Microdistribution of Foraminifera in a Single Bed of the Monterey Formation, Monterey County, California

ROBERTA K. SMITH
and
MARTIN A. BUZAS

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ABSTRACT

Smith, Roberta K., and Martin A. Buzas. Microdistribution of Foraminifera in a Single Bed of the Monterey Formation, Monterey County, California. *Smithsonian Contributions to Paleobiology,* number 60, 33 pages, 4 figures, 2 plates, 7 tables, 1986.—While several papers exist on the small scale spatial distribution of living foraminifera, almost no work exists on the small scale spatial distribution of fossils. The present study took 24 (5 ml) replicates 10 cm apart along one bed of the Montery Formation in California.

The mean density for all replicates is 6084.96 with a standard deviation of 8776.95. Both inspection and a cluster analysis of the data indicate replicates 20–24 have a much higher density and different rank order of abundance than replicates 1–19. The mean density for the total of all species in replicates 1–19 is 2387.47 with a standard deviation of 1175.58. For replicates 20–24 the mean density is 20135.40 with a standard deviation of 11181.40. The spatial variability is so great that four replicates (more than commonly taken) would only allow us to be 95% confident that we are within 50% of the true mean. Because age determination is based on presence of particular taxa rather than on densities, stratigraphic assignment would still be possible.

The three species dominating the 1–19 group make up from 86% to 99% of the fauna. The three species dominating the 20–24 group make up from 77% to 85% of the fauna. Two of these are also dominant in the 1–19 group, but the most dominant species in the 20–24 group constitutes only <1% to 8% in the 1–19 group.

The greatest number of species (22) occurs in the 20–24 group, as would be expected from the densities. The 1–19 group has 16 species. The information function is also highest in the 20–24 group.

An attempt was made to achieve the faunal composition of the 1–19 group for replicates 20–24 by removal of percents of small-sized taxa. Comparable relative abundances are best achieved by removing 100% of *Epistominella subperuviana* and 95% of *Bolivina brevior* and other significant small-sized species. Total specimen numbers for both small- and large-sized species remains higher in replicates 20–24 than in 1–19, however. Thus, analysis of species percentages and species specimen size indicates that while transportation—winnowing—of small specimens (or large specimens) into or out of the environment of deposition may be significant, it does not account for the differences between replicates 1–19 and 20–24. Therefore, either two habitats or some other mode of allocthonous enrichment or depletion rather than particle size winnowing must be invoked to account for the observed distribution.

The low numbers of species, especially with so many individuals, indicates the fauna probably lived under stressful conditions. Low amounts of available oxygen may have caused the stress.

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Contents

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Introduction

Several studies of small-scale spatial distribution exist for living populations of benthic foraminifera (e.g., Parker and Athearn, 1959; Buzas, 1965, 1968, 1970; Olsson and Ericksson, 1974). In general, these studies showed an inhomogeneous distribution. A quantitative estimate of distributional variability is necessary before we can calculate confidence intervals for foraminiferal density or estimate the number of samples required for an arbitrarily chosen degree of confidence. The number of replicates required and the size or proximity of samples requires an understanding of small-scale spatial distribution.

No direct way exists to pursue biology of fossil foraminifera; for paleobiology it is necessary to rely on work from living populations. Obviously, however, adequate sampling is also essential to paleoecological and paleoenvironmental reconstruction. Paleoecological work has lagged behind ecological in the area of sampling and small-scale spatial distribution.

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Scott (1958) showed that fossil foraminifera were inhomogeneously distributed horizontally and vertically in an outcrop in New Zealand. At two stratigraphic levels in the Upper Tertiary of Maryland, foraminiferal species were homogeneously distributed (Buzas and Gibson, unpublished). We know of no other small scale distribution studies of fossils.

In the present study, we examined the small scale spatial distribution in a single bed—the same stratigraphic horizon—with evenly spaced replicates. We hoped to determine (1) the variability among the replicates; (2) the confidence intervals for mean foraminiferal densities, and the confidence interval or precision obtainable for a given number of replicates; (3) the comparable adequacy of sampling for (a) time-stratigraphic, (b) broadly paleoenvironmental, and (c) paleoecological purposes; and (4) perhaps to draw some paleoecological conclusions about the sampled fauna and its environment.

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Survey, Menlo Park, California, were made available to assistant Sandra Carlson by Drs. K. McDougal and R.V. Poore. Part of the technical assistance was funded through Dr. R.E. Garrison by the National Science Foundation (EAR 76-2213). Drs. S.J. Culver, J.F. Evernden, and M. Gowing read and improved the manuscript, and Drs. J.F. Evernden and F.M. Govean gave other valuable assistance also. We are grateful to these persons and institutions.

The term "clorox" is used throughout the text to indicate the commercial household bleach (sodium hypochloride) that was used, full strength, during the laboratory work.

Methods

FIELD.—The Del Ray Canyon Diatomite member of the Monterey Formation is well exposed in a cut on Toro Road, near Monterey, California (see Figure 1). The bed studied by 24 replicate samples lies midway along the exposure, in unit 10 of Govean and Garrison (1981), approximately 70 m (230 ft) stratigraphically above the base of the ash bed marking the base of the measured section. The boulder used in the pilot sample-preparation technique study came from 1½ m stratigraphically above the 24-replicate bed.

The section shows a series of variously laminated and bedded to massive, softly diatomaceous to hard and cherty, mainly cream-colored marine sedimentary rocks. Externally massive-appearing but laminated, relatively thick beds of soft diatomaceous mudstone predominate. One of these was the source of the boulder used in the pilot study. The bed selected for the 24 replicate study is 8 cm thick and appears internally finely shaly and laminated; it is grayish, weathering orange. It was chosen because (1) it is distinct from the more externally massive under- and overlying beds; (2) its thickness is ideal for the diameter of the coring device used; (3) it is soft enough to drive the coring device into; and (4) (a) it could be seen to contain foraminifera, (b) it was believed that the fauna's taxonomic diversity would be relatively low, and (c) preservation appeared adequate to recover specimens from washed residue of the rock. The bed dips east for approximately 8 m diagonally across the road cut exposure from near the natural surface to the road bed level, approximately 3–4 m elevationally lower.

Twenty four replicate samples were taken 10 cm apart for 336 cm along the bed from the road bed level to a point a meter below the base of the soil profile (see Figure 1). The cut face intersects the bedding at 90 degrees, permitting horizontal penetration of the exposure with the coring device. The coring device was a sharpened steel pipe with a 4 cm internal diameter welded to a steel rod and cross-bar. In spite of the diatomite's softness and porosity, its considerable resistance only permitted driving the corer in 5 to 10 cm. Greater penetration could minimize possible surficial weathering effects. As the rock appears very porous, however, leaching may be general and not confined to surficial layers.

After securing each replicate, it was extruded into a small sample jar. As the diatomite tended to fragment, we could not be sure to reject the possibly more weathered surface 2–3 cm.

LABORATORY SAMPLE PREPARATION EXPERIMENTS.—Various laboratories have experimented with simple to complex methods to extract foraminifera from sediments and rocks, but the efficacy of these methods is not evaluated in the literature. We believe it is useful to include evaluation of preparatory methods because the very significant alterations of species densities which preparation techniques can affect can and do go unrecognized. These can just as seriously invalidate observations as can failure to sample adequately in the field. For this reason, sampling and preparation are treated together in this study.

One reason we chose the soft diatomite was to capitalize on its ease of preparation. We made a pilot study to evaluate the effectiveness of the simplest laboratory preparation methods to ob-

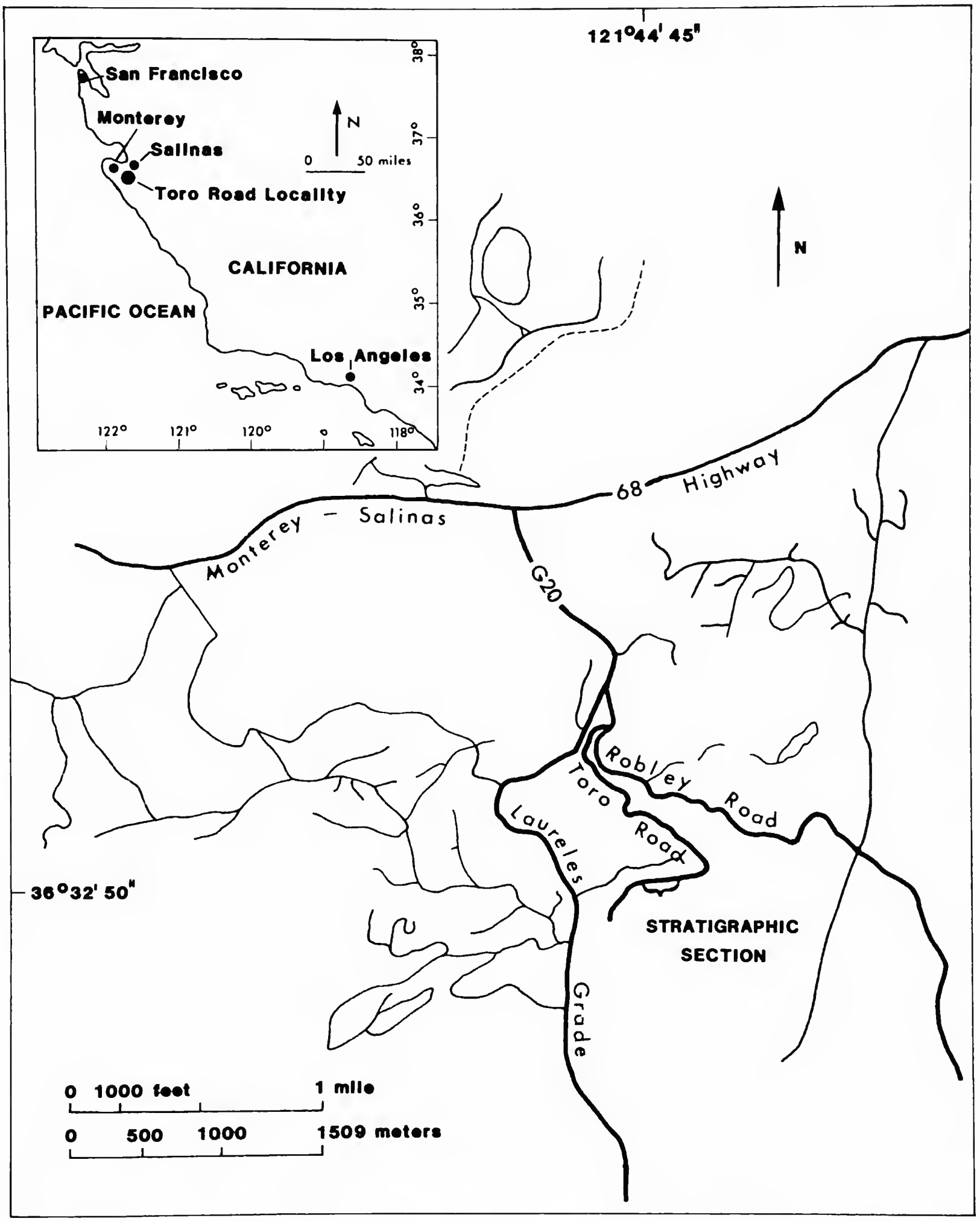


FIGURE 1.—Location of Toro Road stratigraphic section, Monterey Formation, Monterey County, California.

tain (nearly) all tests. The simplest techniques are to soak the material in various solvents, then rinse over sieves with water.

Therefore, we subjected a number of subsamples from a diatomite boulder to soaking for two soaking periods—an arbitrarily chosen 6 months and 24 hours. No regard was paid to the boulder's stratigraphic setting or to spatial relations among subsamples. The first set of 10 subsamples and, later, a second set of 12 (plus one still later) were prepared from "slices" cut from large fragments of the boulder. The "slices" were broken to roughly 1 mm sizes (grains). For each subsample increments of this debris were tamped down until the sediment in a 10-ml beaker reached 5 ml.

Each of the first set of 10 5-ml volumes of sediment was soaked in 20 ml of 10 different solvents (with measured pH values) in closed 100-ml jars, at room temperature, for 6 months; another similar set was soaked for 24 hours. Solvents used were acetone, alcohol, carbon tetrachloride, clorox, hydrogen peroxide, kerosene, kerosene followed by water, mineral oil, distilled water, and unpurified tap water.

For the 24-hour soak, a solution of 10% NaOH in distilled water was added. With both the 6-month and 24-hour soaks, microscopic sediment observations were made: immediately upon wetting; after 4 days; and after 6 months. Later, an additional subsample was prepared with "Quaternary O."

After soaking, each sediment subsample was rinsed over a sieve with 63 μm openings with warm tap water. Sieve residues washed onto filter papers were oven dried at 38°C. Subsequently, all of each residue was examined microscopically.

The total specimen numbers for the 6-month and 24-hour soaks are shown in Tables 1 and 2. Most numbers from the 6 month soak are higher. An analysis of variance produced an $F_{1,7} = 0.55$ value, which is, however, not significant.

