# Climatic Implication of a Late Pleistocene Ostracode Assemblage from Southeastern Virginia

*By* PAGE C. VALENTINE

CONTRIBUTIONS TO PALEONTOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 683-D

*Determination of the inner sublittoral marine climate represented by the ostracode assemblage of the Norfolk Formation of southeastern Virginia, by a comparison of fossil and living ostracode assemblages*

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# CLIMATIC IMPLICATIONS OF A LATE PLEISTOCENE OSTRACODE ASSEMBLAGE FROM SOUTHEASTERN VIRGINIA[1]

By Page C. Valentine


## ABSTRACT

The Norfolk Formation, as used by Oaks and Coch (1963), (upper Pleistocene (Sangamon)) of southeastern Virginia contains a large and well-preserved ostracode assemblage—82 species, 70 of which are still living.

A comparison of the Norfolk ostracode assemblage with Holocene assemblages collected on the continental shelf off the middle Atlantic Coast of the United States indicates that no modern shelf assemblage is closely similar to that of the Norfolk Formation (which contains some forms that today are found only north or only south of Cape Hatteras). A cluster analysis of 91 samples containing 159 ostracode species from the continental shelf between about 32°30′N. and 40°N. reveals the existence of four major biofacies representing two faunal provinces. A study of the temperature tolerances of the species common to the Norfolk Formation and the Holocene indicates that the Norfolk assemblage lived in waters where the bottom temperature in the coldest month was 12.5°–15°C and in the warmest month 20°–22.5°C, a more equable marine climate than now prevails in the inner sublittoral off southeastern Virginia where minimum and maximum average monthly temperatures range from 5°–7.5° C to 22.5°–25° C, respectively. The late Pleistocene assemblage is indicative of a sublittoral faunal province and a warm-temperate climatic zone which do not exist today along the Atlantic Coast of the United States. At present, the convergence of cool- and warm-water masses at Cape Hatteras prevents reestablishment of a warm-temperature faunal province in this region.

Seventy-seven of the species constituting the latest Pleistocene assemblage are illustrated.


## INTRODUCTION

The purpose of this study is to determine the marine climate represented by the ostracode assemblage of the Norfolk Formation as used by Oaks and Coch (1963) (upper Pleistocene) of southeastern Virginia. The Norfolk ostracode assemblage is large and well preserved, and most species are still living in the sublittoral off the Atlantic Coast of the United States. The distributional ranges, temperature tolerances, and associations of these living species are used to infer marine climatic conditions under which the Pleistocene assemblage of southeastern Virginia lived.


## ACKNOWLEDGMENTS

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## PREVIOUS STUDIES

Most descriptive and distributional studies of ostracodes of the Atlantic continental shelf of North America have been restricted to the region from Long Island, N.Y., northward to the Arctic (see Hazel, 1970); only a few investigations of marine ostracodes occurring south of this region have been undertaken. Hulings (1966, 1967) described four new species and provided information on ostracode distribution for the shelf off Virginia and for the shelf and slope from Cape Hatteras, N.C., southward to Jupiter Inlet, Fla. Hazel and

[1] Contribution 2531 of the Woods Hole Oceanographic Institution, based on work done under a program conducted jointly by the U.S. Geological Survey and the Woods Hole Oceanographic Institution and financed by the U.S. Geological Survey.

Valentine (1969) described two new species occurring south of Long Island along the shelf break. Grossman (1967) studied the ecology of the ostracodes of Pamlico Sound, N.C., and described two new species. Benson (1967) listed 36 ostracode species from stations on a transect extending from Cape Lookout, N.C., to the shelf edge.

Hazel (1968) compared Holocene ostracode assemblages to those found in Pleistocene sediments dredged from submarine canyons off the eastern United States. Distributional ranges and temperature tolerances of Holocene species also found as fossils in the canyon sediments indicate that a climatic change and a corresponding northern shift of cold-temperate assemblages have occurred since the glacial-age Pleistocene sediments were deposited. To date there are no published studies of ostracode assemblages from Pleistocene sediments of the Atlantic Coastal Plain of the United States.

The following investigations of Holocene and fossil ostracode assemblages from the eastern and southern United States, the Caribbean Sea, the western and northern Atlantic Ocean, and northern Europe were used in identifying the species found during this study: Baird (1850); Benda and Puri (1962); Benson and Coleman (1963); Blake (1929, 1933); Bold (1946, 1963); Brady (1868a,b 1869, 1870, 1872); Brady, Crosskey, and Robertson (1874); Brady and Norman (1889); Cushman (1906); Darby (1965); Edwards (1944); Grossman (1967); Hall (1965); Hazel (1967a,b); Hazel and Valentine (1969); Howe and others (1935); Hulings (1966, 1967); Hulings and Puri (1964); King and Kornicker (1970); Maddocks (1969); Malkin (1953); McLean (1957, 1966); Morales (1966); Morkhoven (1963); Norman (1865); Plusquellec and Sandberg (1969); Pooser (1965); Puri (1952, 1953, 1958a,b, 1960); Puri and Hulings (1957); Sandberg (1964, 1969); Sars (1865); Stephenson (1938); Swain (1951, 1955); Triebel (1960); Ulrich and Bassler (1904); and Williams (1966).

## PLEISTOCENE COLLECTIONS

Pleistocene samples for this study were collected from blue-gray clayey and silty fine fossiliferous marine sands exposed in borrow pits in the Norfolk, Va., area (see figs. 1, 2, and Pleistocene locality data). Nine samples were processed from 6 localities, and 82 species were identified, of which only 42 have been formally described. Seventy of these species are represented in the Holocene. Ostracode carapaces and valves containing remnants of soft parts were found in all samples. The geographic location and species content of all samples are presented in table 1. Seventy-seven of the 82 Pleistocene species are illustrated on plates 1–4. Illustrated specimens have been deposited in the collections of the U.S. National Museum.

The borrow pits were opened to provide road fill during construction of interstate highways in the area. The pits from which samples were collected are now flooded, with the exception of locality P6 which was being worked in June 1970. Other pits in the area are open and being worked but are still too shallow to offer good exposures of fossiliferous Pleistocene sediments.

## PLEISTOCENE STRATIGRAPHY AND AGE OF THE NORFOLK FORMATION AS USED BY OAKS AND COCH (1963)

The coastal plain of Virginia is characterized by a series of gently eastward-sloping plains delineated by low scarps which trend generally north and south. Eastward from the Fall Line three major plains are separated by the Surry Scarp, the Suffolk Scarp, and the present coast. The region is underlain by sediments of Cretaceous to Holocene age resting on older consolidated rocks.

The stratigraphy of the post-Miocene units of the Virginia coastal plain has been studied since 1839 when W. B. Rogers described post-Miocene sediments extending from the Fall Line to the sea. Oaks (1964) presented a comprehensive review of many conflicting interpretations of the origins of these sediments. The alternating plains and scarps have been described as forming during successive stages of shoreline retreat from the Fall Line, or as a result of headland erosion and sediment deposition during repeated transgressions by the sea, a view which maintains that each plain is underlain by a single formation deposited on sediments of late Miocene age or older. A third interpretation is that each major plain is underlain by several formations which is indicative of deposition during more than one episode of sea-level fluctuation. Transgressions and regressions of the sea have been ascribed both to glacioeustatic control and to tectonically-controlled movements of the land.

The latest and most detailed studies of the stratigraphy of the coastal plain were conducted by R. Q. Oaks, N. K. Coch, and K. F. Bick (Oaks and Coch, 1963; Oaks, 1964; Coch, 1965, 1968; Bick and Coch, 1969) in southeastern Virginia in an area extending from the Fall Line to the present coast. Their studies, which support some earlier findings and also present new information, indicate that: (1) the major scarps and plains of the region are the result of a complex series of sea-level fluctuations; (2) more than one formation underlies each plain; (3) some formations

TABLE 1.—*Occurrences of 171 ostracode species in Holocene samples from the shelf off the middle Atlantic Coast of the United States and in Pleistocene samples from the Norfolk Formation, as used by Oaks and Coch (1963), of southeastern Virginia*

[Sample sources Gos and Ast = current studies of the continental shelf by the U.S. Geol. Survey and the Woods Hole Oceanographic Institution. Locality numbers P1 through P6=Pleistocene of the Norfolk, Virginia area]

| Locality | Sample: Source | Location: Latitude north, deg. | Latitude north, min. | Longitude west, deg. | Longitude west, min. | Depth (meters) |
|---|---|---|---|---|---|---|
| 1 | Gos 1378 | 39 | 38 | 73 | 59 | 24 |
| 2 | Gos 1377 | 39 | 31 | 73 | 45 | 28 |
| 3 | Gos 1316 | 39 | 21 | 74 | 14 | 20 |
| 4 | Gos 1319 | 39 | 20 | 73 | 31 | 48 |
| 5 | Gos 1322 | 39 | 20 | 72 | 46 | 84 |
| 6 | Gos 1346 | 39 | 09 | 74 | 31 | 23 |
| 7 | Gos 1345 | 39 | 10 | 74 | 15 | 21 |
| 8 | Gos 1340 | 39 | 10 | 73 | 15 | 62 |
| 9 | Ast 1965 | 39 | 00 | 74 | 45 | 15 |
| 10 | Gos 1351 | 39 | 01 | 74 | 00 | 38 |
| 11 | Gos 1338 | 39 | 01 | 73 | 01 | 80 |
| 12 | Gos 2026 | 38 | 50 | 74 | 45 | 18 |
| 13 | Gos 1354 | 38 | 51 | 73 | 32 | 62 |
| 14 | Gos 1355 | 38 | 49 | 73 | 15 | 81 |
| 15 | Ast 2027 | 38 | 40 | 74 | 45 | 26 |
| 16 | Gos 2029 | 38 | 40 | 74 | 14 | 39 |
| 17 | Gos 1360 | 38 | 40 | 73 | 30 | 69 |
| 18 | Gos 2105 | 38 | 30 | 74 | 45 | 29 |
| 19 | Gos 1415 | 38 | 30 | 74 | 00 | 57 |
| 20 | Gos 1365 | 38 | 31 | 73 | 26 | 89 |
| 21 | Gos 2032 | 38 | 20 | 74 | 30 | 36 |
| 22 | Gos 1417 | 38 | 10 | 74 | 15 | 41 |
| 23 | Gos 2036 | 38 | 00 | 75 | 00 | 18 |
| 24 | Gos 1418 | 37 | 59 | 74 | 29 | 49 |
| 25 | Gos 1891 | 38 | 00 | 73 | 59 | 129 |
| 26 | Ast 2001 | 37 | 49 | 75 | 25 | 12 |
| 27 | Gos 2038 | 37 | 50 | 74 | 45 | 41 |
| 28 | Gos 2041 | 37 | 40 | 75 | 14 | 24 |
| 29 | Gos 1420 | 37 | 39 | 74 | 42 | 49 |
| 30 | Gos 2045 | 37 | 31 | 75 | 30 | 16 |
| 31 | Gos 1886 | 37 | 31 | 74 | 30 | 64 |
| 32 | Gos 1885 | 37 | 27 | 74 | 29 | 406 |
| 33 | Gos 2047 | 37 | 19 | 75 | 16 | 29 |
| 34 | Gos 1422 | 37 | 20 | 75 | 00 | 38 |
| 35 | Gos 1883 | 37 | 20 | 74 | 46 | 56 |
| 36 | Ast 1997 | 37 | 10 | 75 | 44 | 12 |
| 37 | Gos 2048 | 37 | 09 | 75 | 15 | 30 |
| 38 | Gos 1423 | 37 | 05 | 75 | 01 | 38 |
| 39 | Gos 2050 | 37 | 00 | 75 | 30 | 30 |
| 40 | Gos 2051 | 37 | 00 | 75 | 15 | 36 |
| 41 | Gos 1424 | 37 | 02 | 75 | 00 | 44 |
| 42 | Gos 1880 | 36 | 57 | 74 | 45 | 82 |
| 43 | Gos 2057 | 36 | 49 | 75 | 45 | 22 |
| 44 | Gos 2052 | 36 | 50 | 75 | 15 | 29 |
| 45 | Gos 1425 | 36 | 45 | 74 | 59 | 36 |
| 46 | Gos 2054 | 36 | 39 | 75 | 31 | 20 |
| 47 | Gos 2053 | 36 | 40 | 75 | 15 | 35 |
| 48 | Gos 1426 | 36 | 39 | 74 | 58 | 32 |

| Locality | *Actinocythereis dawsoni* (Brady, 1870) | *A.* aff. *A. gomillionensis* (Howe and Ellis, 1935) | *A. vineyardensis* (Cushman, 1906) | *Anchistrocheles* sp. A | *Argilloecia* sp. A | *A.* sp. B | *A.* sp. C | *A.* sp. D | *Aurila floridana* Benson and Coleman, 1963 | *A. laevicula* (Edwards, 1944) | *Baffinicythere emarginata* (Sars, 1865) | *Basslerites miocenicus* (Howe, 1935) | *B.* sp. A | *Bensonocythere americana* Hazel, 1967 | *B. arenicola* (Cushman, 1906) | *B.* cf. *B. sapeloensis* | *B. whitei* (Swain, 1951) | *B.* sp. A | *B.* sp. B | *B.* sp. C | *B.* sp. D | *B.* sp. E | *B. sapeloensis* (Hall, 1965) | *B.* sp. G | *Bythocypris* sp. A | *Bythocythere* sp. A | *B.* sp. B | *Campylocythere laeva* Edwards, 1944 | *Caudites nipeensis* van den Bold, 1946 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | X | | | X | X | X | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | X | | | X | X | X | X | X | | X | | | | | | |
| 4 | | | | | | | | | | | | | | | X | | | X | X | | | | | | | | | | |
| 5 | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | X | X | | X | X | X | X | X | X | | | | | | X | |
| 7 | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | X | X | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | X | | | | X | | X | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | X | | | X | X | | | | | | | | | | |
| 11 | X | | X | | | | | | | | | | | | | | | X | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | X | | | X | | | X | X | | | | | | | | |
| 13 | | | | | | | | | | | | | | | X | | | X | | | | | | | | | | | |
| 14 | X | | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 15 | | X | | | | | | | X | | X | | | X | X | X | X | X | X | X | X | X | | | | | | X | |
| 16 | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | |
| 17 | X | | X | | | | | | | | | | | X | | | | X | X | | | | | | | | | | |
| 18 | | | | | | | | | | | | | | X | | | | | | X | | | | | | | | | |
| 19 | X | | | | | | | | | | | | | X | X | | | X | X | | | | | | | | | | |
| 20 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | | | | | | | | | | | | | | X | | | | X | X | | | | | | | X | | | |
| 23 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 24 | X | | | | | | | | | | | | | X | X | | | X | X | | X | | | | | | | | |
| 25 | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 26 | | | | | | | | | | | | | | | | | | | X | | | | X | | | | | X | |
| 27 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 28 | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | |
| 29 | X | | | | | | | | | | | | | X | X | | | X | X | | | | | | | | | | |
| 30 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | X | |
| 31 | X | | | | | | | | | | | | | X | | | | X | X | | | | | | | | | | |
| 32 | X | | X | | | | | | | | X | | | X | X | | | X | X | | | | | | | | | | |
| 33 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 34 | X | | | | | | | | X | | | | | X | X | | X | X | X | | | | | | | | | | |
| 35 | X | X | | | | | | | | | | | | X | X | | X | X | X | | | | | | | X | | | |
| 36 | | | | | | | | | X | | | | | X | | | X | | | | | | | | | | | | |
| 37 | | | | | | | | | X | | | | | | X | | | X | X | | X | X | | | | | | | |
| 38 | X | | X | | X | | | | X | | X | | | X | X | X | X | X | X | X | | | | | | X | | | |
| 39 | | | | | | | | | | | | | | X | | | X | | | X | | X | | | | | | | |
| 40 | | X | | | | | | | X | | X | | | X | X | | X | X | X | X | X | X | | | | | | | |
| 41 | X | | | | | | | | | | | | | X | X | | X | X | X | X | | | | | | | | | |
| 42 | | | | | | | | | | | | | | | | | | X | X | X | | | | | | X | | | |
| 43 | | X | | | | | | | | X | | | | | | | X | X | | X | | | X | | | | | | |
| 44 | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | |
| 45 | | X | | | | | | | X | | | | | X | | | X | X | X | | | | | | | X | | | |
| 46 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 48 | X | X | | | | | | | X | | | | | X | X | | X | X | X | X | X | | | | | | | | |

| Locality | *Cushmanidea magniporosa* Hall, 1965 | *C. seminuda* (Cushman, 1906) | *C.* sp. A | *C.* sp. B | *C.* sp. C | *C.* sp. D | *Cyprideis* sp. A | *Cytherella* spp. | *Cytherelloidea* sp. A | *Cytheridena* sp. A | *Cythercis* sp. A | *Cytheromorpha* aff. *C. surta* Edwards, 1944 | *C. warneri newportensis* Williams, 1966 | *C.* sp. A | *Cytheropteron pyramidale* (Brady, 1868) | *C. talquinensis* Puri, 1954 | *C.* sp. A | *C.* sp. B | *C.* sp. C | *C.* sp. D | *C.* sp. E | *C.* sp. F | *Cytherura elongata* Edwards, 1944 | *C. forulata* Edwards, 1944 | *C. howei* (Puri, 1954) | *C. pseudostriata* Hulings, 1966 | *C. reticulata* Edwards, 1944 | *C.* aff. *C. sablensis* (Benson and Coleman, 1963) | *C. wardensis* Howe and Brown, 1935 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | X | X | | | | | | | | | | | | | X | | | | | | | | | | | | | | X |
| 4 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 5 | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | |
| 6 | X | X | X | | | | | | | | | | | | X | | | | | | | | | | | X | | | |
| 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 9 | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | X | | | | | | | | X | | | | | | | | | | | | | |
| 12 | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 14 | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | |
| 15 | X | X | X | | | | | | | X | | | | | X | | | | | | | | | X | X | | | | X |
| 16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 17 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 18 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 19 | X | X | | | | | | | | | | | | | X | | | | | | | | | | | | | | X |
| 20 | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | |
| 21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 24 | | X | | | | | | | | | | | X | | X | | | | | | | | | | | | | | X |
| 25 | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | |
| 26 | X | | | | | | | | | | | | | | | | | | | | | | | X | | | | | |
| 27 | | X | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 28 | X | X | | | | | | | | X | | | | | | | | | | | | | | | | | | | |
| 29 | | X | | | | | | | | | | | | | X | | | | | | | | | | | | | | |
| 30 | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 31 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 32 | | | | | | | | X | | | | | | | X | | | | | | X | | | | | | | | |
| 33 | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 34 | | X | X | | | | | | | | | | X | | X | | | | | | | | | | | | | | X |
| 35 | | X | | | | | | X | | X | | | | | X | | | | | | | | | | | | | | |
| 36 | X | X | | | | | X | | | X | | | | | | | | | | | | | | | | | | | |
| 37 | X | X | X | | | | | | | | | | X | | X | | | | | | | | | X | | | | | X |
| 38 | X | X | X | | | | | | | | | | X | | X | | | | | | | | | X | X | | | | X |
| 39 | X | X | X | | | | | | | X | | | X | | X | | | | | | | | | | | | | | |
| 40 | X | X | X | | | | | | | | | | X | | X | | | | | | | | | | | | | | X |
| 41 | | X | X | | | | | | | | | | | | X | | | | | | | | | X | X | | | | X |
| 42 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 43 | X | | | | | | | | | | | | X | | | | | | | | | | | | | | | | X |
| 44 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 45 | | X | | | | | | | | | | | | | X | | | | | | | | | | | | | | X |
| 46 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 48 | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | X |

TABLE 1.—*Occurrences of 171 ostracode species in Holocene samples from the shelf off the middle Atlantic Coast of the United States and in Pleistocene samples from the Norfolk Formation, as used by Oaks and Coch (1963), of southeastern Virginia*—Continued

| Locality | Sample Source | Latitude north deg. | Latitude north min. | Longitude west deg. | Longitude west min. | Depth (meters) | *Actinocythereis dawsoni* (Brady, 1870) | *A.* aff. *A. gomillionensis* (Howe and Ellis, 1935) | *A. vineyardensis* (Cushman, 1906) | *Anchistrocheles* sp. A | *Argilloecia* sp. A | *A.* sp. B | *A.* sp. C | *A.* sp. D | *Aurila floridana* Benson and Coleman, 1963 | *A. laevicula* (Edwards, 1944) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | Gos 1878 | 36 | 40 | 74 | 45 | 86 | X | -- | X | -- | -- | -- | -- | -- | -- | -- |
| 50 | Gos 2060 | 36 | 20 | 75 | 45 | 16 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 51 | Gos 2062 | 36 | 20 | 75 | 30 | 30 | X | X | -- | -- | -- | -- | -- | -- | -- | -- |
| 52 | Gos 1428 | 36 | 20 | 75 | 14 | 32 | -- | X | -- | -- | -- | -- | -- | -- | X | -- |
| 53 | Gos 2063 | 36 | 10 | 75 | 30 | 26 | -- | X | -- | -- | -- | -- | -- | -- | -- | -- |
| 54 | Gos 1874 | 36 | 09 | 74 | 58 | 43 | X | X | -- | -- | X | -- | -- | -- | X | -- |
| 55 | Gos 1430 | 36 | 00 | 75 | 14 | 35 | -- | X | -- | -- | -- | -- | -- | -- | X | -- |
| 56 | Gos 1431 | 35 | 51 | 75 | 15 | 32 | X | X | -- | -- | -- | -- | -- | -- | -- | -- |
| 57 | Gos 1872 | 35 | 50 | 75 | 00 | 46 | -- | X | -- | -- | -- | -- | -- | -- | X | -- |
| 58 | Gos 1432 | 35 | 40 | 75 | 15 | 34 | X | X | -- | -- | -- | -- | -- | -- | -- | -- |
| 59 | Gos 1871 | 35 | 41 | 75 | 02 | 43 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 60 | Gos 1433 | 35 | 31 | 75 | 15 | 30 | X | X | -- | -- | -- | -- | -- | -- | -- | -- |
| 61 | Gos 1870 | 35 | 29 | 74 | 58 | 42 | X | X | -- | -- | -- | -- | -- | -- | X | -- |
| 62 | Ast 2324 | 35 | 26 | 75 | 27 | 15 | -- | -- | -- | -- | -- | -- | -- | -- | X | -- |
| 63 | Gos 1434 | 35 | 20 | 75 | 15 | 25 | -- | X | -- | -- | -- | -- | -- | -- | X | -- |
| 64 | Gos 1869 | 35 | 21 | 74 | 59 | 70 | X | -- | -- | -- | -- | -- | -- | -- | X | -- |
| 65 | Ast 2323 | 35 | 16 | 75 | 28 | 16 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 66 | Gos 1435 | 35 | 11 | 75 | 15 | 27 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | Ast 2321 | 35 | 09 | 75 | 38 | 16 | -- | -- | -- | -- | -- | -- | -- | -- | X | X |
| 68 | Gos 2320 | 35 | 08 | 75 | 48 | 16 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | Gos 2322 | 35 | 07 | 75 | 29 | 16 | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |
| 70 | Gos 1436 | 35 | 07 | 75 | 21 | 26 | -- | X | -- | -- | -- | -- | -- | -- | -- | -- |
| 71 | Ast 2319 | 35 | 03 | 75 | 57 | 17 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 72 | Gos 1437 | 34 | 59 | 75 | 31 | 44 | -- | -- | -- | -- | -- | -- | -- | -- | X | -- |

| Locality | *Baffinicythere emarginata* (Sars, 1865) | *Basslerites miocenicus* (Howe, 1935) | *B.* sp. A | *Bensonocythere americana* Hazel, 1967 | *B. arenicola* (Cushman, 1906) | *B.* cf. *B. sapeloensis* (Hall, 1965) | *B. whitei* (Swain, 1951) | *B.* sp. A | *B.* sp. B | *B.* sp. C | *B.* sp. D | *B.* sp. E | *B. sapeloensis* (Hall, 1965) | *B.* sp. G | *Bythocypris* sp. A | *Bythocythere* sp. A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | -- | -- | X | X | -- | -- | -- | X | X | X | -- | -- | -- | -- | -- | X |
| 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 51 | -- | -- | -- | X | X | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- |
| 52 | -- | -- | -- | X | X | X | -- | X | -- | -- | -- | X | -- | -- | -- | -- |
| 53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 54 | -- | -- | -- | X | X | -- | X | X | X | X | -- | X | -- | -- | -- | X |
| 55 | -- | -- | -- | -- | X | -- | X | -- | -- | -- | -- | X | -- | -- | -- | -- |
| 56 | -- | -- | -- | X | X | X | X | X | X | -- | -- | X | -- | -- | -- | -- |
| 57 | -- | -- | -- | X | X | -- | X | -- | X | X | -- | -- | -- | -- | -- | -- |
| 58 | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | X | -- | -- | -- | -- |
| 59 | -- | -- | -- | X | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | -- |
| 60 | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 61 | -- | -- | -- | X | X | -- | X | X | X | X | -- | -- | X | -- | -- | X |
| 62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 63 | -- | -- | -- | -- | X | -- | X | -- | -- | -- | -- | X | -- | -- | -- | -- |
| 64 | -- | X | X | X | X | -- | X | X | X | X | -- | X | X | -- | -- | X |
| 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- |
| 70 | -- | -- | -- | X | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 71 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- |
| 72 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality | *B.* sp. B | *Campylocythere laeva* Edwards, 1944 | *Caudites nipeensis* van den Bold, 1946 | *Cushmanidea magniporosa* Hall, 1965 | *C. seminuda* (Cushman, 1906) | *C.* sp. A | *C.* sp. B | *C.* sp. C | *C.* sp. D | *Cyprideis* sp. A | *Cytherella* spp. | *Cytherelloidea* sp. A | *Cytheridea* sp. A | *Cythereis* sp. A | *Cytheromorpha* aff. *C. curta* Edwards, 1944 | *C. warneri newportensis* Williams, 1966 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- |
| 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |
| 51 | -- | -- | -- | X | X | X | -- | -- | -- | -- | -- | -- | X | -- | -- | X |
| 52 | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- |
| 53 | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 54 | -- | X | -- | -- | X | X | -- | -- | -- | -- | -- | -- | X | -- | -- | X |
| 55 | -- | -- | -- | -- | X | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 56 | -- | X | -- | X | X | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |
| 57 | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 58 | -- | -- | -- | X | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |
| 59 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 60 | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 61 | -- | X | -- | X | X | X | X | -- | -- | -- | -- | X | X | -- | -- | X |
| 62 | -- | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 63 | -- | X | -- | X | X | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |
| 64 | X | X | -- | X | X | X | -- | -- | -- | -- | X | -- | -- | -- | -- | X |
| 65 | -- | -- | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 66 | -- | X | -- | X | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | -- | X | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |
| 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | -- | -- | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 70 | -- | X | -- | X | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 71 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |
| 72 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |

