Table 1. Analysis of variance.

| Source of variation | Degrees of freedom | Sum of squares | Mean square | Estimated mean square |
|---|---|---|---|---|
| Between segments | $k-1$ | $np \sum_i (\bar{X}_{i..} - \bar{X}_{...})^2$ | A | $\sigma^2+p\sigma_b^2+np\sigma_a^2$ |
| | 2 | 906.23 | 453.12 | |
| Between outcrops within segments | $k(n-1)$ | $p\sum_i\sum_j (\bar{X}_{ij.} - \bar{X}_{i..})^2$ | B | $\sigma^2+p\sigma_b^2$ |
| | 18 | 4,785.80 | 265.87 | |
| Between lines within outcrops | $kn(p-1)$ | $\sum_i\sum_j\sum_m (\bar{X}_{ijm} - \bar{X}_{ij.})^2$ | C | $\sigma^2$ |
| | 63 | 6,865.35 | 108.97 | |
| Total | $knp-1$ | $\sum_i\sum_j\sum_m (\bar{X}_{ijm} - \bar{X}_{...})^2$ | | |
| | 83 | 12,557.38 | | |

Grand mean: $\bar{X} = 76.54$. Between segments variance: $\sigma_a^2 = 6.33$ (a fixed effect). Between outcrops within segments variance: $\sigma_b^2 = 39.23$. Between lines within outcrops variance: $\sigma^2 = 108.97$. $F = A/B = 1.70$ (tabular values for 1 percent and 5 percent are 6.01 and 3.55). $F' = B/C = 2.44$ (tabular values for 1 percent and 5 percent are 2.55 and 1.77).

Beyond the third segment a granite gneiss, often not clearly distinct from the end members, was present. This made application of our original operational definitions of country rock and granite impossible (without resorting to intuitive notions of the origin of the gneiss), so the population was truncated at that point. Our results apply to the first three segments only.

The measurements of each line were reduced to percentage of country rock ($M \times 100/M + G$). The 84 lines range from 24.4 to 97.1 percent country rock, with a mean of 76.5 percent and a standard deviation of 10.1. The measurements are approximately normally distributed (*3*).

An analysis of variance was run on the outcrop measurements with a two-stage nested classification: lines within outcrops and outcrops within segments. This enabled us to estimate the between-segments variance, the between-outcrops-within-segments variance, and the between-lines-within-outcrops variance.

The segments were put into the experimental design in order to determine the magnitude of regional variation. The between-outcrops variance is a measure of the smaller-scale areal variation. The between-lines variance is an attempt to quantify that real, local variation which is apparent when observing an exposure.

The analysis of variance table (Table 1) gives our results; it is a common model and more or less self-explanatory. The segments are not a random sample from a population of possible segments and $\sigma_a^2$ is consequently the variance of a fixed effect. We consider the following as significant. The F-ratio A/B is very small, indicating that the difference between segments is no larger than might be expected from three samples of seven outcrops each, with the outcrops exhibiting the variation which they do. Consequently $\sigma_a^2$ may not be significantly different from zero and no large-scale regional variation is established for this case. On the other hand, the F-ratio B/C is large: the chance of such a value's occurring by accident is less than one in 100; this indicates that there is a real variation between outcrops.

It is this component of the variance ($\sigma_b^2$) in which we are most interested, and we are presently making compositional analysis of specimens in order to determine, by regression techniques, the reduction in $\sigma_b^2$ given the country rock composition. However, possible functional relationships to metamorphic grade (a measure of temperature or water vapor pressure or both), structural position (position in stress field), or distance from exposed granite plutons are also to be considered.

The very local (within outcrops) variance may also be associated with such variables as temperature, stress, or country rock composition, although it seems unlikely that these have or had steep local gradients. The local variance ($\sigma^2$) is more likely to be related to textural or other fabric characteristics of the country rock. Our present plans, however, call only for tests against the mineralogical and chemical properties of the country rock (*4*).

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4. We acknowledge the advice and aid of W. C. Krumbein and F. A. Graybill and of B. F. Whitney, J. F. A. Jackson, and C. W. Ashcom. This work has been supported by funds from the Wayne State University, graduate division, and the Institute of Science and Technology.