For the solvents tested (twice), short term soaking in kerosene then flushing with water is the most effective method. Long term clorox, hydrogen peroxide, and mineral oil showed relatively good recovery also. The poorest specimen recoveries are shown by carbon tetrachloride, water, plain kerosene, and sodium hydroxide solution (soaked only one day). Acetone shows an intermediate recovery.

With all these solvents, many intact rock grains containing tests remained. As we wanted all tests freed, we next tried a more complex method. We followed manufacturer's directions in a several-step procedure using the strong detergent "Quaternary O." Recovery was significantly better but test-bearing rock fragments still remained. So we transferred our preparation work to the U.S. Geological Survey micropaleontology laboratory at Menlo Park and implemented their tested and more complex method for the 24 replicates, the data from which were used for the spatial study.

LABORATORY PREPARATION OF 24 REPLICATES.—The method described below was adopted for all replicates in order to disaggregate (nearly) all of the diatomite to free all specimens, while minimizing mechanical and chemical test destruction.

The method follows these steps.

1. Some fragmented diatomite was transferred from each field-sample jar to a 10-ml glass beaker. It was then tamped down, moistening slightly to assist compaction. This process was continued until the sediment was leveled at the 5-ml mark in the beaker.

2. Each 5 ml of sediment was placed in a 50-ml beaker and oven-dried overnight at 32°C.

3. The sediment in each beaker was covered with kerosene and left overnight.

4. The kerosene was decanted and the sediment was covered to the 25-ml mark in the beaker with hot water; 2 ml of Na_2CO_3 (soda ash) were added.

5. Each sediment/liquid mixture was then boiled gently on an oscillating hot plate for approximately one hour until break-down of the rock.

6. Material was rinsed through a 63 μm sieve with a small amount of detergent added to help remove the kerosene. Residues were collected on filter papers.

7. Residues in closed filter papers were oven

Table 1.—Check list for 6-month and 24-hour soaking.

CHECK LIST OF FORAMINIFERA IN NUMBERS AND PERCENTS

		6 MONTH SOAKING TIME										24 HOUR SOAKING TIME										
		Acetone	Alcohol	CCl_4	Clorox	H_2O_2	Kerosene	Kerosene–H_2O	Mineral Oil*	H_2O Dist.	H_2O Ind.*	Acetone	Alcohol	CCl_4	Clorox	H_2O_2	Kerosene	Kerosene–H_2O	NaOH*	H_2O Dist.	H_2O Ind.* (spilled)	H_2O Ind.* (new)
Bolivinitids & *Suggrunda*	*Bolivina brevior* Cushman	4 1	0 0	1 1	2 <1	0 0	0 0	0 0	11 2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	506 22
	Bolivina pseudospissa Kleinpell	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 <1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 <1
	Bolivina seminuda Cushman	9 2	4 1	0 0	12 1	0 0	0 0	0 0	27 4	0 0	0 0	0 0	0 0	1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	7 <1
	Suggrunda kleinpelli Bramlette	3 1	0 0	4 3	0 0	0 0	1 <1	1 <1	15 2	1 1	3 1	0 0	0 0	0 0	0 0	0 0	1 <1	2 <1	0 0	1 <1	0 0	29 1
Turrilinids	*Buliminella curta* Cushman	41 8	25 7	1 1	90 10	29 3	9 3	27 4	91 12	8 5	22 7	21 5	11 4	0 0	16 4	32 6	18 6	38 4	4 2	6 2	5 3	507 22
	Buliminella dubia Barbat & Johnson	0 0	1 <1	0 0	1 <1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	Buliminella elegantissima (d'Orbigny)	2 <1	1 <1	0 0	0 0	0 0	0 0	0 0	5 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	107 5
Bulimin ids & Uvigerinids	*Bulimina* cf. *B. pseudoaffinis* Kleinpell	49 9	26 8	1 1	92 10	64 6	25 9	35 5	159 22	5 3	18 6	12 3	14 5	2 2	24 5	37 6	9 3	71 8	17 8	22 6	7 4	0 0
	Globobulimina pacifica Cushman	0 0	1 <1	0 0	1 <1	0 0	0 0	0 0	0 0	0 0	2 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 1	1 1	54 2
	Siphogenerina (?) sp.	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 <1	0 0	0 0	0 0	0 0
Discorbidids & *Epistomaria*(?)	*Epistominella subperuviana* (Cushman)	0 0	0 0	0 0	0 0	0 0	0 0	1 <1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 <1	0 0	158 7
	Valvulineria cf. *V. californica obesa* Cushman	325 62	221 64	81 53	562 62	757 73	208 72	512 68	345 47	98 59	175 55	268 65	189 61	41 35	215 49	403 70	235 76	537 59	109 48	184 53	75 45	585 25
	Valvullneria (?) sp. cf. *V. araucana* (d'Orbigny)	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 <1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 <1
	Epistomaria (?) sp.	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 <1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Nonionids	*Nonionella schencki* (Kleinpell)	92 18	65 19	64 42	148 16	187 18	47 16	174 23	74 10	54 33	98 31	109 27	94 31	72 62	184 42	102 18	45 15	269 29	96 43	129 37	78 47	384 16
	Nonionella (?) sp.	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 <1
	Number of species in assemblage	8	8	6	8	4	5	6	10	5	6	5	4	4	4	4	5	6	4	8	5	12
	Number of specimens in assemblage	525	344	152	908	1037	290	750	729	167	318	411	308	116	439	574	308	918	226	346	166	2343

Number of specimens
Percent of assemblage

(*not comparable)

TABLE 2.—Total numbers of tests recovered from 5 ml of sediment (ranked by 6-month abundance).

Treatment	6 Months	24 Hours
Soaked both periods		
Hydrogen peroxide	1037	574
Clorox	908	439
Kerosene-water	750	918
Acetone	525	411
Alcohol	344	308
Kerosene	290	308
Water-distilled	167	346
Carbon tetrachloride	152	116
Soaked only one period or otherwise not numerically comparable		
Water-industrial, old	318	166 (±⅓ spilled)
Water-industrial, new (different boulder fragment)	–	2339
Sodium hydroxide	–	226
Mineral oil	729	–

dried overnight at 32°C. They were examined microscopically to determine if breakdown was adequate or if steps 2–7 needed repeating. Breakdown appeared adequate and they were retained for later investigation.

MICROSCOPE.—All washed residues from all subsamples and replicates were examined under the microscope. All complete foraminiferal tests and fragments judged to represent individuals (mainly intact juvenile whorls) were picked from all subsamples and one replicate (no. 2) and mounted on slides. For all other replicates all such individuals were identified taxonomically and counted. Only specimens of taxa occurring rarely or requiring further study for identification were picked.

Results

REPLICATES 1–24.—Table 3 shows specimen counts for all 24 replicates. The mean for the total population is 6084.96 and the standard deviation 8776.95. The 95% confidence interval for the mean is given by

$$\hat{\mu} - 1.96(\hat{\sigma}/\sqrt{n}) \leq \mu \leq \hat{\mu} + 1.96(\hat{\sigma}/\sqrt{n})$$

where n is the number of replicates. For the 24 replicates we can be 95% confident the true mean lies between 2573 and 9596. Actually, the confidence probably is lower because the confidence intervals were calculated assuming a normal distribution. A glance at Figure 2 clearly shows this is not the case. Instead, the densities for all species show a pattern we would not expect from random or normally distributed variates. For example, replicates 2–5 (the first examined) are all very close, and had only these four replicates been taken we would have assumed there was very little variability in the outcrop. Similarly, replicates 20–24 exhibit densities an order of magnitude greater than the other replicates.

In order to elucidate the relationships among the replicates we subjected the data to a cluster analysis using the weighted pair group method. Figure 3 portrays the results. Notice that the group 20–24 is clearly separated from the remaining replicates. This separation reaffirms our visual examination of Table 3, which indicates that not only is there a large difference in density but also a change in the abundance of some species. The most significant difference in relative abundance is with *Bolivina brevior*. "Rare" to "few" in replicates 1–19, it is the most abundant species in replicates 20–24. *Valvulineria* cf. *V. californica obesa* is the most abundant taxon in 1–19. It remains common in 20–24. *Buliminella curta* remains in third rank order in both 1–19 and 20–24. *Nonionella schencki* is the secondary dominant in 1–18, but its relative abundance (not density) drops significantly in replicate 19 and considerably more in 20–24. In replicates 1–19, three species comprise approximately 95% of the fauna, whereas seven species do so in 20–24 (Table 3).

Because of the large difference between replicates 1–19 and 20–24, we will examine species density, composition, diversity, and dominance separately for the two groups even though they came from the same horizon.

DENSITY.—*Replicates 1–19:* The results of this phase of the study are striking. The inhomogeneity of densities among replicates 1

through 19 is very great, although the faunal composition is quite consistent. For replicates 1–19 the mean is 2387.47 and the standard deviation is 1175.58. A calculation of the 95% confidence interval indicates that the true mean lies between 1858 and 2916, or the true value varies about 20% from the estimated mean. Now, were we to take only 4 replicates, we would be 95% confident the true value of the mean varies about 50% from the estimated mean. If only a single observation were made (one core), as is often the case in paleontological sampling, we would be 95% confident the true mean lies between 83.33 and 4691.61, or the true value varies about 97% from the estimated mean. We would not, of course, know our sample was so inaccurate because with one observation the standard deviation could not have been calculated. The importance of taking replicate samples for estimates of density is readily apparent. The investigator must balance the desired precision against the amount of work necessary to obtain it. The data presented herein indicate estimates of density are far more inaccurate than most paleontologists would have assumed.

In the present study, replicates 2 through 5 exhibit great consistency (Table 3). This is probably due to chance, but illustrates the real possibility of underestimating the standard deviation if only these samples were taken. We probably would have concluded that faunal homogeneity was great in this setting, when actually, as the other replicates show, there is considerable inhomogeneity.

Replicates 20–24: Even more striking than the inhomogeneity among specimen counts for replicates 1–19 is the difference between these replicates and the 20–24 counts. The number of individuals in replicates 20–24 exceeds those in 1–19 by an order of magnitude (Table 3). The reader should note that replicate 19, which has the highest density in the 1–19 group, appears to be a transition to the 20–24 group. The mean number of individuals for replicates 20–24 is 20135.40 and the standard deviation 11181.40.

Comparison of Replicates 1–19 and 20–24: The mean number of individuals per replicate for the 1–19 set is 2387.47 while that of the 20–24 group is 20135.40. The difference between these means is so large that no statistical test is required to tell us the two groups are different.

The coefficient of variation (σ/μ) is .49 for the 1–19 group and .56 for the 20–24 group. Thus, the variation in the 20–24 group is greater but not by much. More replicates representing the 20–24 group would be desirable.

SPECIES COMPOSITION.—*Replicates 1–19:* Among the first 19 replicates, *Valvulineria* cf. *V. californica obesa* Cushman, *Nonionella schencki* (Kleinpell), and *Buliminella curta* Cushman constitute from 86% to 99% of the fauna, with densities from 589 to 4927 (Table 3). Among these three, *Valvulineria* dominates. It is most abundant in all but seven replicates. It ranges from 22% to 47% and, in densities, from 141 to 2475. No clearcut relationship appears between densities and percentages, although the two replicates with the lowest total numbers of specimens (11 = 630, 17 = 848) also contain the lowest percentages of *Valvulineria* and are dominated by *Nonionella schencki*. Conversely, a trend may exist toward higher percentages of *Valvulineria* with higher total specimen numbers (Table 3).

Nonionella schencki varies more in percentages of the assemblage and less in densities than do *Valvulineria* and *Buliminella curta*. In fact, it dominates replicate 11 in which it has its minimum abundance (251). *Nonionella schencki* ranges from 19% to 57% but to only 31% in the *Valvulineria*- (or *Buliminella*-) dominated assemblages. In density it ranges from 251 to 888 individuals. In the replicates dominated by *Valvulineria*, *Nonionella* ranges from 4% to 26% less than *Valvulineria*, and averages approximately 17% less. In size, the *Nonionella* is larger than the *Valvulineria* and than most specimens of *Buliminella curta* as seen here. Interestingly, Valvulinerias of this lineage usually are as large as or larger than the *Nonionella*.

Buliminella curta ranks third and ranges from

TABLE 3.—Taxonomic and numerical composition of 24 replicates.

