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COMPARISON OF INTERGLACIAL MARINE STRATIGRAPHY IN VIRGINIA, ALASKA, AND MEDITERRANEAN AREAS

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ABSTRACT. Stratigraphic and morphologic features in a sector of the coastal plain in southern Virginia define several former positions of relative sealevel, of pre-Wisconsin Pleistocene age. Comparison of the stratigraphic features with well-documented features of somewhat similar character (1) in the vicinity of Nome, Alaska, and (2) on the island of Mallorca shows similarities among the three sequences. The similarities are independent of altitude, a parameter considered unreliable in the existing state of knowledge. They suggest that with accumulation of further data, long-distance correlation of at least some Pleistocene strandline features, by conventional stratigraphic methods, can be expected.

RECONSTRUCTION OF PLEISTOCENE SEALEVELS

The form of the curve of eustatic sealevel fluctuation through the glacial and interglacial ages of the Pleistocene Epoch has taken on as much interest as has the curve of temperature fluctuation on the lands. Although many local observations and measurements of ancient strandlines have been recorded, it has generally not been possible to distinguish quantitatively between the effects of eustatic changes of sealevel and the effects of movement of the crust. The relations are similar to those involved in measuring the widespread postglacial submergence of coasts. No one doubts that sealevel as a whole is now rising eustatically, but the influence, on this submergence, of local subsidence of the crust is very difficult to measure because no fixed or independent datum is available.

Within a narrow coastal sector the two effects are not directly distinguishable; one can identify only the effect of relative submergence or emergence. Distinction between absolute change of sealevel and change in the local position of the solid surface can only be made through accurate identification and measurement of ancient shorelines through long distances. If a strandline maintains a constant altitude, within the limits of reliable measurement, through a substantial distance, the probability that movement of the crust has influenced its vertical position is small; whereas a strandline that can be traced nearly continuously, yet changes altitude through its known extent, clearly has been deformed. All this demands detailed examination of a very great aggregate length of coastal terrain. Although the time may be far in the future when undeformed strandlines can generally be identified and used as a basis for inference as to absolute changes of sealevel, progress toward that goal can be made through conventional stratigraphic field study. Mean-

while, in the discussion of data it is prudent to describe inferred former sealevels as *relative sealevels*, wherever no attempt is made to distinguish between eustatic variation and movement of the crust.

In most of the literature on emerged Pleistocene marine features, the chief basis of attempts at correlation has been altitude. The use of altitude involves the assumption, usually implicit rather than explicit, that the features reached present altitudes through eustatic change of sealevel, at least in part, rather than through movement of the crust. Apart from the influence of crustal movement the degree of resolution in the measurement of a former shoreline is rarely good enough to permit correlation, at least very precisely, by altitude alone. On a graph, sea-surface altitudes at former times, inferred from geologic features, are expressed realistically by bars rather than by points. Another factor that could hinder close correlation through long distances is the small variation in altitude from place to place that affects the surface of the sea today. For these reasons comparison should be based not on altitude, but on the features commonly used in correlating Pleistocene stratigraphic units of other kinds. These include (a) radiometry, (b) fossils and artifacts, (c) intensity of development of weathering and soils, (d) geomorphology, and (f) evidence of amplitude of regression, if any, intervening between two strandlines. Such means could make possible the stratigraphic zonation of a sequence of strandlines which, in turn, could lead to evaluation of their altitudes. Comparison of altitudes with stratigraphic zonation could lead to discrimination between crustal movement and eustatic movement as factors in the present altitude of a strandline. Differences of this kind have begun to be perceived in parts of the Mediterranean region (for example, E. Bonifay, *in* Howell and others, 1962, p. 343-370). With the location and effects of crustal movement defined, altitudes of strandlines in intervening sectors could acquire significance for correlation.

In this connection distinction must be made between absolute altitude of a strandline and the vertical relation between two strandlines. Crustal movement could change the value of the former, but the "vertical" distance between two strandlines would be the same in most cases even after deformation postdating the two.

