**Marine Terrace Evolution in Southeastern Barbados
and the Stage 5c Highstand**

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INTRODUCTION

Barbados has been a principal source of data on the structure and origin of tropical marine carbonate terraces and reefs and of Late Pleistocene sea level history (Mesolella, 1967,1968; Broecker etal, 1968; Mesolella etal, 1969,1970; Matthews, 1968,1973; Fairbanks and Matthew, 1978; Bender etal, 1979; Edwards etal, 1987,1997; and Gallup etal, 1994). The widely cited Mesolella model, that terraces are essentially barrier reefs that grew in catch-up mode from a deep seabed at an offshore locus at eustatic highstand, was formulated from and applied chiefly to the leeward (western) side of the Barbados. We present a geomorphic, stratigraphic, and geochronologic study of windward, southeastern Barbados which concludes with a substantially different model of terrace and reef evolution: terraces are the result principally of marine erosion and fringe reef growth during transgression and highstand. Moreover, we contribute some new insights to sea level history, including perhaps the strongest evidence yet found for a brief highstand at 105+/-1 ka for the stage 5c interstadial.

Our study of coastal southeastern Barbados (Fig. 1) arises from its content of preserved raised marine terraces, a coved cliffed shoreline that exposes raised terrace stratigraphies, and 3 cored holes drilled by R. G. Fairbanks in 1990. It includes new terrace mapping from an islandwide survey Speed (2001; website xxx) and xxx new mass spectrometric 230 Th dates of surface coral by W. Thompson (Table 1) and from core by J. Rubenstone and R. Mortlock (Table 2). Previous work in this area of Barbados is a site study at Penny Hole by Wood (1999) and another at Gibbons by Blanchon and Eisenhauer (2001), who measured and dated a section in the stage 5e terrace (Fig.2).

ISLAND GEOLOGY

Barbados is an actively rising island at the crest of the Barbados Ridge, an accretionary prism of the Lesser Antilles forearc (Fig. 1). The siliciclastic accretionary foundation is partly capped by limestone, <1 to130 m thick, which records the emergence of the island through the tropical littoral zone during Quaternary time and perhaps, earlier (Senn, 1946; Mesolella, 1968; Speed, 2001. The variable thickness of the limestone cap is partly depositional, but much is erosional, due to onland and marine processes. All parts of the island have been covered by limestone at one time or another, but now a fifth of the cover has been fully lost to erosion (Fig.1).

The uplift of Barbados is related to active horizontal contraction in a NNW-SSE direction. A train of gentle folds of the limestone cap (Fig. 1; Torrini and Speed, 1989; Taylor and Mann, 1991) is the prime structure of this contraction and a principal determinant of the field of uplift rates whose range is near zero to >0.6 m/1000 yr (Speed, 2001).

Some of the surface of the limestone cap is a stairstep of terraces, each terrace a product of marine processes at high levels of eustatic oscillation (Mesolella, 1968; Broecker etal, 1968; Mesolella etal, 1969; Bender etal 1979). More than half of the limestone surface, however, is denuded of preexisting terraces, owing to episodic fresh and storm wave runoff, and there, marine features are degraded or effaced, and marine carbonate terrace cover is partly or wholly stripped. The degree of preservation of raised marine terraces is irregular in geography and age, owing to variability of erosion in position and time. In general, the stage 5a, 5c, and 5e terraces, which occupy a coastal strip, are the most widely preserved and most readily correlated across small tracts of post-terrace denudation by age of limestone cover and elevations of key geomorphic features.

TERRACES OF SOUTHEASTERN BARBADOS

Southeastern Barbados occupies the southern flank of the Christ Church arch, which rises from the shoreline to 100 m elevation (Fig. 2a). The flank is underlain by capping limestone of about 50 to 90 m thickness (Figs. 2b,2c). Below about 70 m elevation, the limestone surface includes four variably preserved raised marine terraces. The raised terrace succession extends inland as much as 1.8 km from the Holocene terrace , which is actively forming at today’s shoreline (Fig. 3).

We have defined the raised marine terraces with geomorphic criteria, as follows (Fig. 4). Each terrace has a backcliff of marine erosional origin and a shoreline angle at the cliff's foot. Seaward of the backcliff is a shallowly seaward-dipping surface called the terrace tread. The tread continues downslope to a truncation at the backcliff of the next younger terrace. Depositional cover of limestone lies below the tread and above the terrace floor, which is an unconformity on older limestone. The shoreline angle is the intersection of the floor and backcliff. A terrace tread is the depositional top of the cover where preservation is 100%. Otherwise, it is an erosional surface at which terrace cover has been partly or wholly denuded.

This scheme of terrace architecture is derived from investigations of the form and process of the present-day shorelines of the limestone coasts of Barbados and assumes that past and present shoreline systems developed similarly. Present-day seacliffs, as high as 35 m, are actively retreating by marine erosion at long term rates of 0.1 to 0.2 m/1000yr at the windward coast (Speed, 2001). The cliffs are coupled to abrasion platforms (terrace floors) whose breadth increases progressively. Sediments on the Holocene abrasion platform are principally clastic whereas those on the slope seaward of the platform are mainly reefal. The shoreline angle is either intertidal or as deep as 1 m where seacliffs are plunging. When the Holocene regression begins, the shoreline angle will mark the highest sustained stand of the Holocene sea, and the same interpretation is applied to the shoreline angles of raised marine terraces.

The four raised terraces are dated by 230Th ages of coral in their cover and(or) by correlation across denudation gaps with dated terraces with similar elevations of shoreline angles. We employ geographic names for the four terraces, given by Fairbanks and Matthews (1978) for a correlative series in SW Barbados: Worthing for the stage 5a terrace, Ventnor, stage 5c, Rendezvous Hill, stage 5e, and Kendal Hill, late stage 7.

Terraces are laterally discontinuous due to erosion of two types. First is the local marine excision of a terrace by landward propagation of a younger terrace during its initial development. An example is the loss of the Worthing terrace from most of southeastern Barbados due to Holocene coastal retreat. Second is subaerial post-terrace denudation by freshwater or stormwave runoff. It is manifested by a shallowly gullied, hummocky surface that is cut down into or below terrace cover. Where such denudation is absent or mild, the tread is subplanar, and the backcliff is relatively steep and sharp, the tread is mapped as a preserved terrace on Figure 3. Where denudation is moderate or severe, terraces are absent and their former existence may be indicated only by a degraded cliff or bluff of low slope and rounded brow.

Such bluffs can locally be shown to be a former backcliff by lateral continuity with preserved terrace features.

The raised marine terraces each includes a variably preserved blanket- or wedge-shaped body of limestone cover between its tread and floor and seaward of its shoreline angle. Unconformities and 230 Th dates permit the division of the succession of such bodies into stratigraphic units, each contemporaneous with a related terrace (Figs. 5,6). Without the excellent exposure of modern seacliffs and gullies and without dates, however, it is commonly impossible to assign a limestone outcrop stratigraphically because it is uncertain whether denudation has lowered the tread of a terrace within or below its cover. Thus, the mapping of limestone units (Fig. 6) includes the possibility or knowledge that terraces defined geomorphologically may be partly underlain by exhumed older substrate.

Two areas of southeastern Barbados are particularly well exposed, more closely studied, and illustrated at large scale: Salt Cave Point-Penny Hole (Fig.7) and South Point (Fig. 8).

CHRONOLOGY AND STRATIGRAPHY

A chronology of southeastern Barbados is based on xx new mass spectrometric 230 Th dates of corals (Figs. 5-8; Tables 1, 2). Used with contacts among units of limestone cover (cross sections, Figs. 6-8), the dates permit the stratigraphic division shown in Figure 5.

Dated coral specimens were processed by progressive crushing, ultrasonic cleaning, and hand-picking. Material used for dating contains no calcite detectable by xray diffraction. Dates considered admissible (Tables 1, 2) are from samples with U concentrations between 2.31 and 3.61 μg/g. Taking initial 234U/238U activity of 1.149+/-0.014 as a criterion (Edwards etal, 1997; Stirling etal, 1998), about a third of our dates can be taken as apparently accurate. For the others, departure from closed-system U-series behavior is evident, owing to initial 234U/238U > 1.163 or equivalently, initial del234U>163 (Tables 1, 2). On occasion, we compare closed-system (measured) dates with dates adjusted for an open system model based on continuous decay-dependent redistribution of 234 Th and 230 Th of Thompson etal (2002). This time adjustment is (-)400(initial 234U/238U – 1.149 x 1000) years.

Five and possibly six stratigraphic units of limestone exist in southeastern Barbados (Fig. 5). Each is named for the terrace to which it is cover except for older limestone, which underlies the Kendal Hill unit. The unit boundaries are drawn to enclose the range of dates assigned to each unit and do not reflect knowledge of true age (Fig.5). Adjustments for departure from the closed system assumption (initial del234U=149) decrease almost all the dates and the scatter as well (Fig. 5). Dates indicate the existence of a substantial lacuna between the stage 7 Kendal Hill unit and the stage 5e Rendezvous Hill unit. In contrast, it is not clear that lacunas exist among the three stage 5 units, or equivalently that such units do not include limestones of the stage 5d and 5b lowstands.

TERRACE DESCRIPTIONS

Holocene Terrace

The modern coastline of southeastern Barbados is described with the premise that coastal processes of the present day and coastal evolution in the transgression from the last glacial are likely to contain elements of past processes and evolution. The modern coast comprises three geomorphic segments, each developed in limestone (Fig. 2): the extensive South Point headland, Oistins Bay to its leeward, and the Gemswick coast to the headland's windward.

Gemswick Coast.

The Gemswick coast trends northeast from the South Point headland for 5 km to Foul Bay where the shoreline turns to a northerly trend. Its plan morphology is a succession of small coves and points, all less than 200 m width and amplitude, which modulate a fundamentally straight shoreline. In profile, it is characterized by limestone cliffs that are 10-30 m high and actively retreating, owing to marine notching and episodic collapse. The active notches are intertidal and connect seaward via a ramp to a subhorizontal shelf floor at 3-5 m depth (Halcrow, 1997)

The shelf extends 500 m seaward of the shoreline to an abrupt slope break. The shelf is rock-floored except for boulder fields, which occur near the shoreline cliff base. Shallow marine scleractinian corals have existed at the shelf-slope break in historic time but are now dead (Lewis, 1985). It is not clear whether such corals existed there as a sustained reefal framework or rather, in scattered tranasient colonies. Bottom TV viewing, dredging, and acoustic profiling on the shelf, however, provide no indication that scleractinian reefs inhabit or inhabited the shelf landward of the shelf-slope break (Halcrow, 1997). The slope beyond the bathymetric break extends down at an average 7 deg to a flat at about 140 m depth (Halcrow, 1997). The slope is rock-floored and has an irregular profile, comprising laterally continuous flats or troughs and intervening bluffs or ridgelets.

South Point Headland.

This broad headland extends 1.5 km south of its intersection with the Gemswick coast (Figs. 2,3) and has very different shoreline morphology. The Gemswick coast continues west 1 km into the headland as the Chancery Lane lagoon. The lagoon is blocked off to seaward by the sandy barrier bar of Long Beach (Fig. 3) The western end of the bar and lagoon intersect higher ground of the headland of South Point, and the high cliff in back of the lagoon is probably entirely Holocene. The south-facing shoreline of the headland west of the lagoon is marked by a low (1-2 m), actively retreating cliff in limestone. Landward of this low cliff is a beveled limestone surface, a 5-10 deg slope that ascends for 100-200 m to the subhorizontal tread of an older (Worthing or Ventnor) marine terrace or a denuded equivalent of those terraces (Fig. 3). The beveled surface includes two limestone stacks (Round Rock and unnamed) whose planar tops are projections of the older, denuded terrace tread to landward. The bevel is thus erosional, older than older terraces, and younger than the low cliff at the current shoreline. Seaward of the current shoreline of the South Point headland, features of the marine shelf and slope are similar to those of the Gemswick coast and curve conformably around the headland.

Oistins Bay.

This broad embayment heads sharply north across the western flank of the South Point headland for about 1.5 km (Figs.2,3) and continues well west. Its active limestone seacliff is 6-10 m high. At the geomorphic corner between the south-facing shoreline of the headland and the west-facing one of Oistin's Bay, the active seacliff abruptly heightens and, coincidentally, the EW-striking bevel of the headland ends. Thus, the erosion causing the bevel operated only at the south-facing shore. We infer later that the bevel is pre-Holocene.

The shelf of Oistins Bay differs from that to the east by its comparatively large breadth (up to 1.6 km) and an extensive and thick cover of carbonate sand (Murray et al, 1977; Halcrow, 1997). The slope off Oistins Bay, however, has similar depth range, dip, and morphology as that to the east. This slope was drilled and cored at several sites by Fairbanks (1989), who found it to be underlain by stage 1 and Holocene reefal and clastic deposits which young upslope as well as upsection. The limestone covering the slope at Oistins Bay is partly overlapped by carbonate sand that at least partly has spilled off the adjacent shelf.