| Locality | *C.* sp. A | *Cytheropteron pyramidale* (Brady, 1868) | *C. talquinensis* Puri, 1954 | *C.* sp. A | *C.* sp. B | *C.* sp. C | *C.* sp. D | *C.* sp. E | *C.* sp. F | *Cytherura elongata* Edwards, 1944 | *C. forulata* Edwards, 1944 | *C. howei* (Puri, 1954) | *C. pseudostriata* Hulings, 1966 | *C. reticulata* Edwards, 1944 | *C.* aff. *C. sablensis* (Benson and Coleman, 1963) | *C. wardensis* Howe and Brown, 1935 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 51 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | X |
| 52 | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |
| 53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 54 | -- | X | -- | -- | -- | -- | -- | -- | -- | X | X | X | X | -- | -- | X |
| 55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X |
| 56 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | X |
| 57 | -- | X | -- | -- | -- | -- | -- | -- | -- | X | X | -- | -- | -- | -- | -- |
| 58 | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | X |
| 59 | -- | X | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 60 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 61 | -- | X | -- | -- | -- | -- | -- | -- | -- | X | X | X | X | -- | X | X |
| 62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | X |
| 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | X | -- |
| 64 | -- | X | -- | X | -- | -- | X | -- | -- | X | X | X | X | -- | X | X |
| 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | X | -- | X | -- | X | X |
| 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | -- | -- |
| 69 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | X | -- | -- | -- |
| 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | X | -- | -- | -- |
| 71 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | -- | -- | -- | X | -- |
| 72 | -- | -- | -- | -- | -- | -- | -- | -- | -- | X | X | -- | -- | -- | X | -- |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73 | Gos 1865 | 35 | 01 | 75 | 17 | 141 | X | | | | | X | | | X | X | | X | | | | X | X | X | | | | X | X | | X | | X | X | X | X | | X | X | | | | X | X | | X | X | X | | X | X | X | X | X | | | | X | X | | X | X | X | |
| 74 | Gos 1439 | 34 | 58 | 76 | 00 | 20 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | X | | | | X | |
| 75 | Gos 1438 | 34 | 56 | 75 | 44 | 27 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | | | | X | |
| 76 | Gos 1863 | 34 | 51 | 75 | 31 | 86 | | | | | | X | | | X | | | | | | X | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | X | X | | X | | | |
| 77 | Gos 1440 | 34 | 50 | 76 | 00 | 28 | | | | | | | | | X | | | | | | | | | | | | | X | | | | | | | | | | X | | | | | | | | | | X | | | | | | | | | | X | X | | | | X | |
| 78 | Gos 1861 | 34 | 46 | 75 | 45 | 41 | | X | | | | | | | X | X | | | | | | | X | | | | | | | | | | X | X | | X | | X | | | | X | | | | X | | X | | | | X | | | | | | | X | X | | X | | X | |
| 79 | Gos 1442 | 34 | 40 | 76 | 15 | 27 | | | | | | | | | X | X | | | | X | | | | | | | | X | | | | | X | X | | | | | | | | X | | | | | | | | | | | | | | | | X | X | | X | | X | |
| 80 | Gos 1860 | 34 | 37 | 75 | 44 | 66 | | | | | | | X | | X | | | | | | | | X | | | | | | | | | | X | X | X | | | | | | | | | | | | | | | | | | | | | | | X | X | | X | | X | |
| 81 | Ast 2313 | 34 | 38 | 76 | 45 | 15 | | | | | | | | | X | X | | | | | | | | | | | | | | | | | | X | | X | | | | | | | | | | | | | | | | | | | | | | | | | X | | X | |
| 82 | Ast 2314 | 34 | 37 | 76 | 38 | 16 | | | | | | | | | X | | | | | | | | X | | | | | X | | | | | | X | | X | | X | | | X | | | | | | | X | | | | | | | | | | X | X | | X | | X | |
| 83 | Ast 2311 | 34 | 33 | 77 | 14 | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | X | | | |
| 84 | Gos 1443 | 34 | 30 | 76 | 17 | 32 | | X | | | | | | | | | | | | | | | X | | | | | | | | | | X | | | | | X | | | | | X | | | | | X | | | | | | | | | | X | X | | X | | X | |
| 85 | Gos 1446 | 34 | 21 | 76 | 47 | 25 | | | | | | | | | X | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | X | | X | | | | | | | | | | X | X | X | X | | X | |
| 86 | Gos 1444 | 34 | 20 | 76 | 16 | 24 | | X | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | |
| 87 | Gos 1449 | 34 | 18 | 77 | 01 | 27 | | | | | | | | | X | X | | | | | | | X | | | | | X | | | | | X | X | | | | X | | | | | X | | | | | | | | | | | | | | | X | X | | X | | X | |
| 88 | Ast 2308 | 34 | 14 | 77 | 44 | 13 | | | | | | | | | X | | | | | | | | X | | | | | X | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | X | X | | X | X | | |
| 89 | Gos 1847 | 34 | 09 | 76 | 44 | 33 | | | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | | X | | X | |
| 90 | Gos 1849 | 34 | 10 | 76 | 14 | 54 | | | | | | | | | X | X | | | | | | | X | | | | | | | | | | X | X | | | | X | | | | | X | | | | | | | | | | | | | | | X | X | | X | | X | |
| 91 | Gos 1453 | 34 | 00 | 77 | 30 | 22 | | X | | | | | | | X | | | | | | | | | | | | | X | | | | | X | X | | X | | X | | | | X | | X | | | | | | | | | | | | | | X | X | | X | | X | |
| 92 | Gos 1845 | 34 | 00 | 76 | 29 | 41 | | | | | | | | | X | X | | | | | | | X | | | | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | X | X | | X | | X | |
| 93 | Ast 2249 | 33 | 49 | 78 | 14 | 14 | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | X | | | | | | | | | | | X | | | X | | |
| 94 | Ast 2306 | 33 | 50 | 77 | 53 | 13 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 95 | Gos 1816 | 33 | 50 | 77 | 16 | 35 | | | | | | | | | X | X | | | | | | | X | | | | | X | | | | | X | X | X | | | | | | | | | X | | | | | | | | | | | | | | X | X | | X | | X | |
| 96 | Ast 2251 | 33 | 43 | 78 | 45 | 12 | | X | | | | | | | X | | | | | | | | | | | | | X | | | | | | X | | | | X | | | X | | | | | | | X | | | | | | | | | | | X | X | X | X | | |
| 97 | Gos 1463 | 33 | 41 | 78 | 16 | 16 | | | | | | | | | X | X | | | | | | | X | | | | X | | X | | | | | X | | | | X | | | | | X | | | | | X | | | | | | | | | | X | X | X | X | X | X | |
| 98 | Ast 2305 | 33 | 39 | 77 | 55 | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 99 | Gos 1458 | 33 | 40 | 77 | 45 | 17 | | X | | | | | | X | X | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | X | | | | | | | | | | | | | | X | X | | X | X | X | |
| 100 | Gos 1821 | 33 | 39 | 76 | 59 | 38 | | | | | | | | | X | | | | | | | | X | | | | | | | | | | X | X | | | | | | | | | | X | | | | | | | | | | | | | | X | X | | | | | |
| 101 | Ast 2252 | 33 | 33 | 78 | 57 | 8 | | | | | | | | | X | | | | | | | | X | | | | | | | | | | | X | | | | | | | X | | | | | | | | | | | | | | | | | | X | | X | | X | |
| 102 | Gos 1465 | 33 | 30 | 78 | 30 | 20 | | | | | | | | | X | | | | | | | | X | | | | | | | | | | | X | | | | | | | | | | X | | | | | | | | | | | | | | X | X | X | X | | X | |
| 103 | Gos 1462 | 33 | 21 | 78 | 15 | 22 | | X | | X | | | | | X | X | | | | | | | X | | | | X | | | | | | X | X | | | | X | X | | | | | X | | | | | | | | | | | | | | X | X | | X | | X | |
| 104 | Gos 1805 | 33 | 29 | 77 | 30 | 22 | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | X | | | | X | |
| 105 | Gos 1467 | 33 | 21 | 78 | 45 | 19 | | | | | | | | | X | X | | | | | | | X | | | | | X | | | | | | X | | | | X | | | | | | X | | | | | | | | | | | | | | X | X | | X | | X | |
| 106 | Gos 1792 | 33 | 22 | 78 | 01 | 28 | | | | | | | | | X | X | | | | | | | X | | | | | X | X | | | | X | X | | | | | | | | | | X | | | | | | | | | | | | | | X | X | | X | | X | |
| 107 | Gos 1813 | 33 | 19 | 77 | 15 | 54 | | X | | | | | | | X | X | | | | | | | X | | | | | | | | | | X | X | | | | | | | | | | X | | | | | | | | | | | | | X | X | X | | X | | X | |
| 108 | Ast 2254 | 33 | 14 | 79 | 06 | 10 | | X | | | | | | | X | | | | | | | X | X | | | | | X | | | | | X | X | | | | | | X | | X | | | X | | | | | | | | | | | | | X | X | | X | X | X | |
| 109 | Gos 1469 | 33 | 10 | 78 | 30 | 21 | | | | | | | | | X | X | | | | | | | X | | | | | X | | | | | X | X | | | | | | | | | | X | | | | | | | | | | | | | | | X | | X | | X | |
| 110 | Gos 1793 | 33 | 10 | 78 | 01 | 38 | | | | | | | | | X | | | | | | | | X | | | | | | | | | | X | X | | | | | | | | | | X | | | | | | | | | | | | | | X | X | | X | | X | |
| 111 | Ast 2258 | 32 | 60 | 79 | 11 | 13 | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | |
| 112 | Gos 1472 | 32 | 59 | 79 | 00 | 16 | | X | | | | | | | X | X | | | | | | X | X | | | | | X | X | | | | | X | | X | | | | | | | | X | | X | | | | | | | | | | | | X | X | | X | | X | |
| 113 | Gos 1789 | 32 | 59 | 78 | 15 | 38 | | | | | | | | | X | X | | | | | | | X | | | | | | | | | | X | X | | X | | | | | | | | X | | | | | | | | | | | | | | X | X | | X | | X | |
| 114 | Gos 1474 | 32 | 49 | 78 | 44 | 32 | | | | | | | | | X | X | | | | | | | X | | | | | | | | | | X | X | | | | | | | | X | | X | | | | | | | | | | | | | X | X | X | | | | X | |
| 115 | Gos 1782 | 32 | 43 | 78 | 30 | 69 | | X | | | | | | | X | X | | | | | | | X | | | | | | | | | | X | | X | | | | | | | | | X | | | | | | | | | | | | | | X | X | | X | | X | |
| P1-1 | | 36 | 48 | 76 | 10 | | X | X | | | | | | | X | | | | | X | | X | | X | | | X | X | X | | | | | X | | X | X | | X | X | | | | | | | | X | | | | | | | | | | | | X | | | X | | X |
| P1-2 | | 36 | 48 | 76 | 10 | | X | X | | | | | | | X | | | | | X | X | X | X | X | X | | X | X | X | | | | | X | | X | X | | X | | | | | | | | | X | | X | | | | | | | | | X | X | X | X | | X |
| P2-1 | | 36 | 51 | 76 | 10 | | | X | | | | | | | X | | | | | X | X | X | X | X | X | | X | X | X | | | | | X | | X | X | | X | | | | | | | | | X | | X | | | | | | | | | X | X | X | X | | X |
| P2-2 | | 36 | 51 | 76 | 10 | | | X | | | | | | | X | | | | | X | X | X | X | X | X | | X | X | X | | | | | X | | X | X | | X | | | | | | X | | | | | X | | | | | | | | | X | X | | X | | X |
| P2-3 | | 36 | 51 | 76 | 10 | | | | | | | | | | X | | | | | X | X | X | X | X | X | | X | X | | | | | | X | | X | X | | X | | | | | | | | | | | X | | | | | | | | | X | | | X | | X |
| P3-1 | | 36 | 52 | 76 | 11 | | | X | | | | | | | X | | | | | X | | X | | X | X | | X | X | X | | | | | X | | | | | X | | | | | | X | | | X | | X | | | | | | | | | X | X | | X | | X |
| P4-1 | | 36 | 50 | 76 | 08 | | | X | | | | | | | X | | | | | X | X | X | X | X | X | | X | X | X | | | | | X | | X | X | | X | | | | | | X | | | X | | X | | | | | | | | | X | X | X | X | | |
| P5-1 | | 36 | 47 | 76 | 14 | | | X | | | | | | | X | | | | | X | X | X | X | X | X | | X | X | X | | | | | X | | X | X | | X | | | X | | | X | | | X | | X | | | | | | | | | X | X | | X | | X |
| P6-1 | | 36 | 46 | 76 | 22 | | | X | | | | | | | X | | | | | | | X | | X | X | | | X | X | X | | | | X | | X | X | | X | | | | | | X | | | | X | X | | | | | | | | | X | X | | X | | X |

TABLE 1.—*Occurrences of 171 ostracode species in Holocene samples from the shelf off the middle Atlantic Coast of the United States and in Pleistocene samples from the Norfolk Formation, as used by Oaks and Coch (1963), of southeastern Virginia*—Continued