In summary, the complex process of correlation should begin with comparison of stratigraphic similarities. When such similarities have been established and a first approximation to stratigraphic ages has been reached, altitudes within the limitation of those ages can be appraised. It should then be possible to discriminate between areas that have been tectonically active and those that have been inactive since the shorelines were recorded. As a result the extent of eustatic influence in the altitude of each strandline could be approximated.

Although this procedure seems sound in theory, it will inevitably encounter the kinds of difficulties that result from lack of critical

stratigraphic information, lack of precision of measurement, and similar obstacles.

REVIEW OF DATA ON SOUTHEASTERN VIRGINIA

The results of an intensive study of a narrow sector of the coastal plain in southeastern Virginia have yielded such detailed information about Pleistocene relative sealevels that it is profitable to compare it with data available from other coasts. The study, made during the period 1961-1964 under contract NONR 609 (40), Office of Naval Research, is the subject of a preliminary report (Oaks and Coch, 1963); a comprehensive report, now in preparation, will be published as a Bulletin of the Virginia Division of Mineral Resources, under the joint authorship of J. E. Sanders, R. Q. Oaks, N. K. Coch, and R. F. Flint.

The most basic of the results achieved in the Virginia study is that the emerged marine features there do not support the "terrace" concept (compare Shattuck, 1901) that for several decades dominated the literature on the Pleistocene of the coastal plain. According to that concept the coastal plain is characterized by a series of terraces, horizontal in the coastwise direction, each consisting of a wave-cut bench thinly carpeted with marine sediments and limited landward by a wave-cut cliff. A frequently expressed corollary of that simple picture is Pleistocene submergence of the continental border by successively lesser amounts.

The Virginia coastal features are not simple terraces. On the contrary, they center in a stratigraphic sequence of several distinct formations, some of which include as many as three sedimentary facies. In all, four facies are recognized: offshore-marine, beach-barrier-dune, lagoon, and alluvial. The facies are similar in character and distribution to those forming in the coastal belt today. Morphologic features are present in the form of barriers and spits, dunes, mainland beaches, and lagoon flats, but without knowledge of the stratigraphy these features would constitute an inadequate basis for interpretation of former sealevels. However, stratigraphy (especially of the beach- and lagoon facies), supported by morphology, makes it possible to fix within specified limits the positions of several former Pleistocene sealevels relative to the land. In all at least seven positions, all of which are believed to antedate the Wisconsin Glacial Age, have been identified.

Most of the stratigraphic units contain invertebrate fossils, all of which are known elsewhere from Pleistocene strata. The assemblages are alike in indicating temperatures comparable with those characteristic of the Virginia coast today or very slightly higher; therefore they imply correlation with interglacial rather than glacial times. Cypress wood found in sediments interbedded with the marine strata likewise implies temperatures comparable with those of today.

Three C^{14} dates (Y-1192, Y-1271, Y1272) from marine units are greater than 40,000 years B. P., and one (Y-1047) is greater than 47,000. Taken in conjunction with the temperature indications derived from the fossils, and with evidence of a profound marine regression separating

these units from postglacial sediments less than 16,000 years old (ML-91), the dates imply that with considerable probability the sedimentary sequence, including the youngest unit, antedates the Wisconsin Glacial Age.