Southwest of Kendal Point (Fig. 3), the Holocene shelf extends about 1 km from the Holocene seacliff, which is cut in the Worthing and underlying Ventnor limestone units, to the shelf-slope break. Drilling at this break indicates the shelf is underlain by 5 m of head coral above 30 m of A. palmata, the latter dated by 230 Th at about 11,000 yr at the base and 7,500 yr at 6-7 m below the top Fairbanks, 1989; Bard etal, 1990). The age of the highest coral is thus younger than 7,500 yr. The A. palmata layer is unconformable on limestone of stage 4-5a age (Bard etal 1993). The Holocene shelf and slope and their underlying Holocene limestone and floor constitute the Holocene terrace. The terrace floor dips seaward an average 3.6 deg from shoreline angle to shelf edge and about 6.5 deg from shelf edge to base of slope, assuming that the floor intersects the seabed at the slope base.

Oceanography.

Waves of substantial amplitude affecting southeastern Barbados come from three sources: trade winds, central Atlantic noncyclonic storms, and cyclonic storms. The first two sources have long fetch, yield wave vectors that range with season and storm from NE to SE and average E, periods as great as 14 sec, and heights that are commonly 1-3 m and more rarely, up to 9 m (xxxxx). Cyclonic storms bring high waves to Barbados with repeat times of 20-30 years (xxx), but wave directions depend position of the eye relative to the island, and any direction seems equally probable. Currents are produced by oblique wave-breaking and by the westward passage of the Western Atlantic countercurrent around Barbados.

The Gemswick coast is windward to tradewind and noncyclonic storm waves with obliquity between zero and 90 deg, most commonly 45 deg. Including refraction, the Gemswick coast receives a signifcant component of normal wave impact, together with SW-directed, wave-derived longshore current. In turn, the eastern flank of the South Point headland is more normal to wave vectors and current flow. Oistins Bay is in the lee of the South Point headland and has little water circulation compared to the other two geomorphic divisions. Cyclonic storm waves appear to have equal liklihood of significant episodic impact on all three divisions.

Worthing Terrace.

The Worthing, the lowest and youngest of raised marine terraces, is well preserved only at the southwestern margin of the South Point headland (Fig. 3). There, it occupies a narrow swath between the retreating Holocene seacliff and the Ventnor terrace and has a shoreline angle at 12+/-1 m elevation at the base of the Worthing backcliff. It continues northward on the western flank of the headland to Oistins Bay, but is there substantially denuded (Fig. 3). Thus, only the most upslope realm of the Worthing terrace is preserved, and this is approximately conformable to the present-day shoreline of the western half of the South Point headland. At the eastern half of the headland, however, the Worthing terrace is absent,owing to coastal retreat in the Holocene.

At the Gemswick coast, we infer that narrow benches at two sites, both at 4 m elevation above the Holocene seacliff, are remnants of the Worthing but without proof by dating. One of these, at the western flank of the Salt Cave Point headland (Fig.7), is a 2-5 m-wide bench that is contiguous with a notch and caves. The bench is a product of marine erosion, as indicated by the horizontality of its tread, truncation of the more steeply dipping Ventnor-Kendall Hill unit unconformity (section EE', Fig.7), association with a preserved notch, and existence of cemented rounded gravel (undated) on the tread. It is not a riverine terrace because no channel extends inland. It is not a karst cavity floor because the floor is planar and wholly within limestone, not at the limestone base as is the typical for Barbadian karst. The second bench of similar morphology and elevation exists along 100 m of the western Gemswick coast. It is probably correlative with the one at Salt Cave Point, because both cut the Ventnor limestone unit (stage 5c) and are cut by the Holocene cliff. Because no emergent benches of Holocene age are recognized on Barbados (Speed, 2001), we assign the benches of the Gemswick coast to the Worthing terrace.

Limestone cover of Worthing terrace, the Worthing unit, is as thick as 7m where exposed on the Holocene seacliff. It overlies an unconformity that is well exposed near Kendall Fort at 2-3 m elevation. The age of the subjacent limestone is uncertain. Basal clastic sediments of the Worthing limestone are up to 1 m of rounded coral-pebble gravel and sand with floating angular coral clasts, both acroporids and head coral. The main body of the limestone is mixed reefal deposit, comprising A. cervicornis, head coral, lesser A. palmata, snails, and algal nodules. A. cervicornis occurs both in in-growth bushes and fragmented sticks. Head corals are in both columnar and domical form and are mainly upright but locally toppled. There is no evident vertical zonation among corals of the main body, but there is an increase north to south in A. palmata content and size of A.cervicornis sticks.

Three 230 Th dates exist from the Worthing terrace of the western half of the South Point headland (Fig. 6). Two new dates are NU 1482, 86,300+/-1200 yr at 7 m below the shoreline angle, and NU 1483, 78,300+/-400 yr at 3 m below the shoreline angle (Table 1). NU 1482 is an apparently very accurate date based on initial del234=149.5. It proves the correlation of this terrace with stage 5a and with the Barbados I terrace, which was identified farther west in southern and western Barbados by Broecker et al, 1968 and Mesolella et al, 1969, and later dubbed Worthing by Bender et al (1979). The NU 1483 date may be suspect because its initial del234U is less than the reference value of 149 (Thompson etal, 2002). An earlier alpha spectrometric date from Mesolella etal (1969), AEH-1 at 82000+/-4000 yr (Fig.6) proves the continuation of the Worthing terrace northward into the denuded region of eastern Oistins Bay (Fig. 2).

Ventnor Terrace.

Geomorphology.

The tread of the Ventnor Terrace caps the South Point headland and extends 1.8 km south from a linear, east-west-trending shoreline angle at Gibbons (Fig. 3). This breadth of this tread is the greatest among preserved terraces on Barbados. At the western half of the headland, the Ventnor tread is truncated by the Worthing backcliff and its denuded remnants whereas at the eastern half of the headland, it is cut by the Holocene seacliff. In contrast to its great breadth on the headland, the Ventnor terrace is preserved along the Gemswick coast only in two narrow segments, one continuing briefly east from the South Point headland and the other between Salt Cave Point and Green Point (Figs 6. 7). The Ventnor terrace's narrowness and segmentation at the Gemswick coast and its absence east of Green Point are due to recession of the Holocene seacliff.

The tread of the Ventnor terrace has two contrasting configurations. In one, the tread is unusually planar and subhorizontal among Bardbadian terraces, and it exists at relatively high local elevation. Such tread exists at an inland strip adjacent to the Ventnor shoreline angle from Gibbons eastward through the Gemswick coast, and at a large discrete tract at South Point (Fig. 3). Its properties suggest this configuration represents the preserved, original depositional top of the Ventnor terrace. The second configuration of tread is hummocky and gullied and lies at elevations 1-5 m lower than those of original tread and is clearly a product of denudation by water flow. It occurs between the areas of original tread, principally as a broad swath of strongly denuded tread that extends landward from the Holocene Chancery Lane lagoon across the South Point headland to Oistins Bay (Fig. 3). The two paleoseastacks, on the south-facing beveled margin of the Ventnor terrace at Silver Sands have flat tops that are correlative by elevation with nearby denuded Ventnor tread (Fig. 3).

We measured precise elevations (+/- 0.5 m) of the preserved original Ventnor tread at four sites (Fig. 9): shoreline angle near Gibbons, 18 m; South Point, 19 m; shoreline angle at Salt Cave Point, 15 m; and tip of Salt Cave Point headland, 12 m. Because the Ventnor shoreline angle was initially at uniform elevation, current elevations indicate this feature has had greater uplift at the South Point headland than at the Gemswick coast, and this is supported by the elevation at South Point. Further, the slightly greater elevation of the Ventnor tread at South Point than at Gibbons implies either greater uplift of the southern than the northern part of the South Point headland.

Unlike the Worthing shoreline angle, the Ventnor shoreline angle is straight and nonconformable with the modern shoreline of the South Point headland (Fig.3). The swath of denudation across the South Point headland affects the Worthing as well as the Ventnor terrace.

An erosional origin of the Ventnor backcliff is especially well documented in southeastern Barbados by geochronologic and stratigraphic evidence. Inland from the South Point headland, the backcliff exposes two layers of dated limestone: Rendezvous Hill unit and Kendal Hill unit with an unconformity between them Fig. 6). At the Gemswick coast,the Ventnor backcliff is underlain solely by dated Kendal Hill unit (Fig. 7). The Ventnor backcliff thus cannot be a growth feature from the preceeding Rendezvous Hill highstand of stage 5e.

Ventnor Limestone Unit.

The Ventnor limestone unit appears to underlie the entire Ventnor tread, that is, post-Ventnor denudation has nowhere exhumed older limestone from below the Ventnor unit, as judged by the absence of detectable unconformities in the denuded areas. Properties of the Ventnor unit are somewhat better determined than those of other limestone units because of many three-dimensional exposures of it on the Holocene and Worthing backcliffs (Fig. 6). The Ventnor unit is divided among three subunits, Lv1, Lv2, and Lv3, by position and constituent particle content. Lv1 is an A. palmata framework, Lv2 a mixed coral framework with local clastic lenses, and Lv3 a clastic deposit. The subunits outcrop in belts across the Ventnor tread (Fig, 6); Lv1 is the most seaward and Lv3, the most landward. Lv1 is stratigraphically below Lv2 at the Gemswick coast, and the same relation is inferred at the South Point headland. Lv3 is inferred to be contemporary with Lv1. We have studied this limestone in some detail at two sites, Salt Cave Point (Fig. 7) and South Point (Fig.8), and discuss them below. .

Salt Cave Point

Salt Cave Point is a small headland on the Gemswick coast that preserves a breadth of Ventnor tread of 135 m, between the Ventnor shoreline angle at 15+/-1 m elevation on the north and the Holocene seacliff at 12+/-1 m on the south (Fig. 7). The tread is nearly planar on the western and central spans of the headland and probably preserves the depositional top of the underlying Ventnor unit. The eastern or windward side of the tread is partly denuded and steps down to sea level on discontinuous ledges quarried by high breaking waves in the Holocene.

A cored rotary drill hole (RGF 90-2) on Salt Cave Point spudded on the Ventnor tread extends through a few meters of Ventnor unit and continues to –43 m below sea level through Kendal Hill unit and older limestone (Fig.7).

Limestone of the Ventnor unit occupies a wedge seen in outcrop to thicken from <1 m at the shoreline angle to 9 m at the southernmost edge of Salt Cave Point above a planar unconformity that dips 5 deg south (section EE', Fig. 7). Dated Kendal Hill unit of late stage 7 age underlies the unconformity, the Ventnor backcliff, and the tread of the next higher Rendezvous Hill terrace.

Ventnor subunit Lv1 overlies the dipping unconformity and continues up to a subhorizontal contact with Lv2. It thickens seaward from a poorly exposed pinchout to 9 m at the tip of Salt Cave Point. Lv1 includes a discontinuous sole, 0.1–0.2 m thick, of sand and tabular, unconformity-hugging head coral (Diploria sp. and Montastrea annularis). Above the sole, A. palmata fronds of moderate and large size (up to 0.5 m diameter) form a framework with no lateral or vertical gradations. A. palmata is the exclusive coral except for A. cervicornis, which occurs with A. palmata in discontinuous thin lenses midway through the subunit. Whereas none of the acroporids of Lv1 are in growth orientation, there is no rounding or sorting of particles that would indicate lateral transport. The subunit thus represents progressive in-place growth and collapse of A.palmata colonies.

Ventnor subunit Lv2 lies above Lv1 with a sharp contact that undulates about horizontal with amplitudes up to 2 m (sections EE', FF', Fig. 7). Its thickness is as great as 3 m below a top that appears uneroded. In a central part of the headland, a dome of Lv1 extends up to the terrace tread, and Lv2 is absent. Lv2 contains mixed coral dominated variously by A. cervicornis, head coral, and Poreites poreites, together with patches rich in shells, sand, and algal balls and occasional singular A. palmata. Heads are principally in columnar form and preserved in growth orientation. The base of Lv2 is commonly marked by tabular head corals that wrap around the undulations in the top of Lv1. There is no truncation of corals in Lv1. The contact must represent an abrupt change in marine depositional environment, and Lv2 appears to fill lows in the top of Lv1 without intervening erosion.

Ventnor subunit Lv3 is composed of coarse grained calcarenite and is probably less than 2 m thick. It occupies a narrow belt between the shoreline angle and Lv2 outcrop. The depositional top of Lv3 is coplanar with that of Lv2, suggesting that the two subunits are at least partly facies although exposures do not permit proof of gradation. A contact between Lv3 and Lv1 is not exposed. It is likely that Lv3 is continuous with the thin basal zone of sand plus tabular head coral in Lv1.

We dated 8 corals from a section of the Ventnor unit at Salt Cave Point, 6 from Lv1 and 2 from Lv2 (Table 1; Fig. 7). The lowest and highest dated corals from Lv1 give dates that are apparently accurate. The lowest specimen is a tabular head coral (NU 1501) that lies on the unit's dipping basal unconformity at 4 m elevation, dated 111,700+/-300 yr (initial del234U = 159.3). The highest is from 11.5 m elevation, 0.5 m below the highest point of the undulating top of Lv1. It is an A. palmata (NU 1505) dated 109,300+/-300 yr (162.3). Between these are inaccurate A. palmata dates: NU 1502, 5 m, 129,100+/-400 yr,(206.1); NU 1503, 8.5 m, 124,600+/-400 yr,(209.5); NU 1478, 9 m, 110,900+/-1500 yr; (176.3); and NU 1504, xx m, 117,100+/-400 yr, 183.5). The two dated corals from Lv2 are both in-place columnar head corals and give apparently accurate dates. NU 1506 at 12 m elevation and 10 cm above the Lv2-Lv1 contact is 106,100+/-300 yr (154.6). NU 1442b at 12 m elevation and >0.5 m above the Lv2-Lv1 contact is dated twice from different samples: 105,600+/-2000 yr (148.2), and 104,900+/-2200 yr (144.7). The dates establish Lv2 as of stage 5c age, about 105,000 yr. The apparently accurate closed system dates of Lv1 suggest it is discretely older than Lv2 and early stage 5c or even stage 5d. Adjusting all 9 dates, apparently accurate or inaccurate, with the open system model, however, their range is 101,000 to 108,000 yr with a mean of 105,000 yr, no correlation with stratigraphic height, and stronger implication that the entire section belongs to stage 5c.

