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°C and 22°C. Temperatures outside this range, but between 16°C 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. Molecular 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) clines. 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

Acknowledgement is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this study at the University of California, Los Angeles. Type specimens used in taxonomic identification
were kindly loaned by Richard Cifelli, U. S. National Museum, and Irene McCulloch, Allan Hancock Foundation. Robert G. Douglas, Case Western Reserve University, cooperated in designing and constructing the circulating aquaria and offered advice and criticism of the early manuscript. Thanks are also due C. C. Daetwyler, Esso Production Research Company, Houston, and Helen Tappan Loeblich, University of California, Los Angeles, for critically reviewing the manuscript.

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 $20\pm1^\circ C$, approximating the average summer water temperature at the collection site. All plumbing consisted of flexible ½-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%o. 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 cultured 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.

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

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:15 a.m.</td>
<td>(Day One) Reproductive cyst completed, parental protoplasm mottled.</td>
</tr>
<tr>
<td>3:30 p.m.</td>
<td>Clear nongranular protoplasm extruded (text fig. 4a).</td>
</tr>
<tr>
<td>4:20 p.m.</td>
<td>First discrete, spherical juveniles formed from extruded protoplasm, averaging 30μ in diameter.</td>
</tr>
<tr>
<td>9:00 p.m.</td>
<td>Additional juveniles tightly grouped around parental aperture; most tripartite, yet they retain an unbroken spherical outline (text fig. 4b).</td>
</tr>
<tr>
<td>9:45 a.m.</td>
<td>(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).</td>
</tr>
<tr>
<td>3:15 p.m.</td>
<td>Juveniles penetrated cyst; pseudopodia radiate from position of primary aperture (text fig. 4d).</td>
</tr>
<tr>
<td>5:10 p.m.</td>
<td>Chamber walls flexible but with silver sheen suggesting initial calcification.</td>
</tr>
<tr>
<td>8:00 p.m.</td>
<td>Walls of two-chambered juveniles rigid and calcified as indicated by optical interference figures.</td>
</tr>
</tbody>
</table>

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 370μ 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° ± 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.

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

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

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× 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 angul-aris was added to each dish as required to maintain a continued nutritional substrate.

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

Text fig. 8 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.

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.
The size-frequency distribution of test length in the natural population (text fig. 10) is relatively symmetrical, with a strong mode at 160-170µ. The corresponding size-frequency distribution in the laboratory population is less symmetrical, with the strongest mode at 200-210µ and lesser modes at 120-130µ and 160-170µ. 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 21µ; 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 33µ. 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 100X; hence the continuous

<table>
<thead>
<tr>
<th>Natural Population</th>
<th>Laboratory Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>0.3356</td>
</tr>
<tr>
<td>a</td>
<td>49.1694</td>
</tr>
<tr>
<td>r</td>
<td>0.7102</td>
</tr>
<tr>
<td></td>
<td>0.2346</td>
</tr>
<tr>
<td></td>
<td>47.8364</td>
</tr>
<tr>
<td></td>
<td>0.8744</td>
</tr>
</tbody>
</table>

**TABLE 3**
Values for slope (b), intercept (a), and correlation coefficient (r) for the linear regression \( y = a + bx \) of test dimensions for *Bolivina doniezi* in natural and laboratory populations (text fig. 9).

**TEXT FIGURE 10**
Test-length frequency distribution in *Bolivina doniezi*.
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 12μ. Diameters falling at or near 15μ 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 21μ, and the curve overlap is suggested to fall between 24 and 27μ.

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

Specimens from natural population

Original inoculants of successive clone cultures

TEXT FIGURE 11
Reproductive test dimorphism in Bolivina doniezi. All illustrated by camera lucida.
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 140-150μ and 240-280μ.

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 dimorphism 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.
In the laboratory, reproduction of *Bolivina doniei* 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, 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. doniei* 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

**DISCUSSION**

**TEXT FIGURE 14**

Chamber number distribution in *Bolivina doniei*.

