Creek Formation, suggests that the barriers occupied an offshore position at the time of their initial formation.

Noteworthy features of this sequence are that the degrees of overlap suggest that the Miocene transgression extended further inland than the Pliocene transgression, suggesting in turn that the Miocene sea level was relatively higher than that in the Pliocene. During the late Miocene regression, non-marine sediments were not deposited on the emerged sea floor, which was not covered by sediment until the Pliocene transgression, with the unusual event of lacustrine sediments deposited behind the sand barrier being transgressive. However, during the late Pliocene regression, the Haunted Hill Gravel was deposited on the emerged sediment surface composed of Moitun Creek and Nyerimalang Formations. Rapid accumulation of Haunted Hill Gravel is suggested by its poorly sorted character and relatively rapid regression is also indicated.

Recent field work[10] at Lake Tyers has demonstrated a regressive sequence in the mid to late Miocene, from the Bairnsdale Limestone to the phosphatic nodule bed (Figs 2 and 3), a fuller account of which will be given elsewhere. This Miocene regression is widely recognisable[11]. The resumption of deposition on the Gippsland continental shelf in the early Pliocene, following the regression, is also compatible with world-wide seismic data[11] and with the transgressive stratotypes of the Pliocene Stages (Tabianian–Piacenzian) in northern Italy[12], overlain by late Pliocene limestone ('Astian' facies). In the Piacenzian, there is also a lower zone of *Globorotalia puncticulata* and an upper zone of *G. inflata*, though with two intermediate zones[12] which have not yet been recognised in Gippsland. In East Anglia (UK) there are no sediments representing the Miocene transgression, but the phosphatic 'boxstones' of Suffolk occur on an unconformity surface[13]—a stratigraphical position compatible with an interpretation of their formation during a period favourable to world-wide phosphatic deposition in the late Miocene[10]. The overlying Pliocene deposits ('Coralline Crag') have been described as submarine banks[14,15] which in a general sense are not greatly different from sand barriers, suggesting an incidence of coastal sand bar formation in the Pliocene, similar to that in Gippsland. One notes also, transgressive–regressive cycles in the Pliocene of South Australia[16], South Africa[17] and Morocco[18].

The strongly onlapping lacustrine sediments of the Moitun Creek Formation (Figs 2 and 3, Bed H) represent deposition at the time of maximum transgression in the Pliocene, after which another regression occurs. The widespread lacustrine sediments require a barrier to account for their non-marine sedimentary facies and a phase of high sea level to account for their areal extent (see Fig. 3). Non-marine clays, sands and gravels (Haunted Hill Gravel) overlie the sediments of phase H–I and these formed during the late Pliocene regression.

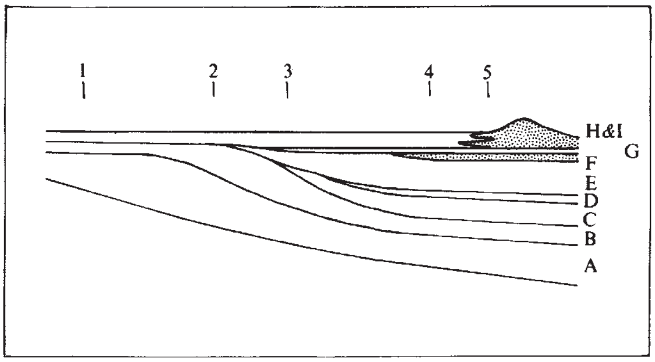


**Fig. 3** Reconstruction of the northeastern part of the Gippsland Basin, showing Neogene formations at the end of the Pliocene transgression, before the late Pliocene regression and Pleistocene erosion (not to scale). 1, Bairnsdale; 2, Swan Reach; 3, Nungurner; 4, Lakes Entrance; 5, Lake Tyers. H, Moitun Creek Formation; I, Nyerimalang Formation. Other lettering as in Fig. 2. Stippling indicates sand barrier formations.

During the Pleistocene, coastal erosion destroyed most of the Pliocene barrier and undoubtedly redistributed its sediments during the periods of high sea level and probably also destroyed some of the lacustrine deposits. In the intervening periods of low sea level, river erosion removed large sections of the lake deposits.

It follows from the field evidence that the initial sand barrier formed after a period of rising sea level. Its establishment may have been due to a period of sea level stability but there is no positive evidence either for or against a postulated still stand. It is clear, however, that a further rise of sea level occurred after the initial barrier formation, causing the destruction of the first barrier, whose remnant can be seen (Bed F) but formation of a second barrier (Bed I) and a further rise of sea level allowed the formation of a coastal lake, in which Bed H was deposited.

The presence of Pliocene barrier remnants in Gippsland suggests that, in areas where extensive sand barriers still exist, it would be worthwhile seeking evidence of Pliocene precursors of these barriers, in view of the support they give to the concept of Pliocene eustasy and to the likelihood that they formed at times of still stand during a generally transgressive regime.