Western Gemswick Coast.

The Ventnor terrace is preserved along the western third of the Gemswick coast with much the same geomorphic and stratigraphic character as at Salt Cave Point (Fig. 6). Subunit Lv1 is assigned without dates by occurrence above a distinct, laterally continuous unconformity and a thin basal zone of sand with tabular head coral. It is has variable thickness between 1 and 6 m. Subunit Lv2, also undated, overlies Lv1 with a sharp undulous contact and is similar in composition as that at Salt Cave Point except for greater content of scattered A. palmata fronds. The thickness of Lv2 is variable between 1 and 7 m, generally greater than that at Salt Cave Point. The summed thickness of Lv1 and Lv2 is a constant 6-8 m, thinning landward. Subunit Lv3 seen in rare exposures appears to occupy a belt between Lv2 and the shoreline angle.

Westward from the Gemswick coast toward the South Point headland (Fig. 6), outcrops on the Ventnor tread contain increasing proportions of clastics, comprising plane and cross laminated calcarenite, pebbly calcarenite, and conglomerate. This probably represents a westward expansion of width of the Lv3 belt relative to that at the Gemswick coast.

South Point Headland.

As noted, the tread of the Ventnor terrace of the South Point headland comprises broad planar remnants interpreted as original and undenuded, together with lower gullied denuded tracts (Fig. 3). At the western half of the headland, the Ventnor terrace is circumscribed by the Worthing terrace. At the eastern southern face of the headland, the Ventnor is intersected by the low Holocene seacliff, and there, its margin is beveled. Figures 8b and 8c illustrate in section the topographic relations among primary and denuded tread, bevel, and paleoseastack at the south face of the South Point headland.

The Ventnor unit of the headland is divided among three subunits that are correlated with those at Salt Cave Point and occupy discrete belts across the headland surface: Lv1 in the south, Lv2 intermediate, and Lv3 in the north (Fig. 6). Each of these subunits extends across the original and denuded surfaces of tread. The tracts of denuded Ventnor tread are cut down as much as 6 m below the original tread level, thus indicating a minimum thickness of subunits Lv1 and Lv2, The relation of the three subunits below this level, however, is uncertain, Lv1 is mainly a thick framework of A. palmata correlated with Lv1 of Salt Cave Point by age and composition. The intermediate belt, Lv2, is an undated mixed coral framework rich in A.cervicornis and head corals, similar to Lv2 of Salt Cave Point . The landward belt, Lv3. is clastic, mainly calcarenite. The contact between Lv1 and Lv2, is poorly exposed; it is not clear from outcrops which one overlies the other, if at all, and the depiction in section BB' of Figure 6 that Lv2 overlies Lv1 is based on observations imported from Salt Cave Point (see below). Similarly, the contact relation of Lv2 and Lv3 is unexposed. What is clear is that the widths of the Lv3 and especially of the Lv2 belts expand substantially westward across the South Point headland from the Gemswick coast. .

Ventnor Subunit Lv1. Lv1 is chiefly a framework of A. palmata. It also includes occasional cells of A.cervicornis framework scattered in the predominant A. palmata successions and basal clastics above an underlying unconformity (Fig. 8c,d). Exposures of A. palmata framework are as thick as 12 m and extend down to the basal clastics at the deepest exposures of the subunit. Lv1 contains mainly large (>0.25 m) fronds, often algal-coated, especially near the top. Cells of small A. palmata framework occur lower in the section. Very few A. palmata fragments suggest preservation of growth orientation, and none indicates reworking, implying they collapsed in place. The A. cervicornis cells reach widths of 80 m and have steeply inclined boundaries that grade with A. palmata and are as high as 5 m. These cells include minor A. palmata and head coral. The basal clastics, exposed only at Inch Marlowe (Fig. 8) are as thick as 2 m. They are mainly calcarenite with lenses of rounded gravel and scattered small head corals. The basal clastics unconformably overlie unit Lx1, which is defined below (Fig. 8b,d).

Two A. palmatas from Lv1 at the South Point headland give apparently accurate dates (Figs. 6, 8b,c). NU 1484 from 1 m below the preserved initial tread at18 m elevation gives 106,000+/-600 yr and initial del234U=155.9. NU 1488, from the Round Rock paleoseastack at 9.5 m elevation, gives 107,800+/-1600 yr and initial del234U=151.3. Both dates indicate time correlation with the Lv1 section at Salt Cave Point. The difference in elevation, 19 and 12 m, of the Lv1 tops at South Point and Salt Cave Point, both with preserved original tread, is attributed to different uplift rates.

Ventnor Subunit Lv2. Lv2 of the South point headland is continuous with Lv2 at the western Gemswick coast (Fig. 6). The mixed coral framework of Lv2 comprises A. cervicornis, head coral, and minor A.palmata and sand lenses. Head corals occur in columnar and domical forms, both commonly in growth orientation. Maximum exposed thickness is 6 m below the original Ventnor tread. As noted, it is uncertain if Lv2 at the South Point headland continues down the base-Ventnor unit unconformity or is underlain by Lv1 as at the Gemswick coast and is hypothesized in Figure 6.

Ventnor Subunit Lv3. Lv3 is chiefly calcarenite, which contains plane lamination and meter-high cross-laminated dunes, and pebbly calcarenite. The downward extent of Lv3 is uncertain below the maximum 2 m exposure depth below preserved original tread.

At the bevel and Holocene seacliffs of the south face of the South Point headland, there are three local limestones that contact the Ventnor unit but are not part of that unit or of any existing terrace. These are called Lx1, Lx2, and Lx3 and described here (Fig. 8bcd). Lx1 is below the Ventnor unit; Lx2 and Lx3 are above it. The Worthing limestone unit lies unconformably above the three Ventnor subunits but is not known to contact Lx2 or Lx3.Undated limestone below the sub-Worthing unconformity near Kendal Point is likely to be Lx1, but instead, is possibly Lv2. A coral from the Kendal Point site gives inadmissible date.

Limestone Lx1. This limestone unconformably underlies Ventnor subunit Lv1 at the Holocene seacliffs and bevel at Inch Marlowe (Fig. 8a,b). The unconformity is defined by a sharp lithic break and the stratified gravelly base of the suprajacent Lv1. The 300 m-long outcrop of Lx1 is a low dome, suggesting the unconformity is erosional. Lx1 may continue east of Inch Marlow near sea level below the Long Beach barrier bar. It may also be the limestone below the sub-Worthing unconformity exposed below 2 m elevation near Kendal Point.

Lx1 is a mixed coral framework, with predominant A. cervicornis and lesser A.palmata, head coral, and calcarenite lenses. Head coral occurs in growth orientation. Acroporids show no rounding or stratification, and both species occur in angular bifurcated fragments. Lx1 appears to be an in-place deposit. We dated an A. palmata, NU 1485-1, from Lx1 at 112,000+/-1800 yr, with initial del234U=160. The closed system value of this apparently accurate date supports the lithic identification of an unconformity between Lx1 and Lv1 (Fig. 8b), implies a stage 5d age, and permits an hiatus between the two limestones to have been as long as 4000 years (comparing NU 1485-1 with NU 1488). The open system model dates for these corals, however, are insignificantly different. Further, the oldest apparently accurate closed system date of Lv1 at Salt Cave Point (NU 1501, 111,700+/-300 yr) is not significantly different from that of NU 1485-1 of Lx1. Thus, our dating does not prove that an hiatus is associated with the Lx1-Lv1 unconformity.

Limestone Lx2. This is a 10 cm-thick marine layer of mixed fine grained stick coral: A. cervicornis, P. poreites, and Madracis sp that is recognized only on the flat top of Round Rock seastack. Lx2 caps the planar eroded top of Lv1 at about 10 m elevation (Fig. 8c). Lx2 might occur elsewhere capping Lv1 below the Ventnor tread but is unseen because of caliche and human development which could prevent recognition of a thin stick-only layer. The stick particles are not rounded or stratified and not apparently a deposit of large lateral transport.

The age of this marine limestone is unknown within the following limits. It is younger than the subjacent unit Lv1, dated 107,800 years (NU 1488) at Round Rock; older than the development of the Round Rock seastack because Lx2 is cut by and does not drape over the stack walls; and older than about 41,000 years, the minimum age of limestone Lx3 at the base of the stack (see below). Two age interpretations are possible: a Worthing (stage 5a) equivalent and a stage 5c regressive deposit. These are discussed further below.

Limestone Lx3. Lx3 is a wedge of clastic carbonate sediment that overlies the most seaward few meters of the beveled surface of Lv1 at Silver Sands, extending landward into the notch on the seaward face of the Round Rock seastack (Fig. 8c). Its base is at 1.5 to 2 m elevation. Lx3 is thickest, about 1.5 m, in the notch and thins seaward due partly to later erosion. It is partly bedded and laminated, and such surfaces indicate the deposition of Lx3 as a seaward- thinning wedge that represents a local aggraded beach face. Lx3 contains three facies, which are interbedded: 1) cross laminated calcarenite with up to 25% broken mollusc shells; 2) calcarenite with floating angular lithic and coral pebbles but few molluscs; and 3) bioturbated massive calcarenite. Calcarenite matrix is reddish and silty and contains minor sand and granules. The shells are judged to a mix of thin- and thick- walled molluscs, some clearly terrestrial snails (Pleurodonte isabella), and some probably marine.

The age of Lx3 is older than about 41,000 yr and younger than Lx2 and Lv1 of Round Rock (Fig. 8c,d). We dated a fragment of a thin-walled snail shell, probably marine, from Lx3 (NU 1486, Fig. 8c), by AMS 14C at the Center For AMS, Lawrence Livermore National Lab, through the courtesy of Susan Trumbore. One aliquot of NU 1486 gives >41,000 yr (modern fraction=-0.000,5+/-0.00.21, del 14C=-1000.4+/--2.1), and a second gives >41,000 yr (modern fraction=-0.0016+/-0.0021, del 14C=-1001.6+/--2.1). Both aliquots of NU 1486 give del 13C=0, implying a normal seawater origin for the mollusc. The conditions above admit that Lx3 and the notch it occupies are either contemporaneous with the conclusion of erosion of the bevel and Round Rock seastack from prexisting Ventnor terrace, or were created in a marine event later than the bevel and Round Rock. Both times require Lx3 and the notch be younger than the stage 5a highstand (about 82,000 yr) because the bevel cuts the Worthing terracewest of Round Rock (Fig. 8b).

Rendezvous Hill Terrace

Geomorphology.

The Rendezvous Hill terrace of stage 5e age spans the entire study area with near-continuity between Foul Bay on the east and Oistins Bay on the west. West from Oistins Bay, it is continuous for 6 km to its type location, which was assigned by Mesolella (1968). East from Foul Bay, it has been cut off by Holocene seacliff recession. The only gap in the terrace occurs at Fairy Valley where the Rendezvous Hill tread is wholly cut out by the Ventnor backcliff (Fig. 3). Correlation of the Rendezvous Hill terrace across this gap is indicated by continuity of the degraded Rendezvous Hill backcliff, continuity of the nearby Ventnor terrace and shoreline angle seaward of the gap, and continuity of well preserved tread of the Kendal Hill terrace landward of the gap.

The tread of the Rendezvous Hill terrace is narrow, <200 m wide, throughout southeastern Barbados. It is a moderately preserved, linear, and east-west trending belt at the Gibbons area, inland of the South Point headland, but substantially denuded and N60E trending east from Fairy Valley along the Gemswick coast (Fig. 3). Across the entire area, the preserved segments of the Rendezvous Hill shoreline angle parallel those of the Ventnor shoreline angle. The preserved tread of the Gibbons area is planar and shallowly seaward dipping (<2 deg), whereas the much denuded tread of the Gemswick coast is hummocky and gullied and has average seaward dips of 5 deg. or more. The Rendezvous Hill backcliff is beveled to low (10-30 deg) slope and gullied along much of the Gemswick coast. Such denudation is continuous with that upslope on areas that were formerly Kendal Hill terrace. Denuded Rendezvous Hill terrace, however, is truncated by the nondenuded Ventnor backcliff. Near its eastern limit, the Rendezvous Hill tread is crossed obliquely by a local deflection of slope that dips about 10 deg south (Fig. 3). The origin of the deflection is unclear; it is possibly the eroded scarp of a normal fault with south-down throw.

Elevations of the Rendezvous Hill shoreline angle are 40+/-1 m at Gibbons, 34+/-1 m at Penny Hole, and 36+/-2 m at Foul Bay (Fig. 9). The differences indicate post-Rendezvous Hill deformation.

