

CONTRIBUTIONS
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VOLUME XII, PART 3, JULY, 1961

224. THE TYPE SPECIES OF *MARGINULINA* D'ORBIGNY, 1826

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ABSTRACT

Marginulina d'Orbigny, 1826, was defined without designation of a type species. The type was first designated by Deshayes, 1832, as *Nautilus raphanus* Linné (part). *Nautilus raphanus* Linné is also the type species of *Orthocera* Lamarck, 1799 (not Modeer, 1789) [= *Nodosaria* Lamarck, 1812]. Both Deshayes and d'Orbigny had noted that Linné had included in this species specimens referable to both *Marginulina* and *Nodosaria*. Reasons are given for the citation of the type species of *Marginulina* as it was described by Deshayes, as *Marginulina raphanus* d'Orbigny, 1826 (not *Nautilus raphanus* Linné).

In preparation of the section on smaller foraminifera for the *Treatise on Invertebrate Paleontology*, it has become evident that many of the "best known" genera of foraminifera are as yet not firmly established on the basis of their type species.

Marginulina was defined by d'Orbigny (1826, p. 258) and has been recognized by nearly all workers on the foraminifera since then, with very little disagreement as to the type of species included. The type species, however, is not as well known. Cushman (1913, p. 79) designated *Marginulina glabra* d'Orbigny, 1826, as type species, and this was followed by Galloway (1933, p. 243), Bykova, Daïn and Fursenko in Rauser-Chernousova and Fursenko (1959, p. 255) and Pokorný (1958, p. 280). However, this designation is invalid, as the type species had been fixed by Deshayes (1832, p. 416). Under the description of the genus *Marginulina*, Deshayes stated that it had been confused by others with the "Orthoceres," such as *Nodosaria*, with which there was some analogy. He stated that Linné gave the name *Nautilus raphanus* to a small multilocular shell, which serves as type of the genus *Marginulina*.

This places the status of *Marginulina* somewhat in doubt for the description of *Nautilus raphanus* Linné does not agree with the specimens figured by Plancus (1739) and Gualtieri (1742), whose figures were mentioned by Linné. These figured specimens appear to be a costate *Nodosaria*, with symmetrically placed aperture (refigured as *Nautilus raphanus* by Ellis and Messina: Catalogue of Foraminifera), and in fact *Nautilus raphanus* Linné had also been cited as type of *Orthocera* Lamarck, 1799. Deshayes and d'Orbigny both commented that *Marginulina* had been previously confused with *Nodosaria* and *Orthocera*, but differed in having an excentric aperture, arcuate test, and slight tendency to an early spiral development. D'Orbigny referred to his Model No. 6, and to his pl. 10, fig. 6 (1826), both obviously *Marginulina* as generally

understood, and he did not mention the figures of Plancus or Gualtieri.

The original description of *Nautilus raphanus*, given by Linné (1758, p. 667), follows: "*Nautilus Raphanus*. 243. N. testa recta attenuata, articulis torosis: striis elevatis sedenis, siphone sublaterali obliquo. Planc. conch. t. 1, f. 6. Gualt. test. t. 19, f. L. Habitat in M. Adriatico, Mediterraneo, minutus."

Thus Linné recognized the oblique and sublateral aperture. Deshayes also commented (1830, p. 416) that the *Nautilus raphanus* of Linné also included a number of species of *Nodosaria* (obviously referring to the Plancus and Gualtieri figures). Among the species included in *Marginulina*, Deshayes (1830, p. 418) described *Marginulina raphanus* d'Orbigny. He did not refer to the species as *Marginulina raphanus* (Linné). Thus both d'Orbigny, who described the genus, and Deshayes, who fixed the type, recognized the species as it was described by Linné, but not as figured by Plancus and Gualtieri although these were mentioned by Linné.

This species as understood by Linné was thus more inclusive than as understood by later workers. Under such situations, when a genus is described with a type species which is understood differently by the author of the genus than by the author of the species, the type species may be cited under the new generic name and the old specific name with the species credited to the author of the new genus. This was actually done by Deshayes. In the present instance, the type of *Marginulina* would thus be cited as *Marginulina raphanus* d'Orbigny, 1826; not *Nautilus raphanus* Linné, 1758. In the interest of stability of nomenclature, we here designate as lectotype for *Marginulina raphanus* d'Orbigny, 1826, the specimen figured by d'Orbigny, 1826, pl. 10, fig. 7, and as lectotype for *Nautilus raphanus* Linné, 1758 = *Nodosaria raphanus* (Linné), the specimen figured by Gualtieri, 1742, pl. 19, fig. L as *Orthoceras minumum* and mentioned by Linné in his synonymy for *N. raphanus*.

Thus the *Nautilus raphanus* Linné and the genus *Orthocera* Lamarck, 1799 (not Modeer, 1789), are *Nodosaria*. The figures of Plancus (1739) may belong to *Nodosaria*, *Marginulina* or *Dentalina*, and probably represent a distinct species from *Nodosaria raphanus* (Linné).

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225. THE TYPE SPECIES OF THE FORAMINIFERAN GENUS
SACCAMMINA CARPENTER, 1869

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ABSTRACT

Saccammina Sars, 1869, is a *nomen nudum*, the genus being first described by and therefore credited to Carpenter, 1869. The status, date and authorship of the genus and its type species are discussed. The type is determined to be *Saccammina sphaerica* Brady, 1871 (not *S. sphaerica* Sars, 1872), fixed by subsequent designation by Cushman, 1928.

The genus *Saccammina* was first discovered in material dredged from off the coast of Norway at 450 fathoms. "*Saccammina sphaerica* Sars, n. g. et sp." was reported in lists of the material obtained (M. Sars, 1869a, p. 248; 1869b, p. 425) but no generic or specific descriptions were given, nor was it figured, hence it remained a *nomen nudum*. Sars sent specimens of this "*Saccammina sphaerica*" to a number of other workers at the time, hence as was later stated by Brady (1884, p. 253), left "no doubt as to the form for which the name was intended." Among others W. B. Carpenter received some of the specimens and the generic name was validated when described by Carpenter (1869a, p. 61). Although the description was based on Sars' specimens, and the *nomen nudum* of Sars was used as the generic name, the description was given by Carpenter, hence according to the Rules of Nomenclature the genus must be credited to Carpenter. This was done by Rhumbler (1904, p. 242), although other workers have erroneously credited the generic name to Sars. No specific name was given in Carpenter's publication, however, hence the species remained a *nomen nudum*, and the genus remained without valid species.

The type species thus may be either the first valid species later to be assigned to the genus (subsequent monotypy) or in the case of more than one species later placed simultaneously in the genus, any of these may be selected as type by that author, or a subsequent reviser.

Rhumbler has been incorrectly credited with fixing the type of *Saccammina* Sars, 1869, as *Saccammina sphaerica* Sars, 1872. Rhumbler did not select the type. He cited the genus as *Saccammina* Carpenter, and under the synonymy listed (1904, p. 242) "1868 *Saccammina* (Typ. *S. sphaerica*) (nom. nud.), M. SARS in: Forh. Selsk. Christian., (1869) p. 248." He was therefore only citing the *nomen nudum* *S. sphaerica* as type of the *nomen nudum* *Saccammina* M. Sars, 1869, as was implied by Sars who listed the form in his table as "*Saccammina sphaerica* n. g. et sp." The remaining generic synonymy given by

Rhumbler included the later references to *Saccammina* by Carpenter, 1869, Bütschli, 1880, Brady, 1884, Rhumbler, 1894, Flint, 1899, and Eimer and Fickert, 1889. Rhumbler then cited two species of *Saccammina*, *S. sphaerica* and *S. socialis* Brady, but did not state that either was type. Later discussions of the genus also cited *S. sphaerica* Sars, 1869, *nom. nud.* as type of the genus (Cushman, 1910, p. 38; 1918, p. 43). Obviously, a *nomen nudum* cannot be the type of the genus.

M. Sars published his first valid description of the species *Saccammina sphaerica* in G. O. Sars (1872, p. 250), and a problem thus arises as to its validity as type species of *Saccammina* Carpenter, 1869. Some of the specimens sent to Carpenter were seen by Brady, who believed them closely related to small spherical bodies he had found in the English Carboniferous, and for which he had previously proposed at a meeting in 1869 the new generic name *Carteria*. This had been validated in publication in 1870 (p. 381) by Brady, but no species were assigned to it either. In 1871 (p. 182-183) Brady decided that the Carboniferous *Carteria* and the Recent *Saccammina* were congeneric, and he then described the Carboniferous form as *Saccammina carteri*. With this species dating from 1871, and *S. sphaerica* Sars dating from 1872 (as commonly considered), *S. carteri* would thus automatically become the type of *Saccammina* by subsequent monotypy. Although apparently obvious, this has not been suggested as type species in any text. Numerous references have been made, however, to the differing dates of valid publication of the genus *Saccammina* and of the species *S. sphaerica* (Brady, 1884, p. 252; Rhumbler, 1904, p. 242; Galloway, 1933, p. 59; Cushman, 1948, p. 78; Ellis and Messina, 1940). Furthermore, *Saccammina carteri* was not regarded as congeneric by later workers and the genus *Saccamminopsis* Sollas, 1921, was proposed for it (as had been the name *Carteria* Brady, 1870, a homonym of *Carteria* Diesing, 1866, *Carteria* Gray, 1867, and *Carteria* Signoret, 1874). Not only was it regarded as generically distinct, but it was stated by Sollas (1921) to have an originally calcareous test, rather than an agglutinated one and under the classification proposed by the present writers would now be placed in a distinct subfamily (Earlandiinae), family (Moravamminidae), superfamily (Parathuramminacea), and suborder (Fusulinina) from *Saccammina sphaerica*. Thus if *S. carteri* were recognized as type species of *Saccammina*, this generic name

would not be available for the foraminifera for which it was intended and to which it has been referred in all micropaleontologic texts and treatises for nearly a century.

Fortunately for the stability in foraminiferal nomenclature there is another solution to this problem. In the paper in which he described *S. carteri*, Brady (1871) also mentioned *S. sphaerica* and gave a sufficiently detailed description of the Recent species to validate it. Brady cited (1871, p. 183) the name *Saccammina sphaerica* of Sars as "a species named in his [Sars'] paper on the deep sea fauna, but, so far as I know, not yet described." He then proceeded to describe the new Paleozoic *S. carteri*, and in so doing gave a description of the Recent *S. sphaerica*. In order that no question as to this solution might arise, the following description is taken from Brady's publication and the quoted remarks are followed by the page and line from which they were taken: *Saccammina sphaerica* (Brady, 1871, p. 183). Material used by Brady: "type slides of deep Atlantic Foraminifera sent by Prof. Sars of Christiania to Dr. Carpenter, and amongst these specimens of his *Saccammina sphaerica*, a species named in his paper on the deep-sea fauna" (p. 183, lines 2-5).

Description of *M. sphaerica* given by Brady: "Chambers always subspherical and have but one aperture (p. 183, lines 23, 24); always occurs in single segments, and there is no reason to believe that it is ever polythalamous (lines 25-27); . . . the test of *S. sphaerica* is somewhat thinner [than *S. carteri*], and nearly smooth both inside and out (lines 29-30); . . . living abundantly on the coast of Norway at a depth of 450 fathoms" (lines 34-35).

Saccammina sphaerica may therefore be regarded as validated by Brady in 1871, but the valid specific name should be credited to Brady, 1871, rather than to Sars, 1872. With validation in 1871 both *S. sphaerica* and *S. carteri* were available for selection as type of *Saccammina* Carpenter, 1869. Although the *nomen nudum* *S. sphaerica* Sars, 1869, had been cited as type of *Saccammina* Sars, 1869 (*nom. nud.*), the valid species was not cited as type by these authors. The first reference which did not add "*nom. nud.*" after the name *S. sphaerica* in citing it as type species is apparently that of Cushman (1928, p. 72), where the genus is given as *Saccammina* M. Sars, 1869, and the type listed as "Genoholotype, *Saccammina sphaerica* M. Sars."

As discussed above the correct citation should be *Saccammina* Carpenter, 1869; type species *S. sphaerica* Brady, 1871, fixed by subsequent designation, Cushman (1928, p. 72), authorship emended herein.

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226. *SPIROTECTA PELLICULA*, N. GEN., N. SP., FROM THE
UPPER CRETACEOUS AND *GIRALIARELLA TRILOBA*, N. SP.,
FROM THE PERMIAN OF WESTERN AUSTRALIA¹

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ABSTRACT

The new genus *Spirotecta* is described, with *S. pellicula*, n. sp., as the type species. This genus is characterized by the wholly involute test and the granular wall structure. *Giraliarella triloba*, n. sp., characterized by the trilobate outline of the test in end view, is described from subsurface Permian beds in the Carnovan Basin, Western Australia.

Family ? CHILOSTOMELLIDAE

Genus *Spirotecta*, n. gen.

Type species.—*Spirotecta pellicula*, n. sp.

Test free, trochospiral, wholly involute, umbilicus closed; wall thin, calcareous, very finely perforate, granular in structure; no internal structure present, septal walls single; aperture interiomarginal, with a narrow lip.

Remarks.—The writer is not certain of the affinities of *Spirotecta*, n. gen., but places it provisionally in the Chilostomellidae. Thin sections and dissected specimens show that the genus is involute throughout and not only in the later growth stages. Other genera of the Chilostomellidae, such as *Quadrimorphina*, *Allo-morphina* and *Rotamorphina* have a granular wall structure and also an interiomarginal aperture. *Spirotecta*, n. gen., has a thin lip bordering the aperture, but lacks the distinct umbilical flap of *Quadrimorphina* and *Rotamorphina* and also differs in the involute nature of the test.

Spirotecta, n. gen., may be referable to the Eponidae. Reiss (1958) stated that some species of *Eponides* have radiate walls but that most have a granular structure. Wood (1949) found that the type species of *Eponides*, *E. repandus* (Fichtel and Moll), possessed a radiate wall structure. However, the concept of this species and also of the genus *Eponides* has changed since they were originally described. *Spirotecta pellicula*, n. sp., has the same involute form as the type specimen of *Eponides repandus* as figured by Fichtel and Moll, one view of which was refigured by Montfort when he established the genus *Eponides* (see Redmond, 1949 and Hofker, 1950).

The generic name is from the Latin *spira*, spire and *tegere*, to cover, referring to the involute coiling of the test.

Spirotecta pellicula, n. sp.

Plate 3, figures 1-8

Diagnosis.—Test trochospiral, unequally biconvex, wholly involute; wall calcareous, finely perforate, gran-

ular in structure; no internal structure present, aperture interiomarginal.

Description.—Test trochospiral, unequally biconvex, wholly involute, umbilicus closed; in top view oval in outline with smooth or slightly indented periphery, in edge view periphery narrowly rounded. Sutures on ventral side narrow, depressed, radial, on dorsal side narrow, smooth, curved; septal walls single. Five chambers visible, increasing slowly in size as added, no internal structure present. Wall of test calcareous, very finely perforate, granular in structure; surface of test smooth. Aperture ventral, interiomarginal, a narrow slit with a small distinct lip, extending from the umbilicus and crossing the periphery of the test but not extending back along the dorsal side.

Dimensions.—

	Length	Max. Width	Thickness
Holotype	0.51 mm.	0.42 mm.	0.27 mm.
Paratype	0.45 mm.	0.35 mm.	0.24 mm.

Occurrence.—Holotype (C.P.C. 3851) from type locality of the Korojon Calcarenite in CY Creek, Carnarvon Basin, Western Australia, latitude 25° 53' S., longitude 114° 07' E., 96 feet above base of formation (Maestrichtian); paratype (C.P.C. 3852) from same locality, 55 feet above base of formation (Campanian); horizontal section (C.P.C. 3853) from same locality and level as holotype; vertical section (C.P.C. 3854) from same locality as holotype, 74 feet above base of Korojon Calcarenite (Campanian); vertical section (C.P.C. 3855) from same locality and level as paratype.

Remarks.—About 40 specimens of *Spirotecta pellicula* have been available for study; all have five chambers visible and all are wholly involute. The species is at present recorded only from the Korojon Calcarenite at the type locality. The specific name is the Latin *pellicula*, diminutive of *pellis*, skin.

The holotype, paratype and thin sections are deposited in the Commonwealth Palaeontological Collection, Canberra, Australia.

Genus *Giraliarella* Crespin, 1958*Giraliarella triloba*, n. sp.

Plate 3, figures 9-13

Diagnosis.—Test elongate, trilobate, smooth, edges at first angulate, then rounded; non-septate; aperture terminal.

Description.—Test free, elongate, straight, trilobate, with one side broader than the other two; usually

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broadening slowly with growth, but sometimes of uniform width throughout; initial portion unknown. Sharply angulate in early portion, in younger stages the angles broadly rounded; each side of test with a deeply depressed central groove. Wall smooth, composed of small quartz grains with much cement; surface of test occasionally with indistinct transverse constrictions, but test non-septate. Aperture terminal, an elongate slit either semicircular in shape or reflecting the trilobate outline of the test; no lip present.

<i>Dimensions.</i> —	<i>Length</i>	<i>Max. Width</i>
Holotype	0.57+ mm.	0.28 mm.
Paratype A	0.45+ mm.	0.23 mm.
Paratype B	0.58+ mm.	0.34 mm.

Occurrence.—Holotype (C.P.C. 3856) and paratypes A and B (C.P.C. 3857 and 3858) from core No. 11, (1083 feet - 1093 feet), B.M.R. No. 9 Bore, Daurie Creek, Carnarvon Basin, Western Australia; Callytharra Formation, Permian (Artinskian).

Remarks.—*G. triloba* has also been found in core No. 10 (992 feet - 1002 feet) in B.M.R. No. 9 Bore. No complete specimen has been found; the initial portion is always broken away, and sometimes also the apertural end. The trilobate outline in end view is a constant feature of all the 18 observed specimens and

is the main feature distinguishing this species from those described by Crespin (1958). The rounded angles of the younger stages are also features shown only by *G. triloba*.

The specific name refers to the trilobate outline of the test in end view.

The holotype and two paratypes are deposited in the Commonwealth Palaeontological Collection, Canberra, Australia.

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EXPLANATION OF PLATE 3

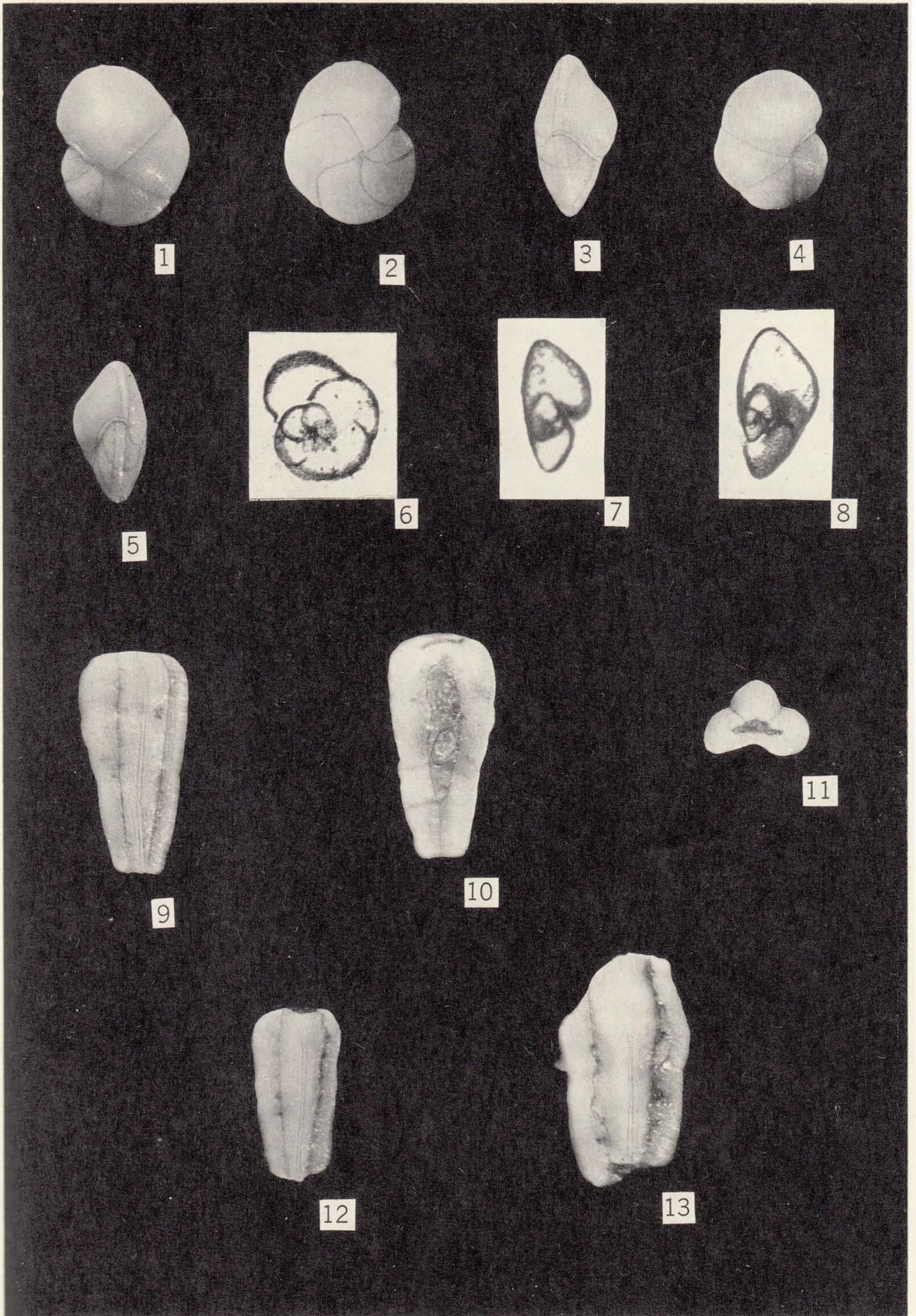
All figures except thin sections are retouched photographs

FIGS.