A. N. CARTER

*School of Applied Geology,*
*University of New South Wales,*
*PO Box 1, Kensington,*
*New South Wales 2033, Australia*

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# Holocene submergence of southern Long Island, New York

RATES of submergence of the northeastern seaboard of the US during the past several thousand years as determined from studies of coastal marsh deposits show considerable variation. The marshes became established on submerging shorelines and have grown upwards and landwards with the continued relative rise in sea level, thereby often forming thick deposits of peat. A series of radiocarbon dates taken at various levels in the marsh can be used to reconstruct the history of submergence. This letter presents a study of the relative change in sea level in southern Long Island, New York, over the past 8,000 yr, and shows that the changing rates of submergence have been an important factor in the initiation and continued development of the area's saltmarshes.

Samples of basal peat from south-central Long Island were dated by the radiocarbon method and a local curve of submergence was constructed for the past 8,000 yr. Three basal-peat samples from marsh areas behind the modern barriers have been dated in the present study. In addition, two previously unpublished dates of organic-rich silty clays (originally back-barrier deposits) from the modern shoreface became available.

Two shallow basal peats from the back-barrier area were collected by hand coring in the saltmarshes fringing the northern margins of western Great South Bay (Fig. 1). Another sample of

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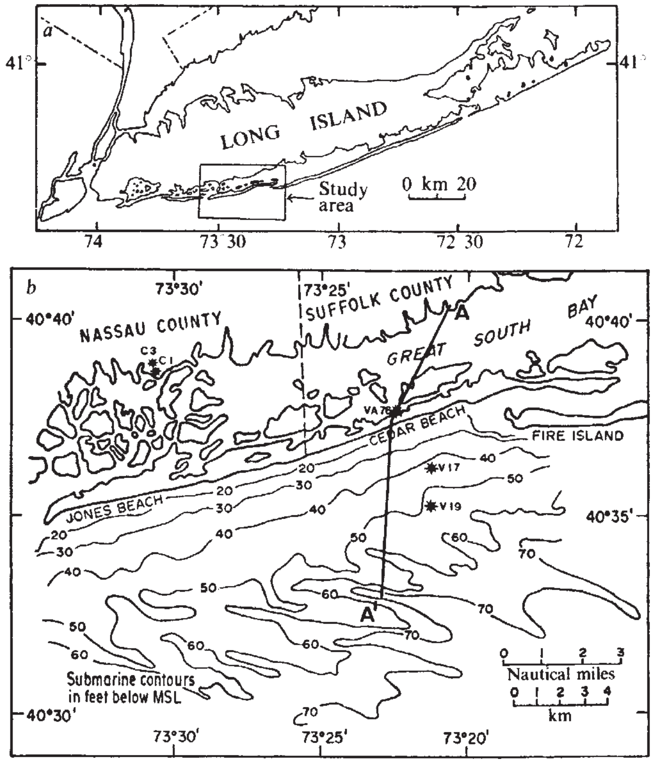


**Fig. 1** Location map of the study area showing positions of the borings and cores (*) from which radiocarbon-dated material was taken. Data from the line of borings, A to A′, were used to construct the section in Fig. 2. Offshore contours after Williams[4].

basal peat was collected by vibracoring at a depth of −10 m MSL directly behind and beneath the modern barrier island. Locations of these radiocarbon-dated cores are shown in Fig. 1; the dates are plotted on a schematic cross-section of the Holocene stratigraphic sequence as determined from several hundred boreholes and cores in Fig. 2.

Basal peat in tube core 1 was dated at 1,015 ± 100 yr BP (Queens College no QC-315) at approximately −1.1 m MSL. Basal peat in tube core 3 was dated at 300 ± 85 yr BP (QC-316) at approximately −0.3 m MSL. The peat sample taken from vibracore VA-76 at approximately −10.1 m MSL was dated at 5,055 ± 120 yr BP (QC-314).

For each of these dates the samples were of salt- to brackish-water peat, directly overlying Upper Wisconsinan glacial outwash. Therefore, compaction of the underlying outwash sands and gravels is thought to have been minimal.

Organic silty clays collected by vibracoring on the modern shoreface (Fig. 1) were also dated by the radiocarbon method. These former back-barrier sediments were taken from vibracore V-17 at a depth in the core of 1.0 m in 12.6 m of water and from vibracore V-19 at 0.16 m core depth, in 16.4 m of water (Fig. 2). The sediments are lagoonal or saltmarsh deposits now exposed on the shoreface by barrier retreat. These deposits mark the position of a former back-barrier lagoon which existed when the barrier islands were located some 7 km south-east of the present shoreline. The detailed history of the retreat of the barriers of southern Long Island will be discussed elsewhere[1]. These back-barrier sediments were probably deposited at or slightly below sea level. They are over-consolidated, which indicates post-depositional compaction. Radiocarbon dating of these silty clays, performed on total organic material in the samples, gave 7,815 ± 300 yr BP for sample V-17 (1.0 m) and 7,130 ± 380 yr BP for sample V-19 (0.16 m) (dating by Teledyne Isotopes).