Rendezvous Hill Limestone Unit

At Gibbons, limestone cover of the Rendezvous Hill terrace, the Rendezvous Hill unit, appears to underlie the full tread, that is between the shoreline angle and brow of the Ventnor backcliff. To the east along the Gemswick coast, however, the Rendezvous Hill tread is mostly or wholly underlain by the Kendal Hill unit of late stage 7 age, and the Rendezvous Hill unit is apparently absent with a couple of possible exceptions (Fig. 6). This lateral change in the existence of cover corresponds approximately to the change from a mainly preserved original tread west of Fairy Valley to denuded tread east of there. Site descriptions of the unit are now presented.

Gibbons. West of about Fairy Valley through Gibbons, the Rendezvous Hill unit includes three subunits in outcrop. From seaward, these are 1). A. palmata framework, 2). mixed coral-clastic , and 3). clastic.

The A. palmata framework is exposed on the brow and face of the Ventnor backcliff. It is variably 10-17 m thick above an unconformable contact with dated Kendal Hill unit, which is also cut by the Ventnor backcliff (Fig. 6, section BB'). It includes no basal clastics.

The A. palmata framework is documented in a well exposed gully that cuts theVentnor backcliff by Blanchon and Eisenhauer (2002, their site PB20). They describe it as composed of cobbles and boulders of clasts of A. palmata and subordinate amounts of A. palmata in place. They gave mass spectrometric ^{230}Th dates over 14 m of this section, most of which indicate a stage 5e age, including one apparently accurate date of 128,900+/-1200 yr at 9.5 m below the subunit top. We add that the subunit section includes no vertical zonation of A. palmata size range, and although there are scattered sand lenses (nonmatrix), there is no evidence for lateral transport of coral clasts. Rather, the A. palmata grew and progressively collapsed in place.

The undated mixed coral-clastic subunit sharply overlies the A. palmata subunit and continues landward where it appears to grade with the clastic subunit. It is as thick as 2.5 m and composed of A. cervicornis, P.porites, small head corals in domal and columnar form, and sandy and pebbly lenses. Some pebbles contain A. palmata The existence of some head coral in growth orientation and of angular stick and bifurcated stick coral fragments implies the mixed coral-clastic subunit is at least partly locally derived.

The clastic subunit is calcarenite, which continues landward to or near the shoreline angle. It is undated.

The floor of the Rendezvous Hill terrace at Gibbons is exposed only at the unconformity on the Ventnor backcliff and at the shoreline angle. The floor's configuration between those points and the geometry of the Rendezvous Hill subunits above it are important unknowns. The height of the unconformity below the terrace tread differs (17 and 14 m) at its two sites exposure at Gibbons and Wilcox Ridge. This suggests the unconformity contains erosional relief. A planar floor would dip south between 5 and 7 deg depending on such relief (section BB', Fig 6).

Western Gemswick Coast. East from the gap at Fairy Valley through a 2 km long area of denudation, the Rendezvous Hill terrace has morphologic definition in the form of a degraded and receded backcliff and hummocky tread with lesser slope than the backcliff (section AA', Fig. 6). No unconformities are evident on this poorly exposed tread. We dated an A. palmata (NU 1490) from a site froma relativehigh on the denuded tread. Its 274,300+/-3700 yr but inaccurate date (Table 1) suggests a stage 7 age. Thus, there appears to be an absence of coralline limestone of the Rendezvous Hill unit in this area. A few scattered outcrops of undated calcarenite at upslope positions on the tread, however, are possible Rendezvous Hill remnants.

Salt Cave Point. The middle reach of the Gemswick coast (Salt Cave Point-Penny Hole) contains moderately well preserved geomorphic features of the Rendezvous Hill terrace: sharp and steep backcliff and shoreline angle (Figs. 3,7), but the tread is denuded and, on average, steeply seaward dipping. Here as at the western Gemswick coast, coralline limestone below the tread is Kendal Hill unit of late stage 7 age, as indicated by dates at two surface sites. NU 1477-4, from the face of the Rendezvous Hill forecliff (Ventnor backcliff), and NU 1476-4 from the Rendezvous Hill tread 20 m landward of the forecliff (Fig. 7a,b). Moreover, it is clear that the Rendezvous Hill limestone unit does not occur below the Ventnor terrace at Salt Cave Point from evidence given earlier. The only possible remnants of the Rendezvous Hill unit in this area are loose rounded coral pebbles on the Rendezvous Hill terrace tread. These do not form a continuous layer but rather are scattered within the calichefied surface and possibly are concentrated in gullys.

Foul Bay. At the eastern reach of the Gemswick coast, the mainly denuded but geomorphically traceable Rendezvous Hill terrace includes of a few patches where the tread is relatively planar and seemingly little denuded. However, mass spectrometric 230 Th dates from such patches indicate a stage 7 age of coralline limestone directly below the tread (216,800+/-1800 and 227,300+/-2200 yr; (Fig. 6) (R. Speed and R.L. Edwards, unpubl. 1999).

Discussion

Preceding site descriptions indicate that at the Gemswick coast we found no in-place cover of the Rendezvous Hill terrace even though the terrace's geomorphic expression can be traced in a degraded condition completely through that area. In contrast, to the west at Gibbons, the terrace exists with little denudation and thick cover. Thus at the Gemswick coast, either no cover was deposited, or cover formerly existed but has been eroded off in a way that did not fully wipe out associated geomorphic features. The latter idea has merit because of the rounded pebbles that could be lag from eroded Rendezvous Hill cover.

Section BB', Figure 6 depicts the Rendezvous Hill unit as existing in part of the subsurface of the South Point headland to the present-day offshore. The basis for such construction is the preservation of limestone unit Lx1 of possible stage 5d age unconformably below the Ventnor unit at the headland's southern flank. In later interpretation, we infer that the unit Lx1 is the regressional continuation of the Rendezvous Hill unit. Thus, some length of the Rendezvous Hill unit should be preserved in the subsurface below and landward of the Lx1 exposure.

Kendal Hill Terrace

Geomorphology.

The Kendal Hill terrace of stage 7 age is the highest and oldest preserved marine geomorphic feature in southeastern Barbados, and the area of Kendal Hill terrace mapped on Figure 3 is the only moderately preserved remnant of this terrace in all of southern Barbados (Speed, 2001). Surfaces higher than the Kendal Hill are completely denuded (Fig.3). The Kendal Hill terrace remnant is defined by a nearly continuous backcliff and shoreline angle of 2 km strike-length near Coverly and a smooth tread that extends from the shoreline angle with diminishing slope across a 1300 m breadth to the Rendezvous

Hill backcliff (section AA’, Fig. 6). The preserved tread underlies the Barbados airport, raising questions whether the smoothness is artifical. According to senior residents, however, the flat existed as such before the airport was constructed. East from the preserved terrace remnant, both the backcliff and smooth tread are lost in a region of severe denudation and lower elevation (Fig. 3). Westward, the flat tread can be traced along the terrace’s seaward margin well west of the end of preserved backcliff. The irregular western boundary of preserved Kendal Hill terrace circumscribes a hilly surface. Such hills may mark a former headland of Kendal Hill age and on whose shoreline the Kendal Hill backcliff was not preserved. The Kendal Hill shoreline angle elevation is 67+/-2 m, and the elevation at the seaward end of preserved tread is 51+/-2 m (Fig. 6).

A stage 7 age for the Kendal Hill terrace remnant comes from its continuity westward behind the landward margin of dated Rendezvous Hill terrace at Gibbons (Fig. 3) and by dating of cover below preserved tread at RGF 90-1 (Fig. 7).

Kendal Hill Unit.

At Gibbons, outcropping limestone is assumed to belong to the Kendal Hill unit on and in back of the Rendezvous Hill backcliff and is proved by dating to occur along the base of the Ventnor backcliff (sect. BB’, Fig. 6). At the Gemswick coast, the unit crops out from the Kendal Hill shoreline angle seaward for 2 km across the Kendal Hill tread and Rendezvous Hill terrace to the face of the Ventnor backcliff (sect. AA’, Fig.6). Seaward from there. the Kendal Hill unit underlies the Ventnor unit and reappears on the Holocene backcliffs (Fig. 7). East and west of the Kendal Hill terrace remnant, the Kendal Hill unit may extend landward to the highly approximate boundary shown in Figure 6, based on elevation and features of denudation but not dating. The base of the unit is recognized nowhere in outcrop, except possibly at Foul Bay, but is identified in drillcore at Salt Cave Point (Fig.7).
Its top has been heterogeneously eroded, both by denudation of the Kendal Hill tread and by marine downcutting during development of the Rendezvous Hill, Ventnor, and Holocene terraces. The Kendal Hill unit extends seaward of the present day shoreline but the distance is unknown. The sectional geometry of the Kendal Hill unit at the Gemswick coast is fairly well controlled by drilling and outcrop (sect. AA’, Fig.6) and shows the unit base dipping xx deg seaward. At Gibbons and the South Point headland, however, the unit’s continuity and thickness are hypothetical (sect.BB’, Fig. 6), due to lack of exposure and to the question whether the Rendezvous Hill unit is there preserved below the Ventnor unit. The Kendal Hill unit is now described at specific sites.

Salt Cave Point and Penny Hole. Here, the Kendal Hill is lowest stratigraphically among outcropping units (Fig. 7). It lies unconformably below the Ventnor unit and is unconformable above older limestone in the subsurface. Its age is late stage 7, based on 6 dates (Fig. 7). The unit is divided stratigraphically between two subunits, Lk1 and Lk2.

The bottom of the Kendal Hill unit, unexposed, is assigned in three drill holes either to the base of the A. palmata framework that is continuous upward to outcrops of subunit Lk1 or to the base of a thin clastic layer below the A. palmata framework (Fig. 7b,c). This horizon is chosen because of the lithic heterogeneity of subjacent limestone, suggesting erosional trauncation, and because the outcropping base of dated Kendal Hill-equivalent limestone above dated older limestone in eastern Barbados 8-12 km north exists in a similar lithic succession (Speed, 2001). At Salt Cave Point, coral dates indicating older limestone (pre-late stage 7 age) are as shallow as 12 m below the assigned base of the Kendal Hill unit (Fig. 7b,c).

Subunit Lk1 is an A. palmata framework. Minor small cells of A.cervicornis and in-growth head corals occur in the lower half of the A. palmata framework. Crusts of coralline algae occur on A. palmata fragments high in the section. In some outcrops, the A. palmata framework is homogeneous and unbroken in thicknesses as great as 15 m, such as at Penny Hole, there examined by Wood (1999). A. palmata fragments are unsorted, and have widths of touching fronds between 10 and 30 cm. They are unrounded and mainly horizontal. Such properties indicate progressive upward growth and collapse in place of A. palmata colonies.

We dated five A. palmatas from Lk1 in this area (Fig. 7; Tables 1 and 2), here discussed in order of increasing elevation. None of the five dates is apparently accurate. NU 1500 is from outcrop at 3 m elevation just below the sub-Ventnor unconformity; its date is 228,000+/-1400 yr (initial del234U=189). Sample 2-3-4 is from well RGF 90-2 at 7 m elevation; its date is 201,000+/-2000 yr (197). Sample 2-2-2 is from well RGF 90-3 at 8.5 m elevation; its date is 204,000/-1000 yr (173). NU 1477-4 is from outcrop at 17 m elevation at mid-height on the Ventnor backcliff. Its date is 225600+/-4500 yr (250). The highest is sample 1-2-1, at 47 m elevation in drillhole RGF 90-1, which was spudded on preserved Kendal Hill tread at Penny Hole. Its date is 208,000+/-3000 yr (198). The open system adjusted dates of the above sequence are 214,000, 184,000,196,000, 192,000, and 191,000 years. All except sample 2-3-4 indicate a late stage 7 age and younging upward.

Subunit Lk2 overlies Lk1 in remnant patches along the seaward margin of the Rendezvous Hill terrace near and east of Salt Cave Point (Fig. 7). Lk2 is 2 m thick in well RGF 90-3, and we assume it is uniformly thin across its breadth of outcrop (Fig.7c). The subunit is mixed A. cervicornis-head coral-shell limestone. Its head corals are mainly in growth orientation, and the other constituents are unreworked and probably of local derivation. A head coral from Lk2 at 23 m elevation, NU 1476-4, is dated 214,400+/-6200 yr (Fig. 7; Table 1). Its initial del234U=149, indicating it is an apparently accurate date. Thus, NU 1476-4 indicates Lk2 and the subjacent Lk1 were deposited late in stage 7 but well before the stage 7.1 highstand (at about 192,000 yr). Their deposition must have been at low sea levels of the major eustatic oscillation late in stage 7. The 1476-4 date also indicates that the true ages of the dated Lk1 samples other than 1-2-1 should be no younger than 214,400 yr and that three of the Lk1 samples have closed system dates that are too young in spite of elevated initial del234U.