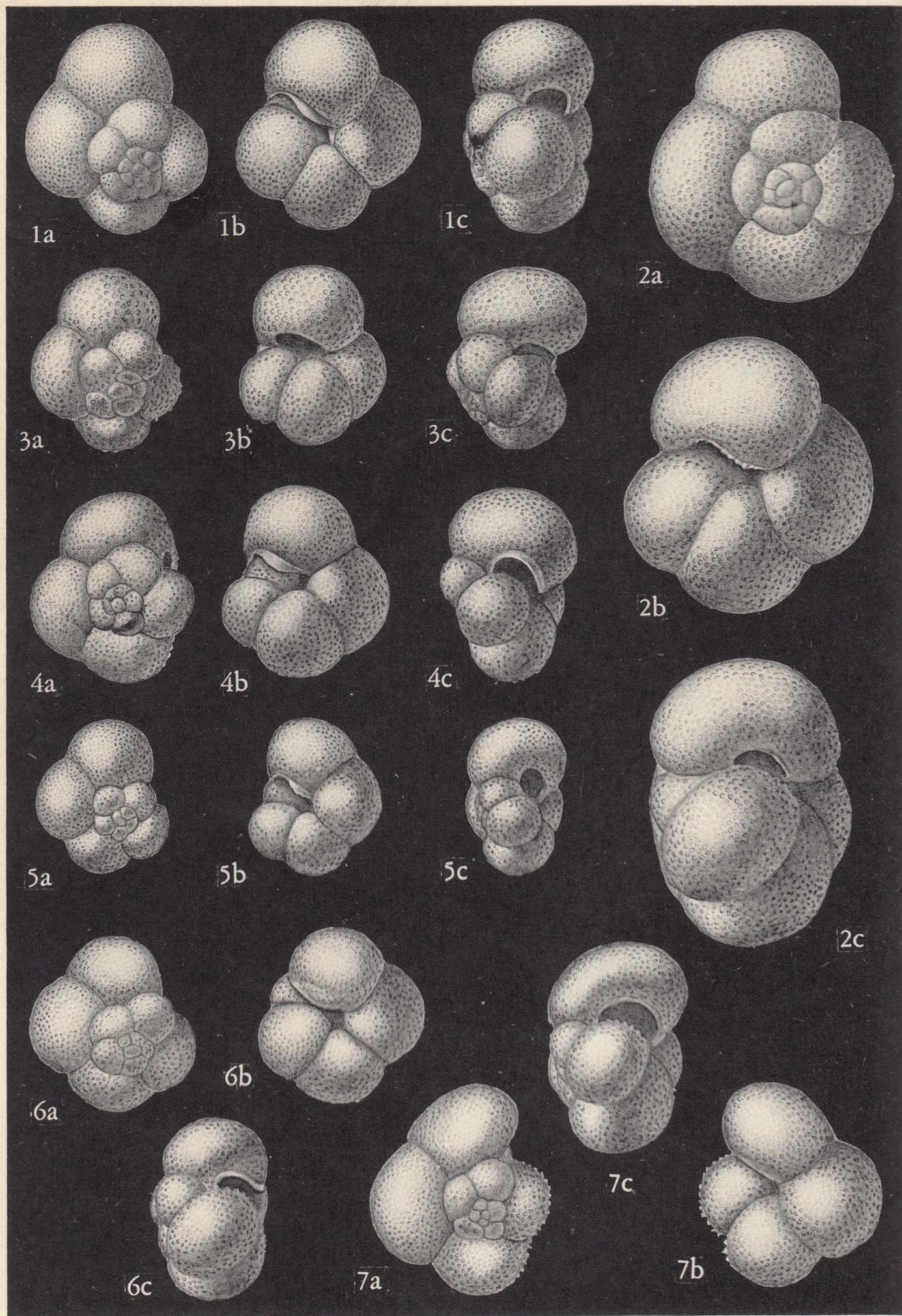
- 1-8. *Spirotecta pellicula*, n. gen., n. sp.
- 1-3. Holotype, C.P.C. No. 3851; 1, ventral view showing small apertural lip; 2, dorsal view showing involute test; 3, edge view showing unequally biconvex test. × 48.
- 4-5. Paratype, C.P.C. No. 3852; 4, ventral view; 5, edge view. × 48.
6. Horizontal section, C.P.C. No. 3853; showing single septal walls. × 48.
- 7-8. Vertical sections, C.P.C. Nos. 3854 and 3855, showing involute coiling of test. × 48.
- 9-13. *Giraliarella triloba*, n. sp.
- 9-11. Holotype, C.P.C. No. 3856; 9, 10 views from opposite sides. 9, showing the angular early stage and rounded younger portion; 10, view of the broadest face, showing the deep central groove; 11, end view showing trilobate outline and the aperture. × 59.
12. Paratype A, C.P.C. No. 3857, side view. × 59.
13. Paratype B, C.P.C. No. 3858, side view. × 59.

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Belford: New genus and species from Western Australia



Cifelli: *Globigerina incompta*, n. sp., from N. Atlantic

CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
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227. *GLOBIGERINA INCOMPTA*,
A NEW SPECIES OF PELAGIC FORAMINIFERA
FROM THE NORTH ATLANTIC^{1,2}

by

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ABSTRACT

A new Recent species of pelagic Foraminifera, *Globigerina incompta*, is recognized from the surface waters of the North Atlantic. This is a common pelagic form, but has been interpreted in various ways by previous workers. Reasons for considering it a separate species are discussed.

INTRODUCTION

The new Recent foraminifer described here, *Globigerina incompta*, was encountered in plankton tows collected from the North Atlantic. This appears to be a common and widely distributed pelagic form in the North Atlantic, but because of its small size and relatively simple structure there has probably been a reluctance in the past to recognize it as a separate species. *G. incompta* is comparable to *G. dutertrei* as originally described and figured by d'Orbigny (1839). However, that name is no longer available for the form indicated in d'Orbigny's figure because the lectotype, as figured (Banner and Blow, 1960, p. 11, pl. 2, fig. 1) is not the same and is comparable to *G. eggeri*. The selection of this lectotype is the latest in a series of complications that has plagued d'Orbigny's species since it was originally described. Most persons appear to have considered *G. dutertrei* as a life stage or variety of *G. eggeri* or *G. pachyderma*. However, *G. dutertrei* as illustrated by d'Orbigny, here redescribed as *G. incompta*, is morphologically separable from *G. eggeri*, and, moreover, is a much more common form in the North Atlantic Slope waters than *G. eggeri*. The relationship to *G. pachyderma* is still not clear,

but the evidence for *G. incompta* and *G. pachyderma* being life stages of a single species is inconclusive and even somewhat contradictory. Therefore, it is believed that the species originally described by d'Orbigny and now recognizable and distinguishable from other species should be retained; it is for this reason that *G. incompta* is proposed here.

MATERIAL

This species was collected from oblique plankton tows, through the upper 200 meters of water, in a series of stations extending across the North Atlantic Slope waters into the Sargasso Sea. The hauls were taken in August, 1960, from the R/V *Crawford* during a Woods Hole Oceanographic Institution cruise. The collections were made as a part of a cooperative program with the Woods Hole Oceanographic Institution to study the ecology of pelagic Foraminifera in the North Atlantic. Travel and ship facilities for this work have been supplied by Woods Hole Oceanographic Institution under contract with The Office of Naval Research (NONR - 2196 (00)). Shipboard assistance and certain collateral data have been available from scientists supported by The United States Atomic Energy Commission (under grant AT (30-1)-1918).

A number 10 net with apertures of 0.158 mm. and a mouth diameter of three quarter meters was used for the towing. The locations of the stations and the percentages of *G. incompta* compared to the total foraminiferal populations are shown in table 1. The percentages of *G. eggeri* to *G. incompta* are also shown for comparison.

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² Contribution No. 1165 from the Woods Hole Oceanographic Institution

EXPLANATION OF PLATE 4

FIGS.	PAGE
1-7. <i>Globigerina incompta</i> Cifelli, n. sp.; all magnifications $\times 95$. 1, Holotype, U.S.N.M. no. 628588; a, dorsal view; b, ventral view; c, edge view. 2, Paratype, U.S.N.M. no. 628589; a, dorsal view; b, ventral view; c, edge view. 3, Paratype, U.S.N.M. no. 628590; a, dorsal view; b, ventral view; c, edge view. 4, Paratype, U.S.N.M. no. 628591; a, dorsal view; b, ventral view; c, edge view. 5, Paratype, U.S.N.M. no. 628592; a, dorsal view; b, ventral view; c, edge view. 6, Paratype, U.S.N.M. no. 628593; a, dorsal view; b, ventral view; c, edge view. 7, Paratype, U.S.N.M. no. 628594; a, dorsal view; b, ventral view; c, edge view.	84

Table 1. Collecting stations and relative abundance of *Globigerina incompta* and *Globigerina eggeri*

Station	N. Latitude	W. Longitude	Percent	
			<i>G. incompta</i>	<i>G. eggeri</i> / <i>G. incompta</i>
Slope				
1	39° 48'	71° 12'	32	0
2	39° 36'	71° 06'	40	0
3	38° 39'	69° 33'	32	6
4	38° 46'	70° 20'	8	32
5				
6	38° 12.5'	69° 18'	13	57
Gulf Stream				
7	37° 21'	69° 07'	1	0
Sargasso				
8	37° 12'	68° 48'	1	0
9	36° 23'	68° 04'	2	25 (1 spec.)
10	35° 35'	67° 20'	2	0
11	35° 47'	66° 29'	3	0

The holotype and paratypes were all collected from station 3, latitude 38° 39' N, longitude 69° 33' W. These specimens are deposited in the national collections of Foraminifera, U. S. National Museum. The illustrations of the specimens were prepared by Mr. Lawrence Isham, scientific illustrator, U. S. National Museum.

***Globigerina incompta* n. sp.**

Plate 4, figures 1-7

Diagnosis.—Test small, coiled low trochospirally, slightly convex on the dorsal side; periphery lobulate, subquadrilateral in side view, rounded in edge view; chambers inflated to slightly appressed, numbering about 9 to 14 and arranged in 2 to slightly less than 3 whorls, with marked increase in size of chambers between whorls; usually 4, but sometimes 4 and a portion of a fifth, chambers visible from the ventral side; final chamber overlapping on ventral side and thus oblique to axis of coiling; sutures radial, deeply depressed; umbilicus deep, but not particularly broad; aperture an elongate rounded opening at the base of the final chamber extending into and beyond the umbilicus, close to the periphery; only the aperture of the final chamber visible from the surface; a thin porous lip projecting at the top of the aperture; wall thin, porous; surface spinose.

Chambers.—The initial whorl consists of a minute proloculus and 4 or 5 additional small chambers. An abrupt increase in size generally occurs at about the sixth and again at about the eighth chamber. There are 4 or 4½ chambers in the second whorl and from 1 to 3 in the final, incomplete whorl. The cameral and spiral sutures are deeply depressed and sharply defined throughout so that the details of the chambers are clearly visible on the test. The last 4 chambers are relatively large and the increase in size of these is uniform. The final chamber is usually highly inflated and is mostly, but not always, the largest. Because of the uniformly large size of the last four chambers the

periphery, in ventral view, is subquadrilateral. In most specimens there are 4 chambers visible from the ventral side but in some there are 4 and a portion of a fifth; the peripheries of these are less quadrilateral. The final chamber overlaps considerably more on the ventral side than do the previous ones, but the amount of overlap is highly variable.

Aperture.—The aperture is at the base of the final chamber and opens into a deep but fairly narrow umbilicus. It extends beyond the umbilicus in most specimens, occasionally almost reaching the periphery. The aperture varies from an elongate narrow opening to one that is rather broad and semi-circular. The aperture of the penultimate chamber can sometimes be seen through this opening, but it connects with the final chamber and does not appear to open directly into the umbilicus. The lip of the aperture of the final chamber is thin, delicate and porous; it was not observed on all of the specimens.

Surface.—Live and wet preserved specimens are covered with fine, elongate spines. These are easily destroyed, however, and are practically never seen on dry specimens. The wall is thin and highly porous and translucent; through it the protoplasm can be seen. It is a dark olive color. The surface of dry specimens is spinose.

Coiling.—No actual count of coiling ratios was made, but in the material examined the majority of specimens are dextral. The coiling direction of this species, however, may be temperature controlled, as has been reported to be the case in other pelagic Foraminifera.

Dimensions.—(in mm.)

	Total no. chambers	Diam.		Diam. Max.	Thick.
		1st whorl	2nd whorl		
Holotype					
USNM no. 628588	14	.06	.18	.36	.21
Paratype					
USNM no. 628589	14	.11	.37	.51	.26
Paratype					
USNM no. 628590	11	.08	.18	.33	.22
Paratype					
USNM no. 628591	13	.08	.19	.32	.34
Paratype					
USNM no. 628592	11	.07	.18	.28	.16
Paratype					
USNM no. 628593	12	.06	.20	.32	.19
Paratype					
USNM no. 628594	13	.07	.19	.34	.22

Comparisons and remarks.—This species is common in parts of the North Atlantic and will probably be familiar to persons acquainted with Recent pelagic Foraminifera. However, because of its small size and rather generalized characters it probably has, in the past, been regarded as a juvenile or variant form of some other species with which it is associated. My first impression was that this species represented an immature stage of *Globigerina eggeri* Rhumbler, which it closely resembles, in mode of coiling and in inflation

of chambers. It was not possible to establish a transition, however, and after study of many specimens I concluded that this small form was a separate species. It is distinguishable from *G. eggeri* in the following ways:

1 — The test of *Globigerina incompta* is coiled low trochospirally while that of *G. eggeri* is high, even in small specimens.

2 — The umbilicus is a larger, more open area in *G. eggeri*. The apertures of the chambers on the ventral side can often be seen in the umbilicus in *G. eggeri*, while only the aperture of the final chamber is visible in the umbilical area of *G. incompta*.

3 — The aperture of *G. eggeri* opens to, and does not extend beyond, the umbilicus. In *G. incompta* the aperture also opens to the umbilicus, but is variable in length, extending outward beyond the umbilicus and almost to the periphery. Of particular importance also is the fact that *G. incompta* was found to be very common in the plankton tows studied from the North Atlantic while *G. eggeri* was rare. In fact, *G. incompta* appears to be one of the most characteristic species of the North Atlantic Slope waters, along with *G. inflata* and *G. bulloides*. In one 200 meter plankton sample collected in August, 1960, at latitude 39° 36' N and longitude 71° 06' W, *G. incompta* was the dominant species and made up 40 percent of the foraminiferal population. In eleven 200 meter plankton samples collected August, 1960, from the North Atlantic Slope waters, the Gulf Stream and the Sargasso Sea, the ratio of *G. eggeri* to *G. incompta* varied from 0 - 57 percent (Table 1). If *G. incompta* were an early stage of *G. eggeri* it would be difficult to understand why so small a percentage of individuals succeed in achieving an adult stage.

Comparing favorably and apparently identical with *Globigerina incompta* is *G. dutertrei* d'Orbigny as originally described and figured by d'Orbigny (1839, p. 84, pl. 4, figs. 19-21). However, the lectotype of *G. dutertrei* selected by Banner and Blow (1960, p. 11, pl. 2, fig. 1) is not identical. The lectotype as figured is, in my opinion, inseparable from *G. eggeri*. I have observed both forms in a bottom sample from off the coast of Cuba, one of the areas from which d'Orbigny recorded *G. dutertrei*. The form comparable to d'Orbigny's figure also compares favorably and is identical with *G. incompta*, although the Cuban specimens have somewhat fewer chambers and slightly less lobulate peripheries. The other form, referable to the lectotype, is clearly of the *G. eggeri* type; besides being larger and having more chambers, it has a higher, less flat coil and has a larger umbilicus and a very broad umbilical aperture. D'Orbigny did not distinguish the two forms and apparently included both in his concept of *G. dutertrei*. It is unfortunate that the lectotype which was selected is not the form figured by d'Orbigny, since that specimen now becomes the name bearer of the species; d'Orbigny's figure no longer has nomenclatural status, even though it appears to be an

accurate illustration. This further complicates a species that has already caused much difficulty in interpretation. *G. dutertrei* now becomes a senior subjective synonym of *G. eggeri*.

A species very similar to *Globigerina incompta* is *G. megastoma* Earland from the Antarctic region. The latter species, however, has a higher spire and a broader aperture. It is also a larger form and has a more elongate final chamber.

The relationships of this species to the form occurring in the Antarctic region and identified as *Globigerina dutertrei* by authors is problematic. Brady (1884, p. 601) regarded *G. dutertrei* as a typical Antarctic species and believed that it was the southern counterpart of *G. pachyderma* which, according to him, does not occur in the Antarctic region. Heron-Allen and Earland (1922, pp. 189-192) recognized *G. dutertrei* as a dominant form in the Antarctic but maintained that it is replaced by and intergrades with *G. pachyderma* in the lowermost latitudes. They felt that *G. pachyderma* is actually a variety of *G. dutertrei*, "due to the suppression of the comparatively large single aperture of the typical *G. dutertrei* combined with a reduction of the general dimensions and particularly with a massive thickening of the shell wall" (Heron-Allen and Earland, 1922, p. 192). Phleger, Parker and Pierson (1953, p. 13) and Uchio (1960, p. 5), on the other hand, consider it unlikely that the thick-walled Antarctic form is conspecific with the species described by d'Orbigny from the coast of Cuba. Uchio (1960, p. 5) found that *G. dutertrei* (of authors, not d'Orbigny) is dominant in the Antarctic sediments, while *G. pachyderma*, a small form, is of secondary importance. *G. cf. G. bulloides*, the only foraminifer occurring in the Antarctic plankton tows, is rare in the bottom sediments. *G. pachyderma* intergrades with *G. dutertrei* and Uchio believes that the Antarctic *G. dutertrei* is the adult stage of *G. pachyderma* (Uchio, 1960, p. 5). The original *G. dutertrei* of d'Orbigny, he feels, is the early stage of *G. eggeri*.

In the Arctic region *G. pachyderma* is dominant in the bottom sediments while a form resembling a juvenile *G. eggeri* or *G. bulloides* is the only foraminifer occurring in the plankton tows of the upper 200 meters of water. The line figure of the plankton form given by Bé (1960, fig. 1c) is suggestive of a type comparable to *G. incompta* although the Arctic form appears to be smaller. In addition, the coil of the Arctic form is sinistral while that of the present species is dextral. Like Uchio, Bé considers this form to be a life stage of *G. pachyderma*. Unlike Uchio, however, Bé regards *G. pachyderma* to be the *adult* stage. According to Bé (1960, p. 65) the juvenile achieves the adult characters by descending to deep waters, below 200 meters. The morphologic changes involved are "in the addition of a reduced final chamber and in the crystalline thickening of the test."

Part of the difficulty in comparing the Arctic and Antarctic forms is that despite the fair abundance of

records and discussions of these forms there have been very few descriptions and, more important, illustrations. Without adequate illustrations and descriptions it is impossible to make meaningful comparisons. The figure of *G. dutertrei* given by Brady (1884, pl. 81, fig. 1) shows a form that appears to be comparable to *G. pachyderma* Earland. The Antarctic form figured by Ovey (*in* Wiseman and Ovey, 1950, p. 65, pl. 2, fig. 1a-c) compares well with *G. incompta*, but only a single specimen is figured, and nothing can be determined about the population structure. Conceivably the species described by d'Orbigny and revived here might be a life stage of *G. pachyderma*; the interpretations of Uchio and Bé seem reasonable if only the areas that they have studied are considered. However, it hardly seems justifiable to regard *G. incompta* a life form of *G. pachyderma* in the lower latitudes where *G. incompta* is common and *G. pachyderma* is rare or absent. Moreover, it is difficult to see how *G. pachyderma* could be an adult stage in the Arctic and a young stage in the Antarctic. Another possibility is that *G. incompta* is a geographic subspecies of *G. pachyderma*. However, this cannot be determined at the present since the descriptions and illustrations are inadequate and the records of occurrences of the high latitude forms cannot be evaluated. For now it seems best to retain for the lower latitudes, at least, a species comparable to the one that d'Orbigny originally described as *G. dutertrei*, even though a name change is involved.

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228. LABORATORY EXPERIMENTS
ON THE ECOLOGY OF FORAMINIFERA¹

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ABSTRACT

Laboratory experiments were conducted on *Ammonia beccarii tepida* (various strains), *Spirillina vivipara*, *Bolivina compacta*, *Massilina* sp., *Rosalina columbiensis*, and *Bolivina vaughani*. Lethal temperatures, based on five-minute exposures, varied from 37.5°C. for *Bolivina vaughani* to 45°C. for *Ammonia beccarii tepida*. Attempts to change the lethal temperatures by temperature acclimation failed but high salinity may have increased the lethal temperatures slightly. Increased temperatures resulted in higher growth and reproductive rates and a decrease in generation time. Temperatures of 25-30°C. were optimal for *A. beccarii tepida*; those below approximately 18-20°C. did not permit reproductive activity. Specimens grown at lower temperatures were larger than those grown at higher temperatures. *A. beccarii tepida* showed the greatest resistance to lowered salinity; *Spirillina vivipara* was least tolerant. At normal salinity (34 o/oo), growth and reproductive rates were highest for *Ammonia beccarii tepida*; at salinities below 15 o/oo growth rates were lower and there was no reproductive activity. Food concentrations (*Dunaliella* sp.) less than 112 cells/mm² did not permit growth or reproduction. Growth rate and reproductive activity increased with additional food. Addition of antibiotics to cultures inhibited growth and increased mortality. *A. beccarii tepida* tolerated extreme pH values; *Spirillina vivipara* was more sensitive. Hydrostatic pressures of more than approximately 400 atmospheres were fatal to *Ammonia beccarii tepida*. No mortality occurred in 3 days at 400 atmospheres. Rates of oxygen consumption of approximately 2500-8000 μ l O₂ per foraminifer per hour were determined for individual specimens using a micro-respirometer. Oxygen consumption for *A. beccarii tepida* increased with increase in temperature.

INTRODUCTION

The definition of marine environments for ecological purposes is a difficult and at times almost an impossible task largely owing to the complexity and interplay of environmental factors. In the laboratory, however, it is possible to single out from the complex natural environment some of those ecologic factors which appear to be of critical importance and to study the effect of these one at a time. It should be possible to determine which factor, or factors, limit the range of each species in the various natural environments, and ultimately, to assess the ecologic interactions of the entire fauna.

The present study describes a series of experiments designed to investigate the influence of temperature, salinity, and food on basic physiological processes, especially the growth rate and survival of some species of Foraminifera. In addition, preliminary observations on the effect of pH, hydrostatic pressure, and

the rate of oxygen consumption under various environmental conditions have been made. A technique for the determination of critical oxygen tensions is described. This paper is a continuation and expansion of earlier studies (Bradshaw, 1955, 1957) initiated to evaluate ecologic factors by experimental procedures.

Many technical problems arise in laboratory experimentation of this kind. A somewhat artificial environment is set up and in most instances a relatively long time period has elapsed between field collection and the experiments. It is possible that short term acclimation processes may so alter basic physiological responses that experimental results may be misleading. Acclimation experiments have been conducted in an attempt to gain some insight into this problem.

Support for these studies has been given by American Petroleum Institute Project 51, the National Science Foundation and a contract of the Office of Naval Research with the Scripps Institution of Oceanography of the University of California. Fred B Phleger gave many helpful suggestions. Thanks are due to P. F. Scholander, B. M. Sweeney and W. H. Thomas for helpful advice and assistance.

MATERIAL AND METHODS

The Foraminifera were cultured from samples of surface sediment collected from localities listed in Table 1. The following species were used in the experiments: *Ammonia beccarii tepida* (Cushman), *Spirillina vivipara* Ehrenberg, *Bolivina compacta* Siedbottom, *Bolivina vaughani* Natland, *Massilina* sp., and *Rosalina columbiensis* (Cushman). For the sake of brevity, generic names will be indicated throughout by initials only. The individual species were isolated and cultured under optimal conditions. Routine culture and experimental techniques have been described previously (Bradshaw, 1955, 1957). It has not yet been possible to obtain bacteria-free cultures but bacterial effects have been kept to a minimum by transfer to fresh media at 3-4 day intervals.

The method used to assess the effect of changes in environmental factors has been to observe qualitative and quantitative changes that occur when a single given factor is altered, all the others being kept constant. This gives a measure of the importance of each factor. Environmental factors are assumed to act directly upon biochemical processes, affecting their extent and velocity. This is reflected by changes in metabolic rate and by other changes such as rate and

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extent of growth. Inhibitory effects and, in extreme situations, death occur when biochemical rate reactions become unbalanced. A convenient measure of assessing response is by comparing growth rates under different conditions. In the following experiments, growth has been estimated by measuring the maximum diameter of the test at 3-4 day intervals.

TEMPERATURE EXPERIMENTS

Temperature has long been known to be of great importance in affecting physiological processes but few experimental data are available concerning its effect upon different species of Foraminifera. It is of importance ecologically in at least two respects: (1) It may limit a species geographically by killing the individuals or by preventing the completion of certain vital activities, such as reproduction. (2) The quantitative effect of temperature on growth, reproductive rates and other vital functions may selectively favor one species more than another.

Temperature Tolerance

Figure 1 illustrates a series of ecologically important

temperature ranges and their critical limits. Individuals of a species will survive in a relatively large temperature range, grow within a smaller range, and reproduce only within a relatively narrow range. The extreme survival range is limited by the maximum and minimum instantaneous lethal temperatures. In the following experiments, instantaneous lethal temperature is defined as that temperature which kills 50% of the specimens during a five-minute exposure.

