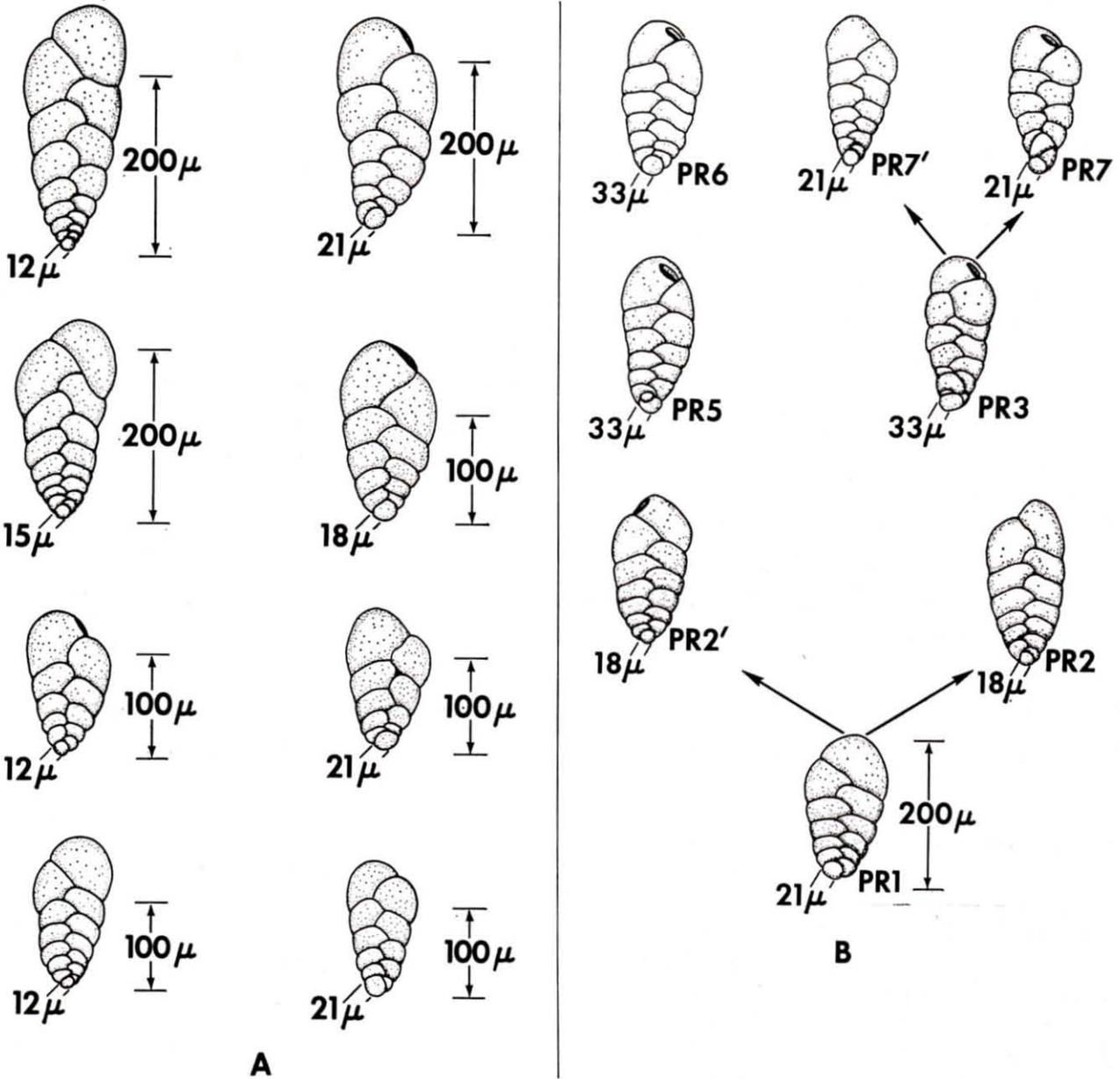
a. Natural population



b. Laboratory population

TEXT FIGURE 10

Test-length frequency distribution in *Bolivina doniezi*.



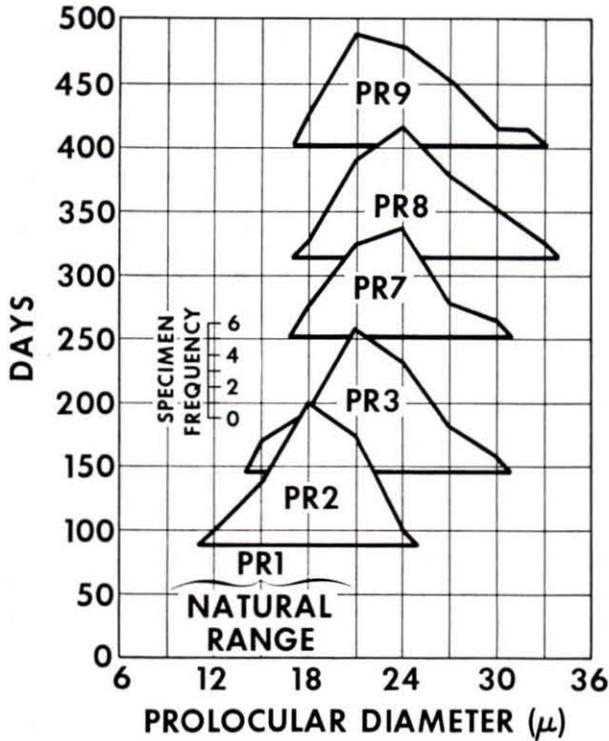
TEXT FIGURE 11
 Reproductive test dimorphism in *Bolivina doniezi*. All illustrated by camera lucida.

rather than bimodal curves. It is suggested that the continuous distributions are formed by the curve overlap of two separate prolocular populations so that the skewness toward smaller diameters represents the effect produced by the larger or microspheric curve. Microsphere-megalosphere size classes thus represent end members of the present curves under these restrictions. In the natural population, the majority of specimens observed are microspheric, with the mode occurring at a prolocular diameter of 12 μ . Diameters falling at or near 15 μ are suggested to include the curve overlap of the two size classes. Microspheres were likewise dominant in the laboratory population; however, the mode increased to 21 μ , and the curve overlap is suggested to fall between 24 and 27 μ .

The frequency distribution of chamber number

in the natural population is relatively symmetrical, ranging from 7 to 15 chambers with the mode at 10 chambers (text fig. 14). In the laboratory population, the distribution is less symmetrical, ranging from 6 to 18 chambers with the mode at 13 chambers. The increase in chamber number observed in the range and mode of the laboratory population is in agreement with the greater test length (text fig. 9).

Size-frequency distributions of prolocular size classes plotted against both test length and chamber number for natural and laboratory populations, while showing subtle variations corresponding to prolocular classes, failed to show significant differences at the 0.95 confidence level of the Kolmogorov-Smirnov statistic. As noted previously, the prolocular size class restrictions are believed to



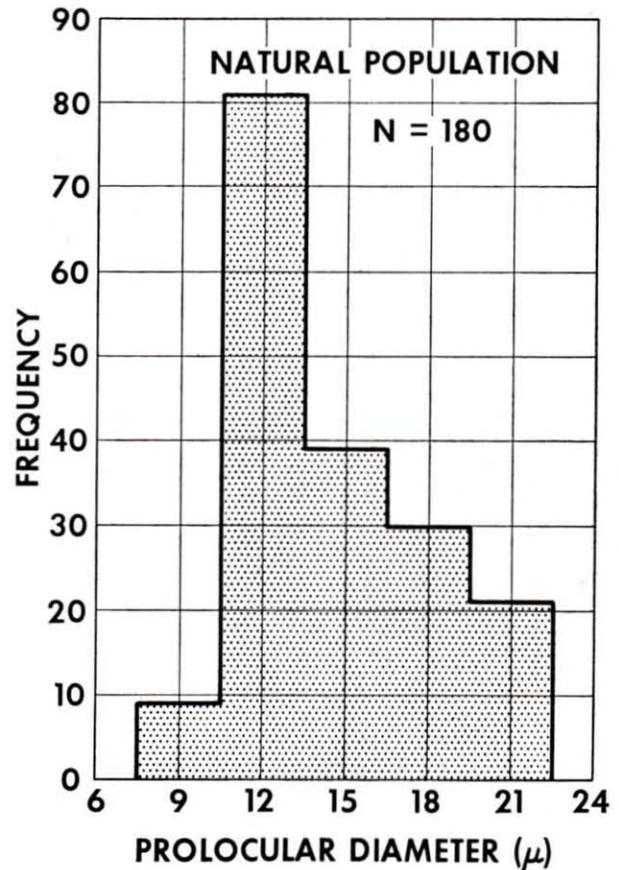
TEXT FIGURE 12

Time-frequency diagram showing distribution of prolocular diameters for juveniles of *Bolivina doniezi* in successive clone cultures.

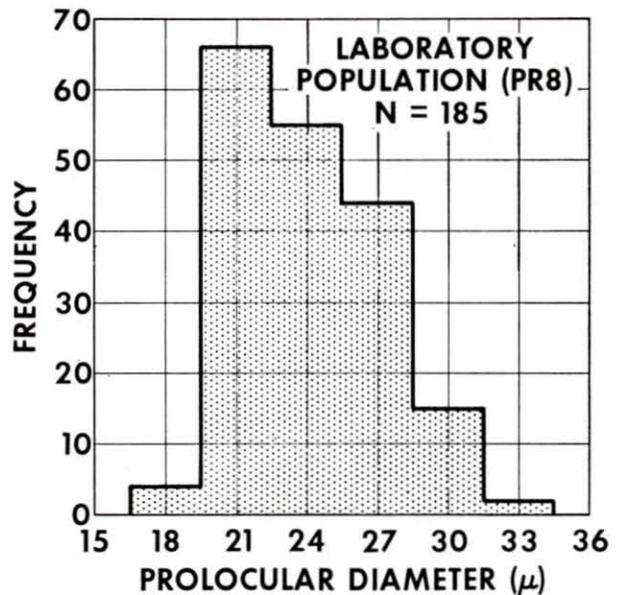
have adversely affected these distributions. Nevertheless, a slight negative correlation was noted between prolocular diameter and chamber number in both natural and laboratory populations.

Prolocular diameters are plotted as a function of test length and average number of chambers for the end members of the prolocular size distribution curves or microspheric-megalospheric tests in text fig. 15. Specimens in the natural population show a distinct correlation between prolocular diameter and average chamber number, but less agreement with test length. In the laboratory population, specimens show much less agreement of prolocular size to test size; no dimorphic correspondence is noted with test lengths between 140-150 μ and 240-280 μ .

In summary, specimens from both natural and laboratory populations show an overall correlation between prolocular size and test length and a slight negative correlation between prolocular size and chamber number. Specimens from the natural population show a subtle but recognizable prolocular dimorphism, with microspheric tests being more numerous and somewhat larger than megalospheric tests. A distinct dimorphism is noted in comparing prolocular diameters with chamber number; tests with microspheres have more chambers than those with megalospheres. Specimens from the laboratory population are relatively longer and thinner than those in nature. The subtle prolocular di-



a. Natural population

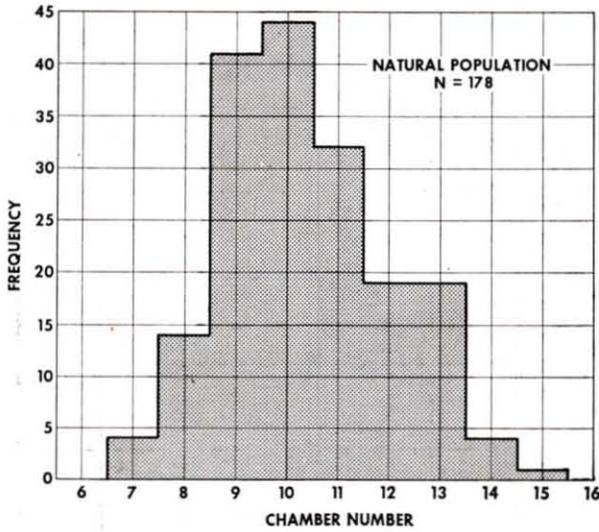


b. Laboratory population

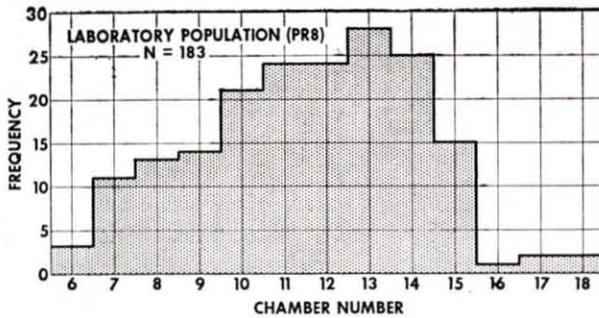
TEXT FIGURE 13

Frequency distribution of prolocular diameters in *Bolivina doniezi*.

morphism trends toward a more uniform size; however, tests with microspheres are more abundant and slightly longer than those with megalospheres. Dimorphism based on the correlation of prolocular size to chamber number and test length in later clones was less distinct despite the continued alternating reproductive cycle.



a. Natural population



b. Laboratory population

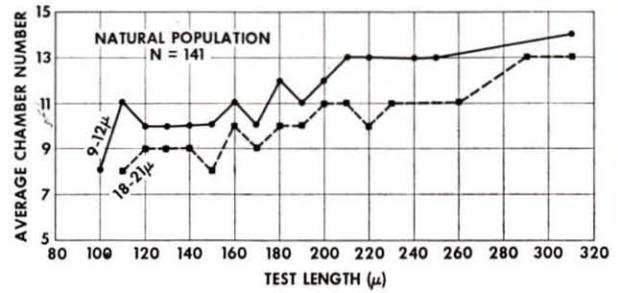
TEXT FIGURE 14

Chamber number distribution in *Bolivina doniezi*.

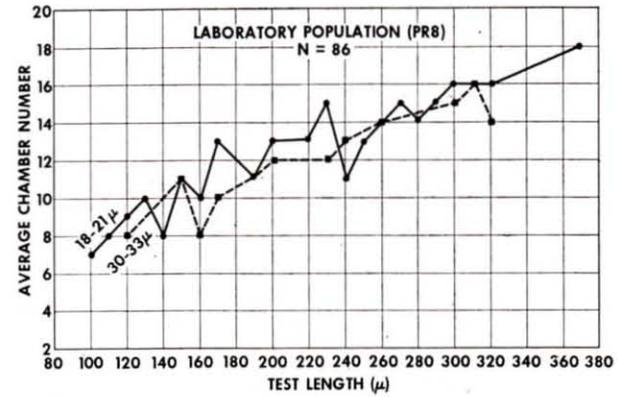
DISCUSSION

In the laboratory, reproduction of *Bolivina doniezi* takes place between temperatures of 18° and 22°C. The reproductive limits fall well within, though in the upper range of, temperatures observed at Malaga Cove, California.

Water temperatures at Malaga Cove were recorded from September 1956 to April 1957 (Reiter, 1959) as one of a series of collection localities for a study of intertidal foraminifers. Temperatures of 19.5°C in September were shown to decrease to an average of 14°C for November through February, and then to increase to 15°C in April. Water temperatures in Santa Monica Bay were recorded during 1955-1956 (Stevenson, Tibby, and Gorsline,



a. Natural population



b. Laboratory population

TEXT FIGURE 15

Prolocular diameters related to test length and the average number of chambers in *Bolivina doniezi*.

1956). Surface temperatures adjacent to Malaga Cove were 19°C during July 1955; during February 1956, bay surface temperatures were nearly uniform, about 13°C.

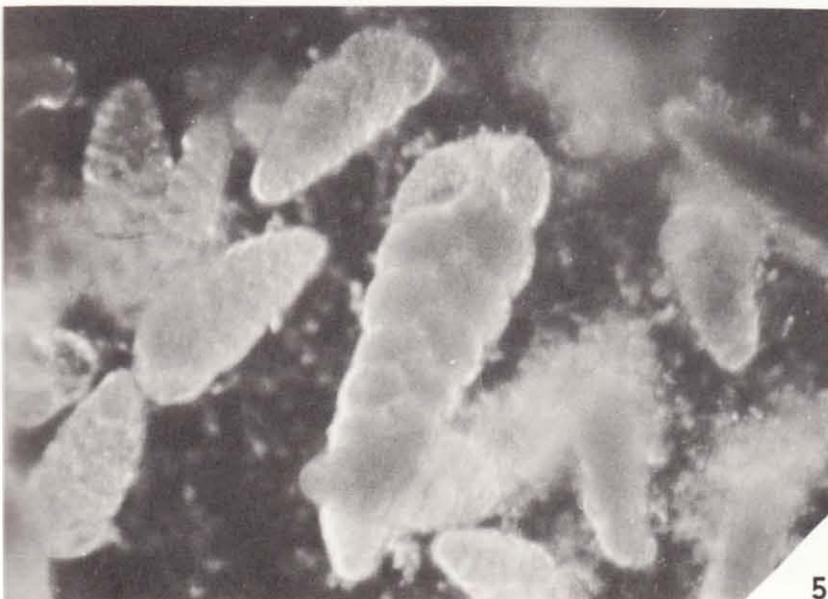
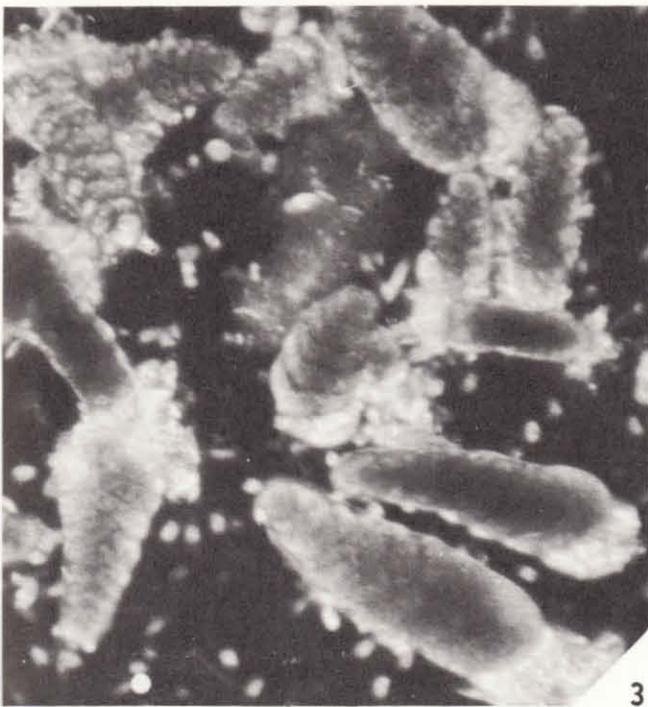
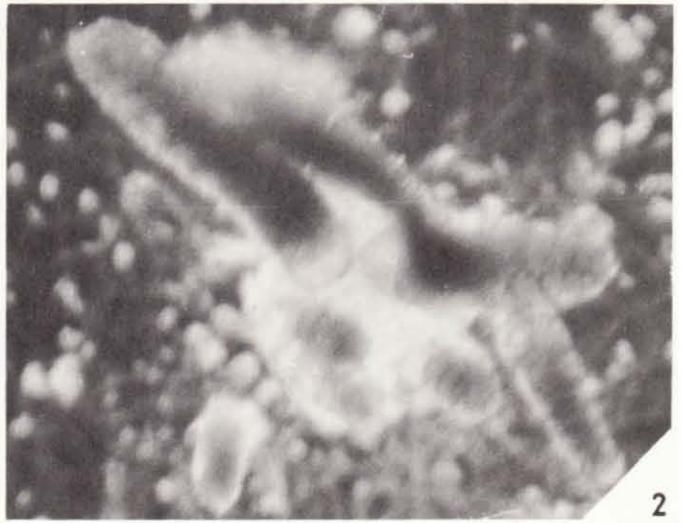
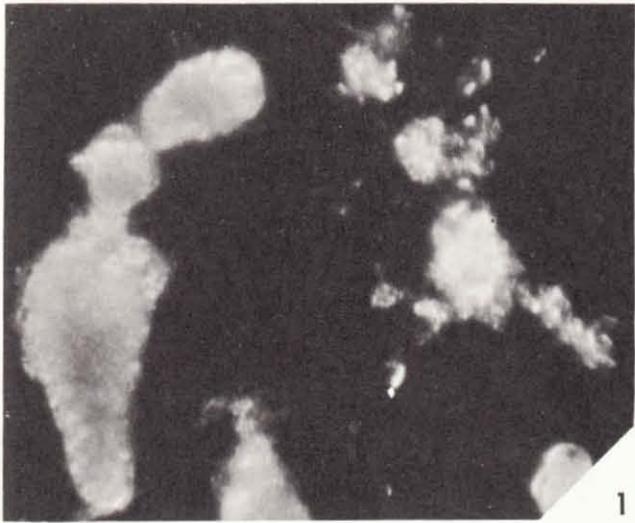
The proposed model suggests that reproduction of *B. doniezi* in field populations at Malaga Cove is limited to those months in which water temperature exceeds 18°C; hence, from May to September. The alternating life cycle of approximately 65 and 95 days established in the laboratory would produce one or possibly two generations in this time span of 150 days. During the months when water temperatures are below 18°C, reproduction would be progressively limited until a period of reproductive dormancy was established. In spring, rising water temperatures would induce renewed reproduction when a specific thermal level of approximately 18°C was reached.

