amorphous SiO_2 are added to the envelope of the device to enhance its structural strength; they comprise 20 to 30 percent of the envelope. Before we received this information (from E. Frisch, Dow Corning Company, Midland, Mich.), we had noted that the envelope gave consistently higher Si counts per second (cps) than did the contained gel. Typical Si counting rates were 1480 ± 20 cps in the gel and 1520 ± 30 cps in the envelope. We did not feel that this apparent difference in silicon volume was due to packing density alone and hypothesized the presence of another silicon-containing compound to explain the difference in the Si contribution to formula weight (37.9 percent at 1480 cps compared to 39.11 percent at 1520 cps).

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Cretaceous Bivalve Larvae

Abstract. *Exceptionally well preserved larval bivalve shells have been isolated from Late Cretaceous (Maestrichtian) sediments. Specimens were readily identified to familial level on the basis of gross morphology and hinge structures. Reconstruction of fossil larval ontogeny, linked with the distribution of adult stages, will provide an important interpretative tool in molluskan phylogenetic and paleoecologic studies.*

Identification of bivalve larvae has been the subject of biological research for over a century (*1*). Despite the paleontological implications of diagnostic larval shell characters, studies to date have dealt almost exclusively with extant species. Larval shells are small and fragile, and, in ancient sediments, have generally been assumed to have been destroyed mechanically or by chemical dissolution. In a pathfinding study, LaBarbera (*2*) described the larval and postlarval development of five species of "Miocene" bivalves (*3*), but his specimens were obtained from sediment retained on a 500-μm diagonal mesh screen. Accordingly, his descriptions of larval ontogeny were based predominantly on prodissoconch characteristics observed on the surface of ontogenetically metamorphosed juveniles; postmetamorphic growth obscured primary larval dentition in the majority of specimens examined. In the present study, disarticulated Cretaceous larval bivalve shells have been isolated from the 125- to 500-μm sediment fraction and identified to familial level on the basis of gross morphology and hinge structures.

In searching for juvenile fossil mollusks, collections were made at a number of Late Cretaceous localities exhibiting unusually good preservation of fossil material (*4*). Bulk samples from the Monmouth Formation (Maestrichtian) near Brightseat, Maryland (*5*), were wet-sieved through a standard Udden-Wentworth sieve series, and the 125- and 250-μm fractions were examined with a dissecting microscope (×50). Larval and early postmetamorphic bivalve shells were removed from the sample with a fine brush (*6*) and carefully mounted on copper conducting tape. Specimens were subsequently coated with gold-palladium (approximately 200 Å thick) in a Polaron diode sputtering system and examined with a scanning electron microscope (ETEC Autoscan).

Cretaceous larval shells, once isolated, have proved to be more than adequately well preserved for identification. The bivalve larval characteristics most useful in routine plankton identifications have been shell length, height, and depth, as well as length of the prodissoconch I hinge line (*1*, *7*–*9*). Rees (*10*) discusses at length the usefulness of larval hinge structures in identification studies for superfamilial separation. More recently, workers have used both optical and scanning electron microscopy to describe in detail the hinge structures of several bivalves and have suggested that such structures may be diagnostic at the generic or even specific level (*11*, *12*). These diagnostic larval shell characters have been found to be extremely well preserved in fossil specimens. For example, the Cretaceous larval shell in Fig. 1, A to C, may be placed in the family Pholadidae on the basis of (i) characteristic pholadacean larval hinge apparatus (*10*, *12*); (ii) height approximately equal to length; (iii) relatively prominent "knobby" umbo [in the sense of Chanley and Andrews (*7*)]; and (iv) broad, flattened internal shell margin (*7*, *12*). Other specimens, such as larval mytilids (Fig. 1D), may be unambiguously identified at the familial level on the basis of hinge structure alone (*10*, *13*). Well-pre-