Within the extreme range of lethal temperatures (as defined) there is a narrower range limited by the upper and lower incipient lethal temperatures. This is the temperature beyond which the organism cannot live for an indefinite period of time. It is an ecologically significant point, which effectively divides the entire survival range into two zones. Within the upper and lower incipient lethal temperatures there is a zone of tolerance in which the organism will never die from the effects of temperature alone. Beyond the incipient lethal temperatures there is a range of resistance in which the foraminifer will ultimately succumb but in which it can survive for a certain period of time.

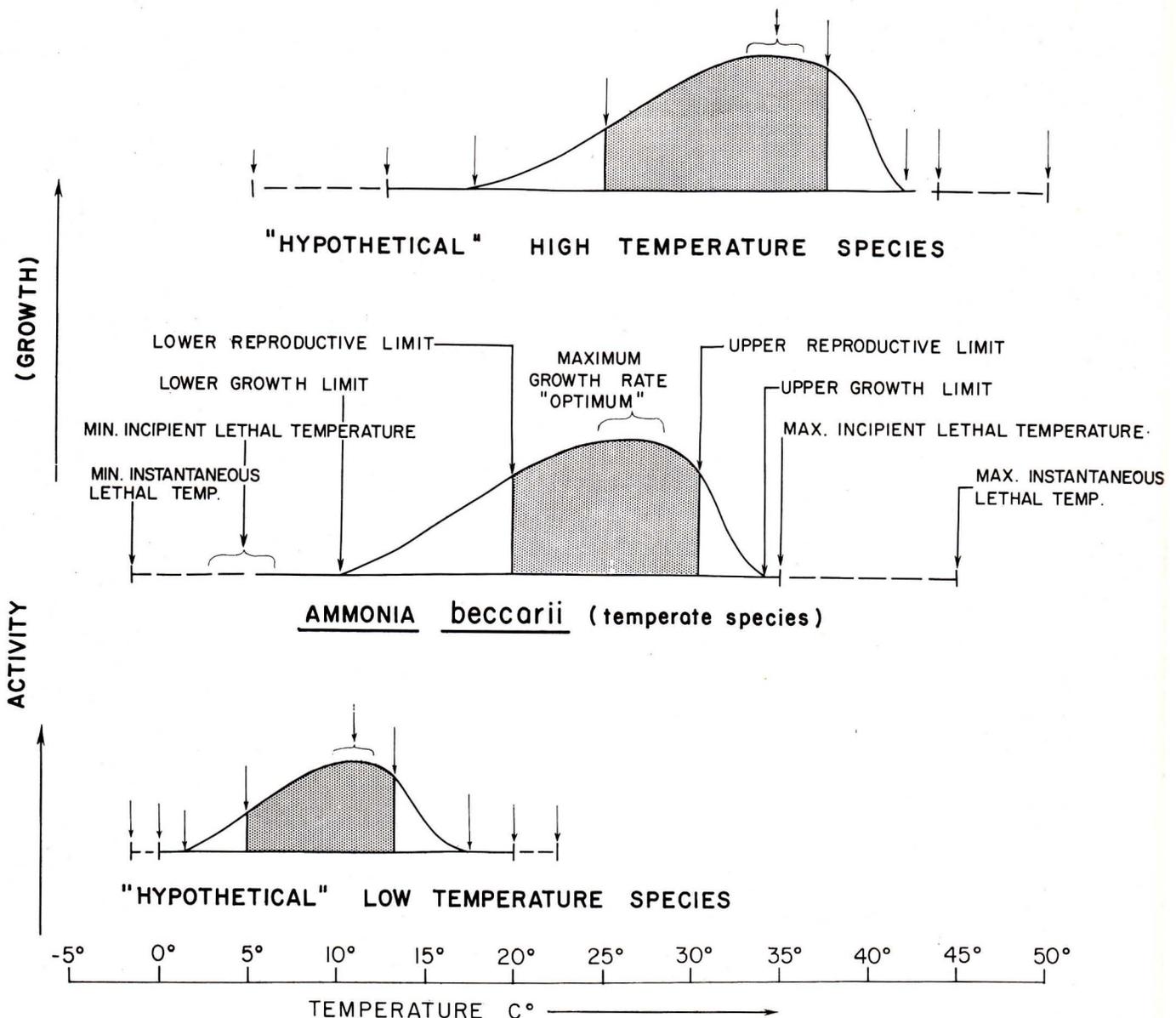


FIGURE 1

Significant temperature ranges showing critical limits.

Growth occurs only within a relatively narrow temperature range. The maximum, or optimum growth rate, is found near the middle of the zone but somewhat closer to the upper than to the lower limits. Near the extremes, the growth rate decreases.

The vital process having the narrowest range of tolerance is reproduction. Reproductive activity can only occur within this temperature zone, even though the animal may move about, feed, grow and exhibit otherwise normal behavior at higher or lower temperatures. The ability of many organisms to resist extreme temperatures varies greatly from species to species (Doudoroff, 1942; Southward, 1958). Such specific differences in the temperature tolerances of marine organisms may explain differences in their geographical distribution and breeding ranges (Orton, 1920). There appear to be characteristic critical temperature limits for each species, which may or may not be the same for others. Moreover, within the range the level of activity in question is not necessarily uniform; there may be an "optimum level," which in these studies is defined as "maximum rate of activity."

The present experiments and most of the tolerance experiments reported in the literature have been conducted under constant conditions. In nature, a non-uniform and often widely fluctuating environment is more often the rule, except in certain specialized habitats such as the deep sea. In correlating natural distributions of Foraminifera with temperature, for example,

is it the occasional extreme temperatures that limit the Foraminifera, or are monthly, seasonal or annual sea temperature means more important? Hutchins (1947) has correlated the distribution of some intertidal animals with temperature by selecting those values of maximum and minimum mean monthly temperatures which best fit the distributions. In the Foraminifera there is little direct evidence for a causal relationship between temperature and distribution. Some observations and experiments have been reported on the effect of temperature on reproduction and rate of growth of a relatively few Foraminifera species (Arnold, 1951, 1954, 1955; Myers, 1935, 1936, 1937, 1940, 1943b; and Bradshaw, 1955, 1957) but little is known of the actual temperature extremes that can be tolerated.

Lethal Temperatures

Lethal temperatures were determined by placing a number of specimens (2-5) in a thinly drawn out pipette, plugging the end with putty, and inserting into sea water of the desired temperatures for specific periods of time. Prior to the test, the specimens were kept at their normal culture temperatures (see Table 1). For the instantaneous lethal points, the batches were immersed in sea water of the desired temperature for exactly 5 minutes. After preliminary trials had located the approximate lethal range, samples were exposed to temperatures at 0.5°C. or 1°C. intervals. After this exposure the Foraminifera were removed

TABLE 1. Species used in experiments and localities where collected.

Species	Environment	Locality collected	Temperature °C. Stock Culture
<i>Ammonia beccarii tepida</i> (Cushman)	Intertidal mud	Coos Bay, Oregon Lat. 43° 24.2' N; Long. 124° 13.8' W	25
<i>Ammonia beccarii tepida</i> (Cushman)	Intertidal mud	Carlsbad Slough, California Lat. 33° 08.7' N; Long. 117° 19.4' W	25
<i>Ammonia beccarii tepida</i> (Cushman)	Intertidal mud	La Paz, Baja California Lat. 24° 10' N; Long. 110° 19' W	25
<i>Bolivina compacta</i> Sidebottom	Dredge, sand 36 feet	VS-102, Gulf of California Lat. 26° 16.5' N; Long. 111° 23.8' W	20
<i>B. vaughani</i> Natland	Kelp holdfast 50 feet	Del Mar, California Lat. 32° 56' N; Long. 117° 15.5' W	20
<i>Massilina</i> sp.	Kelp holdfast 50 feet	Del Mar, California Lat. 32° 56' N; Long. 117° 15.5' W	20
<i>Rosalina columbiensis</i> (Cushman)	Sandy mud 50 feet	La Jolla, California Lat. 32° 52' N; Long. 117° 15' W	20
<i>Spirillina vivipara</i> Ehrenberg	Intertidal, rock	Carmine Island, Baja California Lat. 25° 59' N; Long. 111° 06.5' W	20

from the pipette and allowed to recover at their original culture temperature. That temperature at which one-half the batch was killed is considered to be the lethal point. After the specimens have been subjected to high sub-lethal temperatures, a considerable recovery period (up to 24 hours) often is required before it can be determined whether they are alive or dead.

There appears to be no general agreement on methods or criteria used in the determination of lethal temperatures. Some workers (Southward, 1958) slowly heat the vessel containing the specimens at a specified rate, e.g., 1°C. per 5 minutes, until the required temperature is reached. Slow heating, however, may allow gradual acclimation to successively higher temperatures and also introduces possible lethal effects due to prolonged heating at normally sublethal temperatures. Because of the unknown effect of these factors, it was considered preferable to immerse the specimens directly at the desired temperature and thus allow minimum opportunity for acclimation and other temperature-duration effects.

Death is not always easy to recognize in a relatively

non-motile organism such as a foraminifer. Obvious criteria for living specimens are movement and/or pseudopodial activity. Life may still persist, however, in the absence of these obvious criteria, and it has been found necessary to examine the protoplasm within most tests for the streaming movements which are characteristic of living protoplasm. This final test of viability was made by using a 22× water-immersion lens inserted directly into the water above the specimen.

There is some disagreement about the percentage mortality necessary to provide an estimate of the lethal temperature of a population. Assuming a normal distribution of temperature tolerance, a large sample might be expected to yield a relatively wider range of tolerance before all the specimens were killed than a small sample. According to Andrewartha and Birch (1954), the most instructive figure is the dosage required to kill 50% of the population. This statistic has been used in the present study for comparison of different populations and species, but there was little difference in practice between the 50% and 100% lethal points (Table 2).

TABLE 2. Maximum lethal temperatures determined for various Foraminifera species.

Species	Strain	Lethal point (°C.)			No. of specimens at each temp.	Temp. interval °C.
		0%	50%	100%		
<i>Ammonia beccarii tepida</i>	La Paz	44.5	45	>45	10*	0.5
<i>Ammonia beccarii tepida</i>	Carlsbad	44	44.5	>45	10*	0.5
<i>Ammonia beccarii tepida</i>	Coos Bay	43.5	44.5	46	10*	0.5
<i>Bolivina compacta</i>	VS-102	40	40.5	41	4	0.5
<i>Massilina</i> sp.	Del Mar	39	39.5	40	3	0.5
<i>Spirillina vivipara</i>	Carmine Isl.	38	39	>39	10*	1
<i>Rosalina columbiensis</i>	La Jolla	38	38.5	39	4	1
<i>Bolivina vaughani</i>	Del Mar	37	37.5	38	2	1

*Two groups

After the determination of instantaneous lethal temperatures, the effect of duration at high sublethal temperatures was studied. This was done by immersing batches of specimens, as before, into a water bath held at different specified temperatures. At given time intervals, samples were removed, allowed to recover, and tested for viability.

The possibility that the prior temperature or salinity history of the specimens might have an effect on the lethal temperature was studied in several experiments. To test for temperature acclimation, several groups were kept at temperatures of 10, 15, 20, and 30°C. for periods up to two weeks before determination of the lethal point. The possibility of a salinity influence upon the lethal temperature was tested by keeping the specimens at salinities of 10, 17, 27, 34, 50 and 67 o/oo for one week before and during the actual test.

Results

Table 2 shows the maximum lethal temperatures determined for the various species and strains of

Foraminifera tested. Different populations of *A. beccarii tepida*, even from widely separated localities, show approximately the same lethal temperature (45°C.), but the lethal temperature appears to be different for various species. Of the forms tested, *A. beccarii tepida* shows the greatest tolerance to high temperatures, while *B. vaughani* and *R. columbiensis* showed the greatest sensitivity.

Some species appear to have remarkable tolerance to cold, as shown by the fact that *A. beccarii tepida* withstood temperatures of -2°C. for at least 1 hr. 52 min. (not shown on Table 2). During this period, ice was crystallizing out on the water surface.

Longer periods of exposure will cause death at lower temperatures than the maximum instantaneous lethal points (Figure 2). The maximum lethal temperature decreases as the duration of exposure is increased.

Temperature history immediately prior to the experiments did not appear to have a significant effect upon the maximum instantaneous lethal temperature. Table 3 gives the results of three series of experiments

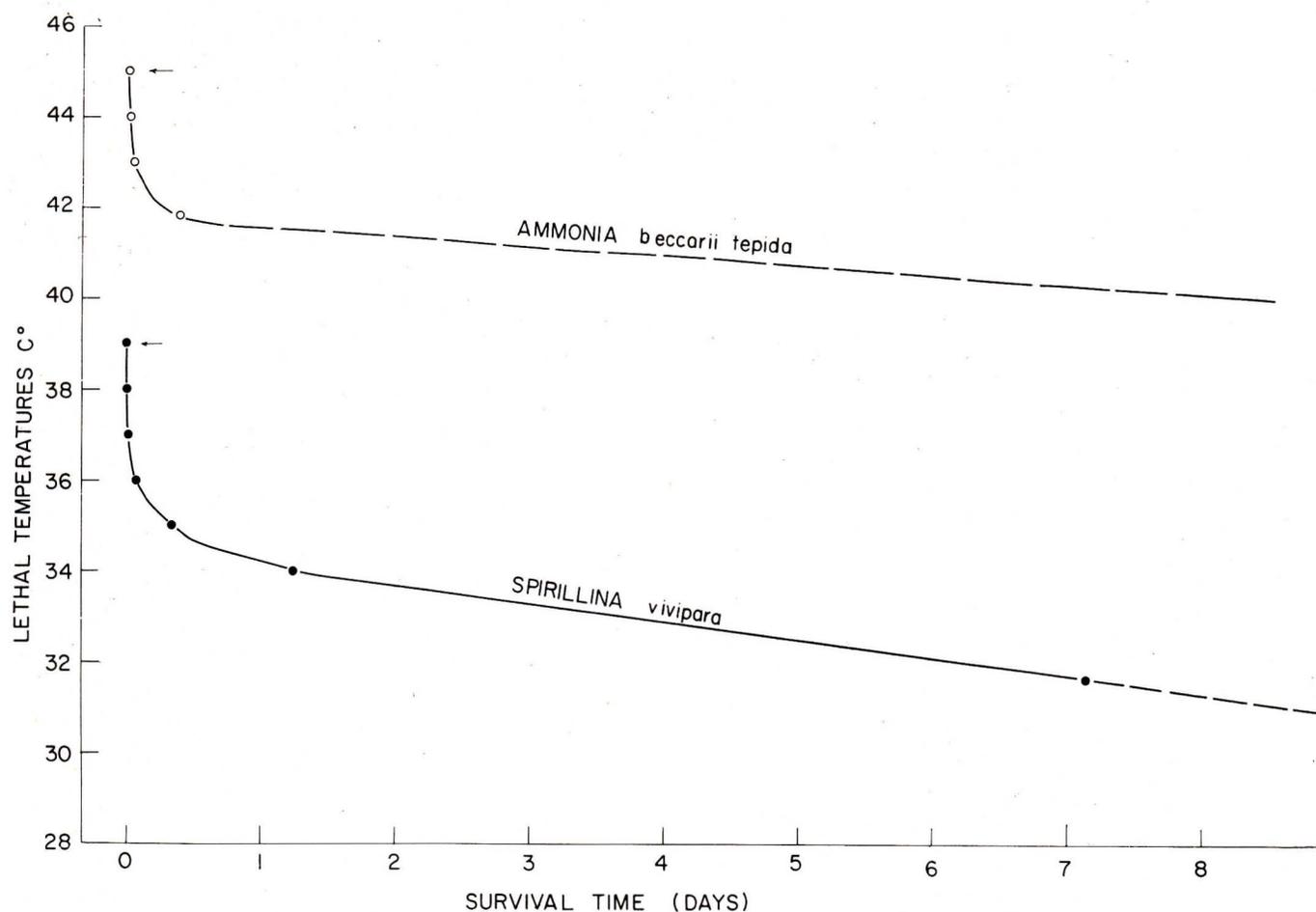


FIGURE 2

The relationship between temperature and duration of exposure in the determination of lethal temperatures. Each point represents the duration and temperature required to kill 50% of the specimens from each batch. The arrows indicate instantaneous lethal temperatures.

TABLE 3. The effect of previous temperature history (acclimation temperatures) upon the maximum lethal temperatures. *A. beccarii tepida* (Coos Bay strain).

Acclimation temperature (°C.)	Lethal point (°C.)			No. of specimens at each temp.	Temp. interval (°C.)	
	0%	50%	100%			
Series I 7-day acclimation	15	<44	44	45	2	1
	20	<43	43	44	2	1
	35	43	44	45	2	1
Series II 7-day acclimation	15	42	42.5	43	2	1
	20	<43.5	43.5	44	2	1
	25	<42	42	43	2	1
	35	44	45	46	2	1
Series III 26-day acclimation	15	43	43.5	44	2	1
	20	<42	42	43	2	1
	24-28	42	42.5	43	2	1
	35	<44	44	45	2	1

designed to determine whether temperature acclimation had occurred for cultures kept at temperatures of 15, 20, 25, 24-28 and 35°C. The Foraminifera were exposed for periods of from 7 to 26 days. Series II (Table 3) shows a difference of 3°C. in the maximum lethal temperatures of the highest and lowest of the acclimation temperature samples, but the irregularity of the data and the small number of specimens tested suggest that this is probably not a significant difference.

Salinity history (Table 4) prior to and during the test does not greatly influence the instantaneous lethal temperature, although minor differences are noted. The difference in the lethal point of 2.5°C. between specimens grown at 10 o/oo and 67 o/oo may be significant. The fact that 50 o/oo salinity appears to lower the lethal temperature is interesting but cannot be explained at present.

TABLE 4. Effect of salinity upon the maximum lethal temperatures for *A. beccarii tepida* (Coos Bay strain).

Salinity o/oo	Lethal point (°C.)			No. of specimens at each temp.	Temp. interval (°C.)
	0%	50%	100%		
10	<43	43-43.5	43.5	5	0.5
17	<43.5	43.5-44	45	5	0.5
27	<44.5-45	44.5-45	45	5	0.5
34	<44.5	44.5-45	45	5	0.5
50	<42.5-43	42.5-43	44	5	0.5
67	43.5	45.5-46	46	5	0.5

Reproductive Temperatures

A novel temperature gradient block for maintaining a wide range of temperatures has been designed by members of the microbiology department at the Scripps Institution of Oceanography. An adaptation suitable for Foraminifera cultures has been made. The device was constructed from a solid aluminum block with depressions bored at evenly spaced intervals to hold the culture dishes. By circulating water of different temperatures through channels at each end, a temperature gradient was set up across the entire block. In this way, eight different temperatures, with four cultures at each temperature, were obtained from only two constant temperature sources. Disposable plastic petri dishes 60 mm. in diameter were used as culture vessels. A small amount of water between the dishes and the aluminum block increased the heat flow.

In any one culture dish, the temperature was found to vary somewhat at various locations because the dish was of large enough diameter to permit temperature gradient across it also. The magnitude of this gradient and the constancy of the temperatures were

determined by the use of a thermistor thermometer inserted at various locations in each dish and at various locations in the block. It was found that the temperature gradient across each dish usually amounted to less than 0.5°C. Similarly the extreme temperatures measured for the four equal temperature cultures did not vary more than $\pm 0.5^\circ\text{C}$. from the value indicated by the central thermometer.

Reproductive temperatures were determined by culturing groups of specimens at closely spaced temperatures in the thermal gradient block and noting the percentage of individuals showing reproductive activity at each temperature. The reproductive temperatures for *A. beccarii tepida* are shown in Table 5. The lowest temperature at which reproduction occurred was 20°C., and the highest 32°C. Within this reproductive range (20-32°C.), temperatures from approximately 25 to 30°C. appear to allow a better chance for reproduction to occur, judging by the percentage of each batch undergoing reproduction. As their reproductive limits are approached, fewer and fewer of each batch appear able to reproduce. Generation time, or the time required from birth to the onset of a new generation,

TABLE 5. The influence of temperature upon growth and reproductive rate of *Ammonia beccarii tepida* (Coos Bay strain).

Temp. (°C.)	Mean growth rate (μ /10 day)	Generation time (days)		Number Specimens	% Repro- duction
		Median	Range		
15*	4	>280		8	0
15.2*	18	>68		10	0
16.7*	27	>55		10	0
18.0*	33	>50		10	0
19.0*	41	>44		10	0
20.0†	41	88	73-101	120	72
21.0*	48	>40		10	0
22.0	52	125	106-128	5	80
23.7	47	108	39-130	6	83
25.0†	72	38	35-49	10	88
25.2	37	76	44-99	5	100
26.6	41	65	56-109	5	80
27.9	49	44	37-87	5	80
29.7	41	47	47-56	5	100
30.0	84	33	26-35	19	67
30.6	21	121	86-121	5	80
32.0	22	121	121-121	5	20
35.0	0	∞		5	0

*Experiment terminated before occurrence of reproduction.

†Median values for more than one culture.

varies greatly within the reproductive range. Table 5 shows the median generation time to vary from a maximum of 88 days at a temperature of 20°C. to a minimum of 33 days at a temperature of 30°C. Median generation times of 125 and 108 days for temperatures of 22.0°C. and 23.7°C. respectively appear to be anomalous and, in view of the small number of specimens used, require verification. Above 30°C. the generation time again appears to show an increase until reproduction ceases entirely at temperatures above approximately 32°C.

Growth Rate

The effect of temperature upon individual rate of growth in *A. beccarii tepida* was determined by growing groups of specimens at standard temperatures of 15, 20, 25, 30 and 35°C. Additional data were obtained from the thermal gradient block set at narrower tem-

perature intervals between 15 and 32°C. Since the growth rate is not uniform throughout the life of the individual, being fastest in young stages and slowing as maturity is reached, it is important to determine the growth rate in a standard manner. This was done by plotting the mean growth curve at each temperature and determining the slope during the steepest part of the growth curve.

The results of growth-temperature experiments for *A. beccarii tepida* are shown on Table 5. The mean growth rate (expressed in microns per 10 days) increased from a minimum value of approximately 4 μ /10 days at 15°C. to a maximum of 84 μ /10 days at 30°C. Above 30°C. there was a sharp decrease in rate until at temperatures above 32-35°C. growth ceased entirely.

Figure 3 illustrates selected growth curves for cultures of *A. beccarii tepida* from Coos Bay grown at various temperatures.