Laboratory experiments on foraminiferal life

EXPLANATION OF PLATE 8

Figs.

- 1-6. *Bolivina doniezi* Cushman and Wickenden in agnotobiotic stock cultures, photographed in dark field, $\times 180$.
 1. Three-chambered juveniles surrounding diatom bolus shortly following reproduction.
 2. Adults and 7-chambered juveniles clustered on diatom bolus.
 - 3-4. Adult cultures showing diatoms gathered at apertures, protoplasmic pigment differentiation, and transparent dead specimens.
 5. Large, nonreproducing specimen following transfer to stock culture.
 6. Similar specimen showing growth interruption in early portion of test caused by transfer from media at 18°C to 24°C.



Sliter: *Bolivina doniezi* in clonal culture



Sliter: *Bolivina doniezi* in clonal culture

TABLE 4
Foraminiferal Reproductive Temperatures

Author	Foraminiferal Species	Reproductive Temperatures
Arnold (1955a)	<i>Allogromia laticollaris</i>	14-32°C—reproductive range
(1964)	<i>Spiroloculina hyalina</i>	14-24°C—range of successful reproduction
Bradshaw (1957, 1961)	<i>Ammonia beccarii</i>	20-32°C—reproductive range
Myers (1935)	<i>Patellina corrugata</i>	18-25°C—optimum reproductive range
(1936)	<i>Spirillina vivipara</i>	18-26°C—optimum reproductive range
(1943)	<i>Tretomphalus</i> sp.	18°C —lower reproduction limit 20°C —optimum reproduction
Sliter (1965)	<i>Rosalina globularis</i>	16-25°C—reproductive range
(this paper)	<i>Bolivina doniezi</i>	18-22°C—reproductive range

cycles (Myers, 1935; Bradshaw, 1961, 1968) have shown that reproduction of *Patellina corrugata* Williamson and *Ammonia beccarii* (Linné) is similarly limited to those seasons having favorable thermal ranges.

The reproductive processes of most animals are restricted to narrower thermal ranges than are the majority of other functions. Most aquatic species begin reproduction when a certain thermal level is reached or in response to certain temperature changes (Kinne, 1963). In middle or higher latitudes, reproduction is associated with spring and summer months when rising temperatures induce maturation of gametes (Gunter, 1957).

The more obvious complications of extending the present laboratory data to natural populations involve variations in the rates of growth, timing of reproductive periods, the presence of more than one reproductive period per individual as described above for *B. doniezi*, and the addition or subtraction of sexual or asexual reproductive stages in the life cycle.

Additional detailed studies of the seasonal variations in natural populations of *B. doniezi*, as well as other species, are needed before generalizations regarding this reproductive model can be verified.

Comparison of the reproductive temperatures of *B. doniezi* with those of other studied foraminifers shows a general agreement (table 4). These species inhabit subtidal or marsh habitats characterized by fluctuating environmental conditions; hence, differences in their reproductive thermal limits are not surprising. *Ammonia beccarii* (Linné) was shown by Bradshaw (1957, 1961) to reproduce at temper-

atures between 20° and 32°C, temperatures somewhat greater than those for *B. doniezi*. This greater temperature tolerance of *A. beccarii* corresponds to its ecologic distribution; it is generally limited to bay and marsh habitats, whereas *B. doniezi* is found in open marine environments.

The results of the temperature experiments on growth agree with the experiments of Bradshaw (1957, 1961), which show that increased size within the morphologic range of a foraminiferal species does not represent optimal environmental conditions. In the present experiments, specimens of *B. doniezi* produced at temperatures greater than 22°C grew larger than those produced at temperatures less than 18°C; nevertheless, in both cases a marked decrease in growth rate was observed at temperatures both above and below the reproductive limits. The increased size resulted from the postponement of sexual maturity and thus prolongation of individual life. As applied to the reproductive model, juveniles of *B. doniezi* present during the winter months in southern California represent a dormant phase produced by reduced rates of metabolism and growth.

Intraspecific variation in test length was noted by Smith (1963) in her study of shelf and slope Bolivinitidae off El Salvador. Specimens of certain species attained a maximum size and abundance at depths coinciding with the oxygen-minimum zone. The present study suggests that the larger size merely indicates unfavorable conditions (whether of temperature or oxygen). The greater abundance of foraminifers, living and dead, at these depths may be correlated with (1) an increase in species

EXPLANATION OF PLATE 9

FIGS.

- 1-5. *Bolivina doniezi* Cushman and Wickenden. Scanning electron photomicrographs of specimens from natural population, all gold-palladium coated.
- 1, 3, 4, 5. Microspheric specimens showing morphometric relationships, surface ornamentation, and pore arrangement. 1. $\times 500$. 3, 5. $\times 550$. 4. $\times 650$.
2. Megalospheric specimen, $\times 550$.

diversity on the outer shelf and upper slope (Bandy and Arnal, 1957), and (2) an absence of burrowing organisms as observed in the Gulf of California by Calvert (1964). Above and below water depths approximating the oxygen-minimum zone, burrowing organisms re-work the surface sediments and dilute the benthic foraminiferal population.

Growth variations in chamber height and test flare were observed in specimens of *B. doniezi* transferred to temperatures outside their reproductive limits. Similar variations were observed in specimens of *Brizalina argentea* (Cushman) by Lutze (1964, text fig. 7) and suggest environmental changes, whether due to downslope movement transporting specimens from slope or transition biotopes into basin environments or to subsequent changes in local microhabitats.

The phenotypic variation observed in *B. doniezi* resembles certain morphologic variation in fossil biserial foraminiferal taxa. For example, elongate specimens of *Heterohelix globulosa* (Ehrenberg) from the Cretaceous of southern California found to be associated with inner-shelf faunas (Sliter, 1968) may represent the morphologic response of this species to limiting environmental conditions. This is further suggested by the absence of such elongate specimens in assemblages of *H. globulosa* from neighboring Cretaceous deposits interpreted to represent bathyal water depths.

Intraspecific variation of *B. doniezi* produced in laboratory cultures includes alteration of test and chamber dimensions, prolocular size, and pore pattern. These variations were established by the third clone culture (text fig. 11B), with little successive variation occurring during the remaining months of culturing. Variations in foraminiferal test shape, size, and ornamentation are usually but not always assumed to be phenotypic and related to various environmental conditions. To date, foraminiferal species are determined by phenetic criteria; hence, it is necessary to distinguish those characters, whether ecologically or genetically induced, that are of taxonomic significance.

Laboratory studies have shown certain foraminiferal species to be more phenotypically plastic than others. Species such as *Cibicides fletcheri* (Galloway and Wissler), *Rotorbinella companulata* (Galloway and Wissler), and *Trochammina pacifica* (Cushman) cultured by the author are relatively conservative in degree of variation, whereas *B. doniezi* resembles more variable calcareous species such as *Spiroloculina hyalina* Schulze, species of *Discorinopsis*, and *Rosalina globularis* d'Orbigny (Arnold, 1954, 1964; Sliter, 1965). Studies of natural foraminiferal populations have shown that differing amounts of intraspecific variation occur among related species. Smith (1963) observed little variation with depth for *Bolivina humilis*

Cushman and Wickenden, *B. pacifica* Cushman and McCulloch, and *B. tongi filacostata* Cushman and McCulloch, whereas great variation was observed in such species as *B. seminuda* Cushman and *B. subadvena* Cushman. From the results of the present study, *B. doniezi* resembles the more plastic species of *Bolivina* and as such may represent a member of a cline.

The progressive loss of prolocular dimorphism is difficult to assess, due to the lack of cytological observations. However, since prolocular diameter variation accompanied test variations in laboratory cultures, the change is believed to be related to physico-chemical conditions, especially since the periodic reproductive cycle continued. Le Calvez (1938) concluded that the size of the proloculus depends on the ratio of maternal protoplasm to number of daughter nuclei, whereas the size of later chambers is dependent on genetic factors and the surface tension of the protoplasm and surrounding media. The present experiments suggest that prolocular size also may be influenced by environmental conditions.

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CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
VOLUME XXI, PART 3, JULY, 1970

387. SOME NEW CRETACEOUS FORAMINIFERA FROM THE
BUDDEN CANYON FORMATION, NORTHWESTERN
SACRAMENTO VALLEY, CALIFORNIA

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ABSTRACT

Twenty-one new species and one new subspecies of foraminifera collected from strata of probable Barremian-early Cenomanian age of the Budden Canyon Formation exposed along the northwestern edge of the Sacramento Valley, California, are described and illustrated. These species are a portion of a moderately rich microfauna, as yet undescribed, most species of which have been reported previously from distant regions. Present in the samples is the genus *Reinholdella*, recorded for the first time from the western hemisphere, and *Spiroplectinata* and *Falsoguttulina* which have never been reported previously from the Pacific Coast of North America.

INTRODUCTION

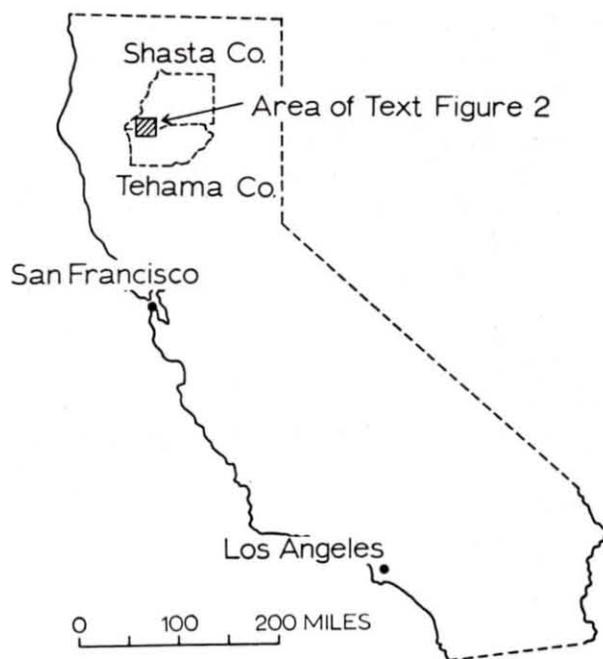
This report describes twenty-one species and one new subspecies of foraminifera collected from the Chickabally Member of the Budden Canyon Formation exposed along the northwestern edge of the Sacramento Valley, California (text fig. 1). These species were uncovered in the course of a Ph.D. dissertation and are described herein in order to validate the new specific names for use in advance of publication of a comprehensive faunal description.

The rock samples which have yielded the foraminifera were collected by the author during the field seasons of 1966-1968 from traverses along the following stream courses: Dry Creek, Tehama County; Roaring River, Mitchell Creek, and North Fork Cottonwood Creek and its tributaries, Shasta County (text fig. 2). The sediments consist of a monotonous series of dark gray mudstones, ranging from almost pure claystone to very sandy mudstone. Thin graywacke sandstone interbeds and also some limestone, either as individual nodules or as discontinuous layers, occur throughout this interval, but they constitute less than one percent of the section.

The only occurrence of foraminifera previously reported from the Budden Canyon Formation is that presented by Marianos and Zingula (1966), who described and figured 27 planktonic species obtained from the upper 14,300 feet of exposures

at Dry Creek in northern Tehama County. A study of 150 samples from several sections collected mainly from the Chickabally Member by the writer reveals the presence of a moderately rich microfauna consisting wholly of small foraminifera. Most of these forms have been reported previously from various regions, such as Alaska, Texas, Trinidad, North Africa, Europe, and Kazakhstan, but they are, by and large, new to California. The present paper, however, deals only with the systematic description and illustration of the more abundantly occurring new species. Their ranges are shown in text fig. 3.

Ammonites locally abundant in the Chickabally Member in southwestern Shasta County suggest a Barremian-Albian age, but the uppermost beds of



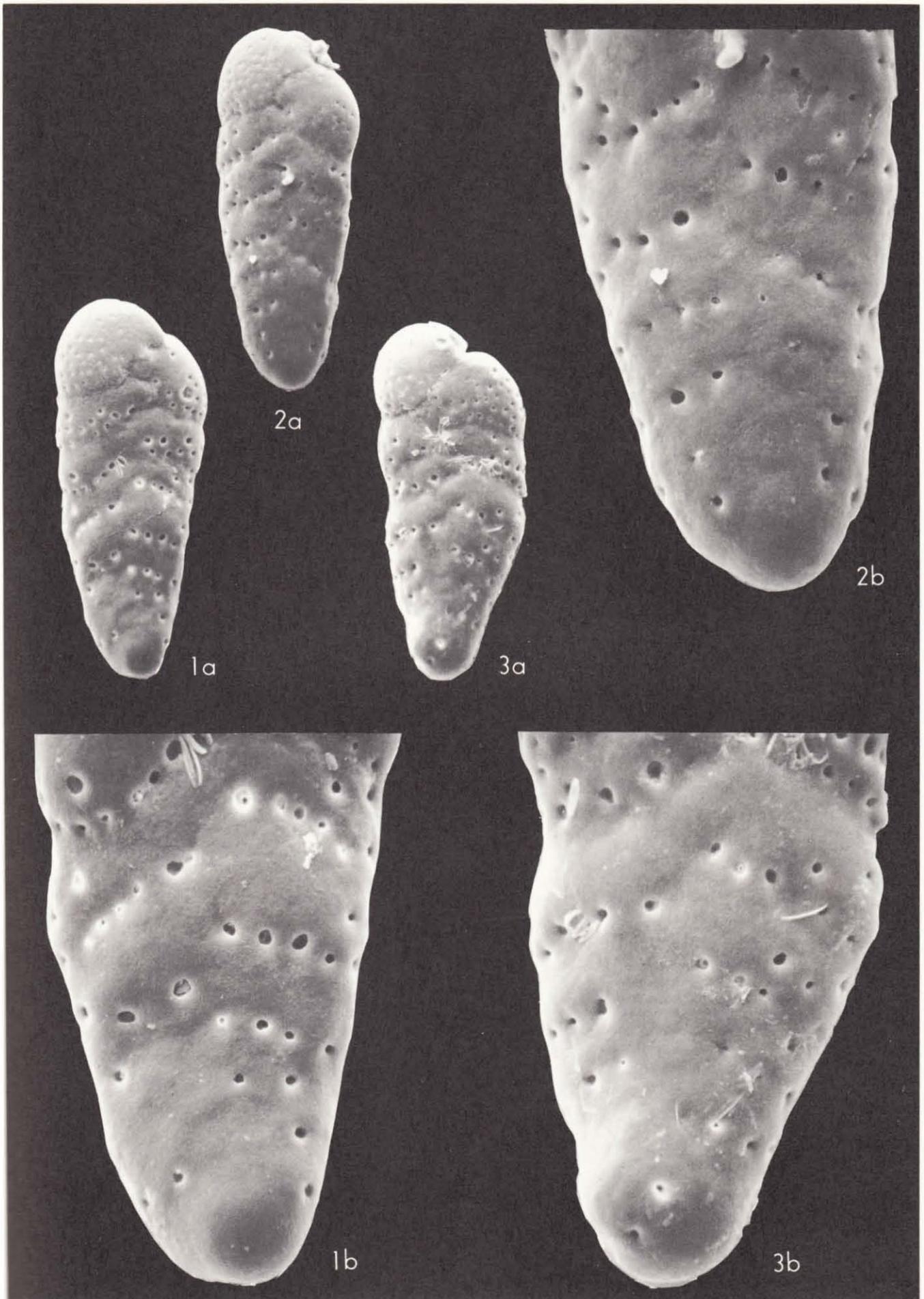
TEXT FIGURE 1

Outline of California showing geographic location of index map.