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## Pleistocene Sea Levels, Southeastern Virginia

Abstract. *Detailed study of post-Miocene stratigraphy in southeastern Virginia reveals at least 13 formations which show six Pliocene (?) and Pleistocene cycles of emergence and submergence, with maximum submergent sea levels near +45, +45, +20, +25, +15, and 0 feet, respectively. The newly established stratigraphic framework disproves earlier interpretations of "terrace-stratigraphy" and sea level chronologies.*

Interglacial sea levels higher than the present one are recorded by characteristic morphologic features and by marine sediments along coasts in many parts of the world (*1*). Where coasts have not been subsequently deformed, such features and sediments are useful for correlation merely on the basis of their altitudes above present sea level.

Although as many as seven interglacial sea levels have been inferred along the Atlantic Coastal Plain of North America, chiefly on the basis of morphologic features, only two have been confirmed by stratigraphic evidence: (i) a sea level near +25 feet, based on the fossiliferous marine Cape May formation in New Jersey and the Pamlico formation in North Carolina; and (ii) a sea level near +90 feet, based on beach sand and lagoon sediments in South Carolina (*2*) and at Trail Ridge, Ga. (*3*).

Our stratigraphic study in southeastern Virginia (Fig. 1) has shown that seven deposits of marine and marine-lagoonal sediments are present east of the Suffolk scarp; these were laid down during five periods of submergence when sea level rose from below its present position to maxima which range from approximately 15 to 45 feet above it. We have completed 10 months of field work in a strip 4.5 miles wide which extends from Sandbridge on the east to Surry on the west. In the process of detailed geologic mapping, we obtained stratigraphic information from four sources: more than 220 natural exposures; more than 300 shallow borings made with hand-auger and 2-inch plastic tubes, with cumulative footage exceeding 2500; 14 deeper drill holes totaling 686 feet; and numerous logs of deep borings made available by drillers (*4*).

Well-developed scarps and "terraces" have been described by previous workers. Four "terraces," plains that slope gently eastward, were mentioned by Wentworth (*5*), from west to east; they include Sunderland, Wicomico, Dismal Swamp, and Princess Anne. These are separated by three east-facing scarps: Surry scarp (crest, +100 to +120 feet; toe, +90 feet) between Sunderland and Wicomico terraces; Suffolk scarp (crest, +50 to +70 feet; toe, +25 feet) between Wicomico and Dismal Swamp terraces; and Princess Anne scarp (crest, +15 to +30 feet; toe, +12 feet) between the Dismal Swamp and Princess Anne terraces. According to Cooke (*6*) the Dismal Swamp terrace is the equivalent of the Pamlico terrace in North Carolina. Several workers (*3, 5–7*) have inferred from morphology that the Surry scarp was cut by an interglacial sea whose level was +90 feet and that the Suffolk scarp was cut by another, whose level was +25 feet. Our study has indicated that stratigraphy provides the best evidence and control for former sea-level positions, and that extensive revision of previous ideas is necessary.

Table 1. Table of post-Miocene stratigraphic units.