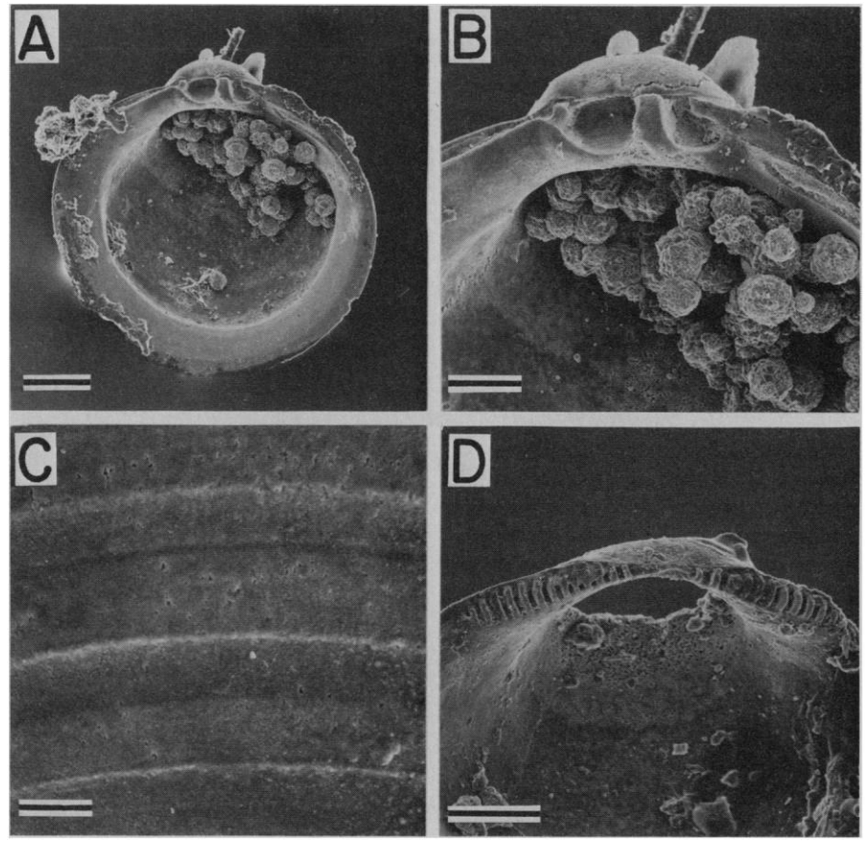

Fig. 1. Scanning electron micrographs. (A) Disarticulated shell valve of a Cretaceous bivalve larva from the Monmouth Formation near Brightseat, Maryland. Larval dentition, length by height (195 by 195 μm) relation, and umbonal shape are characteristic of the family Pholadidae. Framboidal pyrite is seen partially filling shell interior (scale, 40 μm). (B) Enlargement of hinge apparatus of larval valve seen in (A) showing characteristic pholadacean dentition (scale, 20 μm). (C) External shell surface of larval pholad seen in (A). Note fine concentric sculpture (scale, 5 μm). (D) Hinge apparatus (provinculum) of a Cretaceous larval mytilid (shell length, 190 μm) from the Monmouth Formation (scale, 30 μm).

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served external larval shell sculpture, which appears to be of taxonomic significance in certain Recent species (*8, 9*), may also be helpful in the study of fossil forms (Fig. 1C). Detailed examination of sequential growth series from single localities or horizons will permit generic or even specific identification of numerous larval bivalves (*14*) and should be of assistance in phylogenetic studies. The Late Mesozoic was marked by a spectacular bivalve radiation (*15*), and Cretaceous growth series will give insight into the ancestral larval morphologies and hence the relationships between some of the major families of heterodont eulamellibranchs. In addition, it will be possible to test Kauffman's suggestion (*16*) that the vulnerability of certain benthic groups to massive extinction at the end of the Late Cretaceous may be traced to their planktotrophic larval stages. Nonplanktotrophic groups (*17*) might be expected to be relatively unaffected by the Cretaceous-Tertiary boundary event.

Kauffman (*18*) and Scheltema (*19*) have stressed the significant role that pelagic dispersal must have played in shaping bivalve paleobiogeography, particularly in the light of shifting paleocontinental configurations. It appears that an ontogenetic history is available for at least some fossil species. The interpretation of these fossil larvae, linked with the distribution of the adult stages, will be an important step in our understanding of molluskan paleodistributions.