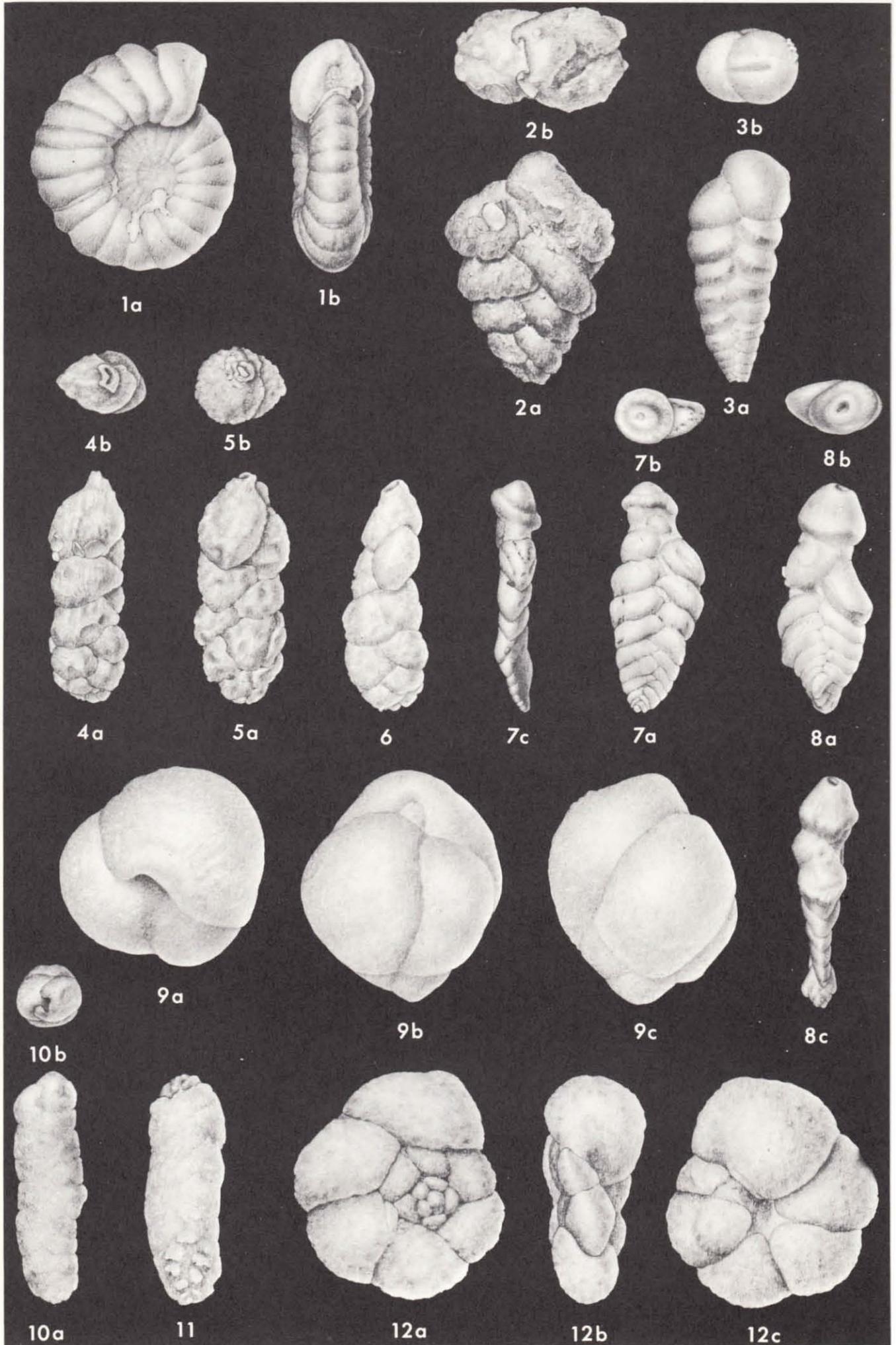
EXPLANATION OF PLATE 10

FIGS.

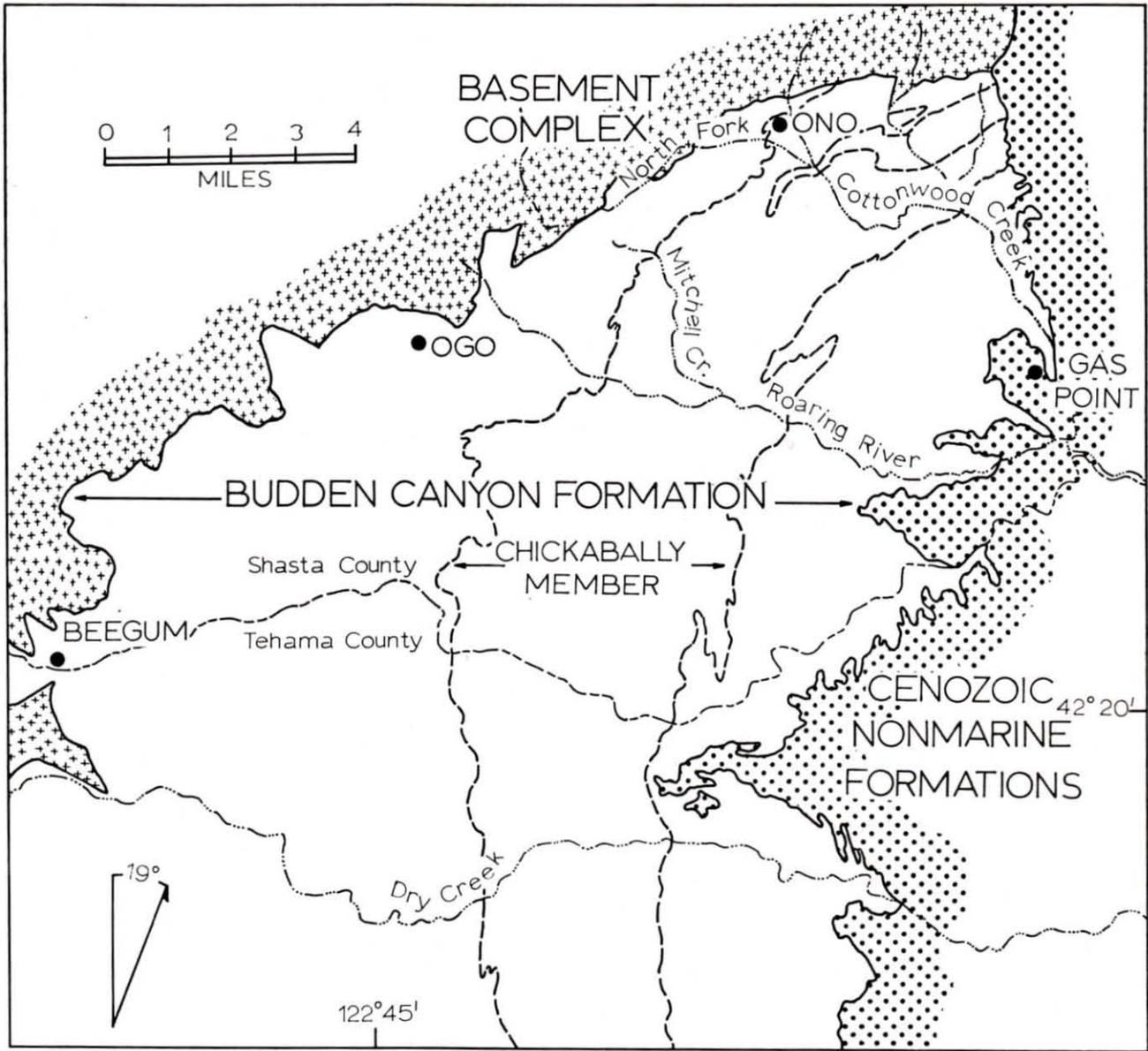
- 1-3. *Bolivina doniezi* Cushman and Wickenden. Scanning electron photomicrographs of specimens from laboratory population, all gold-palladium coated.
1a, 2a, 3a. Specimens showing morphometric relationships, surface ornamentation, and pore arrangement, all $\times 280$.
1b, 2b, 3b. Detail of lower half of each specimen, all $\times 700$.



Sliter: *Bolivina doniezi* in clonal culture



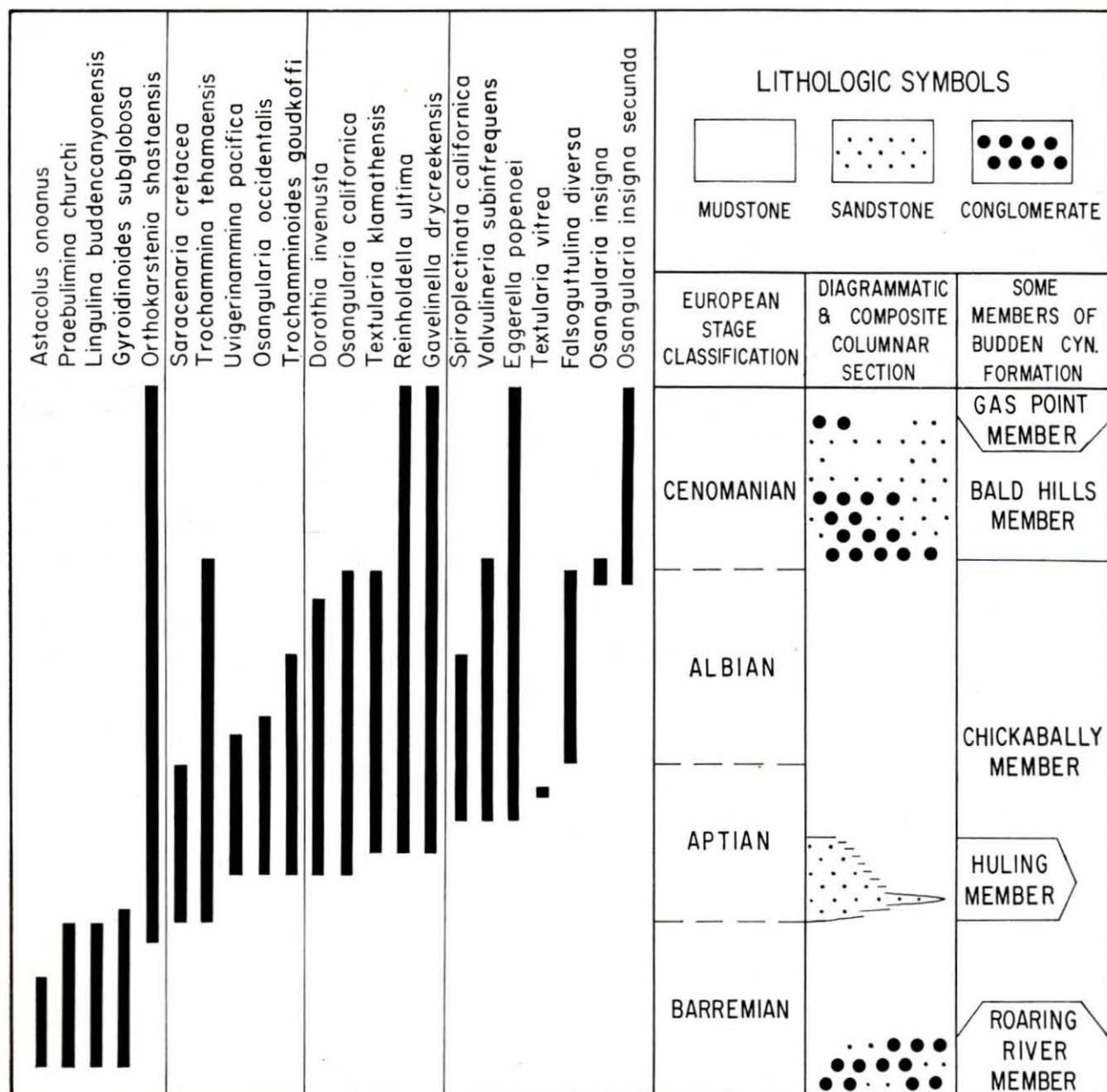
Dailey: California Cretaceous Foraminifera



TEXT FIGURE 2
Index map of the area investigated

EXPLANATION OF PLATE 11

FIGS.	PAGE
1. <i>Trochamminoides goudkoffi</i> n. sp.	103
Holotype 47001, $\times 50$; a. side view, b. peripheral view.	
2. <i>Textularia klamathensis</i> n. sp.	103
Holotype 47004, $\times 50$; a. front view, b. top view.	
3. <i>Textularia vitrea</i> n. sp.	103
Holotype 47007, $\times 42$; a. front view, b. top view.	
4-6. <i>Uvigerinammina pacifica</i> n. sp.	103
4. Holotype 47010, $\times 42$; 5. Paratype 47011, $\times 40$; 6. Paratype 47012, $\times 43$. 4a, 5a, 6. front views; 4b, 5b. top views.	
7-8. <i>Spiroplectinata californica</i> n. sp.	104
7. Holotype 47013, $\times 30$; 8. Paratype 47014, $\times 53$. 7a, 8a. front views; 7b, 8b. top views; 7c, 8c. edge views.	
9. <i>Eggerella popenoei</i> n. sp.	104
Holotype 47017, $\times 77$; a. top view; b. and c. side views.	
10, 11. <i>Dorothia invenusta</i> n. sp.	104
10. Holotype 47020, $\times 35$; 11. Paratype 47021, $\times 33$. 10a, 11. front views; 10b. top view.	
12. <i>Trochammina tehamaensis</i> n. sp.	105
Holotype 47023, $\times 37$; a. dorsal view, b. peripheral view, c. ventral view.	



TEXT FIGURE 3

Stratigraphic distribution of new foraminiferal species in the Budden Canyon Formation. Stratigraphic classification following Murphy *et al.*, 1969.

this unit at Dry Creek contain an ammonite fauna of Cenomanian age (Murphy *et al.*, 1969, p. 19). In addition, Marianos and Zingula (*ibid.*, pp. 331, 334) correlated the top of the Chickabally at Dry Creek with the basal Cenomanian, while a generalized Hauterivian-Barremian age was inferred for the lower few thousand feet of section.

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and gave technical advice; to Dr. V. A. Zullo, who provided access to C. C. Church's figured specimens at the California Academy of Sciences; to Mr. G. R. Hornaday, for curatorial assistance; to Mary E. Taylor, who drew the figured specimens; and to Susan McDonald, who prepared the text figures.

SYSTEMATIC DESCRIPTIONS

The classification followed is essentially that of J. A. Cushman, 1948. All type material is deposited in the micropaleontology collections of the Museum of Paleontology at the University of California, Berkeley, California, and all types and localities refer to these collections at the University of California. Locality descriptions are given in the Appendix.

Family LITUOLIDAE de Blainville, 1825

Genus *Trochamminoides* Cushman, 1910*Trochamminoides goudkoffi* n. sp.

Plate 11, figure 1

Test free, planispirally coiled, evolute to involute, biumbilicate, periphery broadly rounded; chambers numerous, short, faintly inflated, increasing very little in size as added, so that each succeeding whorl contains more chambers than previous one, fifteen to eighteen in last whorl of mature individuals; sutures distinct, straight, radial, depressed; wall finely agglutinated, with much cement, smoothly finished; aperture the open end of the last chamber but obscure in most specimens.

Dimensions: The holotype measures 0.74 mm in greatest diameter and 0.26 mm in thickness. Other specimens range up to 0.85 mm in greatest diameter but most are between 0.30 and 0.65 mm.

Remarks: This species is distinguished by the numerous short chambers of the final whorl in mature individuals, slightly depressed sutures, and varying degree of overlap by succeeding whorls. The Budden Canyon specimens are further characterized by a yellowish-brown color which sets them apart from other individuals in the samples.

This species is named for the late Dr. P. P. Goudkoff for his contributions to the micropaleontology of the Cretaceous of California.

Types: Holotype 47001, locality D-3578; paratypes 47002 and 47003, locality D-3531.

Family TEXTULARIDAE Ehrenberg, 1838

Genus *Textularia* Defrance, 1824*Textularia klamathensis* n. sp.

Plate 11, figure 2

Test free, biserial, elongate, somewhat laterally compressed, strongly tapering, broadly-rounded periphery, lobulate in outline; chambers low, broad, initially slightly inflated with later ones progressively more inflated, five to seven pairs; sutures distinct, depressed, strongly oblique; wall somewhat coarsely agglutinated, surface moderately rough, commonly distorted in preservation; aperture a low narrow arch at inner margin of final chamber.

Dimensions: The holotype measures 0.63 mm in length, 0.43 mm in breadth, and 0.37 mm in thickness. Other specimens range from 0.42 to 1.10 mm in length.

Remarks: This is a variable species both in size and shape, the latter due to distortion in preservation. *Textularia klamathensis* n. sp. most closely resembles two Late Cretaceous Gulf Coast species, *T. glabra* Cushman and *T. ripleysensis* Berry, but can be distinguished by its strongly tapering test, low, broad, somewhat inflated chambers, and strongly depressed and oblique sutures.

Types: Holotype 47004, paratypes 47005 and 47006, locality D-3501.

Textularia vitrea n. sp.

Plate 11, figure 3

Test free, biserial, elongate; initial end compressed and usually sharply pointed when present, commonly twisted, later portion of test increasing in thickness toward apertural end, periphery broadly rounded, slightly lobulate in plan view, a compressed ellipse in apertural view; chambers numerous, initially low and broad, later somewhat inflated and proportionally higher than earlier ones; sutures distinct, straight, somewhat oblique, little depressed initially but more depressed in later portion of test; wall finely arenaceous, with much cement, tending to be smoothly finished; aperture a narrow slit, in plane of biseriality, extending from inner margin almost to apex of final chamber.

Dimensions: The holotype measures 0.74 mm in length, 0.37 mm in breadth, and 0.27 mm in thickness. Other specimens range up to 0.85 mm in length.

Remarks: *Textularia vitrea* n. sp. can be distinguished by its pointed, compressed, and sometimes twisted early portion, somewhat oblique sutures, narrow slit-like aperture in the plane of biseriality and smooth test wall. Similar species are *T. subglabra* Cushman and *T. washitensis* Carsey, both of which lack *T. vitrea's* distinctive aperture. *T. vitrea* n. sp. further differs from the former by its more elongate form and from the latter by its thickened later chambers and by its oblique sutures.

Types: Holotype 47007, paratypes 47008 and 47009, locality D-3467.

Family VERNEUILINIDAE Cushman, 1927

Genus *Uvigerinammina* Majzon, 1943*Uvigerinammina pacifica* n. sp.

Plate 11, figures 4-6

Test free, elongate, initially flaring, four chambers in first whorl, four to five in second whorl, later reduced to loosely triserial arrangement that usually is little flaring or with parallel sides; chambers in initial portion generally indistinct, rapidly increasing in size, closely appressed, later more loosely arranged, distinct, somewhat inflated, increasing gradually in size as they are added, invariably compressed in preservation; sutures distinct only in triserial stage where they are depressed; wall finely to coarsely arenaceous, either smoothly or roughly finished; aperture terminal, rounded, at end of short neck.

Dimensions: The holotype (figure 4) measures 0.74 mm in length and 0.27 mm in breadth. The length of the paratypes in figures 5 and 6 are 0.78 mm and 0.71 mm respectively. Other specimens are from 0.42 to 1.10 mm in length.