**TEXT FIGURE 15**

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

**EXPLANATION OF PLATE 8**


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
cycles (Myers, 1935; Bradshaw, 1961, 1968) have shown that reproduction of *Patella 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.

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

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

**TABLE 4**

**Foraminiferal Reproductive Temperatures**

**EXPLANATION OF PLATE 9**

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. ×500. 3, 5. ×550. 4. ×650.

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.

Infraspecific 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 genetic 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), *Rotothorilla communis* (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 *Rosalia globularis* d'Orbigny (Arnold, 1954, 1964; Sliter, 1965). Studies of natural foraminiferal populations have shown that differing amounts of infraspecific 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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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 Mariano 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

EXPLANATION OF PLATE 10

Figs.

1-3. Bolivina doniezli 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 ×280.
1b, 2b, 3b. Detail of lower half of each specimen, all ×700.
Sliter: Bolivina doniezi in clonal culture
Dailey: California Cretaceous Foraminifera
CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION FOR FORAMINIFERAL RESEARCH

TEXT FIGURE 2
Index map of the area investigated

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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, Mariano 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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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 Majzón, 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 thinner 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, subrounded 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. latata** Loeblich and Tappan from which it can be distinguished by its much larger size and more roughened surface; future 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** Defracne, 1824
**Saracenaria cretacea** n. sp.
Plate 12, figures 1, 2

Test free, elongate, early portion planispirally coiled, compressed, later uncoiling and gently arculate, 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 (Planulalaria) crepidularis crepidularis (Roemer) as described and illustrated 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, subdeltoid 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 quinquiloculine 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 other members of 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* 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 megaspheric 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 ptygmaea* de Klasz 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** Broten, 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-
Genus *Gyroidinoides* Broten, 1942

*Gyroidinoides subglobosa* n. sp.

Plate 13, figure 2

*Quadrimorpha* 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. handyi* (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 *Quadrimorpha* 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* Broten, 1940

*Osangularia californica* n. sp.

Plate 13, figures 3, 4

Test free, circular in plan view, equally biconvex, 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 liminate 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 liminate 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* (= *Pianolina 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. eriksdalenesis* (Broten) 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.

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**EXPLANATION OF PLATE 12**

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<td>Holotype 47043, ×109; a. dorsal view, b. peripheral view, c. ventral view.</td>
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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 central 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, smoothly 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. corderiana* (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, increasing 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 bi-convexity, and tendency of adult tests to be 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.

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**EXPLANATION OF PLATE 13**

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<td>Holotype 47046, ×71; a. dorsal view, b. peripheral view, c. ventral view.</td>
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<td><em>Osangularia californica</em> n. sp.</td>
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<td></td>
<td>3. Holotype 47053, ×100; 4. Paratype 47054, ×100. 3a, 4a. dorsal views; 3b, 4b. peripheral views; 3c, 4c. ventral views.</td>
<td></td>
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<tr>
<td>5.</td>
<td><em>Osangularia insigna</em> n. sp.</td>
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<tr>
<td></td>
<td>Paratype 47057, ×100; a. dorsal view, b. peripheral view, c. ventral view.</td>
<td></td>
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</table>
Osangularia occidentalis n. sp.

Plate 14, figures 3, 4

Test free, low trochospiral, compressed, subcircular 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 aperture 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, trochosiral, biconvex, more or less dorsoventrally, 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 indiscernible; 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.

REFERENCES


Cushman, J. A., 1948, Foraminifera: their classifi-


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-3458. Dry Creek, 70 feet west and 2600 feet south from NW 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, 850 feet east and 490 feet south from NW corner of section 8, T. 28 N., R. 7 W., Chickabally Member, about 2600 feet below top.

D-3461. Dry Creek, 2420 feet east and 490 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, 2600 feet east and 290 feet south from NW corner of section 8, T. 28 N., R. 7 W., Chickabally Member, about 2550 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 2975 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 1550 feet below top.

D-3477. Dry Creek, 620 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, 42 feet below top.