| Sample: Locality | Sample: Source | Location: Latitude north, deg. | Location: Latitude north, min. | Location: Longitude west, deg. | Location: Longitude west, min. | Depth (meters) | *Cytherura* sp. A | *C.* sp. B | *C.* sp. C | *C.* sp. D | *C.* sp. E | *C.* sp. F | *C.* sp. G | *C.* sp. H | *C.* sp. I | *C.* sp. J | *C.* sp. K | *Echinocythereis margaritifera* (Brady, 1870) | *E. planibasalis* (Ulrich and Bassler, 1904) | *E.* sp. A | *Eucythere declivis* (Norman, 1865) | *E. gibba* Edwards, 1944 | *E. triangulata* Puri, 1954 | *E.* sp. A | *Finmarchinella finmarchica* (Sars, 1865) | *Haplocytheridea bradyi* (Stephenson, 1938) | *H. setipunctata* (Brady, 1869) | *Hemicythere villosa* (Sars, 1865) | *Hulingsina americana* (Cushman, 1906) | *H. glabra* (Hall, 1965) | *H. rugipustulosa* (Edwards, 1944) | *H.* sp. A | *H.* sp. B | *H.* sp. C | *H.* sp. D | *Jonesia* cf. *J. acuminata* (Sars, 1865) | *Krithe* sp. A | *K.* sp. B | *Leptocythere angusta* Blake, 1935 | *L.* cf. *L. nikraveshae* Morales, 1966 | *L.* sp. A | *Loxoconcha* aff. *L. granulata* Sars, 1865 | *L. impressa* (Baird, 1850) | *L. matagordensis* Swain, 1955 | *L. reticularis* Edwards, 1944 | *L. sperata* Williams, 1966 | *Loxocorniculum postdorsolatum* (Puri, 1960) | *Macrocypris* sp. A | *M.* sp. B | *M.* sp. C | *M.* sp. D | *M.* sp. E | *Macrocyprina propinqua* Triebel, 1960 | *M.* sp. A | *M.* sp. B | *Megacythere stephensoni* (Puri, 1934) | *M.* sp. A | *M.* sp. B | *Microcytherura choctawhatcheensis* (Puri, 1954) | *M.* sp. A | *M.* sp. B | *M.* sp. C | *Muellerina canadensis* (Brady, 1870) | *M.* aff. *M. lienenklausi* (Ulrich and Bassler, 1904) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Gos 1375 | 39 | 38 | 73 | 59 | 24 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | X | | | X | | | | | | | | | | | | | X | | | | | |
| 2 | Gos 1377 | 39 | 31 | 73 | 45 | 28 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| 3 | Gos 1316 | 39 | 21 | 74 | 14 | 20 | | | | | | | | | | | | | | | | | | | | | | | X | | X | X | | X | | | | | X | | | | X | | | X | | | | | | | | | | | | | X | X | | X | | |
| 4 | Gos 1319 | 39 | 20 | 73 | 31 | 48 | | | | | | | | | | | | | | | | | | | X | | | | | | | | | X | | | | | X | | | X | X | | | | | | | | | | | | | | | | | | | | X | X |
| 5 | Gos 1322 | 39 | 20 | 72 | 46 | 84 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | X |
| 6 | Gos 1346 | 39 | 09 | 74 | 31 | 23 | | | | | | | | | | | | | | | X | | | | X | | | | | | X | | | X | | | | | X | | | X | X | | | X | | | | | | | | | | | | | X | X | | | X | X |
| 7 | Gos 1345 | 39 | 10 | 74 | 15 | 21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | |
| 8 | Gos 1340 | 39 | 10 | 73 | 15 | 62 | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | X | | | | X |
| 9 | Ast 1965 | 39 | 00 | 74 | 45 | 15 | | | | X | | | | | | | | | | | | | | | X | X | | | X | | X | X | | X | | | | | X | | | | | | | X | | | | | | | | | | | | | X | X | | | | X |
| 10 | Gos 1351 | 39 | 01 | 74 | 00 | 38 | | | | | | | | | | | | | | | X | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| 11 | Gos 1338 | 39 | 01 | 73 | 01 | 80 | | | | | | | | | | | | | X | | X | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | X | X |
| 12 | Gos 2026 | 38 | 50 | 74 | 45 | 18 | | | | | | | | | | | | | | | | | | | | | | | X | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | Gos 1354 | 38 | 51 | 73 | 32 | 62 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| 14 | Gos 1355 | 38 | 49 | 73 | 15 | 81 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | X | X |
| 15 | Ast 2027 | 38 | 40 | 74 | 45 | 26 | X | X | | | | | | | X | | | | | | X | X | | | X | X | | | X | | X | X | | X | | | | | X | | | X | X | | | X | | | | | | | | | | | | | X | X | | X | X | X |
| 16 | Gos 2029 | 38 | 40 | 74 | 14 | 39 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| 17 | Gos 1360 | 38 | 40 | 73 | 30 | 69 | | | | | | | | | | | | | X | | | | | | X | | | | | | | | | | | | | | X | | | | X | | | | | | | | | | | | | | | | X | | | | X | X |
| 18 | Gos 2105 | 38 | 30 | 74 | 45 | 29 | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | X |
| 19 | Gos 1415 | 38 | 30 | 74 | 00 | 57 | | | | | | | | | | | | | X | | X | | | | X | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | X | | | | X | X |
| 20 | Gos 1365 | 38 | 31 | 73 | 26 | 89 | | | | | | | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | X | | | | | X | | | | | | | | | | | | | | | X | X |
| 21 | Gos 2032 | 38 | 20 | 74 | 30 | 36 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | Gos 1417 | 38 | 10 | 74 | 15 | 41 | | | | | | | | | | | | | | | X | | | | X | | | | | | | | | | | | | | X | | | | X | | | | | | | | | | | | | | | | | | | | X | X |
| 23 | Gos 2036 | 38 | 00 | 75 | 00 | 18 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | |
| 24 | Gos 1418 | 37 | 59 | 74 | 29 | 49 | | | | | | | | | | | | | | | X | X | | | X | | | | X | | | X | X | | | | | | X | | | | X | | | X | | | | | | | | | | | | | | X | | | X | X |
| 25 | Gos 1891 | 38 | 00 | 73 | 59 | 129 | | | | | | | | | | | | X | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | X | X |
| 26 | Ast 2001 | 37 | 49 | 75 | 25 | 12 | | | | X | | | | | | | | | | | | | | | | | | | | | | X | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | |
| 27 | Gos 2038 | 37 | 50 | 74 | 45 | 41 | | | | | | | | | | | | | | | | X | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 28 | Gos 2041 | 37 | 40 | 75 | 14 | 24 | X | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| 29 | Gos 1420 | 37 | 39 | 74 | 42 | 49 | | | | | | | | | | | | | | | X | | | | X | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | X | X |
| 30 | Gos 2045 | 37 | 31 | 75 | 30 | 16 | | | | | | | | | | | | | | | | | | | | X | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | |
| 31 | Gos 1886 | 37 | 31 | 74 | 30 | 64 | | | | | | | | | | | | | X | | X | | | | X | | | | X | | | | | | | | | | X | | | X | X | | | | | | | | | | | | | | | | | | | | X | X |
| 32 | Gos 1885 | 37 | 27 | 74 | 29 | 406 | | | | | | | | | | | | | X | X | X | | | | X | | | | | | | | | X | | | | | X | | | | | | | | | | | | | | | | | | | | | X | | | X | X |
| 33 | Gos 2047 | 37 | 19 | 75 | 16 | 29 | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 34 | Gos 1422 | 37 | 20 | 75 | 00 | 38 | X | X | | | | | | | | | | | | | X | X | | | X | | | | X | | X | X | | | | | | | X | | | | X | | | X | | | | | | | | | | | | | X | X | | | X | X |
| 35 | Gos 1883 | 37 | 20 | 74 | 46 | 56 | | | | | | | | | | | | | X | X | X | | | | X | | | | X | | X | X | | X | | | | | X | | | X | X | | | | | | | | | X | | | | | | | X | X | | | X | X |
| 36 | Ast 1997 | 37 | 10 | 75 | 44 | 12 | X | | | | | | | | | | | | | | | | | | X | X | | | X | | | | | X | | | | | | | | | X | | | X | | | | | | | | | | | | | X | | | | | |
| 37 | Gos 2048 | 37 | 09 | 75 | 15 | 30 | | | | | | | | | | | | | | | X | | | | | X | | | X | | X | X | | X | | | | | X | | | | | | | X | | | | | | | | | | | | | | | | | X | X |
| 38 | Gos 1423 | 37 | 05 | 75 | 01 | 38 | | | | X | | | | | X | | | | | | X | | | | X | X | | | X | | X | X | X | X | | | | | X | | | X | X | | | X | | | | | | | | | | | | | X | X | | | X | X |
| 39 | Gos 2050 | 37 | 00 | 75 | 30 | 30 | X | | | | | | | | | | | | | | X | | | | X | X | | | X | | X | X | | X | | | | | | | | X | X | | | X | | | | | | | | | | | X | | | X | | | | X |
| 40 | Gos 2051 | 37 | 00 | 75 | 15 | 36 | | | | | | | | | | X | | | | | X | | | | X | X | | | X | | | X | X | X | X | | | | X | | | X | X | | | X | | | | | | | | | | | | | X | X | | | X | X |
| 41 | Gos 1424 | 37 | 02 | 75 | 00 | 44 | X | | X | | | | | | | | | | | | X | | | | X | | | | X | | | | | X | | | | | X | | | | X | | | X | | | | | | | | | | | | | X | X | | | X | X |
| 42 | Gos 1880 | 36 | 57 | 74 | 45 | 82 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | X | X |
| 43 | Gos 2057 | 36 | 49 | 75 | 45 | 22 | X | | | X | | | | | | | | | | | X | | | | | X | | | X | | X | X | | X | | | | | | X | | X | X | | | X | | | | | | | | | | | | | X | | | | | X |
| 44 | Gos 2052 | 36 | 50 | 75 | 15 | 29 | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | X | X |
| 45 | Gos 1425 | 36 | 45 | 74 | 59 | 36 | | | | | | | | | | | | | | X | X | | | | X | | | | | | | X | | X | | | | | X | | | | X | | | X | | | | | | | | | | | | | X | X | | | X | X |
| 46 | Gos 2054 | 36 | 39 | 75 | 31 | 20 | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 | Gos 2053 | 36 | 40 | 75 | 15 | 35 | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48 | Gos 1426 | 36 | 39 | 74 | 58 | 32 |||||||||||||||||||X|||||||||X||||||||||||||X||||||||||||||||||||||X||||X|X|
| 49 | Gos 1878 | 36 | 40 | 74 | 45 | 86 ||||||||||||||X|X|X||X|||||||||||||||||||X||||X|||||||||||||||||||X|||X|X|
| 50 | Gos 2060 | 36 | 20 | 75 | 45 | 16 |||||||||||||||||||||||||X|||||||||||||||||||||||||||||||||||
| 51 | Gos 2062 | 36 | 20 | 75 | 30 | 30 |X|||X|||||||||||X|||||X|||X||X|X|X|X|X||||X|||X|X|||X|||||||||||||||X||||X|
| 52 | Gos 1428 | 36 | 20 | 75 | 14 | 32 ||X|||X||||||||||X|||||X|||X|||X|||X|||||X|||X|X|||X|||||||||||||X|X||X|X|X|
| 53 | Gos 2063 | 36 | 10 | 75 | 30 | 26 |X||||||||||||||X||||||||||X|X|X|||||||||X||||X|||||||||||||||||||
| 54 | Gos 1874 | 36 | 09 | 74 | 58 | 43 |X||||X||||||||X|X|X||||X|X|||X|||X||X|X|||||X|||X|X|||X|||||||||||||X|X|||X|X|
| 55 | Gos 1430 | 36 | 00 | 75 | 14 | 35 ||||X||||||||||||||||||X||X|X|||X||||X||||X|||X|||||||||||||||||X|X|
| 56 | Gos 1431 | 36 | 51 | 75 | 15 | 32 |X||X|X||||||||||||X||||||||X||X|X|X||X||||X|||X|X|||X|||||||||||||X|X|||X|X|
| 57 | Gos 1872 | 35 | 50 | 75 | 00 | 46 |||||||||||||X|X|X|||||X|||X||X|X||X|X||||X|||X|X|||X|||||||||||||X||||X|X|
| 58 | Gos 1432 | 35 | 40 | 75 | 15 | 34 |X||||||||||||||||||||X|||X||X|X|X|X||||||||X|X|||X|||||||||||||X|X|X|||X|
| 59 | Gos 1871 | 35 | 41 | 75 | 02 | 43 |||||||||||||||X||||X||||X|||X|X|X||||||||||||||X|||||||||||||X|||||X|
| 60 | Gos 1433 | 35 | 31 | 75 | 15 | 30 |X||||||||||||||||||||||X|||X|X|X|||||||||X||||X|||||||||||||||||||X|
| 61 | Gos 1870 | 35 | 29 | 74 | 58 | 42 |X|X|||X||X|||X|||X|X|X|X||X|X|X|||X||X|X|X|X|X|X|||X|||X|X||X|X|||||||||||||X|X||X|X|X|
| 62 | Ast 2324 | 35 | 26 | 75 | 27 | 15 |X|||X||||||||||||||||X|||X||X|X|X||||||||||||||||||||||||||X||||||
| 63 | Gos 1434 | 35 | 20 | 75 | 15 | 25 |X|X|X|X||X||||X|||||X|||||X|||X||X|X|X|X|X|||||||X|X|||X|X||||||||||||X|||X|X|
| 64 | Gos 1869 | 35 | 21 | 74 | 59 | 70 |X|X||X|X|X|X|X|||||X|X|X|X|X||X|X|||X|X|X|X|X|X|X|X|X||X|||X|X||X|X|X|||||X|||X||||X|X|||X|X|
| 65 | Ast 2323 | 35 | 16 | 75 | 28 | 16 |X|||||||||||||||||||||||||||||||||||||||||||||||||||||||||X|
| 66 | Gos 1435 | 35 | 11 | 75 | 15 | 27 ||||||||||||||||X||||X||||||X||X|||||X|||X||||||||||||||||||||||
| 67 | Ast 2321 | 35 | 09 | 75 | 38 | 16 |X|||||||||||||||X||||X|X||||X|X|X|X|X|||||||||X|||||||||||||||||X|X||X||X|
| 68 | Ast 2320 | 35 | 08 | 75 | 48 | 16 ||||||||||||||||||||||||||X|||||||||||||||||||||||||||||||||||
| 69 | Ast 2322 | 35 | 07 | 75 | 29 | 16 |X||||||||||||||||||||X|||X||X|X|X|X|||||||||||||X|||||||||||||||||||X|
| 70 | Gos 1436 | 35 | 07 | 75 | 21 | 26 ||||||||||||||||||||X|||X||X|X|X|X||||||||X|||||||||||||||||||||||
| 71 | Ast 2319 | 35 | 03 | 75 | 57 | 17 |X||||||||||||||X|X|X||||X|||X||X|X|X|X|||||||||||||X||||||||||||||X||||||
| 72 | Gos 1437 | 34 | 59 | 75 | 31 | 44 |X|||||X||||||X||X||||||X||||||X|X||||||||X||||||||||||||||||X||||||
| 73 | Gos 1865 | 35 | 01 | 75 | 17 | 141 |||||||||||X|X|X|X|X|X|X||X|||X||X|X|X|X|X|X|X|X||||X|X||X|X|X|X|X|X|X||X|X|||||X||||X|X|
| 74 | Gos 1439 | 34 | 58 | 76 | 00 | 20 |X||||||||||||||||||||X|||||X|X|X|X|||||||||||||||||||||||||||||
| 75 | Gos 1438 | 34 | 56 | 76 | 44 | 27 |X||||||||||||||||||||X|||||X|X|X||||||||||||||||||||||||||||||
| 76 | Gos 1863 | 34 | 51 | 75 | 31 | 86 |X||||||X|||||X|X|X|X|||||||||X|X|X|X||X||||||||||||||||||X|||||X||||||
| 77 | Gos 1440 | 34 | 50 | 76 | 00 | 28 |X||||||||||||||||||||X||||X|X|X|X|X|||||||||||X|||||||||||||X|X|||||
| 78 | Gos 1861 | 34 | 46 | 75 | 45 | 41 |X|X||X||X|X|||||X||X||X|X|||X|||X|X|X|X|X|X|X||||||X||X|X|||||||||||||X|X|||||
| 79 | Gos 1442 | 34 | 40 | 76 | 15 | 27 |X|||||||||||X||||||||X|||||X|X|X|X|||||||||||X|||||||||||||X|X|||||
| 80 | Gos 1860 | 34 | 47 | 75 | 44 | 66 ||||||X|X|||||X|X|X||||||X||||||X|X|X|X|||||||||||X||||||||||X|||||X||||||
| 81 | Ast 2313 | 34 | 38 | 76 | 45 | 15 |X||||||||||||||||||||X|||||X|X|X||||||||X|||||||||||||||||||||||
| 82 | Ast 2314 | 34 | 37 | 76 | 38 | 16 |X|||X||||||||||X||X||||X|||X|X|X|X|X|X|X||||X|||||X|||||||||||||||X|||||
| 83 | Ast 2311 | 34 | 33 | 77 | 14 | 9 ||||||||||||||||||||X|||X|X||X|X|||||||||||||||||||||||||||||||||
| 84 | Gos 1443 | 34 | 30 | 76 | 17 | 32 |X||||||||||||||X|X|||||X|||||X|X|X|X|||||||||||||||||||||||||X|X|||||
| 85 | Gos 1446 | 34 | 21 | 76 | 47 | 25 ||||||X|||||||||||||||||X|X|X|X|||||||||||X|||||||||||||X|X|||||
| 86 | Gos 1444 | 34 | 20 | 76 | 16 | 24 ||||||||||||||||||||X|||||X|X||X||||||||||||||||||||||||||X||||||
| 87 | Gos 1449 | 34 | 18 | 77 | 01 | 27 |X|||||X|X|||||||X||X||||||X|||X|X|X|||||||||||X||X|||||||X|||||X||||||
| 88 | Ast 2308 | 34 | 14 | 77 | 44 | 13 |X||||||||||||||||||||X|||X|X|X|X|X|X|||||||||||X|||||||||||||X|X|||||
| 89 | Gos 1847 | 34 | 09 | 76 | 44 | 33 ||||||X|X|||||||||||||X||||X||X|X|X|||||||||||X|||||||||||||X||||||
| 90 | Gos 1849 | 34 | 10 | 76 | 14 | 54 |X|||||X|X|||||||X||X|X|X||X|||X|X|X|X|X|X|X|||||||||||X|||||||||||||X|X|||||
| 91 | Gos 1453 | 34 | 00 | 77 | 30 | 22 |X|||||||||||||||X|||X|||X|||||X|X|X|X|||||||||||X|||||||X|||||X||||||
| 92 | Gos 1845 | 34 | 00 | 76 | 29 | 41 ||||||X|X|||||||X||||X||X||||X|X|X|X|X|||||||||||X|||||||X|X|||||X||||||
| 93 | Ast 2249 | 33 | 49 | 78 | 14 | 14 |X||||||||||||||||||||X|||||X|X|X|X|||||||||||||||||||||||||X||||||
| 94 | Ast 2306 | 33 | 50 | 77 | 53 | 13 ||||||||||||||||||||X||||||||||||||||X|||||||||||||||||||||||
| 95 | Gos 1816 | 33 | 50 | 77 | 16 | 35 |X|||||X|X||||||X||X|||X|X||X||||X||X|X|X|X||||||||||X|||||||X|X|X||||||||X|
| 96 | Ast 2251 | 33 | 43 | 78 | 45 | 12 |X|||X||||||||||||X|X||||X||||X|X|X|X|X|||||||||||X|||||||||||||X|X|||||
| 97 | Gos 1463 | 33 | 41 | 78 | 16 | 16 |X|||X||X||||||||||||||X||||X|X|X|X|X||||||||||||X|X|||||||||X|||||X||||||
| 98 | Ast 2305 | 33 | 39 | 77 | 55 | 10 |X||||||||||||||||||||X||||||X|X||||||||||||||||||||||||||||||
| 99 | Gos 1458 | 33 | 40 | 77 | 45 | 17 |X|||||X||||||||||||||X||||X|X|X||X|||||||||||||||||||X|||||||||
| 100 | Gos 1821 | 33 | 39 | 76 | 59 | 38 ||||||X|X|||||||X||X|X|||||||X||X|X|||||||||||||X||X||||||X|X|||||X||||||
| 101 | Ast 2252 | 33 | 33 | 78 | 57 | 8 |X||||||||||||||||||||X|||||X|X|X|X||||||||||||||||||||||||||X|||||
| 102 | Gos 1465 | 33 | 30 | 78 | 30 | 20 |X|||||X|X|||||||X||X||||X||||X|X|X|X|X|||||||||||||||||||X|||||X||||||
| 103 | Gos 1462 | 33 | 21 | 78 | 15 | 22 |X||||X|||||||||X|||X|||X||||X|X|X|X|X|X|||||||||||X||X|||||||X|||||X||||||
| 104 | Gos 1805 | 33 | 29 | 77 | 30 | 22 |||||||X|||||||||||X|||X||||||X|||||||||||||||||||||||||||||||||
| 105 | Gos 1467 | 33 | 21 | 78 | 45 | 19 |X|||||||||||||||||X|||X||||X|X|X|X|X|||||||||||X|||||||||X|X||||||X|||||
| 106 | Gos 1792 | 33 | 22 | 78 | 01 | 22 |X|||||X|||||||||X||X|X|||X||||X|X|X|X|X|||||||||||X|||||||||X|X|||||X||||||
| 107 | Gos 1813 | 33 | 19 | 77 | 15 | 54 ||||||X|X|||||||X|X|X|X|X||X||||X|X|X|X|X|X|||||||||||X|||||||||X|X|||||X||||||
| 108 | Ast 2254 | 33 | 14 | 79 | 06 | 10 |X|||X||||||||||||X|X|||X|||X|X|X|X|X|X|||||||||||X|||X||||||||||||X|X||X|||
| 109 | Gos 1469 | 33 | 10 | 78 | 30 | 21 |X|||X||X|X|||||||X||||||||||X|X|X|X|X|||||||||||X|||||||||X|X|||||X||||||
| 110 | Gos 1793 | 33 | 10 | 78 | 01 | 38 |X|||||X|X|||||||X||X|X|X||X||||X|X|X|X|X|||||||||||X|||||||||X|X|X|||X||||||
| 111 | Ast 2258 | 33 | 00 | 79 | 11 | 13 |X|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||
| 112 | Gos 1472 | 32 | 59 | 79 | 00 | 16 |X|||||X|X|||||||X||X|X|X||X||||X|X|X|X|X|||||||||||X||||||||||X|X|||X|X|||||
| 113 | Gos 1789 | 32 | 59 | 78 | 15 | 38 ||||||X|X||||X|||X|||X|||||||X|||X|X|X|||||||||||X|||||||||X|X|X|||X||||||
| 114 | Gos 1474 | 32 | 49 | 78 | 44 | 32 ||||||X|X|||||||X||X||X||X||||X|X|X|X|X|X|||||||||||X|||||||||X||||||X||||||
| 115 | Gos 1782 | 32 | 43 | 78 | 30 | 69 ||||||X|X||||||X||X|X|X|X|||||X|X|X|X|X|X|||||||||||X|||||||||X|X|X|||X||||||
| P1-1 | | 36 | 48 | 76 | 10 | |X|X|||X||||||||||||||||X|X|X|X||X|X|X|X|||||X|||X||X||X|||||||||||X|X|X|X|X||X|
| P1-2 | | 36 | 48 | 76 | 10 | |X|X||X|||||||||||X|X|||X|X|X|X|X||X|X|X|X|||||X|X||X||X||X|||||||||||X|X|X|X|X|X|X|
| P2-1 | | 36 | 51 | 76 | 10 | |X|X||X|||||||||||X|X||||X|X|X|X||X||X|X||||||||X||X||X|||||||||||||X|X||X||X|
| P2-2 | | 36 | 51 | 76 | 10 | |X|X||X|X||||||||||||X|||X|X|X|X|X||X|X|X|X|||||X|||X||X||X||||||||||X|||X|X|X|X|X|X|
| P2-3 | | 36 | 51 | 76 | 10 | |X|X||X||||||||||||X||||X|X|X|||X|X||X||||||||||X||X|||||||||||||X|X|||||
| P3-1 | | 36 | 52 | 76 | 11 | |X|X||X||||||||||||X||||X|X||X||X|X|X|X|||||||X||X||X||X|||||||||||||X|X|X|||X|
| P4-1 | | 36 | 50 | 76 | 08 | ||X||X||||||||||||X|||X|X|X|X|X|X|X|X|X|X|||||X||X|||X||X|||||||||||||X|X|X||X|X|
| P5-1 | | 36 | 47 | 76 | 14 | |X|X||X||||||||||||X||||X|X|X|X||X|X|X||X|||||X|||||X||X|||||||||||||||X||X|X|
| P6-1 | | 36 | 46 | 76 | 22 | |X|X||X||||||||||||X|||X|X|X|X|X||X|X|X|X|X|||||||||X||X|||||||||||||X|X|X|X||X|

TABLE 1.—*Occurrences of 171 ostracode species in Holocene samples from the shelf off the middle Atlantic Coast of the United States and in Pleistocene samples from the Norfolk Formation, as used by Oaks and Coch (1963), of southeastern Virginia*—Continued

| Sample: Locality | Sample: Source | Latitude north: deg. | Latitude north: min. | Longitude west: deg. | Longitude west: min. | Depth (meters) | *Munseyella atlantica* Hazel and Valentine, 1969 | *Neocaudites triplistriatus* (Edwards, 1944) | *N.* sp. A | *Neolophocythere subquadrata* Grossman, 1967 | *N.* sp. A | *Neonesidea?* sp. A | *N.?* sp. B | *Orionina bradyi* van den Bold, 1963 | *O. vaughni* (Ulrich and Bassler, 1904) | *Paracypris* sp. A | *P.* sp. B | *Paracytheridea altila* Edwards, 1944 | *P. rugosa* Edwards, 1944 | *P.* sp. A | *Paradoxostoma delicata* Puri, 1954. | *P.* sp. A | *P.* sp. B | *P.* sp. C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Gos 1378 | 39 | 38 | 73 | 59 | 24 | | | | | | | | | | | | | | | | | | |
| 2 | Gos 1377 | 39 | 31 | 73 | 45 | 28 | | | | | | | | | | | | | | | | | | |
| 3 | Gos 1316 | 39 | 21 | 74 | 14 | 20 | | | | | | | | | | | | | | | | | | |
| 4 | Gos 1319 | 39 | 20 | 73 | 31 | 48 | | | | | | | | | | | | | | | | | | |
| 5 | Gos 1322 | 39 | 20 | 72 | 46 | 84 | | | | | | | | | | | | | | | | | | |
| 6 | Gos 1346 | 39 | 09 | 74 | 31 | 23 | | | | | | | | | | | | | | | X | | | |
| 7 | Gos 1345 | 39 | 10 | 74 | 15 | 21 | | | | | | | | | | | | | | | | | | |
| 8 | Gos 1340 | 39 | 10 | 73 | 15 | 62 | | | | | | | | | | | | | | | | | | |
| 9 | Ast 1965 | 39 | 00 | 74 | 45 | 15 | | | | | | | | | | | | | | | | | | |
| 10 | Gos 1351 | 39 | 01 | 74 | 00 | 38 | | | | | | | | | | | | | | | | | | |
| 11 | Gos 1338 | 39 | 01 | 73 | 01 | 80 | | | | | | | | | | | | | | | | | | |
| 12 | Gos 2026 | 38 | 50 | 74 | 45 | 18 | | | | | | | | | | | | | | | | | | |
| 13 | Gos 1354 | 38 | 51 | 73 | 32 | 62 | | | | | | | | | | | | | | | | | | |
| 14 | Gos 1355 | 38 | 49 | 73 | 15 | 81 | | | | | | | | | | X | | | | | | | | |
| 15 | Ast 2027 | 38 | 40 | 74 | 45 | 26 | | | | | X | | | | | | | | | | X | | | |
| 16 | Gos 2023 | 38 | 40 | 74 | 14 | 39 | | | | | | | | | | | | | | | | | | |
| 17 | Gos 1360 | 38 | 40 | 73 | 30 | 69 | | | | | | | | | | | | | | | | | | |
| 18 | Gos 2105 | 38 | 30 | 74 | 45 | 29 | | | | | | | | | | | | | | | | | | |
| 19 | Gos 1415 | 38 | 30 | 74 | 00 | 57 | | | | | | | | | | | | | | | | | | |
| 20 | Gos 1365 | 38 | 31 | 73 | 26 | 89 | | | | | | | | | | X | | | | | | | | |
| 21 | Gos 2032 | 38 | 20 | 74 | 30 | 36 | | | | | | | | | | | | | | | | | | |
| 22 | Gos 1417 | 38 | 10 | 74 | 15 | 41 | | | | | | | | | | | | | | | | | | |
| 23 | Gos 2036 | 38 | 00 | 75 | 00 | 18 | | | | | | | | | | | | | | | | | | |
| 24 | Gos 1418 | 37 | 59 | 74 | 29 | 49 | | | | | | | | | | | | | | | | | | |
| 25 | Gos 1891 | 38 | 00 | 73 | 59 | 129 | | | | | | | | | | | | | | | | | | |
| 26 | Ast 2001 | 37 | 49 | 75 | 25 | 12 | | | | | | | | | | | | | | | X | | X | |
| 27 | Gos 2038 | 37 | 50 | 74 | 45 | 41 | | | | | | | | | | | | | | | | | | |
| 28 | Gos 2041 | 37 | 40 | 75 | 14 | 24 | | | | | | | | | | | | | | | | | | |
| 29 | Gos 1420 | 37 | 39 | 74 | 42 | 49 | | | | | | | | | | | | | | | | | | |
| 30 | Gos 2045 | 37 | 31 | 75 | 30 | 16 | | | | | | | | | | | | | | | | | | |
| 31 | Gos 1886 | 37 | 31 | 74 | 30 | 64 | | | | | | | | | | | | | | | | | | |
| 32 | Gos 1885 | 37 | 27 | 74 | 29 | 406 | | | | | | | | | | X | X | | | | | | | |
| 33 | Gos 2047 | 37 | 19 | 75 | 16 | 29 | | | | | | | | | | | | | | | | | | |
| 34 | Gos 1422 | 37 | 20 | 75 | 00 | 38 | | | | X | X | | | | | | | | | | | | | |
| 35 | Gos 1883 | 37 | 20 | 74 | 46 | 56 | X | | | | | | | | | | | | | | | | | |
| 36 | Ast 1997 | 37 | 10 | 75 | 44 | 12 | | | | | | | | | | | | | | | | | | |
| 37 | Gos 2048 | 37 | 09 | 75 | 15 | 30 | | | | | | | | | | | | | | | | | | |
| 38 | Gos 1423 | 37 | 05 | 75 | 01 | 38 | | | | | | | | | | | | | | | | | X | X |
| 39 | Gos 2050 | 37 | 00 | 75 | 30 | 30 | | | | | | | | | | | | | | | X | | | |
| 40 | Gos 2051 | 37 | 00 | 75 | 15 | 36 | | | | | | | | | | | | | | | | | | |
| 41 | Gos 1424 | 37 | 02 | 75 | 00 | 44 | | | | | X | | | | | | | | | | | | | |

| Locality | *P.* sp. D | *P.* sp. E | *P.* sp. F | *P.* sp. G | *Paranesidea?* sp. A | *P.?* sp. B | *P.?* sp. C | *P.?* sp. D | *Pellucistoma magniventra* Edwards, 1944 | *P.* sp. A | *Phlyctocythere* sp. A | *P.* sp. B | *Pontocypris* sp. A | *Propontocypris edwardsi* (Cushman, 1906) | *P.* aff. *P. howei* (Puri, 1954) | *Proteoconcha gigantica* (Edwards, 1944) | *P.* multipunctata (Edwards, 1944) | *P.* nelsonensis (Grossman, 1967) | *P.* tuberculata (Puri, 1960) |
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| 14 | | | | | | | | | | | | | X | | | | | | |
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| 24 | | | | | | | | | | | | | | | | | | | X |
| 25 | | | | | | | | | | | | | | | X | | | | |
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| 28 | | | | | | | | | | | | | | | | | | | X |
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| 32 | | | | | | | | | | | | | X | | | | | | |
| 33 | | | | | | | | | | | | | | | X | | | | |
| 34 | | | | | | | | | | | | | | | | | | | |
| 35 | | | | | | | | | | | | | | | | | | | |
| 36 | | | | | | | | | | | | | | | | X | | | |
| 37 | | | | | | | | | | | | | | | X | | | | |
| 38 | | | | | | | | | | | | | | | X | | | | |
| 39 | | | | | | | | | | | | | | | X | | | | |
| 40 | | | | | | | | | | | | | | | X | X | | | |
| 41 | | | | | | | | | | | | | | | X | | | | |

| Locality | *Protocytheretta daniana* (Brady, 1869) | *P.* aff. *P. sahnii* (Puri, 1952) | *Pseudocytheretta edwardsi* Cushman, 1906 | *Pterygocythereis americana inexpetata* (Blake, 1929) | *P.* sp. A | *Puriana fissispinata* Benson and Coleman, 1963 | *P. floridana*, Puri, 1960 | *P. rugipunctata* (Ulrich and Bassler, 1904) | *P.* sp. A | *P.* sp. B | "*Sahnia*" cf. "*S.*" *subulata* (Brady, 1868) | "*S*" sp. A | "*S*" sp. B | *Sclerochilus* sp. A | *S.* sp. B | *S.* sp. C | *S.* sp. D | *Triebelina?* sp. A |
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| 4 | | | X | X | | | | | | | | X | | | | | | |
| 5 | | | | | | | | | | | | | | | | | | |
| 6 | | | X | | | | | | | | X | X | | | | | | |
| 7 | | | | | | | | X | | | | | | | | | | |
| 8 | | | X | | | | | | | | | X | | | | | | |
| 9 | | | | | | | | | | | X | X | | | | | | |
| 10 | | | X | | | | | | | | | | | | | | | |
| 11 | X | | | X | | | | | | | | | | | | | | |
| 12 | X | | X | | | | | X | | | X | X | | | | | | |
| 13 | | | | | | | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | | | | | | | |
| 15 | | | X | | | | | X | | | X | X | | | | | | |
| 16 | | | | | | | | | | | | | | | | | | |
| 17 | | | | X | | | | | | | | X | | | | | | |
| 18 | | | X | | | | | X | | | | | | | | | | |
| 19 | | | X | X | | | | X | | | | X | | | X | | | |
| 20 | X | | | | | | | | | | | | | | | | | |
| 21 | | | X | | | | | | | | | | | | | | | |
| 22 | | | X | | | | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | | | | | | |
| 24 | | | X | X | | | | X | | | | X | | | | | | |
| 25 | | | | X | | | | | | | | | | | | | | |
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| 27 | | | | | | | | | | | | X | | | | | | |
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| 29 | | | X | X | | | | | | | | | | | | | | |
| 30 | | | X | | | | | | | | X | | | | | | | |
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| 32 | | | | X | | | | | | | | X | | | | | | |
| 33 | | | X | | | | | | | | | X | | | | | | |
| 34 | X | X | X | | | | | X | | | | X | | | | | | |
| 35 | | | X | X | | | | X | | | | X | | | X | | | |
| 36 | X | X | | | | | | | | | X | X | | | | | | |
| 37 | X | | X | | | | | X | | | | X | | | | | | |
| 38 | X | | X | X | | | X | X | | | | X | | | | | | |
| 39 | | X | X | | | | X | | | | | X | X | | | | | |
| 40 | X | X | X | | | | X | X | | | | X | | | | | | |
| 41 | | | X | X | | | | X | | | | X | | | | | | |