Remarks: Superficially, this species is similar to *Uvigerinammina manitobensis* (Wickenden) and *U. athabascensis* (Mellon and Wall) but differs in

its beginning trochoid spire of four chambers and by its elongate, slightly-flared to parallel-sided triserial section. Like the Alaskan representatives of *U. manitobensis* identified by Tappan (1962, p. 145, pl. 33, figs. 18-23), this species seemingly has a chitinous base inasmuch as the specimens are generally compressed or otherwise distorted, especially the last-formed chambers, while other species in the same samples often show no distortion. Many of the individuals, particularly the more narrow ones, show a tendency to a biserial arrangement in the final stage of chamber development, a characteristic also developed in the genotype and in the two known Canadian-Alaskan species (Tappan, *ibid.*).

Types: Holotype 47010 and paratype 47011, locality D-3454; paratype 47012, locality D-3455.

Genus *Spiroplectinata* Cushman, 1927

Spiroplectinata californica n. sp.

Plate 11, figures 7, 8

Test free, broadly elongate, compressed, earliest portion triserial, later biserial, commonly with final short uniserial stage; two generations present, a small microspheric one with distinct triserial and biserial stages, and a large megalospheric form with a maximum of twelve biserial chamber pairs and with or without an incipient early triserial portion; periphery sharply rounded to acute, slightly scalloped in plan view; initial triserial chambers triangular in transverse section, biserial chambers long, low, and oblique, regularly enlarged as added except for slightly inflated and narrowed final one or two pairs, uniserial stage limited to one to three swollen chambers; sutures distinct, oblique with long axis of test, slightly depressed, straight; wall finely arenaceous, with much cement, smoothly finished; aperture in biserial portion initially an interiomarginal slit, later rounded and subterminal, but terminal, large, round, and with a short neck in uniserial chambers.

Dimensions: The holotype, a megalospheric individual, measures 1.05 mm in length, 0.48 mm in breadth, and 0.21 mm in thickness. The length of the paratype in figure 8, a microspheric individual, is 0.30 mm. Other megalospheric specimens, although usually with the earliest chambers missing, range up to 1.11 mm in length. The largest microspheric individual at hand is 0.31 mm in length.

Remarks: The microspheric generation invariably is smaller and thicker, and it develops a distinct triserial initial portion, and up to six pairs of biserially arranged chambers. The megalospheric generation is twice the size of the microspheric one, and is very compressed except for the last row or two of chambers. It may develop a minute triserial stage which usually is broken off, or it may simply initially form up to twelve pairs of biserially arranged chambers. If present, uniserial chambers

are bulbous; they may either partially overlap the preceding one or they may be loosely arranged and appear to be connected by stolon-like attachments.

Spiroplectinata californica n. sp. differs from all other described species of the genus *Spiroplectinata* by its rounded periphery, slightly depressed sutures, and, especially in the megalospheric generation, by its distinctive long, low, biserially arranged chambers. The microspheric generation closely resembles *S. annectens* (Parker and Jones) but it can be distinguished by its thicker test, lower chambers, and more rounded periphery.

This is the first record of *Spiroplectinata* from California.

Types: Holotype 47013; paratypes 47014, 47015, and 47016; locality D-3468.

Family VALVULINIDAE Berthelin, 1880

Genus *Eggerella* Cushman, 1933

Eggerella popenoei n. sp.

Plate 11, figure 9

Test free, small, subglobular, the last three chambers taking up nearly the whole periphery of the test, triserial; chambers initially indistinct, later distinct and somewhat inflated, enlarging very rapidly as they are added; sutures initially indistinct, but distinct and depressed in the final whorl; wall arenaceous, typically with a rough exterior but occasionally rather smoothly finished; aperture umbilical, a tiny low arch, sometimes slit-like.

Dimensions: The holotype measures 0.42 mm in length, 0.37 mm in breadth, and 0.41 mm in thickness. Other specimens may be thicker than long, as is the largest individual encountered, its thickness being 0.55 mm.

Remarks: This conspicuous species can be recognized by its very short spire and centrally placed tiny aperture. *Eggerella popenoei* n. sp. is close to *E. inflata* (Franke) from the Senonian of northern Germany, which, however, differs in the development of a lip that surrounds the aperture. Another similar species is *Eggerella* aff. *E. trochoides* (Reuss) from the Cenomanian of Morocco (Corbonnier, 1952, p. 113, pl. V, figs. 3a, b), which can be distinguished from *E. popenoei* n. sp. by its more extended spiral and rather long slit-like aperture.

This species is named for Dr. W. P. Popenoe in recognition of his contributions to the biostratigraphy and invertebrate paleontology of the California Cretaceous.

Types: Holotype 47017, locality D-3503; paratypes 47018 and 47019, locality D-3469.

Genus *Dorothia* Plummer, 1931

Dorothia invenusta n. sp.

Plate 11, figures 10, 11

Test free, elongate, initial portion bluntly rounded, sides nearly parallel, subround in trans-

verse section, periphery broadly rounded; chambers indistinct, numerous in initial portion, probably four to five chambers per whorl, rapidly reduced to two per whorl, with up to seven or eight pairs of chambers; sutures obscure for the most part but occasionally visible in early multiserial stage when dampened, those in biserial stage only occasionally developed as faint depressions; wall thick, fine- to medium-grained, with much cement, smooth to medium granular in appearance; aperture a small low arch at the base of the final chamber.

Dimensions: The holotype in figure 10 measures 0.88 mm in length, 0.32 mm in breadth, and 0.21 mm in thickness. The length of the paratype in figure 11 is 0.96 mm. Other specimens range up to 1.22 mm in length.

Remarks: This species is distinguished by its general lack of external character and by its thickened test wall. *Dorothia invenusta* n. sp. is similar in appearance to *D. hokkaidoana* Takayanagi, from the Late Cretaceous of Japan, but it lacks the constantly distinct depressed sutures in the biserial portion of the test.

Types: Holotype 47020, paratypes 47021 and 47022, locality D-3454.

Family TROCHAMMINIDAE Schwager, 1877

Genus *Trochammina* Parker and Jones, 1859

Trochammina tehamaensis n. sp.

Plate 11, figure 12

Trochammina sp., CHURCH, 1968, p. 533, pl. 1, figs. 1a-c.

Test free, low trochospiral, dorsally flat to gently convex, slightly ventroconvex, umbilicate, outline lobulate, periphery broadly to sharply rounded, all of the two and one-half whorls visible on the dorsal side, only final whorl visible ventrally; chambers distinct, subglobular, five to six in final whorl, gradually increasing in size as added; sutures distinct although occasionally initially indistinct on dorsal side, depressed, radial ventrally, oblique dorsally, straight to slightly curved; umbilicus narrow, depressed; wall coarsely agglutinated, composed of angular quartz grains, with minor cement, somewhat roughly finished; aperture an arched slit at base of ultimate chamber.

Dimensions: The holotype measures 0.89 mm in greatest diameter and 0.37 mm in thickness. Other studied specimens range in greatest diameter from 0.35 to 0.95 mm though deformed individuals may be larger.

Remarks: This species is similar to several others in the literature but its characteristics do not appear to be combined in any other Cretaceous trochamminid. *Trochammina tehamaensis* n. sp. most closely resembles *T. lattai* Loeblich and Tappan from which it can be distinguished by its much larger size and more roughened surface; fu-

ture work, however, may prove them to be synonymous. Other species which might be confused with *T. tehamaensis* n. sp., such as *T. taylorana* Cushman, *T. obliqua* Tappan, and *T. wickendeni* Loeblich, differ in their much smaller size and in their much smoother external surfaces. *T. depressa* Lozo and *T. diegoensis* (Carsey) differ from *T. tehamaensis* n. sp. in possessing more chambers per whorl and more flattened tests; *T. depressa* also is much smaller and its chambers increase rapidly in size as they are added.

This species has been compared with the figured specimen of *Trochammina* sp. of Church (*supra cit.*), from the Hex Formation, Kern County, California, and it appears to be conspecific.

Types: Holotype 47023, locality D-3454; paratypes 47024 and 47025, locality D-3450.

Family LAGENIDAE Schultze, 1877

Genus *Saracenaria* DeFrance, 1824

Saracenaria cretacea n. sp.

Plate 12, figures 1, 2

Test free, elongate, early portion planispirally coiled, compressed, later uncoiling and gently arcuate, roughly triangular in transverse section, dorsal margin acute, slight keel often developed in planispiral stage, ventral margin gently convex, apertural face inflated; five to seven low, elongate, non-inflated chambers in last whorl of coil increasing gradually in size as added, followed by up to four little inflated uniserial chambers increasing very little in height and narrowing slightly in side view; sutures distinct, gently to faintly curved, limbate and flush in planispiral stage but narrow and incised in uniserial stage; wall calcareous, finely perforate, both inner margins with a longitudinal costa, with additional variable costae in between that are continuous across sutures, rarely one to two costae likewise present on sides and parallel to dorsal margin; aperture at peripheral angle, radiate, slightly produced.

Dimensions: The holotype in figure 1 measures 0.58 mm in length, 0.37 mm in breadth, and 0.22 mm in thickness. Measurements of the paratype in figure 2, the largest individual at hand, are length 0.68 mm, breadth 0.41 mm, and thickness 0.27 mm.

Remarks: This species' distinguishing characteristics are a large initial planispirally coiled portion, followed by uniserial chambers characterized by little increase in height and a slight narrowing when viewed from the side, and a variably costate ventral margin. The most similar-appearing species, *Saracenaria reesidei* Fox, from the lower Coloradoan of Wyoming, lacks the large initial planispiral coil and gently curved sutures of *S. cretacea* n. sp. In outline, *S. cretacea* n. sp. is most similar to *S. aculeata* Espitalié and Sigal, but it differs from that species in most other respects.

Types: Holotype 47026, paratypes 47027 and 47028, locality D-3461.

Genus *Lingulina* d'Orbigny, 1826
Lingulina buddencanyonensis n. sp.

Plate 12, figure 3

Test free, small, ovate in outline, uniserially arranged, rectilinear, initial end pointed, sub-elliptical in cross-section; adult with five to six chambers, overlapping, rapidly increasing in size as added, slightly inflated, last chamber making up almost one-half of the test; sutures distinct, flush; wall calcareous, finely perforate, smoothly finished; aperture terminal, a narrow slit parallel to long axis of elliptical cross-section.

Dimensions: The holotype measures 0.34 mm in length, 0.23 mm in breadth, and 0.20 mm in thickness. Maximum length of other specimens ranges from 0.24 to 0.37 mm.

Remarks: *Lingulina buddencanyonensis* n. sp. can be recognized by its ovate shape, sub-elliptical cross-section and small size. A somewhat similar species, *Lingulina* sp. 3, described by Bartenstein and Brand (1951, p. 301, pl. 8, figs. 193a, b) from the Early Cretaceous of northwestern Germany, is more elongate, develops about seven chambers, and is almost twice the length of *L. buddencanyonensis* n. sp.

Types: Holotype 47029 and paratype 47030, locality D-3443.

Astacolus de Montfort, 1808
Astacolus onoanus n. sp.

Plate 12, figure 4

Test free, elongate, compressed, dorsal periphery sharply rounded, initial stage a loose incipient planispiral coil, later uncoiling; chambers not inflated, narrow, arcuate, increasing gradually in size as added; sutures distinct, limbate, elevated, gently curving, coalescing at dorsal periphery to form thickened margin; apertural face flat to slightly convex, bordered by elevated presutural margin; wall calcareous, finely perforate, smooth; aperture terminal, marginal, radiate.

Dimensions: The holotype measures 0.58 mm in length, 0.31 mm in breadth, and 0.14 mm in thickness. Other specimens range in length from 0.41 mm, for immature individuals, to 0.84 mm.

Remarks: *Astacolus onoanus* n. sp. is distinguished from similar-appearing species by its sutures which are gently curved, limbate and elevated, and which fuse at the dorsal margin to form a sharply rounded periphery. It is rather similar to *Cristellaria bradyana* Chapman but does not develop the more narrow and beaded sutures and acute outer margin of that species. It likewise bears some resemblance to *Lenticulina (Planularia) crepidularis crepidularis* (Roemer) as described and illus-

trated by Michael (1967, p. 37, pl. 3, fig. 4; pl. 18, fig. 49; and pl. 19, fig. 29) but it lacks a keel at the outer margin and narrow sutures.

Types: Holotype 47031 and paratype 47032, locality D-3562.

Family POLYMORPHINIDAE d'Orbigny, 1839
Genus *Falsoguttulina* Bartenstein and Brand, 1949
Falsoguttulina diversa n. sp.

Plate 12, figure 5

Test free, small, subdeltoïd to bulbous in side view, irregularly oval to triangular in plan view, triangular in apertural view, greatest diameter in dorsal one-third of the test; chambers elongated, arranged in low quinqueloculine series with each added chamber more removed from base, early chambers embracing and somewhat inflated, later ones less embracing and less inflated to slightly compressed with distal edge correspondingly more sharply rounded; sutures thin, flush to slightly depressed, occasionally indistinct; wall calcareous, finely perforate, smooth; aperture terminal, a thin, straight slit.

Dimensions: The holotype measures 0.27 mm in length, 0.23 mm in breadth, and 0.22 in thickness. Other specimens range in length to 0.30 mm but individuals wider than long occasionally occur, the greatest breadth measured being 0.32 mm.

Remarks: This species differs from others in the genus *Falsoguttulina* in lacking strongly embracing and inflated later chambers and a broadly rounded periphery. Specimens of *F. diversa* are rather variable, especially in outline, thickness, and degree of overlap of the younger chambers.

This is the first record of *Falsoguttulina* on the Pacific Coast.

Types: Holotype 47033 and paratype 47034, locality D-3534; paratypes 47035 and 47036, locality D-3475.

Family BULIMINIDAE Jones, 1875
Genus *Praebulimina* Hofker, 1951
Praebulimina churchi n. sp.

Plate 12, figures 6, 7

Praebulimina sp., CHURCH, p. 570, pl. 8, figs. 1a, b.

Test free, fairly small, triserial throughout, flaring from a bluntly rounded base, greatest breadth about one-third distance from apertural end, sub-circular in transverse section; chambers low, somewhat inflated, increasing rather rapidly in size as added; sutures distinct, depressed, oblique; wall calcareous, finely perforate, generally smooth but occasionally faintly hispid near base; aperture, a very narrow slit paralleling the inner margin of the apertural face, at the base of the last chamber, often indistinct.

Dimensions: The holotype in figure 6 measures 0.31 mm in length and 0.22 mm in breadth. The

paratype in figure 7 is 0.27 mm in length. Other specimens range up to 0.48 mm in length and 0.27 mm in breadth but deformed individuals may exceed these sizes.

Remarks: *Praebulimina churchi* n. sp. can be distinguished easily from all other praebuliminid species by its peculiar small slit-like aperture that parallels the inner margin of the apertural face.

Some specimens of *Praebulimina seebeensis* Tappan figured by Tappan (1962, pl. 49, figs. 10, 13, 17, 18) develop a high arched aperture parallel at the base of the final chamber that is reminiscent of the aperture of *P. churchi* n. sp. However, the two forms are distinct as apertural development in *P. seebeensis* varies from the aforementioned arch to the usual loop-shaped opening. *P. churchi* n. sp. further differs from *P. seebeensis* by its more flaring test, and obliquely arranged sutures.

The figured specimen of *Praebulimina* sp., reported by Church (*supra cit.*) from a single locality in the Hex Formation, Kern County, California, has been compared with this species and found to be conspecific.

This species is dedicated to Mr. C. C. Church, consulting paleontologist, Bakersfield, California, who first reported it in the literature (*ibid.*).

Types: Holotype 47037 and paratype 47038, locality D-3438; paratype 47039, locality D-3508.

Genus *Orthokarstenia* Dietrich, 1935

Orthokarstenia shastaensis n. sp.

Plate 12, figures 8-10

Test free, elongate, slightly tapering, circular in transverse section, initially triserial, rapidly becoming biserial, then uniserial, rectilinear; chambers distinct, about six in number in short triserial portion, increasing rapidly in size as added, followed by about two biserially arranged chambers, and a uniserial stage of three to six slightly inflated chambers which increase very gradually in size as added, broader than high, somewhat overlapping, making up about upper four-fifths of test; sutures distinct, thin, depressed; wall calcareous, perforate, generally smooth but rarely finely papillate; aperture terminal, an elliptical to circular opening usually at end of a short neck.

Dimensions: The holotype in figure 8 measures 0.78 mm in length and 0.30 mm in breadth. Length of the paratype in figure 9 is 0.58 mm, and for the paratype in figure 10, 0.92 mm. Other specimens range up to 1.05 mm in length, including those that are broken and deformed.

Remarks: No internal tooth plate was found in any of the several half-sections and specimens treated with hydrogen fluoride made to determine their presence, but these delicate structures may have been destroyed during fossilization.

There appears to be no distinction between generations, *i.e.*, a triserial initial stage in the microspheric generation versus a biserial beginning portion in the megalospheric generation, as there is in related species previously described from California. Also missing are reentrants along the lower chamber margins and an apertural tooth, morphologic features present in some other species of this genus.

Orthokarstenia shastaensis n. sp. can be recognized by its generally smooth surface, short triserial initial portion but long uniserial stage, uncomplicated aperture, and apertural neck. These characteristics also serve to distinguish it from its closest morphologically similar form, *Siphogenerinoides pygmaea* de Klsz and Rerat, from the Senonian of Gabon. Also similar is *O. clarki* (Cushman and Campbell), from the uppermost Cretaceous of California, but *O. shastaensis* is smaller, thinner walled, and it develops different apertural characteristics.

Types: Holotype 47040, locality D-3465; paratype 47041, locality D-3463; and paratype 47042, locality D-3580.

Family ROTALIDAE Ehrenberg, 1839

Genus *Valvulineria* Cushman, 1926

Valvulineria subinfrequens n. sp.

Plate 12, figure 11

Test free, trochospiral, umbilicate, dorsal side moderately convex, all chambers visible, ventral side concave, periphery rounded, lobulate in plan view; chambers somewhat inflated, about five in last whorl, increasing regularly in size as added; sutures distinct, depressed, slightly oblique, straight dorsally, faintly curved ventrally; wall calcareous, finely perforate, surface smoothly finished; aperture an interiomarginal arch extending from umbilical area nearly to periphery, bordered above by narrow lip that expands into small valvular flap in umbilicus.

Dimensions: The holotype measures 0.27 mm in greatest diameter and 0.13 mm in thickness. Other specimens range from 0.20 to 0.43 mm in greatest diameter.