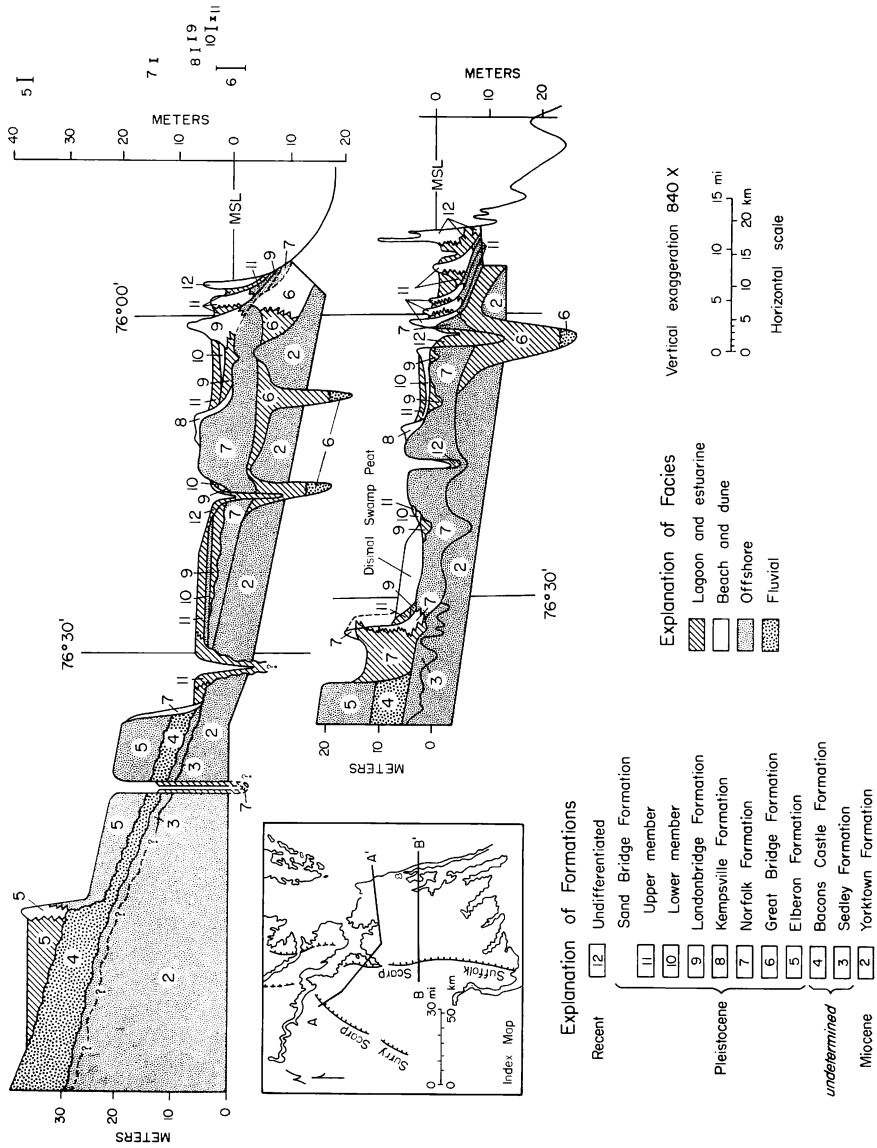
It seems very unlikely that any of the marine sediments in Virginia that lie above the existing sealevel are of Wisconsin interstadial age. Fossil plants of Wisconsin interstades elsewhere in North America indicate temperatures lower than those of today and hence suggest that sealevel must have been lower than it is at present. Therefore, unless movement of the crust has occurred, this reasoning supports our opinion that the sediments in Virginia antedate the Wisconsin Age.

For an understanding of the inferred former sealevels the stratigraphy is viewed best in cross section rather than on a map. The profiles and sections in figure 1 show both facies and formation and, on the right, several positions of sealevel in chronologic order. Finally figure 2B traces successive positions of sealevel, relative to the land in southeastern Virginia, through time. It is apparent that the altitudes of the former sealevels are not related consistently to their relative ages; in other words, during the time span represented by the stratigraphy sealevel fluctuated both downward and upward in an irregular manner and moved downward at least three times to positions below the one it occupies today. To the extent to which these fluctuations are eustatic and controlled by climate, the pattern is expectably similar to that traced by the fluctuations of glaciers, as inferred from their moraines. There is no obvious reason why sealevel should be expected to reach and hold a constant altitude during an interglacial age.