Replicate No.	*Valvulineria* cf. *V. Californica obesa* Cushman		*Buliminella curta* Cushman		*Nonionella schencki* (Kleinpell)		*Bolivina brevior* Cushman		*Bolivina seminuda* Cushman (2 forma)		*Suggrunda kleinpelli* Bramlette (sensu lato)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	1883	43.66	1036	24.02	801	18.57	267	6.19	128	2.97	51	1.18
2	1075	39.79	609	22.54	888	32.86	20	0.74	42	1.55	2	0.07
3	1189	45.16	710	26.97	586	22.26	18	0.68	38	1.44	5	0.19
4	1228	46.67	582	22.12	679	25.81	34	1.29	25	0.95	6	0.23
5	1166	43.62	708	26.49	558	20.88	124	4.64	62	2.32	10	0.37
6	391	33.62	165	14.19	570	49.01	3	0.26	6	0.52	0	0
7	893	35.78	702	28.13	729	29.21	42	1.68	69	2.76	1	0.04
8	692	31.09	613	27.54	785	35.27	27	1.21	60	2.70	2	0.09
9	338	25.06	373	27.65	544	40.33	10	0.74	42	3.11	0	0
10	631	41.79	443	29.34	322	21.32	39	2.58	48	3.18	2	0.13
11	141	22.38	196	31.11	251	39.84	17	2.70	15	2.38	0	0
12	773	37.71	586	28.59	435	21.22	98	4.78	68	3.32	12	0.59
13	618	31.50	705	35.93	415	21.15	137	6.98	52	2.65	12	0.61
14	1055	32.34	1124	34.46	716	21.95	208	6.41	76	2.33	17	0.52
15	1022	35.02	922	31.60	560	19.19	248	8.50	71	2.43	27	0.93
16	735	34.83	618	29.29	644	30.52	63	2.99	24	1.14	3	0.14
17	209	24.65	147	17.33	486	57.31	2	0.24	3	0.35	0	0
18	1021	45.48	684	30.47	433	19.29	46	2.05	28	1.25	6	0.27
19	2475	43.88	1689	29.94	763	13.53	306	5.42	187	3.32	43	0.76
20	1972	15.84	1517	12.19	492	3.95	7096	57.01	142	1.14	423	3.40
21	10559	26.69	7003	17.70	2193	5.54	12869	32.53	852	2.15	1676	4.24
22	4454	26.54	2781	16.57	965	5.75	5892	35.11	351	2.09	600	3.58
23	2782	21.39	1803	13.86	699	5.37	6172	47.46	136	1.05	324	2.49
24	3663	19.40	2199	11.65	712	3.77	8615	45.95	229	1.21	1058	5.60

Replicate No.	*Epistominella subperuviana* (Cushman)		*Bulimina* cf. *B. pseudoaffinis* Kleinpell		*Uvigerina* sp. (large, smooth)		*Uvigerina?* sp. (costate)		*Trifarina* sp. (costate)	
	No.	%	No.	%	No.	%	No.	%	No.	%
1	0	0	25	0.58	0	0	0	0	0	0
2	0	0	4	0.15	0	0	0	0	0	0
3	0	0	7	0.27	1	0.04	0	0	0	0
4	0	0	1	0.04	0	0	0	0	0	0
5	0	0	4	0.15	0	0	0	0	0	0
6	0	0	1	0.09	0	0	0	0	0	0
7	0	0	3	0.12	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	3	0.20	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
12	0	0	1	0.05	0	0	0	0	0	0
13	0	0	0	0	1	0.05	0	0	0	0
14	0	0	7	0.21	0	0	0	0	0	0
15	0	0	6	0.96	0	0	0	0	0	0
16	0	0	2	0.09	1	0.05	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	2	0.09	0	0	0	0	0	0
19	0	0	11	0.02	1	0.02	0	0	0	0
20	396	3.18	10	0.08	1	0.01	1	0.01	1	0.01
21	2170	5.49	87	0.22	4	0.01	0	0	1	0.0025
22	743	4.43	10	0.06	0	0	0	0	0	0
23	620	4.77	5	0.04	0	0	0	0	0	0
24	908	4.81	35	0.19	1	0.01	0	0	0	0

TABLE 3.—Continued.

Replicate No.	*Trifarina* sp. (smooth; may be same sp. as above)		*?Oolina globosa* (Montagu)		*Bolivina brevior* Cushman (sensu lato)		*Bolivina pseudospissa* Kleinpell		*Bolivina rankini* Kleinpell		*Bolivina dunlapi* Kleinpell	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	0	0	0	0	0	0	8	0.19	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	5	0.19	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1	0.04	0	0	0	0
8	0	0	0	0	0	0	1	0.04	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	1	0.16	0	0	0	0	0	0
12	0	0	0	0	0	0	1	0.05	5	0.24	0	0
13	0	0	0	0	1	0.05	1	0.05	1	0.05	0	0
14	0	0	0	0	2	0.06	3	0.09	2	0.06	0	0
15	0	0	0	0	1	0.03	2	0.06	6	0.21	0	0
16	0	0	0	0	1	0.05	1	0.05	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	1	0.04	0	0
19	0	0	0	0	1	0.02	5	0.09	6	0.11	0	0
20	0	0	5	0.04	12	0.10	37	0.30	0	0	0	0
21	4	0.01	75	0.19	34	0.09	55	0.14	2	0.01	0	0
22	0	0	10	0.06	10	0.06	10	0.06	5	0.03	3	0.02
23	0	0	8	0.06	5	0.04	18	0.14	2	0.02	0	0
24	1	0.01	15	0.08	10	0.05	18	0.10	8	0.04	3	0.02

Replicate No.	*Bolivina conica* Cushman?		*Buliminella elegantissima* (d'Orbigny)		*Globobulimina pacifica* Cushman		*Lagena* sp. (inornate)		*Nodosaria?* sp. (inornate)		*Valvulineria?* sp. cf. *V. araucana* (d'Orbigny)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	0	0	84	1.95	28	0.65	0	0	0	0	2	0.05
2	0	0	17	0.63	45	1.67	0	0	0	0	0	0
3	0	0	8	0.30	77	2.92	0	0	0	0	0	0
4	0	0	16	0.61	44	1.67	0	0	0	0	0	0
5	0	0	46	1.72	22	0.82	0	0	0	0	0	0
6	0	0	1	0.09	26	2.24	0	0	0	0	0	0
7	0	0	13	0.52	43	1.72	0	0	0	0	0	0
8	0	0	5	0.22	43	1.72	0	0	0	0	0	0
9	1	0.07	2	0.15	39	2.89	0	0	0	0	0	0
10	0	0	2	0.13	20	1.32	0	0	0	0	0	0
11	0	0	0	0	10	1.59	0	0	0	0	0	0
12	0	0	18	0.88	53	2.59	0	0	0	0	0	0
13	0	0	5	0.25	25	1.27	0	0	0	0	0	0
14	0	0	24	0.74	30	0.92	0	0	0	0	0	0
15	0	0	28	0.96	22	0.75	0	0	0	0	4	0.14
16	0	0	4	0.19	13	0.62	0	0	0	0	2	0.09
17	0	0	0	0	1	0.12	0	0	0	0	0	0
18	0	0	8	0.36	13	0.58	0	0	0	0	4	0.18
19	0	0	124	2.20	20	0.51	0	0	0	0	2	0.04
20	0	0	370	2.97	27	0.22	0	0	0	0	7	0.06
21	0	0	1871	4.73	126	0.32	2	0.01	1	0.0025	7	0.02
22	0	0	810	4.83	10	0.06	0	0	0	0	5	0.03
23	0	0	416	3.20	14	0.11	1	0.01	2	0.02	0	0
24	0	0	1307	6.92	31	0.16	0	0	1	0.01	5	0.03

TABLE 3.—Continued.

Replicate No.	*Holmanella?* sp. cf. *H. valmonteensis* (Kleinpell)		*Epistomaria?* sp.		planktic (opaline filled allochthanous element)		Total "*Bolivina*" (including *Suggrunda*)		Total *Valvulineria, Buliminella curta,* and *Nonionella schencki* Kleinpell		Total in Replicate
	No.	%	No.	0%	No.	%	No.	%	No.	%	No.
1	0	0	0	0	0		454	10.53	3720	86.25	4313
2	0	0	0	0	0	0	64	2.37	2572	95.19	2702
3	0	0	0	0	0	0	61	2.31	2485	94.38	2633
4	0	0	0	0	1	0.04	65	2.47	2489	94.60	2631
5	0	0	0	0	0	0	201	7.52	2432	90.98	2673
6	0	0	0	0	0	0	9	0.77	1126	96.82	1163
7	0	0	0	0	0	0	113	4.53	2324	93.11	2496
8	0	0	0	0	0	0	90	4.04	2090	93.89	2226
9	0	0	0	0	0	0	53	3.93	1255	93.03	1349
10	0	0	0	0	0	0	89	5.89	1396	92.45	1510
11	0	0	0	0	0	0	33	5.24	588	93.33	630
12	0	0	0	0	0	0	184	8.98	1794	87.51	2050
13	0	0	0	0	0	0	204	10.39	1728	88.07	1962
14	0	0	0	0	0	0	308	9.47	2895	88.75	3262
15	0	0	0	0	0	0	355	12.16	2504	85.81	2918
16	0	0	0	0	0	0	92	4.36	1997	94.64	2110
17	0	0	0	0	0	0	5	0.59	842	99.29	848
18	0	0	0	0	0	0	81	3.60	2138	95.23	2245
19	0	0	0	0	0	0	548	9.72	4927	87.34	5641
20	2	0.02	1	0.01	0	0	7710	61.95	3981	31.98	12448
21	0	0	0	0	0	0	15488	39.16	19772	49.98	39561
22	0	0	0	0	0	0	6871	40.95	8200	48.86	16783
23	0	0	0	0	0	0	6657	51.20	5284	40.63	13006
24	0	0	0	0	0	0	9941	52.97	6574	34.82	18879

14% to 36%, while its densities vary from 147 to 1689 individuals. It dominates over *Valvulineria* in four replicates (9, 11, 13, 14) and in two of these (13, 14) it also dominates over *Nonionella,* achieving its maximum 36% of the assemblage in replicate 13. Note that it also achieves a greater maximum density (1689) than *Nonionella*. Its percentage relationship to *Valvulineria* shows some consistency, however, ranging from 3% to 24% less (averaging about 15% less) in the *Valvulinera*-dominated replicates. Most *Buliminella curta* seen here in washed replicates are relatively medium- to small-sized specimens, although a few are quite large; many also clearly are broken; so the species appears to be larger than the present preservation suggests.

The remaining taxa constitute from 1% to 14% of replicates 1–19, with densities of 6 to 714 individuals. The distribution of species abundances and occurrences is a logseries (Buzas et al., 1977, 1982); thus the probability of charting the true distribution of rarely occurring species is low, and we will never have enough replicates for sampling such taxa.

Significant either by reason of consistent presence or density (or both) are the following: the large and fragile *Globobulimina pacifica* Cushman (estimated numbers based mainly on test fragments); the large-for-the-genus *Bolivina seminuda* Cushman; other, small Bolivinas (*Bolivina brevior* Cushman and others) and *Suggrunda kleinpelli* Bramlette; and the small *Buliminella elegantissima*

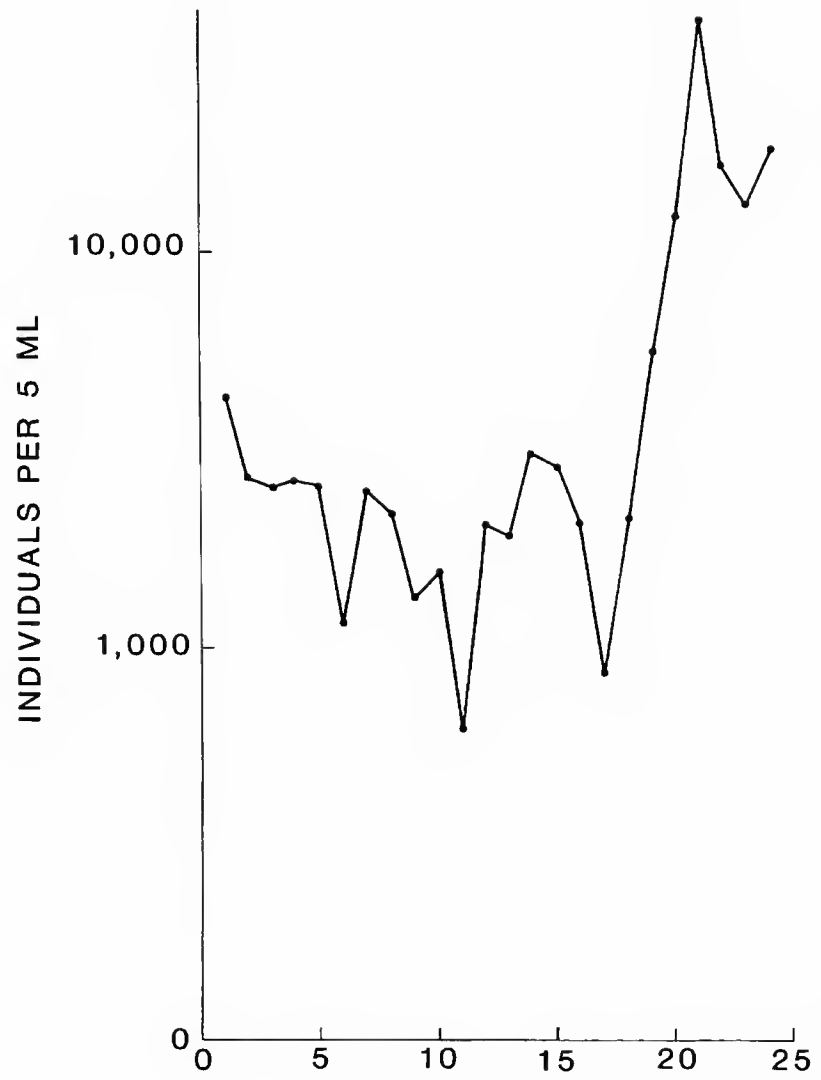


FIGURE 2.—The mean number of foraminiferal specimens found in each of 24 5-ml replicates.