Remarks: This species most closely resembles *Valvulineria infrequens* Morrow but it has only five chambers in the final whorl, a deeper umbilicus, and straight to faintly curved sutures.

Types: Holotype 47043, paratypes 47044 and 47045, locality D-3502.

Genus *Gavelinella* Brotzen, 1942

Gavelinella drycreekensis n. sp.

Plate 13, figure 1

Test free, low trochospiral, commonly nearly planispiral, circular in plan view, plano-convex, dorsal side generally flat, infrequently slightly con-

cave, with small umbonal boss, ventral side convex, periphery sharply rounded to subacute, all of the two and one-half to three whorls visible on dorsal side, only final whorl visible ventrally; chambers numerous, distinct, ten to twelve in final whorl, increasing slowly in size as added, later chambers of final whorl tending to be slightly inflated; dorsal sutures gently curved, initially limbate and raised, final two or three narrow and depressed in mature individuals, usually coalescing along spiral suture to form small clear boss over early chambers; ventral sutures initially limbate and raised but last three or four always narrow and depressed, strongly curved in posterior direction about two-thirds distance to the periphery, often weakly sigmoid; umbilicus shallow, with small plug of clear shell material; wall calcareous, finely perforate, smooth; aperture a low equatorial interiomarginal arch extending to umbilicus, with a thin lip.

Dimensions: The holotype measures 0.41 mm in greatest diameter and 0.20 mm in thickness. Other specimens range from 0.27 to 0.64 mm in greatest diameter.

Remarks: *Gavelinella drycreekensis* n. sp. is distinguished by its strongly curved ventral sutures and planoconvex test. It was derived from *G. andersoni* (= *Planulina andersoni* Church, 1968, p. 567, pl. 8, figs. 7a-c) by inflation of the ventral side and by a narrowing and depressing of the youngest few sutures. Transitional forms are common, especially in some samples collected from Dry Creek. This species also compares with *G. eriksdalensis* (Brotzen) of Sliter (1968, p. 123, pl. 23, figs. 6a-c) from which it differs in developing more strongly curved to sigmoid ventral sutures and a planoconvex cross-section.

Types: Holotype 47046; paratypes 47047, 47048, and 47049; locality D-3502.

Genus *Gyroidinoides* Brotzen, 1942

Gyroidinoides subglobosa n. sp.

Plate 13, figure 2

Quadriformina cf. *Q. ruckeri* (Tappan), CHURCH, 1968, p. 566, pl. 8, figs. 1a-2b.

Test free, tiny, trochospiral, subglobular, spiral side gently convex, umbilical side strongly convex, periphery broadly rounded, slightly lobulate in plan view, all chambers of the two to two and one-half whorls visible dorsally, only last whorl visible ventrally; chambers inflated, four to four and one-half in final whorl, increasing gradually in size as added; sutures distinct, slightly curved, depressed; wall calcareous, finely perforate, smooth; aperture a low interiomarginal slit, bordered above by a narrow lip, extending from umbilical area to just short of periphery.

Dimensions: The holotype measures 0.17 mm in greatest diameter and 0.12 mm in thickness. Greatest diameter of other specimens ranges from 0.10 to 0.20 mm.

Remarks: This species is easily recognized by its small size, subglobular shape, and few chambers per whorl. It most closely resembles *Gyroidinoides nitida* (Reuss) but is smaller and has fewer chambers per whorl. *G. bandyi* (Trujillo) also is similar but has more chambers in the final whorl and is much less globose.

This species has been compared with the figured specimen of *Quadriformina* cf. *Q. ruckeri* (Tappan) of Church (*supra cit.*) and found to be conspecific with it.

Types: Holotype 47050, and paratype 47051, locality D-3441; paratype 47052, locality D-3568.

Genus *Osangularia* Brotzen, 1940

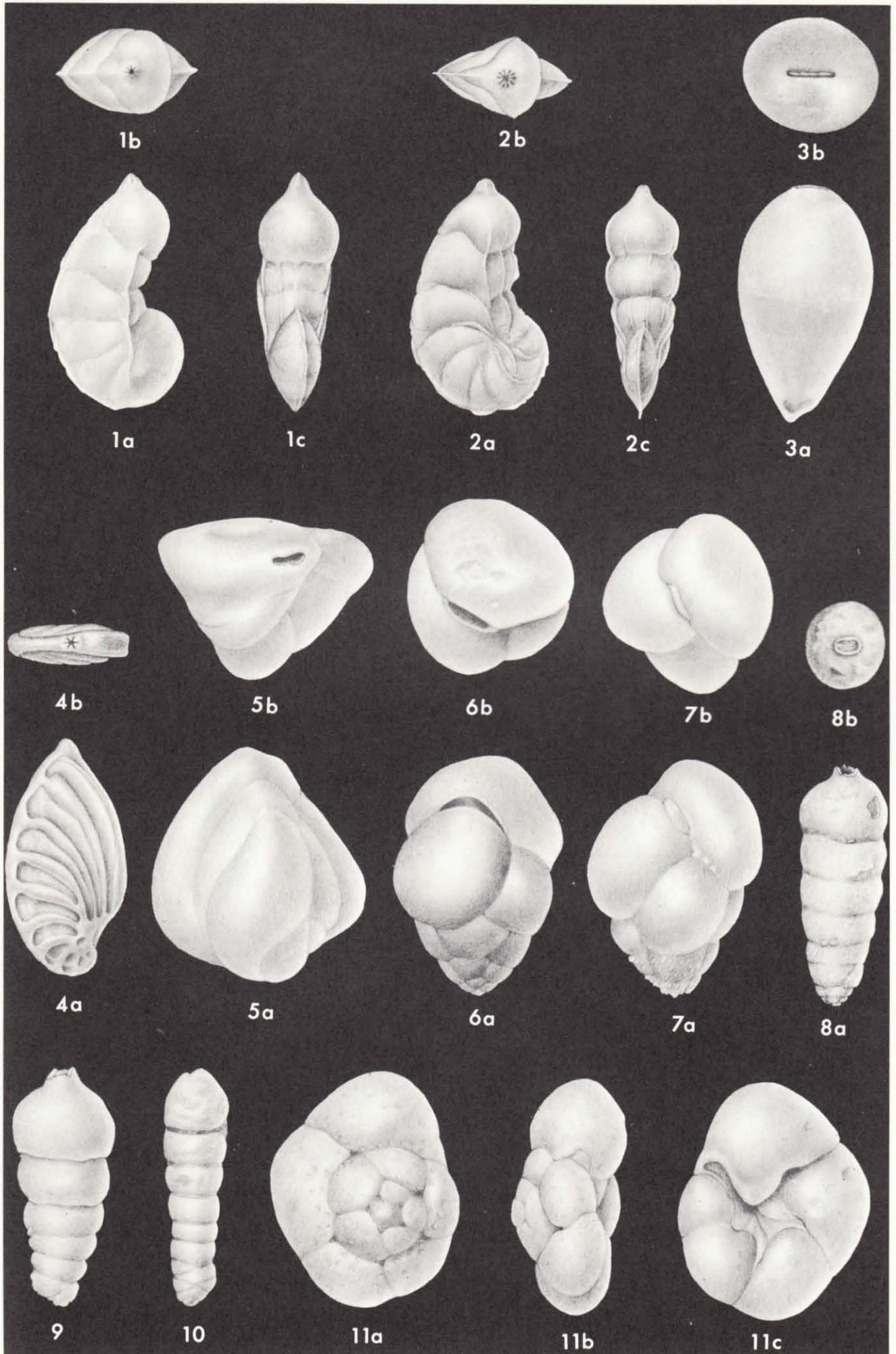
Osangularia californica n. sp.

Plate 13, figures 3, 4

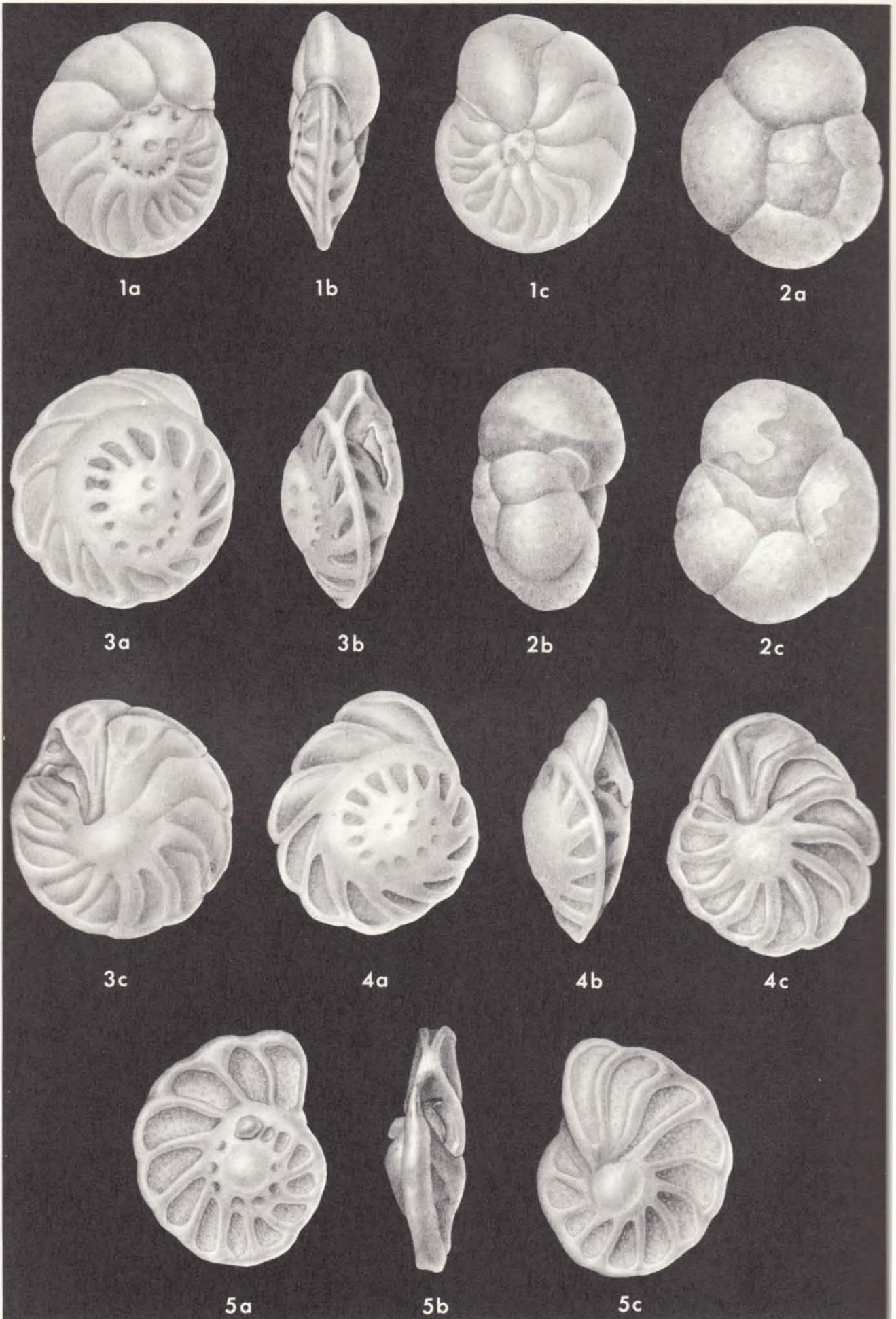
Test free, circular in plan view, equally bicon-

EXPLANATION OF PLATE 12

FIGS.		PAGE
1, 2.	<i>Saracenaria cretacea</i> , n. sp.	105
	1. Holotype 47026, $\times 53$; 2. Paratype 47027, $\times 45$. 1a, 2a. side views; 1b, 2b. top views; 1c, 2c. face views.	
3.	<i>Lingulina buddencanyonensis</i> n. sp.	106
	Holotype 47029, $\times 83$; a. side view, b. top view.	
4.	<i>Astacolus onoanus</i> n. sp.	106
	Holotype 47031, $\times 53$; a. side view, b. top view.	
5.	<i>Falsoguttulina diversa</i> n. sp.	106
	Holotype 47033, $\times 125$; a. front view, b. top view.	
6, 7.	<i>Praebulimina churchi</i> n. sp.	106
	6. Holotype 47037, $\times 100$; 7. Paratype 47038, $\times 109$. 6a, 7a. front views; 6b, 7b. top views.	
8-10.	<i>Orthokarstenia shastaensis</i> n. sp.	107
	8. Holotype 47040, $\times 40$; 9. Paratype 47041, $\times 53$; 10. Paratype 47042, $\times 35$. 8a, 9, 10. side views; 8b. top view.	
11.	<i>Valvulineria subinfrequens</i> n. sp.	107
	Holotype 47043, $\times 109$; a. dorsal view, b. peripheral view, c. ventral view.	



Dailey: California Cretaceous Foraminifera



Dailey: California Cretaceous Foraminifera

vex, trochospiral, periphery acute, two and one-half to three whorls visible on dorsal side, only final whorl visible ventrally, prominent clear ventral umbonal boss, occasional thin deposit of clear shell material deposited over initial whorl on dorsal side; chambers not inflated, commonly ten to twelve in final whorl, increasing gradually in size as added; sutures distinct, oblique, straight to slightly curved dorsally, initially gently curved but becoming strongly curved ventrally, limbate and raised although final two or three often becoming thin and depressed on ventral side, meeting at periphery to form acute elevated margin; wall calcareous, finely perforate, smooth; aperture "V" shaped, a slit at the base of the final chamber then bending obliquely up apertural face, occasionally two isolated slits, one interiomarginal, the other areal.

Dimensions: The holotype in figure 3 measures 0.30 mm in greatest diameter and 0.18 mm in thickness. Greatest diameter of the paratype in figure 4 is 0.31 mm. Other specimens range from 0.14 to 0.37 mm in greatest diameter.

Remarks: *Osangularia californica* n. sp. can be recognized by its equally biconvex test, acute periphery, well developed ventral umbonal boss, and sutures that are strongly curved ventrally but straight or little curved dorsally. *O. californica* n. sp. resembles the Late Cretaceous species *O. cordieriana* (d'Orbigny), *O. glabrata* (Cushman), *O. texana* (Cushman), and *O. navarroana* (Cushman), but it develops raised sutures and a prominent ventral umbonal boss. It can be further distinguished from the first three above by its greater number of the chambers per whorl and from *O. glabrata* by its acute periphery.

Types: Holotype 47053, locality D-3474; paratype 47054, locality D-3477; paratype 47055, locality D-3580.

Osangularia insigna n. sp.

Plate 13, figure 5; plate 14, figure 1

Test free, flat trochospiral, discoidal, rectangular in cross-section, periphery blunt to truncate, two to two and one-half whorls in adult, all chambers visible on dorsal side, only those in final whorl visible on ventral side; chambers not inflated, increas-

ing gradually in size as added: ten to twelve in final whorl; sutures limbate, raised, oblique, straight to gently curved, with final one or two usually faintly sigmoid, coalescing centrally on ventral side to form a small plug of clear shell material, and coalescing at periphery both dorsally and ventrally to form weak double keels; apertural face bordered both dorsally and ventrally by elevated pre-sutural margins; wall calcareous, finely perforate, smoothly finished; primary aperture a thin interiomarginal slit, with a smaller supplementary oblique areal aperture.

Dimensions: The holotype measures 0.34 mm in greatest diameter and 0.13 mm in thickness. Greatest diameter of the paratype is 0.34 mm. Other specimens range from 0.24 to 0.37 mm in greatest diameter.

Remarks: This distinctive form differs from all other osangularid species in its flat trochospiral, discoidal form, and distinctive blunt to truncate periphery.

Types: Holotype 47056 and paratype 47057, locality D-3502.

Osangularia insigna secunda n. subsp.

Plate 14, figure 2

This subspecies differs from the species proper in its sharply rounded periphery, faint but definite biconvexity, and tendency of adult tests to be bi-umbonate.

Dimensions: The holotype measures 0.37 mm in greatest diameter and 0.17 mm in thickness. Other specimens range from 0.21 to 0.48 mm in greatest diameter.

Remarks: Since these specimens occur in some localities in which the typical forms are absent, they are considered to represent a new subspecies of *Osangularia insigna* n. sp. Immature individuals of this subspecies show their kinship to *Osangularia insigna* sp. by the development initially of a truncate periphery, but this is later masked in adult specimens by the coalescing of sutures at the periphery to form a single sharply rounded border of clear shell material.

Types: Holotype 47058, locality D-3501; paratype 47059, locality D-3504.

EXPLANATION OF PLATE 13

FIGS.	PAGE
1. <i>Gavelinella drycreekensis</i> n. sp. Holotype 47046, $\times 71$; a. dorsal view, b. peripheral view, c. ventral view.	107
2. <i>Gyroidinoides subglobosa</i> n. sp. Holotype 47050, $\times 167$; a. dorsal view, b. peripheral view, c. ventral view.	108
3, 4. <i>Osangularia californica</i> n. sp. 3. Holotype 47053, $\times 100$; 4. Paratype 47054, $\times 100$. 3a, 4a. dorsal views; 3b, 4b. peripheral views; 3c, 4c. ventral views.	108
5. <i>Osangularia insigna</i> n. sp. Paratype 47057, $\times 100$; a. dorsal view, b. peripheral view, c. ventral view.	109

Osangularia occidentalis n. sp.

Plate 14, figures 3, 4

Test free, low trochospiral, compressed, sub-circular in plan view, gently convex dorsally, flat to gently convex ventrally, periphery sharply rounded to acute, all of the two to two and one-half whorls visible on dorsal side, only final whorl visible ventrally; chambers not inflated, commonly ten or eleven in final whorl, increasing gradually in size as added; sutures distinct, strongly curved, occasionally weakly sigmoid on ventral side, oblique, limbate, slightly raised, coalescing centrally on ventral side to form small button of clear shell material; wall calcareous, finely perforate, smooth; aperture V-shaped, an interiomarginal slit between the umbilicus and periphery, with oblique extension onto apertural face.

Dimensions: The holotype in figure 3 measures 0.34 mm in greatest diameter and 0.13 mm in thickness. Greatest diameter of the paratype in figure 4 is 0.32 mm. Other specimens range from 0.20 to 0.62 mm in greatest diameter and from 0.11 to 0.27 mm in thickness.

Remarks: The forms included within this species show a great deal of variation in the degree of limbateness and curvature of the sutures and in the character of the periphery. The variation, although found throughout their range of occurrence, is not transitional and no distinct ranges for the variants are apparent. Hence, further differentiation does not appear to be warranted.

A low trochoid, compressed form with strongly curved slightly elevated sutures serves to distinguish *Osangularia occidentalis* n. sp. from other reported species of the genus *Osangularia*.