If the stratigraphic units are in fact interglacial, then at least two interglacial stages appear to be represented. The evidence consists of differences in depth and intensity of weathering and in extent of dissection. Through the Norfolk and younger units, weathering is less intense than in the Elberon and older units. Similarly, dissection of the clay-silt, lagoon facies of the Elberon Formation is considerably more extensive than dissection of similar facies of Norfolk and post-Norfolk units, in which initial texture and topography are comparable. Although weathering characteristics differ among the younger units, they are sufficiently similar to each other to suggest provisional correlation of the group of younger units with a single interglacial stage. As there are in the region no features, still younger than these, which indicate a sealevel higher than the existing one, probably the interglacial represented by these sediments is the Sangamon.

In contrast, the deeper and more intense weathering of the Elberon Formation implies subaerial exposure through a much longer aggregate

Fig. 1. Profiles and cross sections showing Pleistocene stratigraphy and morphology of the coastal plain in southern Virginia. Modified from reconstruction by R. Q. Oaks and N. K. Coch (unpublished). Confidence bars (upper right) for altitudes of former sealevels carry the numbers of the stratigraphic units to which they correspond.



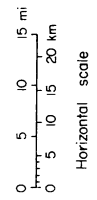
Explanation of Formations

- Recent
 - 12 Undifferentiated
 - Sand Bridge Formation
 - 11 Upper member
 - 10 Lower member
 - 9 Landonbridge Formation
 - 8 Kempsville Formation
 - 7 Norfolk Formation
 - 6 Great Bridge Formation
 - 5 Elberon Formation
 - 4 Bacons Castle Formation
 - 3 Sedley Formation
 - Miocene
 - 2 Yorktown Formation

Explanation of Facies

- Lagoon and estuarine
- Beach and dune
- Offshore
- Fluvial

Vertical exaggeration 840 X



time, although we have not found a means of translating the difference into quantitative terms. Furthermore the Elberon is separated from the younger units by evidence of a major marine regression to at least -80 feet (-25 m). Hence we correlate the Elberon tentatively with the Yarmouth Interglacial Stage, but at the same time we admit the possibility of its correlation with a pre-Yarmouth interglacial. Unless the Sedley Formation is of interglacial age, no pre-Elberon marine interglacial sediments have yet been identified in southeastern Virginia. Hence, if the Elberon is of Yarmouth age, any older strandlines and other marine features may not have reached as high an altitude as the Elberon or may have been destroyed by erosion in pre-Elberon time. Evidence of such features should be sought at other latitudes, where conditions may have been more favorable for their preservation.

Although invertebrate fossils have been found in each of the post-Elberon formational units, their value lies principally in their indications of facies and of temperature in a broad sense. The fossils do not show significant evolutionary differences from living faunas. Consequently no inferences useful for correlation can be drawn from them, apart from the generalization that they imply interglacial rather than glacial temperature.

Although there is little visible evidence of crustal movement in southeastern Virginia during or since the development of the marine features, two observations suggest that slight crustal movement can not be excluded. First, the altitude of the surface of the Elberon lagoon facies appears to be possibly 20 feet (6 m) higher in southern Virginia than in its apparent correlative in a part of South Carolina (Colquhoun and Duncan, 1964, p. 135), nearly 300 miles (500 km) farther south. Second, the altitude of the surface of the Sand Bridge lagoon facies suggests possible post-Sand Bridge tilting with a west-east component (downward toward the east) of around 0.3 foot/mile (6 cm/km). These suggestions indicate the advisability of caution in any attempt to correlate on a basis of altitude alone.

COMPARISON WITH OTHER SECTORS OF THE COASTAL PLAIN

With the foregoing description in mind, we can compare the Virginia features with those elsewhere. Comparisons with Pleistocene stratigraphy south of Virginia are not very useful, because most of the published material on the southern region lacks adequate detail and is based on the "terrace" concept, which our experience in Virginia has shown to be unrealistic. It is likely, however, that correlation, probably close, of stratigraphy through Virginia, the Carolinas, and Georgia will ultimately be possible, in view of detailed studies, with a modern point of view, that are now in progress in areas south of Virginia.