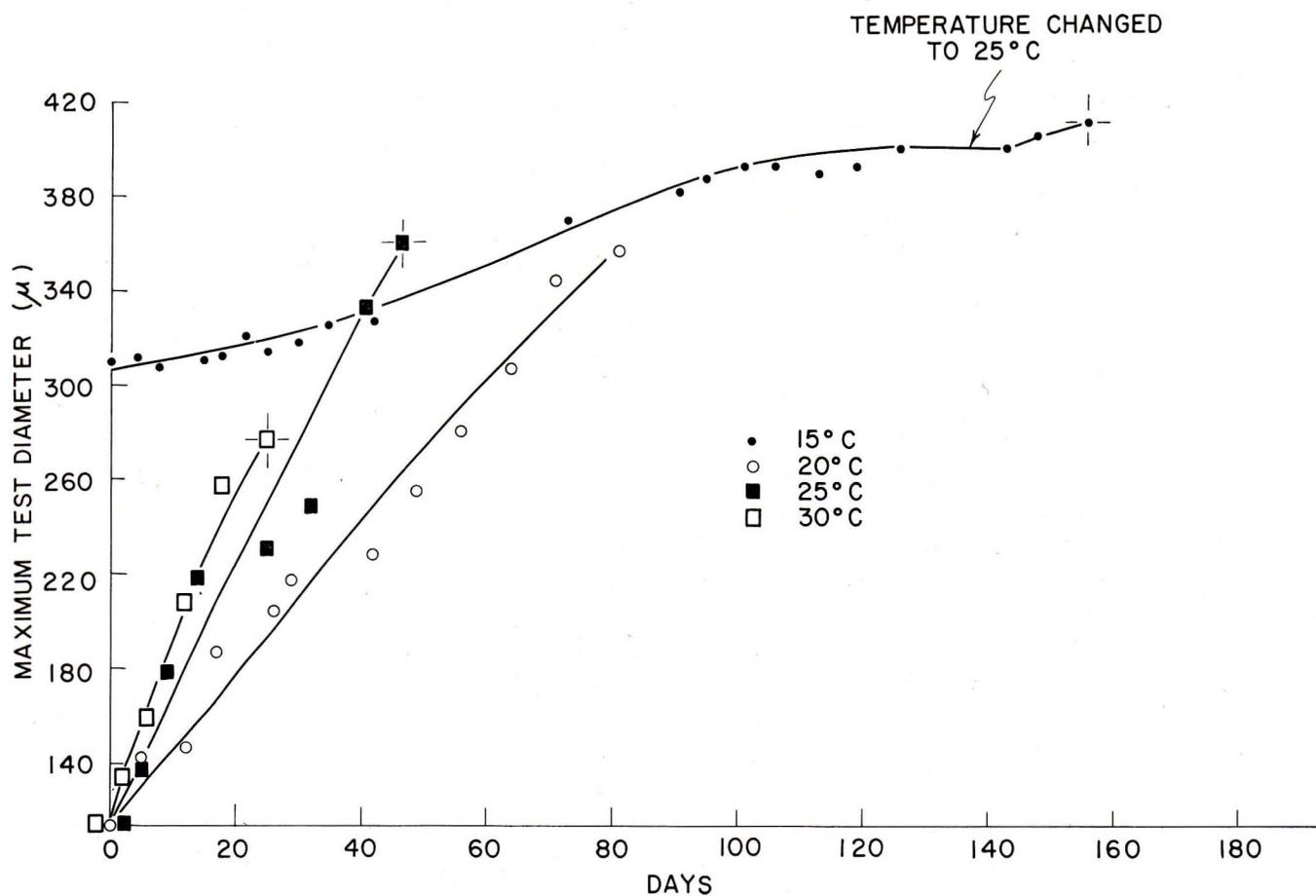


FIGURE 3

Growth of *Ammonia beccarii tepida* at different temperatures. The crosses indicate first occurrence of reproduction in culture.

Effect of Temperature upon Size

Figure 4 shows the effect of temperature upon the maximum diameter of tests at the time of reproduction. It will be noted that the largest tests were found at the lowest temperatures while the smallest occurred under the warmest conditions. A nonparametric method (Tate and Clelland, 1957, p. 78) of fitting the regression line and testing parameters showed a highly significant inverse relationship be-

tween temperature, at which the individuals had been living, and the maximum diameter of the test at the time of reproduction.

SALINITY EXPERIMENTS

General Statement

Relatively few species of Foraminifera are recorded from brackish and hypersaline water as compared to the large number found under normal marine condi-

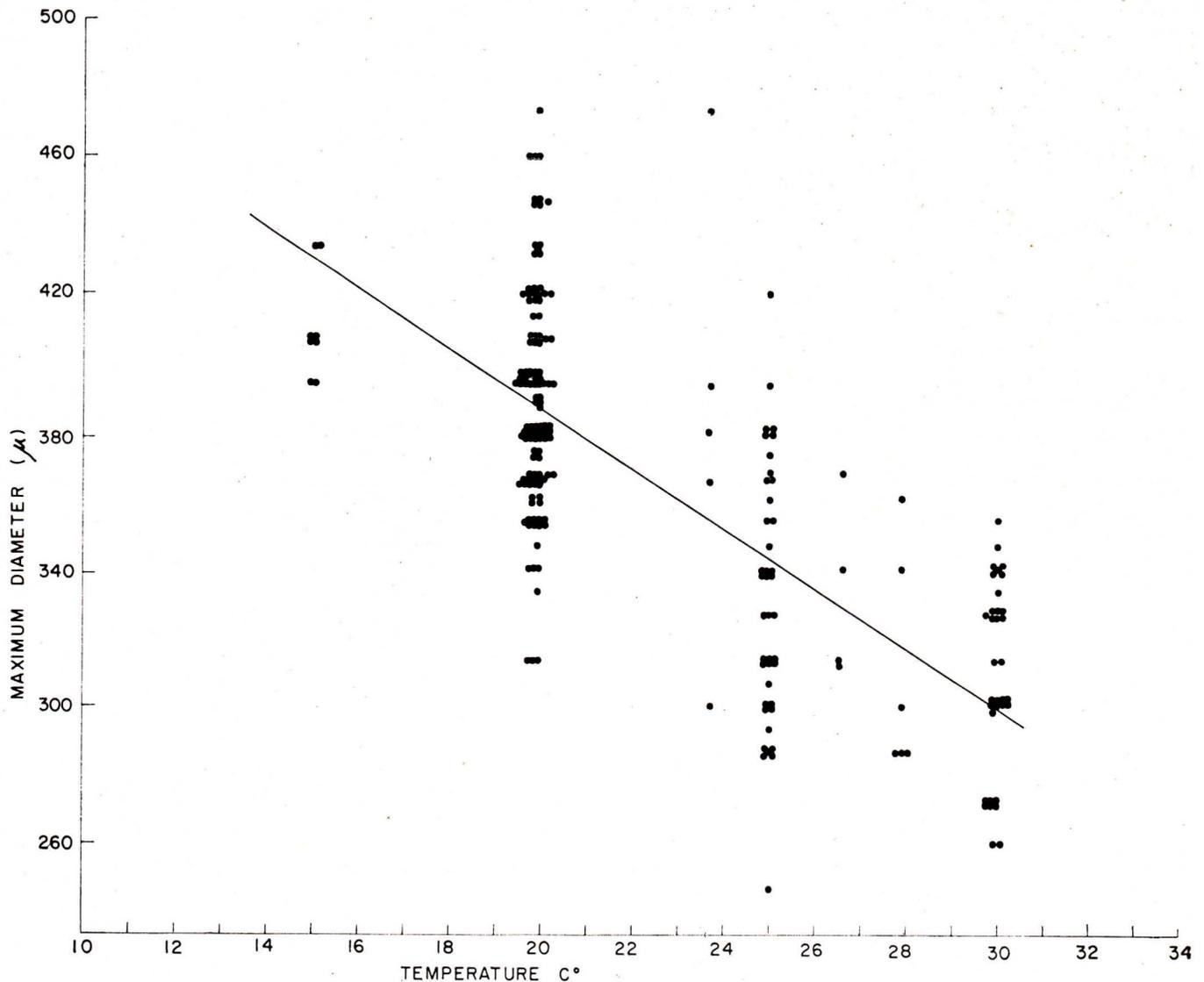


FIGURE 4

Relation between maximum test diameter and culture temperature for *Ammonia beccarii tepida* (Coos Bay population). Regression line drawn using nonparametric methods described in Tate and Clelland (1957, p. 78).

tions (Glaessner, 1947). This suggests that the salinity of the sea water may be a critical factor in limiting the distribution of many species. In the marine environment, lower than normal salinities are found in localities where fresh water from the land flows into the sea, such as river estuaries and polar seas. Land drainage is responsible for the slightly lower than normal salinities that are found along all except arid coasts.

Hypersalinities are uncommon in the ocean but are found in limited areas where evaporation exceeds precipitation. Thus, tropical seas tend to have slightly higher than normal salinities while some semi-enclosed lagoons have salinities of 50-80 o/oo and occasional values up to 155 o/oo (Pearse and Gunter, 1957). In addition, brackish and hypersaline environments commonly have widely fluctuating salinities.

Very few experimental data have been published on the ability of Foraminifera to survive either very high or very low salinities or on their ability to tolerate rapid salinity changes. Arnold (1954) stated that *Discorinopsis aguayoi* (Bermudez) could be grown in the laboratory in salinities from 20-57 o/oo but he did not

note differences in growth rate within this range or determine lethal limits. Myers (1943b) found the upper limit of salinity tolerance for laboratory cultures of *Elphidium crispum* to be 48 o/oo but he also did not note whether this referred to inability to reproduce or to a direct lethal effect. Preliminary salinity studies have been published previously (Bradshaw, 1955, 1957). The following experiments were designed to furnish further evidence on the effect of different salinities upon growth rate and reproductive activity and also to develop new techniques for the study of salinity tolerance.

Salinities of less than 33.5 o/oo were prepared by diluting sea water with double-distilled water. Salinities greater than 33.5 o/oo were prepared by evaporating sea water to the desired concentration.

Lethal Salinities

Lethal salinities were determined by pipetting batches of Foraminifera directly from normal sea water to vessels containing 15 ml of sea water of the desired salinity. The specimens were kept at that

salinity for specified time intervals, after which they were transferred back to normal sea water and allowed to recover. After allowing a time period for recovery (approximately 24 hours), the individuals from each sample were examined for evidence of life and the time required to kill one-half the batch was determined.

It was not possible to find an instantaneous lower lethal salinity for *A. beccarii tepida* on the same basis

as was done for instantaneous lethal temperatures (e.g., 5-minute exposure) because this form was so tolerant of low salinities that it could even withstand direct transfer to distilled water for up to 32 minutes. For this reason, longer exposures were made. Table 6 shows the lower lethal salinities, determined on the basis of 12-hour exposures, required to kill one-half the batch of the forms listed.

TABLE 6. Minimum lethal salinities, determined on the basis of 12-hour exposures. Salinity interval is that interval between successive salinity values used for the experiment.

Species	Lethal point (o/oo)			No. of specimens at each salinity	Salinity interval (o/oo)
	0%	50%	100%		
<i>Ammonia beccarii tepida</i> (Coos Bay)	<2	<2	<2	2	2
<i>Bolivina vaughani</i>	13	7	3	4	3
<i>Massilina</i> sp.	10	10-7	7	4	3
<i>Spirillina vivipara</i>	17	7	7	4	3

Reproductive Salinities

The results of salinity experiments designed to determine the critical salinity for reproduction are shown in Table 7. Here it will be seen that reproduction has occurred at all salinities down to, and including, 15 o/oo. At the other extreme, earlier experiments (Bradshaw, 1957) on the same species from San Antonio Bay, Texas, showed no reproduction above salinities of 40 o/oo.

Within this reproductive range of approximately 15-40 o/oo, the length of time required for completion of each generation does not appear to be uniform. Table 7 shows the median generation time to be approximately 35 days at 34 o/oo, while at 15 o/oo 56 days were required.

Growth Rate

Figure 5 shows the rates of growth of *A. beccarii tepida* populations from Coos Bay, when cultured at different salinities. The highest rate of growth was found in cultures grown at normal salinities of 34 o/oo. Salinities of 8 o/oo allowed no growth. Slight growth was noted at 10 o/oo with gradually increasing rates of growth with increase of salinity up to 34 o/oo. The subsequent resumption of normal growth of the 8 o/oo and 10 o/oo cultures when returned to 34 o/oo sea water shows that there are no lethal effects at salinities of 8 o/oo over a two-week period.

Table 7 summarizes most of the data obtained on growth rate at different salinities. It will be noted that again, in general, the highest growth rates occur in

TABLE 7. Effect of salinity upon growth and reproductive rate of *A. beccarii tepida* (Coos Bay). Five specimens used at each salinity.

Salinity (o/oo)	Mean growth rate (μ /10 days)	Generation time (days)		% specimens reproducing
		Median	Range	
34	90	35	29-56	100
25	32	82	56-96	80
17	51	47	43-56	60
15	41	56	43-87	80
13	44	∞		0
12	27	∞		0
10	4	∞		0
8	0	∞		0

cultures of normal salinity while the lowest rate is found where the salt content is least.

Effect of Salinity on Size

Table 8 gives data on the effect of salinity upon the maximum size of tests of *A. beccarii tepida*. Salinity may influence size but the relationship is not as clear

as it was for temperature. The largest specimens appear to have grown at the lowest salinities, while the smallest tests were produced under normal or slightly brackish conditions. A similar inverse relationship between size and salinity was found previously in specimens of *A. beccarii tepida* from San Antonio Bay, Texas (Bradshaw, 1957).

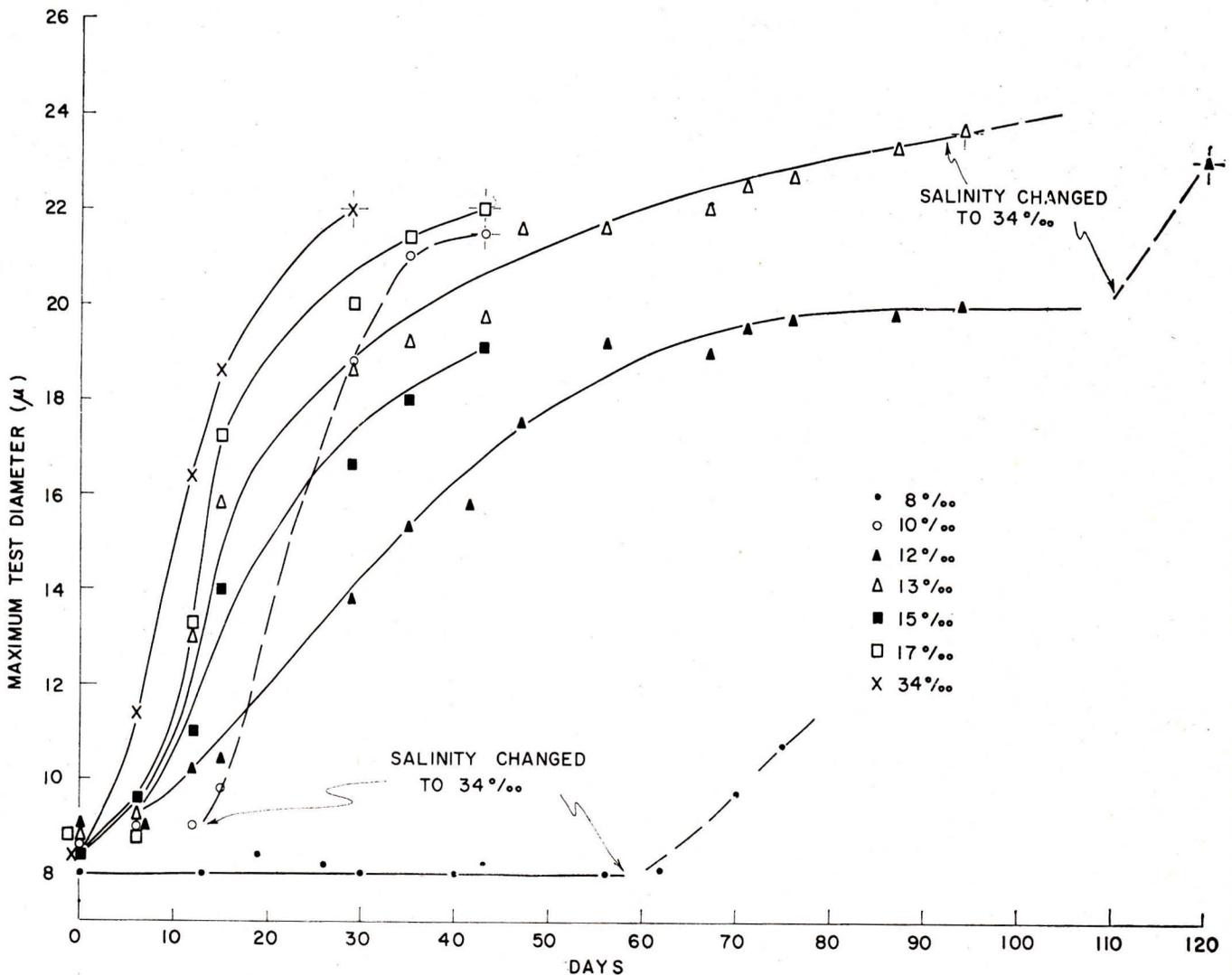


FIGURE 5

Growth of *Ammonia beccarii tepida* (Coos Bay population) at different salinities. The crosses indicate first occurrence of reproduction in culture.

TABLE 8. Effect of salinity upon mean test diameter at time of reproduction. *A. beccarii tepida* (Coos Bay).

Salinity (o/oo)	Max. test diameter (microns)		No. Specimens
	Mean	Range	
34	305	280-340	9
25	290	260-340	4
17	340	230-400	35
15	340	250-392	4

FOOD EXPERIMENTS

General Statement

Food is obviously of importance for growth and maintenance of life, both for the individual and for the population. Very little is known of the food requirements of Foraminifera, either in nature or in the laboratory. They have been reported to feed upon a wide variety of food substances, including decaying vegetation, diatoms, flagellates, algal gametes, filamentous algae, organic debris, copepods and bacteria. The author knows of no field study comparing the natural distribution of a Foraminifera species with known food. Myers (1943b) studied the influence of food in localized natural populations of *Elphidium crispum*.

Although he did not identify the particular food organisms or the amount utilized, growth and reproduction were found to parallel closely the phytoplankton cycle in the sea. Said's (1950) study comparing the concentration of Foraminifera with per cent nitrogen content of the sediments was an attempt to determine the role of food in Foraminifera distribution but the carbon or nitrogen content of the sediments will not necessarily indicate the amount of food available for Foraminifera. Many nitrogen compounds are highly refractory and cannot be considered as a food source. The food must be passive enough for the Foraminifera to catch with their relatively weak pseudopodia. Since the normal operation of the pseudopodia in

benthonic Foraminifera is along a solid surface, suspended organic matter such as plankton or leptoel is of little value until it settles out. Bacteria undoubtedly play a role in nutrition but their relative importance is unknown.

The following experiments were designed to see if useful information could be obtained from laboratory food studies. A necessary condition for accurate nutritional studies is first to make the foraminiferal cultures bacteria free. Several attempts have been made by elaborate washing methods, whereby individual specimens are transferred through many dishes of sterile sea water. Apparently the numerous irregular surfaces on the Foraminifera provide shelter for bacteria so they cannot be washed off readily. Antibiotics have been used by some workers to rid protozoan cultures of associated bacteria. In the following food experiments the possibility of using antibiotics was tested in a parallel set of experiments.

Dunaliella sp., a green flagellate of approximately 8 μ diameter, was used for food. The algae were grown separately in 250-ml Erlenmeyer flasks in sea water enriched with earth extract, nitrate and phosphate. Twice weekly, approximately 25 ml of this stock food culture was centrifuged, and the cells re-suspended in sterile sea water. In this way possible adverse effects of metabolites in the *Dunaliella* medium were avoided. The cells were killed by heating to 50°C. and the number per ml was determined by counting in a hemocytometer. Five specimens of *A.*

beccarii tepida (Coos Bay) with an average diameter of 281 μ were placed in separate petri dishes (60 mm diameter) of sterile sea water containing 15 ml of media and kept at 25°C. throughout the course of the experiments. The following number of *Dunaliella* were added to each dish of one set of cultures: 0; 55,000; 110,000; 220,000; 440,000 and 880,000 cells. In a parallel experiment, 1400 units of penicillin G and 1.5 mg streptomycin were added in addition to the food. The resultant concentration of penicillin and streptomycin per ml of culture medium was 72 units and 83 μ g respectively. Twice weekly, each specimen was transferred to fresh sea water medium, measured and fed.

Results

Figure 6 and Table 9 show the results of the food experiments. It will be noted (Table 9) that the specimens treated with penicillin showed a slightly higher rate of growth than the untreated specimens. The presence of penicillin, however, appeared to increase the time necessary to attain reproductive maturity. The median reproduction intervals (Table 9) show that in each instance where reproduction occurred the specimens that were not treated with antibiotic reproduced before the treated individuals.

When the effect of food apart from the influence of antibiotics is considered, it will be seen that the rate of growth is increased with additional food. Food concentrations below approximately 220,000 cells per culture do not allow any growth or reproduction. As the

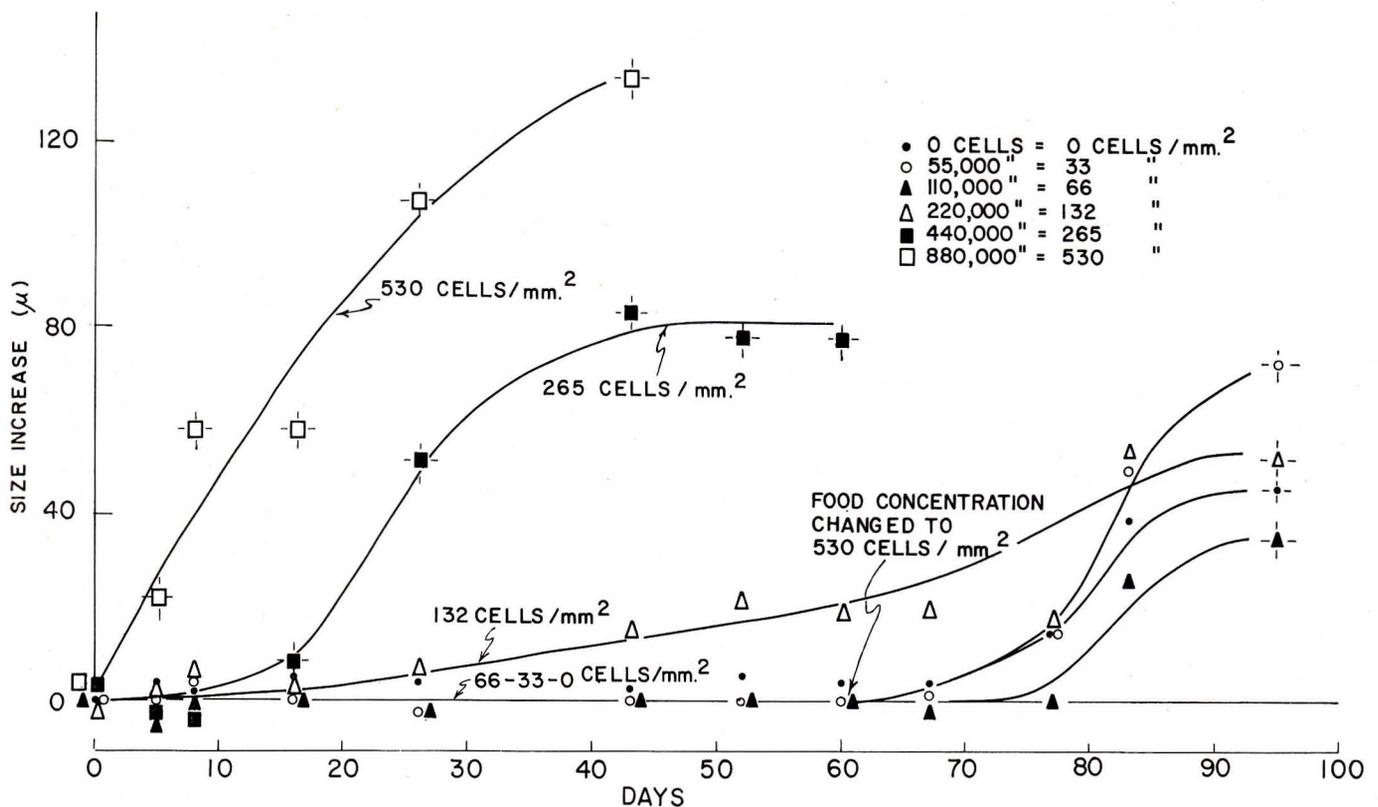


FIGURE 6

Growth of *Ammonia beccarii tepida* (Coos Bay population) fed different concentrations of food (*Dunaliella* sp.). The crosses indicate reproductive activity. Average size (maximum diameter) of specimens at beginning of experiment, 288 μ . mm² = surface area grazed.

TABLE 9. Effect of different concentrations of food (*Dunaliella* sp.) and treatment with antibiotics upon growth rate and reproductive interval of *A. beccarii tepida* (Coos Bay). Five specimens used for each experiment (average diameter 281 μ).