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| | X | | | | | | | | X | | X | X | | | | | | | X | | X | | | | X | | | | | X | X | | | X | X | X | | | | | | X | | | X | | X | X | X | | | | X | X | X | | X | X | | | X | X | | X | X | | X | X | X | | X | X | | | | | | | | | | | |
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| | X | X | X | | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | X | | | X | | X | X | | | | | X | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | X | X | X | | X | X | |
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| 45 | 45 | 15 | 59 | 31 | 15 | 58 | 45 | 45 | 30 | 14 | 30 | 58 | 14 | 15 | 00 | 15 | 02 | 15 | 58 | 27 | 15 | 59 | 28 | 15 | 38 | 48 | 29 | 21 | 57 | 31 | 17 | 00 | 44 | 31 | 00 | 45 | 15 | 44 | 45 | 38 | 14 | 17 | 47 | 16 | 01 | 44 | 44 | 14 | 30 | 29 | 14 | 53 | 16 | 45 | 16 | 55 | 45 | 59 | 57 | 30 | 15 | 30 | 45 | 01 | 15 | 06 | 30 | 01 | 11 | 00 | 15 | 44 | 30 | 10 | 10 | 10 | 10 | 10 | 11 | 08 | 14 | 22 |
| 74 | 75 | 75 | 74 | 75 | 75 | 74 | 74 | 75 | 75 | 75 | 75 | 74 | 75 | 75 | 75 | 75 | 75 | 75 | 74 | 75 | 75 | 74 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 76 | 75 | 75 | 76 | 75 | 76 | 76 | 77 | 76 | 76 | 76 | 77 | 77 | 76 | 76 | 77 | 76 | 78 | 78 | 77 | 77 | 78 | 78 | 77 | 77 | 76 | 78 | 78 | 78 | 77 | 78 | 78 | 77 | 79 | 78 | 78 | 79 | 79 | 78 | 78 | 78 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 |
| 57 | 49 | 50 | 45 | 39 | 40 | 39 | 40 | 20 | 20 | 20 | 10 | 09 | 00 | 51 | 50 | 40 | 41 | 31 | 29 | 26 | 20 | 21 | 16 | 11 | 09 | 08 | 07 | 07 | 03 | 59 | 01 | 58 | 56 | 51 | 50 | 46 | 40 | 37 | 38 | 37 | 33 | 30 | 21 | 20 | 18 | 14 | 09 | 10 | 00 | 00 | 49 | 50 | 50 | 43 | 41 | 39 | 40 | 39 | 33 | 30 | 21 | 29 | 21 | 22 | 19 | 14 | 10 | 10 | 00 | 59 | 59 | 49 | 43 | 48 | 48 | 51 | 51 | 51 | 52 | 50 | 47 | 46 |
| 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 34 | 35 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 32 | 32 | 32 | 32 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 |
| Gos 1880 | Gos 2057 | Gos 2052 | Gos 1425 | Gos 2054 | Gos 2053 | Gos 1426 | Gos 1878 | Gos 2060 | Gos 2062 | Gos 1428 | Gos 2063 | Gos 1874 | Gos 1430 | Gos 1431 | Gos 1872 | Gos 1432 | Gos 1871 | Gos 1433 | Gos 1870 | Ast 2324 | Gos 1434 | Gos 1869 | Ast 2323 | Gos 1435 | Ast 2321 | Ast 2320 | Ast 2322 | Gos 1436 | Ast 2319 | Gos 1437 | Gos 1865 | Gos 1439 | Gos 1438 | Gos 1863 | Gos 1440 | Gos 1861 | Gos 1442 | Gos 1860 | Ast 2313 | Ast 2314 | Ast 2311 | Gos 1443 | Gos 1446 | Gos 1444 | Gos 1449 | Ast 2308 | Gos 1847 | Gos 1849 | Gos 1453 | Gos 1845 | Ast 2249 | Ast 2306 | Gos 1816 | Ast 2251 | Gos 1463 | Ast 2305 | Gos 1458 | Gos 1821 | Ast 2252 | Gos 1465 | Gos 1462 | Gos 1805 | Gos 1467 | Gos 1792 | Gos 1813 | Ast 2254 | Gos 1469 | Gos 1793 | Ast 2258 | Gos 1472 | Gos 1789 | Gos 1474 | Gos 1782 | | | | | | | | | |
| 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | P1-1 | P1-2 | P2-1 | P2-2 | P2-3 | P3-1 | P4-1 | P5-1 | P6-1 |

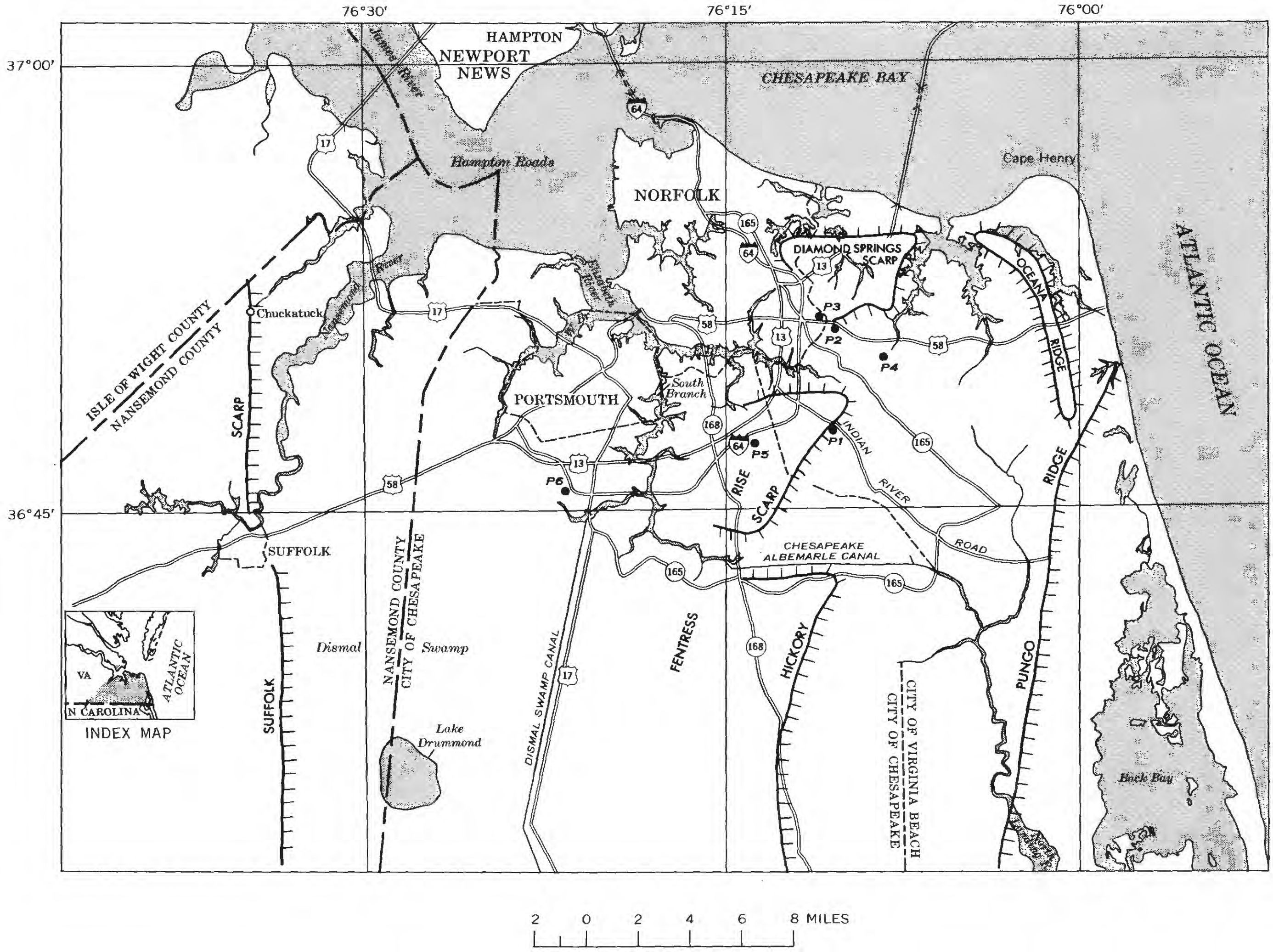


**Figure 1.**—Map of southeastern Virginia indicating important geomorphologic features and localities sampled (P1–P6) in the Norfolk Formation as used by Oaks and Coch (1963).

underlie more than one plain; and (4) both marine and nonmarine formations are present. Five major periods of submergence before the post-Wisconsin submergence have been postulated to explain the stratigraphic relations of the eight post-Yorktown formations which they recognize in this region (the Yorktown Formation is the youngest unit of the Chesapeake Group and in this region is generally considered to be of late Miocene and early Pliocene age).

The post-Yorktown, pre-Holocene sediments which underlie the coastal plain of southeastern Virginia between the Suffolk Scarp and the sea (fig. 3) were designated the Late Columbia Formation and "Pliocene" by Darton (1902); were divided into the Dismal Swamp and Princess Anne Formations by Wentworth (1930); and were designated the Nansemond Formation by Moore (1956). These sediments were divided by Oaks (1964) and Coch (1968) into five formations of Pleistocene age. With the exception of one sample from the overlying Kempsville Formation, the ostracode assemblages for this study were collected from the Norfolk Formation, which is the most widespread and fossiliferous of these formations (see figs. 1, 2, and 3).

The Norfolk Formation was described by Clark and Miller (1906) as consisting of fossiliferous clays and sands of Pliocene age exposed in deep cuts along the Dismal Swamp Canal and buried elsewhere in southeastern Virginia under thick Pleistocene sediments. No type section was designated. The formation was assigned a Pliocene age on the basis of earlier identifications of mollusks (presumably collected from the same beds) made by L. Woolman (in Darton, 1902). Subsequently, Clark and Miller (1912, p. 175, 187–188), on the basis of J. A. Gardner's identification of a molluscan assemblage from the Dismal Swamp Canal, considered these fossiliferous beds to be part of the Talbot Forma-

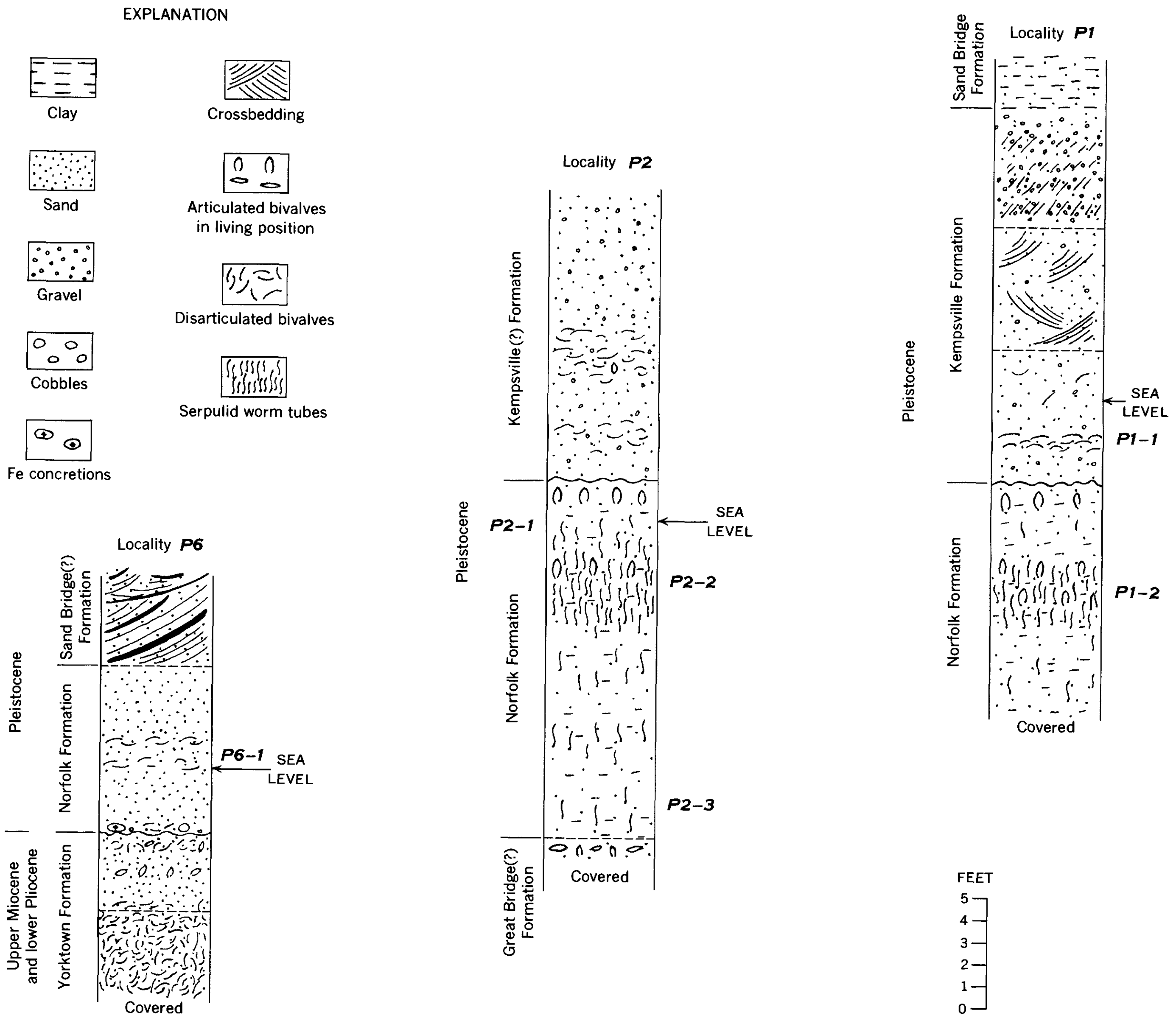


FIGURE 2.—Measured sections at late Pleistocene localities P1, P2, and P6 in southeastern Virginia.

tion of Shattuck (1901) of Pleistocene age. Oaks (1964, p. A10) described a boring in the Dismal Swamp (1.5 miles west of the Dismal Swamp Canal) and designated it the type section of the Norfolk Formation.

The redefined Norfolk Formation extends east and west of the Suffolk Scarp (figs. 1, 3) and consists of two members. The lower member extends in the subsurface eastward from the Suffolk Scarp as a bed of medium to coarse sand and gravel of beach origin. The upper member, west of the Suffolk Scarp, consists of clayey sands of fluvial-estuarine origin exposed at an altitude of 45 to 50 feet or 15–16 m (meters); along the scarp this member crops out as fine to coarse dune and beach sands which reach an altitude of 70 feet. In the area immediately south of the James River, the upper member consists of estuarine silty sands. Marine clayey and silty sands of this member underlie the area farther south of the James River and east of the Suffolk Scarp; the top of the formation in this area is 0 to 10 feet (0–3 m) above present sea level, except in the Fentress Rise where these sediments are exposed at altitude of 17 to 25 feet (5–8 m).

The Norfolk Formation, according to Oaks (1964), represents the marine phase of a late Pleistocene interglacial transgression of the sea. This transgression began with the deposition of the Great Bridge Formation, which comformably underlies the Norfolk Formation and contains a restricted molluscan fauna indicative of

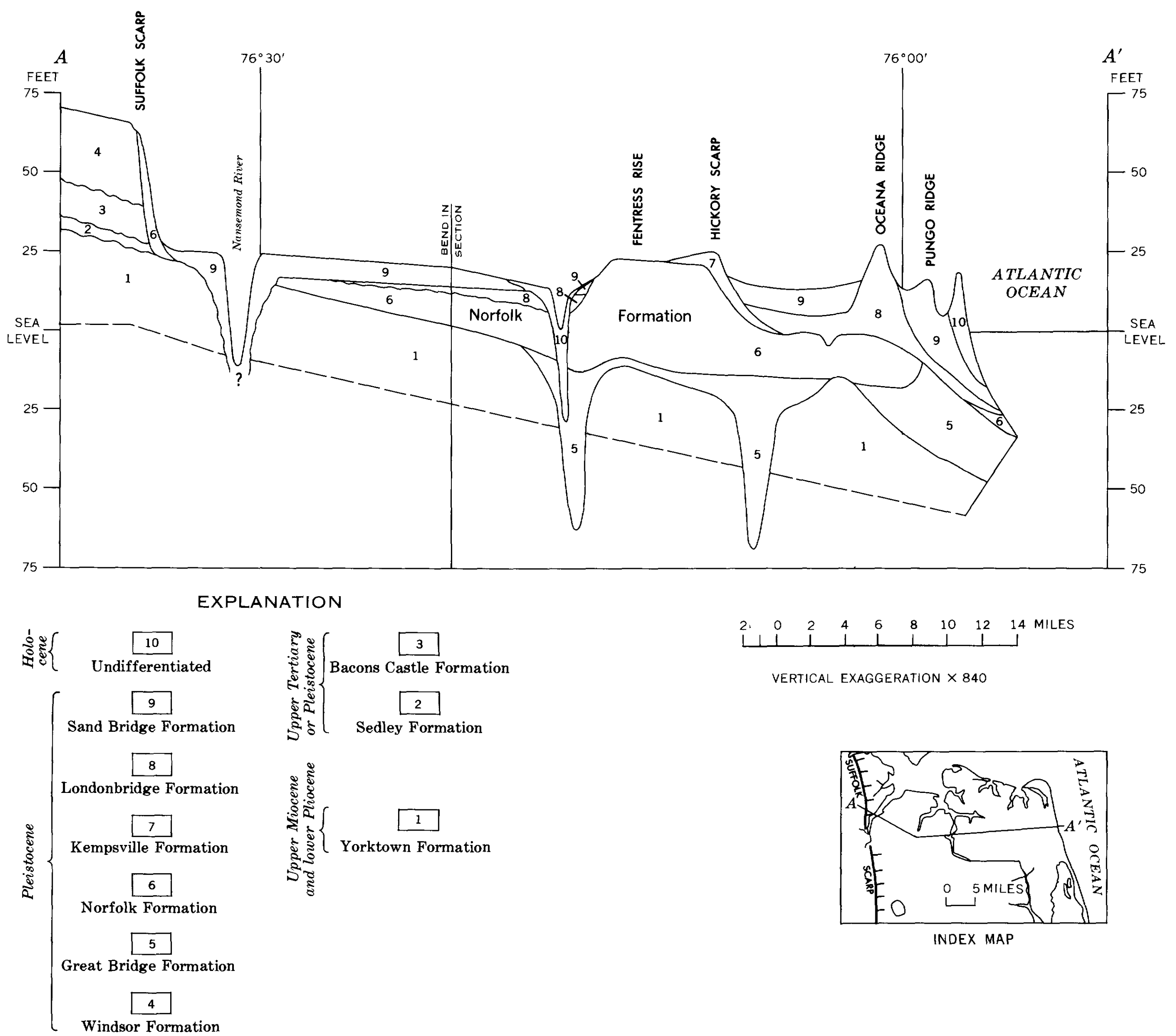


**Figure 3.**—Geologic section across southeastern Virginia from the Suffolk Scarp to the Atlantic coast. Adapted from Oaks (1964, figs. 25, 28) and Coch (1968, fig. 5).

an estuarine or open bay environment of lower than normal salinity (H. G. Richards in Oaks, 1964, p. 109). Although Norfolk sediments are principally marine, estuarine deposits of Norfolk age occur west of the Suffolk Scarp and along the south edge of the James River east of the scarp. The occurrence of beach sands, of Norfolk age at an altitude of 45 feet (15 m)—dune sands occur up to 70 feet (23 m) (Coch, 1968)—along the erosional Suffolk Scarp, and estuarine deposits west of the scarp at 50 feet (16 m) indicate that the sea extended approximately 35 miles (56 km) westward from the present coast and was 45 to 50 feet (15–16 m) above present sea level. The altitude of the collected samples relative to present sea level indicates, if possible minor tectonic effects are discounted, that these marine sediments were deposited at depths of 20 m or less. The thickness of the Norfolk Formation (10–50 ft, about 3–16 m), of both estuarine sediments west and marine sediments east of the Suffolk Scarp, indicates that the transgressive sea of Norfolk time was stable for a long period (Oaks, 1964). According to H. G. Richards (in Oaks, 1964, p. 122), Pleistocene molluscan assemblages of the Norfolk Formation are similar to nearshore assemblages which today occur only farther south in waters warmer than the present coastal waters of southeastern Virginia. Radiocarbon dating of wood found in the Great Bridge, Norfolk, and Kempsville Formations gives an age greater than $40\times10^3$ years B.P. (before present) (Oaks, 1964, table 2), and the Great Bridge-Norfolk transgression is thought to represent the Sangamon Interglaciation.

The maximum development of the last glacial stage in North America, the Wisconsin Glaciation, has been dated at about $16\times10^3$ years B.P. on the basis of radiometric ages of shallow-water marine deposits associated with a maximum regression of sea level to about −425 feet (−130 m) relative to present sea level (Milliman and Emery, 1968). The preceding Sangamon Interglaciation, representing a significant rise in sea level, is much more difficult to date. On the east coast of the United States a Sangamon age has been tentatively assigned to relict shorelines which parallel the present coast and appear to represent the last major stabilized rise of the sea above its present level. Radiocarbon dates of fossil wood in sediments apparently contemporaneous with these shorelines in southeastern Virginia have given ages of greater than $40\times10^3$ years B.P. (Oaks, 1964). Recent radiometric dating of shorelines that are at higher elevations than present sea level suggests that the Sangamon Interglaciation reached its maximum development between $75\times10^3$ years B.P. and $125\times10^3$ years B.P. (Broecker, 1965; Broecker and others, 1968; Hopkins, 1967; Osmond and others, 1965; Veeh, 1966, Veeh and Chappell, 1970).

## HOLOCENE COLLECTIONS

Holocene samples for this study were collected from the continental shelf off the middle Atlantic Coast of the United States from about 32°30′ to 40° N. (fig. 4) as part of the joint U.S. Geological Survey-Woods Hole Oceanographic Institution program of study of the Atlantic continental margin of the United States (Emery, 1966). The geographic location, depth and species content of all samples used in the present study are presented in table 1 (also see Hathaway, 1966). Of the 133 samples processed, 115 contained ostracode assemblages, and 159 species were identified by the author of this report. Only 66 of the species have been formally described; however, several of the undescribed forms have been misidentified and are illustrated in the literature. Nearly all species were represented by living as well as dead specimens. Eighty percent of the samples were collected from depths of 10 to 50 m; only three samples were collected at depths greater than 100 m. The 18 barren samples were composed of very coarse sand or worn shell fragments and were generally from shallow water near the coast (fig. 4).

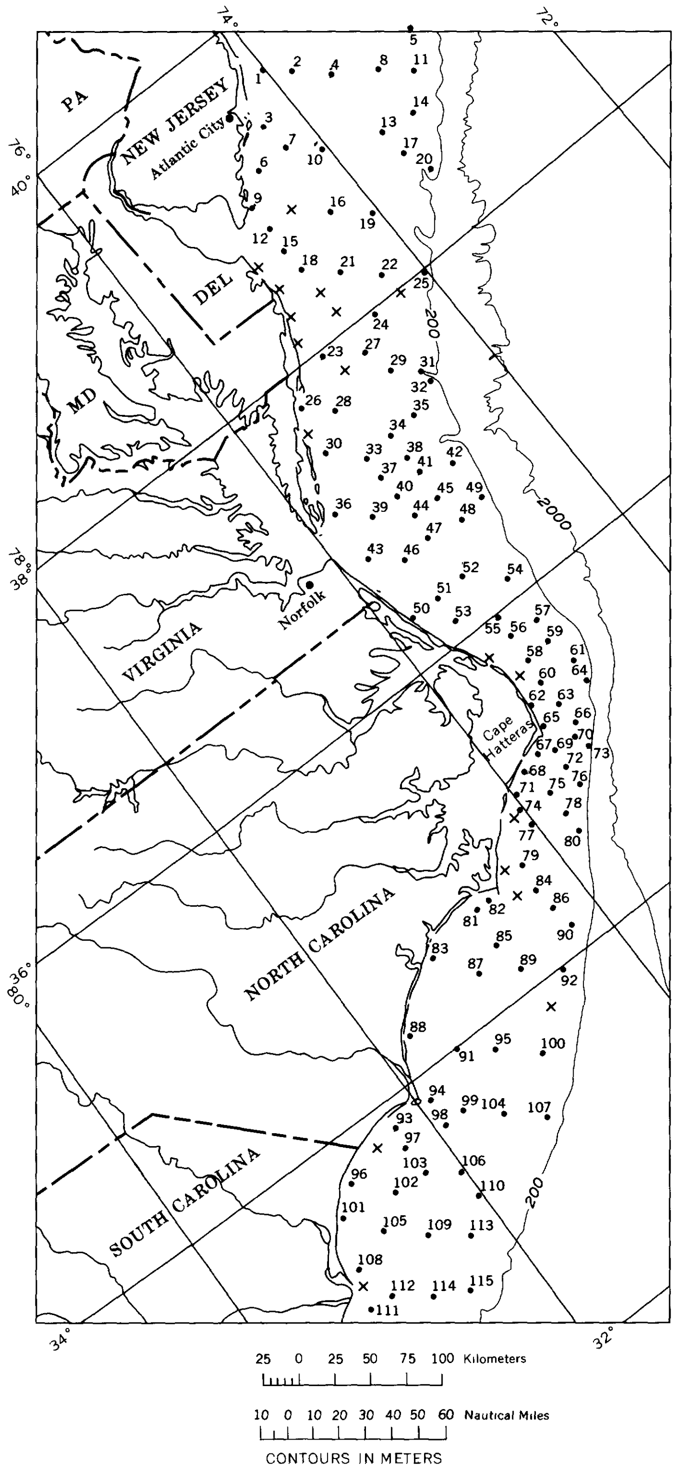


FIGURE 4.—Map showing locations of Holocene sample stations. For exact location see table 1. Symbol X indicates that sample did not contain ostracodes.