(d'Orbigny). Small specimens of *Bulimina* cf. *B. pseudoaffinis* Kleinpell were found in low densities in most replicates. A few other taxa occur very rarely (Table 3).

"Bolivina," taken as a group, and also including *Suggrunda,* ranges from 1% to 12% (5 to 548 individuals). Buliminaceans, other than *Buliminella curta,* and including *Bolivina, Suggrunda, Globobulimina, Bulimina, Buliminella,* and uvigerinids range from 1% to 15%, with a range of 37 to 489 individuals. When *Buliminella curta* is included, buliminaceans range from 18% to 48%, with 202 to 2402 individuals. Besides the taxa discussed above, other taxa constitute less than 2% of the fauna in the 19 replicates.

Replicates 20–24: *Bolivina brevior* is the most abundant species in replicates 20–24, ranging from 5892 to 12869, and constituting from 33% to 57%. The densities of *Valvulineria* cf. *V. californica obesa* (1972–10559) and *Buliminella curta* (1517–7003) remain high—even higher than in replicates 1–19—but they consitute a lesser percentage of the assemblages, namely 16% to 27% *Valvulineria* and 12% to 18% *Buliminella.* The densities of *Nonionella schencki* are more similar to those of replicates 1–19 (492–2193), resulting in much lower percentages for this species (4%–6%).

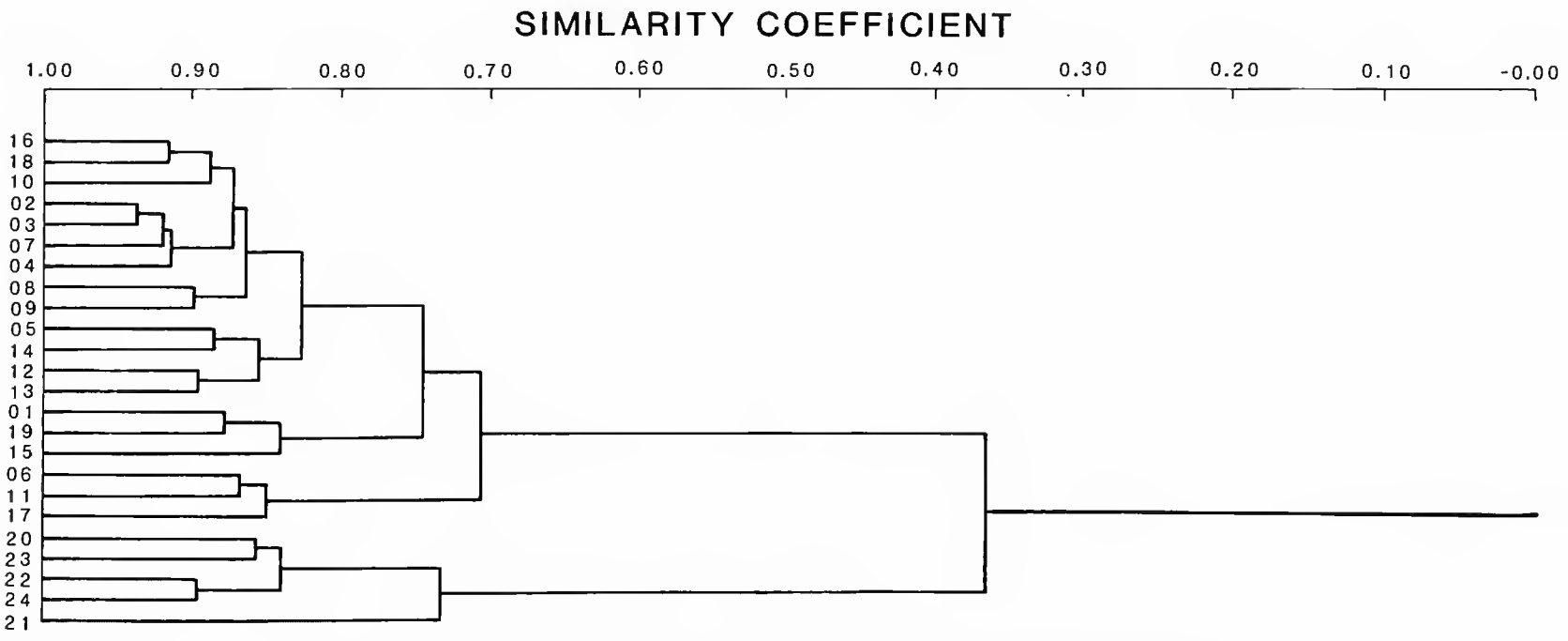


FIGURE 3.—Dendrogram showing the relationships of the 24 replicates.

Other *Bolivina, Suggrunda, Epistominella subperuviana,* and *Buliminella elegantissima* each occur in low percentages (3%–7%), close to those of *Nonionella schencki.* The large-sized *Globobulimina pacifica,* and small specimens of *Bulimina* cf. *B. pseudospissa* and an *Oolina* also occur regularly, but each constitutes less than 1% in all five replicates.

Comparison of Replicates 1–19 and 20–24: Most taxa are common to both replicate sets 1–19 and 20–24. Only two taxa (one specimen each) found in 1–19 were not found in 20–24. Ten taxa from 20–24 were not identified in 1–19; most of these occur rarely and do not appear significant. Exceptions are *Epistominella* and *Oolina.*

The most dramatic change from 1–19 to 20–24 comes from the increased density of *Bolivina brevior.* In replicates 1–19 it occurs in low percentages, while it dominates the fauna in 20–24. The percentage of *Nonionella schencki* plummets in the 20–24 set. Each at 3% to 7%, *N. schencki, Suggrunda kleinpelli, Epistominella subperuviana,* and *Buliminella elegantissima* are important, secondarily significant species in the 20–24 replicates. Note that seven species are then important in the 20–24 set, versus three in the 1–19 set.

One could attach great significance to the sharp decline of *Nonionella schencki.* By looking at Table 3, however, we see that our data have fallen victim to one of the dangers of using percentages uncritically. The densities of *N. schencki* actually increase in the set 20–24 vs 1–19, and, conversely, *N. schencki* has its lowest density in replicate 11 wherein it dominates with 40%. The percentages show a sharp decrease because the density of *N. schencki* increases only slightly while other species increase drastically.

MEASUREMENT OF SPECIES DIVERSITY.—To measure species diversity we used (1) the number of species in a replicate, S; (2) the information function, $H = -\Sigma p_i \ln p_i$ where p_i is the proportion of the ith species; (3) a measure of equitability or evenness, $E = H/\ln S$. We used this measure of equitabilty because the one proposed by Buzas and Gibson (1969), while theoretically more acceptable (Sheldon, 1969), is more unstable when the number of species is low.

SPECIES DIVERSITY.—*Replicates 1–19:* Table 4 shows that the number of species in replicates 1–19 ranges from 6 to 14; the average is 10.25. In all, 16 species are represented. There seems to be a trend toward increasing the number of species with the higher replicate numbers. Note, however, a significant positive correlation exists between species number and the number of individuals (Buzas et al., 1977). Figure 4 shows that relationship holds for the present data set quite well.

Table 4 shows the information function, H, varies from 1.01 to 1.52. In general, it is lowest for the least number of species (replicate 17) and higher for samples with more species. Note, however, species proportions also enter into the calculation.

Species equitability values range from .51 to .68. By looking at S, H, and E simultaneously, some understanding of how replicates differ in species diversity is possible. For example, replicates 15 and 16 both have 13 species, but the value of H for replicate 16 is lower because species equitability, E, is lower. Similarly, replicates 13 and 14 have identical values of S, H, and E. A glance at Table 3 shows just how similar these two replicates are. With the first 19 replicates the same three species always constitute from 86% to 99% of the fauna. One of these almost always constitutes 35% to 45% and each of the two others constitutes roughly 20% to 30% (Table 3). The dominant form is *Valvulineria* cf. *V. californica obesa* in 12 out of the 19 replicates; *Nonionella schencki* dominates five and *Buliminella curta* two. In addition to these three, the remaining 5% to 15% of the replicates includes mainly *Bolivina brevior,* which ranges from <1% to 8%; and both *B. seminuda* and *Globobulimina pacifica,* which range from <1% to 3%. All other species are very rare. This shows a species equitability pattern that may be expressed as 4 : 3 : 2 : 1—a fairly good species equitability for a low-diversity fauna. (Contrast this situation with a fauna sampled by Smith, 1970:687; a 60

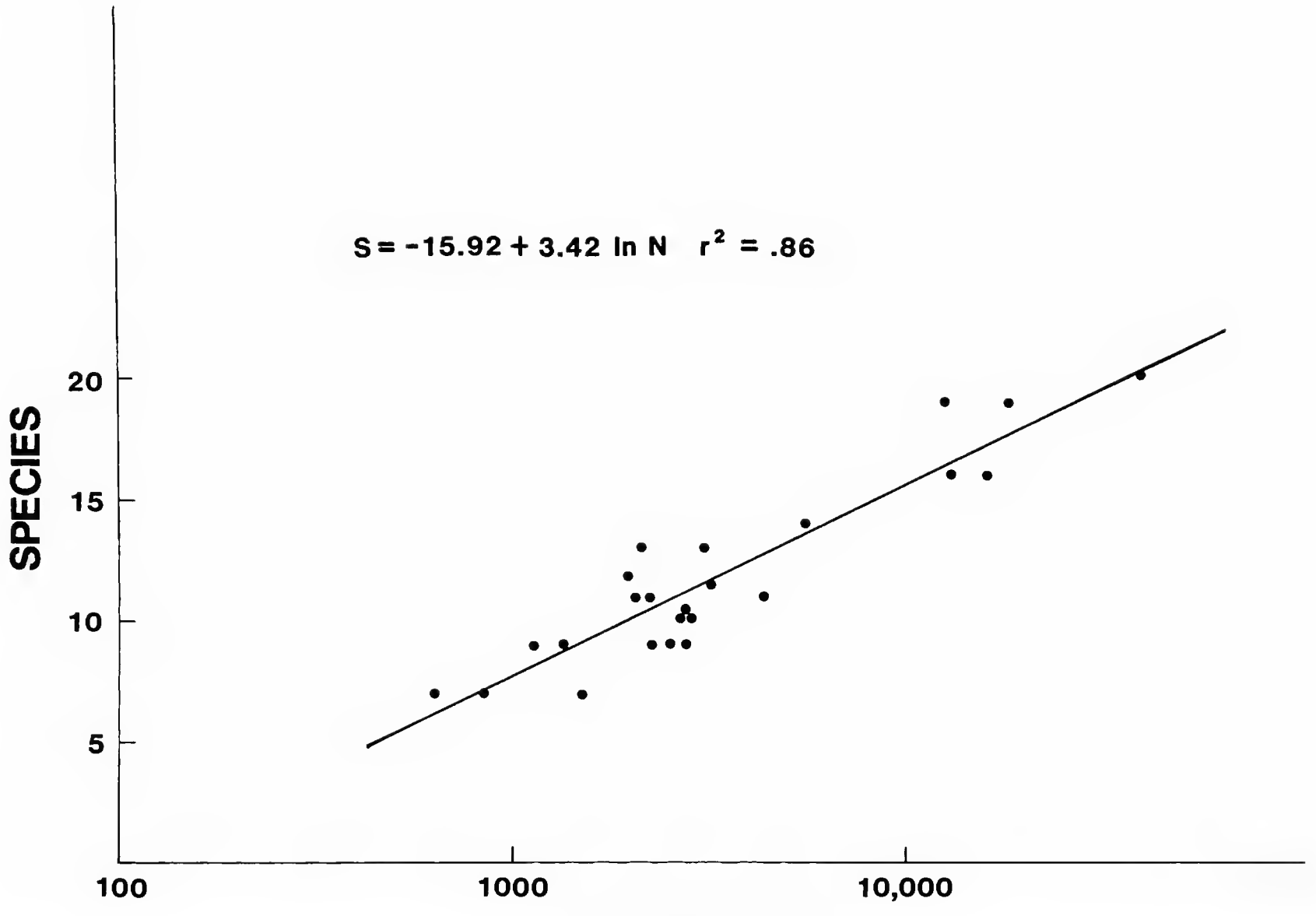


FIGURE 4.—Semilog plot of total number of individuals vs species.

ml volume of sandy sediment contained six species with abundances of 1514, 630, 3, 1, 1, and 1—a low species equitability.)

Replicates 20–24: Table 4 shows that the number of species ranges from 16 to 20. The total number of species represented is 22. There is a general correlation between the number of individuals and the number of species.

The values of H vary from 1.43 to 1.77 and E from .49 to .61. Replicates 22 and 23 have the same number of species but, because of differences in E, replicate 23 has a lower value of H.

The three dominant species, *Bolivina brevior, Valvulineria* cf. *V. californica obesa,* and *Buliminella curta,* account for 77% to 85% of the total fauna.

Comparison of Replicates 1–19 and 20–24: The number of species in replicates 20–24 is greater than in 1–19, which is to be expected because of the large change in the number of individuals. As might also be expected, the value of H is also generally higher in the 20–24 group.