The Pleistocene stratigraphy to the north, between the James River and the region of glaciation, includes much more gravel in relation to fines than do the sediments in southern Virginia and is believed to be

the result of different physical conditions. Streams seem to have played a greater part than have shore processes in building the coastal-plain sediments. Factors that may have influenced this difference include (1) northward narrowing of the coastal plain, apparently because of subsidence, (2) greater late-Cenozoic uplift of the northern Appalachian region than of the southern, with consequent steepening of gradients, and (3) greater production of large clasts by frost weathering during glacial ages in the north than in the south. Whatever the causes of the difference, correlation between southern Virginia and the region to the north does not seem to us feasible at present.

STRATIGRAPHY IN THE NOME DISTRICT, ALASKA

Within North America, the coastal segment with which comparison of the Virginia sequence seems to offer the best possibilities is that in the vicinity of Nome, Alaska, facing the Bering Sea, because the Nome sequence affords clearer stratigraphic and paleontologic relations than are met with elsewhere and is apparently little deformed. That sequence, succinctly set forth by Hopkins, MacNeil, and Leopold (1960), is summarized in table 1. The relative stratigraphic positions of the units, with the exception named, are well established. The correlations suggested for the beaches are based mainly on (1) positions of the beaches relative to tills of major glaciations and (2) differences in the faunas they contain.

Assignment of Second Beach to the Sangamon Interglacial is based on evidence closely similar to that used in Virginia for suggesting a Sangamon age for the units of Great Bridge to Sand Bridge age, inclusive. That evidence is (1) that the related units represent the latest period at which sealevel stood higher relative to the land than it does today; (2) that that sealevel position antedates 38,000 years B.P. (C¹⁴ sample W-810) and hence is at least as old as the middle of the Wisconsin Age, a time when sealevel was lower than it is at present; and that the associated assemblage of marine fossils (3) is essentially modern and (4) implies water temperatures the same as or slightly above those of today.

Because of these similarities it is possible that the post-Elberon units in Virginia are correlative with the Second Beach unit at Nome. In the comparison, altitude has not been considered. Nevertheless the altitudes are comparable, and this suggests (if the possible correlation proves to be valid) that post-Sangamon crustal movement in each of the two areas has not been great.

Comparison of the Elberon Formation with stratigraphy at Nome can not be made in the same way because comparable parameters are lacking. Two of the pre-Sangamon units at Nome have fossils, and the faunas are distinctly more ancient than that of Second Beach. Although no fossils have been found in it, the Elberon Formation contains in its surface a zone of weathering 9 feet (nearly 3 m) thick, indicating an

TABLE 1
Summary of sequence in Nome district, condensed from Hopkins, MacNeil, and Leopold (1960)

Units* or events	Sealevel alt (m)	Local temp	Character of marine-invertebrate fauna	C ¹⁴ Date (yr B.P.)	Correlation
Peat, loess, colluvium Marine regression	Negative			13,000	Wisconsin and Recent
Second Beach	**+10 to +12	Same as today; slightly higher water	Essentially modern	>38,000 (W-810)	Sangamon
Till and outwash of Nome River Glaciation					Illinoian
Third Beach and Intermediate Beach	Somewhat more than +23	Higher than today	Few extinct forms		
Till of Iron Creek Glaciation					Uncertain
Submarine Beach	Higher than -6	Higher than today	Different from later faunas; several extinct forms.		

* An additional unit, not fixed closely as to position, is Fourth Beach, with no fossils, at +35m, older than Nome River Glaciation and probably older than Third Beach.

** At least two positions of sealevel, separated by regression, are indicated (D. M. Hopkins, written communication).

age substantially greater than that of the post-Elberon sediments as a group, from which the Elberon is separated by evidence of major marine regression. Very likely the Elberon Formation compares with one of the pre-Sangamon units at Nome, but there seems to be no basis for specifying which one.