The shelf sediments in the study area are principally relict upper Pleistocene quartzose silts and sands

(Emery, 1968, fig. 8). The carbonate content of the sediments north of Cape Hatteras is low (generally less than 5 percent) but increases significantly south of the cape and locally reaches values greater than 50 percent (Milliman and others, 1968, fig. 3).

## HOLOCENE SPECIES DISTRIBUTIONS

### FAUNAL PROVINCES AND CLIMATIC ZONES OF THE NORTH ATLANTIC OCEAN

The geographic distribution of marine organisms indicates that the sublittoral areas of the world can be divided into regions that are characterized by certain assemblages of species. The boundaries of these regions, or faunal provinces, are areas in which the geographic ranges of assemblages terminate or overlap with assemblages of neighboring provinces. Geographic ranges of marine organisms are influenced by water temperature, salinity, substrate, available food and light, and myriad other ecological relations. The effect of water temperature on the metabolism and reproduction of organisms is considered the fundamental factor determining species and assemblage distribution and therefore the geographic extent of sublittoral faunal provinces (Gunter, 1957; Kinne, 1963; Hall, 1964). The marine temperature of a region of the continental shelf is determined chiefly by its latitudinal position and the configuration of oceanic currents. Coastal topography at many places interferes with marine circulation patterns and causes an abrupt change in the climatic regime, thus creating a province boundary (Valentine, 1963).

Along the Atlantic coast of North America the northerly drift of warm water and the southerly drift of cool water interact at several points and cause isotherm convergences. At Cape Hatteras, warm southern shelf waters, influenced by the offshore Florida Current, meet the cool northern shelf waters of the Virginian Coastal Current. Farther north along the coast a similar situation prevails at Cape Cod, Mass., where cold northern waters influenced by the Labrador Current interact with the warm southern water of the Gulf Stream. The convergence of isotherms creates a temperature gradient which is a formidable barrier to species distribution; as a result the faunal provinces of this part of the western North Atlantic are sharply delineated. The North Atlantic Drift, of which the Gulf Stream is a part, proceeds northeast from off Newfoundland, warms the higher latitudes of the eastern North Atlantic Ocean, and prevents isotherm convergences along the European coast. Consequently, there are no prominent temperature barriers along that coast, and faunal provinces are relatively poorly delineated, the areas of overlapping species ranges being very large.

The sublittoral faunal provinces of the North Atlantic Ocean have been established by many workers on the basis of the distribution of shallow-water and intertidal organisms. The geographic limits of the provinces recognized by various authors differ little, but confusion has been caused by the varied nomenclature of faunal-provinces and climatic-zones. Hazel (1970) reviews the development of the concept of faunal provinces and climatic zones in the North Atlantic Ocean. Six faunal provinces have been delineated along the east coast of North America and are, from north to south: Arctic, Labrador, Nova Scotian, Virginian, Carolinian, and Caribbean (Hazel, 1970). Holocene samples used in the present study were collected from the southern Virginian province (Cape Cod to Cape Hatteras) and from the northern Carolinian province (Cape Hatteras to Cape Kennedy).

The importance of the marine climate on the formation of faunal provinces is expressed in the establishment of sublittoral climatic zones whose boundaries are coincident with those of faunal provinces. Climatic zones, unlike faunal provinces, are characterized by and equated in such qualitative terms as frigid, subfrigid, cold-temperate, mild-temperate, warm-temperate, subtropical, and tropical. The configuration of currents in the North Atlantic and North Pacific ocean basins causes isotherm convergences and temperature gradients in the western parts and produces a more equable marine climate in the eastern parts of the basins; therefore, similarly named climatic zones in eastern (or western) parts of different ocean basins are more likely to resemble each other thermally than similarly named zones on opposite sides of the same basin. The temperature regimes on opposite sides of the same basin are so different that even if the same species were present off both the eastern and western coasts of an ocean basin, faunal provinces on one side would have little similarity to those on the other side. Along the east coast of North America the sublittoral faunal provinces and equivalent climatic zones are: Arctic—frigid; Labrador—subfrigid; Nova Scotian—cold-temperate; Virginian—mild-temperate; Carolinian—subtropical; Caribbean—tropical. At present there is no warm-temperate faunal province in this region.

### LATITUDINAL RANGES OF HOLOCENE SPECIES

The occurrence of Holocene ostracodes on the continental shelf off North America from 32°30′ to 40°N. indicates that the marine climatic conditions that prevail at Cape Hatteras, N.C., form a significant barrier to ostracode species distribution. Of the 159 species identified, 105 occur at more than five stations, and 54 species are rare. The following is a list of 19 well-known species found only north of Cape Hatteras and 28 well-known species found only south of the cape:

*North of Cape Hatteras*

*Actinocythereis dawsoni*
  *vineyardensis*
*Bensonocythere arenicola*
  sp. A
  sp. B
  sp. C
  sp. D
*Bythocythere* sp. A
*Cushmanidea seminuda*
*Cytheridea* sp. A
*Cytheropteron pyramidale*
*Cytherura wardensis*
*Finmarchinella finmarchica*
*Leptocythere angusta*
*Loxoconcha impressa*
  *sperata*
*Muellerina canadensis*
*Neolophocythere* sp. A
*Puriana rugipunctata*

*South of Cape Hatteras*

*Bythocythere* sp. B
*Cytherelloida* sp. A
*Cytherura reticulata*
  aff. *C. sablensis*
  sp. F
  sp. G
*Eucythere triangulata*
*Hulingsina glabra*
*Loxoconcha reticulata*
*Loxocorniculum postdorsolatum*
*Macrocyprina propinqua*
  sp. A
  sp. B
*Neocaudites* sp. A
*Neonesidea?* sp. A
  sp. B
*Orionina bradyi*
*Paracytheridea altila*
  *rugosa*
  sp. A
*Paranesidea?* sp. A
  sp. B
  sp. C
*Pellucistoma magniventra*
  sp. A
*Proteoconcha multipunctata*
*Puriana* sp. A
  sp. B

The late Pleistocene ostracode assemblage from southeastern Virginia comprises 82 species, 70 of which are still living. In order that we may determine if a relation exists between the Pleistocene and Holocene assemblages of the study area, the modern latitudinal ranges of 68 Pleistocene species are plotted in figure 5. The ranges of 64 of the species overlap between 35° and 35°30′ north latitude. This area is just off Cape Hatteras, where the shelf is narrowest for the region (30–35 km), and the shelf-slope break occurs at about 50-m depth. It appears from this evidence that the Pleistocene assemblage may be represented by the same species in a Holocene assemblage in this small area. A comparison of Pleistocene and Holocene samples on the basis of their constituent species was undertaken to explore their relation more fully.

## HOLOCENE SHELF ASSEMBLAGES DEFINED BY CLUSTER ANALYSIS

In order to establish relations between Holocene shelf samples, the author arranged for Dice coefficients of similarity [$(2C/N_1+N_2)\times 100$, where $C$=the number of species in common between the two samples containing $N_1$ and $N_2$ species; see Cheetham and Hazel, 1969] to be calculated and the samples clustered using the unweighted pair-group method of Sokal and Michener (1958). The matrix was 159 species by 91 samples (24 small samples were eliminated). The dendrogram (fig. 6) indicates that the samples segregate into two major clusters, A and B, on the basis of species content. Clusters A and B contain only samples occurring north or south of Cape Hatteras and provide further evidence that there is a boundary between the Virginian and Carolinian faunal provinces at the cape. Each of the major sample clusters has two subclusters. Cluster A contains subclusters 1 and 2 and includes a minor group of samples (12, 28, 30, and 26) which exhibits very low similarity internally between its constituent samples as well as externally to samples in subclusters 1 and 2. Cluster B is composed of subclusters 3 and 4 and also includes samples 83 and 104 which show low similarity to the other samples in cluster B.

A shaded similarity matrix (trellis diagram) (Sokal and Sneath, 1963; Valentine and Peddicord, 1967) using 20-point classes was constructed. The midpoint of each class was used to calculate average similarity coefficients within and between subclusters. See figure 7, a synoptic similarity matrix which provides a somewhat quantitative representation of the relations indicated by the dendrogram (fig. 6).

## BIOFACIES OF THE SHELF

The geographic distribution of the 105 most widespread of the 159 Holocene ostracode species was compared to the distribution of the sample subclusters. Each subcluster contains a characteristic assemblage or biofacies that indicates certain environmental conditions (fig. 8, table 2). Biofacies 1 contains chiefly

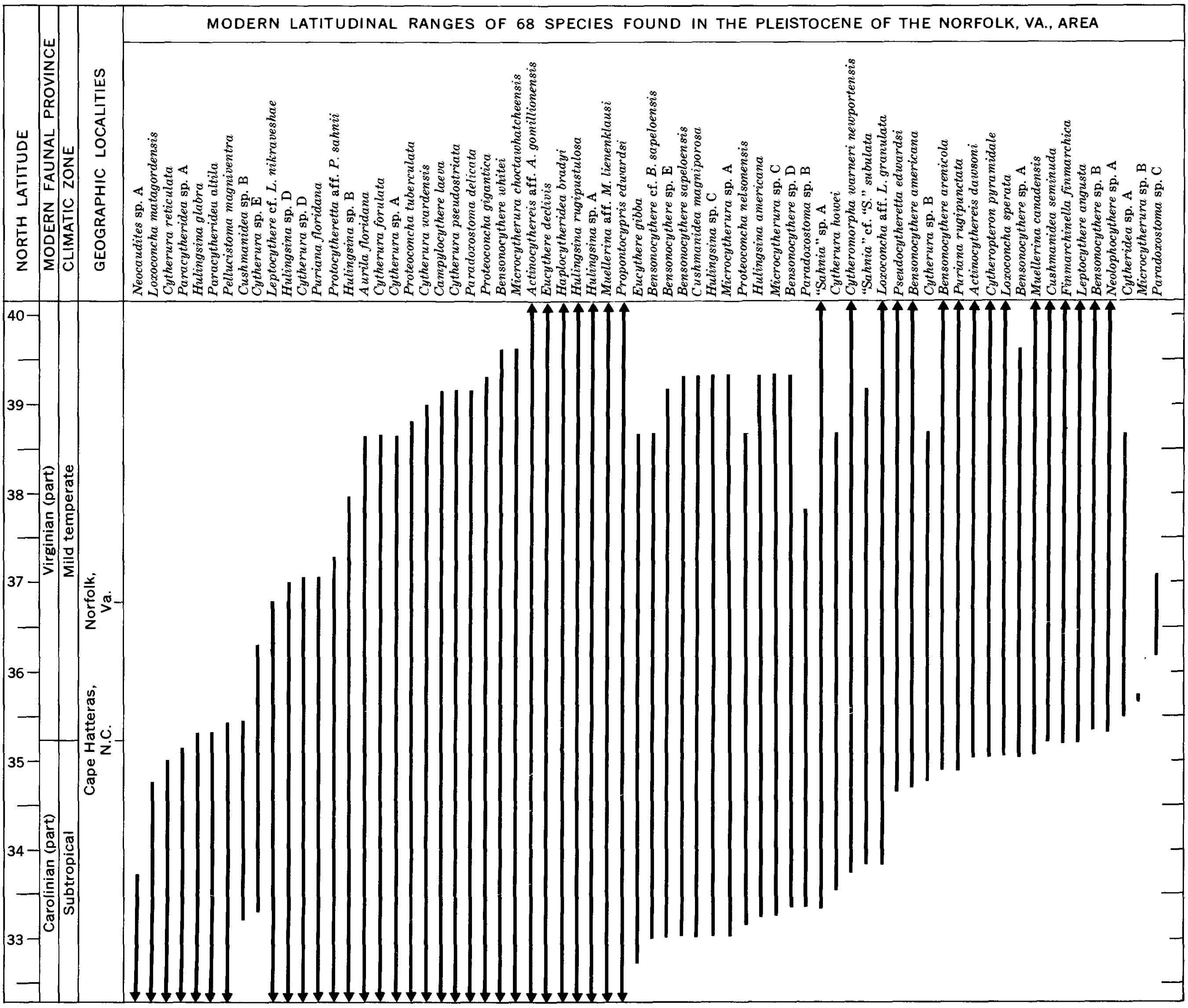


FIGURE 5.—Modern latitudinal ranges along the middle Atlantic Coast of the United States of 68 ostracode species common to the Holocene and the Norfolk Formation as used by Oaks and Coch (1963).

northern forms that do not occur south of Cape Hatteras. Biofacies 2 contains the northern forms of 1 in addition to species that occur north and south of the cape. Biofacies 3 contains species occurring north and south of the cape. Biofacies 4 is composed of species occurring north and south as well as species restricted to south of the cape. Biofacies 2 and 4 have large assemblages, whereas 1 and 3 have less species diversity. Biofacies 2 contains most of the principal species of 1 and 3; biofacies 4 contains most of the principal species of only 3. These relations are shown in figure 7.

The composition of each biofacies is controlled by environmental factors. Temperature is the principal factor in areas as large as those being examined, but in the area occupied by biofacies 3, substrate and energy conditions are important. Temperatures characteristic of the four biofacies were derived from maps showing average monthly bottom temperatures in 2.5°C contour intervals (Walford and Wicklund, 1968). Biofacies 1 experiences a yearly temperature range of 2.5°–5°C to 12.5°–15°C, biofacies 2 a range of 2.5°–5°C to 20°–22.5°C, and biofacies 3 and 4 a range of 12.5°–15°C to higher than 27.5°C.

The effect of substrate on the composition of the biofacies is difficult to determine. Detailed mapping of bottom sediments has been done only south of Cape Hatteras (Cleary and Pilkey, 1968; Milliman and others, 1968, fig. 3). Most shelf sediments are Pleisto-

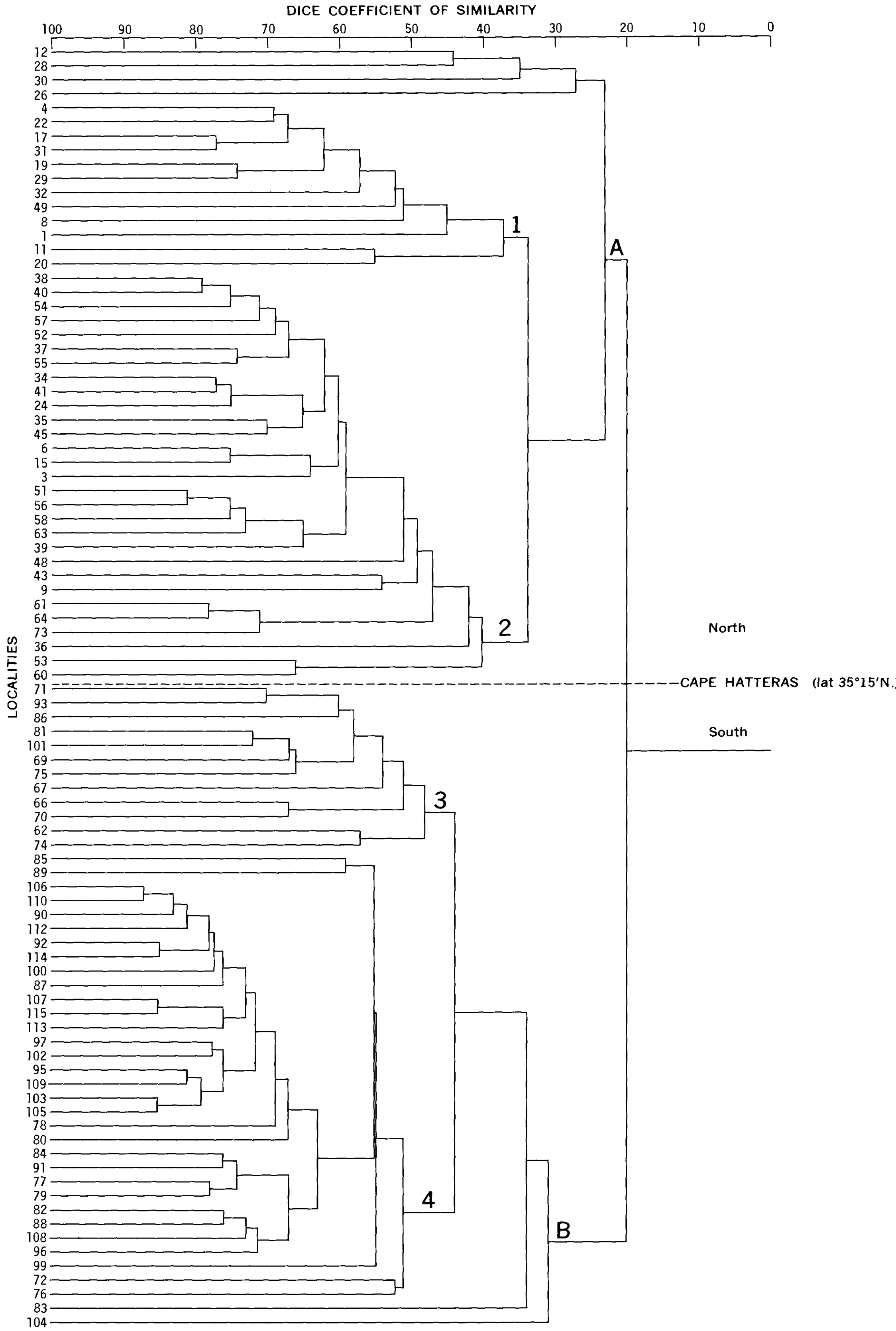


FIGURE 6.—Dendrogram of Holocene sample clusters. Samples are compared on the basis of their ostracode species composition using the Dice similarity coefficient $(2C/N_1+N_2)\times100$; clustering was by the unweighted pair-group method.

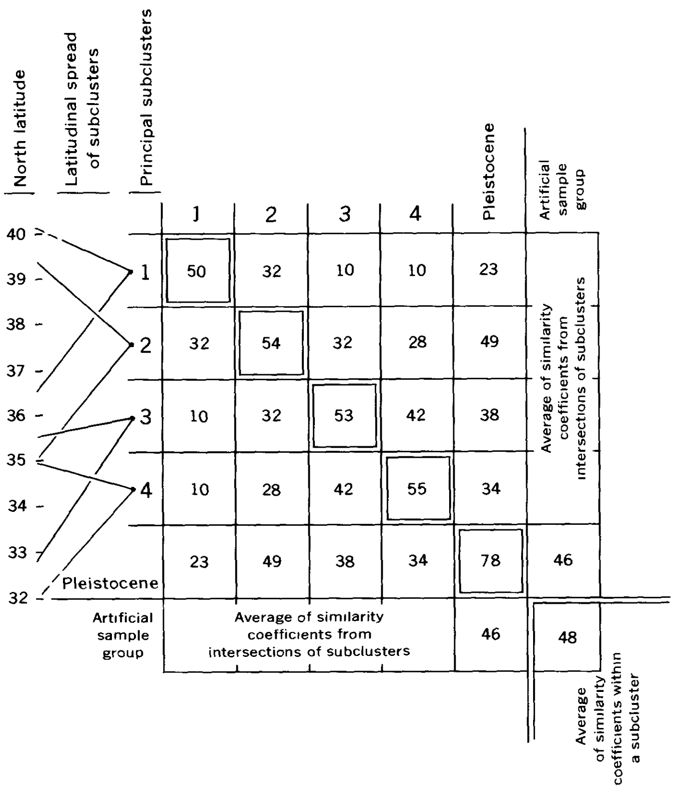


FIGURE 7.—Similarity matrix using Dice coefficient $(2C/N_1+N_2)$ $\times 100$ showing relation between clusters of Holocene and Norfolk Formation samples and also between the Norfolk cluster and an artificial sample grouping based on latitudinal overlaps of species.

cene relict quartz sands, but the carbonate content increases significantly south of the cape. Biofacies 1 and 2 are associated with quartz sands. Biofacies 4 is generally restricted to sediments containing greater than 5 percent calcium carbonate. Biofacies 3, a small assemblage characterized by many robust forms (*Aurila floridana*, *Campylocythere laeva*, *Cushmanidea magniporosa*, *Cytheromorpha warneri newportensis*, *Haplocytheridea bradyi*, *Hulingsina americana*, *Hulingsina rugipustulosa*, *Hulingsina* sp. A, *Hulingsina* sp. B, *Hulingsina* sp. C, *Proteoconcha gigantica*, *Proteoconcha nelsonensis*, *Proteoconcha tuberculata*, *Protocytheretta daniana*, *Protocytheretta* aff. *P. sahnii*, *Puriana floridana*, and *Puriana* sp. A) is restricted to areas of coarse quartzose sediment generally containing less than 5 percent calcium carbonate. These areas are best developed off Cape Hatteras, at Cape Lookout Shoals (loc. 86), Frying Pan Shoals (loc. 98), in the nearshore areas of bays (loc. 68, 74, 101), and off inlets in barrier islands (loc. 71, 81, 93) (fig. 8). Biofacies 3 is best developed in the area off Cape Hatteras and appears discontinuous to the south. Because its species can tolerate temperatures greater than 27.5°C, biofacies 3 may exist intermittently in nearshore areas south of the study area.

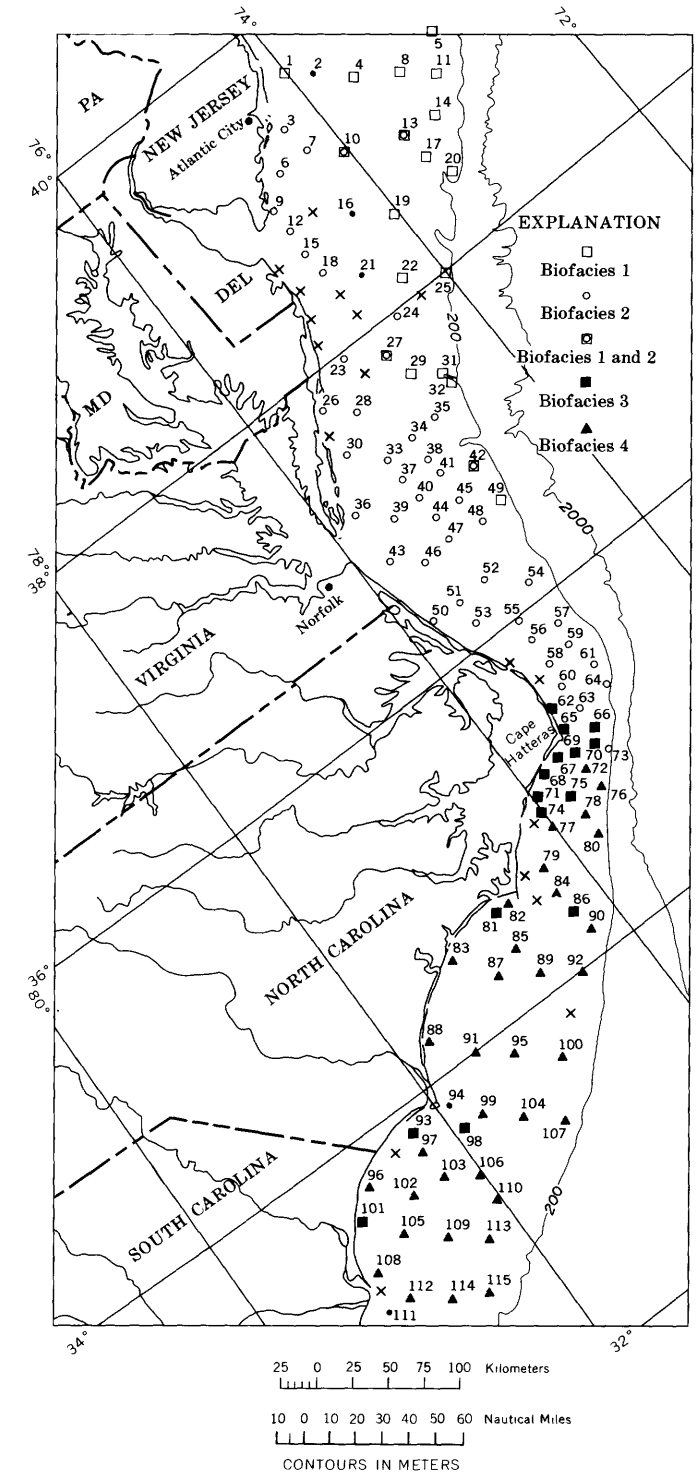


FIGURE 8.—Map showing the geographic extent of four ostracode biofacies delineated on the shelf off the middle Atlantic Coast of the United States. Symbol X indicates that sample did not contain ostracodes; solid dot indicates that sample contained an assemblage too small to be indicative of one of the biofacies.