The measure of equitability, E, does not give such a clear picture. This may be so because, when the species number is low, a change of a few species in the denominator of the equation for E can make a big difference in its value. From the discussion above and an examination of Table 3, however, real differences in species equitability appear. The 1–19 group has the three dominant species accounting for 86% to 99% of the fauna, while the 20–24 group has the three

TABLE 4.—Species diversity for 24 replicates (S = number of species in a replicate; H = information function; E = measure of evenness).

Replicate	Total specimens	S	H	E
1	4313	11	1.50	.63
2	2702	9	1.28	.58
3	2633	10	1.29	.56
4	2631	10	1.26	.55
5	2673	10	1.42	.62
6	1163	8	1.13	.54
7	2496	10	1.36	.59
8	2226	9	1.33	.61
9	1349	8	1.33	.64
10	1510	9	1.34	.64
11	630	7	1.33	.68
12	2050	11	1.50	.63
13	1962	12	1.46	.59
14	3262	12	1.46	.59
15	2918	13	1.52	.59
16	2110	13	1.32	.51
17	848	6	1.01	.56
18	2245	11	1.26	.53
19	5641	14	1.44	.55
20	12448	19	1.43	.49
21	39561	20	1.77	.59
22	16783	16	1.70	.61
23	13006	16	1.54	.56
24	18879	19	1.64	.59

dominant species accounting for 77% to 85%. To achieve from 97% to 99% of the fauna, four more species, which total 14% to 21%, *Nonionella schencki, Suggrunda kleinpelli, Epistominella subperuviana,* and *Buliminella elegantissima,* must be added to the 20–24 group. With replicates 1–19 these (97% to 99%) percents can be achieved by adding a maximum of 14% composed mainly of *Bolivina brevior,* with some *B. seminuda,* and *Suggrunda.* Clearly, patterns of species dominance differ significantly if not greatly between the groups 1–19 and 20–24.

SPECIES DOMINANCE PATTERNS AND SPECIES/SPECIMEN SIZE.—Another way of comparing replicates 1–19 with 20–24 is by percentages of the same taxa. As stated above, summing the dominant *Valvulineria, Buliminella,* and *Nonionella* gives 86% to 99% of the group 1–19 faunas. These three taxa make up 32% to 50% of the 20–24 group (Table 3). The 20–24 group differs from 1–19 by a large increase in *Bolivina brevior*—a small form—plus significant increases of *Suggrunda, Epistominella,* and *Buliminella elegantissima*—all also small forms.

This increase in small specimens is both numerical and relative. Let us assume selective addition (or subtraction) of small forms to/from the 1–19 fauna by some process of transportation. Table 5 shows subtraction of percentages of the small forms from the 20–24 fauna. In three attempts to produce a 1–19 fauna, we subtracted 75%, 90%, and 95% of: *Bolivina brevior* and other small *Bolivina; Suggrunda; Buliminella elegantissima;* and *Oolina, Lagena,* and *Nodosaria;* and 100% of *Epistominella.* Taxa with numbers left intact are *Valvulinera* cf. *V. californica obesa, Buliminella curta, Nonionella schencki, Bolivina seminuda, Globobulimina pacifica,* other buliminaceans, and other taxa. Table 5 shows that (1) the faunal compostion of replicates 1–19 is best achieved by using the 95% reduction (plus 100% of *Epistominella*), but (2) projected total specimen numbers still remain greater in replicates 20–24 than 1–19. Therefore, some factor other than simple addition (or nonremoval) of small forms is significant in accounting for differences in total specimen numbers per replicate between the groups 1–19 and 20–24.

COMPARISON OF 24 REPLICATES WITH SUBSAMPLES FROM THE BOULDER EXPERIMENTS.—Most subsamples from the boulder contain the same fauna, including that prepared in "Quaternary O" but not tabulated. From Table 1 (excluding non-comparable columns) note that (1) *Valvulineria* cf. *V. californica obesa* Cushman dominates (39% to 76% of assemblages), with (2) *Nonionella schencki* (Kleinpell) subdominant (16% to 42%). (3) *Buliminella curta* Cushman (1% to 10%), and (4) *Bulimina* cf. *B. pseudoaffinis* Kleinpell (0% to 22%) are also significant. The first three taxa constitute the majority of the assemblages. Species total 16, with only four more than rarely (>3%) represented. Taxa per subsample range from four to eight.

One of the remaining three subsamples (24-hour soak in CCl_4) shows an unusual *Nonionella*

dominance over *Valvulineria* (62% to 35%). Another (6-month soak in mineral oil) represents a somewhat different fauna. In it taxa mainly are those above but dominance patterns differ, with greater species equitability and total number of taxa (10). Species percentages are (1) and (2) = 57%; plus (3) = 70%; (1) through (4) = 92%; also buliminaceans = 36%, (3) and (4) = 34%, and bolivinids = 7%.

To replace one partly spilled subsample, another was prepared from a different boulder fragment. Although similar to the others, this fauna appears significantly denser and also taxonomically resembles the fauna of replicates 20–24. Taxa (1) and (2) = 41%; (3) = 22%; (4) is absent. Buliminaceans = 27%; 23% bolivines—four species, mainly *Bolivina brevior* Cushman; 5% *Buliminella elegantissima* d'Orbigny; and 2% *Globobulimina pacifica* Cushman. Neither the latter two nor *Epistominella subperuviana* (Cushman), here 7%, occur more than very rarely in other subsamples. Two other taxa (<1% each) complete the assemblage.

In addition to the diatomite assemblages, two porcelanite thin sections from a few cm below the 24 replicate bed contain another perhaps distinguishable fauna (see Table 6), although specimen numbers are too low to be sure.

We have, then, identified three to five distinguishable faunas from this one exposure. We have done this in a study of 336 cm of one bed (the 24 replicates) and limited examinations of two or three other diatomite and porcelanite beds. We can compare these faunas in percents (Table 7), but differences in preparation methods preclude comparison of densities.

Other distinguishable faunas could be represented as well. Some of the faunas described by Govean (1980) from the Toro Road stratigraphic section appear distinct. Time stratigraphic significance may be nil, but paleoecological significance may be considerable.

Discussion

The 24 replicate samples enabled us to document the variability of fossil foraminifera in the horizon studied. Studies of spatial distribution of modern foraminifera (Buzas, 1968, 1970; Olsson and Eriksson, 1974) indicate living and dead populations are inhomogeneously distributed. The very large and abrupt change observed herein, however, has never before been recorded in either a modern or a fossil population. Unfortunately, very few studies documenting microdistributions exist. Whether or not we are observing a bizarre phenomenon in the present study cannot be ascertained until more studies are made. Normal paleontological sampling would not detect the changes observed herein.

The very high densities observed in this study are seldom recorded in living populations. Densities as high as about 4000 per 5 ml were recorded in caging experiments (Buzas, 1978), and Sen Gupta et al. (1981) recorded living densites of 3132 in 3 ml of sediment on the continental slope off Daytona Beach, Florida. Interestingly, the most abundant species recorded by Sen Gupta et al. (1981) belonged to the genus *Bolivina*. Usually, densities are in the tens or hundreds per 5 ml for living populations. Even for total populations, densities of thousands and tens of thousands are seldom recorded. They do, however, occur (see for example, Phleger, 1951; Buzas, 1965). We are, then, probably observing in this fossil population the accumulation of tests over some period of time.

Traditional, though undocumented, micropaleontological sampling techniques may have taken into account specimen patchiness—both horizontal and vertical. These techniques include hand lens examination of rocks in the field. Such examination reveals some concentrations of foraminifera on bedding planes, scattered to concentrated foraminifera in areas and volumes of rocks, and sparsely populated or barren rock. The intent of the examination is to assure that fossiliferous rocks are collected—not to document distribution. The assumption has been that whatever is collected will be "representative"—especially when rock ages primarily are sought. While this assumption is probably true relative to age, it is far less true relative to paleoecology. Distribution and abundance provides the frame-

TABLE 5.—Replicates 20–24, species numbers and percentages adjusted in attempt to achieve the faunal composition of replicates 1–19.

Replicate number	Various totals				Taxa reduced by 0%				
	Total in replicate	Total all except *Valvulineria, B. curta,* and *Nonionella*	Total *Valvulineria* cf *V. c. obesa, B. curta,* and *N. schencki*	Total "*Bolivina*" including *Suggrunda*	Other taxa	Other buliminaceans	*Globobulimina pacifica*	*Bolivina seminuda*	*Nonionella schencki*
20	12448	8467	3981	7710	10	10	27	142	492
	100%	68%	32%	62%	<1%	<1%	<1%	1%	4%
	6156	2175	(3981)	2034	(10)	(10)	(27)	(142)	(492)
	(100%)	35%	65%	33%	<1%	<1%	<1%	2%	8%
	4965	984	(3981)	899	(10)	(10)	(27)	(142)	(492)
	(100%)	20%	80%	18%	<1%	<1%	1%	3%	10%
	4568	587	(3981)	520	(10)	(10)	(27)	(142)	(492)
	(100%)	13%	87%	11%	<1%	<1%	1%	3%	11%
21	39561	19806	19755	15188	7	87	126	552	2193
	100%	50%	50%	39%	<1%	<1%	<1%	1%	6%
	24674	4919	(19755)	4211	(7)	(87)	(126)	(552)	(2193)
	(100%)	20%	80%	17%	<1%	<1%	1%	2%	9%
	22180	2425	(19755)	2016	(7)	(87)	(126)	(552)	(2193)
	(100%)	11%	89%	9%	<1%	<1%	1%	2%	10%
	21357	1602	(19755)	1284	(7)	(87)	(126)	(552)	(2193)
	(100%)	7.5%	92.5%	6%	<1%	<1%	1%	3%	10%
22	16783	8583	8200	6871	5	10	10	351	965
	100%	51%	49%	40%	<1%	<1%	<1%	2%	6%
	10412	2212	(8200)	1981	(5)	(10)	(10)	(351)	(965)
	(100%)	21%	79%	19%	<1%	<1%	<1%	3%	9%
	9310	1110	(8200)	1003	(5)	(10)	(10)	(351)	(965)
	(100%)	12%	88%	11%	<1%	<1%	<1%	4%	10%
	8944	744	(8200)	677	(5)	(10)	(10)	(351)	(965)
	(100%)	8%	92%	8%	<1%	<1%	<1%	4%	11%
23	13006	7722	5284	6657	0	5	14	136	699
	100%	59%	41%	51%	0%	<1%	<1%	1%	5%
	7176	1892	(5284)	1766	(0)	(5)	(14)	(136)	(699)
	(100%)	26%	74%	25%	0%	<1%	<1%	2%	10%
	6134	850	(5284)	788	(0)	(5)	(14)	(136)	(699)
	(100%)	14%	86%	13%	0%	<1%	<1%	2%	11%
	5187	503	(5284)	462	(0)	(5)	(14)	(136)	(699)
	(100%)	9%	91%	8%	0%	<1%	<1%	2%	12%
24	18879	12305	6574	10001	5	35	31	229	712
	100%	65%	35%	53%	<1%	<1%	<1%	1%	4%
	9411	2837	(6574)	2435	(5)	(35)	(31)	(229)	(712)
	(100%)	30%	70%	26%	<1%	<1%	<1%	2%	8%
	7984	1410	(6574)	1206	(5)	(35)	(31)	(229)	(712)
	(100%)	18%	82%	15%	<1%	<1%	<1%	3%	9%
	7429	855	(6574)	718	(5)	(35)	(31)	(229)	(712)
	(100%)	11.5%	88.5%	10%	<1%	<1%	<1%	3%	10%

TABLE 5.—Continued.