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References and Notes

1. S. Loven, *K. Sven. Vetenskapsacad. Handl.* **4**, 299 (1848); N. H. Odhner, *Zool. Anz.* **44**, 156 (1914); M. V. Lebour, *J. Mar. Biol. Assoc. U.K.* **23**, 119 (1938); B. Werner, *Zool. Jahrb. Abt. Anat. Ontog. Tiere* **66**, 1 (1939); C. B. Jørgensen, *Medd. Dan. Fisk. Havunders.* **4**, 277 (1946); C. M. Sullivan, *Bull. Fish. Res. Board Can.* **77**, 1 (1948); K. A. Zakhvatkina, *Trudy Sevastop. Biol. Stn. Akad. Nauk Ukr. SSR* **11**, 108 (1959); I. Miyazaki, *Jpn. Soc. Sci. Fish. Bull.* **28**, 955 (1962); G. E. Newell and R. C. Newell, *Marine Plankton: A Practical Guide* (Hutchinson Educational Ltd., London, 1963); V. L. Loosanoff and H. C. Davis, in *Advances in Marine Biology*, F. S. Russell, Ed. (Academic Press, London, 1963), vol. 1, p. 1; ——, P. E. Chanley, *Malacologia* **4**, 351 (1966).
2. M. LaBarbera, *J. Paleontol.* **48**, 265 (1974).
3. P. Huddleston [personal communication, cited in (*2*)] has suggested that LaBarbera's material came from sediments of Middle Pliocene, rather than Miocene, age.
4. The clayey silt-fine sands of the Ripley Formation of Mississippi and Georgia, the Owl Creek Formation of Mississippi, the Coon Creek Formation of Tennessee, and the Monmouth Formation of Maryland appear to protect original aragonitic and calcitic shells from groundwater dissolution or recrystallization (or both). All of these horizons thus produce an unusually complete record of the carbonate-secreting fauna. S. Weiner, H. A. Lowenstam, and L. Hood [*Proc. Natl. Acad. Sci. U.S.A.* **73**, 2541 (1976)] have also examined mollusk shell proteins from the Coon Creek Formation.
5. W. B. Clark [in *Maryland Geological Survey, Upper Cretaceous* (Johns Hopkins Univ. Press, Baltimore, 1916), p. 23], J. Gardner (in *ibid.*, p. 371), and J. P. Owens *et al.* [*A Field Guide to Cretaceous and Lower Tertiary Beds of the Raritan and Salisbury Embayments, New Jersey, Delaware and Maryland* (American Association of Petroleum Geologists/Society of Economic Paleontologists and Mineralogists convention, Washington, D.C., 1977), p. 52] recently proposed that this massive clayey silty sand be renamed the Severn Foundation.
6. Larval shells were found at a density of roughly one specimen per cubic centimeter of sediment fraction.
7. P. Chanley and J. D. Andrews, *Malacologia* **11**, 45 (1971).
8. Various workers have also made extensive use of soft-part anatomical features beyond the reach of the paleontologist [R. D. Turner and P. J. Boyle, *Am. Malacol. Union Inc. Bull.* **1974**, 59 (1974)].
9. P. J. Boyle and R. D. Turner, *J. Exp. Mar. Biol. Ecol.* **22**, 55 (1976).
10. C. B. Rees, *Hull Bull. Mar. Ecol.* **3**, No. 19, 73 (1950).
11. E. Pascual, *Invest. Pesq.* **35**, 549 (1971); *ibid.* **36**, 297 (1972); M. Le Pennec, *Cah. Biol. Mar.* **15**, 475 (1974); M. LaBarbera, *Malacologia* **15**, 64 (1975); P. Dinamani, *J. Moll. Stud.* **42**, 95 (1976).
12. R. D. Turner and A. C. Johnson, *Annu. Rep. Am. Malac. Union Inc.* **1969**, 9 (1969); R. S. Scheltema, *Mar. Biol.* **11**, 5 (1971); J. L. Culliney and R. D. Turner, *Ophelia* **15**, 149 (1976); P. E. Chanley, *Chesapeake Sci.* **6**, 162 (1965).
13. For Recent larval mytilid hinge structure descriptions, see M. Le Pennec and M. Masson, *Cah. Biol. Mar.* **16**, 113 (1976); S. E. Siddall, *Proc. Natl. Shellfish. Assoc.*, in press; R. A. Lutz, *ibid.*, in press.
14. D. Jablonski and R. A. Lutz, in preparation.
15. S. M. Stanley, *J. Paleontol.* **42**, 214 (1968).
16. E. G. Kauffman, *ibid.* **51**, No. 2 (Suppl.), 16 (1977).
17. Criteria for distinguishing planktotrophic from nonplanktotrophic larval shells are discussed by LaBarbera (*2*) and references therein.
18. E. G. Kauffman, *Geol. Assoc. Can. Spec. Pap.* **13**, 163 (1975).
19. R. S. Scheltema, in *Concepts and Methods of Biostratigraphy*, E. G. Kauffman and J. E. Hazel, Eds. (Dowden, Hutchinson and Ross, Stroudsburg, Pa., 1977), p. 73.
20. We thank R. D. Turner for comments and aid in identification of larval shells; A. S. Pooley for technical assistance with the scanning electron microscopy; M. LaBarbera, R. D. Turner, D. C. Rhoads, E. G. Kauffman, T. R. Waller, and M. R. Carriker for reviews of the manuscript; and W. K. Sacco for his assistance with photographic reproductions. Supported in part by NOAA Sea Grant 04-7-158-44034 and a grant-in-aid of research from the Society of Sigma Xi. Contribution 109 from the Ira C. Darling Center, University of Maine, Walpole.