It is evident at Salt Cave Point-Penny Hill that the Kendal Hill unit has been considerably eroded according to the downstepped profile of the unit top across the Rendezvous Hill, Ventnor, and Holocene backcliffs and treads (Fig. 7b). Such excavation was wholly marine in the development of the latter two terraces. The Rendezvous Hill terrace includes an initial marine phase and a later denudational phase, which was subaerial. Eroded thicknesses of the Kendal Hill unit can be estimated in two ways. A maximum estimate comes from the assumption that the unit top initially extended planarly seaward 0.6 deg from the edge of preserved Kendal Hill terrace tread at 51 m elevation. This dip value is that of the planar seaward realm of the preserved initial tread (Fig.3). Eroded thicknesses are 19 m at the Rendezvous Hill backcliff, 39 m at the Ventnor backcliff, and 47 m at the Holocene backcliff. A minimum estimate is given by the height of the backcliffs of the three younger terraces: 19 m, 5 m, and 3 m, respectively. The assumption for the minimum values implies that the initial unit top intersected the brows of each of the future backcliffs and took on a substantial increase in dip seaward of the preserved remnant of Kendal Hill tread. The minimum value assumption is improbable, and a greater depth of erosion than the minimum value is likely.

Eastern Gemswick Coast. East from Salt Cave Point, Kendal Hill subunit Lk1 is continuous as a thick A. palmata framework on Holocene seacliffs to Olivers Cave (Fig. 6). There, Lk1 thins to a few m. Farther northeast across Holocene cliffs at Foul Bay, however, the A. palmata framework of Lk1 thickens abruptly northeast, reaching 16 m thickness above a possibly older limestone. The Kendal Hill A. palmata framework is there dated 216,800+/-1800 yr (R. Speed and R.L. Edwards, 1999, unpubl), confirming the subunit assignment.

At Foul Bay, Lk1 is overlain by a mixed coral-clastic limestone that is a probable correlative of Lk2. It contains cells of predominate A. cervicornis, head coral, .or A. palmata and cells of pebbly calcarenite. The Lk2 equivalent continues from the Holocene seacliff landward across the denuded Rendezvous Hill tread, where it is dated 227,300 yr (R. Speed and R.L. Edwards), and presumably, inland beyond the Rendezvous Hill backcliff.

Western Gemswick Coast. West from Salt Cave Point along the Gemswick coast, the Kendal Hill unit occupies the stratigraphically lowest outcrops above unexposed base (Fig. 6). Such outcrops are assumed to be continuous from the Ventnor backcliff to the Kendal Hill backcliff at Coverly, a breadth of 2 km (sect. AA', Fig.6). The Kendal Hill unit is similar to that at Salt Cave Point, with a few differences: more lithic variability in subunit Lk1, greater preserved extent and thickness of subunit Lk2, and preservation of a third subunit, Lk3.

The thick A. palmata framework of Lk1, as seen along the Holocene seacliff and Ventnor backcliff includes cells of A.cervicornis framework and of calcarenite. One large calcarenite cell is strongly burrowed and has advanced diagenesis in the form of total cementation and partial neomorphism.

Subunit Lk2 underlies seaward segments of the denuded Rendezvous Hill tread and locally occurs farther landward on the Kendal Hill tread. It is here a mixed coral framework of mainly A. cervicornis and head coral and frequent cells of small A. palmata. We dated an A. palmata, NU 1490, from Lk2 on the Rendezvous Hill tread at 274,300+/-3700 yr; the initial del234U is extreme at 328, implying the true age is much younger, perhaps around 214,000 yr, according to the adjustment for open system.

Subunit Lk3 occurs well landward along the upland fringe of the Kendal Hill terrace within about 300 m of the shoreline angle (Fig. 6). It is a clastic limestone comprised of coral clasts with various degrees of rounding and sorting and of calcarenite. No dates exist from this unit, and its thickness is unknown.

Section AA' of Figure 6 depicts the sectional geometry of the Kendal Hill unit inland from the western Gemswick coast assuming that seaward of the Rendezvous Hill backcliff, the configuration of the unit base is like that of this unit at Salt Cave Point, and that inland of that backcliff, the base is planar to the Kendal Hill shoreline angle at Coverly. The interpretive distribution of the three subunits is argued later.

Gibbons. In the Gibbons area, which is landward of the South Point headland, the Kendal Hill unit crops out along the base of the Ventnor backcliff and on and landward of the face of the Rendezvous Hill backcliff (BB', Fig. 6).

At the Ventnor backcliff, the Kendal Hill unit is overlain by the Rendezvous Hill unit at about 23-26 m elevation and 5-8 m above the Ventnor shoreline angle. The contact is either an inconspicuous planar discontinuity between the A. palmata frameworks of the two units or at lenses of head coral between them. The Kendal Hill unit here contains only A. palmata fronds: mixed sizes up to very large (up to 30 cm diam), touching, mostly horizontal, and unreworked. We dated an A. palmata from 22 m elevation on the Ventnor backcliff, NU 1479, at 204,100+/-3300 yr, initial del234U=200 (Fig. 6; Table 1). In back of the Rendezvous hill terrace at Gibbons, undated Kendal Hill unit is assigned to the Rendezvous Hill backcliff and farther landward. The assignment is based on near-continuity of the Rendezvous Hill backcliff as a geomorphic feature to the east 4-5 km where it is faced with dated Kendal Hill unit at Penny Hole (Fig. 7) and the same distance to the west (at Warners) where Blanchon and Eisenhauer (2002) give a similar date. Throughout the Gibbons area, the unit is an A. palmata framework, which includes scattered individual domical head corals in growth orientation and occasional cells of A. cervicornis.

Discussion

The principal limestone of the Kendal Hill unit in both extent and thickness is A. palmata framework. It comprises subunit Lk1 at the Gemswick coast and the less extensively exposed limestone of the Gibbons area, which we correlate with Lk1 by comparable lithology, dates, elevation range, and positions relative to geomorphic markers (Figs. 3,6). Thus, the Kendal Hill A. palmata framework is taken to be continuous on strike (shore-parallel) throughout southeastern Barbados, a 12 km length, except for a possible gap at Olivers Cave. It is exposed in a dip (shore-normal) direction only about 300 m at the Gemswick coast, but it spans some 50 m of elevation across that length above a seaward-dipping base. Lk1 almost certainly extends up- and downdip from its coastal belt of exposure in the subsurface and below sea, but it is unclear how far. Section AA’ of Figure 6 is constructed with the assumption that Lk1 continues updip to a transition with clastic subunit Lk3.

Kendal Hill subunit Lk2 is known with reasonable certainty to be a sheet with eroded top that overlies Lk1 at the Gemswick coast. The extent of Lk2 updip of its exposure belt is unclear, and it is unknown whether it originally continued west to the South Point-Gibbons area. Section BB’ of figure 6 is constructed with the assumption that Lk2 and Lk1 are coextensive. The same section proposes that the Kendal Hill unit (undivided) extends in the subsurface from Gibbons south through the South Point headland to the offshore. This interpretation is influenced by the possible existence of the Rendezvous Hill unit in the headland’s subsurface.

OLDER LIMESTONE

Older limestone is a unit that includes capping limestone below the Kendal Hill unit and thus, limestone older than late stage 7. Older limestone is assigned to widespread outcrops that are upland from outcropping Kendal Hill unit (Fig. 6). Outcrop of older limestone may also crop out at the base of Holocene seacliffs at Foul Bay (Fig. 6). The existence of older limestone in the subsurface is known from dated drillcore at Salt Cave Point (Fig. 7) and implied from total thickness data on Quaternary limestone in southeastern Barbados (Fig. 2).

The upland exposure belt of older limestone has been little examined, except by Wood (1999) at Harlington quarry, and is undated. The boundary between older limestone and Kendal Hill unit on Figure 6 is highly approximate except at the Kendal Hill shoreline angle, where it is probably exact.

Limestone cropping out in the basal few meters of the Holocene seacliff below subunit Lk1 of the Kendal Hill unit at Foul Bay that may be older limestone is constituted by reefal facies with predominate A. cervicornis and by calcarenite. It is undated.

Drillholes RGF 90-1, 90-2, and 90-3 at Salt Cave Point and Penny Hole do not reach the base of Quaternary limestone but indicate total limestone thicknesses of >50 m, >55, and >41 m, respectively (Fig.7). Thicknesses of older limestone in the three holes are >34 m, >43 m, and >34 m, respectively. Logs of the three cores indicate vertically and laterally varied coralline and clastic facies and no evident stratigraphic correlation among the three holes. Older limestone includes one A. palmata-rich layer in RGF 90-1, two such layers in RGF 90-2, and three in RGF 90-3 (Fig. 7). A. palmata from both layers are dated in RGF 90-2 (Table 2). Sample 2-15-1 at about 10 m below the base of the Kendal Hill unit gives 245,000+/-xxxx yr (initial del234U=197). Sample 2-21-3 at about 20 m below the same horizon gives 322,000+/-xxxx yr (238). Two horizons of A. palmata are dated in RGF 90-3. Sample 3-16-3, about 16 m below the base of the Kendal Hill unit, is dated 295,000+/-xxxx yr (283). Sample 3-22-2 at about 25 m below the same horizon is dated 323,000+/-xxxx yr (231). The youngest of the four dates probably represents a stage 7 age but one that is older than the closed system dates from the overlying Kendal Hill unit. The other three are probably older than stage 7 and cannot be linked with the isotopic time scale.

Data from unlogged waterwells which intersect the base of the limestone aquifer indicate that capping limestone is between 40 and 100 m thick over much or all of southeastern Barbados (Fig. 2) , indicating that the thick limestone at Salt Cave Point is regional. Because most of the limestone section at Salt Cave Point is older limestone, it is reasonable to assume that this is the case throughout southeastern Barbados. Where total limestone thickness is greatest, the surface rock is thought to be older limestone,and the unit must there be as thick as 90-100 m. Thus, the older limestone unit appears to be an extensive seaward-dipping sheet of substantial but variable thickness that extends from the Christ Church arch south into the offshore (Fig. 2c). The unit is probably a composite of many early terrace covers of wide age span, the youngest of which might be early stage 7 on the basis of dated sample 2-15-1.

TECTONICS

This section addresses two subjects of the active tectonics of southeastern Barbados: rates of surface uplift as functions of position from late stage 7 to the present and the structure and motions of the Christ Church arch, whose southern flank contains our study area.

Surface Uplift

The uplift (w) of a surface marker is the difference between its current elevation (z1) and elevation (z2) at the time the marker formed: w=z1-z2. Such uplift is in fact the net elevation difference if vertical motions proceeded at variable rates since the marker formed. The average uplift rate is w/t=z1-z2/t where t is the age of the marker. Sea level is the evident elevation reference, and we employ raised shoreline angles to measure uplift because they formed at sea level at the ends of eustatic highstands. Highstand elevation relative to present-day sea level is the variable, z2.

Shoreline angles are more precise uplift markers than coral because they do not include the uncertainties in depth relative to sea level that corals do, i.e. whether grown in transgression or highstand, depths at growth, and depth of collapse. The ages of shoreline angles, however, are not directly measurable and require estimation from varied local and global highstand age data. Because they are isochronous markers, error in assigned ages is a constant for all sites on a given shoreline angle. While corals provide directly measured ages of their sites, the departure from true age of each apparently accurate coral date is rarely known, and this introduces a nonconstant error into uplift rate calculations.

We estimate uplift rates 9 sites in southeastern Barbados with the following data and assumptions. 1). Current elevations, z1, are indicated with error and measurement technique in Table 3. 2). The value of highstand elevation, z2, for the Rendezvous Hill terrace, stage 5e, is taken as +6 m, a value (+/-2 m) that has been estimated on tectonically stable terrains for many years (Ku etal, 1974; Stirling etal, 1998). 3).

Values for z2 of the Ventnor (stage 5c) and Worthing (stage 5a) shoreline angles are calculated assuming that at Salt Cave Point-Penny Hole where all three stage 5 markers occur in close proximity, the uplift rate was constant over the 38,000 year span between stages 5e and 5a: for stage 5c, z2=-10 m and for stage 5a, z2= -15 m. Such values are like those determined at other rising coral coasts such as New Guinea (Chappell and xxxx). 4). For the Kendal Hill shoreline angle, z2 is assumed zero, which is close to estimates elsewhere by Chappell and xxx (xxxx), Matthews (1973), and Gallup et al (1994). 5). Ages, t, for shoreline angles are estimated at Worthing, 82,000+/-2000 yr from accurate ages of the highest stage 5a corals on Barbados, Ventnor, 105,000+/-1000 yr from the paper; Rendezvous Hill, 120,000+/-2000 yr from Speed etal (2002), and Kendal Hill, 192,000+/-2000 yr from Speed (2002).

Mean calculated uplift rate values at the 9 sites (Fig. 9) indicate the rate field in southeastern Barbados is nonuniform, with a maximum of 0.35 m/1000 at the most inland site (Coverly), a minimum of 0.23 m/1000 yr at Salt Cave Point, and thus, a range of 0.12 m/1000yr, which is clearly significant relative to parameter errors (Table 3). Rates indicate that the South Point headland region (including South Point, Gibbons, and Fairy Valley) has risen faster since 120,000 yr (or earlier) than the Gemswick coast as represented by Salt Cave Point. Moreover, South Point (0.33 m/1000 yr) has risen faster than Gibbons (0.27-28 m/1000 yr), assuming steady rates at each site. Toward the eastern limit of the Gemswick coast at Foul Bay, the rate is slightly greater (0.25) than at Salt Cave Point (0.23). The calculated values provide no gauge whether rates have changed with time.