Taxon reduced by 100%	Taxa reduced by 75%, 90%, and 95%						
Buliminella curta	*Valvulineria* cf. *V. californica obesa*	*Epistominella subperuviana*	*Oolina, Lagena,* and *Nodosaria?*	*Buliminella elegantissima*	*Suggrunda kleinpelli*	*Bolivina brevior* and other small *Bolivina*	
1517	1972	396	5	370	423	7145	Original No. — 100%
12%	16%	3%	<1%	3%	3%	57%	% of Fauna
(1517)	(1972)	0	1	93	106	1786	No. Reduced 75%
25%	32%	0%	<1%	2%	2%	29%	% of Fauna
(1517)	(1972)	0	1	37	42	715	No. Reduced 90%
31%	40%	0%	<1%	1%	1%	14%	% of Fauna
(1517)	(1972)	0	<1	19	21	357	No. Reduced 95%
33%	43%	0%	<1%	<1%	<1%	8%	% of Fauna
7003	10559	2170	78	1871	1676	12960	Original No. — 100%
18%	27%	5%	<1%	5%	4%	33%	% of Fauna
(7003)	(10559)	0	20	468	419	3240	No. Reduced 75%
28%	43%	0%	<1%	2%	2%	13%	% of Fauna
(7003)	(10559)	0	8	187	168	1296	No. Reduced 90%
32%	48%	0%	<1%	1%	1%	6%	% of Fauna
(7003)	(10559)	0	4	94	84	648	No. Reduced 95%
33%	49%	0%	<1%	<1%	<1%	3%	% of Fauna
2781	4454	743	10	810	600	5920	Original No. — 100%
17%	27%	4%	<1%	5%	4%	35%	% of Fauna
(2781)	(4454)	0	3	203	150	1480	No. Reduced 75%
27%	43%	0%	<1%	2%	1%	14%	% of Fauna
(2781)	(4454)	0	1	81	60	592	No. Reduced 90%
30%	48%	0%	<1%	1%	1%	6%	% of Fauna
(2781)	(4454)	0	1	41	30	296	No. Reduced 95%
31%	50%	0%	<1%	<1%	<1%	3%	% of Fauna
1803	2782	620	11	416	324	6197	Original No. — 100%
14%	21%	4%	<1%	3%	2%	48%	% of Fauna
(1803)	(2782)	0	3	104	81	1549	No. Reduced 75%
25%	39%	0%	<1%	1%	1%	22%	% of Fauna
(1803)	(2782)	0	1	42	32	620	No. Reduced 90%
29%	45%	0%	<1%	1%	1%	10%	% of Fauna
(1803)	(2782)	0	1	21	16	310	No. Reduced 95%
31%	48%	0%	<1%	<1%	<1%	5%	% of Fauna
2199	3663	908	16	1307	1058	8714	Original No. — 100%
12%	19%	5%	<1%	7%	6%	46%	% of Fauna
(2199)	(3663)	0	4	327	265	2179	No. Reduced 75%
23%	39%	0%	<1%	3%	3%	23%	% of Fauna
(2199)	(3663)	0	2	131	106	871	No. Reduced 90%
28%	46%	0%	<1%	2%	1%	11%	% of Fauna
(2199)	(3663)	0	1	65	53	436	No. Reduced 95%
28%	49%	0%	<1%	1%	1%	5%	% of Fauna

TABLE 6.—Faunal composition and rank for two thin sections from porcelanite bed.

Abundance	Rank of species
Abundant	1. *Valvulineria* cf. *V. californica obesa*
Common-abundant	2. *Bolivina brevior* and other small bolivinids, including *Suggrunda*
	3. *Buliminella curta*
Few-common	4. *Bolivina seminuda*
Few	5. *Globobulimina pacifica*
	6. *Nonionella schencki*
	7. *Buliminella elegantissima*
Rare-few	8. *Epistominella subperuviana*
Rare	9. *Bulimina* cf. *B. pseudoaffinis* (small)

work for paleoecology as it does for ecology.

We have herein established that one fauna could not be derived from the other by simple transportation. How closely the fossil population resembles the living populations of the Miocene sea floor is difficult to evaluate. We cannot be sure if we are witnessing a true change in the fauna due to some abiotic or biotic change or if the fauna was transported from somewhere else or both.

Any and all replicates provide for the same assignment of Mohnian Age (of Kleinpell, 1938) based on the presence of *Nonionella schencki*. Similarly, any and all provide for the same paleoenvironmental interpretation of "medium depths," "probably upper bathyal." Govean (1980) and Govean and Garrison (1981) have described the Toro Road section as forming near the top of the bathyal zone at 150 to 500 m. Note that this classical sort of paleoenvironmental interpretation concerns itself primarily with broad-scale depth ranges (relating to basin reconstruction). Such other (actual paleoecological) variables as temperature, salinity, and available oxygen, as well as redeposition, are also considered where evidence appears to exist for their interpretation.

In this case, it is reasonable to assume "cool temperatures" and "normal marine salinity." This is so even though the species diversity is fairly low, a condition suggesting some sort of stress situation for foraminifera as a group. No foraminifera thought to represent either high or low or variable salinity ranges or particularly warm or cold temperatures were found.

Regarding available oxygen, Govean (1980) and Govean and Garrison (1981) have interpreted some parts of the stratigraphic sequence exposed on Toro Road as representing "oxygen-minimum" conditions. The present replicates showing a relatively low species diversity would lend themselves to that (stress) interpretation. They do not, however, contain abundant specimens of taxa specifically interpreted as representing 0_2 minima, although *Bolivina seminuda* and *Suggrunda* occur (see Phleger and Soutar, 1973; Byers, 1977; Ingle et al., 1980). Overall, the faunal composition would not necessarily be taken to indicate 0_2 minima, although it may indicate somewhat reduced 0_2 conditions.

On the other hand, the fine laminations seen particularly well developed within the bed sampled are also believed to indicate 0_2 minima. This is because lamina develop and remain undisturbed where low oxygen concentrations prohibit burrowing organisms that would disrupt laminae.

The *Valvulineria* specimen size (small for the *V. californica* group) may reflect 0_2 minima or, simply, stress conditions for many foraminifera; a "population explosion" of small specimens of a taxon may result from the absence of competition or predators. Another explanation is that the small area represented by replicates 20–24 was for some reason extremely good for foraminifera. On the Mississippi Delta, Lankford (1959) found where foraminifera were most abundant the tests were the smallest. We also observed that the smallest tests occur where the densities are the highest. Perhaps there was a population explosion that correlated with variation in O_2 content.

Systematic Paleontology

Herein the classification of Loeblich and Tappan (1964, 1974) is followed, with some modification. All commoner taxa have been compared with types erected by Kleinpell (1938) and deposited in the micropaleontology museum collections of Stanford University. Access to these types was kindly provided by Dr. J.C. Ingle. Some preliminary identifications were made by Dr. F.M. Govean of AMOCO Production Company, Tulsa, Oklahoma. Unfortunately, most specimens of rarely occurring taxa were lost in transit between Tulsa and Santa Cruz, California, preventing their comparison with types.

Order FORAMINIFERIDA Eichwald, 1830
- Family NODOSARIIDAE Ehrenberg, 1838
  - Genus *Nodosaria* Lamarck, 1812
  - Genus *Lagena* Walker and Jacob, 1798
- Family GLANDULINIDAE Reuss, 1860
  - Genus *Oolina* d'Orbigny, 1839
- Family TURRILINIDAE Cushman, 1911
  - Genus *Buliminella* Cushman, 1911
- Family BOLIVINITIDAE Cushman, 1927
  - Genus *Bolivina* d'Orbigny, 1839
  - Genus *Suggrunda* Hoffmeister and Berry, 1937
- Family BULIMINIDAE Jones, 1875
  - Genus *Bulimina* d'Orbigny, 1826
  - Genus *Globobulimina* Cushman, 1927
- Family UVIGERINIDAE Haeckel, 1894
  - Genus *Siphogenerina* Schlumberger, 1883
  - Genus *Trifarina* Cushman, 1923
  - Genus *Uvigerina* d'Orbigny, 1826
- Family DISCORBIDAE Ehrenberg, 1838
  - Genus *Epistominella* Husezima and Maruhasi, 1944
  - Genus *Valvulineria* Cushman, 1926
- Family EPISTOMARIIDAE Hofker, 1954
  - Genus *Epistomaria* Galloway, 1933
- Family NONIONIDAE Schultze, 1854
  - Genus *Nonionella* Cushman, 1926
- Family ANOMALINIDAE Cushman, 1927
  - Genus *Holmanella* Loeblich and Tappan, 1962

Nodosaria? sp.

Four broken nodosarine specimens, each with two elongate chambers, were found. They closely resemble *Nodosaria parexilis* Cushman and Stewart (in Stewart and Stewart, 1930) or *N. tympaniplectriformis* Schwager of Haller (1980:235, pl. 3: fig. 10), identified from Pliocene beds near the northern California coast.

Hypotype: USNM 382514.

Lagena sp.

Three inornate specimens belong to *Lagena*.

?Oolina globosa (Montagu)

[?]*Oolina globosa* (Montagu).—Kleinpell, 1938:225 (= *Lagena globosa* Montagu).

This inornate *Oolina* is consistently present in replicates 20–24, totaling approximately 125 specimens.

Hypotype: USNM 382515.

Buliminella curta Cushman

PLATE 1: FIGURES 1, 2

Buliminella curta Cushman, 1925:33, pl. 5: fig. 13; 1926:55.—Kleinpell, 1938:248, pl. 7: fig. 4, pl. 16: fig. 8.

Thirty Stanford University collections hypotypes from the Salinas shale and Modelo, Temblor, Monterey, and possibly other formations have been examined. Most of the abundant present specimens had the final few large chambers fragmented or broken off from earlier whorls (probably in sample preparation). This makes the population superficially appear to be composed of relatively small specimens. Yet, it still is clear that the population shows considerable range of variation in specimen height/breadth—as do the Stanford hypotypes.

Figured Hypotypes: USNM 387632, 387633.

Hypotype: USNM 382516.

Buliminella dubia Barbat and Johnson

Buliminella dubia Barbat and Johnson, 1934:13, pl. 1: figs. 14, 15.—Kleinpell, 1938:249, pl. 16: fig.7.

Two small Toro Road specimens (one each from alcohol and clorox six-month soaks) com-

Table 7.—Check list for all observations.

■ ABUNDANT (33–100%)
● COMMON (12–33%)
○ FEW (3–12%)
△ RARE (<1–3%)

24 REPLICATE SAMPLES FROM ONE BED

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Buliminaceans																								
Bolivinitids & Suggrunda																								
Bolivina brevior	○	△	△	△	○	△	△	△	△	○	○	○	○	○	○	○	△	△	○	■	■	■	■	■
Bolivina seminuda	○	△	△	△	△	△	○	○	○	○	△	○	○	△	△	△	△	△	○	△	△	△	△	△
Bolivina spp. (4)	△				△		△	△	△		△	△	△	△	△	△		△	△	△	△	△	△	△
Suggrunda kleinpelli	△	△	△	△	△		△	△		△		△	△	△	△	△		△	△	○	○	○	△	○
Turrilinids																								
Buliminella curta	●	●	●	●	●	●	●	●	●	●	●	●	■	■	●	●	●	●	●	●	●	●	●	●
Buliminella dubia	△	△	△	△	△	△	△			△		△		△	△	△		△	△	△	△	△	△	△
Buliminella elegantissima	△	△	△	△	△	△	△	△	△			△	△	△	△	△		△	△	○	○	○	○	○
Buliminids																								
Bulimina cf. B. pseudoaffinis																								
Globobulimina pacifica	△	△	○	△	△	△	△	△	○	△	△	○	△	△	△	△	△	△	△	△	△	△	△	△
Uvigerinids																								
Siphogenerina sp.																								
Trifarina sp(p).																				△	△			△
Uvigerina sp(p).			△										△			△			△	△	△			△
Cassidulinaceans																								
Nonionids																								
Nonionella schencki	●	■	●	●	●	■	●	■	■	●	■	●	●	●	●	●	■	●	●	○	○	○	○	○
Discorbaceans																								
Discorbids																								
Epistominella subperuviana																				○	○	○	○	○
Valvulineria cf. V. californica obesa	■	■	■	■	■	■	■	●	●	■	●	■	●	●	■	■	●	■	■	●	●	●	●	●
Valvulineria (?) sp. cf. V. araucana	△														△	△		△	△	△	△	△		△
Nodosariaceans																								
Glandulinids																								
Oolina sp.																				△	△	△	△	△
Lagenids																								
Lagena sp. & Nodosaria (?) sp.																					△		△	△
Others (5 spp.)				△																△				
TOTAL NO. SPECIES IN REPLICATE /*SUBSAMPLE*	11	9	10	10	10	8	10	9	8	9	7	11	12	12	13	13	6	11	14	19	20	16	16	19
TOTAL NO. SPECIMENS IN REPLICATE /*SUBSAMPLE*	4313	2702	2633	2631	2673	1163	2496	1510	1349	1510	630	2050	1962	3262	2918	2110	848	2245	5641	12448	39561	16783	13006	18879

pared favorably with the holotype and paratypes and the specimen figured by Kleinpell, all from Upper Miocene rocks, in the Stanford collections. From the specimens seen, this form is nearly bulimine in coiling—barely if exceeding three chambers per whorl.

Hypotype: USNM 382517.