These dates from south-central Long Island have been compared with other published dates and curves of Holocene sea level from the Long Island area[2–4], and with the submergence curves which have been constructed for adjacent areas of the Atlantic Coastal Plain[5–8] (Fig. 3).

The submergence curve constructed from the data for southern Long Island represents the combined effects of eustatic sea-level rise, local tectonism, tidal variation, water loading and other variables. Therefore, the curve cannot be extrapolated directly to other areas. However, the submergence curve for south-central Long Island can be used in palaeogeographic reconstructions to locate the position of the palaeoshoreline, and as an indicator of changes in the relative rates of submergence during the past 8,000 yr.

The submergence curve constructed from these data suggests that between 7,000 and 3,000 yr BP the Long Island coast was being submerged at a rate of about 25 cm per 100 yr, and that during the past 3,000 yr, the submergence rate slowed markedly to about 10 cm per 100 yr. Rates of submergence before 7,000 yr BP are uncertain. Sea-level data presented here show considerable scatter before 7,000 yr BP (Fig. 3). It has been suggested that, between 9,000 and 7,500 yr BP, submergence rates in adjacent coastal areas were as high as 50 cm per 100 yr (refs 9, 10).

The submergence curve for Long Island, therefore, shows a marked reduction in submergence rate at about 3,000 yr BP, and the possibility of an earlier reduction in the rate of submergence at around 7,000 yr BP. Studies of relative sea-level rise in other areas of the Atlantic coast have outlined a similar history of changes in the submergence rate[5,11–13]. For example, the submergence rate for the Delaware coast was approximately 47 cm per 100 yr between 10,000 and 7,000 yr BP, slowed to 20 to 30 cm per 100 yr from 7,000 to 4,000 yr BP, and has continued at about 8.0 to 12.5 cm per 100 yr for the past 3,000 to 4,000 yr (refs 14, 15). Note, however, that the smoothly averaged curves presented here could be reinterpreted in terms of fluctuating relative sea level.

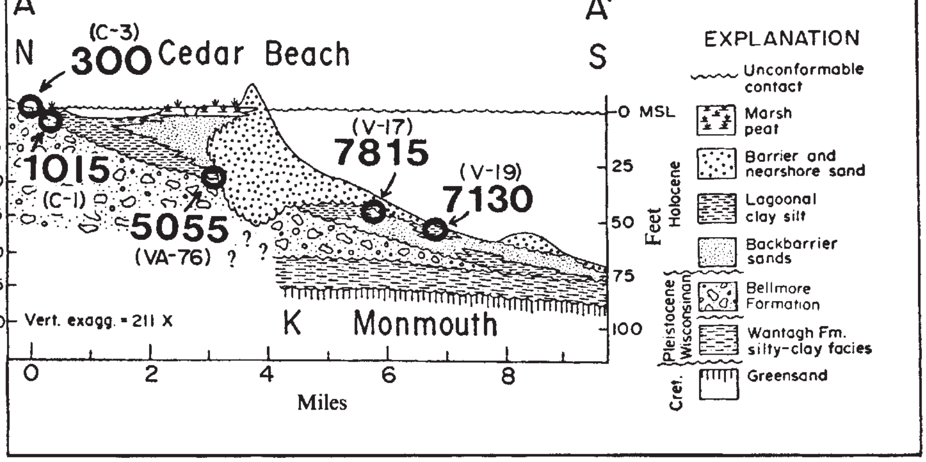


**Fig. 2** Radiocarbon-dated samples plotted on schematic, interpretive profile and section A to A′ showing the Holocene and Late Pleistocene stratigraphy of south-central Long Island. The positions of samples C-1 (1,015 ± 100 yr BP) and C-3 (300 ± 85 yr BP) are projected from cores to the west of this section.

The method of determining relative sea level by point-plotting the ages of basal-peat samples, and then drawing a best-fit curve will average out any fluctuations in the history of submergence. Postulated curves of fluctuating sea level[16] cannot be adequately tested in this manner. Careful stratigraphic analyses are required to test such an hypothesis.

One possible method is to study the stratigraphy of saltmarshes to determine changes in vegetational patterns and shifts in marsh environments that would accompany variations in sea level. No such consistent variations were found in examination of the cores of marsh sediment recovered in the present study.