Types: Holotype 47060, locality D-3580; paratype 47061, locality D-3462; paratype 47062, locality D-3539.

Genus *Reinholdella* Brotzen, 1948*Reinholdella ultima* n. sp.

Plate 14, figures 5, 6

Test free, trochospiral, biconvex, moreso dorsally than ventrally, circular in plan view, periphery subacute, all of the two and one-half whorls visible on dorsal side, only final whorl visible ventrally, often weakly biumbonate with centrally-located callus-like thickening of shell material; chambers not inflated, five to six in final whorl, gradually increasing in size as added, narrow and arcuate dorsally, triangular-shaped ventrally; dorsal sutures distinct, elevated, limbate, so oblique as to almost parallel the periphery; ventral sutures thin, very slightly curved, flush or slightly depressed, often indistinct; wall calcareous, finely perforate, smooth; primary aperture a low interiomarginal arch at base of last formed chamber; secondary apertures near umbilicus extending as narrow slits anteriorly and

obliquely from sutures, all but youngest one secondarily covered with shell material; internal partition apparently present, extending from umbilical side upward at 45° angle to spiral wall of chamber.

Dimensions: The holotype in figure 5 measures 0.44 mm in greatest diameter and 0.27 mm in thickness. Greatest diameter of the paratype in figure 6 also is 0.44 mm, but its thickness is only 0.22. Greatest diameter of other specimens ranges from 0.20 to 0.54 mm and in thickness from 0.17 to 0.37 mm.

Remarks: The distinctive features of *Reinholdella ultima* n. sp. are its narrow arcuate dorsal chamber pattern and long elevated, limbate dorsal sutures. *Reinholdella perforata* (Kaptarenko-Chernousova), originally described from the Middle Jurassic of the Ukraine, is very similar to *R. ultima* n. sp. but has less oblique, shorter, and less gently curved dorsal sutures.

Internal partitions seem to be present in this species. A half-section cut parallel to the axis of coiling in one specimen does indicate an internal structure, in the chambers of the youngest whorl, extending from the umbilical side upward at a 45° angle to the spiral wall. However, additional sections and treatment with hydrogen fluoride failed to disclose either their definite presence in other chambers or any additional characteristics. All specimens are calcite filled and possibly this structure often was destroyed during fossilization.

This is the first record of *Reinholdella* in the western hemisphere and, also, its first known occurrence in strata as young as Middle Cretaceous. Previously, *Reinholdella* has been reported only from Jurassic strata of Europe (Loeblich and Tappan, 1964, p. C776).

Types: Holotype 47063, locality D-3503; paratype 47064, locality D-3532; paratype 47065, locality D-3477.

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- D-3461. Dry Creek, 2420 feet east and 400 feet south from NW corner of section 8, T. 28 N., R. 7 W., Chickabally Member, about 2225 feet below top.
- D-3462. Dry Creek, 2590 feet east and 290 feet south from NW corner of section 8, T. 28 N., R. 7 W., Chickabally Member, about 2150 feet below top.
- D-3463. Dry Creek, 2230 feet west and 260 feet south from NE corner of section 8, T. 28 N., R. 7 W., Chickabally Member, about 2075 feet below top.
- D-3465. Dry Creek, 675 feet N 61 W from B.M. 879, Chickabally Member, about 1850 feet below top.
- D-3467. Dry Creek, 480 feet N 59 W from B.M. 879, Chickabally Member, about 1775 feet below top.
- D-3468. Dry Creek, 225 feet N 33 W from B.M. 879, Chickabally Member, about 1700 feet below top.
- D-3469. Dry Creek, 180 feet due north from B.M. 879, Chickabally Member, about 1675 feet below top.
- D-3474. Dry Creek, 120 feet east and 100 feet south from NE corner of section 9, T. 28 N., R. 7 W., Chickabally Member, about 1375 feet below top.
- D-3475. Dry Creek, 210 feet east and 60 feet south from NE corner of section 9, T. 28 N., R. 7 W., Chickabally Member, about 1350 feet below top.
- D-3477. Dry Creek, 630 feet east and 50 feet south from NW corner of section 9, T. 28 N., R. 7 W., Chickabally Member, about 1175 feet below top.
- D-3501. Dry Creek, 1015 feet west and 95 feet south from NE corner of section 9, T. 28 N., R. 7 W., Chickabally Member, 75 feet below top.
- D-3502. Dry Creek, 975 feet west and 100 feet south from NE corner of section 9, T. 28 N., R. 7 W., Chickabally Member, 43 feet below top.
- D-3503. Dry Creek, 450 feet N 74 E from B.M. 788, Gas Point Member, 90 feet above base.
- D-3504. Dry Creek, 555 feet N 80 E from B.M. 788, Gas Point Member, 115 feet above base.
- D-3508. Mitchell Creek, 2925 feet east and 325 feet north from SW corner of section 21, T. 30 N., R. 7 W., Chickabally Member, about 945 feet below base of Huling Member.
- D-3531. Mitchell Creek, 2400 feet east and 2360 feet south from NW corner of section 34, T. 30 N., R. 7 W., Chickabally Member, about 1700 feet below top.
- D-3532. Mitchell Creek, 2230 feet west and 2345 feet south from NW corner of section 34, T. 30 N., R. 7 W., Chickabally Member, about 1650 feet below top.
- D-3534. Roaring River, 110 feet east from mouth of Mitchell Creek, Chickabally Member, about 1510 feet below top.
- D-3539. Roaring River, 1400 feet west and 2050 feet north from SE corner of section 34, T. 30 N., R. 7 W., Chickabally Member, about 1220 feet below top.
- D-3562. Wall outcrop at unnamed quarry, 800 feet west and 615 feet north from SE corner of section 1, T. 30 N., R. 7 W., Chickabally Member, about 625 feet below base of Huling Member.
- D-3568. North Fork Cottonwood Creek, 735 feet east and 1830 feet north from SW corner of section 12, T. 30 N., R. 7 W., Chickabally Member, 150 feet below base of Huling Member.
- D-3578. North Fork Cottonwood Creek, 840 feet west and 3290 feet south from NE corner of section 13, T. 30 N., R. 7 W., Chickabally Member, about 1520 feet above top of Huling Member.
- D-3580. Huling Creek, 1960 feet west and 910 feet east from NE corner of section 17, T. 30 N., R. 6 W., Chickabally Member, about 400 feet below top.

APPENDIX

Locality Descriptions

Type specimens of the foraminiferal species included in this report have been collected from the following localities in the Ono Quadrangle (scale 1:62500, edition of 1952). The locality numbers refer to the collections of the Museum of Paleontology at the University of California.

- D-3438. Dry Creek, 70 feet west and 2600 feet south from NE corner of section 12, T. 28 N., R. 7 W., Chickabally Member, about 1070 feet above base.
- D-3441. Dry Creek, 170 feet west and 2430 feet south from NW corner of section 7, T. 28 N., R. 7 W., Chickabally Member, about 1175 feet above base.
- D-3443. Dry Creek, 855 feet east and 1920 feet south from NW corner of section 7, T. 28 N., R. 7 W., Chickabally Member, about 1475 feet above base.
- D-3450. Dry Creek, 675 feet west and 160 feet north from SE corner of section 6, T. 28 N., R. 7 W., Chickabally Member, about 2450 feet below top.
- D-3454. Dry Creek, 660 feet east and 330 feet south from NW corner of section 8, T. 28 N., R. 7 W., Chickabally Member, about 2650 feet below top.
- D-3455. Dry Creek, 860 feet east and 400 feet south from NW corner of section 8, T. 28 N., R. 7 W., Chickabally Member, about 2600 feet below top.

CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
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388. ADDITIONAL OBSERVATIONS ON THE FORAMINIFERAL
GENUS *BULIMINOIDES* CUSHMAN¹

GEORGE A. SEIGLIE²

ABSTRACT

Additional evidence on the plastogamic reproduction of the genus *Buliminoides* Cushman is given. Plastogamic specimens of *B. parallela* are illustrated, while specimens of *B. williamsoniana* and *B. stainforthi* found in the same sample are compared to show morphologic differences. The genus *Buliminoides* is redescribed and the new family *Buliminoididae* is described.

INTRODUCTION

The genus *Buliminoides* Cushman was recently redescribed by Seiglie (1970) based on the description of the genus in the previous literature and on numerous specimens of the genus found off the coast of Puerto Rico and Venezuela. Five species have been reported for Venezuela (Seiglie, 1964, 1965, and 1967).

Seiglie (1969) reported four species for the Cabo Rojo platform, western Puerto Rico. Further sampling off Mayagüez Bay, Puerto Rico, supplied the largest number of specimens found by the writer, including plastogamic pairs that justify an additional note to the paper by Seiglie (1969).

The station that supplied the material for this paper, Pl-2, is located at 18°13'19" North latitude and 67°13'26" West longitude at a depth of 183 meters, off Mayagüez Bay, and 1 Km north of Manchas Grandes Reefs, western Puerto Rico. The sample was taken from a submarine terrace (according to the echo-sound profile) by means of a pipe dredge. The terrace was covered in part by deep-water corals and growing sponges. Difficulties during sampling were caused by bottom prominences, apparently of larger dimensions than deep water corals and offering stronger resistance to

dredging than do sponges. Five hours of work were necessary to obtain the sample, and several times the dredge was almost lost. Snags in the winch cable during the dredging showed the presence of numerous hard prominences in the bottom.

Nearly two hundred specimens of five species of the foraminiferal genus *Buliminoides* were observed at 183 meters. None of the specimens were living, which is in accord with Seiglie's statement (1969) that all the well-known species of the genus live in shallow-water reefs. Their presence at this depth has two possible explanations:

1) The foraminifers were recently transported from the neighboring shallow reefs. However, the many samples taken from the neighboring shallow reefs have yielded no specimens of this genus. 2) *Buliminoides* specimens constitute part of a relict shallow-water reef fauna of Pleistocene age.

The amended description of the genus *Buliminoides*, originally published in Spanish (Seiglie, 1969), is herein given in English with modifications.

The five species found in station Pl-2 were *Buliminoides williamsoniana* (Brady), *B. parallela* (Cushman and Parker), *B. milleti* (Cushman), *B. sp. cf. B. curta* Seiglie, and *B. stainforthi* Seiglie. Six Holocene species of this genus have been reported for the Caribbean Sea and four for the Indo-Pacific region. Two of these, *Buliminoides stainforthi* Seiglie and *B. curta* Seiglie, have not been reported for the Indo-Pacific region, while *B. madagascarensis* has not been reported in the Caribbean Sea.

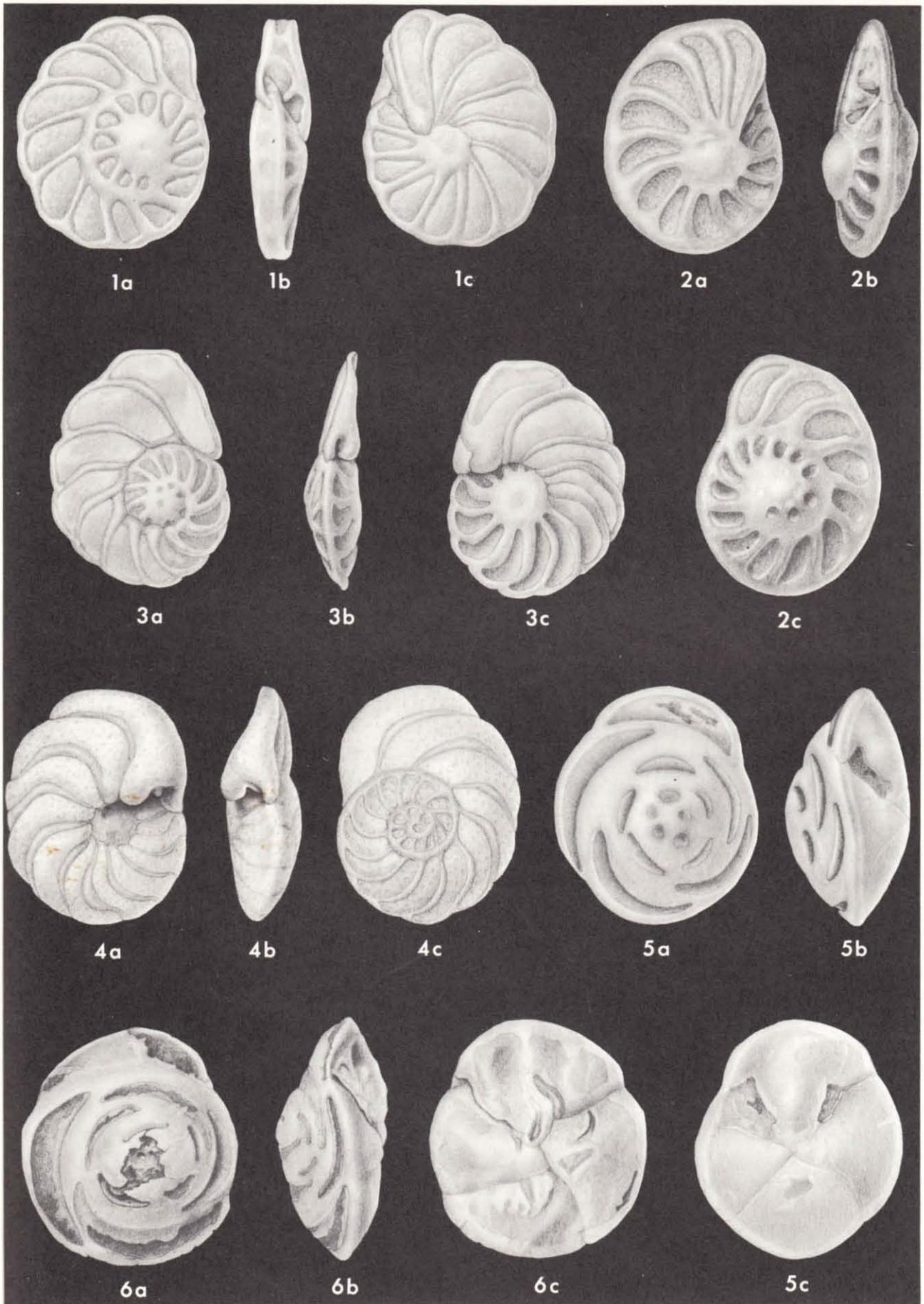
Loeblich and Tappan (1964) included in the genus *Buliminoides* the fossil species *B. chattonensis* (Finlay), and Seiglie (1969) included *B. californica* (Cushman). Also, *Buliminella gracilis* Collins, 1953, clearly belongs in the genus *Buliminoides*.

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EXPLANATION OF PLATE 14

FIGS.	PAGE
1. <i>Osangularia insigna</i> n. sp. Holotype 47056, ×91; a. dorsal view, b. peripheral view, c. ventral view.	109
2. <i>Osangularia insigna secunda</i> n. subsp. Holotype 47058, ×83; a. ventral view, b. peripheral view, c. dorsal view.	109
3, 4. <i>Osangularia occidentalis</i> n. sp. 3. Holotype 47060, ×100; 4. Paratype 47061, ×100. 3a, 4c. dorsal views; 3b, 4b. peripheral views; 3c, 4a. ventral views.	110
5, 6. <i>Reinholdella ultima</i> n. sp. 5. Holotype 47063, ×67; 6. Paratype 47064, ×71. 5a, 6a. dorsal views; 5b, 6b. peripheral views; 5c, 6c. ventral views.	110



Dailey: California Cretaceous Foraminifera

The following species may also belong in this genus: *Buliminella apiculata* (Chapman) var. *hebetata* Cushman and Parker, 1937, *B. bicostata* Parr, 1952, *B. multicamera* Cushman and Parker, 1938, and *B. choctawensis* Cushman and McGlamery, 1938. The holotype of the last species does not show a striated aperture, but the shape of its test is similar to the *Buliminoides* tests and the last chamber appears to be missing.

Other species included in the genus *Buliminella* should be studied for possible removal to a new genus. The inflated test, ornamentation and striated aperture appear to separate them from the genera *Buliminoides* and *Buliminella*. These questionable species include: *B. beaumonti* Cushman and Renz, 1946, *B. dominicana* Bermúdez, 1949, *B. grata* Parker and Bermúdez, var. *spinosa* Parker and Bermúdez, 1937, *B. sculpturata* Keyzer, 1953, and *B. septata* Keyzer, 1953.

The family Glabratellidae and the genus *Buliminoides* possess some common morphological characteristics and, of particular interest, plastogamic reproduction. Two phases of reproduction are present in the life cycle of plastogamic foraminifers, (Loeblich and Tappan, 1964), gamogony and schizogony. Two gamonts are associated in gamogony, fusing by the umbilical surface and producing, without sexual differentiation, gametes, from which, following fertilization, schizonts develop. The schizonts reproduce by multiple fission, a form of asexual reproduction. The chambers of many Glabratellidae and *Buliminoides* increase in size slowly; this, together with the radially arranged striae in the umbilical side or in the terminal face, may be interpreted as a trend to radial symmetry. Both groups of foraminifers inhabit hard bottoms and are especially found in reefs. Radial symmetry characterizes another group of organisms, the coelenterates, many of which incorporate both sexual and asexual modes of reproduction in their cycles. They, too, live mainly on hard bottoms, especially on reefs.

All the specimens were deposited in the collection of the Department of Geology, University of Puerto Rico, Mayaguez, Puerto Rico, with the exception of the specimen represented in text fig. 13, deposited in the collection of foraminifers of the Museo Argentino de Ciencias Naturales, Buenos Aires, Argentina.

Thanks are due to Pedro J. Bermúdez for the critical reading of this paper and to Steve Walsh and the crew of the R/V *Shimada* of the Puerto Rico Nuclear Center, Mayaguez, Puerto Rico.

SYSTEMATICS

BULIMINOIDIDAE FAM. NOV.

Description: Test high, trochospiral, four to five chambers per whorl; wall finely perforate; aperture

in the middle of the terminal face; plastogamic reproduction. Oligocene - Holocene.

Remarks: The plastogamic reproduction of the genus *Buliminoides* justify its separation from the family Turriliniidae Cushman or Buliminidae Jones and the erection of a new family.

Buliminoides Cushman, 1911

Emended description

Buliminoides CUSHMAN, 1911, Bull. 71, U. S. Nat. Mus., pt. 2, p. 90.

Type species: *Buliminoides williamsoniana* (Brady) = *Bulimina williamsoniana* BRADY, 1881, Quart. Jour. Sci., v. 21, p. 56; BRADY, 1884, Rept. Challenger, Zool., v. 9, p. 408, pl. 51, figs. 16, 17.