Buliminella elegantissima (d'Orbigny)

PLATE 1: FIGURE 3

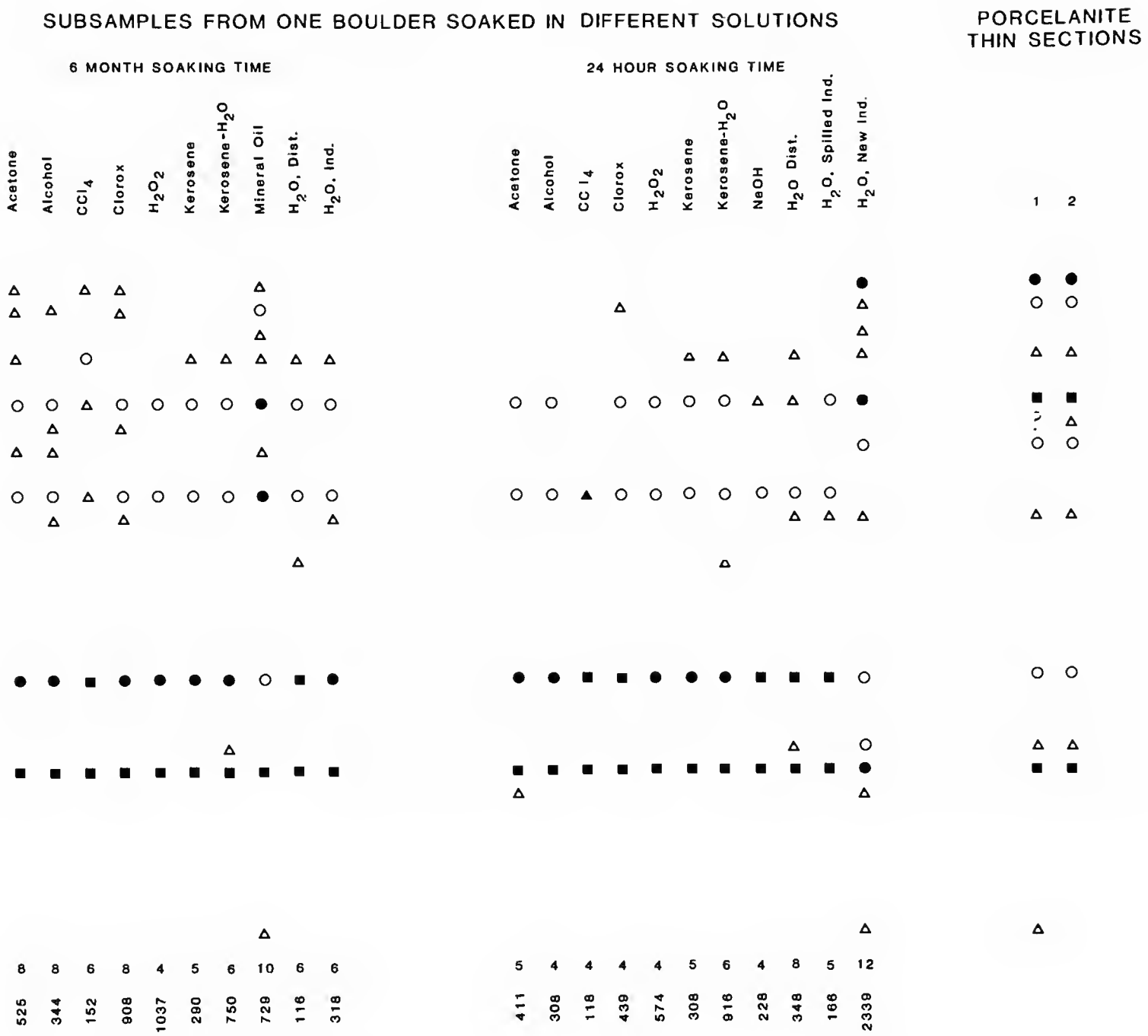
Bulimina elegantissima d'Orbigny, 1839:51, pl.7: figs. 13, 14.
Buliminella elegantissima (d'Orbigny).—Kleinpell, 1938:249, pl. 16: fig. 10.—Smith, 1978:141, pl. 2: fig. 1.—Buzas, Smith, and Beem, 1977:71, pl. 1: figs. 19, 20.

Twelve Miocene hypotypes in the collections of Stanford University ascribed to the species by Kleinpell (1938) and many hypotypes at the National Museum of Natural History (Smith, 1978; Buzas, Smith, and Beem, 1977; and others) have been examined. Like d'Orbigny's, most USNM types are Recent, but the species seems little changed since the Paleocene. Perhaps detailed time-morphology studies would reveal evolutionary patterns.

Figured Hypotype: USNM 387634.

Hypotype: USNM 382518.

Table 7.—Continued.



Bolivina brevior Cushman

PLATE 1: FIGURES 4–8

Bolivina brevior Cushman, 1925:31, pl. 5: fig. 8a,b; 1926:54.—Kleinpell, ed., 1980, pl. 7: fig. 11.

Bolivina brevior brevior Cushman.—Kleinpell and Tipton, 1980:72.

California hypotypes examined in the Stanford collections are (1) three "Upper Miocene" from a Kettleman Hills well; (2) one "Miocene" from the Salinas shale, Reliz Canyon, Monterey County; (3) two from the Gould shale, Zemorra Creek, Kern County; (4) and four from the Monterey formation, Santa Barbara County. This species occurs in all the material studied and dominates replicates 20–24 with thousands of specimens.

Figured Hypotypes: USNM 387635–387637.

Hypotype: USNM 382519.

?Bolivina conica Cushman

[?]*Bolivina conica* Cushman, 1925:30, pl. 15: fig. 4a,b; 1926:54.—Kleinpell, 1938:269, pl. 7: fig. 7a,b.

A single, large, conical, costate specimen is so referred.

Bolivina dunlapi Kleinpell

Bolivina dunlapi Kleinpell, 1938:271, pl. 15: fig. 2.
Bolivina brevior dunlapi Kleinpell.—Kleinpell and Tipton, 1980:72.

The holotype was examined. Kleinpell and Tipton (1980) state that "except for its costae, this small form is very similar to *Bolivina brevior*. *Bolivina dunlapi* Kleinpell is herein reinterpreted as the costate subspecies of *B. brevior*." We, however, presently retain *B. dunlapi* as a separate species to which a few specimens from Toro Road seem best referred, although they also resemble *B. sulphurensis* Cushman and Adams.

Hypotype: USNM 382520.

Bolivina pseudospissa Kleinpell

PLATE 1: FIGURE 13

Bolivina pseudospissa Kleinpell, 1938:279, pl. 21: fig. 6.—Kleinpell, ed., 1980, pl. 7: fig. 4.

A few, distinctive, compressed specimens with very neatly arranged nonlobate arcuate sutures seem best referred to this species. Compared with the holotype, they have the same chamber and suture pattern and considerable degree of compression but lack a keel. Populations of *Bolivina pseudospissa* were not available for comparison, however. These Toro Road *Bolivina* also closely resemble *B. paula* Cushman and Cahill from the Pliocene Yorktown formation of the East Coast.

Figured Hypotype: USNM 387641.

Hypotype: USNM 382521.

Bolivina rankini Kleinpell

Bolivina rankini Kleinpell, 1938:288, pl. 22: figs. 4, 9.

A few specimens from Toro Road appear very similar to the holotype, but distinct from *Bolivina seminuda* Cushman, being more tapering and compressed. They appear best referred to this species.

Hypotype: USNM 382522.

Bolivina seminuda Cushman

PLATE 1: FIGURES 9–12

Bolivina seminuda Cushman, 1911:34, fig. 55.—Kleinpell, 1938:281.
Bolivina seminuda Cushman *forma seminuda* Govean, 1980:146, pl. 1: figs. 1–5, pl. 3: figs. 2–6, pl. 4: figs. 1–6, pl. 5: figs. 3, 4, 6, pl 6: figs. 4, 5, pl. 7: figs. 1–6, pl. 8: figs. 1–5, 7, pl. 9: figs. 1–3, pl. 10: figs. 1–5.
Bolivina seminuda seminuda Cushman.—Kleinpell, ed., 1980, pl. 8: figs. 5, 6, 9, 10.
Bolivina foraminata R.E. Stewart and K.C. Stewart.—Kleinpell, ed., 1980, pl. 8: figs. 7, 8.
Bolivina seminuda Cushman subspecies *foraminata* Stewart and Stewart.—Govean, 1980:145, pl. 2: figs. 1–3, pl. 3: fig. 1, pl. 5: figs. 1, 2, 5, pl. 6: figs. 1–3, pl. 7: fig. 7, pl. 8: fig. 6.

The 16 Stanford hypotypes referred to *Bolivina seminuda* and the 12 referred to *B. seminuda foraminata* by Kleinpell (1938:281) were examined. Govean (1980) showed that the *B. seminuda* and *B. foraminata* forms are ecophenotypes. The species was found throughout the Toro Road material studied but in relatively small numbers.

Figured Hypotypes: USNM 387638–387640.

Hypotype: USNM 382523.

Suggrunda kleinpelli Bramlette

PLATE 1: FIGURES 14–17

Suggrunda kleinpelli Bramlette, in Woodring and Bramlette, 1950:59, pl. 23: figs. 4, 5, 9.

The present specimens, numbering several hundred, clearly belong to *Suggrunda*. Many closely resemble Bramlette's type figures. The holotype comes from a "road cut on Laureles grade," very near the present location and apparently from the same stratigraphic unit. Yet, much variation occurs in the present population of *Suggrunda*—as to (1) quadrateness, (2) compression, (3) marginal sharpness, and (4) spine development—four related characters. Determining whether or not distinct morphological groups and possibly taxa are represented would require further study. Populations of Bramlette's

form also should be examined. *Suggrunda* was placed in the Caucasinidae of the Cassidulinacea by Loeblich and Tappan (1964), but is retained in the Bolivinitidae herein.

Figured Hypotypes: USNM 387642, 387643.

Hypotype: USNM 382524.

Bulimina cf. *B. pseudoaffinis* Kleinpell

PLATE 2: FIGURES 1, 2

This form commonly constitues from 1%–10% of the assemblages from the boulder subsamples, but was not found in any of the 24 replicates from one bed. Kleinpell's holotype was examined, but no other specimens were seen in the Stanford collections. The holotype is preserved differently than the present specimens—giving a different appearance. Its apertural area also appears to have been somewhat squashed. This may give *this* specimen the "thickest near middle" outline described by Kleinpell (1938:257, pl. 9: fig. 9). If that characteristic represents his populations, however, it may not match the present specimens; they are thickest from middle to upper third. Their sutures also appear a bit more depressed than Kleinpell's holotype, but in the absence of a population, it is not possible to know certainly if this is true. Our specimens also appear a bit smaller than the holotype of *B. pseudoaffinis*; this could be environmental, however.

Kleinpell had originally identified the holotype as a member of *B. affinis* d'Orbigny and remarked (1938:258) that *B. pseudoaffinis* is "apparently closely related to" that taxon. Interestingly, the figures given by Haller (1980:246, pl. 7: fig. 6a,b) for *Globobulimina affinis* (d'Orbigny) (from the Pliocene Rio Del Formation) very closely resemble the present specimens. No Haller specimens were seen, but perhaps the Toro Road form is intermediate and *B. pseudoaffinis* is the ancestor. As to generic identity, the present specimens could be placed in either *Bulimina* or *Praeglobulimina* or *Globobulimina* on the basis of the degree of overlap/envelopment of chambers. The condition of the specimens studied herein did not allow for investigation of tooth-plate characteristics.

Figured Hypotypes: USNM 387644, 387645.

Hypotype: USNM 382525.

Globobulimina pacifica Cushman

PLATE 2: FIGURE 3

Globobulimina pacifica Cushman, 1927:67, pl. 14: fig. 12a,b.—Kleinpell, 1938:260, pl. 8: fig. 7.

Both the holotype and Kleinpell's figured specimen have been examined. This species is well represented throughout the Toro Road materials, although never common. Most tests were broken in sample preparation. Numerical abundances were estimated from fragmentary specimens.

Figured Hypotype: USNM 387646.

Hypotype: USNM 382526.

Siphogenerina sp.

A single early-test portion is questionably referred to this genus. It was found in the distilled water one-day-soak boulder subsample. It is robust, nearly rounded, and has sutural lobation; it is biserial. It could be a *Bolivina* but seems better referred to *Siphogenerina*.

Trifarina sp(p).

Trifarina is represented by two costate and five smooth specimens in this Toro Road material. Other than ornamentation, they are very similar. Such ornamented and unornamented *Trifarina* may belong to more than one species.

Uvigerina spp.

Uvigerina is represented by fewer than 20 specimens in the Toro Road material. These all are

large; most are smooth and one generically questionable specimen is costate. Hypotype USNM 382527 represents the smooth variety.

Hypotype: USNM 382527.

Epistominella subperuviana (Cushman)

PLATE 2: FIGURES 4–6

Pulvinulinella subperuviana Cushman, 1926:63, pl. 9: fig. 9.

The holotype is deposited in the National Museum of Natural History. A specimen in the Stanford collection (LSJU type no. 943, slide 1045) might be a paratype (see Cushman, 1926:63) but was figured by Kleinpell (1938:321, pl. 14: fig. 10a–c) as *Eponides* sp. It is from the Salinas shale, Monterey County, California. This specimen and two hypotypes also identified by Kleinpell as *Eponides* sp. have been examined and appear to be *Epistominella subperuviana*. These two hypotypes are from the upper type Monterey Formation and the Monterey Formation of the Nipomo Quadrangle, respectively.

A very similar species is *Epistominella relizensis* (Kleinpell). The holotype of *Pulvinulinella relizensis* Kleinpell (1938:329, pl. 10: fig. 10a–c) is missing. Only one other specimen so ascribed is in the Stanford colections. Yet, (1) the type descriptions of "*P.*" *relizensis* and "*P.*" *subperuviana* and (2) comparison with the one specimen ascribed to the former and the three ascribed to *Eponides* sp. by Kleinpell indicate that the Toro Road specimens are probably not best referred to *Epistominella relizensis* but to *E. subperuviana*. *Epistominella relizensis* is described with a smaller holotype than *E. subperuviana*. The smaller size is in keeping with the present specimens, but otherwise they are more like *E. subperuviana*. (Note that some Toro Road species—as *Valvulineria*—are smaller than elsewhere.)