Food concentration No. cells per dish (15 cc)	Growth rate (μ /10 day)	Reproduction interval (days)		% repro- duction	% mortality
		Median	Range		
0	0	∞		0	20
0*	0	∞		0	100
55,000	0	∞		0	40
55,000*	0	∞		0	100
110,000	0	∞		0	0
110,000*	0	∞		0	80
220,000	4	95	43-122	60	40
220,000*	48	∞		0	80
440,000	8	34	16-60	80	20
440,000*	68	95	26-95	40	0
880,000	68	8	5-43	100	0
880,000*	82	43	16-95	100	0

*72 units penicillin and 83 μ g streptomycin added per ml culture medium.

food supply was increased above this limiting value of 110,000 - 220,000 cells, the growth rate increased until the maximum food concentration given in this experiment (880,000 cells) was reached.

The results of the food experiments show that a food concentration of at least 220,000 cells per dish is necessary for minimal growth and reproduction. Assuming that all the food cells settle out on the dish bottom and sides, this is equivalent to approximately 112 cells/mm² of surface of the culture dish. Table 9 shows that a food concentration one-half this value (110,000 cells or 56 cells/mm²) is apparently too low to support any growth or reproduction. Although this food concentration is too low for growth, it yields enough energy to keep the specimens alive for at least 60 days. Figure 6 shows that at the end of this time when a food concentration of 880,000 cells (450 cells/mm²) was added, growth resumed and ultimately reproduction occurred. Even the complete withholding of food for a period of at least 60 days did not cause death, although growth was halted. When food was again added, growth did not occur immediately, but 1 to 2 weeks elapsed before normal growth resumed. At the end of 60 days of fasting, the protoplasm in each of the specimens had contracted into the earlier chambers leaving the last 4 to 6 chambers empty. One week after feeding, the protoplasm had resumed its normal size but a further period of approximately one week was needed to show renewed growth.

Growth rate and reproductive efficiency appear to increase with the continuous addition of food, at least to the maximum value of 880,000 cells or 530 cells/mm² supplied in the experiment. The effect of food concentrations higher than this was not determined. It is possible that a large excess of food might be deleterious because of the high bacterial concentrations that occur when food decomposes.

The effect of food upon reproductive activity may be estimated by the percentage of individuals com-

pleting reproduction at each food concentration and by the time period required for reproduction to occur. Table 9 shows that in both the penicillin-treated and the untreated cultures the percentage of individuals completing reproduction increased with the addition of food and that the reproduction interval decreased.

PRELIMINARY pH EXPERIMENTS

Although the range of pH in the open sea varies from approximately 7.5 to 8.5, in marine bottom deposits, tide pools, bays and estuaries the pH may exceed 8.5 or fall below 7.0 (ZoBell, 1946). Values of pH of 9.0 are common in localized regions of high plant production such as in tide pools or in dense phytoplankton blooms. Values as high as 10.0 have been noted by Moore (1958) resulting from the photosynthetic activity of *Ulva* in tide pools. Carpelan (1957) has reported pH values as high as 9.8 from salt ponds in San Francisco Bay. These recorded values suggest that under certain conditions, at least, the pH may have an effect upon the Foraminifera.

Solutions of different pH values were prepared by adding concentrated HCl or NaOH to sea water until the desired pH was reached. Individual specimens of *A. beccarii tepida* were pipetted from their normal media (pH 8.1) to the various pH solutions for specified periods of time. After exposure, the specimens were transferred back to their original media and allowed to recover.

The results of the pH experiments (Table 10) show that as the pH becomes increasingly basic or acidic the survival time is decreased. At a pH of 2.0, *A. beccarii tepida* can survive for a period of 25 minutes to 1 hour 15 minutes. A preliminary experiment on *Spirillina vivipara*, on the other hand, shows that it may be more sensitive to low pH, as is indicated by its much shorter survival time (2-6 minutes).

It was noted during the course of the pH experiments that it was possible under sublethal conditions

to dissolve the CaCO_3 test and yet not kill the specimen. This observation was made on both *Spirillina vivipara* and *A. beccarii tepida*. Individuals of *A. beccarii tepida* that had been left in sea water with a pH of 2.0 for 5 minutes showed slight dissolution of the

later chambers. Specimens left for 10 minutes under these conditions showed dissolution of their last 4 chambers, while 15 and 25-minute exposures resulted in dissolution of all the CaCO_3 , with nothing but a thin chitinous membrane remaining to show the out-

TABLE 10. pH tolerance of *A. beccarii tepida*. Time required to reach 50% mortality at indicated pH levels.

pH	No. drops conc. HCl or NaOH per 100 ml medium	Survival time	No. Specimens
2.0	10		
2.0	8	25 min. - 1 hr. 15 min.	1
2.0	3	>5 min.	1
2.4	2	>1 min.	1
3.2	1	>25 min.	1
8.1	0		10
8.5	0.5	>13 hr. 15 min.	2
8.9	1	>13 hr. 15 min.	2
9.0	4	>64 hr. 45 min.	4
8.8	4	>14 hr.	4
9.1	5	>14 hr.	4
9.1	6	>37 hr. 30 min.	2
9.3	7	>42 hr. 30 min.	2
9.5	8	14 hr. - 37 hr.	8
9.9	9	<14 hr.	4
10.0	10	<14 hr.	2

line of the test. At the end of all these exposures, however, normal streaming of the protoplasm was still evident. Two days later all the individuals exhibited normal pseudopodial activity, except for the specimens exposed for 25 minutes. Here the only indication of life was a faint movement in the earlier chambers. Twenty-four hours later protoplasmic movement had extended throughout the entire cell. The three specimens with major shell solution showed no indication of recalcification by the second day, but 24 hours later the specimen which had lost its four distal chamber walls showed replacement of the calcareous covering. While the specimens were being transferred from the acid media, the later chambers were somewhat damaged in the process and consequently the chambers were recalcified in an abnormal manner. Three weeks later, of the three specimens which had showed signs of solution, all appeared to be in normal condition and two had reproduced.

PRELIMINARY HYDROSTATIC PRESSURE EXPERIMENTS

The presence of faunal depth zonation in the sea has stimulated much speculation as to its cause. The direct relationship that exists between depth and pressure suggests that hydrostatic pressure may be a limiting factor in this zonation. Since the range of pressure found in the sea varies up to 1000 atmospheres, it seems probable that there may be specific differences in pressure tolerance over such a wide range of values. Regnard (1891), Fontaine (1930), and Oppenheimer and ZoBell (1952) have studied pressure effects upon

organisms ranging from crustaceans to bacteria. They found that marked physiological changes occurred with increased pressure, the effects depending upon the species studied. Some species, particularly shallow-water forms, are killed by pressures approaching those found in abyssal water. It appears likely that those species living at great depths must be especially adapted for life at high pressures and that their biochemistry may be very different from shallow-water forms.

There is no information concerning the effect of pressure upon the Foraminifera. In order to see if a pressure relationship exists for the Foraminifera similar to that found for other forms, a series of experiments was conducted on a nearshore species, *A. beccarii tepida* (Coos Bay). The apparatus described by ZoBell and Morita (1959) was used to develop the required pressures. Five specimens were selected at random, measured, and transferred to small test tubes (10x50 mm) completely filled with sea water. The tubes were plugged with neoprene stoppers, care being taken to ensure the complete removal of air bubbles. Duplicate tubes were placed in cylinders at the following pressures: 1, 100, 200, 400, 500, 800, and 1000 atmospheres. Duplicate samples also were placed in 60-mm plastic petri dishes at one atmosphere and kept at 25°C. as a control. The cylinders were left at the indicated pressures for 3 and 8 days at a temperature of 25° ± 0.5°. After this period the specimens were removed from the test tubes, measured and allowed to recover at atmospheric pressure.

The results of the hydrostatic pressure experiments are shown in Table 11. All the *A. beccarii tepida* spec-

imens withstood pressures as high as 400 atmospheres for 3 days, but pressures of 1000 atmospheres were sufficient to kill all individuals within this same time period. Specimens subjected to longer exposures (8 days) also showed lethal effects at pressures greater than approximately 400 atmospheres. The greater mortality shown for specimens at 8-day exposures as compared to those at 3-day exposures suggests the lethal effect of prolonged exposure to pressures which could be successfully withstood for shorter periods.

Growth was slowed considerably while the specimens were kept under these experimental conditions. It was not possible to attribute this decrease in growth entirely to pressure effects, however, since the specimens in the pressure cylinder at one atmosphere also showed negligible growth when compared to the control group. Upon removal from the cylinders, the growth rate of the survivors increased, the specimens which had been subjected to the lowest pressures growing faster than the individuals kept at higher pressures.

TABLE 11. Pressure tolerance of *A. beccarii tepida* (Coos Bay).
A and B represent two different experiments; + represents relative growth.

Pressure (atmospheres)		3-day exposure			8-day exposure		
		% survival	Growth	No. Speci- mens	% survival	Growth	No. Speci- mens
0	(control)	100	+++	10	100	+++	10
0	A	100	+	10	80	0	5
0	B				90	0	10
100	A	100	+	10	100	0	10
200	A	100	0	10	60	+	10
200	B				100	+	10
400	A	100	+	10	65	0	10
500	B				0	0	10
800	B				0	0	10
1000	A	0	0	5	0	0	10

OXYGEN CONSUMPTION EXPERIMENTS

Respiration is a basic mechanism affected by environmental factors and the rate of oxygen consumption is a valuable index of growth and other activity. Rate of respiration provides another convenient measure of the quantitative effect of various environmental factors. Thus, oxygen consumption might be expected to correspond more or less closely to growth and hence provide a measure of the latter. In this way, information on the effects of environmental factors might be obtained in a short time that would take weeks with usual growth experiments. In addition, there is a possibility of obtaining ecological information from delicate species that so far have resisted attempts to culture in the laboratory.

A very sensitive micro-respirometer technique devised by Scholander *et al.* (1952) was used to measure the oxygen consumption of individual specimens of Foraminifera. The method is essentially a manometric technique that is based on the measurement of the pressure change required to keep an air bubble a constant volume while an organism is consuming oxygen from it. The general method and techniques described by Scholander *et al.* (1952, 1958) have been followed. Close temperature control in this technique is extremely important. In the following experiments, temperatures were kept to within $\pm 0.01^\circ\text{C}$. of the required value by the use of a specially designed water bath.

Because of the relationship of oxygen consumption to size, the maximum diameter of the test was measured prior to each experiment and the same individual

was used when comparing the effect on respiration by any factor.

The effect of temperature upon respiration was studied by measuring the oxygen consumption of the same individual over a wide temperature range. In the following experiments the oxygen consumption was first determined for the lowest temperature (10°C .), after which the bath temperature was raised by successive 5° increments and the oxygen consumption measured at the end of each increment. Approximately 10 minutes were required after each temperature change for the system to equilibrate. After this equilibration period, 10 to 20 minutes were usually adequate to yield a reliable oxygen consumption curve.

Results

Figure 7 shows the pressure changes in the micro-respirometer caused by the respiration of a single specimen of *A. beccarii tepida*. The straight line portion of the curve, representing a constant rate of oxygen consumption, was used for the determination of oxygen consumption. In most cases the oxygen consumption experiments were terminated while still in the linear portion of the graph. Figure 7 shows the situation that occurs when a specimen is left in the respirometer for a longer period of time. The pressure, which is proportional to the oxygen tension, first falls at a steady rate until it reaches a certain point, after which the rate of decrease becomes less until it finally ceases altogether at a particular oxygen tension. At a relatively high partial pressure the rate of consump-

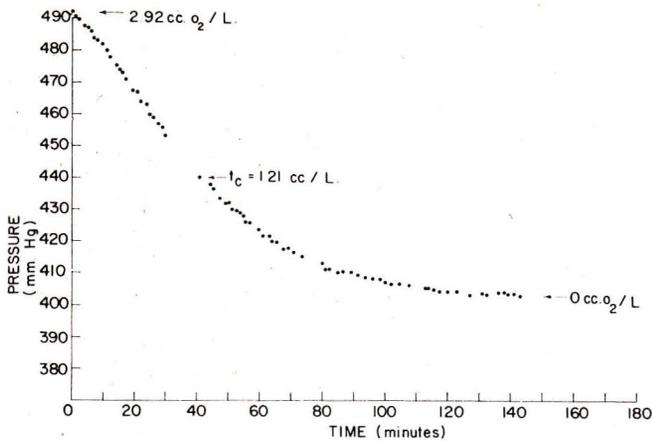


FIGURE 7

Pressure changes in micro-respirometer caused by respiration of a single specimen of *Ammonia beccarii tepida* (Carlsbad population). Maximum test diameter 288 μ ; Salinity 25 o/oo; temperature 26.0°C. t_c represents critical oxygen tension. Change of 1 mm. pressure is equivalent to 23.8 $\mu\text{l O}_2$.

tion was independent of the oxygen concentration but below a certain partial pressure the rate of consumption was in part dependent upon the oxygen concentration.

The point at which the curve begins to show oxygen dependence has been termed the "critical oxygen tension" (Bishop, 1950). The critical oxygen, t_c , is an important index of ability to survive in environments of low oxygen. A species with a low t_c may be able to survive indefinitely in water of low oxygen concentration, whereas a species with a high t_c requires a higher concentration. If it is assumed that the point of no oxygen consumption represents the point at which all the oxygen has been exhausted from the water, the oxygen concentration at any pressure during the experiment can be calculated, since the rate of oxygen uptake is known. In this manner the critical oxygen tension for the species portrayed in Figure 7 was found to be 1.21 cc oxygen/liter.

Figure 8 shows the relationship between maximum

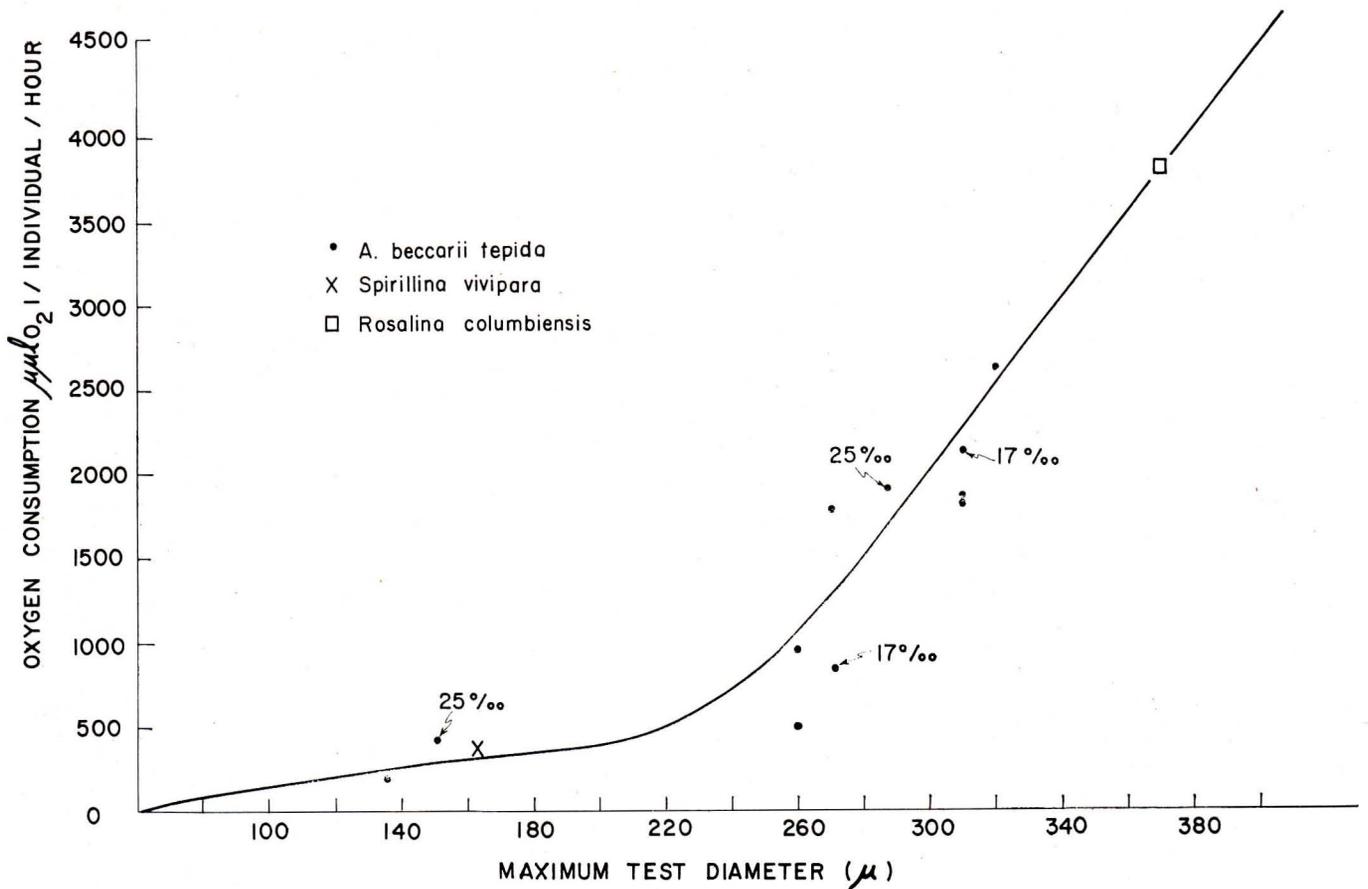


FIGURE 8

Effect of size (maximum diameter) upon oxygen consumption per individual. Temperature 26.0°C; salinity 33.5 o/oo unless otherwise indicated.

test diameter and oxygen consumption for the three species examined. It will be noted that under equivalent conditions there appeared to be a direct relationship between size and oxygen uptake with the result that the larger individuals (and species) consumed oxygen at a more rapid rate than did smaller individuals (or species).

Figure 9 shows the effect of temperature upon oxygen consumption in *A. beccarii tepida*. The oxygen

consumption rose gradually from low values between 10-15°C. to a maximum between temperatures of 35-40°C. Above 40°C. oxygen consumption decreased rapidly until death at approximately 45°C.

The relationship between size and oxygen consumption found in the present study agrees with Zeuthen's (1947) study of the relationship between size and activity for many animal groups. The values obtained at 25°C. for oxygen consumption (2500 - 8000 $\mu\text{l O}_2$

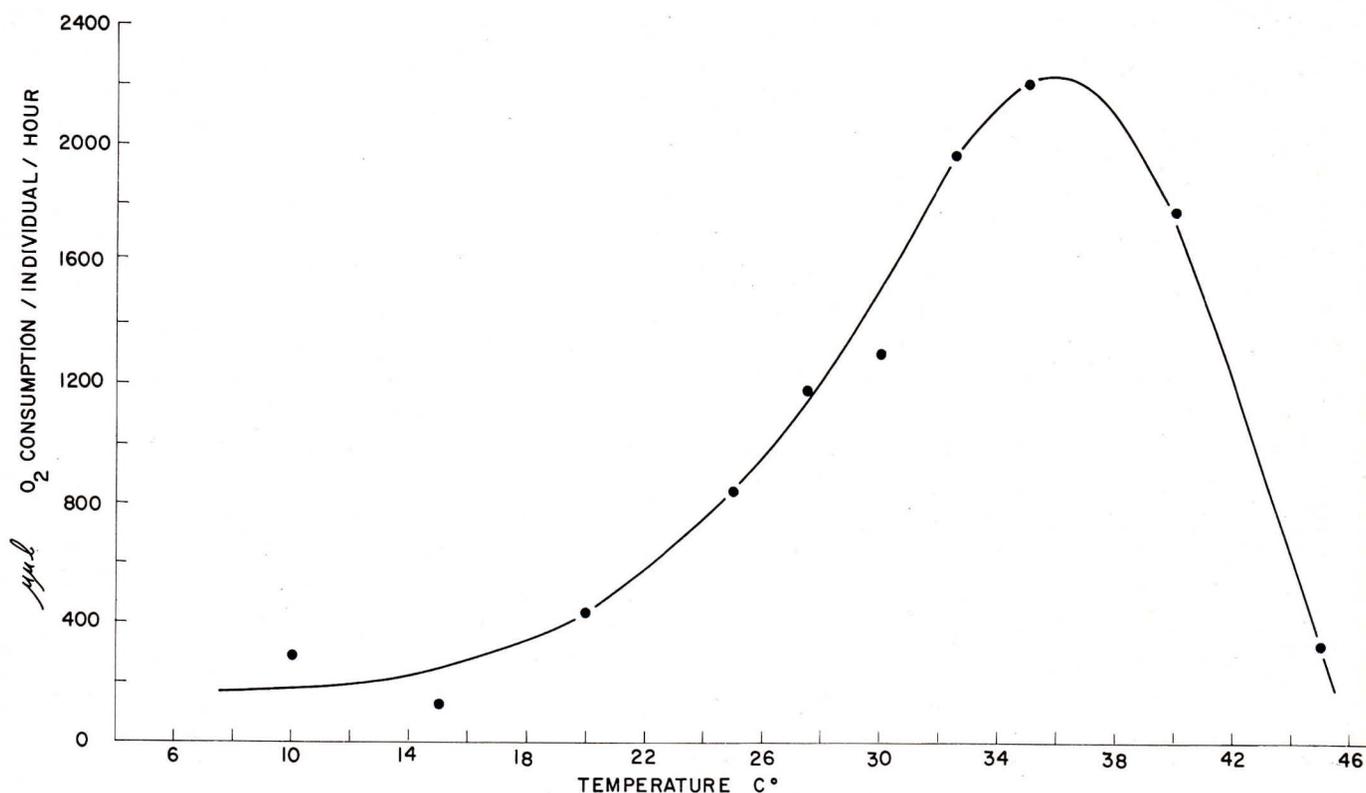


FIGURE 9

Effect of temperature upon oxygen consumption of one specimen of *Ammonia beccarii tepida* (Coos Bay Population). Maximum test diameter 245 μ ; Salinity 33.5 o/oo.

per individual per hour) agree in general with values reported for other protozoan types (Bishop, 1950).

The increase of oxygen consumption with temperature is well known for many organisms and may be expressed in terms of a temperature coefficient, Q_{10} . This is the ratio of the rate of activity at any temperature to the rate at a temperature 10° lower. For most biological processes it varies from 2-4 over most of the biological temperature range (Bishop, 1950). The Q_{10} for the oxygen consumption of *A. beccarii tepida* over the range from 10-35°C. (figure 8) is approximately 3.2.

The maximum oxygen consumption occurred at approximately 35°C. This is approximately 5°C. higher than the temperature for maximum growth and reproductive rate for the same species, as shown in Table 5 and Figure 3. This type of discrepancy between maximum activity rates and maximum oxygen consumption was noted by Fry (1947). He found that metabolism, as measured by rate of oxygen consumption, does not give a direct measure of an activity, such as growth or reproductive rate. The important metabolic measure of activity is the difference between the maximum and minimum metabolic rates, but not any single rate. This is illustrated by data showing the temperature relationship between active and standard metabolism in the goldfish (Fry, *op. cit.*). Standard metabolism appears to increase with temperature right up to the lethal level, but the maximum oxygen consumption (active metabolism) shows a peak at about 30°C., apparently representing the extreme capacity of the system involved. Fry (*op. cit.*, fig. 24)

believes the difference between the two oxygen consumption curves approximates the metabolism available for external work. If this is true, a temperature of approximately 28°C. should correspond to an optimum temperature for many activities of the goldfish. For this form, the relation of cruising speed to temperature does indeed show a maximum at about this point.

The concept of the optimum, derived from the relationship of metabolism to activity, advanced by Fry (1947), promises to be a useful tool in laboratory study of environmental relationships. A major difficulty to be overcome is the development of a method whereby the active metabolism of Foraminifera can be measured.