| Formation | Thickness (ft) Max. | Thickness (ft) Av. | Altitude (ft) Top | Altitude (ft) Base | Composition | Source of name |
|---|---|---|---|---|---|---|
| | | | *Recent* | | | |
| Recent (undiv.) | >80 | Var. | +60 | <−170 | Dune and beach sand; peat; alluvial silt | |
| Dismal Swamp peat | 11 | 5 | +25W<br>+15E | +9 | Freshwater peat | New |
| | | | *Late Pleistocene* | | | |
| Sandbridge | 20 | 8 | +15 | <−5 | Dune and beach sand in east; lagoon clay and clayey sand in west | New |
| Londonbridge | 35 | 8 | +30 | −5 | Dune and beach sand with shells in east; lagoon clay in west | New |
| Kempsville | 15 | 5 | +20 | 0 | Beach sand, gravel, and shells | New |
| | | | *Middle or Late Pleistocene* | | | |
| Diamond Springs | >15 | >15 | +20 | <+5 | Fluvial sand and gravel | New |
| Norfolk | 30 | 20 | +18 | −15 | Near-shore marine sand, clayey sand, sandy clay, and shells; basal gravel member | Clark and Miller, 1906 (*17*) |
| Great Bridge | 55 | 40 | −10 | −70 | Beach ridge sand inferred in east; lagoon clay in west | New |
| North Landing | 20 | 15 | −55 | −80 | Beach sand, gravel, and shells | New |
| | | | *Early Pleistocene* | | | |
| Nansemond | 25 | 20 | +20 | 0 | Clayey and silty sand, clay, beach sand; basal cobble zone | W. E. Moore, 1956 (*14*) |
| Benns Church | 40 | 20 | +42 | +25 | Beach and dune sand | New |
| | | | *Pliocene or Early Pleistocene* | | | |
| Kilby | 65 | 45 | +110W<br>+50E | +50W<br>+20E | Fluvial sand and gravel; basal cobble zone | W. E. Moore, 1956 (*14*) |
| Canal Run | 15 | 10 | Variable | | Fluvial sand, silt, and clay | New |
| | | | *Pliocene or Late Miocene* | | | |
| Sedley | 23 | 8 | +50W<br>+20E | Var.<br>to +5 | Fluvial silt and silty sand | W. E. Moore, 1956 (*14*) |
| | | | *Late Miocene* | | | |
| Yorktown | 37 exposed max. | | +40W<br>−80E | ? | Stiff clay, silt, and coquinite | Clark and Miller, 1906 (*17*) |

The surficial sediments of southeastern Virginia range in age from Late Miocene to Recent. Our interest was centered upon the post-Yorktown (Upper Miocene) deposits; the pronounced unconformity at their base served as a convenient and easily located reference surface.

Subdivisions are based on composition and unconformities. Unconformities between marine units east of the Suffolk scarp are marked by weathering and erosion. The deposits of each submergence, therefore, are considered to be a genetic unit. During submergence, the beach zone may encroach upon the land or a barrier may form. A barrier, once formed, may prograde seaward, transgress landward, or grow upward in place as submergence proceeds (*8*). In the sheltered back-barrier region, lagoonal sediments typically accumulate. Although rapid compositional changes occur near former barriers in Virginia, the back-barrier sediments are generally characterized by relatively thin, widespread, and distinctive materials which can be followed in the shallow subsurface; this indicates that extensive erosion did not occur during times of emergence.

With this approach, we have recognized numerous units east of the Suffolk scarp whereas previous workers described only a single marine unit which was supposed to have been deposited during a single episode of submergence. The units we have recognized and their relationships to one another are shown schematically in Fig. 2. Table 1 summarizes data on thickness, altitude of top and base, composition, and source of name of each formation.

The Suffolk scarp is an important stratigraphic as well as morphologic boundary; it separates the post-Miocene units into a western group of weathered nonmarine formations and into an eastern group of much less weathered, predominantly marine formations. The western group includes, from base to top, Sedley, Canal Run, and Kilby formations; the Benns Church sand overlies the Kilby Formation at the Suffolk scarp (Fig. 2). The eastern group includes, from base upward, Nansemond, North Landing, Great Bridge, Norfolk, Diamond Springs, Kempsville, Londonbridge, and Sandbridge formations.

The geologic age of these formations is post Late Miocene and pre-Recent. Their relative ages are based on superposition of units, and the tentative age assignments shown in Table 1 are based chiefly on relative amounts of weathering. A few radiocarbon ages have been measured (Table 2).

Recent sediments in the area consist of dune sand; near-shore fine sand and clayey sand; beach sand, gravel, and shells; lagoon clay and silt; tidal-marsh clay, and the Dismal Swamp peat. Of these, only the Dismal Swamp peat is of interest in this discussion.

The Dismal Swamp peat underlies a low area east of the Suffolk scarp (vertical lines, Fig. 1). Previously the peat was thought to have accumulated in a former lagoon (*9*), but Whitehead's study of the pollen (*10*) indicates conclusively that the peat is entirely of freshwater origin. Contours on the base of the peat (*11*) show a dendritic channel pattern in the oxidized underlying deposits, which we believe to be evidence that the depression in which the peat accumulated originated in part by fluvial action.