TABLE 2.—*Principal Holocene species of shelf biofacies; their occurrence in the Norfolk Formation (upper Pleistocene); their occurrence north and south of Cape Hatteras area*

[X, characteristic species of the biofacies; o, species rarely occurring in the biofacies; P, species present]

| Species | Biofacies | | | | Pleistocene | Cape Hatteras area | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | North | South |
| *Actinocythereis dawsoni* | X | X | | | P | P | |
| *vineyardensis* | X | o | | | | P | |
| aff. *A. gomillionensis* | | X | o | X | P | P | P |
| *Aurila floridana* | | X | X | X | P | P | P |
| *laevicula* | | o | o | X | | P | P |
| *Bensonocythere americana* | X | X | o | o | P | P | P |
| *arenicola* | X | X | | o | P | P | |
| cf. B. *sapeloensis* | | X | | o | P | P | P |
| *whitei* | o | X | o | X | P | P | P |
| sp. A | X | X | | | P | P | |
| sp. B | X | X | | | P | P | |
| sp. C | o | X | | | | P | |
| sp. D | | X | | o | P | P | P |
| sp. E | | X | o | X | P | P | P |
| *sapeloensis* | | X | o | X | P | P | P |
| *Bythocythere* sp. A | X | X | | | | P | |
| sp. B | | | | X | | | P |
| *Campylocythere laeva* | | X | X | X | P | P | P |
| *Cushmanidea magniporosa* | o | X | X | X | P | P | P |
| *seminuda* | o | X | o | | P | P | |
| sp. A | | X | o | X | | P | P |
| *Cytherelloidea* sp. A | | o | | X | | | P |
| *Cytheromorpha warneri newportensis* | | X | X | X | P | P | P |
| *Cytheropteron pyramidale* | X | X | | | P | P | |
| *Cytherura elongata* | | o | o | X | | P | P |
| *forulata* | | X | X | X | P | P | P |
| *howei* | | X | | X | P | P | P |
| *pseudostriata* | | o | X | X | P | P | P |
| *reticulata* | | o | o | X | P | | P |
| *wardensis* | o | X | o | | P | P | |
| aff. *C. sablensis* | | o | o | X | | | P |
| sp. A | | X | X | X | P | P | P |
| sp. B | | X | | o | P | P | P |
| sp. D | | X | | X | P | P | P |
| sp. F | | o | | X | | | P |
| sp. G | | o | | X | | | P |
| *Echinocythereis margaritifera* | o | o | | X | | P | P |
| *planibasalis* | X | X | | o | | P | P |
| sp. A | o | X | o | X | | P | P |
| *Eucythere declivis* | X | X | o | o | P | P | P |
| *gibba* | o | X | o | X | P | P | P |
| *triangulata* | | o | o | X | | | P |
| sp. A | o | o | | X | | P | P |
| *Finmarchinella finmarchica* | X | X | o | | P | P | |
| *Haplocytheridea bradyi* | | X | X | X | P | P | P |
| *Cytheridea* sp. A | | X | | | P | P | |
| *Hulingsina americana* | o | X | X | X | P | P | P |
| *glabra* | | o | o | X | P | | P |
| *rugipustulosa* | | X | X | X | P | P | P |
| sp. A | | X | X | X | P | P | P |
| sp. B | | X | X | X | P | P | P |
| sp. C | o | X | X | X | P | P | P |
| sp. D | | X | | X | P | P | P |
| *Leptocythere angusta* | X | X | o | | P | P | |
| *Loxoconcha impressa* | X | X | o | | | P | |
| *reticularis* | | o | o | X | | | P |
| *sperata* | o | X | o | | P | P | |
| aff. *L. granulata* | o | X | o | o | P | P | P |
| *Loxocorniculum postdorsolatum* | | o | | X | | | P |
| *Macrocyprina propinqua* | | o | | X | | | P |
| sp. A | | o | | X | | | P |
| sp. B | | o | | X | | | P |
| *Microcytherura choctawhatcheensis* | o | X | X | X | P | P | P |
| sp. A | o | X | o | X | P | P | P |
| sp. C | | X | o | o | P | P | P |
| *Muellerina canadensis* | X | X | | | P | P | |
| aff. *M. lienenklausi* | X | X | o | o | P | P | P |
| *Neocaudites* sp. A | | | | X | P | | P |
| *Neolophocythere* sp. A | | X | | | P | P | |

TABLE 2.—*Principal Holocene species of shelf biofacies; their occurrence in the Norfolk Formation (upper Pleistocene); their occurrence north and south of Cape Hatteras area*—Continued

| Species | Biofacies | | | | Pleistocene | Cape Hatteras area | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | North | South |
| *Neonesidea* ? sp. A | | o | | X | | | P |
| ? sp. B | | o | | X | | | P |
| *Orionina bradyi* | | o | | X | | | P |
| *Paracytheridea altila* | | o | X | X | P | | P |
| *rugosa* | | o | o | X | | | P |
| sp. A | | o | o | X | P | | P |
| *Paradoxostoma delicata* | | X | X | X | P | P | P |
| sp. B | | X | | o | P | P | P |
| sp. D | | o | | X | | P | P |
| *Paranesidea* ? sp. A | | o | o | X | | | P |
| ? sp. B | | o | | X | | | P |
| ? sp. C | | o | o | X | | | P |
| *Pellucistoma magniventra* | | o | X | X | P | | P |
| sp. A | | | | X | | | P |
| *Phlyctocythere* sp. A | | o | o | X | | | P |
| sp. B | | o | | X | | | P |
| *Pontocypris* sp. A | o | | o | o | | P | P |
| *Propontocypris edwardsi* | | o | | X | P | P | P |
| aff. *P. howei* | o | X | o | X | | P | P |
| *Proteoconcha gigantica* | | X | X | X | P | P | P |
| *multipunctata* | | | o | X | | | P |
| *nelsonensis* | | o | o | o | P | P | P |
| *tuberculata* | | o | X | X | P | P | P |
| *Protocytheretta daniana* | o | X | X | X | | P | P |
| aff. *P. sahnii* | | X | X | X | P | P | P |
| *Pseudocytheretta edwardsi* | X | X | o | o | P | P | P |
| *Pterygocythereis americana inexpectata* | X | X | | | | P | |
| sp. A | | o | o | X | | P | P |
| *Puriana floridana* | | X | X | X | P | P | P |
| *rugipunctata* | o | X | X | o | P | P | |
| sp. A | | o | X | X | | | P |
| sp. B | | | | X | | | P |
| "*Sahnia*" cf. "*S*" *subulata* | | X | o | o | P | P | P |
| sp. A | X | X | o | o | P | P | P |
| sp. B | | X | o | X | | P | P |

Thirty samples were not included in the four biofacies by the cluster analysis (24 small samples not included in the cluster program and six samples which showed low similarity to samples in the major clusters A and B). The species content of these samples was compared with the typical assemblages of the biofacies, and 21 samples (5, 7, 12, 14, 18, 23, 25, 26, 28, 30, 33, 44, 46, 47, 50, 59, 65, 68, 83, 98, and 104) were assigned to a particular biofacies on this basis. Four samples (10, 13, 27, and 42) are transitional between biofacies 1 and 2, and five samples (2, 16, 21, 94, and 111) contained an assemblage too small to be indicative of one of the biofacies (fig. 8).

## FAUNAL PROVINCES IN THE CAPE HATTERAS AREA

Two recent zoogeographic studies have been conducted in the Cape Hatteras area. Cerame-Vivas and Gray (1966) investigated the benthic invertebrate assemblages of a relatively small area from Cape Lookout to north of Cape Hatteras. They recognized three areas characterized by distinctive assemblages and equated these areas with parts of three faunal provinces: the Virginian north of Cape Hatteras, the Carolinian on the inner shelf south of the cape, and the Tropical or Caribbean on the outer shelf south of the cape and north to about 36° N. (Cerame-Vivas and Gray, 1966, figs. 3, 5). Maturo (1968) studied the bryozoan distribution on the shelf from the Florida Keys to 40° N. and concluded that he could recognize only two faunal provinces near Cape Hatteras, the Carolinian plus Tropical south of the cape, and the Virginian to the north.

The geographic extent of the four ostracode biofacies established in this study is indicated in figure 8. Biofacies 2, 3, and 4 all occur in the Cape Hatteras area. The dendrogram (fig. 6), on which a delineation of the Virginian and Carolinian faunal provinces may be based, indicates that biofacies 3 and 4 constitute the northern part of the Carolinian province, and biofacies 1 and 2 the southern part of the Virginian province. Biofacies 3, although an entity, is closely related to biofacies 4; in fact, all major species characteristic of 3 are found in 4.

## COMPARISON OF LATE PLEISTOCENE AND HOLOCENE ASSEMBLAGES

The Dice coefficients of similarity between late Pleistocene samples are very high. The average of similarity coefficients within the Pleistocene samples is 78 and indicates the very close relation between the samples, on the basis of their species composition. The similarity matrix (fig. 7) illustrates the relation between the Pleistocene sample cluster and the Holocene sample subclusters. The Pleistocene assemblage is most similar to biofacies 2, 3, and 4, in descending order and least similar to biofacies 1, an assemblage composed principally of species restricted to the area north of Cape Hatteras. Although the Pleistocene assemblage is most similar to biofacies 2, the two assemblages are not equivalent and show less similarity to each other than the Holocene biofacies show internally.

The author attempted to create an artificial assemblage which would resemble that of the late Pleistocene. Holocene samples were selected from the area in which there are overlaps of latitudinal ranges of Holocene species which also occur in the Pleistocene samples (figs. 5, 8). This artificial group includes samples from biofacies 2 and 3 from latitudes between 35° and 30°30′ N. (localities 61, 62, 63, 64, 67, 69, 70, 71, and 73). The similarity between the artificial group and the Pleistocene samples is somewhat lower than the similarity between biofacies 2 and the Pleistocene samples, and the internal similarity of the artificial group is lower than that of any of the biofacies, Holocene or Pleistocene (fig. 7). The Pleistocene ostracode assemblage does not closely resemble assemblages extant in the study area, but this does not prevent determining marine climatic conditions prevailing during deposition of the Norfolk Formation (upper Pleistocene).

## LATE PLEISTOCENE MARINE CLIMATE OF SOUTHEASTERN VIRGINIA

### HOLOCENE MARINE BOTTOM TEMPERATURES

The distribution of marine organisms, though easily mapped, is often difficult to explain except in terms of the climatic tolerances of the species involved. The existence of major faunal provinces has been explained on temperature tolerances of organisms. Limiting temperatures, however, do not include extremes of short duration. According to Hall (1964), the number of consecutive days or months that shallow sea water is at temperatures required for reproduction and early growth determines the distribution of organisms and therefore faunal provinces and climatic zones.

The configuration of average monthly bottom temperatures in the study area, as illustrated by Walford and Wicklund (1968), shows that Cape Hatteras is a point of isotherm convergence during the coldest (February) and warmest (August-September) months of the year (figs. 9, 10). At Cape Hatteras in February

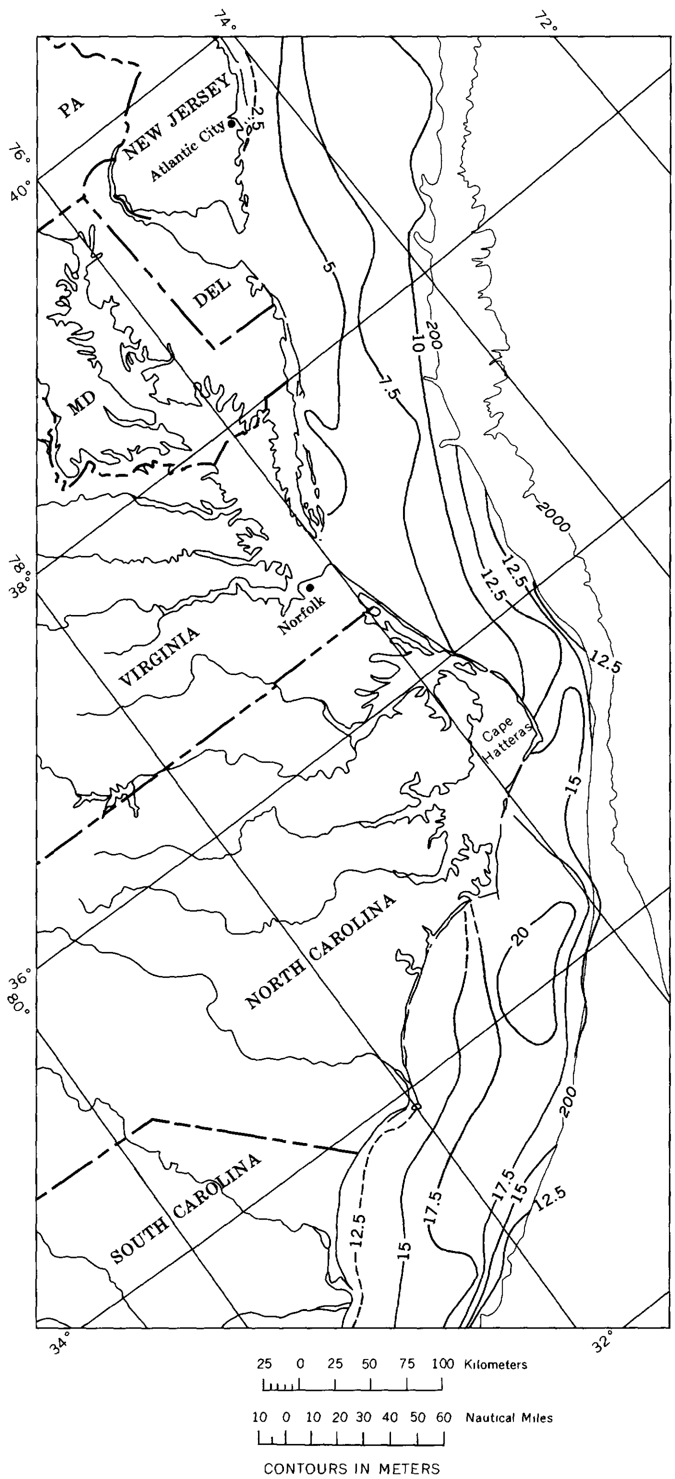


FIGURE 9.—Bottom-temperature map for the shelf off the middle Atlantic Coast of the United States for February, the coldest month of the year (redrawn from Walford and Wicklund, 1968, pl. 13). Temperature in °C.

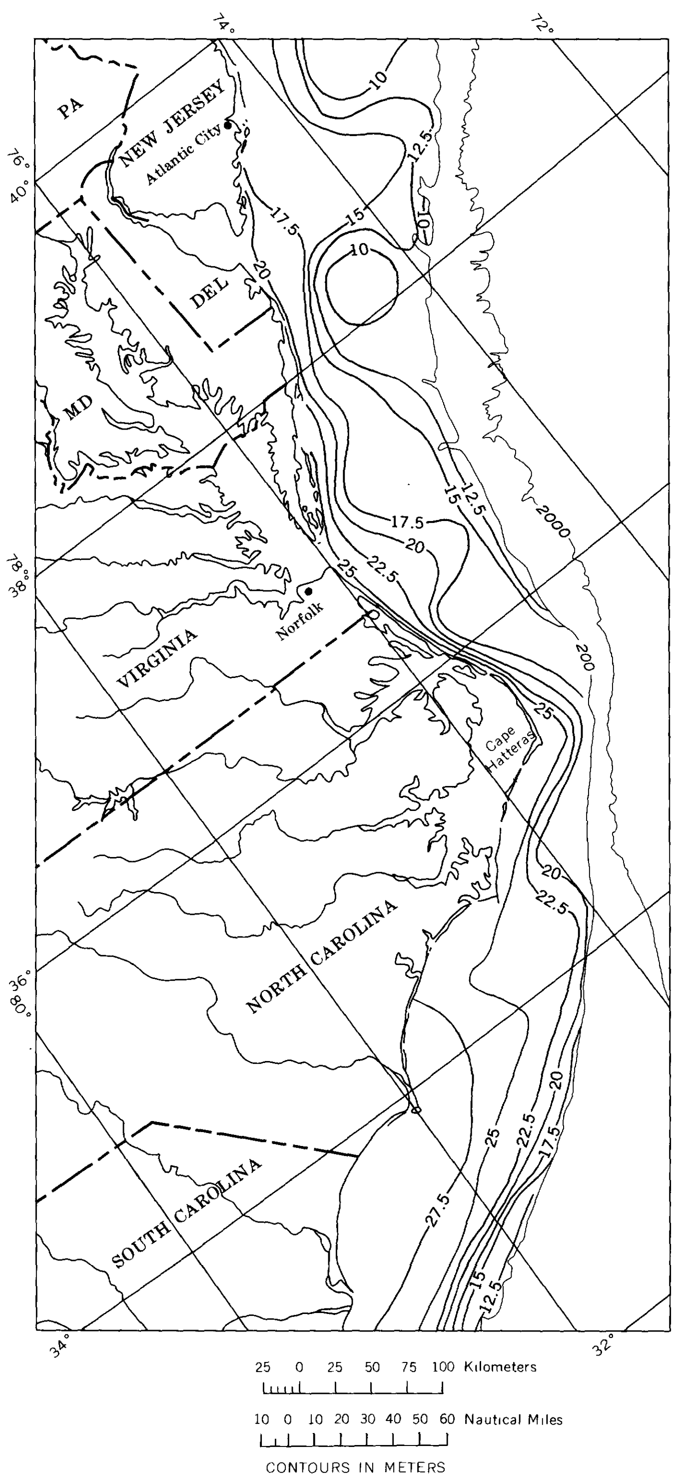


FIGURE 10.—Bottom-temperature map for the shelf off the middle Atlantic Coast of the United States for August-September, the warmest part of the year. Bottom temperatures are highest in August immediately south of Cape Hatteras and highest in September immediately north of the cape (redrawn from Walford and Wicklund, 1968, pls. 14, 15). Temperature in °C.

the bottom temperature is about 12.5°C, ranging from 10° to 15°C. North of the cape temperatures of the waters off the coast of New Jersey may reach as low as 2.5°C, but in general temperatures of the waters in the northern area range from 5° to 12.5°C. South of Cape Hatteras, temperatures in February may reach as low as 12.5°C in the shallow waters of Long Bay, but range from 15° to 20°C over most of the shelf. Bottom temperatures are highest in August south of the cape and in September north of the cape, but the temperature regime in the cape area is identical for both months when isotherms ranging from 17.5° to 25°C converge at Cape Hatteras. North of the cape, temperatures reach a maximum of 25°C in nearshore waters off the North Carolina and Virginia coasts, but generally the bottom temperatures on the shelf range from 10° to 22.5°C. South of Cape Hatteras, bottom temperatures of the shelf range from 12.5°C to greater than 27.5°C off the coast of North and South Carolina.

## LATE PLEISTOCENE BOTTOM TEMPERATURES

Biofacies 1, 2, 3, and 4 are indicative of certain maximum and minimum average monthly water temperatures. Although the late Pleistocene assemblage represents none of these biofacies, the marine climate of the Pleistocene can be inferred by determining temperature tolerances of species common to the Holocene and Pleistocene. The geographic distribution of these species was plotted on bottom-temperature maps for the warmest and coldest months of the year, and species temperature tolerances were determined (fig. 11). Temperature ranges were plotted in 2.5°C classes to adjust for inherent errors in sea-water-temperature maps which are all based on nonsystematic sampling and relatively few data points for the large areas mapped.

The overlap of species temperature tolerances (fig. 11) permits determining marine bottom temperatures in southeastern Virginia during that part of the Pleistocene represented by the Norfolk Formation. On the basis of the temperature tolerances of eight ostracode species, the minimum bottom temperature during the coldest part of the year was between 12.5° and 15°C. All these species occur only south of Cape Hatteras, and the distribution of four, *Hulingsina glabra*, *Paracytheridea altila*, *Paracytheridea* sp. A, and *Pellucistoma magniventra*, is very well known in the study area. In fig. 11, the temperature tolerances of five species, *Actinocythereis dawsoni*, *Cytheropteron pyramidale*, *Cytherura* sp. B, *Cytheridea* sp. A, and *Neolophocythere* sp. A, suggest that the bottom temperature in the warmest month was between 17.5° and 20°C. However, the first species is very rare in the Pleistocene, and the distribution of the last three is not well documented in the Holocene.

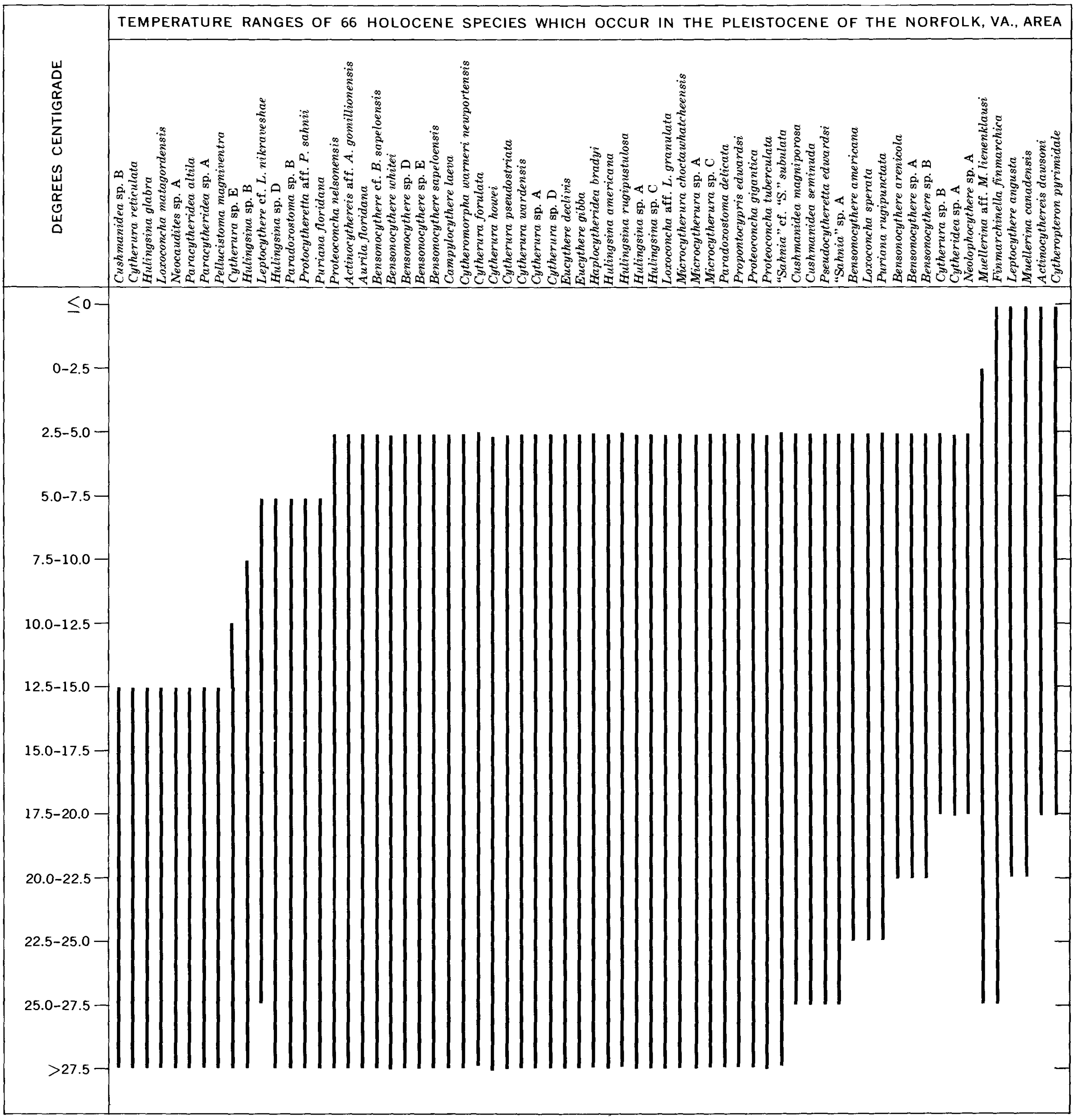


FIGURE 11.—Temperature ranges of 66 ostracode species common to the Holocene and the Norfolk Formation (upper Pleistocene).

Five other species, *Bensonocythere arenicola*, *Bensonocythere* sp. A, *Bensonocythere* sp. B, *Leptocythere angusta*, and *Muellerina canadensis* have upper limits between 20° and 22.5°C; these taxa are common in the Pleistocene, except for *Muellerina canadensis*, and their Holocene distribution is well documented. These data strongly suggest that the bottom temperature in shallow water during the warmest part of the year was between 20° and 22.5°C. Thus, the bottom-temperature range indicated for the late Pleistocene in this area was between 12.5°–15°C minimum and 20°–22.5°C maximum, a yearly range of about 7.5°C. These temperature values are contrasted with those of inner shelf waters off southeastern Virginia which today have bottom temperatures ranging from a minimum of 5°–7.5°C to a maximum of 22.5°–25°C (very near shore), a range of about 17.5°C, or 10°C greater than during the late Pleistocene in southeastern Virginia. Most of this increase in the yearly temperature range results from the difference between the Pleistocene and Holocene winter minima and indicates that during the late Pleistocene interglaciation, the marine environment of southeastern Virginia had warmer winters than now occur off southeastern Virginia, whereas summer maxima differed little.