Test free, short, elongate, conical elongate; chambers arranged in a high trochospiral, the first chambers sometimes in a low trochospiral, four to five chambers per whorl; sutures not depressed, smooth and limbate, sometimes difficult to observe; aperture in a depression of the terminal face of the last chamber, with a tendency to be loop-shaped and provided with radially arranged striae and a tooth-plate; plastogamic reproduction; after plastogamy, aperture enlarged, generally devoid of striae, and frequently covered with a plastogamic plate, the septa resorbed.

Remarks: The genus *Buliminoides* is differentiated from *Buliminella* by the radially striated and non-depressed aperture, the non-globose chambers and by the plastogamic reproduction. *Buliminella* lives generally on nutrient-rich muddy bottoms of the shelf, frequently in embayments having quiet water and, sometimes, a scarcity of oxygen. *Buliminoides* lives in shallow-water reefs in areas of high wave activity and, therefore, in well-oxygenated waters.

After plastogamy, the aperture appears enlarged and open or covered by a yellow to brown plastogamic plate. The septa appear resorbed in each case. The plastogamic plate is also present in at least several species of the genus *Glabratella*.

Seiglie (1969) indicated the similarity between the radial umbilical ornamentation of the Glabratellidae and the radial ornamentation of the terminal faces of *Buliminoides*. This type of ornamentation, at least for these foraminifers, appears to be related to plastogamy and is undoubtedly of taxonomic importance.

Buliminoides williamsoniana (Brady)

Text Figures 1, 2

Bulimina williamsoniana BRADY, 1881, Quart. Jour. Sci., v. 21, p. 56; BRADY, 1884, Rept. Challenger, Zool., v. 9, p. 408, pl. 51, figs. 16, 17.

Remarks: This is the first report of *Buliminoides williamsoniana* in the Caribbean Sea. It is il-

illustrated herein to show the differences with *B. stainforthi* Seiglie. The costae are continuous along the test and they bifurcate when the width of the test increases. The sutures may be observed in the walls between the costae. Four specimens occurred in this station. The two smaller specimens, not illustrated, did not show an enlarged aperture. This species occurs also in Ortigosa Bay, Cuba, at 4 meters depth.

Buliminoides stainforthi Seiglie
forma *typica* and variants

Text Figures 3-6

Buliminoides stainforthi SEIGLIE, 1965, Inst. Oceanogr. Univ. Oriente, Bol., v. 4, no. 1, p. 55, pl. 1, figs. 1-4.

Remarks: All the observed specimens of this species forma *typica* were plastogamic. However, some of the smooth variants are post-plastogamic with an open enlarged aperture or with the aperture covered by a plastogamic plate. A few specimens are intermediate between the rugose typical form and the smaller, smooth variant.

Twenty specimens of this species were observed.

Buliminoides parallela (Cushman and Parker)
Text Figures 13, 14

Buliminella parallela CUSHMAN and PARKER, 1931, U. S. Nat. Mus., Proc., v. 80, art. 3, p. 13, pl. 3, figs. 15a-c.

Remarks: Seiglie (1969) illustrated pre-plastogamic specimens of this species and also post-plastogamic ones with enlarged apertures. The plastogamic specimens illustrated in this paper confirm the type of reproduction for the species.

More than one hundred fifty specimens were observed in the sample from station PI-2.

Buliminoides sp. cf. *B. curta* Seiglie
Text Figure 7

Buliminoides curta SEIGLIE, 1964, Caribbean Jour. Sci., v. 4, No. 4, p. 507, pl. 4, figs. 7-9.

Remarks: This species differs from the typical form in having a more inflated test and weaker costae. However, some specimens of *B. curta* occurring on Cabo Rojo Shelf (Seiglie, 1969) also have weak costae, and the inflated test may be explained by the larger number of chambers.

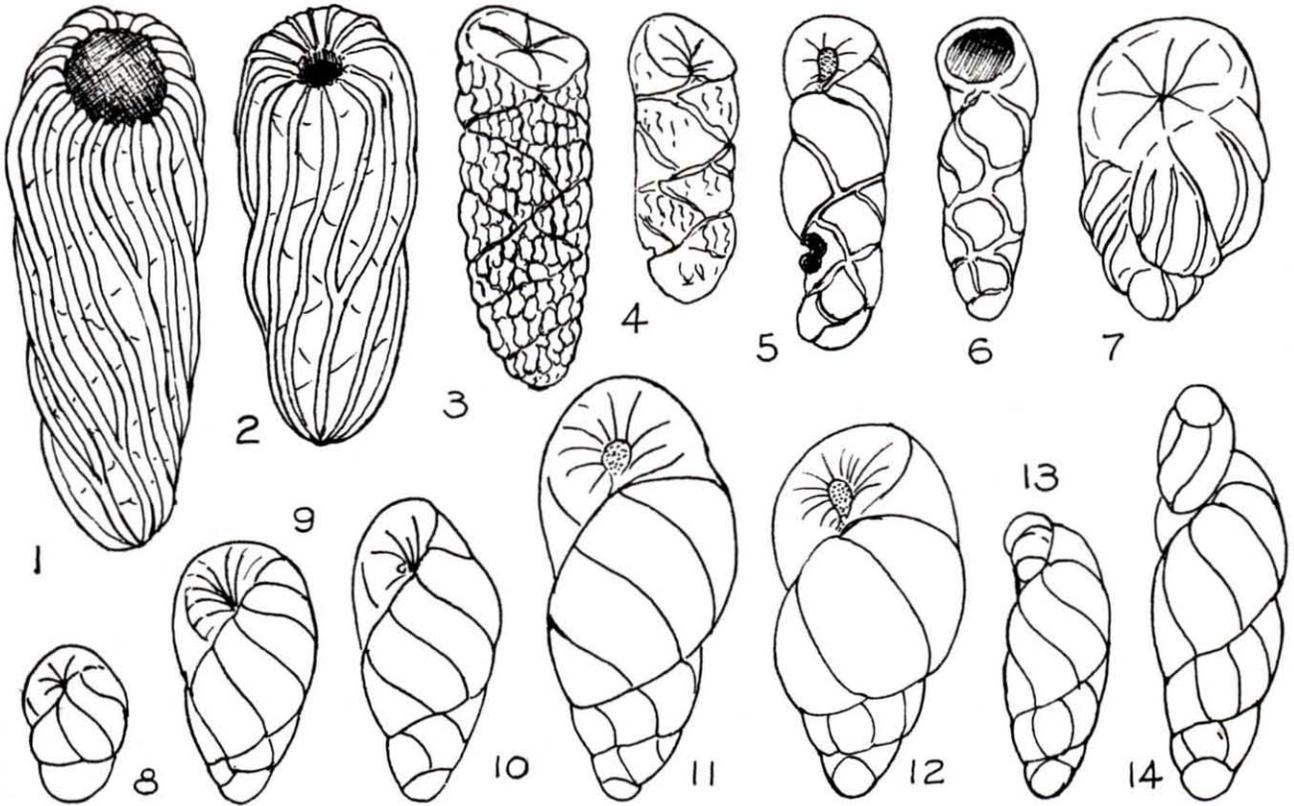
Buliminoides milletti (Cushman)
Text Figures 8 to 12

Buliminella milletti CUSHMAN, 1933, Cushman Lab. For. Res., Contr., v. 9, p. 78, pl. 8, figs. 5, 6.

Remarks: The two largest specimens of *B. milletti* are provided with a plastogamic plate of reddish brown color. Another interesting characteristic of this species is that the size of the proloculus increases as the size of the test decreases, see text figs. 8 to 12. Sidebottom (1905, pl. 2, figs. 8 to 12) illustrated several plastogamic pairs of *B. milletti* from the island of Delos, Mediterranean Sea.

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DESCRIPTION OF TEXT FIGURES

(All specimens from Station Pl-2)

- Text Figs. 1, 2. *Buliminoides williamsoniana* (Brady); fig. 1, length 0.43 mm; fig. 2, length 0.33 mm.
- Text Fig. 3. *Buliminoides stainforthi* Seiglie forma *typica*, preplastogamic specimen, length 0.31 mm.
- Text Figs. 4-6. *Buliminoides stainforthi* Seiglie variants; fig. 4, intermediate variant, between the typical form and the smooth variant, preplastogamic specimen, length 0.22 mm; fig. 5, smooth variant, specimen with plastogamic plate, length 0.24 mm; fig. 6, smooth variant, postplastogamic specimen, length 0.23 mm.
- Text Fig. 7. *Buliminoides* sp. cf. *B. curta* Seiglie; length 0.24 mm.
- Text Figs. 8 to 12. *Buliminoides milletti* (Cushman); fig. 8, preplastogamic specimen, length 0.12 mm; fig. 9, preplastogamic specimen, length 0.21 mm; fig. 10, preplastogamic specimen, length 0.22 mm; fig. 11, postplastogamic specimen, with plastogamic plate, length 0.33 mm; fig. 12, postplastogamic specimen with plastogamic plate, length 0.28 mm.
- Text Figs. 13, 14. *Buliminoides parallela* (Cushman); plastogamic specimens; fig. 13, length 0.20 mm; fig. 14, length 0.295 mm.

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VOLUME XXI, PART 3, JULY, 1970
RECENT LITERATURE ON THE FORAMINIFERA

Below are given some of the more recent works on the Foraminifera that have come to hand.

- ANDAL, PACITA P. A report on the discovery of fusulinids in the Philippines.—Philippines Bureau of Mines, Rept. of Invest., No. 58, March 1966, p. 1-12, pls. 1, 2, text fig. 1 (map).
- ARNOLD, ZACH M. Biological clues in interpreting the biogeography of the foraminifer *Nubecularia lucifuga* DeFrance.—Proc. Internat. Conf. on Tropical Oceanography, 1965, Univ. Miami: Studies in Tropical Oceanography, No. 5, 1967, p. 622-631, text figs. 1-12 (photomicrographs).—Interesting study of specimens collected at Banyuls, France, as well as cultures of the species. On broad intact blades of *Posidonia*, the foram is usually planispiral, and its degree of agglutination appears to be correlated with turbulence. On shreds of dead blades the foram assumes irregular forms. Type of coiling depends on attitude of prolocular stage at time of its attachment. The infraspecific variability revealed in cultures indicates a great inherent variation potential and probable synonymy of many species and genera.
- ATKINSON, KEITH. The association of living Foraminifera with algae from the littoral zone, south Cardigan Bay, Wales.—Jour. Nat. Hist., v. 3, 1969, p. 517-542, text figs. 1-6 (distrib. and abund. table, range chart, graphs, drawings).—The exposed coast, lacking an algal cover, has a very restricted living fauna, only 4 species. Thirteen kinds of algae from rock pools in the eulittoral zone contained numerous living specimens (27 species). Certain algal types provide better environments than others in the same zone. Holdfasts of *Laminaria* in the sub-littoral zone contain the most abundant specimens. Sixty-two species of Foraminifera are recorded, 34 living; 2 species and 2 subspecies are new.
- BARASH, M. S., and GROMOVA, T. S. Paleotemperature analysis of cores by planktonic Foraminifera (in Russian).—Akad. Nauk SSSR, Okean. Komiss., Moscow, 1969, p. 153-164, text figs. 1-3 (graphs), tables 1, 2.—Two Pleistocene cores from the North Atlantic.
- BARTENSTEIN, HELMUT. Das Problem der Gattungs- und Art-Trennung bei Brackwasser-Foraminiferen am Beispiel der weltweit verbreiteten *Jadammina polystoma* und ihrer Verwandten.—Senckenbergiana lethaea, Band 50, No. 4, Nov. 3, 1969, p. 367-375, text figs. 1-22 (drawings).—Discussion of close relationships between *Jadammina* and some brackish-water haplophragmiids and trochamminids.
- BARTLETT, GRANT A. Cretaceous biostratigraphy of the Grand Banks of Newfoundland.—Maritime Sediments, v. 5, No. 1, April 1969, p. 4-14, text figs. 1-4 (correl. diagram, range chart, zone chart, map).—Several hundred feet of section in two wells drilled on the Banks. Sixty-one planktonic species, mostly tethyan, are recorded and indicate ages from Neocomian to Maestrichtian.
- BÉ, ALLAN W. H., and HEMLEBEN, CHRISTOPH. Calcification in a living planktonic foraminifer, *Globigerinoides sacculifer* (Brady).—Neues Jahrb. Geol. Paläont. Abh., Stuttgart, Band 134, heft 3, Jan. 1970, p. 221-234, pls. 25-32, text fig. 1 (diagrams).—The "dehiscens" terminal growth stage occurs rarely in populations of *G. sacculifer* and is considered aberrant. Formation of a calcite crust over the spinose test leads to a smooth cortex and the metamorphosis of *G. sacculifer* into *Sphaeroidinella dehiscens*. Excellent photomicrographs illustrate the transitional stages.
- BELJAEVA, N. Planktonnye Foraminifery v Osadkakh Atlanticheskogo Okeana.—Doklady Akad. Nauk SSSR, tom 183, No. 2, 1968, p. 445-448, text figs. 1, 2 (distrib. maps).
- The distribution of planktonic Foraminifera in sediment cores and methods of their study (in Russian).—Akad. Nauk SSSR, Okean. Komiss., Moscow, 1969, p. 165-175, text figs. 1-3 (graphs).—Two cold and two warm stratigraphic horizons in the Indian Ocean.
- BERGER, WOLFGANG H., and SOUTAR, ANDREW. Preservation of plankton shells in an anaerobic basin off California.—Geol. Soc. America Bull., v. 81, No. 1, Jan. 1970, p. 275-282, text figs. 1-3 (graphs, map), tables 1-5.—*Globigerina bulloides* is more abundant in anaerobic than in aerobic part of Santa Barbara Basin. *G. dutertrei* is more abundant in aerobic than in anaerobic part. Proportion of variant forms, such as small terminal chamber, differs above and below sill depth.
- BERMUDEZ, PEDRO J., and BOLLI, HANS M. Consideraciones sobre los sedimentos del Mioceno Medio al Reciente de las costas central y oriental de Venezuela. Tercera parte. Los

- Foraminiferos planctonicos.—Venezuela Minist. Minas e Hidrocarburos, Bol. Geol., v. 10, No. 20, Dec. 1969, p. 137-222, pls. 1-18, text figs. 1-6 (range charts, map, correl. diagrams).—Sixty-three species and subspecies, 5 species and 1 subspecies new.
- BIELECKA, WANDA, and STYK, OLGA. Assemblage of foraminifers and ostracods in the deposits of clay-siltstone-arenaceous facies of Kujavian and Bathonian age within the Polish Lowland area (English summary of Polish text).—Poland Instit. Geol., Kwart. Geol., tom 13, 1969, p. 619-628, tables 1, 2 (range charts).
- BLANC-VERNET, L., CHAMLEY, H., and FROGET, C. Analyse paléoclimatique d'une carotte de Méditerranée nord-occidentale. Comparaison entre les résultats de trois études: Foraminifères, ptéropodes, fraction sédimentaire issue du continent.—Palaeogeography, Palaeoclimatology, Palaeoecology, v. 6, No. 3, Sept. 1969, p. 215-235, text figs. 1-4 (graphs).—Stages from Würm I/II to post-glacial in a 620-cm core off Provence.
- BLONDEAU, ALPHONSE. Remarques sur *Nummulites germanicus* Bornemann.—Nachr. Akad. Wissenschaft. Göttingen, Math.-phys. Kl. II, Jahrg. 1969, Nr. 14, Aug. 1969, p. 129-135, 1 pl.
- BOLTOVSKOY, ESTEBAN, and LENA, HAYDÉE. Los epibiontes de "Macrocystis" flotante como indicadores hidrológicos.—Neotropica, v. 15, No. 48, 1969, p. 135-137.—Forams attached to floating seaweed can give evidence of the place of origin of the seaweed and thus direction of the surface currents.
- BURMISTROVA, I. I. Quantitative distribution of benthonic Foraminifera in Recent sediments of north region of the Indian Ocean (in Russian).—Akad. Nauk SSSR, Okean. Komiss., Moscow, 1969, p. 176-187, text figs. 1-5 (graphs, distrib. maps).—Quantitative distribution of calcareous and agglutinated forams shown on maps.
- BUTTERLIN, JACQUES, and MONOD, OLIVIER. Biostratigraphie (Paléocène à Éocène moyen) d'une coupe dans le Taurus de Beysehir (Turquie). Etude des "Nummulites cordelées" et révision de ce groupe.—Eclogae geol. Helvetiae, v. 62, No. 2, Dec. 31, 1969, p. 583-604, pls. 1-6, text figs. 1, 2 (map, geol. section, distrib. chart).—Three species of *Ranikothalia*, one new.
- CIFELLI, RICHARD, and SMITH, ROBERTA K. Distribution of planktonic Foraminifera in the vicinity of the North Atlantic current.—Smithsonian Contr. to Paleobiol., No. 4, April 13, 1970, p. 1-52, pls. 1-6, text figs. 1-22 (maps, graphs, check list, diagrams, drawings), tables 1-8.—Twenty-four species (1 new) and 2 subspecies (1 new) from plankton samples from 30 stations across the North Atlantic with quantitative records for some of the species.
- COLE, W. STORRS. Larger Foraminifera of late Eocene age from Eua, Tonga.—U. S. Geol. Survey Prof. Paper 640-B, March 11, 1970, p. 1-17, pls. 1-5.—Nine species, one indeterminate.
- CONKIN, JAMES E., and CONKIN, BARBARA M. Middle Devonian arenaceous Foraminifera of central Ohio. Part 1—Revision of the genus *Webbinoidea* Stewart and Lampe, 1947.—Micropaleontology, v. 16, No. 1, January 1970, p. 1-14, pls. 1-4, text figs. 1, 2 (correl. and stratig. tables).—Many synonyms placed in the type species, *W. similis*, emend., and 4 morphological groups recognized in the single species.
- DANIELS, CURT H. VON, and RITZKOWSKI, SIEGFRIED. Marines Miozän (*Orbulina suturalis*-Zone) in Istrien/Jugoslawien.—Göttinger Arb. Geol. Paläont., Band 5, H. Martin-Festschrift, March 15, 1970, p. 31-36, text figs. 1, 2 (maps), table 1 (range chart).—Marine Miocene confirms existence of a connection between Tethys and Paratethys crossing Istria.
- DHILLON, D. S. An abnormal *Ammotium* from the Holocene, West Malaysia.—Micropaleontology, v. 16, No. 1, January 1970, p. 59-60, text fig. 1 (drawings).—A single specimen of *A. salsum* having 2 apertures.
- DUNCAN, JOHN R., FOWLER, GERALD A., and KULM, L. D. Planktonic foraminiferan-radiolarian ratios and Holocene-Late Pleistocene deep sea stratigraphy off Oregon.—Geol. Soc. America Bull., v. 81, No. 2, Feb. 1970, p. 561-566, text figs. 1-3 (map, correl. diagram, graph).—The change in dominance from planktonic forams below to radiolarians above is dated at about 12,500 years B.P., and marks the Pleistocene-Holocene boundary. Earlier periods of increased radiolarian dominance suggest slight warming periods during the Pleistocene.
- DURDANOVIC, ZARKO. Eine neue Form von *Trocholina* aus den Karnischen Ablagerungen südwestlich von Vojsko (Slowenien-Jugoslawien).—Bull. Géol., Instit. Recherches Géol. Zagreb et Soc. Géol. Croate, tome 21, 1967 (1968), p. 105-110, pl. 1, text figs. 1-5 (drawings).—*Trocholina procera multispiroides* n. subsp.
- EICHER, DON L., and WORSTELL, PAULA. *Lunatriella*, a Cretaceous heterohelical foraminifer from the western interior of the United States.—Micropaleontology, v. 16, No. 1, January 1970, p. 117-121, pl. 1, text figs. 1, 2 (index map, range chart).—*Lunatriella spinifera* n.