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Glutamine-Selective Membrane Electrode That Uses Living Bacterial Cells

Abstract. *A novel bioselective membrane electrode for* L-*glutamine has been constructed by coupling living bacteria of the strain* Sarcina flava *to a potentiometric ammonia gas sensor. Tests in aqueous standards and human serum show that the electrode combines excellent sensitivity and selectivity with rapid response and a useful lifetime of at least 2 weeks.*

The development of membrane electrode probes (*1*) for biological substances need not be limited to the use of immobilized enzymes as mediators between the material to be measured and the internal potentiometric sensor; indeed, an entire hierarchy of possible mediators, ranging from enzymes through immunoagents and intact vesicles, has recently been proposed (*2*). We describe here a novel membrane electrode probe which uses intact living bacterial cells in situ to produce a highly selective and sensitive potentiometric response to the amino acid L-glutamine in aqueous standards and in human serum. The bacterial electrode also shows a greatly improved lifetime over earlier potentiometric sensors (*3*) based on the unstable enzyme glutaminase (E.C. 3.5.1.2).

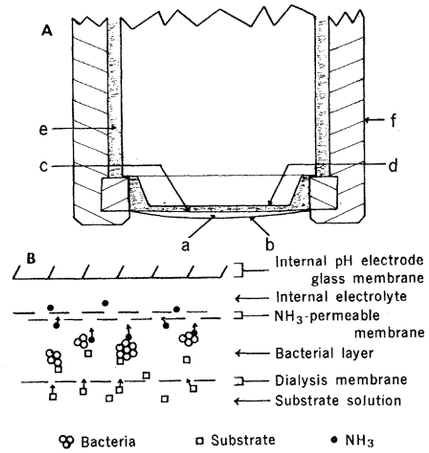

Fig. 1. (A) Schematic diagram of the bacterial electrode: *a*, bacterial layer; *b*, dialysis membrane; *c*, gas-permeable membrane; *d*, internal sensing element; *e*, internal filling solution; and *f*, plastic electrode body. (B) Detail of the membrane phases.

One prepares the glutamine electrode by holding a layer of whole cells of the bacterium *Sarcina flava* (American Type Culture Collection 147) at the surface of an ammonia-sensing membrane electrode (Orion 95-10) with a dialysis membrane, as shown in Fig. 1A. The bacteria are freshly grown on agar slants of nutrient broth at 30°C for 3 days, then harvested and washed by centrifugation in tris-HCl buffer (*p*H 7.5) containing 0.01 mole per liter of $MnCl_2$ as activator. No special sensitization or treatment of the bacteria is required.

Figure 1B illustrates in detail the vari-

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