In a study of the ostracodes of some Texas bays and lagoons (depth to 9 ft, salinity 10–50‰), King and Kornicker (1970) observed temperature ranges for several species that occur in the late Pleistocene of southeastern Virginia. Temperature ranges of *Aurila floridana* (=*Aurila conradi littorala* of King and Kornicker), *Cytherura forulata*, *Hulingsina rugipustulosa* (=*Hulingsina sandersi* of King and Kornicker), *Haplocytheridea bradyi*, and *Haplocytheridea setipunctata* (a species which does not occur in the Holocene samples of this study but is common in the Pleistocene) indicate that these species could live within the temperature limits of 12.5° to 22.5° C established for the late Pleistocene of southeastern Virginia.

*Hemicythere villosa* occurs commonly in the Pleistocene samples but is absent in the Holocene samples from the shelf area studied. This species occurs today in the Bay of Biscay, off the coasts of northern Europe and eastern Canada and south to Vineyard Sound, Mass., in depths to 37 m (Hazel, 1970). Elofson (1941) describes this species as an algal feeder living in shallow water at temperatures from 0° to 22° C. The modern known geographic range of *Hemicythere villosa* does not extend south of Vineyard Sound, but this may be due to inadequate collecting in shallow nearshore areas or to some unknown ecological factor. The temperature and depth tolerances of this species would allow it to live in the Pleistocene environment characterized by bottom temperatures of 12.5° to 22.5° C and depths of approximately 15 to 20 m or less.

### LATE PLEISTOCENE SEA-SURFACE TEMPERATURES

In a comparison of average monthly bottom temperatures (figs. 9, 10) and average monthly sea-surface temperatures north of Cape Hatteras off southeastern Virginia (Schroeder, 1966, figs. 2, 8), it is noted that the sea surface is coldest in February (5°–12.5° C) and that the surface and bottom isotherms are nearly coincident. Therefore, the late Pleistocene sea-surface temperatures for nearshore areas during the coldest part of the year were possibly equivalent to the bottom temperatures and ranged from 12.5° to 15° C. The sea surface is warmest in August, and the configuration of the surface isotherms differs markedly from the bottom isotherms for August and September. Sea-surface isotherms trend northeast-southwest, range from 25° to 27.5° C, and average about 26° C. In contrast, bottom isotherms for this part of the inner shelf parallel the coastline, range from 20° to 25° C, and average 22.5° C, or approximately 4° C lower than the sea-surface temperature. Therefore, the late Pleistocene sea-surface temperatures for nearshore areas during the warmest part of the year ranged possibly from 24° to 26.5° C, or 4° C higher than the bottom-temperature range of that time (20°–22.5° C). If these postulated sea-surface maxima (24°–26.5° C) and minima (12.5°–15° C) are correct, the range of the late Pleistocene sea-surface temperatures in southeastern Virginia was about 11° or 12° C.

### LATE PLEISTOCENE FAUNAL PROVINCE AND CLIMATIC ZONE OF SOUTHEASTERN VIRGINIA

Modern or contemporaneous sublittoral faunal provinces of the middle latitudes in different ocean basins (the North Atlantic and North Pacific, for example) or off opposite coasts of the same ocean basin contain different species and assemblages and therefore cannot be equated. Because populations, communities, and provinces are constantly evolving (Valentine, 1968), provinces existing at different times in the same region will not be equivalent even under similar climatic conditions, and similarity between provinces decreases as difference in age increases. Late Cenozoic fossil faunal provinces can, however, be fairly closely equated with modern provinces in the same region if many constituent species are extant and if the past and present marine climates are similar. Although 85 percent of the species of the late Pleistocene ostracode assemblage of the Norfolk Formation are still living, the assemblage is unlike any found today on the inner shelf off eastern North America. The species still exist but are found in different associations because the climatic regime has altered.

The Norfolk ostracode assemblage is indicative of a marine climate which may be described in modern climatic zone terminology as warm-temperature, a climatic regime which does not now exist off the middle Atlantic Coast of North America. If sea level rose about 15 m above present sea level, a very wide shelf would be created in the Virginia-North Carolina area (where the mild-temperature Virginia faunal province and the subtropical Carolinian faunal province meet now on the present narrow shelf); in Virginia the shoreline would be at the Suffolk Scarp (fig. 1). This shelf would be approximately 160 km wide off southeastern Virginia and about 135 km wide off North Carolina at the latitude of Cape Hatteras. The path of the Florida Current, which follows the continental slope and extends to a depth of 800 m over the Blake Plateau (Pratt, 1966), would probably be little altered by a rise in sea level of 15 m; however, the cold Virginia Coastal Current which flows southward over the shelf would be diffused over a much larger area. A broad expanse of shallow water extending inland from the present coast would therefore be less influenced by warm southern and cool northern waters than are present shelf waters in the area, and the marked convergence of isotherms at Cape Hatteras would be eliminated.

A rise in sea level (to an altitude of +15 m relative to present sea level), a consequent increase in shelf area and diffusion of thermal currents, and a general atmospheric warming all apparently contributed to establish a Pleistocene marine climate with a very narrow annual range in temperature and, therefore, markedly different from any now found in the western North Atlantic. Ostracode species that today are restricted to subtropical and warmer waters or mild-temperature and cooler waters coexisted and suggest that along the middle Atlantic Coast of the United States during the Sangamon Interglaciation there was a distinctive faunal province and corresponding warm-temperate climatic zone which have since been eliminated. The convergence of cool- and warm-water masses at Cape Hatteras profoundly influences the marine climate and consequently the distribution of marine organisms and at present prevents the reestablishment of a warm-temperate faunal province in this region.

## SUMMARY

1. The Norfolk Formation (upper Pleistocene (Sangamon)) of southeastern Virginia contains a large and well-preserved ostracode assemblage, 82 species, 70 of which are still living.
2. No modern shelf assemblage off the middle Atlantic Coast of the United States is closely similar to that of the Norfolk Formation; the Norfolk assemblage includes forms which today are restricted to the area north or south of Cape Hatteras.
3. The boundary between the modern Virginian and Carolinian faunal provinces at Cape Hatteras, already well established on the geographic distribution of other organisms, is also reflected in the distribution of ostracode species on the continental shelf. From the cluster analysis of 91 Holocene samples containing 159 ostracode species, four biofacies are recognized on the shelf between 32°30′N and 40°N. Temperature is the principal factor controlling the composition of the biofacies, although substrate and energy conditions are important in defining the species composition of biofacies 3.
4. The Norfolk ostracode assemblage lived at depths of 20 m or less, and temperature tolerances of ostracode species common to the Pleistocene and the Holocene indicate that the assemblage lived in waters where the bottom temperature in the coldest month was between 12.5° and 15°C and in the warmest month between 20° and 22.5°C.
5. The late Pleistocene marine climate of the inner sublittoral was more equable than now exists on the inner shelf off southeastern Virginia where minimum and maximum monthly temperatures range from 5°–7.5° C to 22.5°–25° C, respectively. The inner sublittoral of southeastern Virginia had warmer winters during the late Pleistocene interglaciation than now occur on the inner shelf off southeastern Virginia, whereas summer maxima differed little.
6. During the Sangamon Interglaciation a rise in sea level (+15 m relative to present sea level), a consequent increase in shelf area, diffusion of cool and warm oceanic currents over a broad area, and a general atmospheric warming apparently all contributed to establish a warm-temperate marine climate off the middle Atlantic Coast of the United States.
7. The late Pleistocene ostracode assemblage is indicative of a sublittoral faunal province and warm-temperature climatic zone which has no modern counterpart off the Atlantic Coast of the United States. At present, the convergence of cool and warm water masses at Cape Hatteras prevents there being a warm-temperate faunal province in this region.

## PLEISTOCENE LOCALITIES

*Locality P1.*—Borrow pit 0.4 mile southeast of Acredale (Bonneys or Mears Corner; intersection of Virginia State Route 190 and Indian River Road) on south side of Indian River Road; Virginia Beach, Va.; USGS Kempsville 7.5-min quadrangle (1965); 36°47′30″ N., 76°10′13″ W. USGS Cenozoic loc. 24796. Section measured and collected in southwest corner of pit in October 1968. Pit being flooded by ground water in January 1970.

| *Unit and description* | *Thickness (ft)* |
|---|---|
| Sand Bridge Formation: | |
| 1. Silty clay, unfossiliferous | 3.0 |
| Kempsville Formation: | |
| 1. Interbedded sand and gravel, cross-bedded, unfossiliferous | 4.5 |
| 2. Fine-medium sand, crossbedded, contains wood | 5.5 |
| 3. Fine-medium sand; burrowed, bivalve ghosts; wood | 4.0 |
| 4. Medium-coarse sand, very fossiliferous; nested, disarticulated bivalves (*Spisula*) (sample P1–1) | 2.0 |
| Norfolk Formation: | |
| 1. Fine sand, argillaceous, very fossiliferous; articulated bivalves in living position (*Mercenaria*); serpulid worm tubes very abundant (sample P1–2, collected 5 ft. from top) | 10.5 |
| Total Exposed | 29.5 |

*Locality P2.*—Borrow pit 0.6 mile east of Davis Corner (intersection of U.S. Route 58 and Newtown Road) on south side of U.S. Route 58 at the end of Toy Ave., in Boulevard Manor subdivision of Virginia Beach, Va.; USGS Kempsville 7.5-min quadrangle (1965); 36°50′30″ N., 76°10′20″ W.; (USGS Cenozoic loc. 23780). Section measured and collected by T. R. Waller in July 1966. Pit flooded in May 1968.

| *Unit and description* | *Thickness (ft)* |
|---|---|
| Kempsville(?) Formation: | |
| 1. Coarse sand and gravel, unfossiliferous | 6.0 |
| 2. Medium-coarse sand mixed with gravel, very fossiliferous; disarticulated worn bivalves (*Spisula*) | 7.0 |
| Norfolk Formation: | |
| 1. Fine sand, argillaceous, very fossiliferous; articulated bivalves in living position (*Mercenaria*), serpulid worm tubes very abundant (sample P2–1 collected from top 3 ft; P2–2 collected 5 ft from top; P2–3 collected from bottom 3 ft) | 16.0 |
| Great Bridge(?) Formation: | |
| 1. Sand, argillaceous; contains *Crassostrea-Mya-Rangia* fauna; bivalves in living position (*Crassostrea virginica* and *Mya*) | 2.0 |
| Total exposed | 31.0 |

*Locality P3.*—Borrow pit 0.4 mile north of Davis Corner (intersection of U.S. Route 58 and Newtown Road) 0.2 mile west of Newtown Road, Virginia Beach, Va., USGS Kempsville 7.5-min quadrangle (1965); 36°51′30″ N., 76°11′00″ W.; (USGS Cenozoic loc. 23800). Section collected by T. R. Waller in July 1966. Pit flooded in July 1966.

| *Unit and description* | *Thickness (ft)* |
|---|---|
| Norfolk Formation: | |
| 1. Sand, very fossiliferous; contains *Mercenaria* and serpulid worm tubes (sample P3–1) | 5.0 |
| Total exposed | 5.0 |

*Locality P4.*—Borrow pit 0.4 mile southeast of Powells Crossroads (intersection of Holland Road and Virginia State Route 646) on north side of Holland Road and south of Interstate 264; Virginia Beach, Va.; USGS Kempsville 7.5-min quadrangle (1965); 36°50′00″ N., 76°08′00″ W.; (USGS Cenozoic loc. 23801). Section collected by T. R. Waller in July 1966. Pit flooded in May 1968.

| *Unit and description* | *Thickness (ft)* |
|---|---|
| Kempsville(?) Formation: | |
| 1. Sand, unfossiliferous | 5.0 |
| 2. Coarse sand and gravel, very fossiliferous; disarticulated bivalves (*Mercenaria*, Spisula) | 2.5 |
| 3. Coarse sand, unfossiliferous | 3.0 |
| Norfolk Formation: | |
| 1. Sand, argillaceous, very fossiliferous (*Ensis*, *Busycon*, sand dollars) (sample P4–1) | 10.0 |
| Total exposed | 20.5 |

*Locality P5.*—Borrow pit 0.6 mile east of Greenbriar Road; on a farm road that intersects Greenbriar Road 0.2 mile south of intersection of Greenbriar Road, and Interstate 64; Chesapeake, Va.; USGS Kempsville 7.5-min quadrangle (1965); 36°47′00″ N., 76°13′30″ W.; (USGS Cenozoic locs. 23802, 24797). Section measured and collected by T. R. Waller in July 1966. Recollected in May 1968. Pit flooded in October 1968.

| *Unit and description* | *Thickness (ft)* |
|---|---|
| Norfolk Formation: | |
| 1. Sand and clay, unfossiliferous | 1–2 |
| 2. Sand, argillaceous, very fossiliferous; large serpulid worm tube concentrations, articulated *Mercenaria* in living position (sample P5–1) | 12.0 |
| Total exposed | 13.0–14.0 |

*Locality P.6*—Borrow pits 0.5 mile southwest of Yadkin, Va., and 0.3 mile south of Norfolk and Western Railroad near the intersection of Portsmouth Ditch and powerlines; 0.6 mile south of Yadkin on Gallberry Road, turn right at cemetery, turn right at first dirt road (0.2 mile), 0.5 mile to pit; Cheseapeake, Va.; USGS Norfolk South 7.5-min quadrangle (1965); 36°45′30″ N., 76°22′00″ W. (USGS Cenozoic loc. 24798). Section measured and collected in cuts between north and south pits in May 1968 and April 1969. Pits being worked in June 1970.

| *Unit and description* | *Thickness (ft)* |
|---|---|
| Sand Bridge(?) Formation | |
| 1. Sand; large-scale crossbedding; interbedded with thin layers of clay and peat | 4.0 |
| Norfolk Formation | |
| 1. Fine-medium sand; contains fossiliferous beds (*Ensis*) and scattered shell fragments; thin bed at bottom contains broken shell fragments, iron concretions, and cobbles (sample 6–1 collected 3.5 ft. from top) | 7.5 |
| Yorktown Formation | |
| 1. Medium sand; iron cemented in part; very fossiliferious; broken shells and bivalved *Corbicula* | 3.5 |
| 2. Sandy shell hash | 4.0 |
| Total exposed | 19.0 |

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# PLATES 1–4

[Contact photographs of the plates in this report are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225]

# PLATE 1

[All figures × 50]

FIGURES 1, 6, 11, 12. *Bensonocythere sapeloensis* (Hall, 1965).
1. Lateral view left valve, female. Sample P5–1. USNM 168641.
6. Lateral view right valve, female. Sample P4–1. USNM 168642.
11. Lateral view left valve, male. Sample P1–2. USNM 168643.
12. Lateral view right valve, male. Sample P1–2. USNM 168644.

2, 3, 7, 8. *Bensonocythere americana* Hazel, 1967.
2. Lateral view left valve, female. Sample P4–1. USNM 168645.
3. Lateral view left valve, male. Sample P2–2. USNM 168646.
7. Lateral view right valve, female. Sample P5–1. USNM 168647.
8. Lateral view right valve, male. Sample P4–1. USNM 168648.

4, 9, 15, 20. *Bensonocythere* sp. E.
4. Lateral view left valve, female. Sample P4–1. USNM 168649.
9. Lateral view right valve, female. Sample P1–2. USNM 168650.
15. Lateral view left valve, male. Sample P4–1. USNM 168651.
20. Lateral view right valve, male. Sample P5–1. USNM 168652.

5, 10, 16, 21. *Bensonocythere* sp. D.
5. Lateral view left valve, female. Sample P4–1. USNM 168653.
10. Lateral view right valve, female. Sample P4–1. USNM 168654.
16. Lateral view left valve, male. Sample P1–2. USNM 168655.
21. Lateral view right valve, male. Sample P2–2. USNM 168656.

13, 18. *Bensonocythere* sp. A.
13. Lateral view right valve, female. Sample P4–1. USNM 168657.
18. Lateral view left valve, male. Sample P4–1. USNM 168658.

14, 19. *Bensonocythere whitei* (Swain, 1951).
14. Lateral view left valve, female. Sample P5–1. USNM 168659.
19. Lateral view left valve, male. Sample P5–1. USNM 168660.

17, 22, 30. *Bensonocythere* sp. B.
17. Lateral view left valve, female penultimate. Sample P4–1. USNM 168661.
22. Lateral view right valve, female. Sample P1–2. USNM 168662.
30. Lateral view left valve, male. Sample P4–1. USNM 168663.

23. *Bensonocythere* sp. G.
23. Lateral view right valve, female. Sample P6–1. USNM 168664.

24, 25, 26, 27. *Cushmanidea* sp. B.
24. Lateral view left valve, male. Sample P1–1. USNM 168665.
25. Lateral view right valve, male. Sample P1–1. USNM 168666.
26. Lateral view left valve, female. Sample P1–1. USNM 168667.
27. Lateral view right valve, female. Sample P1–1. USNM 168668.

28, 29. *Bensonocythere* cf. B. *sapeloensis* (Hall, 1965).
28. Lateral view left valve, female. Sample P1–2. USNM 168669.
29. Lateral view left valve, male. Sample P1–2. USNM 168670.

31. *Bensonocythere arenicola* (Cushman, 1906).
31. Lateral view right valve, female. Sample P4–1. USNM 168671.

32, 33, 36, 37. *Campylocythere laeva* Edwards, 1944.
32. Lateral view left valve, female. Sample P2–2. USNM 168672.
33. Lateral view left valve, male. Sample P1–2. USNM 168673.
36. Lateral view right valve, female. Sample P2–2. USNM 168674.
37. Lateral view right valve, male. Sample P1–2. USNM 168675.

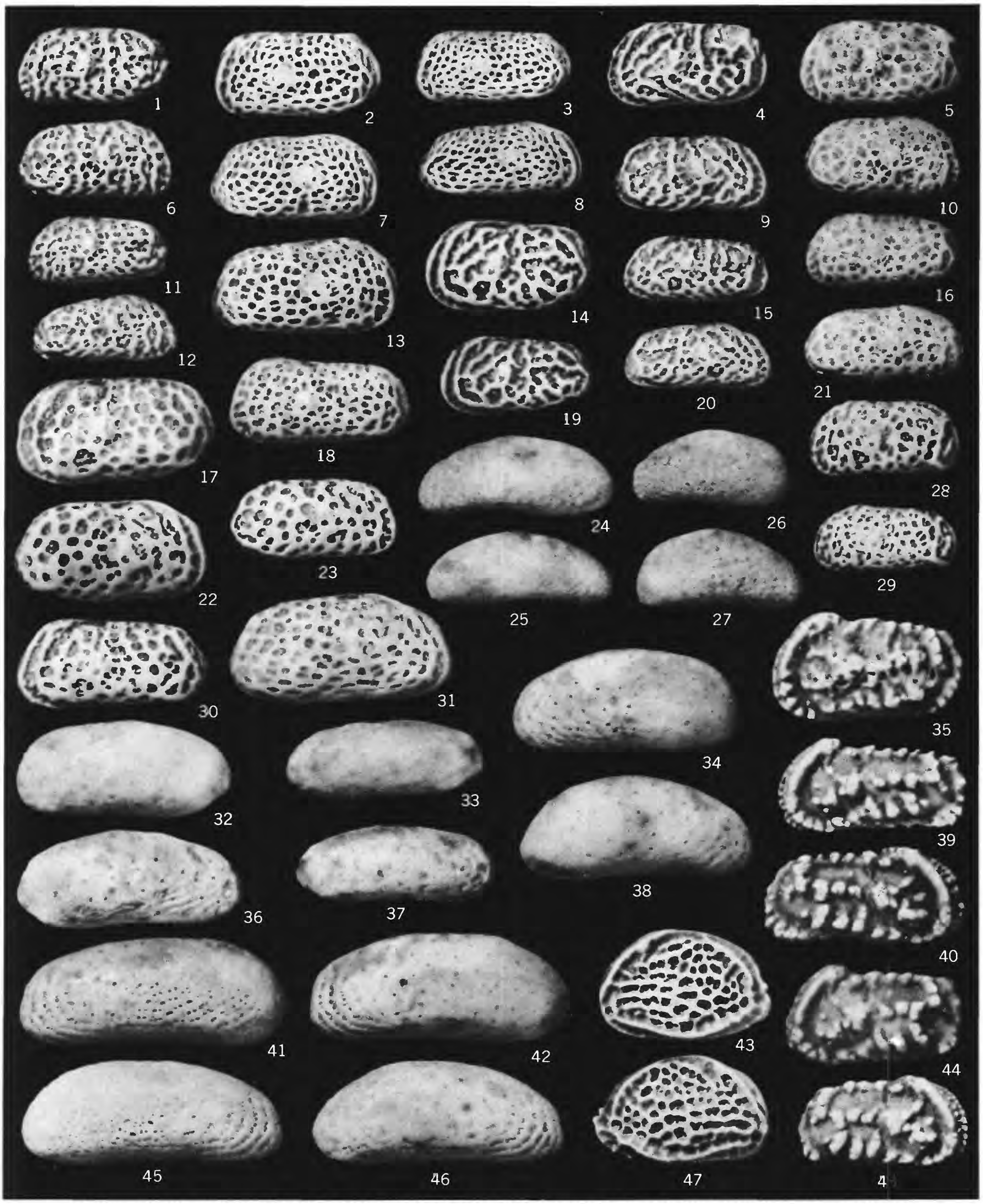
34, 38. *Cushmanidea seminuda* (Cushman, 1906).
34. Lateral view left valve, female. Sample P4–1. USNM 168676.
38. Lateral view right valve, female. Sample P4–1. USNM 168677.

35. *Actinocythereis dawsoni* (Brady, 1870).
35. Lateral view left valve, female. Sample P1–1. USNM 168678.

39, 40, 44, 48. *Actinocythereis* aff. *A. gomillionensis* (Howe and Ellis, 1935).
39. Lateral view left valve, male. Sample P6–1. USNM 168679.
40. Lateral view right valve, male. Sample P2–2. USNM 168680.
44. Lateral view left valve, female. Sample P6–1. USNM 168681.
48. Lateral view right valve, female. Sample P2–2. USNM 168682.

41, 42, 45, 46. *Cushmanidea magniporosa* Hall, 1965.
41. Lateral view left valve, female. Sample P4–1. USNM 168683.
42. Lateral view left valve, male. Sample P4–1. USNM 168684.
45. Lateral view right valve, female. Sample P4–1. USNM 168685.
46. Lateral view right valve, male. Sample P4–1. USNM 168686.

43, 47. *Aurila floridana* Benson and Coleman, 1963.
43. Lateral view left valve, female. Sample P6–1. USNM 168687.
47. Lateral view right valve, female. Sample P6–1. USNM 168688.




*BENSONOCYTHERE, CUSHMANIDEA, CAMPYLOCYTHERE, ACTINOCYTHEREIS,* AND *AURILA*

## PLATE 2

[All figures × 50]

FIGURES

1, 7. *Cytherura howei* (Puri, 1954).
1. Lateral view left valve, female. Sample Pl–2. USNM 168689.
7. Lateral view right valve, female. Sample Pl–2. USNM 168690.

2, 8. *Cytherura* sp. E.
2. Lateral view left valve. Sample P1–1. USNM 168691.
8. Lateral view right valve. Sample P2–2. USNM 168692.

3, 4, 9, 10. *Cytherura* sp. B.
3. Lateral view left valve, female. Sample P1–2. USNM 168693.
4. Lateral view right valve, female. Sample P1–2. USNM 168694.
9. Lateral view left valve, male. Sample P1–2. USNM 168695.
10. Lateral view right valve, male. Sample P1–2. USNM 168696.

5, 6, 11, 12. *Cytherura reticulata* Edwards, 1944.
5. Lateral view left valve, female. Sample P1–2. USNM 168697.
6. Lateral view right valve, female. Sample P1–2. USNM 168698.
11. Lateral view left valve, male. Sample P1–2. USNM 168699.
12. Lateral view right valve, male. Sample P1–2. USNM 168700.

13, 19. *Cytherura wardensis* Howe and Brown, 1935.
13. Lateral view left valve, female. Sample P1–2. USNM 168701.
19. Lateral view left valve, male. Sample P1–2. USNM 168702.

14, 20. *Cytherura pseudostriata* Hulings, 1966.
14. Lateral view right valve, female. Sample P4–1. USNM 168703.
20. Lateral view right valve, male. Sample P1–2. USNM 168704.

15, 16, 21, 22. *Cytherura* sp. A.
15. Lateral view right valve, female. Sample P1–2. USNM 168705.
16. Lateral view left valve, female. Sample P1–2. USNM 168706.
21. Lateral view right valve, male. Sample P1–2. USNM 168707.
22. Lateral view left valve, male. Sample P1–2. USNM 168708.

17, 18, 23, 24. *Cytherura* sp. D.
17. Lateral view left valve, female. Sample P2–1. USNM 168709.
18. Lateral view right valve, female. Sample P2–1. USNM 168710.
23. Lateral view right valve, male. Sample P2–1. USNM 168711.
24. Lateral view left valve, male. Sample P2–1. USNM 168712.