STRATIGRAPHY IN THE MEDITERRANEAN REGION

The literature on Pleistocene strandlines in the Mediterranean region exceeds that from any coastal belt of equivalent length elsewhere. Despite the existence of the effects of late-Cenozoic crustal movement in parts of that region, it appears that more useful comparison of the Virginia sequence can be made with features of Mediterranean coasts than with any other apart from that at Nome.

Some of the older Mediterranean literature stresses altitude rather than stratigraphy and fails to consider water depth, and hence relation to sealevel, of sediments and fossils. Recent literature, however, emphasizes faunal- and cultural-stratigraphic relations and evidence of marine regressions. Reported altitudes of these features range up to more than 100 meters above present sealevel; but until lately few attempts seem to have been made to separate, on a basis of field data, eustatic from tectonic influence on altitude. Recent authors have emphasized the influence of Pleistocene tectonic movements in the Mediterranean region. It is no longer thought likely that a strandline having an altitude of 100 meters records a former sealevel that rose eustatically to that altitude.

The bulky literature on the Mediterranean also employs several stratigraphic names. Some of the names are used with different meanings by various authors, and apart from this, various and in some cases conflicting opinions have been expressed as to the correlation of marine units in the Mediterranean with marine units elsewhere. For comparison with features of other coasts, therefore, stratigraphic names, at least at present, hinder rather than help the geologist.

Recent summaries of the Pleistocene marine sequence in the Mediterranean region include a general review and summary by Mars (1963) and a series of more detailed summaries, by regions, gathered into an excellent symposium (Howell and others, 1962). From these contributions it appears that apart from range of altitude of strandlines, which is of little value for correlation, useful stratigraphic parameters include marine fossils, artifacts, ancient soils, and evidence of marine regressions intervening between the transgressions implied by many of the marine features. Radiometry will undoubtedly also prove useful, but as yet it has furnished only a very small body of data.

The current literature shows that there are marine sediments, widely referred to as *Tyrrhenian*, with a distinctive "warm" mollusk fauna, now extinct in the Mediterranean, but resembling the fauna existing off the coast of Senegal. There are suggestions that this fauna may have two facies, or at least variations in composition, that could be related to

two very different times of deposition. The sediments are nearly universally considered to be interglacial, mainly on the evidence of their fauna. It appears further that, very locally, there may be two groups of Tyrrhenian sediments, belonging to two different interglacial stages. Finally there are recognized at least two groups of sediments of pre-Tyrrhenian Pleistocene age.

It is not possible, in the present state of knowledge, to compare the Virginia sequence with that of the Mediterranean region in general, beyond the statement that Virginia seems to be represented by strata of at least two different interglacial ages, and that the same is possibly true of the Tyrrhenian part of the Mediterranean sequence. Comparison can, however, be made with the sequence on the island of Mallorca, recently studied in detail by Butzer and Cuerda (1962). Those authors established a sequence based on invertebrate fossils, character of weathering zones, transgressive/regressive stratigraphic relationships, eolianites, and altitude. Mallorca is the only place in the Mediterranean region where good detail through a considerable stratigraphic range has been elaborated as yet. Butzer and Cuerda recognized two major marine transgressions which they referred to as Tyrrhenian I and II, and which they correlated with the Holstein (Mindel/Riss) and Eem (Riss/Würm) Interglacials, respectively. Their curve showing fluctuation of relative sealevel with time is shown (fig. 2A) for comparison with the analogous curve from Virginia (fig. 2B), which has been scaled to fit without violating the few available controls.

Although a general similarity between the two curves is obvious, similarity in detail is not necessarily expectable (even though correlation were assumed), owing to differences of lithology. Some of the closely spaced former positions of sealevel in Virginia might have left a less complete record in the stratigraphy and morphology if the coast had consisted of bedrock rather than of easily erodible sediment. The rocky coast might record only strandlines that resulted from long-enduring stands of relative sealevel at one position, or from a long episode of slow encroachment of the sea upon the land. On the other hand the erodible sediments related to one sealevel position in Virginia could have been destroyed, during a subsequent transgression, with greater ease than on a rocky coast. For this reason complete, one-to-one correlation of a sequence of former shorelines, between the Virginia coast and a rocky coast such as is common in the Mediterranean, is not likely to be achieved. Hence, despite the similarities in the curves, no specific correlation between Virginia and Mallorca is suggested, pending the accumulation of data that can afford positive stratigraphic identification of the units in Virginia.