DISCUSSION

The results of the temperature experiments clearly show the effect of temperature upon such ecologically important characteristics as survival, growth and reproductive rates when other variables such as salinity, pH, etc., are held constant. The observation that acclimation to various temperatures did not cause highly significant changes in the lethal temperatures is of considerable interest. It indicates that the ability of Foraminifera to tolerate high temperatures may be an inherent genetic trait that is not subject to great environmental variation. This finding was surprising in view of the widespread evidence showing considerable temperature acclimation for many invertebrate species (Bullock, 1955). The variability of the data (Table 3), however, suggests that if more specimens had been used, a small amount of acclimation might have been

noted. Further studies are needed to establish this point. The apparent ability of previous salinity history to influence the lethal temperature is also of ecologic significance. Similar observations showing that hypersaline conditions enable many organisms to tolerate high temperatures have been reported by Gunter (1957).

Although the concept of an instantaneous lethal temperature (or salinity, etc.) appears to offer a useful and reproducible index of ability to tolerate extreme conditions, it may have little direct application to nature. Temperatures of 45°C. acting for 5 minutes and even long exposures to temperatures slightly above the upper incipient lethal temperature, which have been shown to kill *A. beccarii tepida*, are probably rarely experienced by this species in its natural habitat. Probably of much greater importance to the survival of the species is the relationship of the more usually experienced environmental levels to vital activities such as reproduction and rates of development. Although *A. beccarii tepida* has been shown in the laboratory to have a wide range of tolerance to both temperature and salinity, it will reproduce only within a temperature range of approximately 18-30°C. and between salinities of approximately 13-40 o/oo.

In nature, this species is found throughout the tropic and temperate regions but does not occur in the cold water north of Bergen, Norway and the Faroe Islands (Nørvang, 1945), or in Alaska (Tappan, personal communication). Throughout this area, *A. beccarii tepida* appears to be a euryhaline, shallow-water species that has not been recorded *living* at depths where the temperature is usually below its lower reproductive limit. (Recorded occurrences in deeper water do not include specimens known to be *living in situ*.) The overall latitudinal distribution of this particular species, therefore, appears to be largely governed by prevailing temperature conditions. Within these wide limits, however, the influence of other factors such as salinity, pH, etc., or competition with other species may serve to exclude this form from localized areas.

The relationship of environmental factors to size is of considerable interest. Experiments with *A. beccarii tepida* have shown a greater increase in size for specimens grown under colder conditions 15-20°C. than for those grown under warmer temperatures 25-30°C. In nature, Nicol (1944) and Parker (personal communication) have reported finding larger specimens of other Foraminifera species from the colder higher latitudes of their ranges. The difference in size of the tests of *Elphidium crispum* throughout its range was so extreme that Nicol divided it into two subspecies, the northern group having larger tests. Gunter (1957) has summarized observations of many different organisms in the natural environment, showing a similar inverse relationship between size and temperature. The relationship between salinity and size (Table 8 and Bradshaw, 1957), while not so marked, nevertheless shows that the smallest tests were found under the optimal salinity. The above observations suggest that larger

tests within the range of a species do not represent optimal environments, as commonly assumed, but possibly represent marginal environmental conditions. Under these marginal conditions reproductive maturity is delayed and the individuals continue to grow in size.

The effect of salinity upon such ecologically important factors as survival, reproduction rate, and rate of growth as determined in laboratory cultures suggest that a corresponding effect might be expected in natural environments. The fact that relatively few species have been recorded from natural brackish areas is apparently explained by the experimental results. The species that do occur and flourish in brackish situations are those that are adapted to survive, grow and reproduce under conditions that are adverse to other species. A comparison of *A. beccarii tepida* and *Massilina* sp. will illustrate this difference in adaptability. *A. beccarii tepida* survived salinities as low as 2 o/oo for periods of at least 12 hr (Table 6). *Massilina* sp., however, died when exposed to salinities of 7 o/oo for the same period. A similar lack of tolerance to decreased salinity has been observed in other open-ocean species (Table 6).

The results of the food experiments agree with the observations of Myers (1943b) and Bradshaw (1955) that when adequate food is available growth is continuous and rapid but is retarded when food is sparse. It has been assumed that all the energy for growth has come from the *Dunaliella* sp. supplied for food. At 25°C., the breakdown of algal cells was relatively rapid so that in the 3-4 day interval between feedings a certain percentage of the algae had already broken down. The percentage of material thus transformed into unusable, dissolved organic matter and/or into bacteria is unknown. Presumably some of the bacteria are ingested but proof of their value as food is lacking.

The presence of penicillin and streptomycin caused no apparent ill effects to *A. beccarii tepida*, at least for short periods of time. Long-continued use of antibiotic at these concentrations, however, coincided with a slackening of growth and increased mortality in some cultures (Table 9). Dense growths of fibrous molds surrounding the specimens were noted in the penicillin-treated cultures by the twenty-sixth day of the experiment. No molds were observed in the untreated dishes. Attempts to clean away the contaminant failed and the mold continued to persist as long as the antibiotics were present. When antibiotic treatment was discontinued, the mold eventually disappeared but most of the specimens did not recover. The eventual dominance of molds when the associated bacteria are inhibited is well known. It is possible that it was the direct or indirect influence of the mold and not the presence of antibiotics that contributed to the delayed maturity and death of the Foraminifera specimens.

The pH experiments indicate that the species of Foraminifera tested were relatively highly resistant to pH changes. Values of pH as low as 2.0, for example, are probably never found in the marine environment,

yet *A. beccarii tepida* could withstand such an extreme value for more than 25 minutes. The ability to resist low pH values appears to vary between different species. *A. beccarii tepida* can tolerate the same pH (2.0) for a much longer period of time than can *Spirillina vivipara*. The normal habitat of *Spirillina* is reported to be in the open ocean from depths of 0 to 300 meters, where little change of pH is expected, whereas *A. beccarii tepida* is characteristic of near-shore areas and shallow bays and lagoons where it may occasionally experience low pH.

Reliable data on the distribution of pH in natural environments are meager. Stevenson and Emery (1958) report a series of pH values of water and surface sediment from their study of plant communities in the marsh at Newport Bay, California, as follows:

Zone	Tidal Stage	
	High	Low
Water	7.88	7.78
Tidal flat	7.24	7.64
<i>Spartinetum</i>	6.73	7.62
<i>Salicornietum</i>	6.88	7.10

The pH decreased with distance from the marsh edge and with an increase in percentage of organic matter. If pH values less than 7.8 do indeed dissolve calcareous tests (Krumbein and Garrels, 1952), the above observed pH values must be an important control upon the distribution of species living under such conditions. Parker and Athearn (1959), in a study of marsh Foraminifera in Poponesset Bay, Massachusetts, noted that the calcareous species from surface sediment were represented for the most part by living specimens and that very few empty tests were found. Stevenson and Emery (1958) found that the surface of the Newport marsh was littered with *Cerithidea californica*, both living and dead. These gastropods, however, were found only on the surface and in the upper 5 mm of the soil. No remains were found below this layer down to the underlying sand. These observations suggest that pH values sufficiently low for test solution occur below the sediment surface but that pH values in the living micro-environment of the species are within the normal range for existence of CaCO_3 . The author knows of no measurements showing the detailed vertical distribution of pH for the uppermost layers of sediment and across the sediment-water interface. Values of pH derived in the usual manner by insertion of electrodes deep into the sediment and from sediment slurries may not be representative of those of the actual micro-environment of the Foraminifera.

It is of interest that the experiments showing complete lack of tolerance for hydrostatic pressures greater than approximately 400 atmospheres and lethal effects at lower pressures agree, in general, with reports of other workers studying other organisms.

Regnard (1891), the first to study effects of hydrostatic pressure on organisms, found that fermentation

of sugar by yeast, while normal at 400 atmospheres, was stopped at 600 atmospheres and that trout eggs which hatched normally at pressures of 300 atmospheres were destroyed at pressures of 400-650 atmospheres. *Paramecia* and other ciliated protozoans withstood pressures to 300 atmospheres but became immotile at 400-600 atmospheres. Salmon eggs exposed for six hours to pressures of 200 atmospheres developed normally but were inhibited at 300 atmospheres and stopped development at 400 atmospheres.

Studies of the effect of hydrostatic pressure on *Amoeba* are of particular interest because of their similarities to Foraminifera. Marsland and Brown (1936), using a special pressure cylinder with a glass window, found that pseudopodial movement in *Amoeba* ceased at 250 atmospheres. With increase in pressure, no further effect was noted until 450 atmospheres when the pseudopodia suddenly retracted and the specimen became spherical. A one-hour exposure at pressures above 300 atmospheres was lethal.

From the evidence presented, it appears that the protoplasm of normally shallow-living forms is destroyed, or at least inhibited, by pressures found at abyssal depths. The protoplasm of Foraminifera found in deep water, therefore, must be especially adapted for life at high pressures. In this regard, Phleger (1960) has suggested that the Foraminifera faunal boundary existing at 2000 meters may be due to a "pressure threshold" at 200 atmospheres pressure. Oppenheimer and ZoBell (1952) found that many shallow-water bacteria were intolerant of pressures exceeding 200 atmospheres. They suggested that the physiological action of pressure was through its effect on solubilities and dissociation constants and on pH and Eh values. Nicol (1960, p. 24) summarizes present knowledge on the physiological effect of hydrostatic pressure as follows: "At high pressures protein molecules are compressed, denatured and altered in structure and chemical activity. In the ocean depths two factors, low temperatures and high pressures, both of which affect the rate of biological processes, are acting concomitantly, and the animals of the abyss must be genetically modified to withstand the conditions obtaining there."

Experiments thus far have only concerned pressure tolerance and have not furnished information on more sensitive growth and reproductive activities. Nevertheless, the results with Foraminifera and other organisms show that hydrostatic pressure may be of the greatest importance in determining the faunal composition of the deep sea.

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CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
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229. NEW EVIDENCE FOR THE AGE OF THE "G-1 ZONE"
IN THE UPPER CRETACEOUS OF CALIFORNIA

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ABSTRACT

Strata in the San Luis Creek Quadrangle, Merced County, California, have yielded Campanian ammonites, an *Inoceramus*, and planktonic foraminifera, which indicate that the "G-1 Zone" of Goukoff, formerly regarded as of Coniacian and Santonian ages, also contains beds as young as Campanian.

Foraminiferal faunas in the Upper Cretaceous of California are generally assigned to biostratigraphic

subdivisions as defined by Goukoff (1945). These units were given stage names and alphabetical zonal designations by Goukoff and correlated with Texas Cretaceous groups. Subsequently the "zones" have been referred to the European standard Cretaceous stages, the schemes of Bandy (1951) and Popenoe, Imlay and Murphy (1960) being representative:

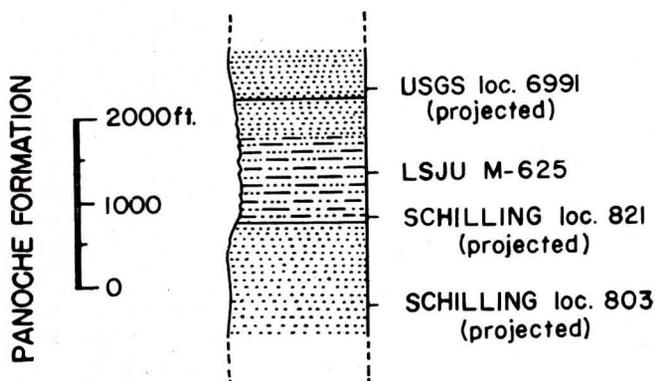
European Stages	<i>California "Zones"</i>		
	Modified from Bandy (1951)	Popenoe <i>et al.</i> (1960)	
Maastrichtian	B C D-1	B C D-1 D-2	
Campanian	Senonian	D-2 E F-1 F-2	E F-1
Santonian		G-1	F-2
Coniacian		G-2	G-1
Turonian		G-2	
Cenomanian	H	H	
		?	

Micropaleontologists in California are in fair agreement on these relationships; however, a dissenting group has arisen among the students of megafossils, particularly among those working with ammonites. This divergence of opinion has been noted by Matsu-

moto (1960, p. 181), and orally confirmed by others. One point of discrepancy is in regard to the "G-1 Zone" of Goukoff as a unit of pre-Campanian time. Ammonite specialists have stated that in many areas in California where foraminiferal assemblages are as-

signed to the "G-1 Zone," these faunules actually are associated with Campanian rather than Coniacian-Santonian ammonites. Also, some researchers in megafossils are inclined to consider that the foraminifers are reworked from older sediments and thus their assigned age is incorrect. Indeed, this may be the proper explanation in some cases. However, in others it does not seem to be appropriate, as is apparent from the planktonic foraminiferal fauna herein described. California Upper Cretaceous megafossils as a rule are rare, a single specimen often serving as the sole evidence for dating hundreds of feet of strata. In the San Luis Creek Quadrangle area studied, megafossils are even more scarce than usual owing partly to lack of topographic relief and to thick soil cover.

Dana Clark and Frederick A. Schilling, Jr., a Stanford University graduate student, while engaged in stratigraphic studies in the San Joaquin Valley during the summers of 1959 and 1960, discovered a well-preserved and significant Upper Cretaceous foraminiferal assemblage from the bottom of a five-foot pit in which a light-gray, thin-bedded shale was exposed beneath four feet of soil. (The locality—designated LSJU loc. M-625—is near the crest of a low north-west-southeast trending hill, 1775 feet north, 550 feet west of the southeast corner of sec. 35, T. 9S., R. 8E., M.D.B. & M., San Luis Creek Quadrangle, Merced County, in strata mapped by Anderson and Pack (1915) as part of the Panoche Formation.) This microfauna, in addition to containing numerous benthonic forms typical of the "G-1 Zone" of California (generally regarded as early to middle Senonian in age), carries eleven planktonic species that clearly point to a Campanian age. In addition, Mr. Schilling has called our attention to beds containing megafossils stratigraphically above and below LSJU loc. M-625. These, on the basis of his mapping, have been projected into our stratigraphic column (Text fig. 1). The Schilling Locality 803, about 11 miles northwest of LSJU loc. M-625 and stratigraphically 1,600 feet lower, contains *Inoceramus subundatus* Meek (identification by Dr. David L. Jones, U. S. Geol. Survey); his Locality 821, about 3½ miles northwest of LSJU loc. M-625 and 600 feet stratigraphically lower, has



TEXT FIGURE 1

Columnar section in sec. 35, T.9 S., R.8 E., M.D.B. & M., Merced Co., Calif., showing stratigraphic position of fossil localities.

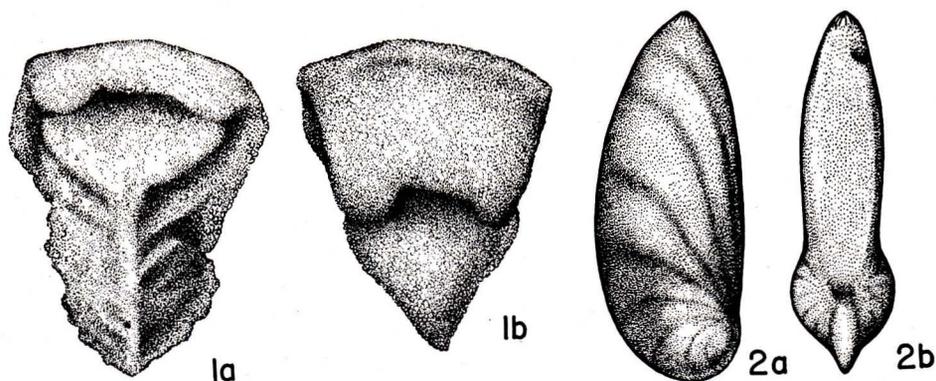
the ammonite *Tetragonites* cf. *T. popetensis* Yabe (identification by Dr. Tatsuro Matsumoto, Kyushu University). Three and one-half miles northwest of LSJU loc. M-625 is U. S. Geol. Survey Loc. 6991, 950 feet stratigraphically higher than the aforementioned foraminiferal locality and containing the ammonite *Metaplacenticerias* sp. (identification by Dr. David L. Jones, U. S. Geol. Survey). All of the above-mentioned mollusks are cited as of Campanian age by Matsumoto (1959, pt. 2, p. 136, 152-154; 1960, Pl. 1) and by Popenoe, Imlay and Murphy (1960, Chart 10e).

Thirty-eight species of benthonic foraminifera were found at the Merced County locality:

1. Allomorphina allomorphinoides (Reuss) VR¹
2. Aragonia sp. C
3. Bermudezina uvigeriniformis Martin (MS) F
4. Bulimina aff. *B. reussi* Morrow C
5. Clavulinoides cf. *C. aspera* (Cushman) R
6. Cribrostomoides cretacea Cushman and Goudkoff R
7. Dentalina basiplanata Cushman R
8. Dentalina cf. *D. communis* d'Orbigny VR
9. Dentalina cf. *D. consobrina* d'Orbigny VR
10. Ellipsoidella sp. of Cushman and Church AB
11. Eponides sp. AB
12. Fissurina marginata (Walker and Jacob) VR
13. Frondicularia cf. *F. tetragona* (Reuss) VR
14. Gaudryina pyramidata Cushman AB
15. Gavelinella sp. VR
16. ?Globulina horrida Reuss VR
17. Gyroidina aff. *G. umbilicata* (d'Orbigny) AB
18. Haplophragmoides sp. VR
19. Lingulina sp. R
20. Marginulina bullata Reuss VR
21. Marginulina cf. *M. cretacea* Cushman VR
22. Marginulina aff. *M. jarvisi* Cushman VR
23. Marssonella turris (d'Orbigny) AB
24. Neoflabellina sp. VR
25. Nodosarella sp. VR
26. Nodosaria aspera Reuss VR
27. Nodosaria concinna (Reuss) AB
28. Nuttallinella florealis (White) AB
29. ?Osangularia sp. VR
30. Planularia tricarinnella Cushman and Goudkoff [non Reuss] R
31. Planulina sp. VR
32. Pullenia cretacea Cushman VR
33. Pseudonodosaria sp. VR
34. Quinqueloculina sp. VR
35. ?Ramulina cf. *R. ornata* Cushman VR
36. Robulus muensteri (Roemer) C
37. Robulus sp. R
38. Spiroplectammina sp. R

¹ Abundance symbols: R = Rare
AB = abundant VR = very rare
C = common F = few

Of these species, *Gaudryina pyramidata* Cushman (Text fig. 2-1a, b) and *Planularia tricarinnella* Cushman and Goudkoff [non Reuss] (Text fig. 2-2a, b) are



TEXT FIGURE 2

- 1, *Gaudryina pyramidata* Cushman. $\times 40$. a, front view; b, top view.
2, *Planularia tricarinella* Cushman and Goudkoff [non Reuss]. $\times 60$.
a, side view; b, edge view.

listed by Goudkoff (1945, Table II and p. 991) as particularly characteristic of his "G-1 Zone." The other elements of the microfauna are compatible with this zonal designation.

The planktonic species associated with the benthonic forms—and their stratigraphic ranges as reported by Bolli (1957), Brönnimann and Brown (1956), Dalbiez (1955), Edgell (1957), Frizzell (1954), Gandolfi (1955), Hofker (1956, 1957, 1960), Hiltermann and Koch, 1960, and Subbotina (1953)—are shown in Table 1.

These open-sea floating forms, as their time ranges are now known, suggest a Santonian-Campanian age for the associated strata. However, the range of *Rugoglobigerina rugosa* apparently does not extend into pre-Campanian time. In North America, the species *Globotruncana fornicata*, *G. ventricosa*, and *G. linneiana tricarinata* most commonly are regarded as indicative of the Campanian stage. Therefore, the writers consider the Merced County microfauna as Campanian (probably early) in age. This conclusion is consistent with the available megafaunal evidence and raises the inescapable argument that the time range of the "G-1 Zone" of Goudkoff is as young as Campanian. Hence, within the limits given by Goudkoff, the "G-1 Zone" encompasses sediments of Coniacian, Santonian, and Campanian time.

To what extent microfaunas of the "G-1 Zone" attain an early Campanian age in other regions of the State remains to be determined. The possibility arises that the elements regarded by Goudkoff as indicative of this "zone" may be, at least in part, reflections of changes in ecology with time. Thus the "top" of the "G-1 Zone" of Goudkoff may be suspected as not being a true time line.

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Camera lucida drawings are by Perfecto M. Mary, staff artist, School of Mineral Sciences, Stanford University.

DESCRIPTION OF SPECIES

Family HETEROHELICIDAE Cushman, 1927,
emended Montanaro Gallitelli, 1957

Genus *Heterohelix* Ehrenberg, 1841

Heterohelix striata (Ehrenberg)

Plate 5, figures 4a, b

Textularia striata EHRENBURG, 1838 (1840), K. Akad. Wiss. Physik. Abh., p. 135, pl. 4, figs. 1-3, 9.

Gümbelina striata (EHRENBURG) (in part). EGGER, 1899 (1902), K. bayer. Akad. Wiss., Math.-naturh. Abt., Abh., Kl. 2, vol. 21, p. 33, pl. 14, figs. 37-39.

Textularia globulosa f. *striata* (EHRENBURG). FRANKE, 1925, geol. pal. Institut Univers. Greifswald IV Abh., p. 11.

Test.—small, subtriangular, increasing in size throughout, width about twice the thickness; periphery broadly rounded, lobate.

Wall.—faintly striate, finely perforate.

Chambers.—13 biserially arranged, globular, rapidly increasing in size.

Sutures.—distinct, straight, slightly oblique, depressed.

Aperture.—low arch at base of septal face, apertural periphery slightly thickened.

Dimensions.—length: 0.240 mm.; width: 0.208 mm.; thickness: 0.112 mm.

Remarks.—The rare specimens all have the last-formed chamber broken. The species is assigned to the genus *Heterohelix* on the basis of the study of Montanaro Gallitelli (1957, p. 137-138).

Figured specimen.—Stanford Univ. Paleo. Type Coll. No. 9320.

Heterohelix sp.

Plate 5, figures 3a, b

Test.—small, subtriangular, progressive increase in size throughout, width about $2\frac{1}{3}$ times the thickness, periphery rounded, moderately lobed, sides nearly parallel in edge view.

Wall.—finely perforate, faint striae developed on periphery and on early chambers in edge view, late chambers smooth.

Species	Senonian			Campanian	Maastrichtian	References
	Turonian	Coniacian	Santonian			
1. "Globigerinella" aspera (Ehrenberg)			-----	-----	---	Hofker, 1957; 1960
2. Globotruncana fornicata Plummer	-	-----	-----	-----	---	Frizzell, 1954 Dalbiez, 1955 Gandolfi, 1955 Brönnimann & Brown, 1956 Bolli, 1957 Edgell, 1957
3. Globotruncana linneiana (d'Orbigny)	-----	-----	-----	-----		Brönnimann & Brown, 1956
4. Globotruncana linneiana tricarinata (Quereau)	---	-----	-----	-----	---	Gandolfi, 1955 Dalbiez, 1955 Bolli, 1957 Edgell, 1957 Hiltermann & Koch, 1960
5. Globotruncana aff. G. paraventricosa (Hofker)	---	-----	----- ?	-----		Hofker, 1956 Edgell, 1957 Hiltermann & Koch, 1960
6. Globotruncana ventricosa White		-----	-----	-----	-----	Frizzell, 1954 Dalbiez, 1955 Gandolfi, 1955 Bolli, 1957
7. Heterohelix striata (Ehrenberg)		-----	-----	-----	---	Frizzell, 1954 Hofker, 1957
8. Heterohelix sp.				? - ?		
9. Pseudotextularia elegans (Rzehak)		-----	-----	-----	---	Frizzell, 1954
10. Rugoglobigerina aff. R. ordinaria (Subbotina)	-----	-----	-----	-----	-----	Subbotina, 1953
11. Rugoglobigerina rugosa (Plummer)				-----	-----	Frizzell, 1954 Gandolfi, 1955 Brönnimann & Brown, 1956 Edgell, 1957

TABLE 1
Stratigraphic ranges of eleven planktonic species from Merced County, California

Chambers.—17 biserially arranged, longitudinally compressed, gradually increasing in size.