D-3503. Dry Creek, 450 feet N 74 E from B.M. 788, Gas Point Member, 50 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, 235 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 24, 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 24, 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-3528. Roaring River, 1400 feet west and 2650 feet north from SE corner of section 24, T. 30 N., R. 7 W., Chickabally Member, about 1220 feet below top.

D-3522. 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 510 feet east from NE corner of section 17, T. 30 N., R. 6 W., Chickabally Member, about 400 feet below top.
CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
VOLUME XXI, PART 3, JULY, 1970

388. ADDITIONAL OBSERVATIONS ON THE FORAMINIFERAL
GENUS BULIMINOIDES CUSHMAN1
GEORGE A. SEIGLIE2

ABSTRACT
Additional evidence on the plastogramic reproduction
of the genus Buliminoïdes Cushman is given. Plastogramic
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 Buliminoïdes is redescribed and the new family
Buliminoïdidâe is described.

INTRODUCTION
The genus Buliminoïdes Cushman was recently
redescribed by Seiglie (1970) based on the descrip-
tion 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 sam-
ppling off Mayagüez Bay, Puerto Rico, supplied the
largest number of specimens found by the writer,
including plastogramic pairs that justify an addi-
tional 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 (acc-
cording to the echo-sound profile) by means of a
pipe dredge. The terrace was covered in part by
depth-water corals and growing sponges. Difficulties
during sampling were caused by bottom promi-
ances, 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 Buliminoïdes 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 trans-
ported from the neighboring shallow reefs. How-
ever, the many samples taken from the neighbor-
ing shallow reefs have yielded no specimens of this
genus. 2) Buliminoïdes specimens constitute part
of a relict shallow-water reef fauna of Pleistocene
age.

The amended description of the genus Bulimino-
oides, originally published in Spanish (Seiglie,
1969), is herein given in English with modifications.
The five species found in station Pl-2 were
Buliminoïdes 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 re-
ported for the Caribbean Sea and four for the
Indo-Pacific region. Two of these, Buliminoïdes
stainforthi Seiglie and B. curta Seiglie, have not
been reported for the Indo-Pacific region, while B.
madagascariensis has not been reported in the
Caribbean Sea.

Loeblich and Tappan (1964) included in the genus
Buliminoïdes the fossil species B. chattontensis
(Finlay), and Seiglie (1969) included B. califor-
nica (Cushman). Also, Buliminoïda gracilis Collins,
1953, clearly belongs in the genus Buliminoïdes.

EXPLANATION OF PLATE 14

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   3. Holotype 47060, ×100; 4. Paratype 47061, ×100. 3a, 4c. dorsal views; 3b, 4b. pe-
      ripheral views; 3c, 4a. ventral views.
5, 6. Reinholdella ultima n. sp. ................................. 110
   5. Holotype 47063, ×67; 6. Paratype 47064, ×71. 5a, 6a. dorsal views; 5b, 6b. periph-
      eral views; 5c, 6c. ventral views.
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 Buliminoidea 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. Gamonts 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 coleolaterates, 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, Mayagüez, 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.

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SYSTEMATICS

BULIMINOIDEIDAE 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 Turrilinidae Cushman or Buliminidae Jones and the erection of a new family.

Buliminoides Cushman, 1911

Emended description


Type species: Buliminoides williamsoniana (Brady) = Bulmina 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

Bulmina 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.

**Buliminoïdes stainforthi** Seiglie

*forma typica and variants*

Text Figures 3-6


**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.

**Buliminoïdes parallela** (Cushman and Parker

Text Figures 13, 14


**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.

**Buliminoïdes sp. cf. B. curta** Seiglie

Text Figure 7


**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.

**Buliminoïdes milletti** (Cushman

Text Figures 8 to 12

*Buliminella milletti* Cushman, 1933, *Cushman Lab. Foram. 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.

**BIBLIOGRAPHY**


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 paralela* (Cushman); plastogamic specimens; fig. 13, length 0.20 mm; fig. 14, length 0.295 mm.
CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
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.


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 Bayyuls, 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 proclocular stage at time of its attachment. The intra-specific 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 abnd. 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.


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