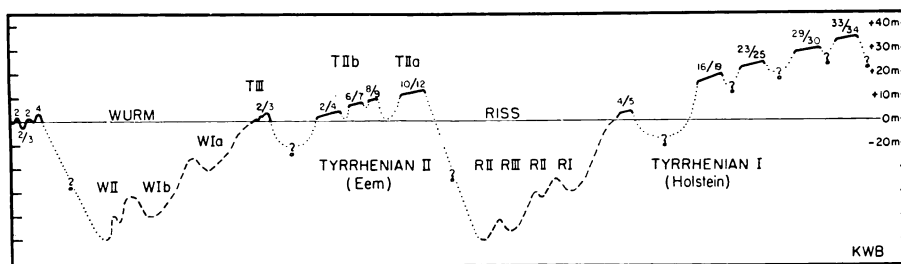
DISCUSSION

Comparison of the data indicates similarities between the marine sequence in Virginia and the sequences at Nome and on Mallorca, which in time could lead to correlation. The Virginia and Mallorca features

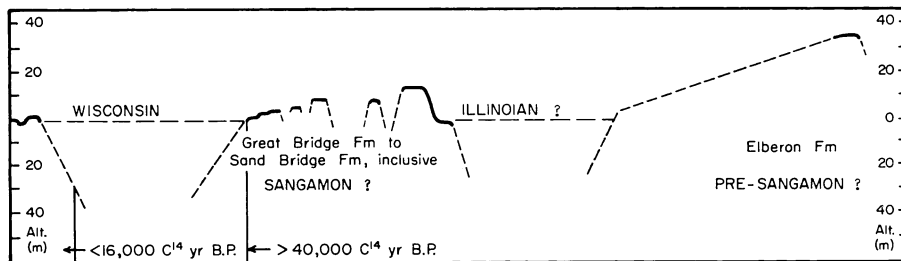
suggest that sealevels can be expected to have occupied several positions during a single interglacial, much as glacier termini fluctuated during glacial times. In many instances probably only the highest or the longest-enduring sealevels within a particular interglacial have left good records. The sealevel positions that seem to have been occupied through the longest time intervals, as inferred from the volumes of related sediments in the Virginia stratigraphic units, are those marked by the Elberon, Norfolk, and Sand Bridge Formations. Examination of features on other coasts, with this inference in mind, might aid in correlation of individual units.

The notion has been put forward (compare Zeuner, 1959, p. 303) that each interglacial sealevel was relatively lower than the preceding interglacial sealevel, owing to causes such as progressive continental uplift, ocean-basin subsidence, or progressive residual build-up of the Antarctic Ice Sheet through Pleistocene time. The sequence of marine features in Virginia throws little light on this concept, contributing no more than that on that coast the highest Sangamon (?) sealevel stood substantially lower than the Elberon, the only identified older sealevel.

Fig. 2.



A. "Generalized curve of relative sealevel deduced from Pleistocene deposits of southern Mallorca. Time scale is relative. Solid line indicates recognizable transgressive beaches; dashed line indicates relative extent of regressions attested by aeolianites; dotted line indicates presumed transgressive oscillations. Scale below modern sealevel is only relative". Reproduced from Butzer and Guerda, 1962, p. 414.



B. Diagram showing inferred fluctuation of relative sealevel through time on the coastal plain of southern Virginia, with suggested glacial/interglacial correlations. Time scale not calibrated. Data, from figure 1, are plotted to vertical and horizontal scale of figure 2A for comparison.

The pre-Elberon Sedley Formation extends to somewhat greater altitude, but neither its exact maximum altitude nor its exact position in the sequence is known.

ACKNOWLEDGMENT

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