Kleinpell (1938) stated that the "test of *P[ulvinulinella] relizensis* is more strongly and symmetrically biconvex than in *P. subperuviana*, typical specimens of which also are present in Reliz Canyon." The present specimens have the test approximately as biconvex as does *Epistominella subperuviana*—not more. The one type of *E. relizensis* in the Stanford collections does show a more biconvex form.

We compared Kleinpell's (1938:329, pl. 16: fig. 5a–c) specimen of "*Pulvinulinella*" *relizensis* to another from Reliz Canyon (Lower Delmontean part of the section) ascribed to and figured as *P.* cf. *P pontoni* Cushman. They are very similar except that the "*P.*" *relizensis* specimen has flush sutures. Populations can, however, show both flush and depressed sutures.

Five specimens of the form referred to *P.* cf. *P. bradyana* Cushman by Kleinpell (1938:327) were examined also. The sutures range from flush to slightly depressed. They also closely resemble the "*P.*" *relizensis* specimen. They are from the "Upper Modelo" Formation in Los Angeles County—"Lower Delmontean." Thus, this form and "*P.*" cf. *P. pontoni* (above) are younger than the Kleinpell specimens of "*P.*" *subperuviana* and "*P.*" *relizensis* (Relizian and Luisian). The Toro Road specimens are of Mohnian age.

Figured Hypotypes: USNM 387647, 387648.

Hypotype: USNM 382528.

Valvulineria sp. cf. *V. araucana* (d'Orbigny)

A few specimens, distinct from *Valvulineria* cf. *V. californica* subsp. *obesa*, are so referred. They are similar to "*V. araucana* (d'Orbigny) var. *malagaensis*" Kleinpell (1938:308, pl. 22: figs. 10–12).

Hypotype: USNM 382529.

Valvulineria cf. *V. californica* Cushman subsp. *obesa* Cushman

PLATE 2: FIGURES 7–12

Valvulinerias in the Stanford University type collections include many specimens pertinent to the problem of identifying the abundant Toro Road form. The Stanford types include paratypes and hypotypes (and "plesiotypes") ascribed by Kleinpell (see Kleinpell, 1938) and others to the taxa discussed below.

Valvulineria miocenica Cushman (1926:61, pl. 8: figs. 9, 10, pl. 9: fig. 3a–c; Kleinpell, 1938:313, pl. 61: fig. 1a–c) clearly is more compressed than the Toro Road *Valvulineria* and has sutures much more curved and nearly flush and thus has a less lobate periphery.

Like *V. miocenica, V. californica californica* Cushman (*V. californica* Cushman, 1926:60, pl. 9: fig. 1a–c; Kleinpell, 1938:308, pl. 13: fig. 6a–c, pl 16: fig. 4a–c) and *V. grandis* Cushman and Galliher (1934:26, pl. 4: fig. 12a–c; Kleinpell, 1938:312) are more compressed than the Toro Road form.

Valvulineria californica appressa Cushman (*V. californica* Cushman var. *appressa* Cushman, 1926:60, pl. 9: fig. 5a–c; Kleinpell, 1938:309, pl. 13: fig. 7a–c) and *V. californica obesa* Cushman (*V. californica* Cushman var. *obesa* Cushman, 1926:61, pl. 9: fig. 2a–c; Kleinpell, 1938:310, pl. 10: fig. 12a–c, pl 14: fig. 12a–c) are not more compressed. Yet they are larger and appear to have less depressed sutures and consequently much less lobate periphery than the Toro Road form. Marginal sutural depression is so great with the later chambers of the Toro Road specimens than many nearly appear to approach "uncoiling." They also have thinner walls than these *V. californica* types from Stanford. They do not, however, appear to closely resemble any other *Valvulineria* species.

The Toro Road *Valvulineria* come from a very well studied formational and time-stratigraphic unit. It seems unlikely that they represent a previously undescribed species or even subspecies. Although, if subspecies is conceived as applicable or relative to a geographic or ecologic morphological (evolutionary) adaptation, a "new" subspecies could/may be represented.

The most likely explanation of the morphology of the Toro Road *Valvulineria* follows. (1) The thinness of the wall—relative to characteristic and typical *V. californica*—reflects lesser availablility of $Ca^{++} + CO_3^{--}$ in the life environment. (2) The "thinness" also expresses itself as less sutural filling, giving more depressed (appearing) sutures and lobate margin. (3) This "thinness" and apparent marginal sutural depression "culminate" in the final chambers appearing almost detached from the earlier whorl. It is possible, however, that an evolutionary trend toward extreme sutural depression—and even separation—*is* represented herein. (4) Relatively small specimen size may also reflect the life environment. One explanation is that an abundance of small specimens represents rapid proliferation of a taxon in an optimum environment, or one without predators or competitors.

All of these (kinds of) morphological factors have been correlated with some environmental stress conditions for foraminifera. In the present case, these could correlate with an oxygen-minimum environment (Ingle, pers. comm., 1983). Whether or not a new subspecies is represented here seems moot, but at present it also seems best to refer these specimens tentatively to *Valvulinera californica* subsp. *obesa*. A study of the distribution of the Toro Road form is needed before this taxonomic problem can be resolved.

Figured Hypotypes: USNM 387649–387654.

Hypotype: USNM 382530.

Epistomaria sp.

One specimen from a boulder subsample is so referred.

Nonionella schencki (Kleinpell)

PLATE 2: FIGURES 13–16

Nonion schencki Kleinpell, 1938:235, pl. 16: fig. 11a,b.—Kleinpell, ed., 1980, pl. 2: fig. 2, pl. 3: figs. 1a,b, 2a,b, 5.

The Toro Road specimens appear conspecific with the holotype from "4 mi. E. of Del Monte, Monterey County, California." The paratype from the "Salinas Shale—Miocene" is larger than most of the abundant present specimens but has a very good likeness. Two hypotypes identified by Kleinpell from the "Santa Margarita Shale . . . Nipomo Quadrangle" are similar to the Toro Road form but preservation differs. Nine of Kleinpell's (1938) specimens from the "Upper type Monterey" also show a very good likeness

to the Toro Road form. These types are in the Stanford collections. It is not entirely clear whether this form should be placed in *Nonionella* or *Florilus*.

Figured Hypotypes: USNM 387655–387658.

Hypotypes: USNM 382531–382533.

Nonionella sp.

Two specimens are so referred; they are not *Nonionella schencki* (Kleinpell).

Hypotype: USNM 382534.

Holmanella sp. cf. *H. valmonteenis* (Kleinpell)

This form is very rare here. Specimens probably are smaller than *Discorbinella valmonteensis* Kleinpell (1938:350, pl. 21: figs. 14–16). It is described as "test large," a point reiterated in the discussion. The holotype is at the National Museum of Natural History. A/some paratype(s) and hypotypes reportedly were deposited in the Stanford collections but were not found.

The small size of the Toro Road specimens is like that of the *Valvulineria* here. It may reflect environmental conditions. Yet, both specific and generic assignments are in question at this time.

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PLATES

PLATE 1

Buliminella curta Cushman
1. Side view, hypotype, USNM 387632, ×135.
2. Side view, hypotype, USNM 387633, ×175.

Buliminella elegantissima (d'Orbigny)
3. Side view, hypotype, USNM 387634, ×180.

Bolivina brevior Cushman
4. Side view, hypotype, USNM 387635, ×250.
5. Apertural view, hypotype, USNM 387636, ×165.
6. Side view, hypotype, USNM 387636, ×155.
7. Apertural view, hypotype, USNM 387637, ×260.
8. Side view, hypotype, USNM 387637, ×220.

Bolivina seminuda Cushman
9. Apertural view, hypotype, USNM 387638, ×125.
10. Side view, hypotype, USNM 387638, ×140.
11. Side view, hypotype, USNM 387639, ×95.
12. Side view, hypotype, USNM 387640, ×205.

Bolivina pseudospissa Kleinpell
13. Side view, hypotype, USNM 387641, ×90.

Suggrunda kleinpelli Bramlette
14. Apertural view, hypotype, USNM 387642, ×190.
15. Combination view, hypotype, USNM 387642, ×175.
16. Apertural view, hypotype, USNM 387643, ×155.
17. Side view, hypotype, USNM 387643, ×190.


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PLATE 2

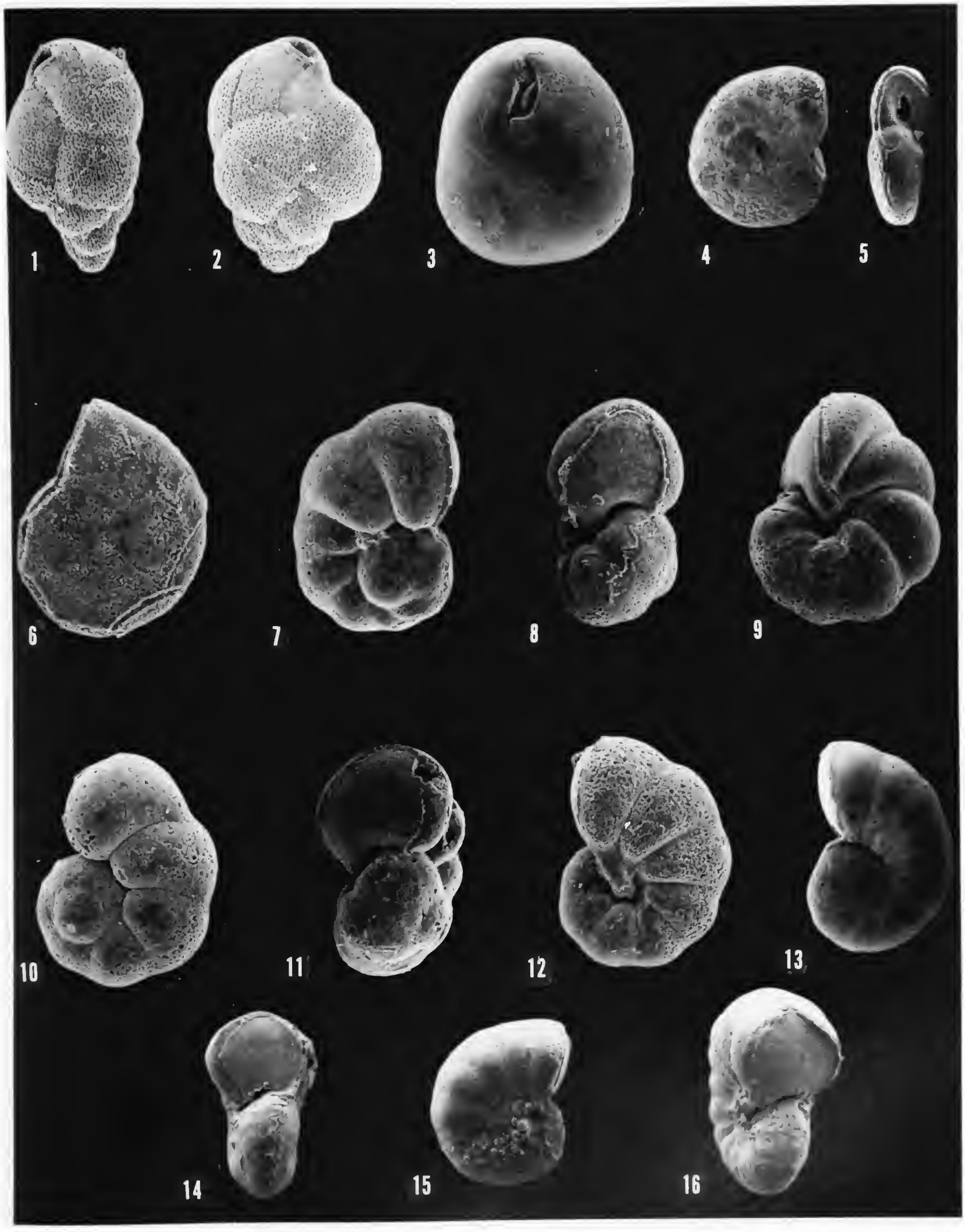
Bulimina cf. *B. pseudoaffinis* Kleinpell
1. Side view, hypotype, USNM 387644, ×120.
2. Side view, hypotype, USNM 387645, ×165.

Globobulimina pacifica Cushman
3. Apertural view, hypotype, USNM 387646, ×75.

Epistominella subperuviana (Cushman)
4. Side view, hypotype, USNM 387647, ×210.
5. Marginal view, hypotype, USNM 387647, ×185.
6. Side view, hypotype, USNM 387648, ×290.

Valvulineria cf. *V. californica obesa* Cushman
7. Spiral view, hypotype, USNM 387649, ×165.
8. Marginal view, hypotype, USNM 387650, ×185.
9. Umbilical view, hypotype, USNM 387651, ×160.
10. Spiral view, hypotype, USNM 387652, ×200.
11. Marginal view, hypotype, USNM 387653, ×215.
12. Umbilical view, hypotype, USNM 387654, ×160.

Nonionella schencki Kleinpell
13. Spiral view, hypotype USNM 387655, ×95.
14. Marginal view, hypotype, USNM 387656, ×95.
15. Umbilical view, hypotype, USNM 387657, ×95.
16. Marginal view, hypotype, USNM 387658, ×95.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