It has been suggested that changes in the rate of submergence have been an important factor in the development and maintenance of back-barrier saltmarshes[5,11,17]. The radiocarbon dating of basal peats from southern Long Island sheds light on the mode of formation of the marsh areas. Peat samples from approximate depths of −1.1 and −0.3 m MSL gave radiocarbon ages of 1,015±100 and 300±85 yr BP, respectively (Fig. 2). These samples of brackish to saltmarsh peat presumably mark the approximate positions of sea level at those times. The fringing and mid-bay marsh areas of Great South Bay are therefore rather young. Peat has been probed with steel rods to depths of about −2 m MSL which, according to sea-level curves for adjacent areas, would put the inception of these marsh areas at about 2,000 yr BP (Fig. 3).

This conclusion is supported by the report of a basal peat layer at a depth of −7.5 feet (−2.4 m) MSL in Shinnecock Bay, in eastern Long Island, dated at 2,300 yr BP[18]. This date indicates that the back-barrier marshes in eastern Long Island were established at least 2,300 yr ago.

It seems that a back-barrier environment, with open-lagoonal conditions, existed for some time before the more recent development of the saltmarshes. The colonisation of previously open-lagoon environments by marsh grasses may have been related to a lessening in the submergence rate in the area about 3,000 yr BP. A decrease in the rate of submergence would have allowed sedimentation to build the floor of the lagoon to a level at which the marsh grass *Spartina alterniflora* could grow. As stands of *S. alterniflora* became established and began to trap fine sediment particles, a thin layer of peat would form across former tidal-flat areas. Once the level of the marsh had built to about mean high water, *Spartina patens* could colonise the marsh surface, and marsh building would continue to keep pace with submergence, thus forming the present marshes[5].

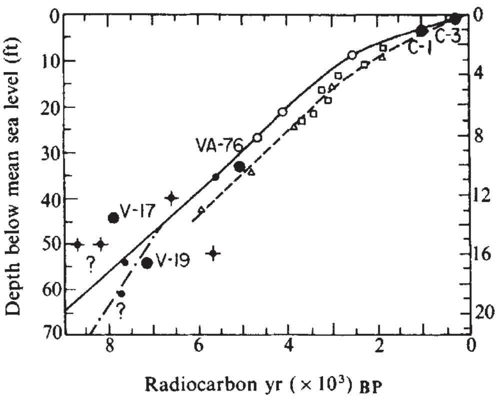


**Fig. 3** Submergence curve for southern Long Island during the past 8,000 yr (solid curve). The curve is based on radiocarbon-dated samples reported in this paper (large solid circles) and on previously published dates from northern Long Island[3,4] (crossed solid circles), southern Long Island[2,4] (small solid circles) and Iona Island, New York[7] (open circles). The dashed and dotted curve indicates possible submergence rates of ~50 cm per 100 yr before 7,000 yr BP suggested for adjacent areas[9,14]. The dashed curve is drawn through points of dated samples from New Jersey[6] (triangles) and Cape Cod, Massachusetts[5] (open squares). An assumption of relatively smooth change in sea level has been made in constructing these curves.

In many studies of saltmarshes of the northeastern United States, a relationship has been established between marsh initiation and a marked slowing in the submergence rate between 3,000 to 4,000 yr BP[5,11,13,17]. It seems likely that the change from open lagoon with intertidal-flat areas to saltmarsh was initiated in western Great South Bay by a decrease in the rate of submergence at about 3,000 yr BP. This slowing of the submergence rate allowed sedimentation to build up the floor of the lagoon by about 2,000 yr BP, to a point at which marsh grasses could colonise former tidal-flat areas along the northern margins of the lagoons and also grow on former tidal-delta deposits. For the past 2,000 yr, upward marsh building has for the most part kept pace with the slow submergence.

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M. R. RAMPINO*

*Department of Geological Sciences,*
*Columbia University,*
*New York, New York 10027*

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* Present address: NASA, Goddard Institute for Space Studies, New York, New York 10025.

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# Mössbauer spectral studies of the diagenesis of iron in a sulphide-rich sediment core

ONE stage in sedimentary pyrite formation[1–3] is 'FeS'+S→$FeS_2$, where 'FeS' represents black precursor sulphides such as amorphous iron sulphides and fine-grained mackinawite ($Fe_{1+x}S$). We report here a Mössbauer spectral study of the formation of pyrite, in sulphide-rich sediments, from the reaction of $H_2S$ with hydrated ferric oxides and with ferrous ions in fine-grained chlorite or in amorphous silicates. Approximately 50% of total Fe deposited is converted to pyrite within a few years, with the remainder being converted over several hundred years. Less than 10% of total Fe is present as precursor sulphides. With suitable constraints in computation, Mössbauer methods show considerable potential for measuring rates of reaction of iron compounds in sediments.

Lake St George is a kettle lake situated 60 km north of Toronto, Ontario. It has a surface area of 10 hectares, a maximum depth of 14 m, and is strongly stratified from May until turnover in late October, with the thermocline at ~9 m. The