Rotation of Kendal Hill Floor

The floor of the Kendal Hill terrace dips an average 3.7 deg seaward from its shoreline angle to the present-day shoreline, across 1200 m as projected on strike of both features (Fig. 3). How much of this angle is due to tectonic rotation and how much represents a slope that preceded Kendal Hill deposition? The difference in uplift rates at the two sites, Coverly and Salt Cave Point, 0.12 m/1000yr, over 192,000 yr gives 1.1 deg rotation down to the SSE. Thus, the Kendal Hill floor dipped an average 2.6 deg. toward the SSE at the time of deposition of the Kendal Hill unit.

Structures

Active structures of southeastern Barbados comprise the Christ Church arch and the South Point structure. The area does not apparently include normal faults, except possibly near Foul Bay; such faults are widespread elsewhere in southern Barbados and permit incremental slip downslope of the capping limestone (Speed, 2001).

The Christ Church arch is defined by elevation, dip of capping limestone, and a window of foundation (Fig. 6). It is asymmetric about an axis shown in Figure3. Its northern flank descends steeply down to the St. Georges trough and causes vertical offset of features as young as stage 5e. This flank is probably based on a south-dipping thrust fault (Speed, 2001). The southern flank of the Christ Church arch dips shallowly southward across the study area into the offshore. The South Point structure is superimposed on the southern flank. The uplift rate difference between Coverly and the Gemswick coast probably reflects continuing rotation of the arch's southern limb. There are also easterly elevation and uplift rate gradients, both diminishing on the arch's axis. This observation assumes that the uplift rate at the western reach of the arch axis is greater than that at Coverly (0.35 m/1000yr) because its elevation is greater (110 m vs 67 m). The lower rate on the arch's axis at Foul Bay (0.25 m/1000yr) indicates an eastward plunge of the axis. The structure of the arch crest at the window of foundation is unclear, whether the foundation is diapiric or it is exhumed by faulting, because of meager exposure.

The Christ Church arch is interpreted as an upwarp in the train of contractile folds and faults that affect the northern Barbados Ridge (Fig.1) and have caused the modern emergence of the island. The cause of the easterly plunge of its axis is unclear.

The South Point structure is identified from the uplift rate field (Fig.9) on two counts: the greater rate of the South Point headland relative to the Gemswick coast to the east, and on the headland, the greater rate of South Point than Gibbons. The structure is of recent origin, beginning between Ventnor and Worthing times. Evidence is the nearly linear and parallel shoreline angles of the Ventnor and Rendezvous Hill terraces across all southeastern Barbados compared to the large deflections of the Worthing and Holocene shoreline angles around the South Point headland (Fig. 3). The geometry of the South Point structure is undefined except for the upward motion of the headland relative to areas east and west and of the headland tip relative to its landward reach. Some conceivable ideas for this structure are: diapir in foundation centered near the headland tip; seaward stretching and thinning of the adjacent regions, Gemswick coast and Oistins Bay, by normal faulting (support for this exists at Oistins Bay but not Gemswick; Speed, 2002), and a N-S trending anticline through the headland (such fold orientations in southern Barbados were proposed by Taylor and Mann, 1991, but not at the South Point headland).

TERRACE AND LIMESTONE EVOLUTION: INTERPRETATIONS

In this section, we interpret the formative processes and timing of marine terraces in southeastern Barbados in sequence from youngest to oldest.

Holocene

Today's coastal geography in southeastern Barbados is somewhat similar to that in stage 5a, 80,000 yr ago, although sea level was then about 15 m lower. The Gemswick coast and South Point headland existed then in generally current form. Principal Holocene modifications to the shore zone are the new seacliff, abrasion platform, lagoons and barrier bars, and nearly complete excision of the Worthing terrace at the Gemswick coast. The large Chancery Lane lagoon of Holocene age is explained by focused marine erosion at the join of the South Point headland and the Gemswick coast by waves that ran obliquely west along the Gemswick coast. Such erosion diminshed when the length of eroded platform became large. Since then, the longshore flow has built up a sand bar that is stable relative to wave impact and isolates the inner erosional tract as a lagoon.

The stage 1 and stage 2 terrace, created in transgression and highstand since the glacial maximum,underlies a 1-2 km breadth of tread from the Holocene shoreline angle, seaward across the present-day shelf, to the base of slope, as interpreted from drilling by Fairbanks (1989). Of this terrace, the Holocene part exists wholly on the shelf. The Holocene terrace is inferred to be a seaward-thickening wedge of limestone and carbonate sediment between a tread dipping <1 deg and floor dipping an average 3-4 deg. Still actively forming, the wedge represents a duration of deposition between about 11,000 yr and the present. The Holocene seacliff at the present-day shoreline is erosional, not inherited or constructional, because the cliff cuts down through multiple older limestone units and because the cliff is currently retreating, as indicated by toppled slabs. The floor is actively following the retreating seacliff. Thus, the depth of the floor, i.e. the base of the Holocene limestone, at the shelf edge indicates that sea level and the shoreline angle were at -45 m elevation at about 11,000 yr and have since transgressed landward to today's position. It is doubtful the Holocene floor is planar because the rate of sea level transgression greatly diminished in the Holocene(Fairbanks, 1989), and hence, the rate of marine downcutting increased, during the Holocene. Thus, we infer that the Holocene floor is steeper and less downcut to seaward and much shallower to landward, the latter a result of approximately constant sea level over the last 6,000 yr (xxx).

Because the Holocene A. palmata layer occurs directly on the terrace floor, the layer must represent a fringing reef, whose growth immediately followed the passage of sea level during transgression. This implies the A. palmata layer propagated up (retrograded) the newly created terrace floor as transgression continued. Moreover, the fringe reef continued to grow vertically, keeping up with the average 12 m/1000 yr rate of sea level rise between 11,000 and 7500 years to yield a wedge-shaped deposit of A. palmata that is 30 m-thick at its seaward end. It is not known how far landward the A. palmata layer extends. The suprajacent layer of head coral at the shelf edge, 5 m thick and known only as younger than 7,500 yr, implies the demise of the aggrading A. palmata fringe reef after 7500 yr ago. It is doubtful that the demise was due to drowning in water because the rate of transgression slowed after 7,500 yr. Rather, it may have been caused by the attainment of highstand at about 6,000 yr and an increased rate of local clastic sediment production at the seacliff and proximal floor. It may also have been related to the onset of longshore sand transport on the tread to the leeward of the South Point headland. This latter explanation predicts that the A. palmata layer may not have expired to windward, at the Gemswick coast. Support for this prediction comes from the existence of A. palmata debris with a 1000 yr 14C date on the tread above the shelf edge at the Gemswick coast (Lewis, 1985).

Bevel, Seastacks, and Units Lx2 and Lx3

The bevel and seastacks on the south-facing coast of the South Point headland were formed by erosion after the Worthing highstand but before about 41,000 yr. Marine unit Lx2 was deposited before the formation of the Round Rock seastack. Unit Lx3 and its related notch are either contemporaneous with the final erosion of the bevel and Round Rock stack or they are younger than those features but older than 41,000 yr. We propose the following origin of these features with a theme that the bevel and stacks were eroded during the stage 5a regression by a combined marine-subaerial process. 1). Unit Lx2, which is preserved on the flat top of Round Rock seastack, is interpreted to be of Worthing age. It is the remnant of a lagoonal facies between a hypothetical reef barrier to seaward and a nearby Worthing backcliff to landward, both features now totally eroded near Round Rock. This stratigraphic assignment is compatible with the 10m elevation of the base of Lx2 relative to the nearby Worthing shoreline angle at 12 m, which is assumed originally to have existed uniformly across the South Point headland. 2). Beginning at or before the stage 5a regression, westerly storm waves impacted the windward flank of the newly emergent South Point headland and episodically flooded the subaerial surface of the headland's southern eastern flank. The flood water drained west and south across the headland, eroding the denudation zones mapped on Figure 3. Such flooding totally excised the Worthing terrace on the windward side of the headland, except for the top of the future Round Rock. A large patch of Ventnor terrace plus contiguous Worthing terrace was bypassed by the runoff at the leeward southern end of the headland (Fig. 3). The bevel may represent progressive denudation by this mechanism as sea level lowered. The hypothesis offers no special reason for the formation of the seastacks as denudation remnants and does not explain why the bevel continues west across the seaward face of the preserved Worthing terrace. 3). Unit Lv3 was created before about 41,000 yr during a short stillstand in the regression at 10 m below the stage 5a highstand. The alternative that Lx3 represents a later rise in sea level is less likely because of the apparent absence in the global record of a sea level rise to within 10 m of the Stage 5a highstand during stages 4 or 5a. 4) Landward propagation during the Holocene of a low seacliff on the south face of the South Point headland, owing to recession against a low-angle, beveled slope.

Worthing Terrace

The Worthing terrace developed after the onset of uplift of the South Point headland relative to the Gemswick coast and Oistins Bay. At the western flank of the South Point headland, the Worthing backcliff is cut into the Ventnor limestone unit. At the Gemswick coast, it cuts across the Ventnor-Kendal Hill unit unconformity. Backcliffs at both places are clearly of marine erosional origin.

The Worthing terrace's seaward margin at sea level is the Holocene shoreline, but in the subsurface off South Point, dated drill core (Fairbanks,1989; Bard etal,1993) shows that a regressional equivalent of the Worthing terrace cover as young as 70,000 yr underlies the Holocene terrace at and seaward of the shelf edge and at ≥45 m depth. The Worthing terrace breadth, from Worthing shoreline angle to modern shelf edge, is thus at least 1 km. At South Point, the depth of stratigraphic downcutting through the Worthing terrace by Holocene terrace development differs with position: completely through the Worthing unit into the Ventnor at the Holocene shoreline angle and apparently very little at the modern shelf edge. The difference supports the premise that downcutting during marine transgression is inversely related to rate of sea level rise.

The small remnants of marine terraces assigned to the Worthing at the Gemswick coast indicate that the Worthing highstand extended landward to the present-day Gemswick coast and that some Gemswick shoreline morphology (e.g. Salt Cave Point) is inherited from erosion in stage 5a. Thus, the curvy Worthing shoreline around the South Point headland also exists in small form at the Gemswick coast and contrasts with the Ventnor shoreline which runs nearly linearly through both areas.

Limestone of the Worthing unit at South Point and Oistins Bay is wholly a mixed coral framework with much in-place coral and no vertical stratigraphy, except for thin basal clastics. The size of A. cervicornis and proportion of A. palmata increase southward within this framework, toward the headland's south face. This facies indicates a quiet marine environment but one with increasing circulation seaward from Oistins Bay. A barrier to large breaking waves must have existed seaward of the mixed coral framework to create this environment and permit preservation of some delicate, in-place coral colonies. The barrier may have been either the headland itself or a reefal shoal. The first idea is that the headland reduced the height of the westerly swell enough for sustained lagoonal coral growth on its leeward side. This may be doubtful from the existence of relatively high and retreating Holocene seacliffs on the headland's leeward flank. The alternative idea is that a shoal of A. palmata existed on the Worthing terrace south of today's headland. The shoal was eroded away in the Holocene.

The history of the Worthing terrace at South Point has the following sequence of development: 1) erosion of the floor as exposed at 2 m elevation on the Holocene seacliff at Kendal Point; 2) propagation of the floor and backcliff landward to its final highstand position at the Worthing shoreline angle at 12 m elevation; 3) aggradation of mixed coral above the floor and basal clastics; and 4) regression from the Worthing highstand, reaching an elevation not lower than –45 m at 70,000 yr, and progressive aggradation on the submerged regressional tread.

The timing of floor erosion and reef deposition presented above (items 2 and 3) assumes that the preserved reefal limestone could not have survived the wave impact needed to propagate the floor, even at a water depth of 10 m (Sunamura, 1994). The depth for reef destruction by waves may in fact have been shallower, in which case the reef may have begun growth before the floor reached the shoreline angle and have propagated diachronously landward and upward following a shallowing sea level. In either case, reefs may have grown at shallow depths on the transgressive floor but were episodically destroyed and converted to clastic sediment that is retained in part in the basal clastics. If an A. palmata reef barrier existed, its growth to shoal depths was probably concurrent with cessation of floor propagation.

NU 1482 is the only apparently accurate coral date (86,300+/-1200 yr) with which to time Worthing events 2) and 3). The coral grew at 7 m below highstand, This date is older than the 80,000-85,000 yr range commonly thought to contain the stage 5a highstand (xxx). Thus, NU 1482 indicates either a) that the lower mixed coral reef grew in transgression and the depth of marine erosion was shallow (<7 m), b) that the Worthing highstand existed from 86,300 yr or before to a time within the younger range, or c) that the apparently accurate date is inaccurate.

Ventnor Terrace

The Ventnor terrace developed before the onset of tectonic uplift of the South Point headland relative to the Gemswick coast and Oistins Bay. Its shoreline at the conclusion of the stage 5c highstand in southeastern Barbados was straight, in the sense that headlands and coves, like those of the subsequent Worthing shoreline, did not exist. The straight shoreline suggests that the wave climate of stage 5c was weaker than that of stage 5a, assuming that coves develop at sites of sustained high swash. If true, the tectonic emergence of the large South Point headland after stage 5c may have influenced later local wave climate.

The Ventnor backcliff and landward reach of the floor are of erosional origin because they truncate the Rendezvous Hill terrace and cut down into the subjacent Kendal Hill limestone unit. In contrast, the Ventnor floor at the south face of the South Point headland, a well-offshore site in Ventnor time, may have been little downcut because the regressive limestone, Lx1, of stage 5d or 5e age, is at least partly preserved there below the Ventnor unit. It may represent a position of rapid Ventnor transgression and little marine downcutting, compared to the substantial downcutting at places near the highstand locus.