Stratigraphic evidence permits both direct and indirect determination of the altitudes of former submergent sea levels. Direct stratigraphic evidence consists of beach sediments. Indirect evidence consists of: water depths inferred from faunal criteria and composition of near-shore marine or lagoon sediments, the lowest position of nonmarine sediments, and indications of subaerial weathering and erosion between successive marine units.

Relative sea level positions inferred from the stratigraphic evidence are shown graphically in Fig. 3 and may be summarized briefly as follows. The nonmarine Sedley and Kilby formations indicate an emergence to below +5 and +20 feet, respectively, during their deposition. The Surry scarp is cut into the Kilby Formation and may indicate a post-Kilby submergence to between +90 and +100 feet. We have not yet found any marine sediments in southeastern Virginia

Table 2. Radiocarbon ages of samples taken from Dismal Swamp peat, Kempsville Formation and Sandbridge Formation.

| Yale laboratory No. | Formation | Age (years ago) |
|---|---|---|
| Y-1146 | Dismal Swamp peat; basal part at +9 ft, where peat is thickest (11 ft) | 7,670 ± 60 |
| Y-1194 | Kempsville Formation; driftwood | > 40,000 |
| Y-1272 | Sandbridge Formation; wood in peat | > 40,000 |

that can be attributed to such a submergent episode; the idea is based entirely on morphology. The Suffolk scarp cuts the Sedley and Kilby formations; the sea that fashioned this scarp is also thought to have deposited the Nansemond Formation and Benns Church sand. The altitude of the Nansemond submergent sea level ranged between a minimum of +20 feet, the highest occurrence of Nansemond sediments, and +42 feet, the highest occurrence along the Suffolk scarp of the Benns Church sand, a beach and dune complex.

An episode of emergence followed deposition of the Nansemond Formation, during which sea level dropped to below −80 feet. Thereafter, a submergence raised relative sea level to a position between −55 and −80 feet, as indicated by the transgressive beach sand, gravel, and marine shells of the subsurface North Landing Formation. From this level a further transgression took place to about −10 feet, during which the thick lagoonal Great Bridge Formation was deposited landward of an upgrowing barrier, judged to have existed farther east than the present shoreline (Fig. 2). This Great Bridge barrier is thought to have been drowned by a later rapid submergence that destroyed the old lagoon and shifted the surf zone to the vicinity of the Suffolk scarp for the second time. The Norfolk Formation was deposited during a stillstand at this position. Southwest of Kempsville the fauna and sediments of the Norfolk Formation at +18 feet indicate near-shore open-shelf marine