25, 26. *Cytherura forulata* Edwards, 1944.
25. Lateral view left valve, female. Sample P1–2. USNM 168713.
26. Lateral view right valve, male. Sample P2–1. USNM 168714.

27, 28. "*Sahnia*" cf. "*S*" *subulata* (Brady, 1868).
27. Lateral view left valve, female. Sample P1–2. USNM 168715.
28. Lateral view right valve, female. Sample P1–2. USNM 168716.

29. *Megacythere* sp. B.
29. Lateral view left valve. Sample P1–1. USNM 168717.

30, 35. *Eucythere declivis* (Norman, 1865).
30. Lateral view left valve, female. Sample P1–2. USNM 168718.
35. Lateral view left valve, male. Sample P1–2. USNM 168719.

31, 36. *Puriana rugipunctata* (Ulrich and Bassler, 1904).
31. Lateral view left valve. Sample P4–1. USNM 168720.
36. Lateral view right valve. Sample P4–1. USNM 168721.

32, 37. *Puriana floridana* Puri, 1960.
32. Lateral view left valve, disarticulated carapace. Sample P5–1. USNM 168722.
37. Lateral view right valve, disarticulated carapace. Sample P5–1. USNM 168723.

33, 38. "*Sahnia*" sp. A.
33. Lateral view right valve, female. Sample P1–2. USNM 168724.
38. Lateral view left valve, female. Sample P1–2. USNM 168725.

34. *Megacythere stephensoni* (Puri, 1954).
34. Lateral view left valve. Sample P2–2. USNM 168726.

39. *Pellucistoma magniventra* Edwards, 1944.
39. Lateral view left valve, male. Sample Pl–2. USNM 168727.

## PLATE 2—Continued

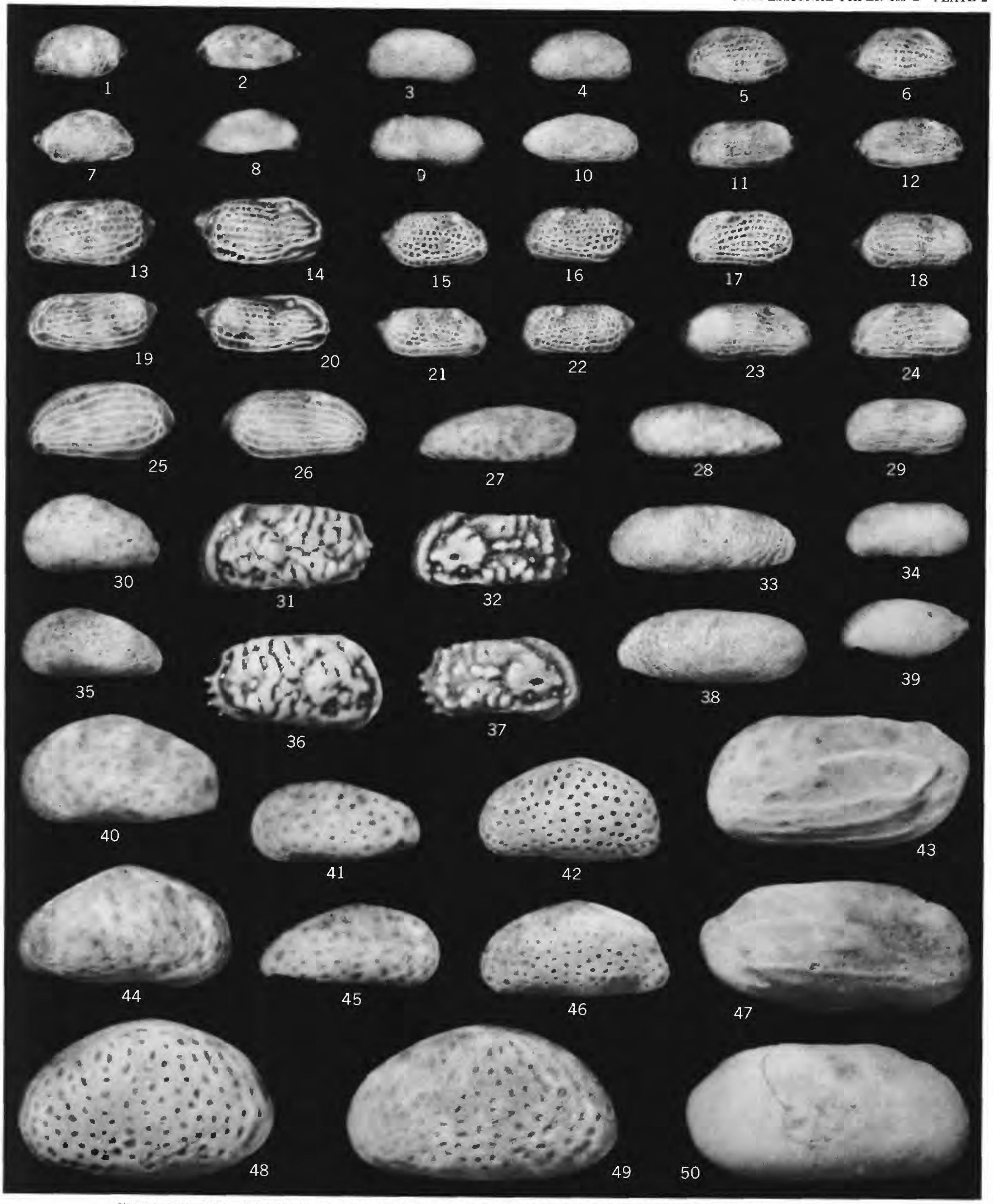
FIGURES 40, 41, 44, 45. *Eucythere gibba* Edwards, 1944.
- 40. Lateral view left valve, female. Sample P5–1. USNM 168728.
- 41. Lateral view left valve, male. Sample 5–1. USNM 168729.
- 44. Lateral view right valve, female. Sample P5–1. USNM 168730.
- 45. Lateral view right valve, male. Sample P6–1. USNM 168731.

42, 46. *Haplocytheridea bradyi* (Stephenson, 1938).
- 42. Lateral view left valve, female. Sample P6–1. USNM 168732.
- 46. Lateral view right valve, male. Sample P6–1. USNM 168733.

43, 47. *Protocytheretta* aff. *P. sahnii* (Puri, 1952).
- 43. Lateral view left valve. Sample P6–1. USNM 168734.
- 47. Lateral view right valve. Sample P6–1. USNM 168735.

48, 49. *Haplocytheridea setipunctata* (Brady, 1869).
- 48. Lateral view left valve, female. Sample P6–1. USNM 168736.
- 49. Lateral view left valve, male. Sample P6–1. USNM 168737.

50. *Pseudocytheretta edwardsi* Cushman, 1906.
- 50. Lateral view right valve, penultimate. Sample P5–1. USNM 168738.




*CYTHERURA, "SAHNIA," MEGACYTHERE, EUCYTHERE, PURIANA, PELLUCISTOMA, HAPLOCYTHERIDEA, PROTOCYTHERETTA,* AND *PSEUDOCYTHERETTA*

# PLATE 3

[All figures × 50]

FIGURES

1, 2, 6, 7. *Hulingsina* sp. D.
- 1. Lateral view left valve, female. Sample P6–1. USNM 168739.
- 2. Lateral view left valve, male. Sample P6–1. USNM 168740.
- 6. Lateral view right valve, female. Sample P6–1. USNM 168741.
- 7. Lateral view right valve, male. Sample P6–1. USNM 168742.

3. *Hulingsina glabra* (Hall, 1965).
- 3. Lateral view right valve, female. Sample P4–1. USNM 168743.

4, 5, 9, 10. *Hulingsina* sp. B.
- 4. Lateral view left valve, female. Sample P5–1. USNM 168744.
- 5. Lateral view left valve, male. Sample P5–1. USNM 168745.
- 9. Lateral view right valve, female. Sample P5–1. USNM 168746.
- 10. Lateral view right valve, male. Sample P5–1. USNM 168747.

8, 12, 13, 14. *Hulingsina americana* (Cushman, 1906).
- 8. Lateral view left valve, female. Sample P2–2. USNM 168748.
- 12. Lateral view right valve, female. Sample P2–2. USNM 168749.
- 13. Lateral view right valve, male. Sample P2–2. USNM 168750.
- 14. Lateral view left valve, male. Sample P2–2. USNM 168751.

11, 15, 16. *Hulingsina* sp. A.
- 11. Lateral view left valve, female penultimate. Sample P4–1. USNM 168752.
- 15. Lateral view right valve, female penultimate. Sample P4–1. USNM 168753.
- 16. Lateral view right valve, female. Sample P3–1. USNM 168754.

17, 18, 21, 22, 25, 26, 29, 30. *Hulingsina rugipustulosa* (Edwards, 1944).
- 17. Lateral view left valve, female. Sample P5–1. USNM 168755.
- 18. Lateral view left valve, female. Sample P5–1. USNM 168756.
- 21. Lateral view right valve, female. Sample P5–1. USNM 168757.
- 22. Lateral view right valve, female. Sample P5–1. USNM 168758.
- 25. Lateral view left valve, male. Sample P5–1. USNM 168759.
- 26. Lateral view left valve, male. Sample P5–1. USNM 168760.
- 29. Lateral view right valve, male. Sample P5–1. USNM 168761.
- 30. Lateral view right valve, male. Sample P5–1. USNM 168762.

(Note pronounced development of pustules in specimens illustrated in figures 18, 22, 26, and 30).

19, 20, 23, 24. *Hulingsina* sp. C.
- 19. Lateral view left valve, female. Sample P6–1. USNM 168763.
- 20. Lateral view right valve, female. Sample P6–1. USNM 168764.
- 23. Lateral view left valve, male. Sample P6–1. USNM 168765.
- 24. Lateral view right valve, male. Sample P6–1. USNM 168766.

27, 28. *Finmarchinella finmarchica* (Sars, 1865).
- 27. Lateral view right valve, female. Sample P4–1. USNM 168767.
- 28. Lateral view left valve, male. Sample P4–1. USNM 168768.

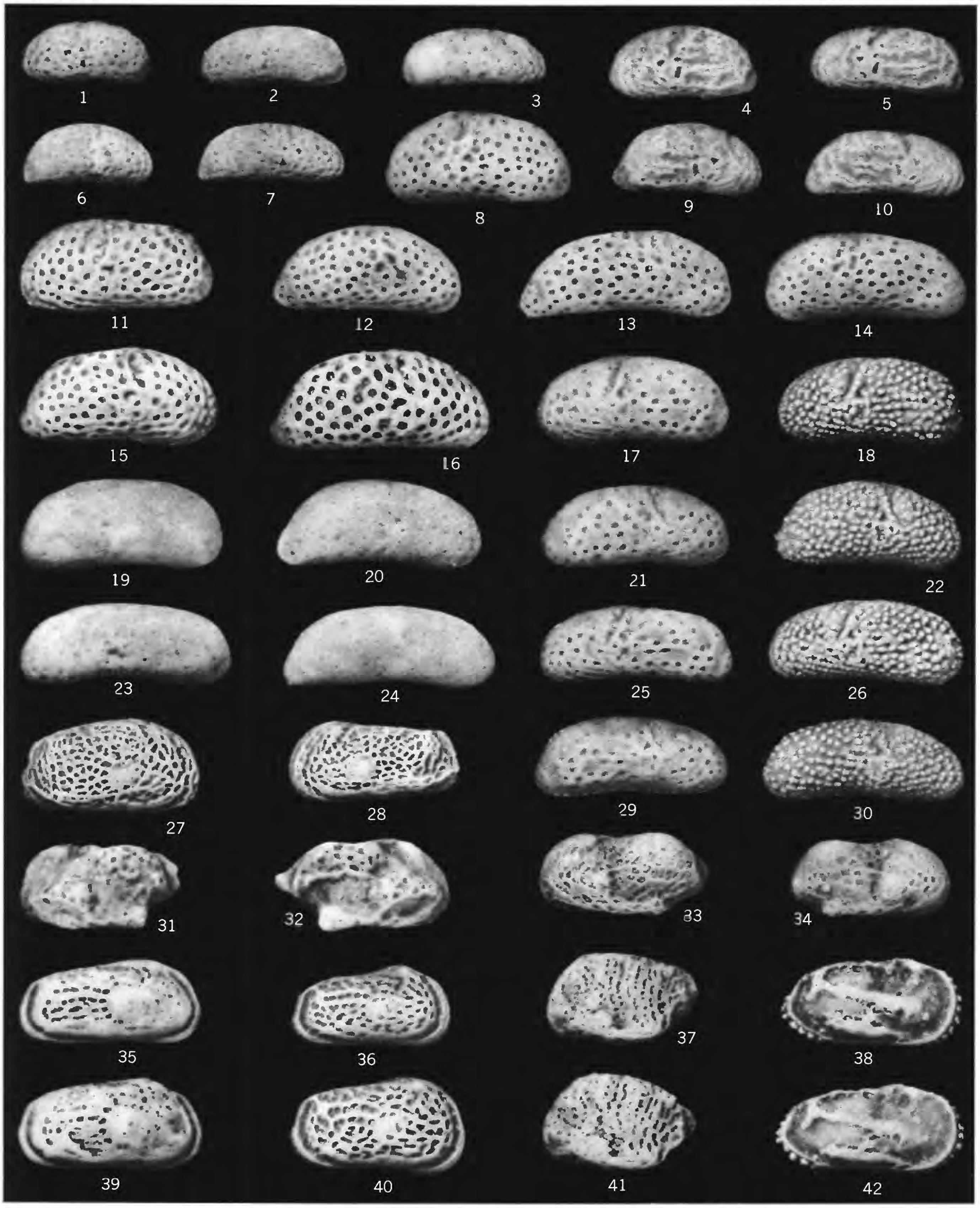
31, 32, 33, 34. *Paracytheridea altila* Edwards, 1944.
- 31. Lateral view left valve, female. Sample P6–1. USNM 168769.
- 32. Lateral view right valve, female. Sample P6–1. USNM 168770.
- 33. Lateral view left valve, male. Sample P2–2. USNM 168771.
- 34. Lateral view right valve, male. Sample P5–1. USNM 168772.

35, 39. *Muellerina canadensis* (Brady, 1870).
- 35. Laterial view right valve, male. Sample P4–1. USNM 168773.
- 39. Lateral view right valve, female. Sample P4–1. USNM 168774.

36, 40. *Muellerina* aff. *M. lienenklausi* (Ulrich and Bassler, 1904).
- 36. Lateral view right valve, male. Sample P2–1. USNM 168775.
- 40. Lateral view right valve, female. Sample P4–1. USNM 168776.

37, 41. *Cytheropteron pyramidale* (Brady, 1868).
- 37. Lateral view left valve, male. Sample P4–1. USNM 168777.
- 41. Lateral view left valve, female. Sample P4–1. USNM 168778.

38, 42. *Neocaudites* sp. A.
- 38. Lateral view right valve, female. Sample P2–1. USNM 168779.
- 42. Lateral view right valve, male. Sample P3–1. USNM 168780.




*HULINGSINA, FINMARCHINELLA, PARACYTHERIDEA, MUELLERINA, CYTHEROPTERON,* AND *NEOCAUDITES*

# PLATE 4

[All figures × 50]

FIGURES 1, 7. *Microcytherura* sp. C.
1. Lateral view left valve, female. Sample P1–2. USNM 168781.
7. Lateral view right valve, female. Sample P1–2. USNM 168782.

2, 3, 8, 9. *Microcytherura* sp. B.
2. Lateral view left valve, female. Sample P1–2. USNM 168783.
3. Lateral view right valve, female. Sample P1–2. USNM 168784.
8. Lateral view left valve, male. Sample P6–1. USNM 168785.
9. Lateral view right valve, male. Sample P6–1. USNM 168786.

4. *Paradoxostoma delicata* Puri, 1954.
4. Lateral view left valve. Sample P2–1. USNM 168787.

5, 6, 11, 12. *Cytheromorpha warneri newportensis* Williams, 1966.
5. Lateral view left valve, female. Sample P4–1. USNM 168788.
6. Lateral view right valve, female. Sample P4–1. USNM 168789.
11. Lateral view left valve, male. Sample P1–2. USNM 168790.
12. Lateral view right valve, male. Sample P1–2. USNM 168791.

10. *Paradoxostoma* sp. B.
10. Lateral view left valve. Sample P1–2. USNM 168792.

13, 14, 19, 20. *Microcytherura* sp. A.
13. Lateral view left valve, female. Sample P1–2. USNM 168793.
14. Lateral view right valve, female. Sample P1–2. USNM 168794.
19. Lateral view left valve, male. Sample P1–2. USNM 168795.
20. Lateral view right valve, male. Sample P1–2. USNM 168796.

15, 16, 21, 22. *Paradoxostoma* sp. F.
15. Lateral view left valve, male. Sample P1–2. USNM 168797.
16. Lateral view right valve, male. Sample P1–2. USNM 168798.
21. Lateral view left valve, female. Sample P1–2. USNM 168799.
22. Lateral view right valve, female. Sample P1–2. USNM 168800.

17., *Leptocythere* sp. A.
17. Lateral view left valve. Sample P4–1. USNM 168801.

18, 24. *Leptocythere* cf. *L. nikraveshae* Morales, 1966.
18. Lateral view right valve, female. Sample P1–2. USNM 168802.
24. Lateral view left valve, female. Sample P1–2. USNM 168803.

23. *Paradoxostoma* sp. G.
23. Lateral view right valve. Sample P1–1. USNM 168804.

25, 30. *Microcytherura choctawhatcheensis* (Puri, 1954).
25. Lateral view left valve, female. Sample P1–2. USNM 168805.
30. Lateral view left valve, male. Sample P4–1. USNM 168806.

26. *Sclerochilus* sp. D.
26. Lateral view right valve. Sample P5–1. USNM 168807.

27. *Sclerochilus* sp. C.
27. Lateral view left valve. Sample P1–2. USNM 168808.

28. *Paradoxostoma* sp. C.
28. Lateral view left valve. Sample P1–1. USNM 168809.

29, 34. *Leptocythere angusta* Blake, 1933.
29. Lateral view left valve, female. Sample P1–2. USNM 168810.
34. Lateral view left valve, male. Sample P1–2. USNM 168811.

31, 32, 35, 36. *Neolophocythere subquadrata* Grossman, 1967.
31. Lateral view left valve, female. Sample P1–2. USNM 168812.
32. Lateral view right valve, female. Sample P1–2. USNM 168813.
35. Lateral view left valve, male. Sample P1–2. USNM 168814.
36. Lateral view right valve, male. Sample P1–2. USNM 168815.

## PLATE 4—Continued

33, 37. *Neolophocythere* sp. A.
- 33. Lateral view right valve, male. Sample P4–1. USNM 168816.
- 37. Lateral view left valve, female. Sample P2–1. USNM 168817.

38, 39, 43, 44. *Loxoconcha matagordensis* Swain, 1955.
- 38. Lateral view left valve, male. Sample P1–2. USNM 168818.
- 39. Lateral view left valve, female. Sample P1–2. USNM 168819.
- 43. Lateral view right valve, male. Sample P1–2. USNM 168820.
- 44. Lateral view right valve, female. Sample P1–2. USNM 168821.

40, 45. *Loxoconcha* aff. *L. granulata* Sars, 1865.
- 40. Left lateral view of carapace, female. Sample P3–1. USNM 168822.
- 45. Right lateral view of carapace, female. Sample P3–1. USNM 168822.

41, 46. *Loxoconcha sperata* Williams, 1966.
- 41. Lateral view left valve, male. Sample P5–1. USNM 168823.
- 46. Lateral view left valve, female. Sample P5–1. USNM 168824.

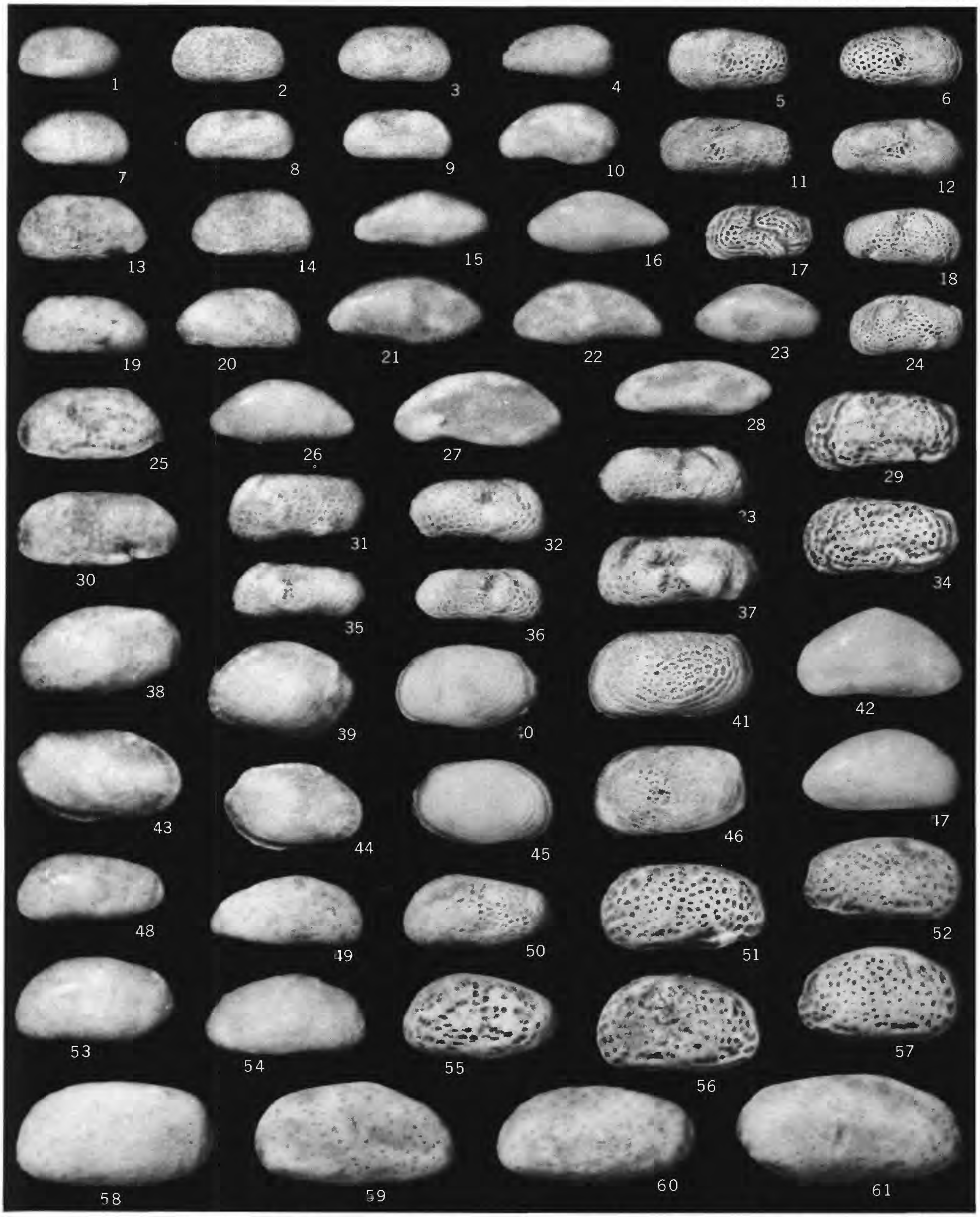
42, 47. *Propontocypris edwardsi* Cushman, 1906.
- 42. Lateral view left valve. Sample P1–2. USNM 168825.
- 47. Lateral view right valve. Sample P1–2. USNM 168826.

48, 49, 53, 54. *Proteoconcha tuberculata* (Puri, 1960).
- 48. Lateral view left valve, male. Sample P1–2. USNM 168827.
- 49. Lateral view right valve, male. Sample P1–2. USNM 168828.
- 53. Lateral view left valve, female. Sample P1–2. USNM 168829.
- 54. Lateral view right valve, female. Sample P1–2. USNM 168830.

50, 55. *Proteoconcha nelsonensis* (Grossman, 1967).
- 50. Lateral view left valve, male. Sample P1–2. USNM 168831.
- 55. Lateral view left valve, female. Sample P5–1. USNM 168832.

51, 52, 56, 57. *Hemicythere villosa* (Sars, 1865).
- 51. Lateral view left valve, male. Sample P1–2. USNM 168833.
- 52. Lateral view right valve, male. Sample P1–2. USNM 168834.
- 56. Lateral view left valve, female. Sample P1–2. USNM 168835.
- 57. Lateral view right valve, female. Sample P1–2. USNM 168836.

58, 59, 60, 61. *Proteoconcha gigantica* (Edwards, 1944).
- 58. Lateral view left valve, female. Sample 5–1. USNM 168837.
- 59. Lateral view right valve, female. Sample P4–1. USNM 168838.
- 60. Lateral view left valve, male. Sample P2–2. USNM 166839.
- 61. Lateral view right valve, male. Sample P4–1. USNM 168840.



*MICROCYTHERURA, PARADOXOSTOMA, CYTHEROMORPHA, LEPTOCYTHERE, SCLEROCHILUS, NEOLOPHOCYTHERE, LOXOCONCHA, PROPONTOCYPRIS, PROTEOCONCHA,* AND *HEMICYTHERE*