At the Gemswick coast with particular reference to Salt Cave Point, the Ventnor limestone subunit Lv1, a thick A. palmata framework, is interpreted to be a diachronous transgressive fringe reef. Evidence is as follows. Lv1 lies on a steeply dipping erosional contact or on contemporaneous thin basal clastics. The lowest exposure of Lv1 is 12 m below the Ventnor highstand, and the base of Lv1 almost certainly extended to even lower elevations before erosion in the Holocene. Such depths indicate that A.palmata low in Lv1 were deposited in transgression because ≥12 m is too deep for growth of a reef that would produce such a coarse framework. Lv1 at Salt Cave Point is diachronous because its growth propagated up the dipping unconformity. It also aggraded vertically during sea level rise, as indicated by its nearly horizontal top and by the upward younging of its apparently accurate dates (Fig. 10). The keep-up aggradation of A. palmata in Lv1 at Salt Cave Point stopped at 3-4 m below the Ventnor shoreline angle (the stage 5c highstand). The sharp but undulous, nontruncated top of Lv1 suggests a sudden cessation of growth of A. palmata.

At Salt Cave Point, Ventnor subunit Lv2, a mixed coral limestone with delicate forms preserved in growth orientation, was deposited on Lv1 after a switch from a high to low energy environment. The wrapping of encrusting head corals of Lv2 around the undulations at the top of Lv1 and the occurrence of columnar heads of Lv2 in lows on Lv1 indicates a fill-in and smoothing of the Lv1 surface by Lv2. Because Lv2 is a sheet whose top is only 2-3 m below the shoreline angle, the subunit must have been deposited during the highstand of stage 5c and have been preserved for the most part during succeeding regression. The cause of the switch to a low energy environment during highstand is almost certainly due to the development of a barrier seaward of the preserved breadth of Ventnor terrace at the Gemswick coast. We propose this barrier is was formed by the continuing aggradation and by progradation of the Lv1 A. palmata reef at a locus seaward of Salt Cave Point. In other words, the fringe reef responded to the attainment of highstand by prograding seaward, thus causing the breaker zone to migrate progressively offshore, producing a shallow but expanding lagoon. The hypothesis proposes that Lv1 originally extended as a wedge well to seaward of Salt Cave Point and that its uppermost reach younged seaward.

The narrow belt of clastics, subunit Lv3, on the Ventnor tread of the Gemswick coast must represent a beach that fronted the retreating Ventnor backcliff in its final days before regression rendered it inactive, high, and dry. We infer that Lv3 is continuous with the basal clastics of Lv1. It is thus taken to represent a diachronous beach deposit that during transgression preceded deposition of the Lv1 fringe reef and followed the receding backcliff and then, intervened during highstand between the Lv2 and the presumably static backcliff. With this hypothesis, the narrowness of the surficial Lv3 belt at the Gemswick coast implies that the duration of highstand and of deposition of Lv2 was short.

We now discuss the apparently accurate coral dates from the Ventnor unit in the evolutionary context outlined above with goals of dating events (Fig. 10). NU 1501, from the dipping base of Lv1 at Salt Cave Point indicates the maximum age of passage of the transgressing sea and first coral growth at 11 m below highstand at 111,700+/-300 (107,700) yr, the first date with closed system assumptions, and the parenthetical date adjusted with Thompson open system model assumptions. The water depth at growth of this tabular pioneer head coral in sand was probably ≤2 m so that the sea level at this time was between 9 and 11 m below highstand. An A. palmata from the top of Lv1 at Salt Cave Point, NU 1505 at 109,300+/-300 yr (104,100) yr, gives a maximum age for the end of aggradation of the Lv1 fringe reef, the onset of this reef's progradation at a unknown locus seaward of Salt Cave Point, and the switch from a high energy to a lagoonal environment. The true age of these events is younger because NU 1505 is 0.5 m below the highest point of the undulatory top of Lv1 and 3.5 m below highstand. An A. palmata from Lv1 at the southern margin of the South Point headland, NU 1484, 106,000+/-600 (103,200) yr, is within 1 m of the top of Lv1. Because the subunit top is there interpreted as undenuded, original terrace tread, the date gives a maximum age of highstand. However, because NU 1484 is 1.8 km seaward of the Ventnor shoreline angle, the subunit top here is likely to have been deposited in the progradation of Lv1, thus giving further support for deposition at highstand or perhaps, in early regression. The highstand sea level at South Point is unknown because it contains no shoreline angle and appears to be uplifting more rapidly than the Gibbons area where the Ventnor shoreline angle occurs. Assuming a depth of growth and collapse of 1 m each for A. palmata at the subunit top at the NU 1484 site, highstand was about 3 m above NU 1484 at a time no older than its closed system date. Another A. palmata, NU 1488, from the southern South Point headland at 10 m below the Lv1 top at the NU 1484 site, is dated 107,800+/-1600 (106,900) yr. Dates from subunit Lv2 at Salt Cave Point, 105,600+/-2000 (105,900) yr and 104,900+/-2200 (106,600) yr for NU 1442b and 106,100+/-300 (103,900) yr for NU 1506, represent times after the attainment of highstand and the switch to a lagoonal environment., and before or at the onset of regression.

The three closed system model ages from Lv2 and that of NU 1484 from Lv1 imply the stage 5c highstand existed during a time between 105,000 and 106,000 yr. The open system model ages for the same corals give equivalent limits between 102,500 and 106,000 yr. The clustering of the four closed system dates suggests greater accuracy, and 105,000 yr appears to be a time at which regression began, the Lv2 lagoonal corals stopped growth, and the offshore progradative part of the Lv1 fringe reef (NU 1484) was extinguished. The passage of transgressive sea level at 9-11 m below highstand was probably between about 112,000 (closed) and 108,000 (open) yr (NU 1501), and at a depth a little shallower than 10 m below highstand between about 108,000 (closed) and 107,000 (open) (NU 1488). The closed system date of NU 1505, which is at the limit of the accuracy definition, errs on the old side compared to the stratigraphically lower but apparently more accurate NU 1488 date. Another constraint on timing of the stage 5c transgression is a maximum age at about 20 m below highstand supplied by 112,000+/-1800 yr closed system date of NU 1485-1 in unit Lx1, which underlies the Ventnor unit.

The subsurface stratigraphy of the Ventnor unit below the1.8 km breadth South Point headland is unknown. Alternative models of such stratigraphy assume 1) that subunit boundaries at the surface mark vertical contacts and 2) that the stratigraphic relations of the Ventnor unit at the Gemswick coast apply to the South Point headland. Model 1 assumes that the contacts in present-day exposures are the subunits' most landward extent. This implies that in stage 5c, a protoheadland at South Point existed as a bathymetric feature shallow enough to force the transgressive Lv1 fringe reef to a highstand locus that was well offshore relative to the Lv1 locus of the Gemswick coast. It also implies that landward of this relatively seaward reefal barrier, there was a very broad (> 1km) lagoon in which Lv2 was deposited, satisfying the observation of westward broadening of the Lv2 outcrop belt across the headland. Model 2 assumes that the protoheadland had no bathymetric expression in stage 5c and that

Lv1 extends in the headland's subsurface to a locus near the shoreline angle, as at the Gemswick coast and as drawn in section BB' of Figure 6. In model 2, the top few meters of Lv1 prograded well seaward during highstand, permitting the deposition of a thin but very broad Lv2 stratum across much of what later emerged as the headland. Model 2 is preferable because it employs a similar evolution at both coasts, which may be required by the straight Ventnor shoreline angle at both coasts, and does not have to explain the exceedingly broad highstand erosional platform at the South Point highland that is required of model 1. Further, at the Gemswick coast, the distance seaward of highstand progradation of Lv1 and original breadth of Lv2 are unknown and could have been equal to what is observed at the South Point headland.

Relative to post-terrace denudation, the Ventnor terrace was both preceded and followed by denudational activity. The terrace's backcliff and proximal floor retreated into previously denuded areas of the Rendezvous Hill terrace at the Gemswick coast and at the western Gibbons area. The Ventnor terrace was in turn denuded onland at the eastern southern South Point headland during the stage 5a regression and across much of the central headland in Holocene time.

Rendezvous Hill Terrace

The initial breadth of the Rendezvous Hill terrace is largely unknown because marine erosion during Ventnor time diminished its preserved tread to a narrow belt no more than 200-400 m seaward of the Rendezvous Hill shoreline angle. A large, 2 km breadth in the subsurface, is implied, however, at least below the South Point headland, taking limestone unit Lx1 as a regressive equivalent of the Rendezvous Hill unit (section BB', Fig. 6).

Features of the undenuded Rendezvous Hill terrace at Gibbons are remarkably like those of the Ventnor terrace at Salt Cave Point, both sites including comparable terrace breadth from their shoreline angles and good exposure: a steeply seaward-dipping (5-7 deg) floor, direct cover of the floor by a thick wedge of A. palmata framework, overlap of the A. palmata framework by a thin mixed coral subunit, and contact landward with a narrow belt of calcarenite. The similarity implies like processes of terrace development. The A. palmata framework of the Rendezvous Hill unit is thus a transgressive fringe reef that followed rising sea level landward and aggraded until stage 5e highstand. A transgressive origin for at least much of the framework is required because a water depth of 10-17 m is too deep for such large A. palmata to have grown at highstand. We hypothesize that, as with the Ventnor Lv1 subunit, the A. palmata reef prograded at highstand and created a seaward-migrating barrier and a lagoon in which the suprajacent mixed coral subunit of the Rendezvous Hill unit was deposited. The calcarenite belt represents the clastic lag from the end of retreat of the Rendezvous Hill backcliff, perhaps at the beginning of or during expansion of the lagoon and highstand. Our study contributes nothing to the problem of the timing and duration of the Rendezvous Hill highstand.

The apparent absence of the Rendezvous Hill limestone unit on the Rendezvous Hill terrace at the Gemswick coast, except possibly for scattered pebbles on the tread, requires explanation. We hypothesize that Rendezvous Hill cover along this coast was easily eroded sediment, probably little lithified beach sand and gravel, in a belt continuous with the calcarenite at Gibbons. The hypothesis requires the width of the Rendezvous Hill clastic belt to have expanded eastward from Gibbons, from about 100 to >300 m; this is reasonable because the terrace gained more windward exposure to the east. The clastics were swept off and the floor eroded during denudation before the stage 5c highstand, thus at a time in the stage 5e-5d regression. Because the denudation appears to have been mainly or wholly coastal and probably by storm-wave flooding, a time early in the regression is more probable for denudation. Such timing also fits the idea of a low degree of lithification of the terrace's clastic cover.

Considering the stage 5e-5d regression, the top of unit Lx1 near South Point was about 51 m lower than the Rendezvous Hill highstand at Gibbons. This figure, which accounts for the uplift rate differential of the two sites, gives a maximum depth of sea level descent at 112,100 yr (closed system date of NU 1485-1) in the stage 5d regression. The 51 m depth below highstand is a maximum because of several unknowns: depth of growth and collapse of Lx1 coral, depth of erosion of Lx1 in the stage 5c transgression, and the possibility that the true age of NU 1485-1 is somewhat younger, toward the open system date of 108,000 yr.

Kendal Hill Terrace

At the Gemswick coast, elements of the Kendal Hill terrace are identified over a dip-length (breadth) as great as 1.7 km, between the Kendal Hill shoreline angle and Holocene seacliffs. At Salt Cave Point, the projected floor has a mean seaward dip of 3.7 deg, of which about a quarter is due to tectonic rotation. The rest of the dip, 2.6 deg, is original, that which existed upon completion of the stage 7.1 transgression and highstand. The original depth of the floor below highstand level at the Holocene cliff was about 55 m, and the floor undoubtedly does or did continue seaward and deeper in the present-day offshore. About 42% of the stage 7.2-7.1 glacial-interglacial amplitude is thus onland, assuming the amplitude was the same 130 m as the most recent one. As noted, the top of the terrace was much eroded during the marine excisions of the Rendezvous Hill, Ventnor, Holocene, and probably, Worthing terraces.

Kendal Hill subunit Lk1, an A. palmata framework of late stage 7 age, is extensive on strike through souheastern Barbados, outcrops across a dip-length of 400 m, and probably continues well inland below poor exposure (sect. AA', Fig.6) and offshore of the outcropping increment. The subunit base is interpreted in drillcore to contact subjacent older limestone or to include thin clastics above older limestone (Fig. 7b). Because the outcropping interval of Lk1 represents a depth range from 55 to 16 m below highstand and because the subunit Lk1 is on the terrace floor, this interval of Lk1 is a fringe reef that grew during transgression toward the stage 7.1 highstand. Dates of Lk1 at Salt Cave Point do not constrain well the timing of transgression. The closed system dates are scattered between 201 and 228 ka, without the strong correlation with elevation expected of an aggrading reef. The open system dates appear to be too young (184-196) for late stage 7 transgression, except for the 214 ka of the lowest coral, NU 1500.