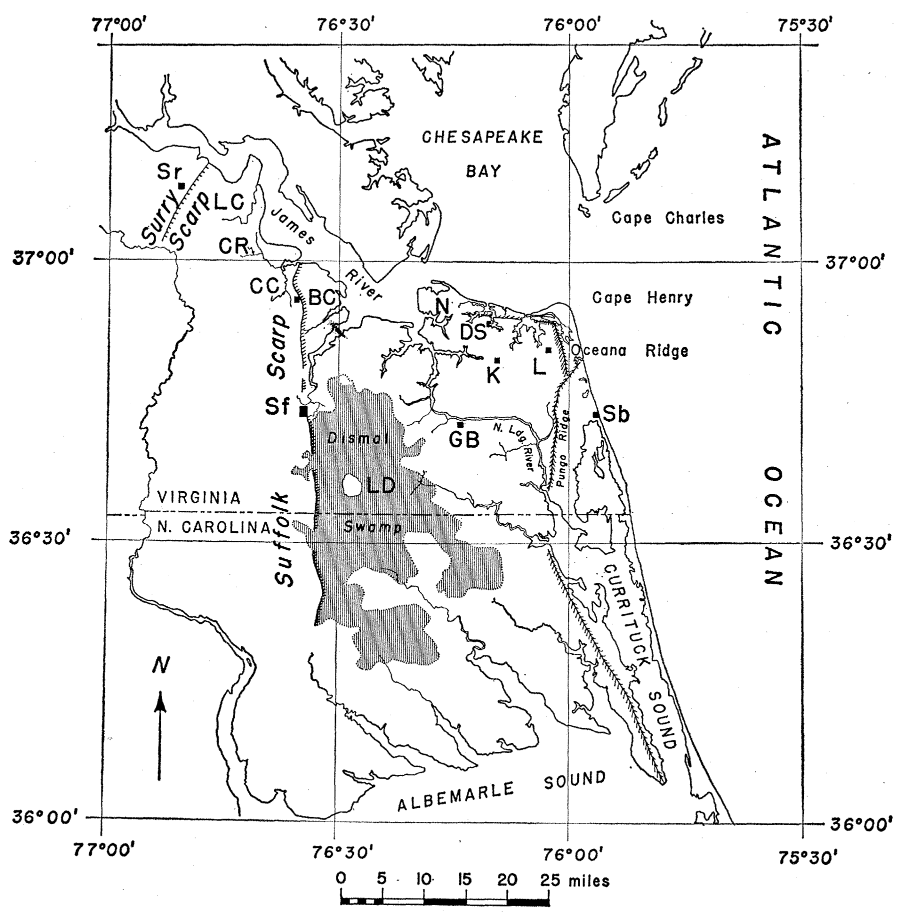


Fig. 1. Index map of southeastern Virginia which shows features that were studied. BC, Benns Church; CC, Cypress Creek; CR, Canal Run; DS, Diamond Springs; GB, Great Bridge; K, Kempsville; L, Londonbridge; LC, Lawnes Creek; LD, Lake Drummond; N, Norfolk; Sb, Sandbridge; Sf, Suffolk; and Sr, Surry.

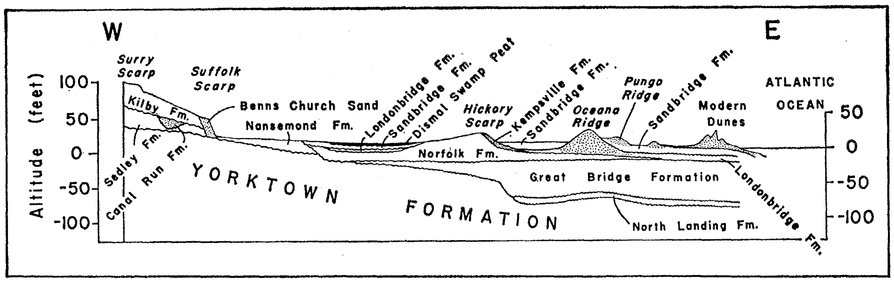


Fig. 2. Schematic stratigraphic section at right angles to the present coast, southeastern Virginia, which shows relationships of the stratigraphic units. Topography schematized. Section is 60 miles long; lefthand side is appreciably foreshortened; distance from Suffolk scarp to Atlantic Ocean is 35 miles. Stippled, sand; black, Dismal Swamp peat; and wavy lines, unconformities between stratigraphic units.

conditions with water depth of approximately 25 to 30 feet. Accordingly, a minimum altitude of approximately +43 feet is inferred for Norfolk sea level. The maximum thickness of the Norfolk Formation is 30 feet, which indicates that the sea level and the land remained at a nearly constant relative level for a protracted period of time.

The morphology of the Suffolk scarp and absence in areas west of it of any marine sediments or features of Nansemond or Norfolk age are evidence that neither Nansemond nor Norfolk submergence reached higher than approximately +50 feet.

East-west valleys cut into the Norfolk Formation near Kempsville and Great Bridge, and the fluvial deposits of the Diamond Springs Formation just south of Chesapeake Bay, indicate emergence to below +5 feet after deposition of the Norfolk Formation. Possibly the alluvial fills found along Lawnes Creek and Cypress Creek were deposited in connection with this emergence and the subsequent submergence.

Three successive post-Norfolk submergent episodes, separated by two intervals of emergence during which oxidation and minor subaerial erosion occurred, are indicated by the marine Kempsville Formation and the marine-lagoonal Londonbridge and Sandbridge formations.

An early Kempsville submergence to a maximum of +15 to +20 feet is inferred from the highest beach gravel and sand south of Kempsville. A later Kempsville relative sea level between +7 and +11 feet is inferred from progradational beach sand east of the earlier, higher beach deposits.