- gen., n. sp., seems to have evolved from *Heterohelix pulchra* through the presence of spine-like projections on the later chambers and troughlike flanges below the aperture.
- ERICSON, DAVID B., and WOLLIN, GOESTA. Pleistocene climates in the Atlantic and Pacific Oceans: a comparison based on deep-sea sediments.—*Science*, v. 167, No. 3924, March 13, 1970, p. 1483-1485, text figs. 1-3 (graphs), table 1.—Frequency of the *Globorotalia menardii* complex, coiling direction of *G. truncatulinoides*, and magnetic reversals in 3 cores from the southeast Pacific suggest that times of warm surface water in this area of the Pacific were partly synchronous with times of cool water in the Atlantic.
- FARÈS, F. Foraminifères imperforés du Lias moyen du massif de l'Ouarseries (Algérie).—*Revue de Micropaléontologie*, v. 12, No. 2, Sept. 1969, p. 67-74, pls. 1-3, text fig. 1 (map).—Four species, studied in thin section.
- FUENMAYOR, ANGEL N. Notas sobre *Globigerina sellii* (Borsetti) y su posición estratigráfica.—*Asoc. Venez. Geol., Min. y Petrol.*, v. 12, No. 10, Oct. 1969, p. 357-366, pl. 1, tables 1, 2.—First record of species in Venezuela.
- GLAÇON, GEORGETTE, and SIGAL, JACQUES. Précisions morphologiques sur la paroi du test de *Globorotalia truncatulinoides* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny) et *Globigerinoides trilobus* (Reuss). Réflexions sur la valeur taxinomique des détails observés.—*Compte rendu Acad. Sci. Paris*, tome 269, Sept. 15, 1969, p. 987-989, pl. 1.—Stereoscan illustrations of wall of *G. truncatulinoides* show blunt spines.
- GREINER, GARY O. G. Distribution of major benthonic foraminiferal groups on the Gulf of Mexico continental shelf.—*Micropaleontology*, v. 16, No. 1, January 1970, p. 83-101, text figs. 1-15 (current, temp., salinity charts, maps, graphs, distrib. charts), table 1.—Distributions of agglutinated and porcelaneous groups are plotted on maps. Availability of CaCO_3 is the controlling environmental factor, and this factor depends upon temperature, salinity, and depth.
- GUDINA, V. I., and GOLBERT, A. V. Stratigraphy of marine Pleistocene of North Siberia according to Foraminifera (English summary of Russian text).—*Acad. Sci. USSR, Siberian Branch, Instit. Geol. and Geophys., Problems of the Quaternary Geol. of Siberia, VIII Congress of INQUA, Paris, 1969, Moscow, 1969*, p. 44-55, text figs. 1-10 (diagram, faunal assemblage photos).
- HANSEN, HANS JORGEN, and ANDERSEN, BRUNO BOGE. The occurrence of clinoptilolite-replaced Foraminifera in the Danish Upper Selandian non-calcareous greensand.—*Bull. Geol. Soc. Denmark*, v. 19, haefte 2, Copenhagen, Sept. 11, 1969, p. 197-203, pls. 1-4, text fig. 1 (map), table 1.—Paleocene age determined by replaced Foraminifera (9 species).
- HANSEN, H. J., REISS, Z., and SCHNEIDERMANN, N. Ultramicrostructure of bilamellar walls in Foraminifera.—*Rev. Española Micropaleontología*, v. 1, No. 3, Sept. 1969, p. 293-316, pls. 1-8.—Chamber walls are built of 3 layers: an organic median layer between outer and inner calcareous layers. Illustrations from *Heterolepa*, *Gavelinella*, *Ceratobulimina*, *Globigerinoides*, *Globorotalia*, and *Pulleniatina* by transmission and scanning electron micrographs.
- HERMANN, YVONNE. Arctic ocean Quaternary microfauna and its relation to paleoclimatology.—*Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 6, no. 4, Dec. 1969, p. 251-276, pls. 1, 2, text figs. 1-8 (maps, profile, graphs, diagram), tables 1-3.—Study based on 7 deep-sea cores from the Arctic Ocean Basin between 168° E and 168° W in which Foraminifera-rich beds alternate with Foraminifera-poor beds. Age of cores goes back about 220,000 years. Evidence of Foraminifera and pteropods shows an unchanged cold period back to 70,000 years preceded by a milder interglacial period to 220,000 years. Fourteen planktonic species and over 20 benthonic species of Foraminifera are recorded.
- HILTERMANN, HEINRICH. Fortschritte der Mikropaläontologie in Deutschland mit einer Bibliographie für das Jahr 1968.—*Paläont. Zeitschr.*, Stuttgart, Band 43, Heft 3/4, Sept. 1969, p. 215-229.
- HILTERMANN, H., and KEMPER, E. Vorkommen von Valangin, Hauterive und Barrême auf Helgoland.—*Ber. Naturhist. Ges.* 113, Hannover, 1969, p. 15-37, pls. 1-3.—Foraminifera species listed and a few illustrated from the Barremian.
- HOTTINGER, L. The foraminiferal genus *Yaberinella* Vaughan 1928, remarks on its species and on its systematic position.—*Eclogae geol. Helvetiae*, v. 62, No. 2, Dec. 31, 1969, p. 745-749, pls. 1-5, text figs. 1, 2 (drawings).—*Y. jamaicensis* and *Y. trelawniensis* from the basal middle Eocene of central Jamaica.
- ILYINA, A. P. Nizhneeothenovaja Fauna Mangyslak. —*Russia Vses. nef. nauchno-issl. geol. razved. instit., Trudy, vyp. 268, Paleont. Sbornik 4, 1969*, p. 130-150, pls. 1-7, check

- list.—Includes 6 nummulites and one astero-cyclinid.
- Nummality Verkhnego Eothena Okrestnostej Krasnoarmejska.—Russia Vses. neft. nauchno-issl. geol.-razved. instit., Trudy, vyp. 268, Paleont. Sbornik 4, 1969, p. 164-167, pls. 1, 2.—Five nummulites.
- ILYINA, A. P., and SHMIDT, O. I. Verkhnepaleothenovaja Fauna Mangyshlaka.—Russia Vses. neft. nauchno-issl. geol.-razved. instit., Trudy, vyp. 268, Paleont. Sbornik 4, 1969, p. 84-105, pls. 1-12, map, check list.—Includes one species of *Nummulites*.
- INGMANSON, DALE, and ROSS, ARNOLD. Seasonal changes in Foraminifera at Seahorse Key.—Quart. Jour. Florida Acad. Sci., v. 32, No. 2, June 1969 (Feb. 27, 1970), p. 108-118, text figs. 1-3 (map, graphs), tables 1, 2.—Study based on 5 samples. Species listed and the aggregate fauna plotted quantitatively by months.
- KACHARAVA, Z. D. On new species of *Nummulites* from the upper Eocene deposits of Georgia (English summary of Russian text).—Bull. Acad. Sci. Georgian SSR, v. 55, No. 1, 1969, p. 241-244, text fig. 1.—One new species.
- KHERADPIR, AHMAD. Foraminiferal trends in the Quaternary of Tanner Basin, California.—Micropaleontology, v. 16, No. 1, January 1970, p. 102-116, text figs. 1-11 (maps, graphs, photo of core).—Alternations between cold water faunas (left-coiling *Globigerina pachyderma*) and warmer water faunas (right-coiling *G. pachyderma* and associated warm species) reflect worldwide climatic changes. The two cold water periods are synchronous with low stands of sea level and increase in benthonic numbers.
- KOEHN-ZANINETTI, LOUISETTE. Les Foraminifères du Trias de la Région de l'Almtal (Haute-Autriche).—Jahrb. Geol. Bundes., Wien, Sonderband 14, 1969, p. 1-155, pls. 1-12, text figs. 1-44 (map, drawings, phylogenetic diagram).—Specimens studied in thin section, mostly in Involutinidae, Fischerinidae, and Ammodiscidae, 35 species (5 new and 6 indeterminate) and 3 subspecies (1 new).
- KORNEVA, F. R., and SAIDOVA, KH. M. Sediments stratigraphy of the eastern Mediterranean Sea by benthonic Foraminifera (in Russian).—Akad. Nauk SSSR, Okean. Komiss., Moscow, 1969, p. 188-199, text figs. 1-4 (graphs).
- KRAEVA, E. JA., and ZERNETHKIJ, B. F. Paleontologicheskij Spravochnik, tom 3, Foraminifery Paleogena Ukrainy, 1969, p. 1-197, pls. 1-76, zonal chart.—Illustrated systematic catalog of about 550 species (none new) of smaller and larger Foraminifera from Paleocene to lower Miocene.
- KRASENNIKOV, V. K., MULDINI-MAMUZIC, S., and DZODZO-TOMIC, R. Signification des Foraminifères planctoniques pour la division du Paléogène de la Yougoslavie et comparaison avec les autres régions examinées (French summary of Yugoslavian text).—Bull. Géol., Institut. Recherches Géol. Zagreb et Soc. Géol. Croate, tome 21, 1967 (1968), p. 117-145, correl. chart.—Correlation with other planktonic sequences.
- KURESHY, A. A. The Cretaceous larger Foraminifera of Agra, Iraq.—Jour. Geol. Soc. Iraq, v. 2, No. 1, 1969, p. 13-15.—Species listed from upper Senonian and Maestrichtian.
- KUZNETSOVA, K. I. Kimmeridgian, Volgian and Portlandian stages compared on foraminiferas (based on materials from England and Russian platform) (in Russian).—Izvest. Akad. Nauk SSSR, ser. Geol., No. 10, 1969, p. 119-126, text figs. 1, 2 (drawings), zonation chart.—Two new species, in *Lenticulina* and *Planularia*.
- LÉVY, A., MATHIEU, R., MOMENI, I., POIGNANT, A., ROSSET-MOULINIER, M., ROUVILLOIS, A., and UBALDO, M. Les représentants de la famille des Elphidiidae (Foraminifères) dans les sables des plages des environs de Dunkerque. Remarques sur les espèces de *Polystomella* signalées par O. Terquem.—Revue de Micropaléontologie, v. 12, No. 2, Sept. 1969, p. 92-98, pls. 1, 2, text fig. 1 (map).—Five species of *Cribronion*, 4 of *Elphidium*, and 1 of *Protelphidium*.
- LIPPS, JERE H., and ERSKIAN, MALCOLM G. Plasmogamy in Foraminifera: *Glauertella ornatisima* (Cushman).—Jour. Protozoology, v. 16, No. 3, 1969, p. 422-425, text fig. 1 (stereoscan micrographs).—Illustrated from exposed tide-pools, Bodega Bay, California. Appears to be an adaptation to life in turbulent waters.
- MCGOWRAN, B., and LINDSAY, J. M. A middle Eocene planktonic foraminiferal assemblage from the Eucla Basin.—Geol. Survey South Australia, Quart. Geol. Notes, No. 30, April 1969, p. 2-10, pls. 1, 2, text fig. 1 (range charts).—Illustrations of 16 species.
- MALLORY, V. STANDISH. Lower Tertiary Foraminifera from the Media Agua Creek drainage area, Kern County, California.—Thomas Burke Memorial Washington State Museum, Univ. Wash., Research Rept. No. 2, 1970, p. 1-210, pls. 1-15, text figs. 1-4 (maps, columnar section, check list).—Study based on 91 samples from the Lodo and Tejon formations, 3 members in each. Age ranges from Paleocene to

- lower part of Upper Eocene (Ynezian to lower Narizian). Systematic catalog and check list of 545 species (none new) about a quarter of them illustrated.
- MOHAN, MADAN, and SOODAN, K. S. Middle Eocene planktonic foraminiferal zonation of Kutch, India.—*Micropaleontology*, v. 16, No. 1, January 1970, p. 37-46, pls. 1, 2, text figs. 1-3 (stratig. chart, range chart, columnar section).—Illustration of 24 planktonic species; 4 zones proposed.
- NICHOLS, MAYNARD, and NORTON, WARREN. Foraminiferal populations in a coastal estuary.—*Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 6, No. 3, Sept. 1969, p. 197-213, text figs. 1-6 (maps, drawings, graphs).—In the James River estuary of Chesapeake Bay, 19 species are present; 2 are dominant: *Ammobaculites crassus* and *Elphidium clavatum*. An *Ammobaculites* fauna inhabits the upper reaches and an *Elphidium* fauna the lower estuary. The faunal boundary is sharp and extends upstream in the center of the channel. The boundary is related to salinity (about 14‰) and the distributions shift with the seasons and the changing river flow. Estuarine faunas are characterized by distinct patterns of distribution and sharp boundaries.
- NIKITINA, A. P. First representatives of *Obsoletes*, *Protriticites* and *Fusulina* from the Upper Carboniferous of the Primorye (in Russian).—*Palaeont. Zhurnal*, No. 4, 1969, p. 3-11, pls. 1, 2.—Nine species and 1 subspecies, all new.
- OBA, TADAMICHI. Biostratigraphy and isotopic paleotemperature of some deep-sea cores from the Indian Ocean.—*Sci. Repts. Tohoku Univ.*, 2nd Ser. (Geol.), v. 41, No. 2, Nov. 20, 1969, p. 129-195, pls. 20-23, text figs. 1-27 (maps, profile, graphs, diagrams, foram drawings), tables 1-21.—In 3 cores south of India, 2 temperature oscillations are found.
- PAZDRO, O. Middle Jurassic Epistominidae (Foraminifera) of Poland.—*Zaklad Nauk Geol., Studia Geol. Polonica*, v. 27, 1969, p. 1-92, pls. 1-15, text figs. 1-17 (drawings, graphs), tables 1-3.—Twenty-four species (7 new) and 2 new subspecies.
- PAZOTKA VON LIPINSKI, GÜNTER, and WIEGANK, FRIEDRICH. Foraminiferen aus dem Holozän der Doggerbank.—*Deutsche Akad. Wissenschaften Berlin, Institut für Meereskunde, Beiträge zur Meereskunde, Heft 24-25, III, Sediment und Benthos*, 1969, p. 130-174, pls. 1-14, text figs. 1-3 (drawings, graphs), table (abund. and distrib. chart).—Illustrated systematic catalog of 79 species (none new) and quantitative record of their occurrence in 25 samples of a 3.3-meter core.
- REICHEL, M., SIGAL, J., and MONOD, O. Description d'une Lacazine nouvelle (Foraminifères, Miliolidés) dans le Paléocène du Taurus de Beysehir (Turquie).—*Rev. Española Micropaleontologia*, v. 1, No. 3, Sept. 1969, p. 317-326, pls. 1, 2, text figs. 1-3 (strat. column, diagrams).—*Lacazina blumenthali* n. sp.
- REYMENT, R. A. *Textilina mexicana* (Cushman) from the Western Niger Delta.—*Bull. Geol. Institut. Univ. Uppsala, n. ser.*, v. 1, April 1969, p. 75-81, pls. 1-4, text figs. 1-4 (graphs, drawings, photomicrograph), tables 1-6.
- ROBINSON, E. Stratigraphy and age of the Dump Limestone Lenticle, Central Jamaica.—*Eclogae Geol. Helvetiae*, v. 62, No. 2, Dec. 31, 1969, p. 737-743, pls. 1-3, text figs. 1, 2 (map, geol. section).—Five species, *Fabularia colei* new, from near boundary of Lower/Middle Eocene.
- RUGET, CHRISTIANE, and SIGAL, JACQUES. Les Foraminifères du sondage de Laneuveville-devant-Nancy. (Lotharingien de la région type).—*Sciences de la Terre*, tome 12, Nos. 1-2, March-June 1967, p. 33-70, pls. 1-9, table 1 (range chart).—A predominantly lagenid fauna, containing 96 species, 2 new and 27 indeterminate.
- SAIDOVA, KH. M. Foraminifera, in Tikhij Okean, *Biologija Tikhogo Okeana, Kniga II, Otdel'nyj Ottisk*.—*Akad. Nauk SSSR, Institut. Okean.*, 1968, p. 17-26.—List of species with recorded depths and localities.
- The paleogeography of benthonic Foraminifera and stratigraphy of sediments of boreal and tropical regions of Pacific (in Russian).—*Akad. Nauk SSSR, Okean. Komiss., Moscow*, 1969, p. 200-240, text figs. 1-13 (maps, graphs), tables 1-3.—Numerous Pleistocene cores.
- SAKAGAMI, SUMIO. Fusulinacean Fossils from Thailand, Part IV. On some Permian Fusulinaceans from Peninsular Thailand, in KOBAYASHI, TEIICHI, and TORIYAMA, RYUZO, *Geology and Palaeontology of Southeast Asia*, vol. 6.—*Univ. Tokyo Press*, 1969, p. 265-275, pls. 27, 28.—Ten species, 1 new and 5 indeterminate.
- SALAJ, JOZEF. Essai de zonations dans le Trias des Carpathes Occidentales d'après les Foraminifères.—*Geol. Práce, Geol. Ustav Dion. Stúra, Bratislava, Správy* 48, 1969, p. 123-128, pls. 1-4, table 1 (range chart).—Eleven foram zones between Scythian and Rhaetian.
- SAMANTA, B. K. Taxonomy and stratigraphy of the Indian species of *Discocyclina* (Foraminifera).—*Geol. Mag.*, v. 106, No. 2, March-April

- 1969, p. 115-129, text figs. 1, 2 (range chart, phylogenetic chart), tables 1, 2.—Eighteen valid species.
- SAMPO, M. Microfacies and microfossils of the Zagros area, southwestern Iran (from-pre-Permian to Miocene).—Internat. Sedimentary Petrographical Ser., vol. XII, 1969, p. 1-102, pls. 1-105, text figs. 1-6 (maps, geol. sections, correl. chart).—Book includes many photomicrographs illustrating microfacies. Many Foraminifera are identified in the thin sections.
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