Sutures.—distinct, straight, oblique, slightly limbate, depressed.

Aperture.—small arch at base of septal face.

Dimensions.—length: 0.368 mm.; width: 0.256 mm.; thickness: 0.112 mm.

Remarks.—The few forms in our sample lack the beaded sculpture of *Ventilabrella deflandraensis* Sigal and the medial plate characteristic of *Ventilabrella compressa* van der Sluis. The compressed test in the plane of biseriality suggests that it may be close to *Planoglobulina* Cushman (= *Ventilabrella* Cushman). The form is tentatively regarded as a *Heterohelix*, following Montanaro Gallitelli (1957, p. 137-138).

Figured specimen.—Stanford Univ. Paleo. Type Coll. No. 9321.

Genus *Pseudotextularia* Rzehak, 1891, emend.

Montanaro Gallitelli, 1957

Pseudotextularia elegans (Rzehak)

Plate 5, figures 5a, b

Cuneolina elegans RZEHAK, 1891, Naturh. Hofmus., Ann., vol. 6, p. 4.

Pseudotextularia varians RZEHAK, 1895, (In part), Naturh. Hofmus., Ann., vol. 10, p. 217, pl. 7, figs. 1a, b.

Gümbelina elegans (RZEHAK). WHITE, 1929, Jour. Paleontology, vol. 3, pt. 1, p. 34, pl. 4, figs. 8a, b.

Pseudotextularia elegans (forma typica) (RZEHAK). GLAESSNER, 1936, Probl. Paleontology, vol. 1, p. 99, text figs. 1a, b; pl. 1, figs. 1, 2.

Gümbelina plummerae LOETTERLE, 1937, Nebr. Geol. Surv., Bull. 12, p. 33, pl. 5, figs. 1, 2.

Gümbelina striata var. *deformis* KIKOINE, 1948, Bull. Soc. Géol. France, ser. 5, vol. 18, fasc. 1-3, p. 20, pl. 1, figs. 8a-c.

Pseudotextularia elegans RZEHAK. NOTH, 1951, Jahrb. Geol. Bundesanstalt, Sonderb. 3, p. 61, pl. 7, figs. 15, 16, 17a, b.

Brönnimannella plummerae (LOETTERLE). MONTANARO GALLITELLI, 1956, Contr. Cushman Found. Foram. Res., vol. 7, pt. 2, p. 35, pl. 7, figs. 1, 2.

Test.—small, subtriangular, rapidly increasing in size throughout, width about $1\frac{1}{4}$ times the thickness, periphery broadly rounded, lobate.

Wall.—with distinct striae curving toward aperture, finely perforate, pores alligned between and parallel to striae.

Chambers.—8 biserially arranged, globose, rapidly increasing in size, final one about $\frac{1}{3}$ size of test.

Sutures.—distinct, straight, oblique, depressed.

Aperture.—broad arch at base of septal face.

Dimensions.—length: 0.304 mm.; width: 0.256 mm.; thickness: 0.208 mm.

Remarks.—a single immature specimen was found.

Figured specimen.—Stanford Univ. Paleo. Type Coll. No. 9322.

Family GLOBOTRUNCANIDAE Brotzen, 1942

Genus *Rugoglobigerina* Brönnimann, 1952

Rugoglobigerina rugosa (Plummer)

Plate 5, figures 1a-c

Globigerina cretacea D'ORBIGNY. CARSEY, 1926, Univ. Texas, Bull. 2612, p. 43, pl. 5, figs. 5a-b.

Globigerina rugosa PLUMMER, 1927, Univ. Texas Bull. 2644, p. 38, pl. 2, figs. 10a-d.

Rugoglobigerina rugosa rugosa (PLUMMER). BRÖNNIMANN, 1952, Bull. Amer. Paleontology, vol. 34, no. 140, p. 28, text figs. 11-13.

Test.—small, subcircular, low trochoidal, globigerine, diameter $1\frac{1}{2}$ times height; periphery lobate, broadly rounded.

Wall.—finely perforate, ornamented with rugosities meridionally arranged on each chamber.

Chambers.—10 making up two whorls, globose, rapidly increasing in size throughout.

Sutures.—distinct, straight, depressed.

Aperture.—not clearly visible but appears to be a broad arch opening into umbilicus.

Dimensions.—max. diameter: 0.256 mm.; height: 0.176 mm.

Remarks.—specimens are very rare but appear to be typical for the species.

Figured specimen.—Stanford Univ. Paleo. Type Coll. No. 9323.

Rugoglobigerina aff. *R. ordinaria* (Subbotina)

Plate 5, figures 2a-c

Rotundina ordinaria SUBBOTINA, 1953, (In Russian). Trudy Vses. Neft. Naukno-Issledov. geol.-razved.

Inst., N.S. 76, p. 166, pl. 3, figs. 3a-c—9a-c; pl. 4, figs. 1a-c—9a-c.

Rugoglobigerina ordinaria (SUBBOTINA). BYKOVA and SUBBOTINA, 1959, in *Osnovy Paleontologii*, General Pt., Protozoa, p. 303, figs. 693a-c.

Test.—subcircular, trochoid, dorsal side prominently convex, ventral side slightly concave, diameter about $1\frac{3}{4}$ times height, periphery rounded, lobate.

Wall.—finely perforate, coarsely papillate except for the nearly smooth final chamber.

Chambers.—14 arranged in $2\frac{1}{2}$ whorls, globose, rapidly increasing in size in the initial $1\frac{1}{2}$ whorls which are nearly planispiral, slowly increasing in size in the final whorl which is trochoid.

Sutures.—distinct, straight, radial, deeply depressed.

Aperture.—broad arch opening into umbilicus; tegilla broken.

Dimensions.—max. diameter: 0.350 mm.; height: 0.208 mm.

Remarks.—This species is common in our sample. Forms of this type usually have been referred to *Globigerina cretacea* d'Orbigny. However, Banner and Blow (1960) have reillustrated the type and give basis for assigning it to *Globotruncana*. *Rugoglobigerina*

Test.—subcircular, rotaloid, slightly biconvex, double-keeled, carinal band nearly vertical, periphery lobate.

Wall.—finely perforate except for beaded carinal band, smooth except for sutures.

Chambers.—19 arranged in 3 whorls, 6 in the last whorl, inflated on dorsal side and slightly so on ventral side, petaloid on dorsal side.

Sutures.—beaded, dorsal ones curved, slightly raised, ventral ones straight, depressed.

Aperture.—opens into wide umbilicus, remnants of tegilla present.

Dimensions.—max. diameter: 0.432 mm.; height: 0.208 mm.

Remarks.—Specimens are common in our sample. They differ from the forms illustrated by Edgell (1957), Brotzen's *G. ventricosa* and those of Hofker by having beaded sutures and carinae. Beading of the sutures is probably not a specific character.

Figured specimen.—Stanford Univ. Paleo. Type Coll. No. 9328.

Globotruncana linneiana (d'Orbigny)

Plate 5, figures 11a-c

Rosalina linneiana D'ORBIGNY, 1839, in RAMON DE LA SAGRA, "Histoire physique, politique et naturelle de l'île de Cuba," A. Bertrand, editeur, Paris, p. 101, vol. 8, pl. 5, figs. 10-12.

Rosalina linnei D'ORBIGNY, type 1, DE LAPPARENT, 1918, Mém. carte géol. France, p. 7; p. 4, text-fig. 1a, c.

Globotruncana canaliculata, of authors. (for list see TRUJILLO, 1960, Jour. Paleontology, vol. 34, no. 2, p. 341-342).

Globotruncana linnei (D'ORBIGNY). RENZ, 1936 (part), Eclog. Geol. Helv., vol. 29, no. 1, pl. 6, figs. 32-34.

Globotruncana lapparenti BROTZEN, 1936, Sver. Geol. Undersökning, ser. C, no. 396, p. 175.

Globotruncana linnei typica VOGLER, 1941, Paleontographica, Suppl. Bd. 4, Abt. 4, Lief. 4, Abschnitt 4, p. 286, pl. 23, figs. 12-21.

Globotruncana lapparenti lapparenti BROTZEN. BOLLI, 1944 (1945), Eclog. Geol. Helv., vol. 37, no. 2, p. 230, text-fig. 1 (15-16), pl. 9, fig. 11.

Globotruncana linneiana (D'ORBIGNY). BRÖNNIMANN and BROWN, 1955, Eclog. Geol. Helv., vol. 48, no. 2, p. 540, pl. 20, figs. 13-17; pl. 21, figs. 16-18.

Test.—subcircular, rotaloid, convex on dorsal side, broad carinal band nearly vertical, periphery lobate.

Wall.—finely perforate except for carinal band, smooth.

Chambers.—22 in 3 whorls, 8 in last-formed whorl, flat on dorsal and ventral sides, petaloid in shape on dorsal side.

Sutures.—dorsal ones curved, raised, beaded to smooth on last two chambers; ventral ones nearly straight, slightly raised, beaded to smooth.

Aperture.—remnants of tegilla present, opening into wide umbilicus.

Dimensions.—max. diameter: 0.536 mm.; height: 0.256 mm.

Remarks.—the illustrated specimen is the largest of the few specimens present; most individuals have six or seven chambers in the last-formed whorl. Hofker's illustrations of *G. linneiformis* suggest that species may be a synonym of *G. linneiana*.

Figured specimen.—Stanford Univ. Paleo. Type Coll. No. 9329.

Family HANTKENINIDAE Cushman, 1927

Genus *Globigerinella* Cushman, 1927

"*Globigerinella*" *aspera* (Ehrenberg)

Plate 5, figures 6a-c

Rotalia aspera EHRENBURG, 1854, Mikrogeologie, p. 24, pl. 23, fig. 28; pl. 27, figs. 57-58; pl. 28, fig. 42; pl. 31, fig. 44.

Phanerostomum asperum EHRENBURG, 1854, Mikrogeologie, pl. 30, figs. 26a, b; pl. 32 (group 1), fig. 24; pl. 32 (group 2), fig. 42.

Globigerina aspera (EHRENBURG). EGGER, 1899 (1902), K. bayer. Akad., Wiss., Math.-naturh. Abt. Abn., Kl. 2, vol. 21, p. 170, pl. 21, figs. 18-20.

Globigerinella aspera (EHRENBURG). CARMAN, 1929, Jour. Paleontology, vol. 3, no. 3, p. 315, pl. 34, fig. 6.

Test.—small, subcircular, nearly planispiral, diameter nearly 2½ times thickness, periphery rounded, lobate.

Wall.—finely perforate, minutely spinose.

Chambers.—11 making up about 2 whorls, globose, moderately increasing in size throughout.

Sutures.—distinct, depressed, slightly curved on both dorsal and ventral sides.

Aperture.—a broad, low slit at base of septal face, extending laterally to the umbilicus and with a small, thin lip above the aperture.

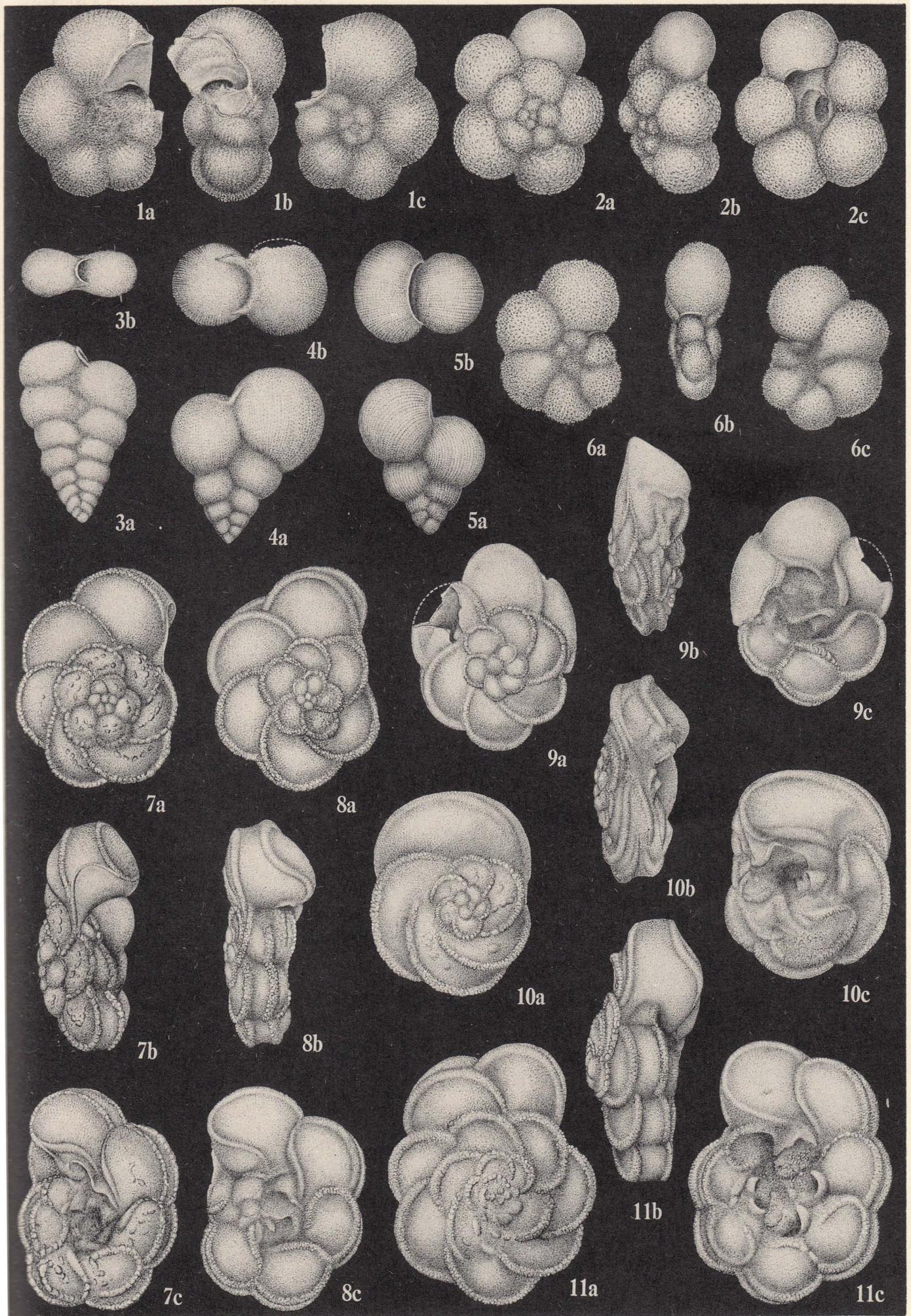
Dimensions.—diameter: 0.208 mm.; height: 0.088 mm.

Remarks.—Specimens are rare. They may be referred to a form intermediate between Hofker's forma *plana* and *subplana*. The stratigraphic range given in figure 2 for this species is that of forma *plana* and *subplana*.

Figured specimen.—Stanford Univ. Paleo. Type Coll. No. 9330.

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Graham and Clark: California Upper Cretaceous (Campanian) Foraminifera

CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
VOLUME XII, PART 3, JULY, 1961
RECENT LITERATURE ON THE FORAMINIFERA

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

- ADAMS, C. G. Eocene and Miocene Foraminifera from limestone and shale in the middle Baram valley, Sarawak.—Borneo, British, Geol. Survey Dept., Ann. Rept. for 1959, 1960, p. 64-77, pls. 14, 15, table 10.—Planktonics and orbitoids, mostly indeterminate, listed from many samples.
- AGALAROVA, D. A. Stratigrafija i mikrofauna Jurskikh Otlozhenij severozapadnogo Turkmenistana.—Baku, Azerbaidzhan. nauchno-issl. instit. dobyche nefti, Trudy, vyp. 10, 1960, p. 56-87, pls. 1-9.—Nineteen species (2 new) and 5 varieties (1 new and 4 indeterminate) from the Jurassic of northwestern Turkmenistan.
- ARNAL, ROBERT E. Limnology, sedimentation, and microorganisms of the Salton Sea, California.—Geol. Soc. America Bull., v. 72, No. 3, March 1961, p. 427-478, text figs. 1-27 (maps, graphs, diagrams), tables 1-11.—Foraminifera, accidentally introduced into this salt lake where they have become its most abundant micro-organisms, constitute a dwarf fauna with many malformed individuals. Quantitative distribution patterns of species are plotted. The pH of sediments seems to be the determining ecologic factor. Three facies: coastal, central, and deltaic, are defined.
- BANDY, ORVILLE L. Distribution of Foraminifera, Radiolaria, and diatoms in sediments of the Gulf of California.—Micropaleontology, v. 7, No. 1, January 1961, p. 1-21, pls. 1-5, text figs. 1-14 (maps, graphs), tables 1-3.—Through quantitative analysis 17 Foraminifera faunas are recognized (from lagoonal and beach to lower bathyal faunas at more than 3,000 meters) and selected representative species are illustrated. Evaluation of these modern biofacies patterns permits paleoecologic interpretations of Moreno and Kreyenhagen shales. Maximum foraminiferal numbers and diversity of species occur on the outer shelf and upper slope. Radiolaria and diatoms are less abundant than Foraminifera on the continental shelf and in the upper bathyal zone, but are most abundant in basin bottoms. Malformed specimens are commonest in inshore waters. Dwarfism appears to be commonest in deep closed basins. Sill depths seem to control basin assemblages. Benthonic biofacies are different from basin to basin leaving planktonic assemblages the primary common denominator between basins.
- BERGGREN, W. A. Paleogene biostratigraphy and planktonic Foraminifera of the SW Soviet Union. An analysis of Recent Soviet investigations.—Acta Univ. Stockholm, Stockholm Contrib. in Geology, v. 6:5, Aug. 15, 1960, p. 63-125, text figs. 1, 2 (maps), tables 1-8.—Development of planktonic faunas is essentially the same as that recorded in other parts of the world. Most supposedly mutually exclusive species result from unfamiliarity with all faunas. Notations of synonymous species are made. Tables show local zonations and correlations with Europe and North America.
- BERTHOIS, LÉOPOLD, and LE CALVEZ, YOLANDE. Deuxième contribution à l'étude de la sédimentation dans le Golfe de Gascogne.—Rev. Trav. Inst. Pêches marit., v. 23, No. 3, 1959, p. 323-376, pl. 1, text figs. 1-17 (map, graphs, diagrams), tables 1-20.—Includes quantitative analysis of Foraminifera in 3 cores from 35, 171, and 875 meters. About 90 species were found, with different assemblages in the 3 cores. A few species are described and illustrated; 3 are new.
- BETTENSTAEDT, FRANZ. Die stratigraphische Bedeutung Phylogenetischer Reihen in der Mikropaläontologie.—Geol. Rundschau, Stuttgart, Band 49, heft 1, 1960, p. 51-69, text figs. 1, 2 (range chart, graph).—Examples used are a group of selected species from the Lower Cretaceous having widely variable abundance throughout their ranges, and evolution of shape in *Bolivinooides decorata* through the upper Campanian.
- BIZON, G., and BIZON, J. J. A propos de *Choffatella occulta* Bach 1959.—Revue de Micropaléontologie, v. 3, No. 3, Dec. 1960, p. 143.—The species belongs in *Trochammina*.
- BLANC, JEAN-J. Observations sur la microfaune du Pliocene et du Quaternaire de Milazzo (Sicile)—Bull. Mus. Hist. Nat. Marseille, tome 18, Ann. 1958, p. 21-31, text figs. 1, 2 (geol. section, graphs).—A deep (300-400 meters) Pliocene fauna and a shallow (few to 45 meters) Quaternary fauna are listed.
- BOLLI, HANS M. *Bireophax*, a new genus of the foraminiferal family Reophacidae.—Eclogae Geol. Helvetiae, v. 53, No. 2, 1960 (Jan. 31, 1961), p. 493-496, pl. 1.—*Bireophax guaricoensis* n. gen., n. sp., a bifurcating *Reophax* from the Cretaceous of Venezuela.
- BORSETTI, ANNA MARIA. Tre nuovi Foraminiferi planctonici dell'Oligocene Piacentino.—Giornale Geol., Ann. Mus. Geol. Bologna, ser. 2, v. 27, 1956-57 (1959), p. 205-212, pl. 1.—*Catapsydrax gortanii*, *C. venzoi*, and *Globoquadrina sellii* from lower Oligocene beds.
- CARALP, MICHELLE, JULIUS, CHARLES, and VINGNEAUX, MICHEL. Considérations sur le miocène inférieur aquitain.—Mitteil. Geol. Gesellschaft Wien, Band 52, 1959 (Dec. 1960), p. 49-66, text fig. 1 (map), distrib. table.—Smaller Foraminifera are listed from 7 sections across an area transitional from a littoral facies (the Aquitanian and Burdigalian) to a deeper-water facies (the Girondian of equivalent age).
- CARLOS, ABELARDO G. A preliminary study on the size variation of Pliocene Foraminifera from Mindoro.—The Philippine Geologist, v. 14, No. 3, Sept. 1960, p. 81-86, pl. 4, text fig. 1 (graph), table 1.—Possibility of bathymetric zonation by size of specimens appears promising. Seven planktonic and 3 benthonic species were measured from previously determined middle and lower bathyal zones, 9 samples from the former and 12 from the latter. Specimens from the deeper zone were larger.
- CHALILOV, D. M. Novye Vidy *Asterigerina* iz Verkhnehothenovnykh Otlozhenij Azerbaidzhana.—Baku. Akad. Nauk Azerbaidzhan. SSR, Izvestiia, No. 5, 1960, p. 43-54, pls. 1-3.—Five new species, 2 with new varieties, described from upper Eocene.
- Danian stage Azerbaidzhan (English summary of Russian text).—Internat. Geol. Congress, 21st Sess., Rept. Soviet Geologists, Problem 5, The Cretaceous-Tertiary Boundary, Moscow, 1960, p. 139-147, text fig. 1 (map), distrib. table.—Occurrence and abundance in several regions are listed for 55 species.
- CHIJI, MANZO. Microbiostratigraphy of the Neogene formation in the "Nadaura" district, Toyama Pre-