The barrier facies of the Londonbridge Formation at Oceana Ridge indicates a gradual submergence from −5 to +25 feet. The highest beach sand and gravel here indicate a maximum submergence to +25 feet in Londonbridge time. Eolian sand has built the top of the ridge up to +30 feet locally.

The barrier facies of the Sandbridge Formation at Pungo Ridge shows that an early Sandbridge submergence progressed from −5 feet to between +10 and +15 feet. A maximum stand at this level is inferred from the highest beach sand and lagoon clay of the Sandbridge Formation and from the morphology of Pungo Ridge. A later Sandbridge relative sea level between 0 feet and +5 feet is demonstrated by beach sediments and beach-ridge morphology east of Pungo Ridge.

A major emergence after the Sandbridge submergence is indicated by the cross-axial and parallel stream network that developed on the Sandbridge Formation. The freshwater peats described by Harrison and Rusnak (*12*) from the mouth of Chesapeake Bay are also related to this post-Sandbridge emergence. Radiocarbon ages and altitudes of the peats are shown in Table 3.

The freshwater Dismal Swamp peat and its radiocarbon age indicate that the area has not been submerged to as high as +10 feet during the past 8000 years at least; a sea which reached such a height would have found easy access to the Dismal Swamp through the stream valleys that drain it (Fig. 1). A recent submergence of at least 8 feet is marked by fresh-water stumps rooted in clay near mean low tide; these are generally overlain by modern beach sand, but are exposed during storms. A radiocarbon age of an *in situ* stump from near False Cape is 730 ± 70 years (sample Y-924, Yale Univ.) (*13*).

In summary, six post-Miocene episodes of submergence are indicated by seven marine and marine-lagoonal formations and the Recent sediments east of the Suffolk scarp. Six episodes of emergence are indicated by the subaerial weathering and erosion of the marine deposits. These six episodes of submergence and emergence probably have been caused chiefly by glacio-eustatic changes of sea level during Pleistocene time, although the possibility of crustal movement as a modifying factor has not been dismissed (*12*). The maximum altitudes reached by the sea during episodes of submergence range between +15 and +45 feet. Three major episodes of emergence are indicated, following deposition of the Nansemond, Norfolk, and Sandbridge formations, respectively. The Sandbridge, Londonbridge, Kempsville, and Norfolk formations are so little

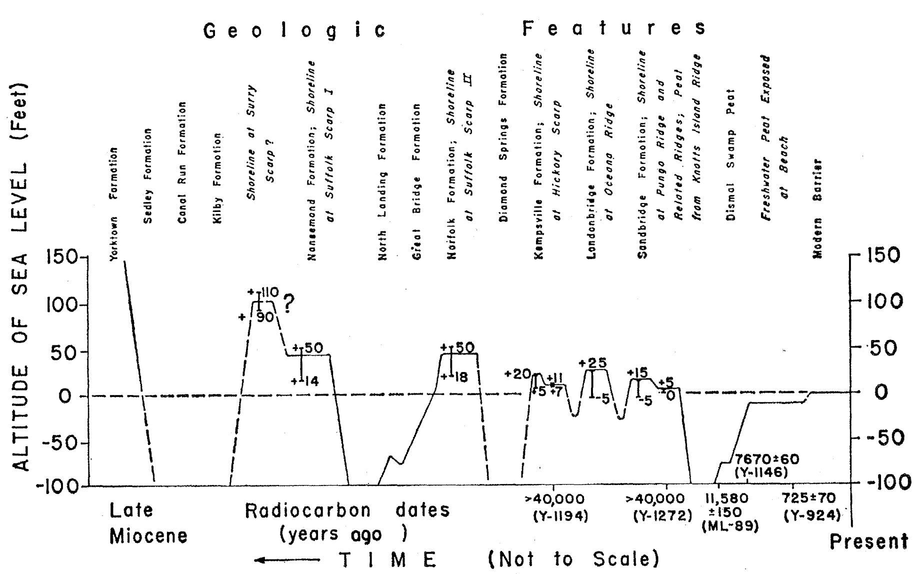


Fig. 3. Diagram of relative positions of land and sea level, based on stratigraphy of southeastern Virginia, showing geologic features and radiocarbon dates.