Kendal Hill subunit Lk2, a mixed coral limestone that overlies Lk1, supplies important constraints on terrace evolution. Its lowest exposed base (original depth) is 35 m below Kendal Hill highstand, a depth too great for a lagoonal origin at highstand. The switch in environments from Lk1 to Lk2 thus must represent a drowning of A. palmata during transgression and onset of growth of head coral and A. cervicornis, which are better adapted to lower circulation or/and deeper water. The age of the switch is 214+/-6 ka or slightly earlier. This is given by the date of NU1476 from Lk2, whose accuracy is implied by the equality of its closed and open system values. The subunit succession indicates that Lk1 did not aggrade above a thickness of about 8 m at hole RGF 90-3 before drowning (Fig. 7b). Somewhat downslope at RGF 90-2, however, the thickness of Lk1 was greater, perhaps as great as 17 m before erosion in Ventnor time, and upslope at RGF 90-1, the thickness was ≥17 m. Differences in thickness of aggradation of Lk1 along the dipslope of the Kendal Hill floor may be correlated inversely with rate of transgression.

The Kendal Hill clastic subunit, Lk3, is interpreted as an apron that extended from the shoreline angle to seaward for a few hundred meters. It probably existed during the stage 7.1 highstand and was sourced by erosion of bioherms that attempted growth in the breaker zone and of older limestone at the retreating Kendal Hill backcliff. It is unknown whether a highstand lagoon developed at the upslope realm of the Kendal Hill terrace as it did at younger raised terraces of southeastern Barbados.

Severe post-terrace denudation affected the Kendal Hill terrace in the Gibbons area before the development of the Rendezvous Hill terrace, thus between stages 7.1 and 5e. Inland from the eastern Gemswick coast, denudation of the Kendal Hill terrace may have been wholly after the stage 5e highstand or both before and after that highstand.

TERRACE AND LIMESTONE EVOLUTION: SYNTHESIS

Our study of southeastern Barbados has identified and characterized with varying degrees of resolution five marine terraces, which are from highest and oldest to lowest and youngest: Kendal Hill, late stage 7; Rendezvous Hill, stages 5e and 5d; Ventnor, stage 5c; Worthing, stage 5a; and the still actively developing Holocene terrace. Each has some similarities of geometry, carbonate rock cover, and developmental history. This terrace sequence is similar to that identified by earlier workers in western Barbados (Mesolella, 1968, Mesolella etal, 1970), but our criteria of terrace definition and interpretations of terrace evolution differ markedly from the earlier ones.

Each terrace consists of elements formed during eustatic transgression, highstand, and regression. Bounding geometric elements are a seaward-dipping floor and tread which join at a shoreline angle at the landward end of the terrace. The shoreline angle is at the base of an erosional backcliff and marks the highest sustained sea level during terrace development. Downslope, the tread is excavated at the backcliff of the next younger terrace. This younger backcliff may or may not cut down below the floor. The greatest depth of floor observed in our study is 55 m below highstand level (Kendal Hill terrace, corrected for tectonic rotation), and if not subsequently eroded away, floors presumably continue down and seaward to lowstand levels.

The floor and tread bound a marine limestone (terrace cover) which was deposited during terrace development. At the terrace's landward realm, which is the preferentially preserved and accessible part of ancient terrace anatomy, the floor dips more steeply than the tread, and the limestone is there a seaward-thickening wedge (as detected at the Rendezvous Hill, Ventnor, and Holocene terraces). The realm of wedge-shaped cover may be equivalent to the modern shelf of the Holocene terrace. Farther seaward, however, the floor and tread appear to be more parallel and the intervening limestone more sheetlike (detected at the Kendal Hill terrace).

Each terrace floor and the backcliff at the floor's leading edge are erosional, according to evidence presented earlier. Each floor diachronously tracked sea level and the retreating, wave eroded backcliff during eustatic transgression and highstand. The tread is a surface either of final deposition (eg Ventnor at Salt Cave Point) or of erosion during or after regression (eg Rendezvous Hill at Gemswick coast). The depth of downcutting during floor development is large (as great as 20 m) at terraces' landward realm, but may be small well seaward (suggested at the Holocene shelf and offshore Ventnor). To explain this we propose that downcutting is proportional to the duration of sea level at each bathymetric increment (years/m) and thus, inverse to the rate of transgression. In this hypothesis, maximum downcutting occurred at highstand,

We have identified six facies in the limestone covers of the five terraces; no terrace is seen to contain all the facies because of different levels of exposure and sampling of the terraces or because they may not always occur. The facies are: 1) discontinuous thin basal clastics above the floor (Worthing, Ventnor); 2) diachronous transgressive fringe reef, a blanketform A. palmata framework above the basal clastics (observed in all terraces except in the eroded Worthing but where its former existence is inferred); 3) deeper water mixed coral reef above drowned fringe reef (Kendal Hill); 4) lagoonal mixed coral reef above fringe reef (Rendezvous Hill, Ventnor, Worthing?); 5) beach clastics in narrow belt bounding shoreline angle (all terraces); and 6) regressive coralline cover far downslope on tread (Worthing, Rendezvous Hill).

The major facies of the six is the transgressive fringe reef by virtue of its large extent and continuity on terrace strike (kms) and dip and large thickness, up to 30 m. Because transgressive fringe reefs exist in each of the five terraces, including the Worthing by inference, it is reasonable to propose that all the terraces have (including the subsurface) or had (before erosion) all six facies. With this assumption, a model of terrace and facies evolution is as follows. During transgression in a eustatic oscillation, a migrating backcliff is followed by an expanding floor with clastic cover (facies 1) that was created by erosion of the backcliff and of contemporaneous bioherms. On the seaward side of the breaker zone, the A. palmata fringe reef (facies 2) colonizes above remnant clastics or/and directly on the floor, and its leading edge follows this environment upslope in transgression. Earlier increments of the fringe reef aggrade in the attempt to keep up with sea level rise. Ultimately ,each increment expires, either by drowning during a rate of sea level rise above survival threshold or by some other deathly phenomenon. Such growth thus explains the development of a diachronous blanketform reef with varying thickness upslope (Kendal Hill). Upon giving up at a site seaward of the advancing breaker zone, the fringe reef is overgrown by mixed coral reef (facies 3) that is comfortable under deeper water conditions (Kendal Hill). When sea level arrives at highstand, the fringe reef grows to shoal and bars the shallow marine area to landward, causing development of a lagoon in which mixed coral (facies 4) is deposited in very shallow water. The fringe reefs then begins to prograde. At this time, the backcliff and beach development become inactive or only episodically active in storms, owing to a progressive seaward shift of the breaker zone. The clastic belt (facies 5) is the abandoned beach and inferred to be continuous below the lagoon with facies 1. Upon regression, the shoreline angle is left as the highstand marker. The lagoonal and upper fringe reef facies may be left almost entirely in tact (Ventnor, Rendezvous Hill at Gibbons) or they and the floor may be stripped in regression (Rendezvous Hill at Gemswick coast). Farther seaward during regression, coralline limestone (facies 6) covers the terrace tread (Rendezvous Hill, Worthing), in principle either conformably on facies 3 or unconformably on facies 2. Some of the regressive facies may survive the next transgression if its thickness is great enough or if the ensuing erosion is minor.

CONCLUSIONS

1. Southeastern Barbados contains a succession of four raised marine terraces above the active Holocene terrace: Worthing (stage 5a), Ventnor (stage 5c), Rendezvous Hill (stage 5e +5d), and Kendal Hill (late stage 7). Each of these terraces and its limestone cover is argued to have evolved similarly during eustatic transgression, highstand, and regression along the lines of the following model. The terrace floor is an erosional surface that during transgression extended progressively upslope behind a retreating wave-eroded seacliff. The floor was covered by thin clastic deposits and a diachronous, blanketform transgressive fringe reef of A. palmata. The fringe reef subsequently aggraded to thicknesses as great as 30 m, perhaps more, and then locally or widely gave up and was covered by deeper water mixed coral. As sea level reached highstand, the shoaled fringe reef began progradation, causing the breaker zone to migrate seaward, a lagoon to develop landward, and the abandonment of the seacliff as the leading edge of the terrace. Upon regression, the highstand deposits of upslope realms of terraces were variably eroded or preserved, whereas the downslope realms received regressional deposits. This evolutionary model differs markedly from that of Mesolella (1968) and Mesolella etal (1970) for leeward (western) Barbados, wherein terraces are the result of the catch-up growth of a ridged reef at a deep offshore locus upon attainment of highstand. The Mesolella model does not consider erosion an important evolutionary mechanism.
2. Our principal contribution to the timing and sea level of eustatic events from field study and apparently accurate 230 Th dates in southeastern Barbados concerns the stage 5c interstadial. At Salt Cave Point, well preserved Ventnor terrace tread is underlain by a thin lagoonal mixed reef limestone, whose top is just below highstand level and whose base is on transgressive fringe reef. The lagoonal deposit is thought to have begun

growth in a short lived highstand and to have expired upon regression. Four coral dates from this limestone are between 105 and 106 ka with a closed system model and betweeen 104 and 106 ka with an open system model. The dates indicate the brief highstand was at 105+/-1 ka, which is substantially constrained relative to age ranges commonly quoted for stage 5c highstand. The elevation for this highstand is –10 m, calculated assuming the global elevation of the stage 5e highstand is +6 m. Our stage 5c elevation is close to that determined from uplifting limestone islands (xxxx) but different from the near-zero elevations determined from stable coasts (xxxx). Further measures of sea level during stage 5c are ≤10 m below highstand level at 108 ka and ≤20 m below highstand at about 112 ka.

3. Some measures related to eustatics of other terraces are as follows. We found no markers of a sustained Holocene sea level above the present sea in southeastern Barbados. Elevation of the Worthing (stage 5a) highstand is calculated to be –15 m. As with the stage 5c elevation, this one is like those from tectonic islands and discordant to the near-zero elevations for stage 5a from stable coasts. Sea level during the stage 5d regression was ≤51 m below stage 5e highstand at 112+/-1.8 ka. Finally, sea level during late stage 7 at 214+/-2 ka was ≤24 m below the stage 7.1 highstand.
4. Southeastern Barbados is actively uplifting and deforming. The area includes a range of local uplift rates between 0.23 and 0.35 m/ka calculated from shoreline angle elevations and approximate ages. Principal uplift rate gradients are related to south-down rotation of the southern limb of the Christ Church arch and to uplift of the southern South Point headland relative to sites east, west, and north. The Christ Church arch is probably thrust hangingwall with northerly heave whereas the tectonics of the South Point headland is unclear.

FIGURE CAPTIONS

Figure 1 Map of Barbados, showing area of study in southeastern Barbados, region underlain by the capping limestone, and crestal traces of active major folds.

Figure 2 Southeastern Barbados. A) topography and place names; elevation contours, 10 m; B) capping limestone thickness; dots are well data; C) NS section through capping limestone

Figure 3 Geomorphic map of southeastern Barbados, showing raised marine terraces.

Figure 4 Sectional geometry of a model terrace with nomenclature

Figure 5 Stratigraphic units and 230 Th dates of capping limestone of southeastern Barbados, shown in west – east section. Filled symbols are closed system dates, open symbols are dates adjusted for open-system evolution. Circles, data from this study; squares from other work (Blanchon and Eisenhauer, 2001; R. Speed and R.L. Edwards, unpubl). Dashed lines indicate unit boundaries that are probably either too old or too young relative local dates.

Figure 6 Map of southeastern Barbados showing areas of limestone units, including approximate restoration for stripping by post-terrace (onland) denudation. Restored unit boundaries are dashed. Symbols indicate sites of 230 Th dates. Dates at Salt Cave Point-Penny Hole sited in Figure 7.

Figure 7 Map and sections of Salt Cave Point-Penny Hole area. Area locator in Figure 6. A) whole area map; B) enlargement of Salt Cave Point.

Figure 8 Map and sections of southern face of South Point headland. A) area map; B) Section of exposed Ventnor unit lithology Worthing backcliff, bevel, and Holocene seacliff; C) section through Round Rock raised seastack and the bevel; D) stratigraphic column

Figure 9 Map of sites of calculated uplift rates

Figure 10 Plot of Ventnor unit dates vs depth below Ventnor shoreline angle at Salt Cave Point. Filled symbols are closed system (measured) dates; open symbols are dates adjusted for open system behavior as prescribed in text. Geochronology errors are 2-sigma.

Table 3 Uplift rate calculations for sites 1-9, located in Figure 9. sa is shoreline angle. Z1 is elevation of marker; number after slash is estimated error in elevation. Z2 is elevation of past highstand and t is estimated age of past highstand; see text.

Site#	Site Name	Z1, m	Z2, m	t, ka	Rate, m/ka	Marker
1	South Point	12/1	- 15	82	0.40	Worthing sa, stg 5a
2	South Point	19/1	-10	105	≥0.33	Original Ventnor tread; stg 5c
3	Gibbons	40/1	+6	120	0.27	Rend. Hill sa; stg 5e
4	Gibbons	18/1	-10	105	0.28	Ventnor sa; stg 5c
5	Coverly	67/2	0	192	0.35	Kendal Hill sa; stg 7.1
6	Penny Hole	34/1	+6	120	0.23	Rend. Hill sa; stg 5e
7	Salt Cave Pt.	15/1	-10	105	0.23	Ventnor sa; stg 5c
8	Salt Cave Pt.	4/1	-15	82	0.23	Worthing sa; stg 5a
9	Foul Bay	36/2	+6	120	0.25	Rend. Hill sa; stg 5e