- fecture, Japan (in Japanese with English abstract).—Bull. Osaka Mus. Nat. Hist., No. 12, March 1960, p. 63-95, text figs. 1-3 (maps, section), distrib. tables.—Six zonules based on smaller Foraminifera are recognized, and the distribution and abundance of many species are shown.
- CHISAKA, TAKESHI. On some Permian Fusulinids from the Takagami Conglomerate, Choshi Peninsula, Chiba Prefecture, Japan.—Journ. College Arts Sci., Chiba Univ., v. 3, No. 2, August 1960, p. 235-254, pls. 1-9, text fig. 1 (map), tables 1-16.—Fourteen species, 4 new and 3 indeterminate.
- CICHA, IVAN, and DORNIC, JAN. Die Entwicklung des Miozäns der Boskowitz Furche zwischen Tisnov und Usti nad Orlici (German summary of Czeck text).—Ustred. Ustavu Geol., Sbornik, v. 26, pt. 1, 1959 (1960), p. 393-434, pls. 1-14, 1 geol. section.—Photographs of small Foraminifera assemblages.
- CLOSS, DARCY, and COSTA BARBERENA, MARIO. Foraminiferos recientes da Praia do Cassino (Rio Grande, R. G. S.).—Escola de Geol., Univ. Rio Grande do Sul, Bol. No. 5, 1960, p. 1-29, pls. 1-3, text figs. 1, 2 (maps).—Beach fauna consisting of 21 species, subspecies, and forma, none new. *Elphidium* predominates.
- Foraminiferos Recentes da Praia da Barra, Salvador, Bahia.—Escola de Geol., Univ. Rio Grande do Sul, Bol. No. 6, 1960, p. 1-50, pls. 1-7, text figs. 1, 2 (maps).—A beach fauna consisting of 43 species, varieties, and forma (the forma new) and having West Indian affinities. Miliolidae and Peneroplidae predominate.
- COLE, W. STORRS. Names of and variation in certain Indo-Pacific camerinids—No. 2. A reply.—Bull. Amer. Pal., v. 43, No. 195, Jan. 16, 1961, p. 107-128, pls. 14-16.—Additional illustrations and discussion of evidence indicating that species have been too much subdivided along lines of variation and that there are only 3 species, *Camerina ammonoides*, *C. complanata*, and *C. venosa*.
- Upper Eocene and Oligocene larger Foraminifera from Viti Levu, Fiji.—U. S. Geol. Survey Prof. Paper 374-A, 1960 (Feb. 27, 1961), p. A1-A7, pls. 1-3, text fig. 1 (map), table 1.—First records of pre-Miocene in Viti Levu. Eight species are from upper Eocene (Tertiary b) and 3 (1 indeterminate) from Oligocene (Tertiary c); most are illustrated.
- COLOM, GUILLERMO. in collaboration with JOSÉ MARIA OLIVEROS and BARTOLOMÉ ESCANDELL in five papers in the volume "Temas Geológicos de Mallorca".—Mem. Instit. Geol. Min. España, tome 61, 1960, p. 1-407, illust.—Foraminifera recorded and some illustrated from Mallorca in (a) Ludian-lower Stampian lacustrine deposits with lignite, (b) upper Oligocene (continental lacustrine Aquitanian), (c) upper Burdigalian brackish-lacustrine deposits, and (d) post-Burdigalian deposits.
- CRESPIN, IRENE. Upper Devonian Foraminifera from Western Australia.—Palaeontology, v. 3, pt. 4, March 1961, p. 397-409, pls. 64-67, text fig. 1 (map).—Ten species (8 new and 2 indeterminate) are the first Devonian Foraminifera in Australia.
- DURAND DELGA, MICHEL, and MAGNÉ, JEAN. Une coupe du Tertiaire prébélique de Benitachell (prov. d'Alicante, Espagne).—Bull. Soc. Géol. France, ser. 7, tome 2, No. 3, 1960 (Feb. 1961), p. 302-307, table 1 (distrib. and abund.).—Species of an upper Oligocene globigerine facies are listed.
- DUSENBURY, A. N., JR. Revision of the microfauna described from the Cretaceous metamorphics in Quebrada Yaguapa, eastern Miranda.—Asoc. Venez. Geol., Min. y Petrol., Bol. Informativo, v. 3, No. 11, Nov. 1960, p. 316-317.—Additional thin sections reveal that all the previously reported Foraminifera were misidentified pyrite spherules, mud lumps, or unidentified radiolaria.
- ECKERT, RUEDI. Reinigungs- und Anreicherungsversuche an Kleinforaminiferen.—Eclogae Geol. Helvetiae, v. 53, No. 2, 1960 (Jan. 31, 1961), p. 645-648, text fig. 1 (diagram).—On cleaning and concentration.
- ELLERMANN, CLARA. Foraminiferen aus dem Oligozän des Schachtes Kapellen (Niederrhein) mit Variationsstatistik von *Elphidium subnodosum* Roemer.—Geol. Jahrb., Band 77, Oct. 1960, p. 645-709, pls. 51-56, text figs. 1-10 (map, graphs).—About 130 species are reported from well samples; some are illustrated. Two subspecies are new. Statistical analysis of variation reveals a separation into two subspecies of *Elphidium subnodosum*.
- EREMEEVA, A. I. Nekotorye Novye Vidy Foraminifer iz Melovykh i Tretichnykh Otlozhenij Vostochnogo Sklona Urala.—Akad. Nauk SSSR, Ural. fil., Sverdlovsk, Gorno-geol. instit., Trudy, vyp. 28, No. 4, 1957, p. 9-15, pl. 1.—Seven species (3 new and 3 new names) and 2 new varieties from Upper Cretaceous, Paleocene, and upper Eocene.
- ERICSON, DAVID B., EWING, MAURICE, WOLLIN, GOESTA, and HEEZEN, BRUCE C. Atlantic deep-sea sediment cores.—Geol. Soc. America Bull., v. 72, No. 2, Feb. 1961, p. 193-285, pls. 1-3, text figs. 1-50 (maps, diagrams, graphs), tables 1-6.—A summary of evidence bearing on processes and rates of sedimentation, Pleistocene chronology, and pre-Pleistocene history of the Atlantic Basin that has been derived from study of the lithology, particle-size distribution, and micropaleontology of 221 cores ranging in length from 35 to 1,275 cm. In 41 cores pre-Pleistocene sediments were penetrated and their ages determined by means of Foraminifera and discoasters, the oldest sediment penetrated being Late Cretaceous. Where undisturbed through catastrophic deposition by turbidity currents, six zones (u to z) are recognized in cold-warm alternations extending from the last interglacial period (beginning about 235,000 years ago) to the present (the post-glacial period beginning about 11,000 years ago). The interglacial, interstadial, and post-glacial zones (v, x, and z) are recognized by assemblages essentially similar to those now living in the superjacent waters while the glacial zones (u, w, and y) are characterized by dominance of species now abundant only in higher latitudes. Zone x (interstadial warmer period during last glaciation) is characterized by abundant *Globorotalia menardii flexuosa* (Koch), which appears to have become extinct during the last glacial stage. In the post-glacial layers (zone z) *G. menardii menardii* (d'Orbigny) and *G. menardii tumida* (Brady) occur together with a bimodal distribution. Sedimentation on the nearly level tops of isolated rises is most likely to be uninterrupted slow particle-by-particle accumulation. Proof of unbroken climatic record may be had by means of layer-by-layer correlation between cores from widely separated stations within the same oceanographic province.
- GRIGELIS, A. A. Age and microfauna of transition layers between the Cretaceous and the Paleogene in southern Baltics (English summary of Russian text).—Internat. Geol. Congress, 21st Sess., Rept. Soviet Geologists, Problem 5, The Cretaceous-Tertiary Boundary, Moscow, 1960, p. 101-104.—Age of transition beds in southwest Lithuania determined by Foraminifera to be early Paleocene.

- HERMES, J. J. A simplified method for cleaning Foraminifera.—*Revue de Micropaléontologie*, v. 3, No. 3, December 1960, p. 155-156.
- HERRICK, S. M. Some small Foraminifera from Shell Bluff, Georgia.—*Bull. Amer. Pal.*, v. 41, No. 187, May 6, 1960, p. 113-130, pls. 14-16, text fig. 1 (map).—Twenty species and subspecies, none new, are recorded and illustrated from this outcrop of late Eocene or younger age.
- HO YEN. On a new species of *Boultonia*.—*Acta Palaeontologica Sinica*, v. 4, No. 1, 1956, p. 64-66, pl. 1.
- HOFKER, JAN. Foraminiferen aus dem Golf von Neapel.—*Paläont. Zeitschr.*, Band 34, Nr. 3/4, Nov. 1960, p. 233-262, text figs. 1-6; figs. 7-184 on fold-out pls. A-F.—About 135 species (none new) recorded and illustrated from 34 samples between strand and 250 meters.
- The gens *Globigerina cretacea* in northwestern Europe.—*Micropaleontology*, v. 7, No. 1, Jan. 1961, p. 95-100, pl. 1, diagrams 1, 2.—The evolution of a single biological unit beginning in the Aptian-Albian as *Praeglobotruncana infracretacea* (Glaessner) and extending into the Maestrichtian as aberrant forms called *Rugoglobigerina rugosa* (Plummer), is illustrated by specimens and statistical diagrams.
- HULME, S. G. A mechanized method of breaking down and washing foraminiferal rock samples.—*Micropaleontology*, v. 7, No. 1, Jan. 1961, p. 107-113, text figs. 1-10.
- JANISZEWSKA-PACTWA, HALINA. Foraminiferal assemblage from the *Pleurotoma* clays at Karsy near Jędrzejów (in Polish with English summary).—*Ann. Soc. Géol. Pologne*, v. 30, fasc. 3, 1960, p. 327-332.—A listed fauna of 67 species indicates a Miocene (possibly lower Tortonian) age and deposition in warm shallow waters.
- JURKIEWICZ, HENRYK. Foraminifera in Czarnorzeki-shales in the eastern part of the Silesian Unit (Carpathians) (in Polish with English summary).—*Ann. Soc. Géol. Pologne*, v. 30, fasc. 3, 1960, p. 333-343, pl. 37, text fig. 1 (columnar sections), table 1.—Paleocene age is based on listed fauna of 55 species (1 described as new).
- KAEVER, MATTHIAS. Biostratigraphische Auswertung der Windungsrichtung von Foraminiferen.—*Geol. Jahrb.*, Band 77, Dec. 1960, p. 821-832, text figs. 1-3, tables 1-3.—Regarding coiling direction of *Globorotalites* in well samples between middle Turonian and upper Campanian, and the possibility of an indirect relationship with ecology.
- KAHLER, FRANZ. Der Wert der Fusuliniden für stratigraphische Vergleiche auf Grosse Entfernungen.—*Geol. Rundschau*, Stuttgart, Band 49, heft 1, 1960, p. 92-97, text figs. 1, 2 (maps).—Long-distance and intercontinental correlation by fusulinids.
- KANDINOV, N. N., and IVANOVA, V. A. Stratigrafija Paleogena Juzhnogo Priaral'ja.—*Glavgaz pri Sovete Ministrov SSSR, Sojuznaja geol. Kontora (SGPK), Trudy*, vyp. 1, 1960, p. 54-84, text figs. 1, 2 (map, columnar section), range table.—Ranges between Paleocene and Oligocene are shown for over 150 species.
- KAPTARENKO-CHERNOUSOVA, O. K. Jurs'ki Liagenidi Pivnichno-Skhidnoj Chastini Ukrain'skoj RSR.—*Akad. Nauk Ukrain. RSR, Kiev, Instyt. geol. Nauk Trudy*, ser. strat. i paleo., vyp. 22, 1960, p. 1-103, pls. 1-10, text figs. 1-5.—Illustrated catalog includes 91 species (11 new) and 1 new variety of Jurassic liagenids.
- KENNARD, M. C., and SMITH, ALEC J. A simple micro-sample splitter.—*Jour. Paleontology*, v. 35, No. 2, March 1961, p. 396-397, text figs. 1, 2.—Standard petrological microscope slides set at right angles in alternating series with openings equal to thickness of slides.
- KIRK, H. J. C. Progress report on the Semporna Peninsula Survey; Memoir 14.—*Borneo, British, Geol. Survey Dept., Ann. Rept. for 1959, 1960*, p. 182-195, pls. 41-46, text fig. 26 (map), tables 22.—Foraminifera, mostly planktonics and orbitoids, are listed from Eocene, Oligocene?, and Miocene beds.
- DE KLASZ, I., MARIE, P., and MEIJER, M. *Gabonella* nov. gen., un nouveau genre de Foraminifères du Crétacé Supérieur et du Tertiaire basal de l'Afrique Occidentale.—*Revue de Micropaléontologie*, v. 3, No. 3, Dec. 1960, p. 167-182, pls. 1, 2, maps, range charts.—Eight species and 1 subspecies are described by de Klasz and Meijer from Gabon and Angola and 6 species are described by Marie from Morocco. All are new and are included in *Gabonella* (genotype *G. elongata* n. sp.) which belongs in the Heterohelicidae.
- KLAUS, JEAN. La répartition stratigraphique des Globotruncanidés au Turonien et au Coniacien.—*Eclogae Geol. Helvetiae*, v. 53, No. 2, 1960 (Jan. 31, 1961), p. 694-704, text fig. 1 (range chart).—Ranges in Tunisia and Switzerland are compared.
- Rotalipores et Thalmanninellen d'un niveau des Couches rouges de l'Anticlinale d'Aï.—*Eclogae Geol. Helvetiae*, v. 53, No. 2, 1960 (Jan. 31, 1961), p. 704-709, 1 pl.—Five species illustrated.
- Sur quelques *Globorotalia* isolées dans les Couches rouges des Préalpes médianes.—*Eclogae Geol. Helvetiae*, v. 53, No. 2, 1960 (Jan. 31, 1961), p. 709-715, 1 pl.—Five species illustrated from Danian-lower Paleocene.
- KOPEK, G., and KECSKEMETI, T. Gliederung des Bakonyer Eozäns auf Grund von Grossforaminiferen (German summary of Hungarian text).—*Földtani Közlöny*, Bull. Hungarian Geol. Soc., v. 90, pt. 4, Oct-Dec. 1960, p. 442-455, text figs. 1-4 (graphs), table 1.—Changes in percent of total population are graphically shown for many species of larger Foraminifera (mostly nummulites and discocyclinids) in 8 horizons between Ypresian and Bartonian.
- KRISTAN-TOLLMAN, EDITH. Rotaliidea (Foraminifera) aus der Trias der Ostalpen.—*Jb. Geol. B. A., Sonderband 5*, Nov. 1960, p. 47-78, pls. 7-21, text figs. 1, 2.—Descriptions and illustrations of 17 species, all new, placed in 6 genera, all new, as follows: *Variostoma* nov. gen. (genotype *V. spinosum* nov. spec.), *Diplotremina* nov. gen. (genotype *D. astrofimbriata* nov. spec.), *Duostomina* nov. gen. (genotype *D. biconvexa* nov. spec.), *Plagiostomella* nov. gen. (genotype *P. inflata* nov. spec.), *Asymmetrina* nov. gen. (genotype *A. biomphalica* nov. spec.), and *Involvina* nov. gen. (genotype *I. obliqua* nov. spec.). The first three mentioned genera are placed in the subfamily Discorbinae and the last three in the Anomaliniinae.
- KÜPPER, INGE. Konservierung von Foraminiferen mit Nitrolack.—*Verhandl. Austria Geol. Bundes.*, 1960, heft 2, p. 252-253.
- LE CALVEZ, JEAN, and LE CALVEZ, YOLANDE. Répartition des Foraminifères dans la Baie de Villefranche. I.—*Miliolidae*.—*Ann. Institut. Océanographique*, n. ser., tome 35, fasc. 3, July 5, 1958, p. 159-234, pls. 3-16, text figs. 1-5 (maps, graphs), tables 1-5.—Systematic catalog includes 91 species and varieties; 7 species and 2 varieties new and 6 given new names. Quantitative analysis of 30 samples in 3 groupings (*Posidonia* grass, coastal muds, and deep muds) from

- depths between 5 and 700 meters. Restricted depth ranges are indicated for about 60 of the species.
- LE CALVEZ, YOLANDE. Les Foraminifères de la Mer Celtique.—Rev. Trav. Inst. Pêches marit., v. 22, No. 2, 1958, p. 147-209, pls. 1-3, map, distrib. table.—Systematic catalog includes about 140 species and varieties (2 new). Study is based on 19 bottom samples from around Brittany and south of the British Isles taken from depths between 15 and 210 meters.
- LINARES, ASUNCION. Données micropaléontologiques sur les environs de Domingo-Pérez (chaîne subbétique, prov. de Grenade, Espagne).—Bull. Soc. Géol. France, ser. 7, tome 2, No. 3, 1960 (Feb. 1961), p. 322-323.—Lists of species from Upper Cretaceous, Eocene, and Miocene.
- LOEBLICH, ALFRED R., JR., and TAPPAN, HELEN. *Saedeleeria*, new genus of the family Allogromiidae (Foraminifera).—Proc. Biol. Soc. Washington, v. 73, Dec. 30, 1960, p. 195-196.—For *Gromia gemma* Penard 1889 formerly included in *Diplogromia* Rumbler 1904.
- Suprageneric classification of the Rhizopodea.—Jour. Paleontology, v. 35, No. 2, March 1961, p. 245-330.—Eight new subfamilies of Foraminifera are proposed, and 4 new subfamily names. Many others are corrected or changed in rank. Three new generic names are proposed to replace homonyms in the Foraminifera.
- MAJZON, L. The Hantkeninae of Hungary (English summary of Hungarian text).—Földtani Közlöny, Bull. Hungarian Geol. Soc., v. 90, pt. 4, Oct.-Dec. 1960, p. 428-441, pls. 22-24.—Several species illustrated and used in correlation.
- MALAKHOVA, N. P. Nekotorye Novye Vidy Foraminifer iz Nizhnokamennougol'nykh Otlozhenij Urala.—Akad. Nauk SSSR, Ural. fil., Sverdlovsk, Gorno-geol. instit., Trudy, vyp. 28, No. 4, 1957, p. 3-8, pls. 1, 2.—Ten species, 8 new and 1 indeterminate, from Lower Carboniferous of the Urals.
- MANDWAL, N. K. Smaller Foraminifera from the Subathu beds (Eocene) near Dharampur, Simla Hills.—Geol. Soc. India Jour., v. 1, 1959, p. 156-166, text figs. 1, 2, (pls.).—Twenty-one species and varieties, 10 indeterminate, recorded and illustrated.
- MANGIN, JEAN PHILIPPE. Le Nummulitique Sud-Pyreneen a l'ouest de l'Aragon.—Pirineos, Rev. Instit. Estudios Pirenaicos, Zaragoza, Num. 51-58, 1959-1960, 631 p., pls. a-s, 113 text figs., map, geol. sections.—Two faunas composed predominantly of alveolines, nummulites, orbitoids, and planktonics (from the lower Eocene and the middle to upper Eocene) are recorded with a few species illustrated in section. Described as new are *Operculina pseudoheberti* and *Planorbulina antiqua* from the lower Eocene.
- MAYNC, WOLF. Morphology and occurrence of the foraminiferal genus *Orbitopsella*.—Riv. Ital. Pal. Stratig., v. 66, No. 4, 1960, p. 491-525, pls. 44-49, text figs. 1-4 (outline drawings, map).—Illustrations and records of occurrence of this Liassic genus on the carbonate shelf of the Tethys region. Two species, one new.
- Remarks on the foraminiferal genus *Sornayina*.—Eclogae Geol. Helvetiae, v. 53, No. 2, 1960 (Jan. 31, 1961), p. 497-500, pl. 1.—The 3 coexisting species are combined as one species showing trimorphism.
- MILIZINA, V. S. Stratigraphy of the Danian stage in the Southembian region on the basis of the fauna of foraminifers (English summary of Russian text).—Internat. Geol. Congress, 21st Sess., Rept. Soviet Geologists, Problem 5, The Cretaceous-Tertiary Boundary, Moscow, 1960, p. 162-169.—The Cretaceous-Tertiary boundary is placed at the base of the **Globobulimina crassata** zone, which zone overlies the Danian stage with traces of erosion. The Danian, placed in the Cretaceous, is divisible into lower and upper horizons on the basis of Foraminifera.
- MORIKAWA, ROKURO. Fusulinids from the Iwaizaki Limestone.—Sci. Repts. Saitama Univ., ser. B (Biol. and Earth Sci.), v. 3, No. 3, 1960, p. 273-299, pls. 46-53, text figs. 1-3 (map, stratig. section, microphotograph), tables 1-16.—Eighteen species, 9 new.
- MORIKAWA, ROKURO, and ISOMI, HIROSHI. A new genus, **Biwaella**, *Schwagerina*-like **Schubertella**.—Sci. Repts. Saitama Univ., ser. B (Biol. and Earth Sci.), v. 3, No. 3, 1960, p. 301-305, pl. 54, table 1.—Type species, **B. omiensis** n. sp.
- MORIKAWA, ROKURO, and KOBAYASHI, NORIO. Two new species of **Oketaella** from Kanto Massif, Japan.—Sci. Repts. Saitama Univ., ser. B (Biol. and Earth Sci.), v. 3, No. 3, 1960, p. 307-312, pl. 55, tables 1-3.
- MOROZOVA, V. G. Stratigraphical zonation of Danian-Montian deposits in the USSR and the Cretaceous-Paleogene boundary (English summary of Russian text).—Internat. Geol. Congress, 21st Sess., Rept. Soviet Geologists, Problem 5, The Cretaceous-Tertiary Boundary, Moscow, 1960, p. 83-100, correl. table.—Evidence of the planktonic Foraminifera supports the placement of Danian as the lower unit of the Paleogene. The Maestrichtian-Danian boundary is marked by the disappearance of Globotruncanidae, Rugoglobigerinidae, striate **Gümbelina**, and other highly specialized forms, and by the first appearance of the subgenus **Eoglobigerina** (smooth-shelled Globigerinidae).
- MOULLADE, M. Les Orbitolinidae des microfaciès Barremiens de la Drôme.—Revue de Micropaléontologie, v. 3, No. 3, Dec. 1960, p. 188-198, pls. 1-3.—Five species (3 new) and 1 new subspecies are described and illustrated.
- NARCHI, WALTER. Reencontro de **Carpenteria** no Brasil (Foraminifera).—Anais Acad. Brasil. Ciencias, v. 32, Nos. 3/4, Dec. 31, 1960, p. 391-394, pl. 1.—Two species from the continental shelf of Brazil, one new.
- D'ONOFRIO, SARA. Foraminiferi di una carota sotto marina del medio Adriatico.—Giornale Geol., Ann. Mus. Geol. Bologna, ser. 2, v. 27, 1956-57 (1959), p. 147-194, pls. 1, 2, 1 distrib. table.—Quantitative analysis of a 579-cm. submarine core reveals 2 climatic periods colder than present. Ninety-two species and subspecies are recorded and some illustrated; one new.
- PAPP, A. Beobachtungen in den eozanen Kalk- und Flyschsedimenten, in Beobachtungen im Flysch von Triest.—Verhandl. Austria Geol. Bundes., 1960, heft 2, p. 174-179, text fig. 3 (outline drawings).—Nummulites.
- PAPULOV, G. N., and KYPRIANOVA, F. V. Danian stage of the eastern slope of the Urals and of Transurals (English summary of Russian text).—Internat. Geol. Congress, 21st Sess., Rept. Soviet Geologists, Problem 5, The Cretaceous-Tertiary Boundary, Moscow, 1960, p. 170-180, diagram, table 1.—Foraminifera of the Danian deposits are more similar to those of the Maestrichtian than the Paleogene.
- PETROVIC, MIODRAG V. Beitrag zur Kenntnis der Torton-Sarmat Foraminiferen von Tuzla und ihrer engeren Umgebung (German summary of Serbian text).—Ann. Geol. Penin. Balkan., tome 26, 1959, p. 195-201, pls. 1, 2, text fig. 1 (map), 1 range and abund. chart.—Range and abundance shown for about 75 species; many illustrated.
- PREMOLI SILVA, I. Le Buliminidae del Langhiano delle Langhe.—Riv. Ital. Pal. Stratig., v. 66, No. 4,

- 1960, p. 551-589, pls. 53-56, text figs. 1-3 (columnar sections, distrib. charts).—Illustrations, descriptions, and occurrences of 27 species and varieties, none new, in two Miocene sections.
- PREY, S. Zu den Kleinforaminiferen der untersuchten Profile des Flysches von Triest, in Beobachtungen im Flysch von Triest.—Verhandl. Austria Geol. Bundes., 1960, heft 2, p. 179-182.—Middle Eocene age is indicated.
- PROTO DECIMA, FRANCA. Nuova specie di *Bolivina* nel Tortoniano del Veneto.—Atti Accad. Naz. Lincei Rend., Cl. sci. fis. mat. nat., v. 28, fasc. 6, June 1960, p. 889-892, 1 pl.—*Bolivina ferasinii*.
- ROMPF, IRENE. Foraminiferen aus dem Cenoman von Sachsen, unter besonderer Berücksichtigung der Umgebung von Dresden.—Freiberger Forschungshefte, No. C89, Oct. 1960, p. 5-123, pls. 1-22, text figs. 1-7 (map, geol. section, columnar sections, graphs), table 1, distrib. table.—About 124 species, 33 with open nomenclature, none described as new.
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