Table 3. Radiocarbon ages and altitudes of peat samples from Chesapeake Bay borings (*12*).

| Laboratory No. | Altitude | Age (years ago) |
|---|---|---|
| ML–91 | −89 | 14,870 ± 200 |
| ML–89 | −85 | 11,180 ± 150 |
| ML–90 | −82 | 9,930 ± 130 |

weathered that their age may be no older than Sangamon.

Our detailed mapping verifies the hypothesis of Moore (*14*) that in southeastern Virginia the Wicomico and Sunderland "terraces" of Wentworth (*5*) are both underlain by the Sedley and Kilby formations. Moore believed that the Kilby Formation underlying the Wicomico "terrace" is of marine origin, but we believe that the Kilby Formation is of fluvial origin throughout. It can be traced through the Surry scarp, the boundary which Moore used between supposedly marine Kilby and supposedly nonmarine Kilby. No changes other than a gradual increase in altitude of the basal cobble zone and a slight increase in grain size occur from east to west across the scarp. Because the Surry scarp is cut into the Kilby Formation it must be younger than the Kilby.

Similarly, Wentworth supposed that the sea which cut the Suffolk scarp also simultaneously fashioned a wave-cut bench seaward of it and deposited upon this bench a single marine formation, the Pamlico "terrace-formation," presumably in a shallow open-shelf environment. Although marine deposits do lie east of the Suffolk scarp, only one unit, the Norfolk Formation, can be ascribed to shallow open-shelf conditions. Furthermore, the Norfolk Formation is overlain by sediments of two younger depositional cycles which are products of barrier-island and lagoon environments, the Londonbridge and Sandbridge formations, and by the Kempsville Formation, a beach deposit. The Norfolk Formation also overlaps two other formations, the Great Bridge and North Landing formations, which are lagoon and littoral deposits confined entirely to areas east of the Dismal Swamp. With the possible exception of the surface underlying the Norfolk Formation near the Suffolk scarp, and the surface underlying the Kempsville Formation near the Hickory scarp, no wave-cut "bench" can be identified between these formations; instead, their surfaces of contact are irregular and show evidence of oxidation. Undoubtedly they are depositional surfaces modified by stream erosion.

Our stratigraphic studies, based on outcrops and drilling, show that the older concept in southeastern Virginia of terraces and open-shelf, shallow-marine "terrace-formations" is completely erroneous. The area formerly thought to comprise the Pamlico and Princess Anne terraces is actually underlain by a complex of at least seven marine, littoral, and lagoon formations. The so-called Wicomico and Sunderland terraces prove to be underlain by the non-marine Sedley and Kilby formations which extend under both of them.

The term "terrace," as used in a morphologic sense along the Atlantic Coastal Plain, has acquired a genetic implication which is invalid in the area we studied. We believe that the term "plain" (*15*) is more appropriate than the term terrace, and that different names should be used for stratigraphic units to distinguish them from morphologic features such as plains, swales, scarps, and rises. In line with this principle we have not used "Pamlico," "Wicomico," and "Sunderland" as formation names. In our judgment further application of these terms will hinder progress in study of Pleistocene coastal stratigraphy because of the genetic implications which have become associated with them through long usage (*3, 5–7, 16–18*).

Finally, we emphasize that study of stratigraphy gives better control on the extent of Pleistocene submergences and emergences, and produces a more accurate and complete geologic history than can be obtained from morphologic study alone (*19*).

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25 March 1963

## Fatty Acids: In vivo Synthesis by the Green Peach Aphid, Myzus persicae (Sulzer)

Abstract. *After feeding through an artificial membrane on an 18 percent sucrose solution containing either acetate-1-*$C^{14}$ *or uniformly-labeled glucose-*$C^{14}$, Myzus persicae *incorporated 75 percent of the carbon-14 into palmitoleic, stearic, and oleic acids. Small amounts were incorporated into myristic, linoleic, and linolenic acids; no significant amounts were incorporated into the short-chain fatty acids.*

A recent technique (*1*) for feeding aphids substantial amounts of liquids through an artificial membrane now makes the study of aphid nutrition feasible. The use of radioisotopes to study an insect's nutrition provides results in general agreement with the classical deletion method (*2*), and it has been used to determine the amino acid requirements of an insect which cannot